Project Miura II
Final Science Report

Colorado Space Grant Consortium

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December 13, 2018

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Abstract

Miura II was a demonstration of a reusable, pressurized, soft-shell habitat for long-duration spaceflight. The habitat was pressurized using CO_2 canisters, pressure regulators, and solenoid valves. Retraction was carried out using a stepper motor and a winch which wheeled up retraction strings attached to the payload. Based on the requirements met during flight, the payload confirmed the feasibility of such a design on small scales. The primary issues facing the success of the payload were the leaks caused by the compression and folding of the payload during retractions. These were remedied using a design including rip-stop, heat sealing along seams, and a plasti-dip coating to strengthen all weak points. The habitat met all mission requirements, and the project is evidence that reusable, soft-shell structures are an effective mode of improving long-duration spaceflight in the future.

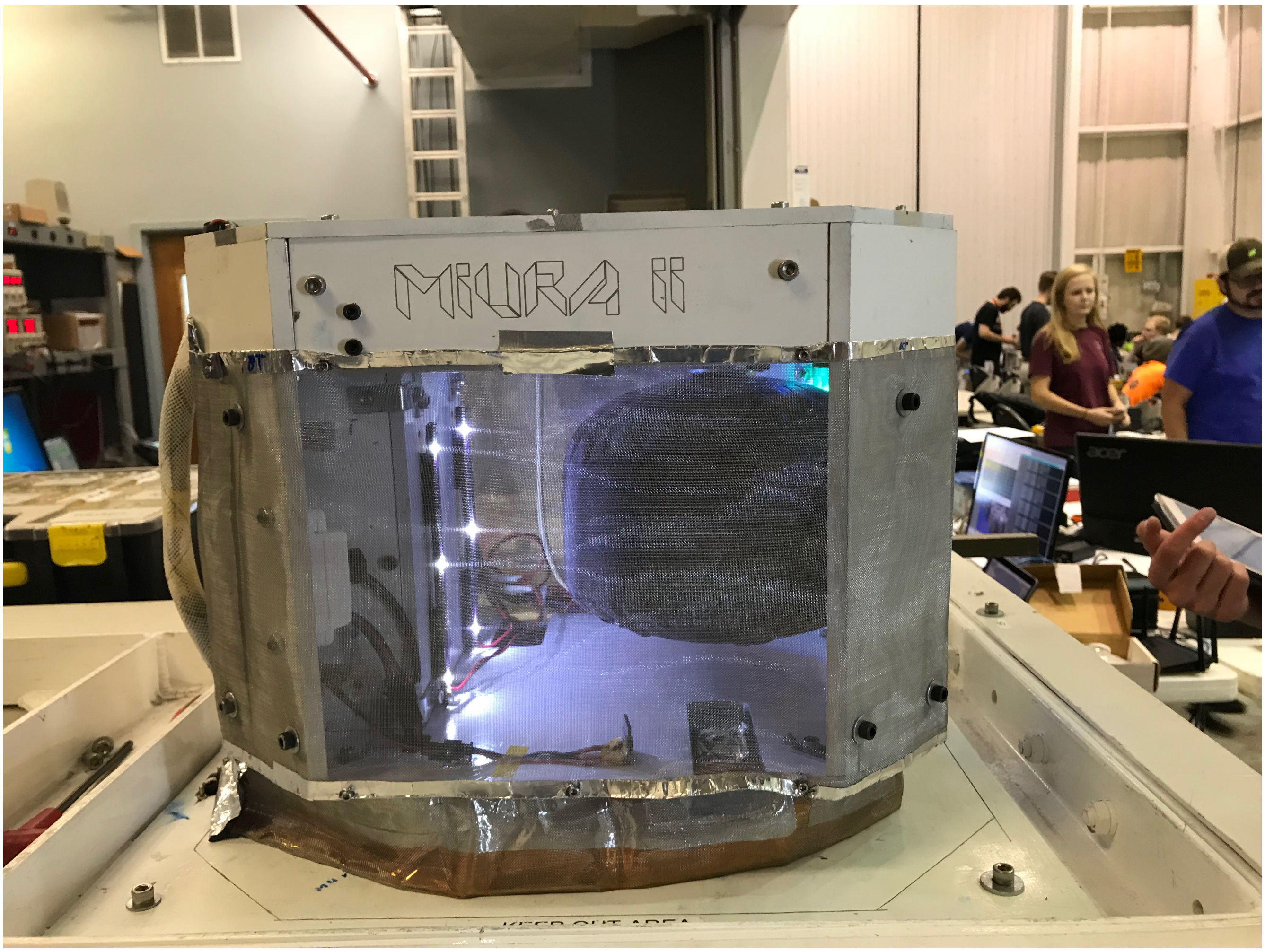


Figure 1: The Miura II payload at HASP Integration in Palestine, TX

1 Mission Premise

1.1 Background

In 2016, the Bigelow BEAM, a soft-shell expandable structure, was successfully deployed on the ISS [1]. Soft-shell structures can be transported in a compact state and subsequently expanded, making them far more volume-efficient than traditional hard sided structures. However, current soft-shell structures are not retractable. Thus, they cannot be depressurized, transported, and then safely re-pressurized. The Miura II payload shall demonstrate one possible application of a reusable, expandable soft-shell structure in a near-space environment. The deployable structure will attempt to recreate thermal and barometric internal conditions that are livable for humans.

1.2 Mission Statement

Miura II shall repeatedly expand, sustain, and contract a pressurized, soft-shell structure on the High Altitude Student Platform while monitoring and documenting the deployment process, internal pressure, and the material performance in order to evaluate the viability of a reusable, collapsible, soft-shell structure in a near-space environment.

1.3 Mission Success Criteria

- Inflate the habitat to max volume at least twice during flight.
- Sustain the habitat at at maximum volume at least twice during flight.
- Retract the habitat least once during flight.
- Achieve a pressure of 0.5 ± 0.05 atm in at least one cycle.
- Sustain a pressure between 0.55 atm and 0.3 atm inside the habitat at least once during flight.

This was a success criteria at the start of the mission, but was descoped in June for feasability concerns:

- Sustain a temperature between 15 ± 5°C from 5 minutes into sustention until contraction inside the habitat at least once during flight.

1.4 Concept of Operations

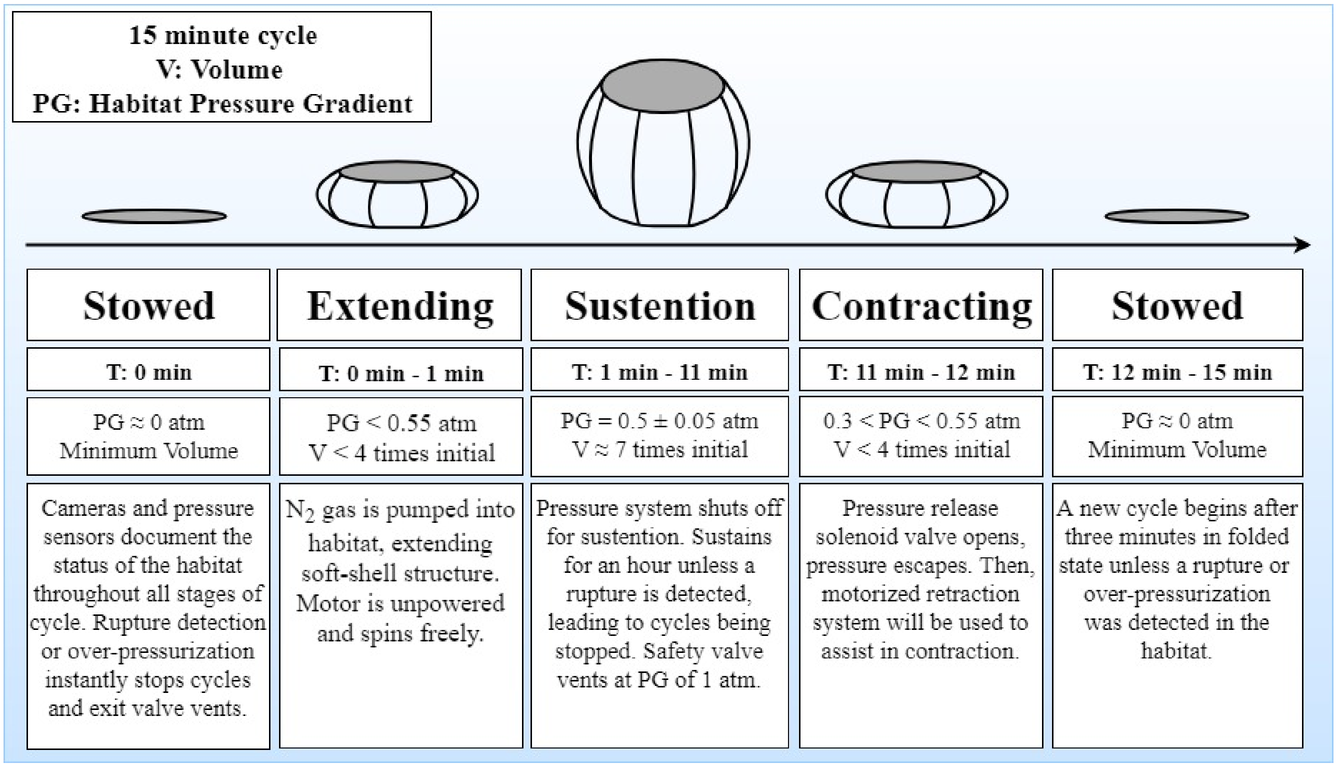


Figure 2: HASP CONOPS

1.5 Potential Future Applications

The success of this project would contribute to the push for long-term spaceflight to destinations sch as Mars as it is an efficient way to have a higher volume spacecraft that is optimized for both launch and flight. Additionally, the reusable habitat technology could mean that the habitat could be used on flight, stowed for landing, and redeployed on the surface of the destination. This reduces waste and increases efficiency.

2 Design

2.1 Design Overview

Since this payload deals with very high pressures, the primary emphasis in design is on safety. The habitat, pressure system, flight software, and structural design will all work together to ensure the system is four fault tolerant. Below in Figure 3 is a flow chart showing the three-fault tolerance of the system, the possible failures, and the consequences of these failures.

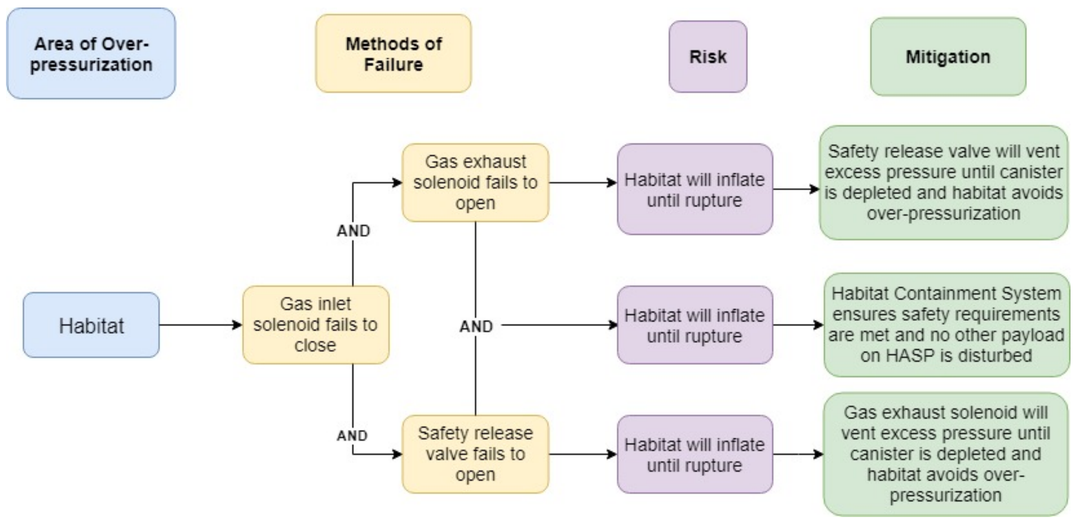


Figure 3: Pressure system failure flowdown

With the inclusion of the mesh containment system, the inlet and exhaust solenoid valves, and safety release valve, the payload actually four-fault tolerant before there is any risk posed to other payloads on HASP or any people involved. Furthermore, extensive testing has been carried out to demonstrate the unlikeliness of these failures occurring. These procedures are detailed in Section 3.
The following subsections detail the design of specific subsystems.

2.2 Habitat

2.2.1 Habitat Design

Iteration 1: Sewed Seams with Pressure Chamber
The initial design of the habitat was constructed from a polyurethane coated Ripstop fabric. The light weight and strong fabric was sewn together from nine individual segments to form a sphere. This design was intended to expand along all three axes from its contracted state.

A preliminary prototype was constructed using 3D printed plates and two layers of Ripstop fabric. The prototype was used for size modeling, motor integration testing, and to give a better insight to the predicted manufacturing method. Full manufacturing and assembly of this prototype took approximately three hours.

The habitat was to integrate with the full payload through a pressure chamber that would house the internal temperature and pressure sensors. The chamber was to completely seal with the fabric and screw into the main payload with an o-ring to make the seal between the metal surfaces. The bottom of the habitat was to be compressed by two aluminum plates that would interface with the retraction method to contract the habitat.

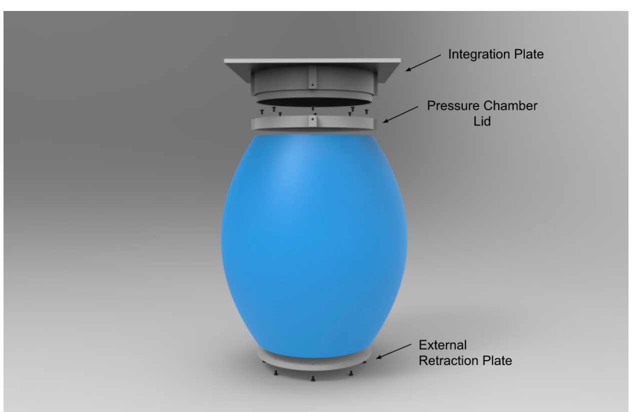


Figure 4: Design 1 Exploded View

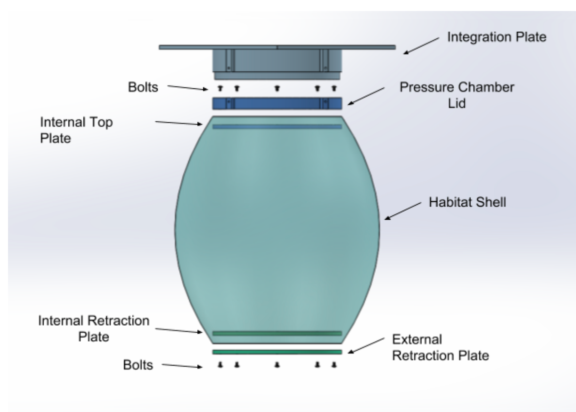


Figure 5: Design 1 Transparent View

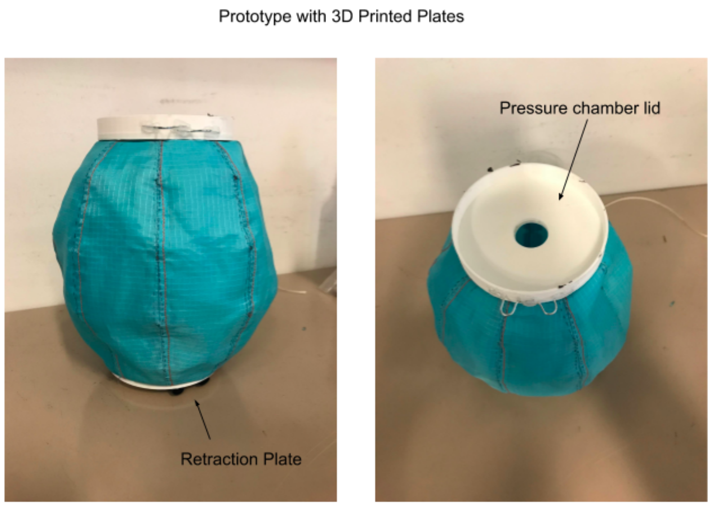


Figure 6: Habitat Design 1 Prototype

After initial testing with the prototype the entire design was deemed unfit to meet mission requirements. The quality of the fabric was much lower than predicted and would not be able to maintain pressure during flight. Along with the fabric leaking, the sewed seams were extremely challenging to seal completely. The design was discarded for its inability to hold pressure complication of the manufacturing process.

Iteration 2: Heat Sealable Ripstop with Pressure Chamber
The second design of the habitat was changed from the original sphere shape into a cylindrical model. The fabric selected was a Heat Sealable Nylon Diamond Ripstop. The diamond pattern increased the strength of the material and was intended to stop the propagation of tears if the fabric were to rupture. This was considered to increase the safety of the habitat because if there was a failure all the pressure would be released through a small tear rather than a catastrophic rupture.

The habitat was heat sealed along one vertical seam and used folded tabs to seal the base and top to the side wall. The polyurethane coating and heat seal made the fabric non-porous and able to maintain flight pressure. This design still included a pressure chamber to allow the habitat to interface with the main structure. Shown below are images of the heat sealing process to form the top and bottom of the habitat shell.

Figure 7: Heal Seal of Top

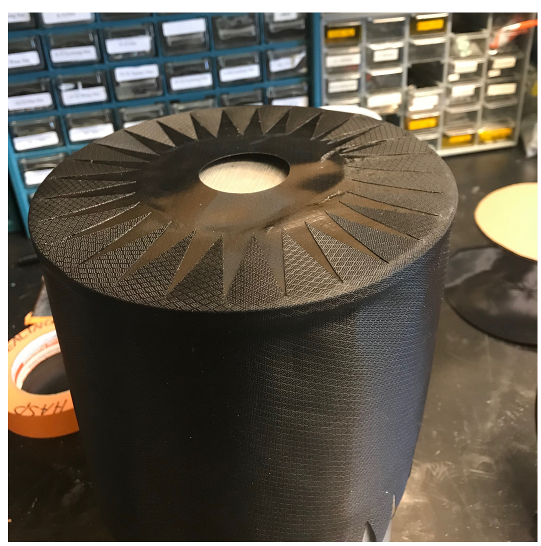


Figure 8: Fully Sealed Top of Habitat

Similar to the first design, making an airtight seal between the fabric and pressure chamber proved extremely difficult. Several different methods were attempted to bond the fabric to the pressure chamber including epoxy, adhesive caulk, rubber o-rings, and liquid rubber coating. All methods proved insufficient to hold pressure, however the method of manufacturing the habitat shell was both efficient and successful. It took approximately two hours to construct each habitat with this method.

To test each habitat it was connected to a pressure regulator and submerged in water. The habitat was visually inspected to see the rate and location of leaks. The valve was then closed to determine if the habitat was able to hold pressure. All of the prototypes leaked only around the connection to the pressure chamber so the entire pressure chamber was discarded in favor of a redesign.

Iteration 3: Heat Sealable Ripstop with Pressure System
The final design of the habitat included a completely fabric shell with one brass connector that would screw in the full pressure assembly. Similar to Design 2, the shell was sealed with one vertical seam and fold tabs on the top and base. The connector sealed to the fabric using an o-ring on the interior and exterior of the habitat. Since the opening of the habitat was significantly smaller it was much easier to form a complete seal.

Figure 9: Exterior of Pressure Connector

Figure 10: Interior of Pressure Connector

These connectors were able to replace the entire pressure chamber and greatly simplify the manufacturing process of the habitats. Each model took approximately 1.5 hours to complete.

For a redundant seal, the tabs along the top and base of the habitat were coated in liquid rubber that was flexible and air tight. This helped hold pressure as the heat seal would begin to fatigue after several pressurization cycles.

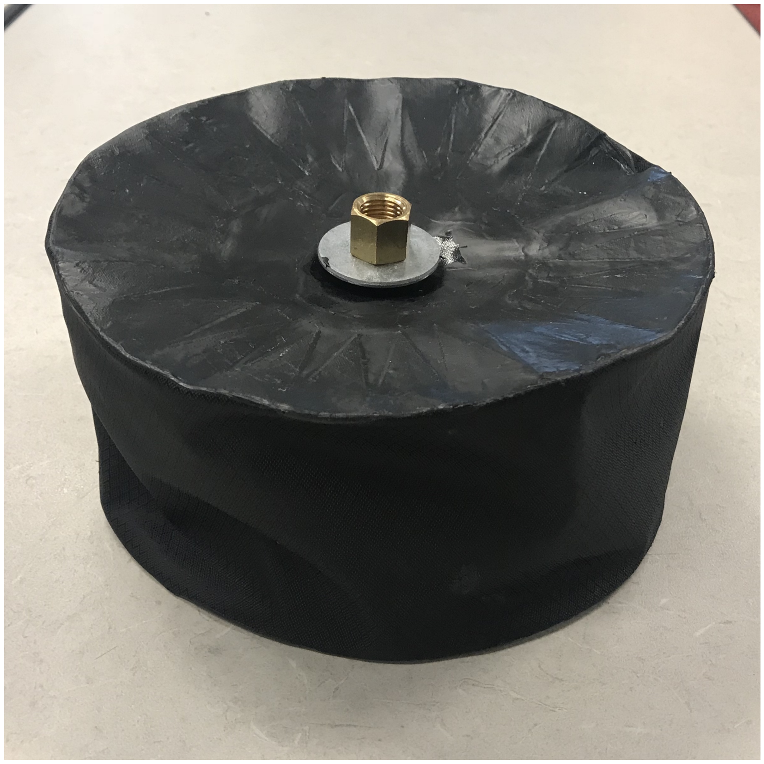


Figure 11: Final Habitat Design Fully Constructed

2.3 Retraction Method

A stepper motor was chosen as the method to retract the habitat from its extended to retracted states. The retraction method was initially designed with two strings that ran under the the habitat and were tied to the motor shaft. The only design iteration changed the retraction method from two strings to one. Since the habitat shape and size remained fairly constant it was easy to adapt the retraction method the the final habitat design by adding tabs at the bottom that would act as guides for the string.

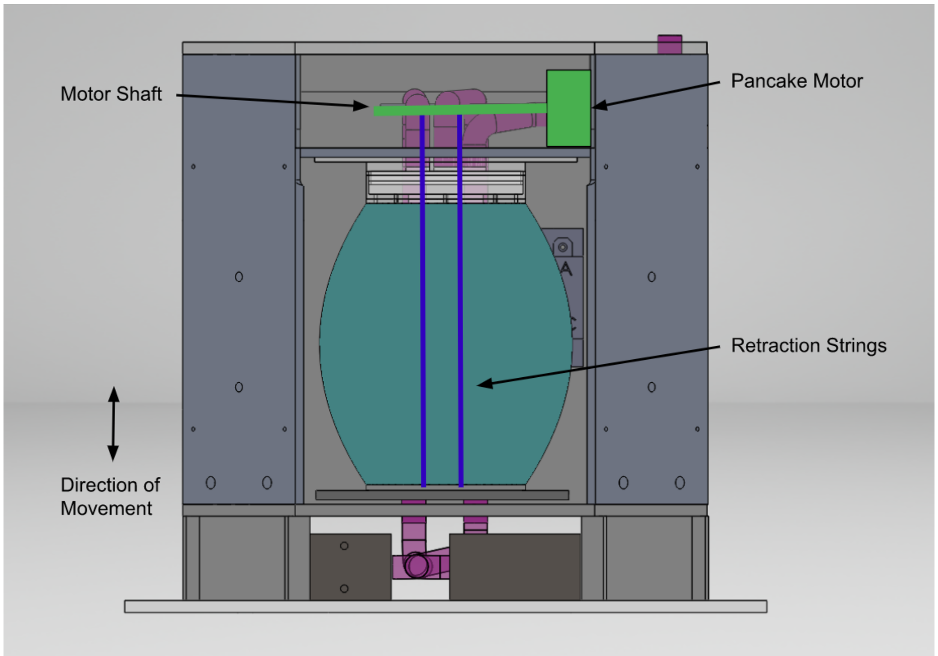


Figure 12: Initial Retraction Method Design

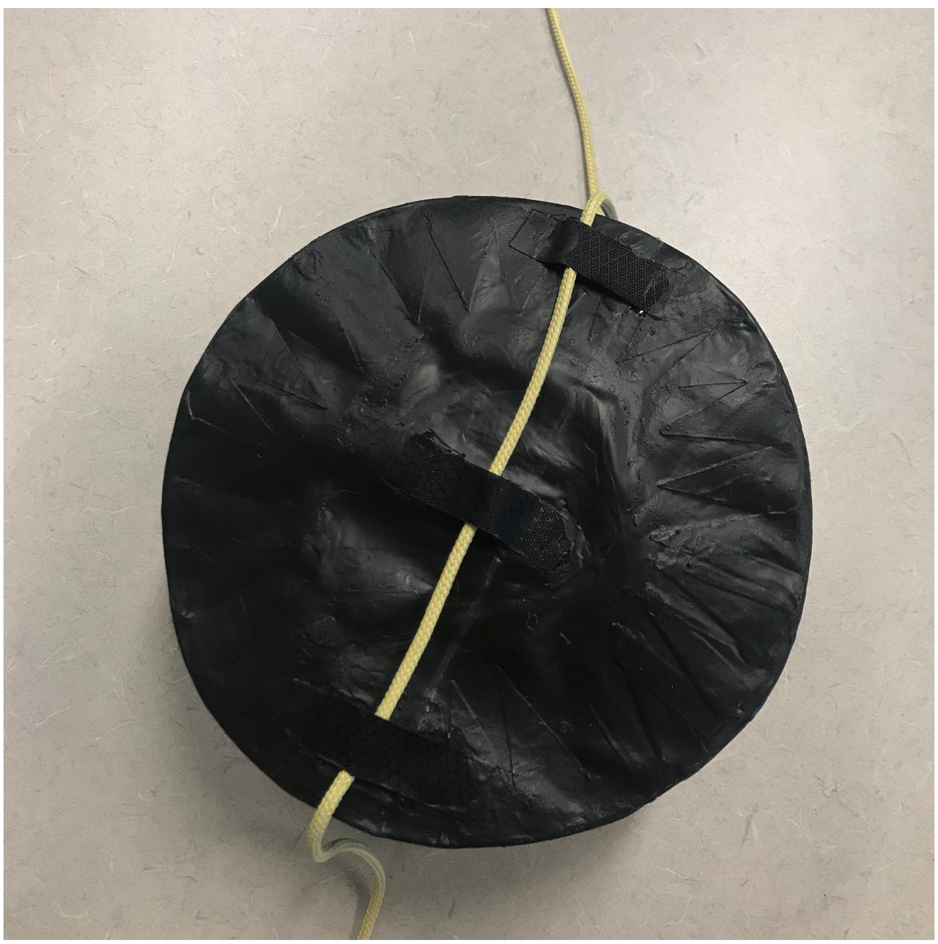


Figure 13: Retraction String Interface with Habitat

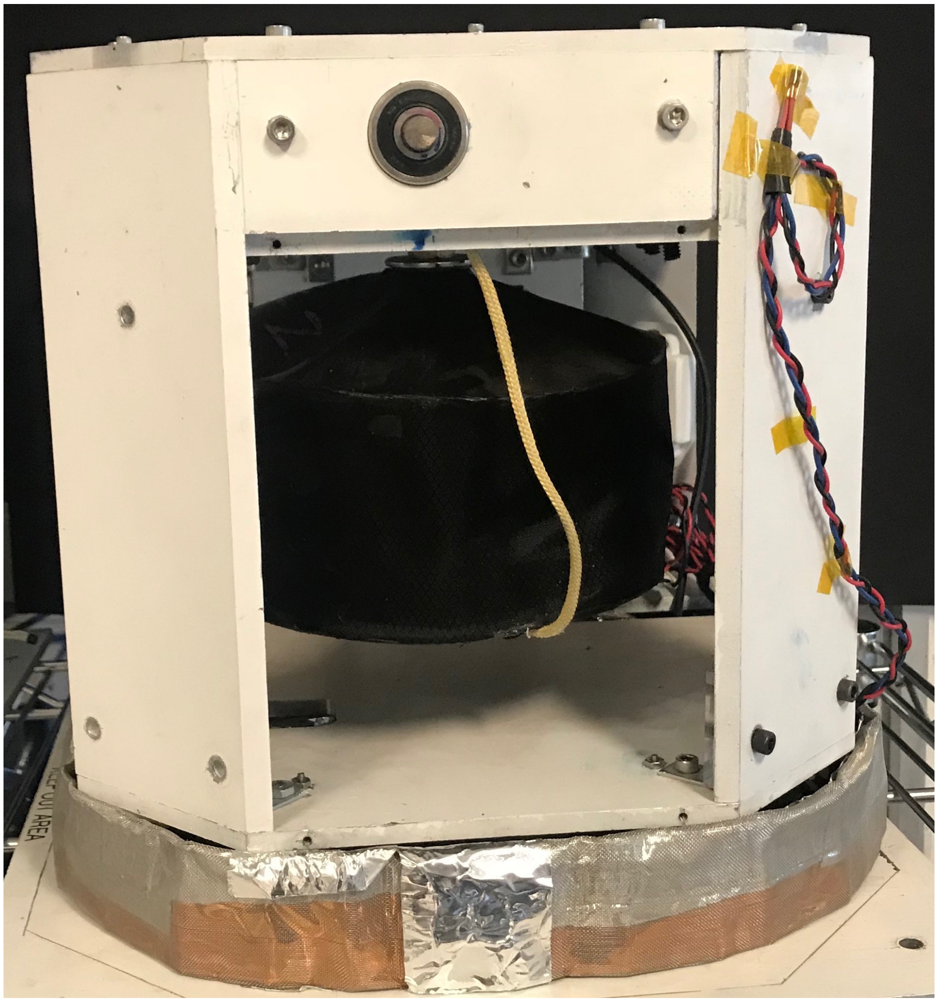


Figure 14: Integrated Retraction method

2.4 Pressure System

After the pressure chamber was removed from the habitat design, an alternative solution was made out of a system of brass tubing. The new pressure assembly interfaced directly to the inlet solenoids and had components that connected the exhaust solenoid, safety release valve, pressure transducer, and habitat.

The new pressure system was integrated in the top housing of the structure

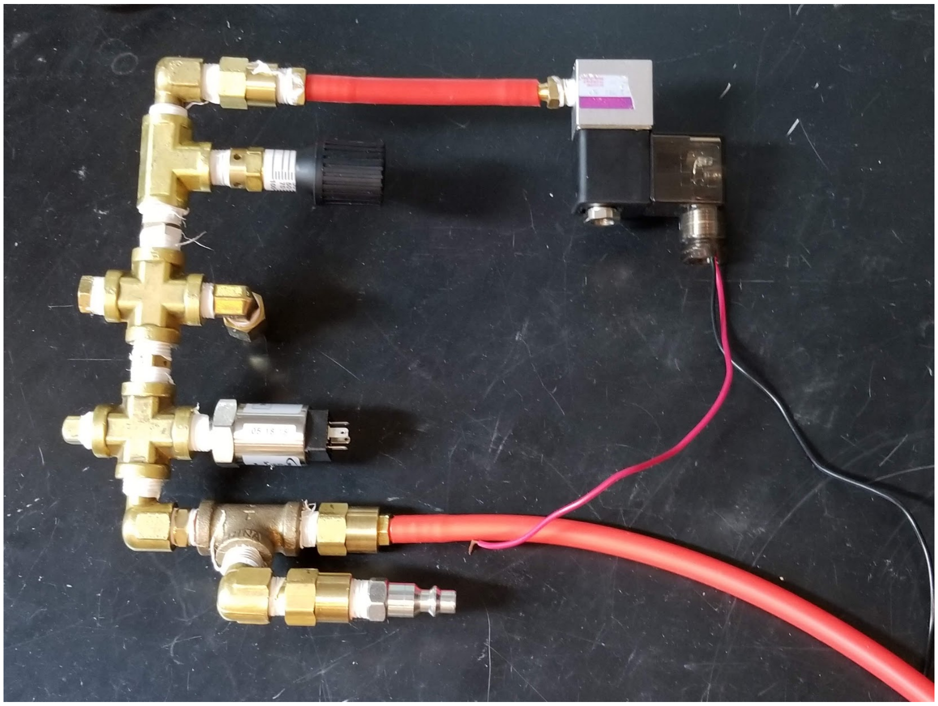


Figure 15: Brass Pressure System

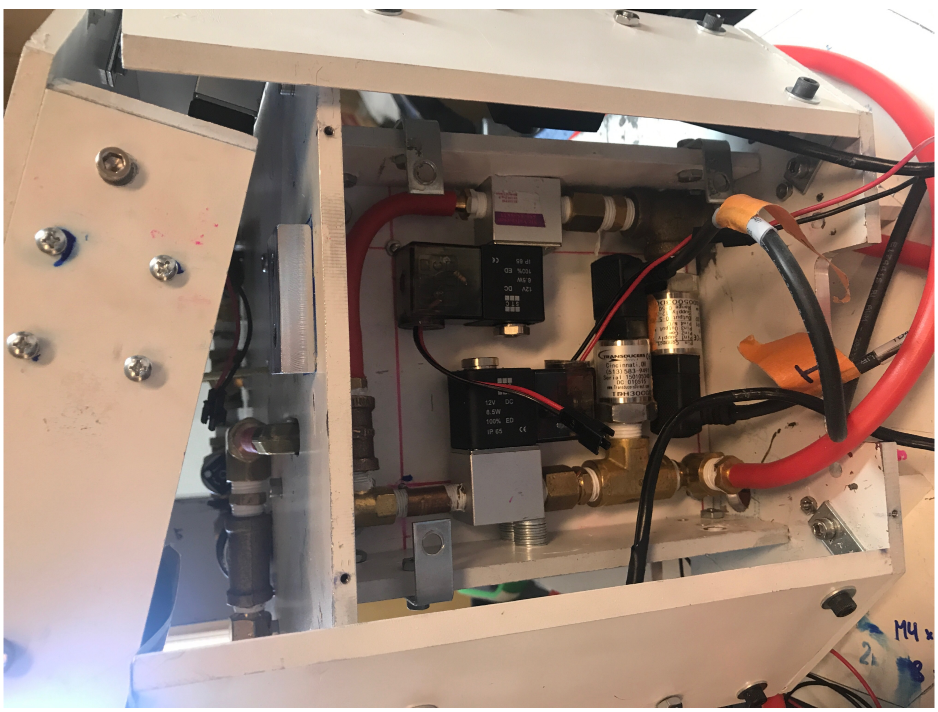


Figure 16: Inlet Solenoid Attachment

2.5 Structures

The structure was mostly designed according to the Miura I mission. The main differences were that two new chambers had to be created. Firstly, as can be seen in Figure 18, the chamber at the top of the payload housed the tubing (not shown) as well as the motor to retract the payload. Secondly, as can be seen in Figure 19, the chamber at the bottom contained the Raspberry Pi as well as the gas canisters and regulators (not shown). The box at the back of the payload housed the tubing and served as a point of attachment for the PCB. Finally, the cameras were mounted on the back side walls, as can be seen in Figure 17, to capture the whole habitat.

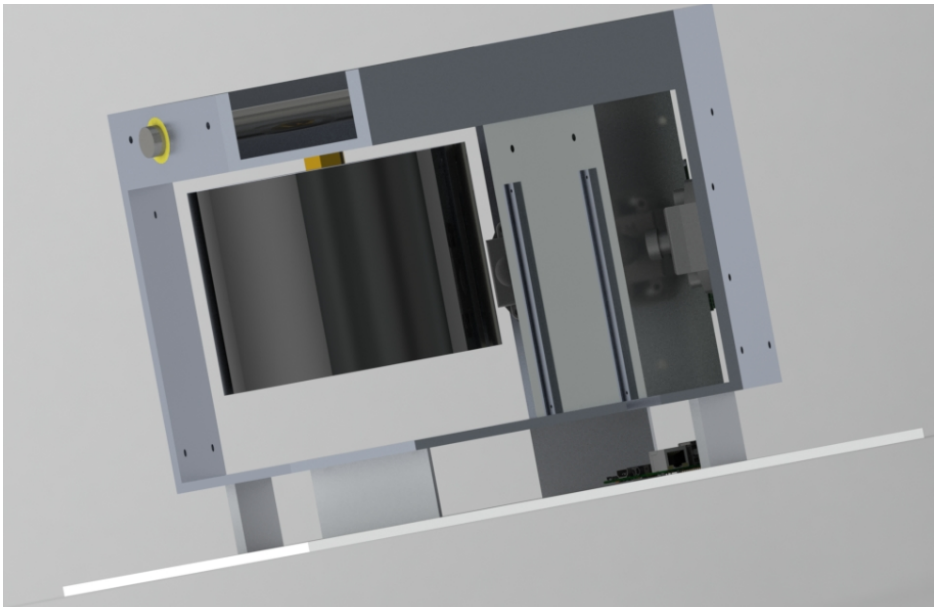


Figure 17: View of structure showing habitat, cameras, and struts to provide clearance for pressure regulators

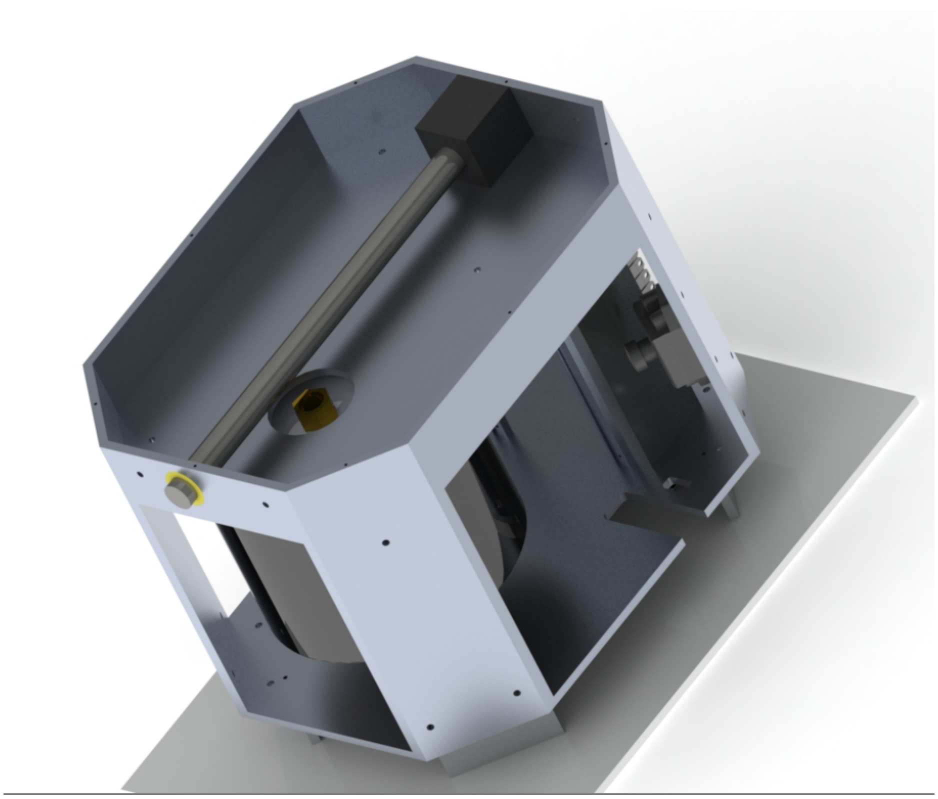


Figure 18: View of structure showing open upper housing with motor shaft and pressure inlet

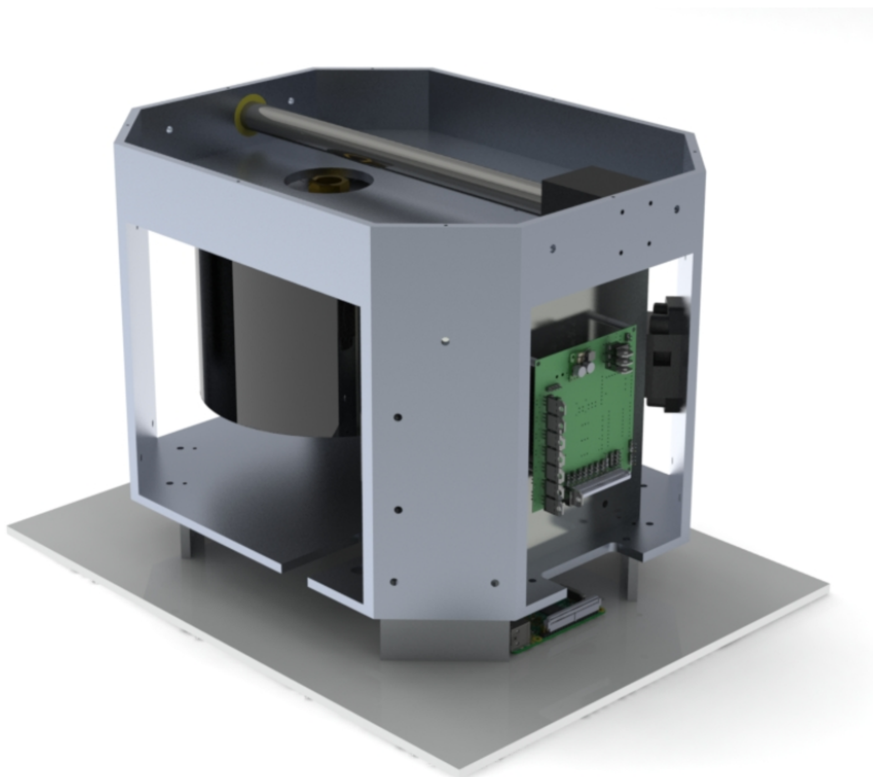


Figure 19: View of structure showing mounting locations of EPS board and Raspberry Pi

The whole structure was made of Aluminum that mounted onto the HASP interface plate. The pressure regulators were placed in the bottom chamber to minimize damage if something went wrong. The box as seen in Figure 17 next to the cameras shielded the tubing up to the top of the payload to minimize damage. All of the components were fixed down with appropriate fasteners and slots were cut at appropriate places that allowed the components to fit but still maintain the structural integrity.

2.6 Command and Data Handling

2.6.1 Overview

Flight software was written in Python 3, and a Raspberry Pi 3 was used to control hardware and read data. The code was threaded, with pressure regulation being controlled in one thread and sensor data, uplink, downlink, and heater control functioning in the other thread.

2.6.2 Uplink Commands

0x01 0x01: Ping Pi
0x01 0x02: Manual Mode
0x01 0x03: Continue Automation Mode
0x01 0x04: Restart Automation Mode
0x01 0x05: Retract Motor
0x01 0x06: Take Picture
0x01 0x07: Reboot Pi

0x02 0x01: Open Solenoid Valve 1
0x02 0x02: Close Solenoid Valve 1
0x02 0x03: Open Solenoid Valve 2
0x02 0x04: Close Solenoid Valve 2
0x02 0x05: Open Exhaust Value

0x02 0x06: Close Exhaust Valve

0x03 0x01: Disable Valve 1
0x03 0x02: Enable Valve 1
0x03 0x03: Disable Valve 2
0x03 0x04: Enable Valve 2

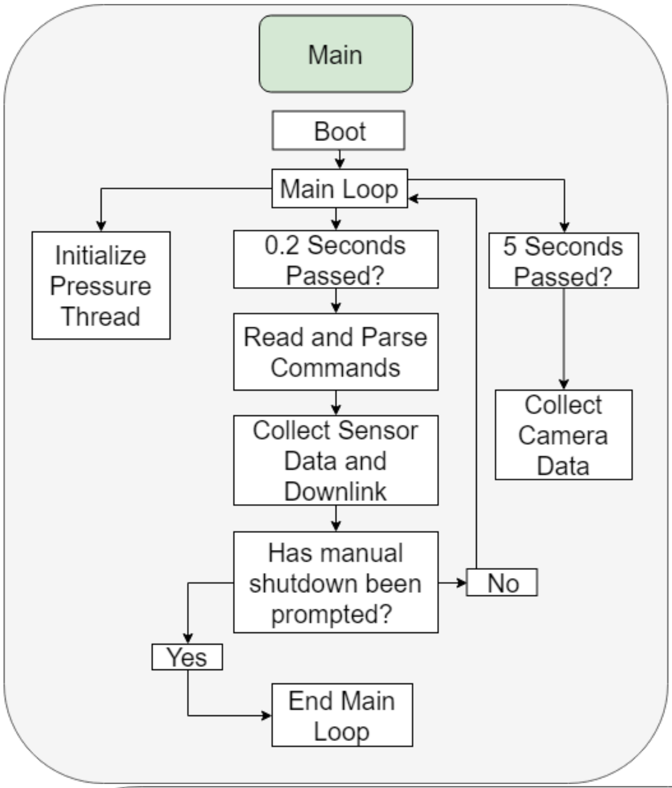
0x04 0x01: Turn On Solenoid Heaters
0x04 0x02: Turn Off Solenoid Heaters
0x04 0x03: Turn On Regulator Heaters
0x04 0x04: Turn Off Regulator Heaters

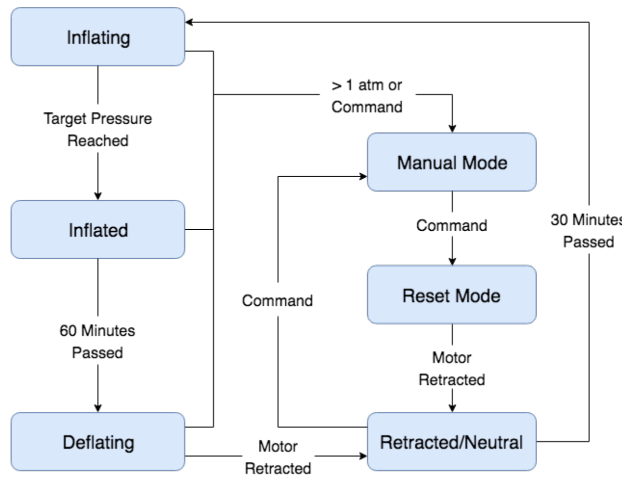
2.6.3 Downlink Packets

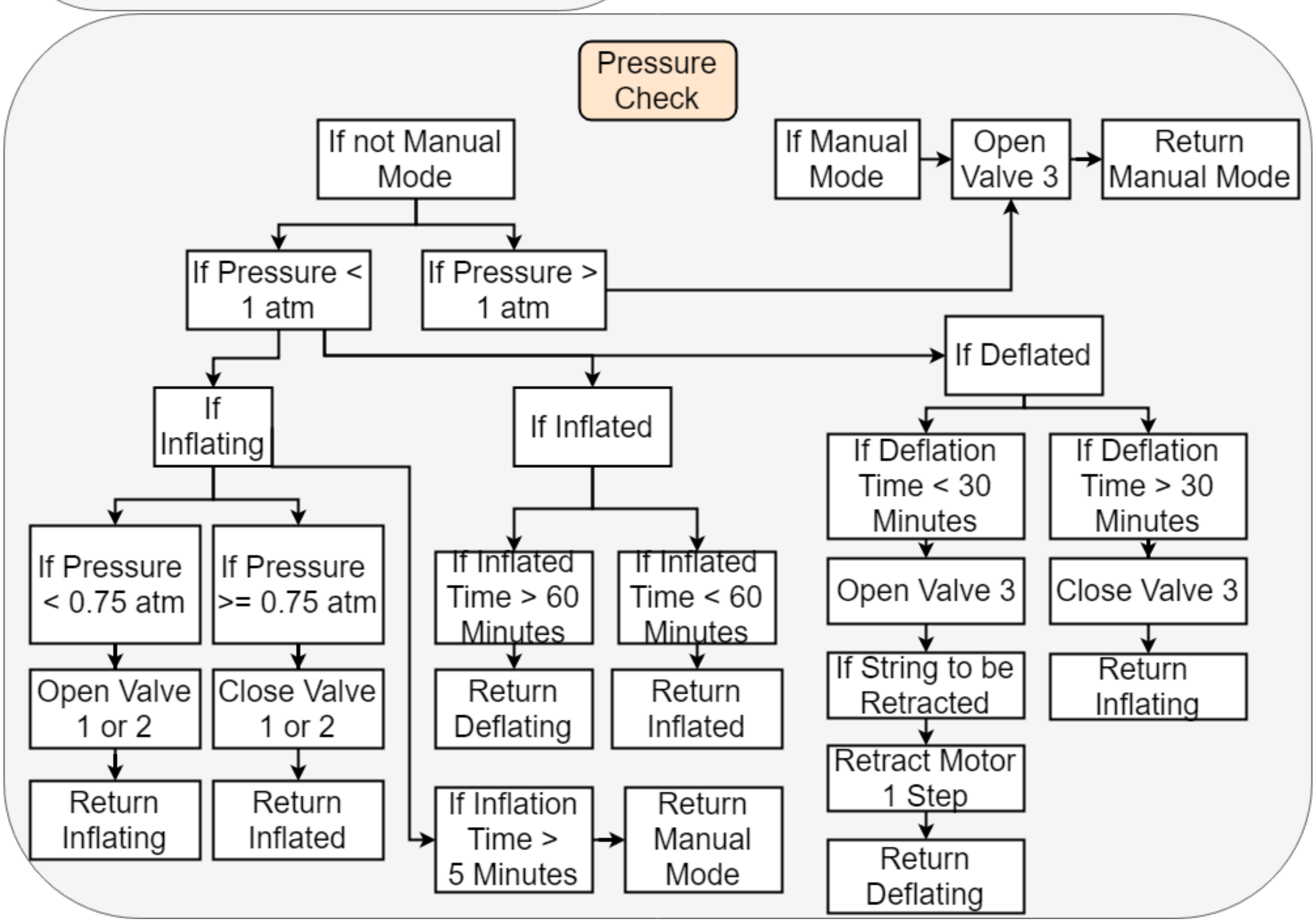
Mission Packet Format:CU MI2 <sender> <data type> <time> <checksum> <stage> <data>

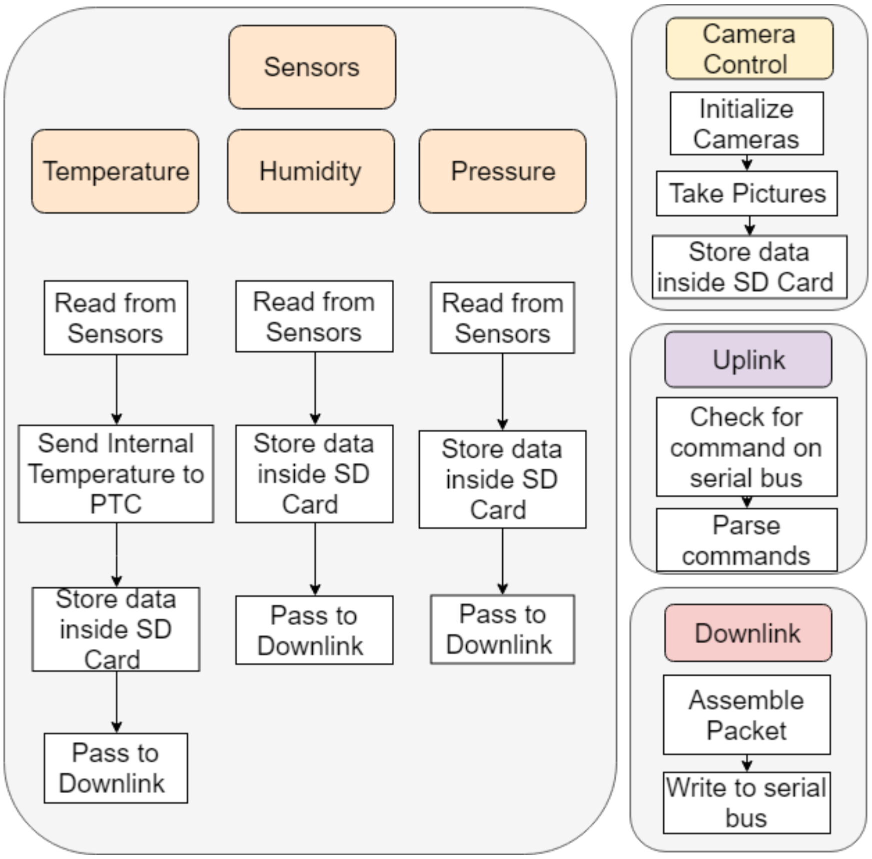
Sensors' Downlink Packet Format Information:
Humidity = ['SE','HU']
Ambient Temperature = ['SE','TE']
Ambient Pressure = ['SE','PR']
Temperature Transducer = ['SE','TT']
Pressure Transducer = ['SE', 'PT']

2.6.4 Code FBD


Main
Boot
Main Loop
Initialize Pressure Thread
0.2 Seconds Passed?
5 Seconds Passed?
Read and Parse Commands
Collect Camera Data
Collect Sensor Data and Downlink
Has manual shutdown been prompted?
No
Yes
End Main Loop


Inflating
Target Pressure Reached
Inflated
60 Minutes Passed
Deflating
> 1 atm or Command
Manual Mode
Command
Reset Mode
Motor Retracted
Command
30 Minutes Passed
Motor Retracted
Retracted/Neutral


Pressure Check
If not Manual Mode
If Manual Mode
Open Valve 3
Return Manual Mode
If Pressure < 1 atm
If Pressure > 1 atm
If Deflated
If Inflating
If Inflated
If Deflation Time < 30 Minutes
If Deflation Time > 30 Minutes
If Pressure < 0.75 atm
If Pressure >= 0.75 atm
If Inflated Time > 60 Minutes
If Inflated Time < 60 Minutes
Open Valve 3
Close Valve 3
Open Valve 1 or 2
Close Valve 1 or 2
Return Deflating
Return Inflated
If String to be Retracted
Return Inflating
Return Inflating
Return Inflated
Retract Motor 1 Step
If Inflation Time > 5 Minutes
Return Manual Mode
Return Deflating



2.7 Electrical and Power Systems

The EPS sub system was tasked with the purpose of powering the components of the payload with the power provided from the HASP platform in order to maintain functionality, control, and communication with the components. The payload kept below the 30V, 2.5A power requirements, averaging around 0.50 A, maxing at 1.29A. Subsequently, the voltage draw averaged at 28.17V and maxed at 29.64V.

2.7.1 HASP Integration

An EDAC connector (Fig. 20) supplies the power and grounding for the experiment. Pins A, B, C, and D are used for power, and W, T, U, and X are used for ground. The DB9 transmits the serial data to send information back to the ground station.

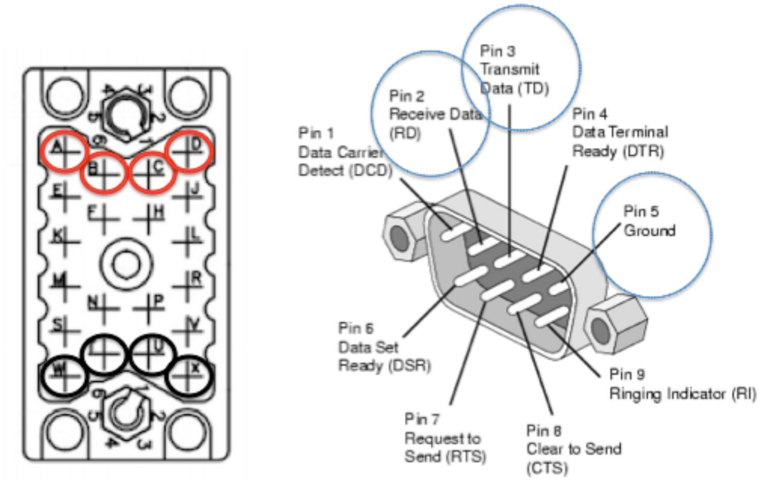


Figure 20: EDAC(left) and DB9 (right)

2.7.2 Power Budget

An initial power budget (Figure 21) was created to estimate the amount of power the entire system would draw to ensure the payload did not go over the power allocated. During flight (Figure 23), the power spiked during inflation and retraction, and remained steady during sustaining and stowing periods. The overall power average was 14.1 Watts, and the maximum power used was 35.3 Watts.

Mission Phase	Component	Voltage (VDC)	Current (A)	Power Usage (W)
Inflation	Solenoid Valve	12.0	0.56	6.72
	Transducer (x2)	12.0	0.020	0.24
	Raspberry Pi	5.00	2.50	12.5
	Heating Pads (x4)	5.00	2.40	12.0
	Lighting LEDs (x32)	5.00	1.28	6.40
	USB Cameras (x2)	5.00	0.240	1.20
	Sensors + Misc. LEDs	5.00	0.100	0.500
	Best Estimate Efficiency			**45.0**
	Best Estimate + 10%			**49.5**
Sustaining / Deflation	Transducer (x2)	12.0	0.020	0.24
	Solenoid Valve	12.0	0.560	6.72
	Raspberry Pi	5.00	2.50	12.5
	Lighting LEDs (x32)	5.00	1.28	6.4
	Heating Pads (x4)	5.00	2.40	12
	USB Cameras (x2)	5.00	0.240	1.2
	Stepper Motor (x1)	5.00	2.00	10
	Sensors + Misc. LEDs	5.00	0.100	0.5
	Best Estimate Efficiency			**54.5**
	Best Estimate + 10%			**60.0**

Figure 21: Estimated Power Usage

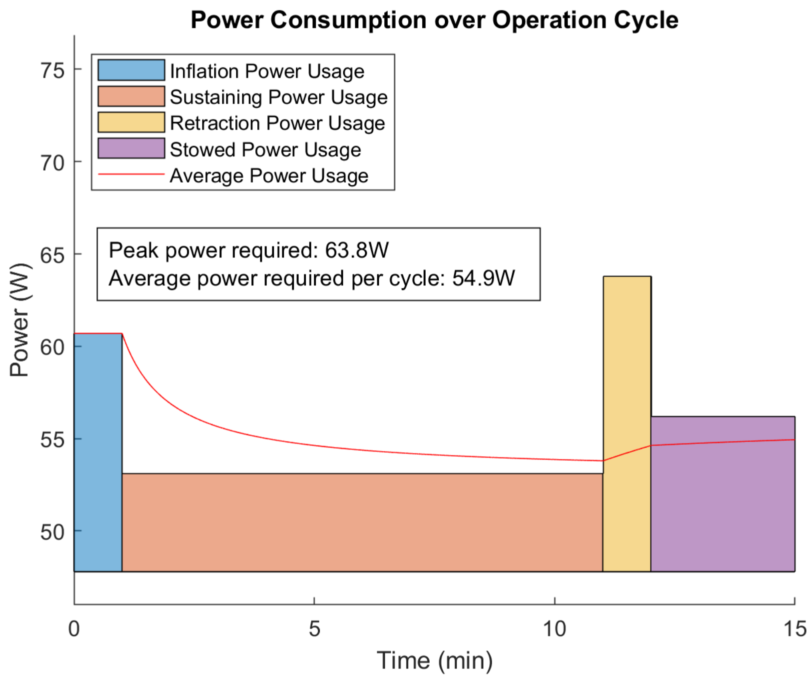


Figure 22: Initial Power Estimation

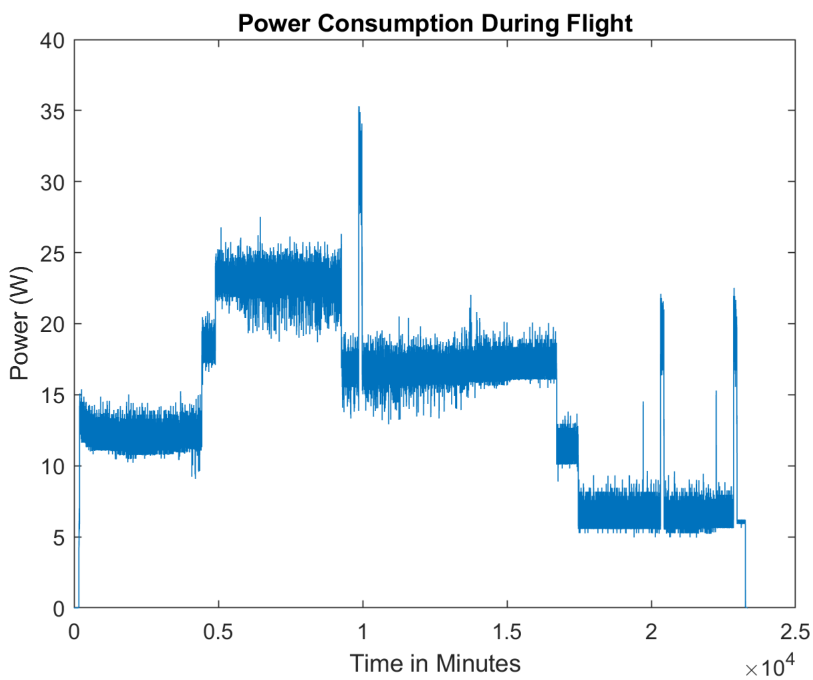


Figure 23: Power Consumption During Flight

2.7.3 Printed Circuit Board Design

Two PCBs were designed in total. The first one was the main PCB that controlled all the components, Figure 24, and the second one controlled the power distribution to the Buck Converters, Figure 25.

The Main PCB went through many iterations to reach the final design. The high power lines and components were separated from the low power components in order to avoid any unnecessary damage. A ground plane was implemented on both layers in order to ensure that there were no floating connections. All of the components that radiated the majority of the heat energy were attached to Aluminum heat sinks. Finally, all of the identical components were placed together in order to make wiring easier and to identify components more easily.

The Power PCB was implemented in order to distribute power to the motor, transducer and buck converters from the main HASP power line.

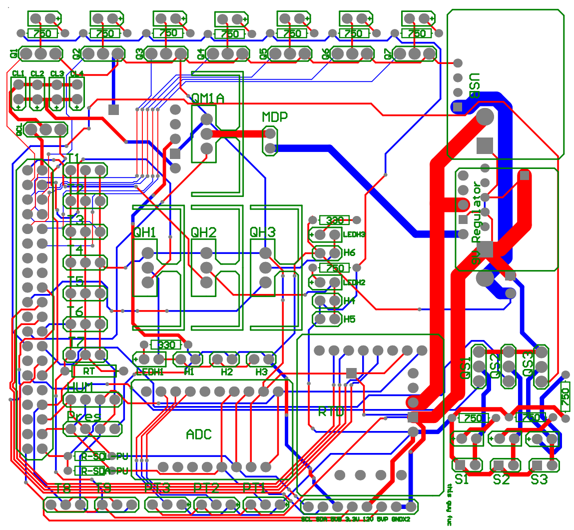


Figure 24: Main PCB Design

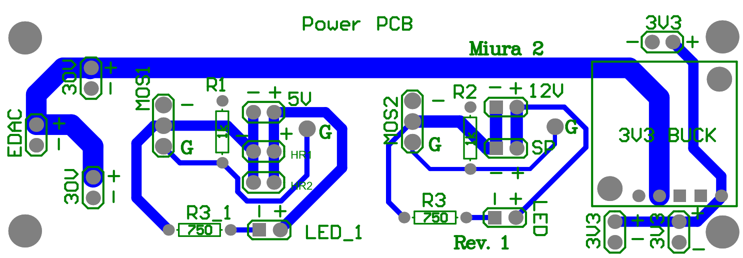


Figure 25: Power PCB Design

2.7.4 Wire Management

In order to reduce sources of error in wiring, wires were made as short as possible to reach their necessary destinations, twisted and zip - tied together, and then labeled. This is seen in Figure 26. Finally, the entire wire box was covered with a combination of kapton tape and electrical tape.

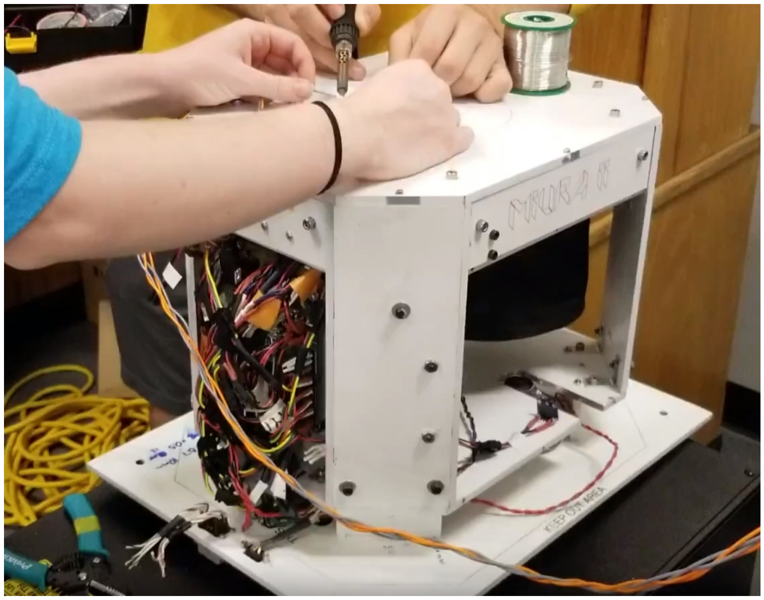


Figure 26: Final Wire Management

3 Testing

3.1 Habitat Testing Failure Methods

The habitat was tested in different variations to predict the habitat's behavior under different circumstances of failure.

3.1.1 Habitat Testing Results - Methods of Failure

There where two main ways in which the habitats would fail under varying conditions.

Habitat Connector After cycling the habitat through the pressure and retraction systems, it was inflated to at least three times flight pressure to ensure it met the factor of safety requirement. There was no failure of the material but the hole around the connector which is sealed by o-rings stretched enough to allow air flow out of the habitat. In the case of this failure there is no debris or tearing of material. This test simulated the scenario where the inlet solenoid fails and continuously feeds in pressure from the regulator. If this were to occur on flight the habitat would allow air to vent until the canister is depleted with no danger posed to other payloads.

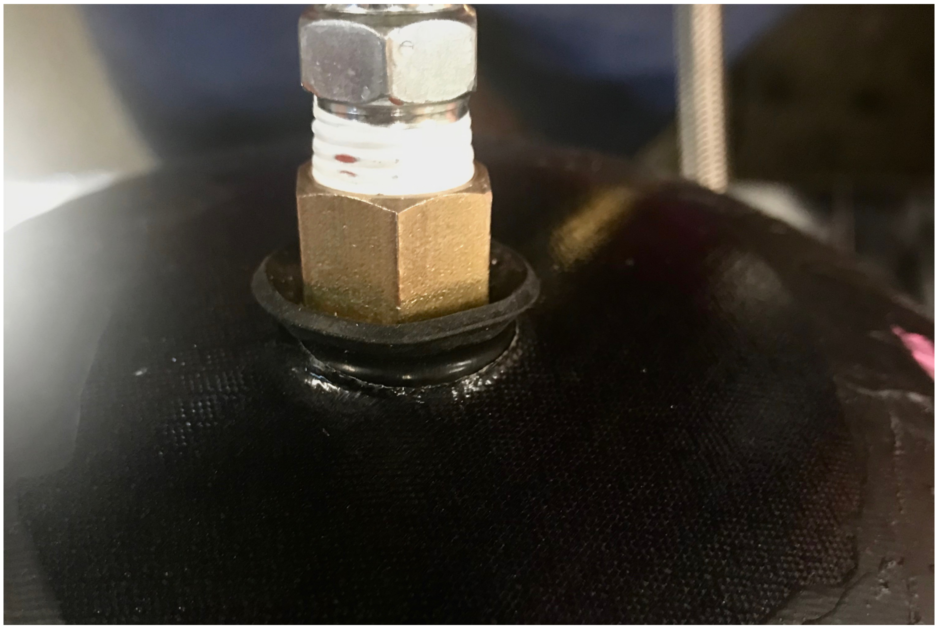


Figure 27: Habitat Connector Failure

Rupture Failure

In the event that the solenoid, regulator, and safety release valve failed, the habitat will be pressurized so rapidly it will not have the ability to stretch quickly enough to equalize the pressure. To create this scenario the habitat was inflated using a compressed air source at 90 psi to simulate the flow rate of the canisters directly into the habitat. Within one second that habitat was inflated beyond its maximum pressure and displayed a rupture failure. The habitat tore at opposites sides of the connector and propagated completely down both sides. The habitat and acrylic plate where both safely contained within the steel mesh. In the event that every safety mechanism in place fails, the habitat will still remain within the structure posing no danger to other payloads.

Figure 28: Rupture Failure

3.2 Habitat Testing Plan

3.2.1 FOS of 2

In the event that both the regulator and solenoids failed that habitat would be pressurized to a much higher psi than designed for. It was tested to 15 psi which includes a factor of safety of 2. The habitat successfully passed this test because it did not have any visual material failure, the only effect was the leak rate increasing.

3.2.2 Leak Rate

To meet mission requirements, the habitat had to be able to retain a pressure between 7.5 psi and 4.4 psi through the sustention stage. During manufacturing, each habitat was submerged in a full water bath to visually inspect any leaks which would produce bubbles. This was to ensure consistency in the manufacturing process. The leak rate test was performed by inflating a habitat to the flight pressure of 7.5 psi and proving that it remained above 4.4 psi for ten minutes. Habitats were randomly chosen for leak rate testing and since they all passed, it was assumed the manufacturing method was consistent enough across all habitats being tested. The final habitat chosen for flight was leak rate tested once before integration with the payload.

3.2.3 Cycle Testing

In order to understand how the durability of the habitat changed with multiple cycles, the habitat's failure pressure was tested after 1, 20, and 100 cycles.

1 Cycle Failure Test The data for the 1 Cycle Failure Test shows the habitat failing at 25.0 psi. The habitat connection failed causing the mass flow rate into the habitat to equilibrate with the mass flow rate out. This caused the pressure to equalize which can be seen after minute 3 in Figure 2. The sharp drop off is caused by the pressure being vented from the habitat to ensure that personnel and hardware remain safe. This test is considered successful because the payload failed at a pressure of 24.9 psi, which is greater than three times that of flight pressure.

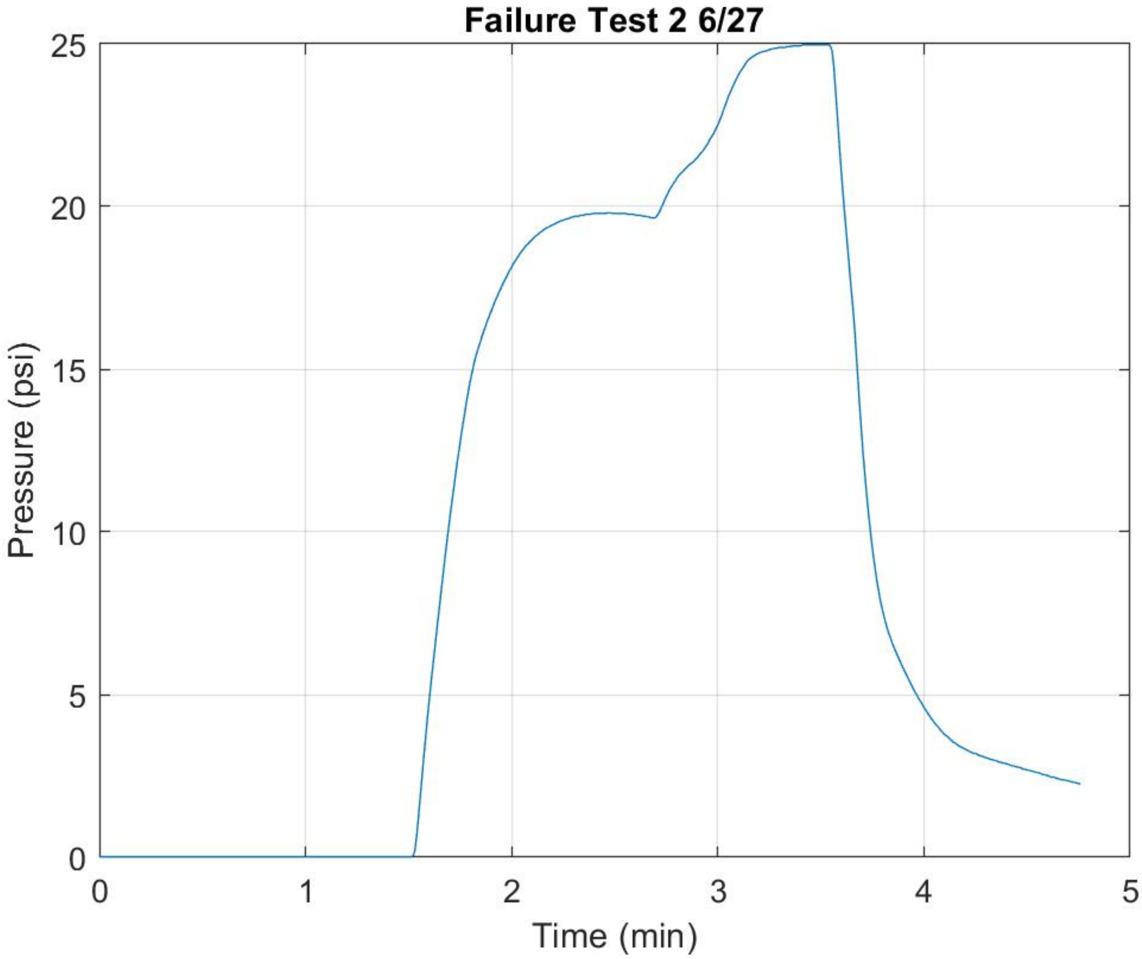


Figure 29: Pressure Profile inside of the Habitat

20 Cycle Failure Test The habitat failed in the same way as the 1 Cycle Failure Test, at the habitat connector, at 22.5 psi. The internal pressure of the habitat is shown as a function of time. After minute 3 of the test the mass flow rate into the habitat equaled the mass flow rate out of the habitat which is classified as a habitat failure. This test was also cut off to maintain personnel and hardware safety. The test is considered successful because the habitat failed at greater than three times flight pressure.

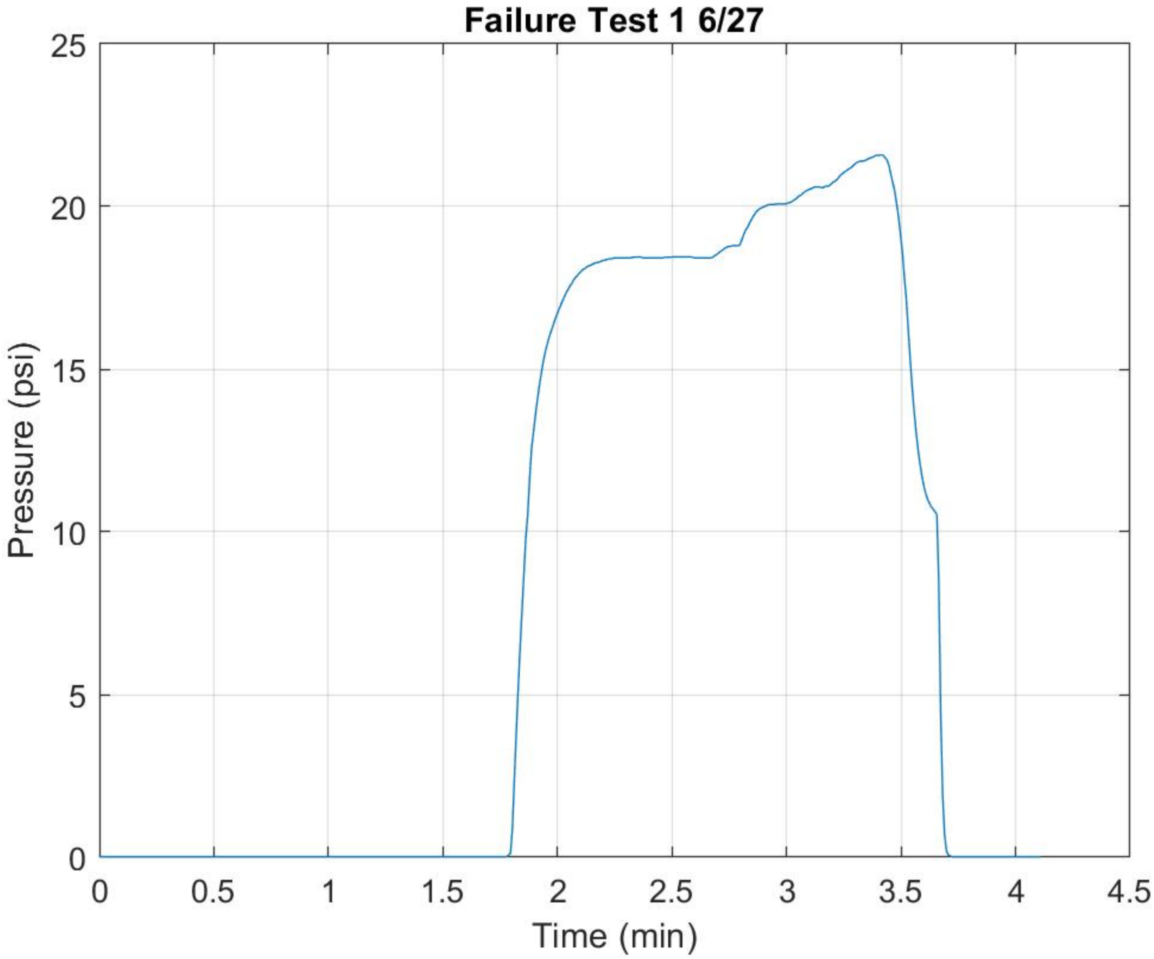


Figure 30: Pressure Profile inside of the Habitat

100 Cycle Failure Test After a 100 cycles the habitat failed at the connector at 19.5 psi.

3.2.4 Habitat Containment Test

To mitigate the risk of any other payloads or the HASP platform being harmed by shrapnel from a catastrophic failure, the steel mesh was tested to ensure complete containment of the habitat. Below, the Habitat Containment System Testing set-up is shown. The Containment System is made out of 304 Stainless Steel with a wire diameter of 0.0065 inches. The openings in the mesh are 0.0185 square inches in size and the wire has a tensile strength of 75,000 psi. The Habitat Containment System was also tested during the 1 and 20 Cycle Failure Tests. During those two tests the habitat only failed via the habitat connector. The next test failed via rupture and the ripstop was able to partially escape the mesh. To mitigate the risk of the ripstop coming out of an edge of the containment mesh, ten screws were added which secured the mesh to the top and bottom plates of the payload. The mesh was tested in another rupture test where it successfully contained all habitat debris.

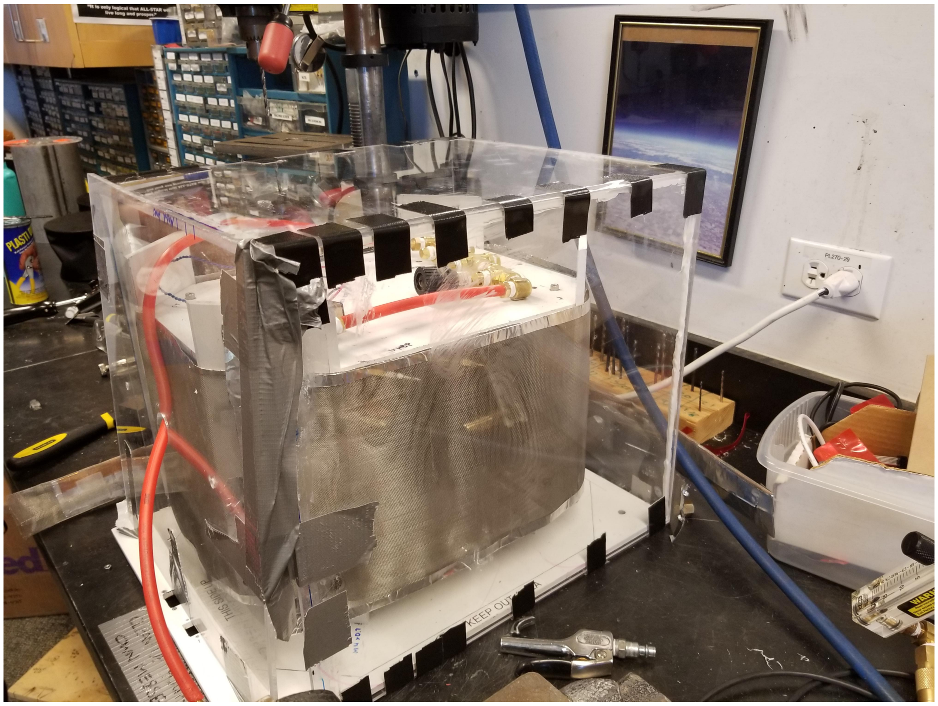


Figure 31: Habitat Catastrophic Failure Testing

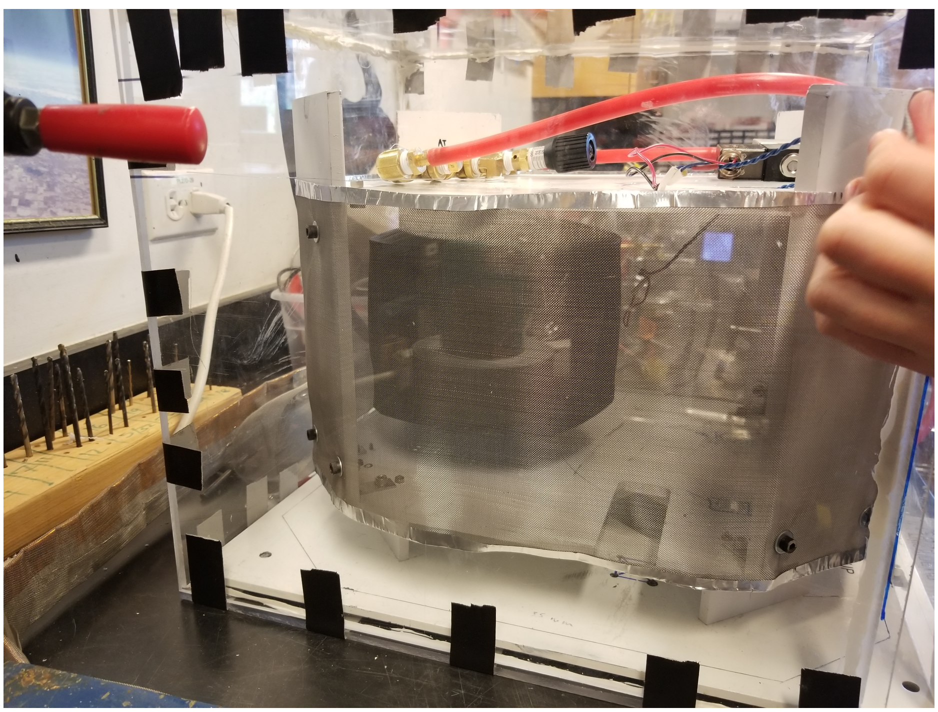


Figure 32: The Set-up for the Habitat Containment Test

Figure 33: The location of the Ripstop after rupture

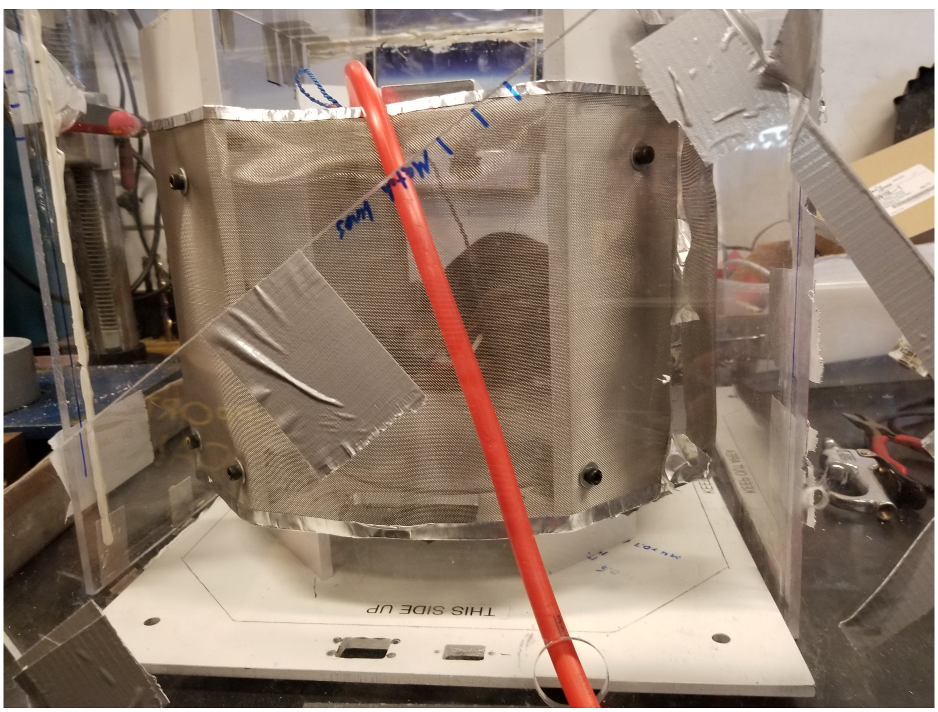


Figure 34: The acrylic box and habitat after rupture

3.3 Computational Analyses

3.3.1 Habitat Finite Element Analysis

A finite element analysis was performed on the habitat at the flight pressure of 7.5 psi. The results were analyzed to understand where the material was subject to the greatest amount of stress. The model was characterized by an even distribution of pressure on all faces of the habitat walls.

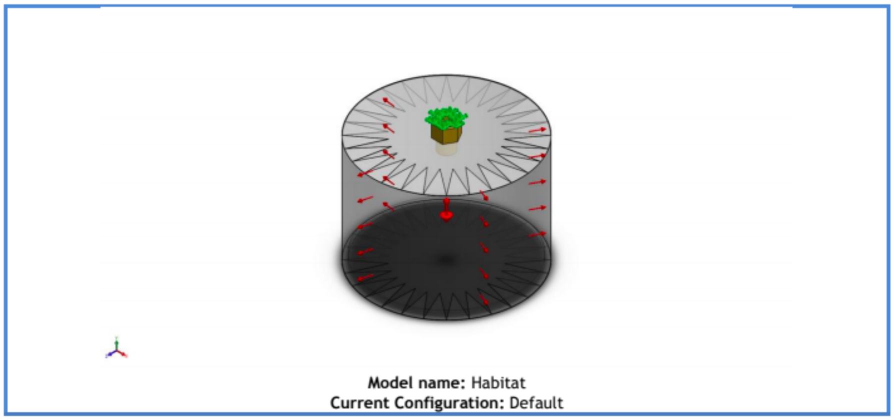


Figure 35: Habitat Pressure Distribution 7.5 psi

Name	Type	Min	Max
Amplitude1	AMPRES: Resultant Amplitude Plot for Mode Shape: 1(Load Factor = -0.00767648)	0.000e+000 Node: 34425	1.211e-002 Node: 96238

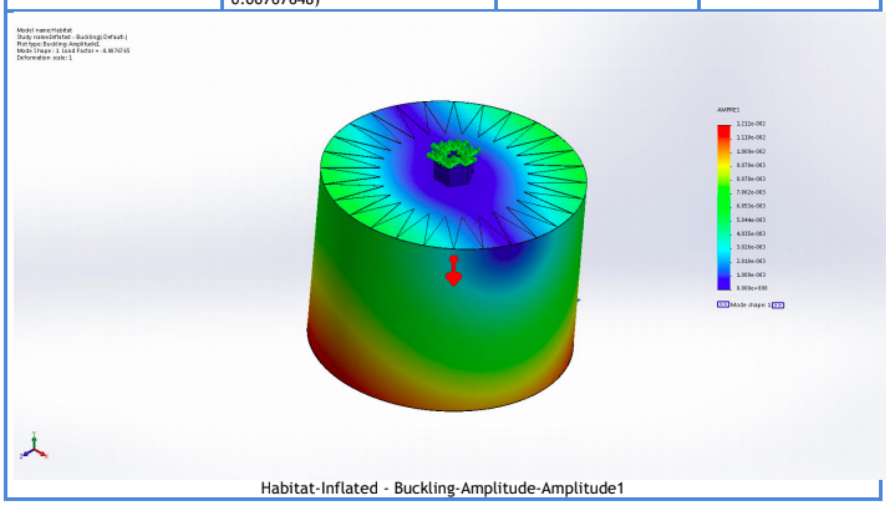


Figure 36: Material Stress

The FEA displayed a pressure distribution that was symmetrical about a single axis of the habitat. However, the model does not take into account the pressure at the top connector of the habitat. With this in mind it was predicted that the stress would greatly increase around the connector but still follow the axial characteristics displayed in the FEA. The maximum pressure is experienced at the bottom edge were the seam is heat sealed together. During testing, almost all habitats failed around the habitat connector which is inconsistent with the predictions of the FEA. While useful to understand the stress on the material, the FEA was not accurate enough to predict failures.

3.3.2 Structural Finite Element Analysis

A finite element analysis was performed on the structure to make sure it would be able to withstand the forces it would undergo on the HASP platform. The structure was tested in SolidWorks, with properties of the aluminum applied. The first test was a 10g vertical force and the second test was a 5g horizontal force, as those are the maximum forces the structure would undergo during flight.

Both simulations showed that the structure would be able to withstand the forces on the platform. The 10g simulation caused the most bending in the structure, on the side without the electronics box, but the amount of bending caused by the 10g force would not interfere with the habitat's expansion or contraction.

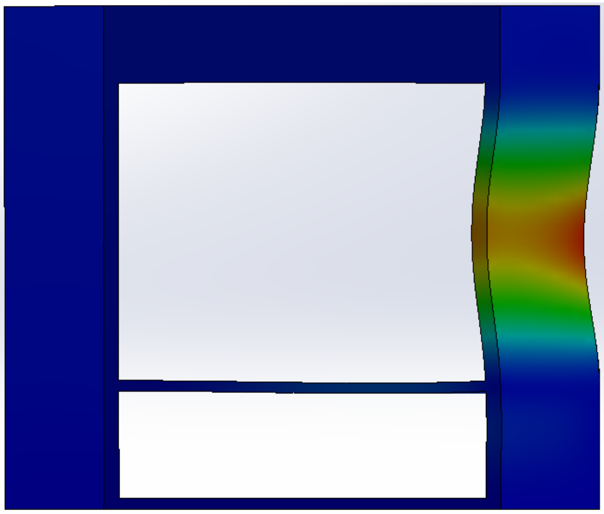


Figure 37: Front view: 10g Vertical Force

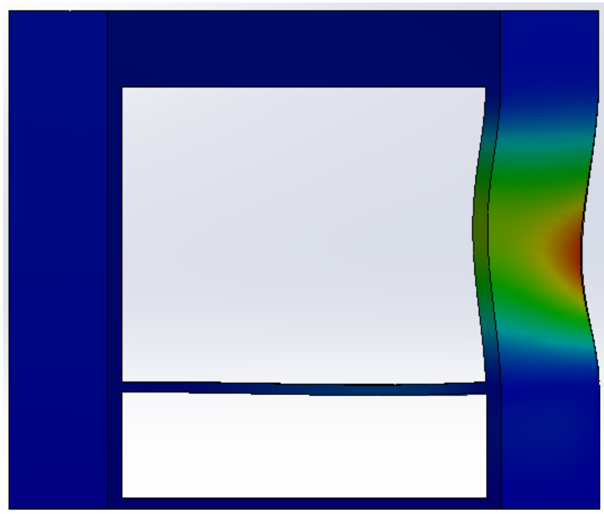


Figure 38: Front View: 5g Horizontal Force

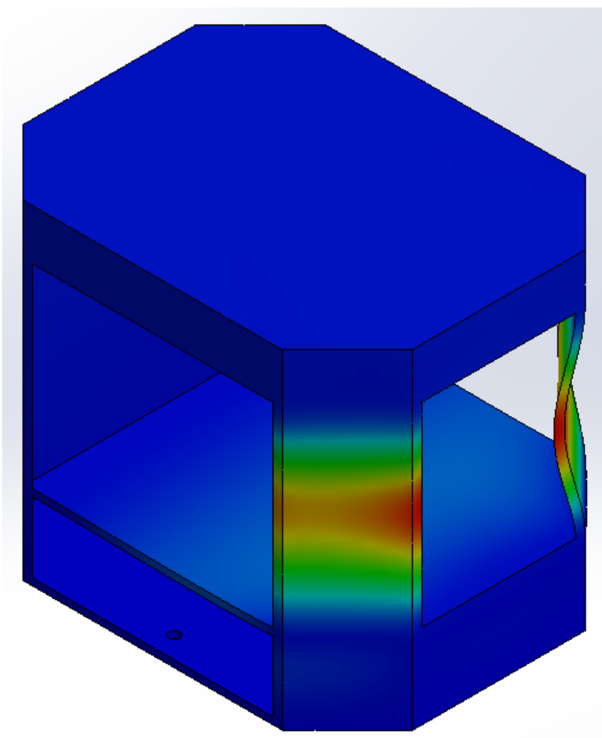


Figure 39: Isometric view: 10g Vertical Force

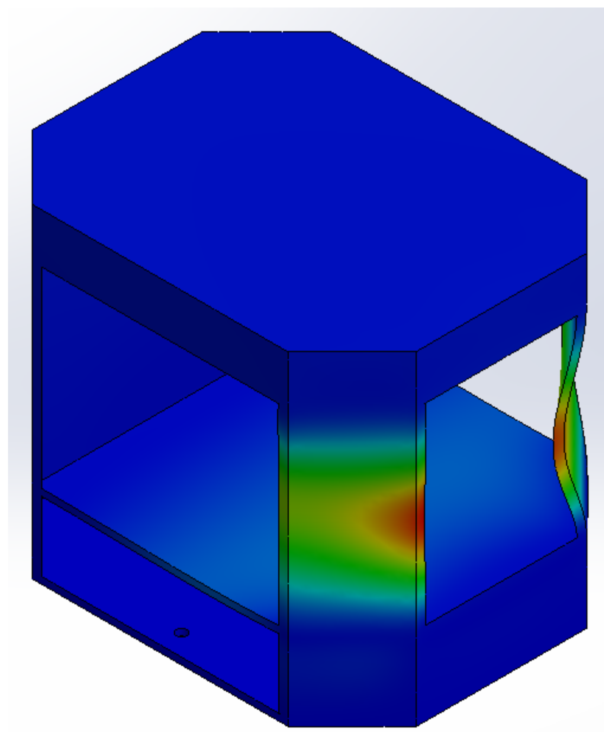


Figure 40: Isometric View: 5g Horizontal Force

3.4 Payload Testing

3.4.1 Optical Testing

The redundant two-camera system was tested by running an automated flight cycle and checking the resulting data for successful pictures. The pictures were considered successful if the payload was in focus, the white balance allowed for the payload to be seen in front of the background, and indicator LEDs could be seen during stow. Pictured below in figures 41 and 42 are two example test images demonstrating these criteria.

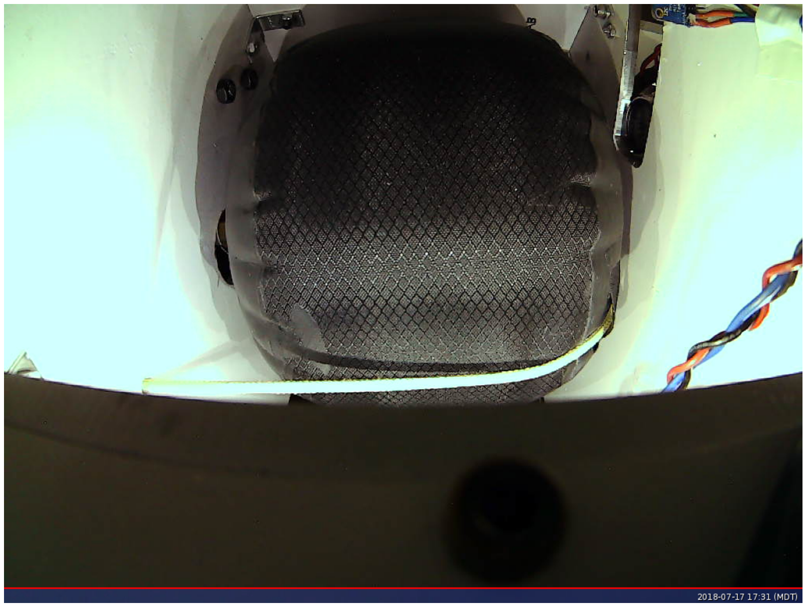


Figure 41: Optical Test Image of Inflated Payload

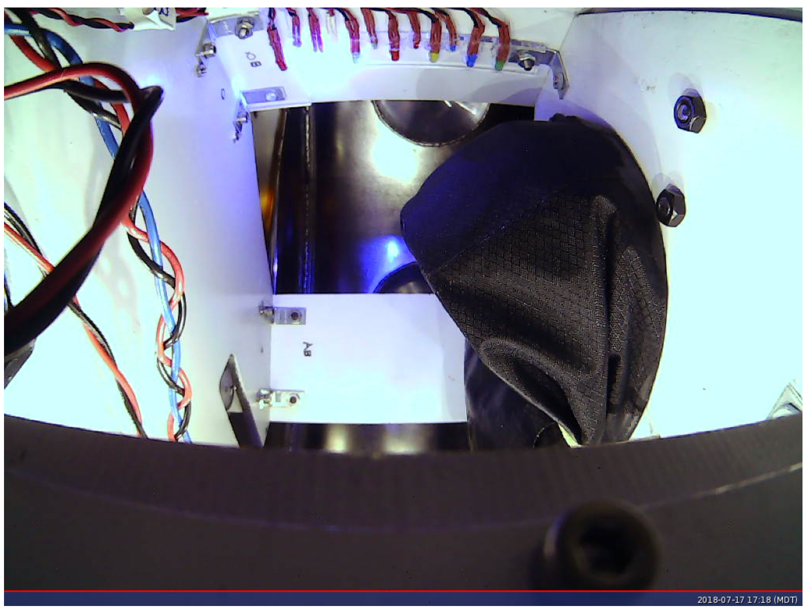


Figure 42: Optical Test Image of Stowed Payload

3.5 Safety Testing

The primary safety measures on the payload were the solenoid valves to control habitat pressure, the pressure release valve to vent pressure above 15 psi in the habitat, the regulators to control the pressure let out of the canisters, the aluminum structure, and the steel mesh. Each of these components were tested individually and then extensively used throughout verification of system functionality. Each component functioned properly on its own and was verified not to cause failures in other subsystems when the payload was integrated.

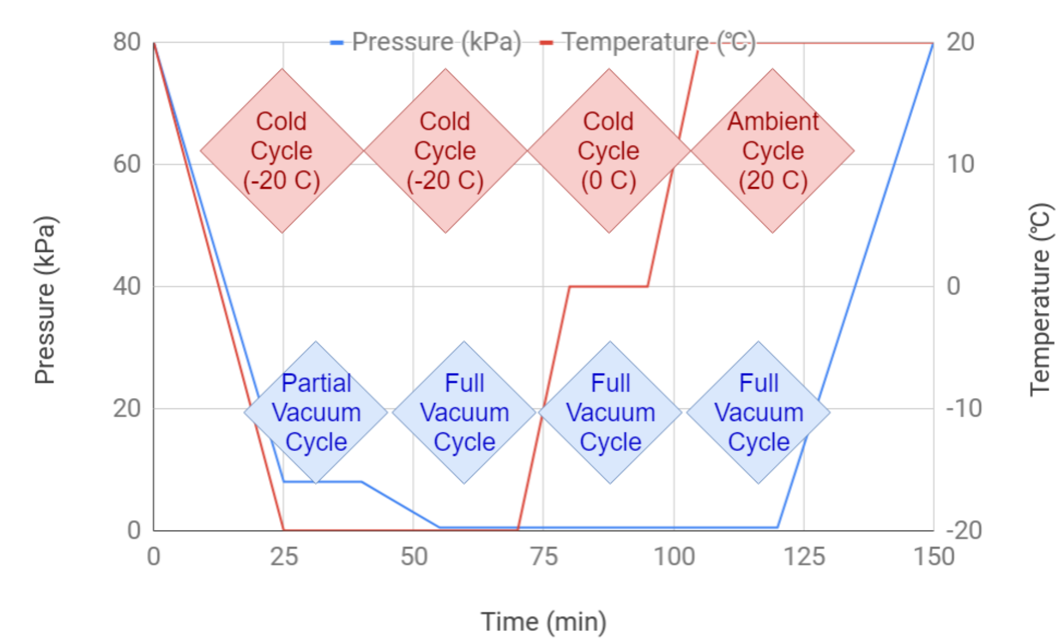


Figure 43: Temperature and Pressure Profile

3.6 Systems Testing

3.6.1 Vacuum Testing

Among the systems tests carried out by the team, the most meaningful occurred at the NCAR High Altitude Observatory where they graciously extended us access to their vacuum chamber. The test verified that systems all functioned in accordance with requirements when integrated together and under the atmospheric pressure present in flight. A preliminary system functionality test was carried out before VAC testing to ensure that the payload functioned with all systems integrated. Upon verifying this, the payload was tested in the vacuum chamber. Pictured above in figure 43 is a temperature and pressure profile for a cold test and vacuum test that would verify payload functionality for flight.

3.6.2 Thermal Testing

Besides the low-pressure testing, thermal testing was also carried out to verify that the payload could perform while exposed to the harsh temperatures of flight. This test involved using the COSGC cold chamber, an insulated box with integrated temperature sensors. 10 lbs of dry ice was placed in the cold chamber and the team waited until the internal temperature had reached -60°C. At this point, the payload was placed inside the cold chamber and three mission cycles were executed. The cycles proved successful. The payload was then removed, and when it returned to room temperature a lot of condensation formed, and it was a concern that the water was going to damage the Pi, PCB, or pressure regulators. Components were tested and verified to be in working order. For the following cold testing, the procedure was edited to leave the payload inside the cold chamber overnight with a small crack in the lid to allow the pressure to gradually increase and prevent condensation from forming.

3.7 Integration Testing

In mid-July, the team traveled to Palestine, TX to integrate Miura II with the HASP Platform. With the assistance of Dr. T. Gregory Guzik and the personnel of the Columbia Scientific Balloon Facility, thermal vaccum testing was carried out as part of the integration procedure. This was a full mission-simulation test, with a temperature and pressure profile similar to that of flight, communication with the payload through serial downlink to monitor data, and uplink commands used to control payload functionality. Following a successful integration and aliveness test on the platform, the payload met all mission success criteria during the first TVAC test. All critical uplink commands were tested and confirmed to be functional, the payload downlinked data matching the expected data from the chamber, and the habitat cycles met reusability and leak rate requirements.

Figure 44: The team installing the payload on the HASP platform prior to TVAC testing

Due to the success of the TVAC test, the payload was left in the care of HASP personnel who shipped it to Fort Sumner, NM for launch along with the platform.

4 Flight Operations Overview

Launch occurred on September 4th, 2018. It was initially scrubbed due to poor weather, this launch date was a make-up launch. The payload was at float for 9 hours out of the 11.5 hour total flight.

Time	Event
8:03	Launch
10:10	Ran an automated cycle, was at low pressure. Put payload in manual mode to wait for float
10:30	Payload Reached float
11:15	Continue Automation Mode - 4 Successful Cycles
19:31	Flight Termination

5 Results and Analysis

5.1 Environmental Data

Ambient Pressure

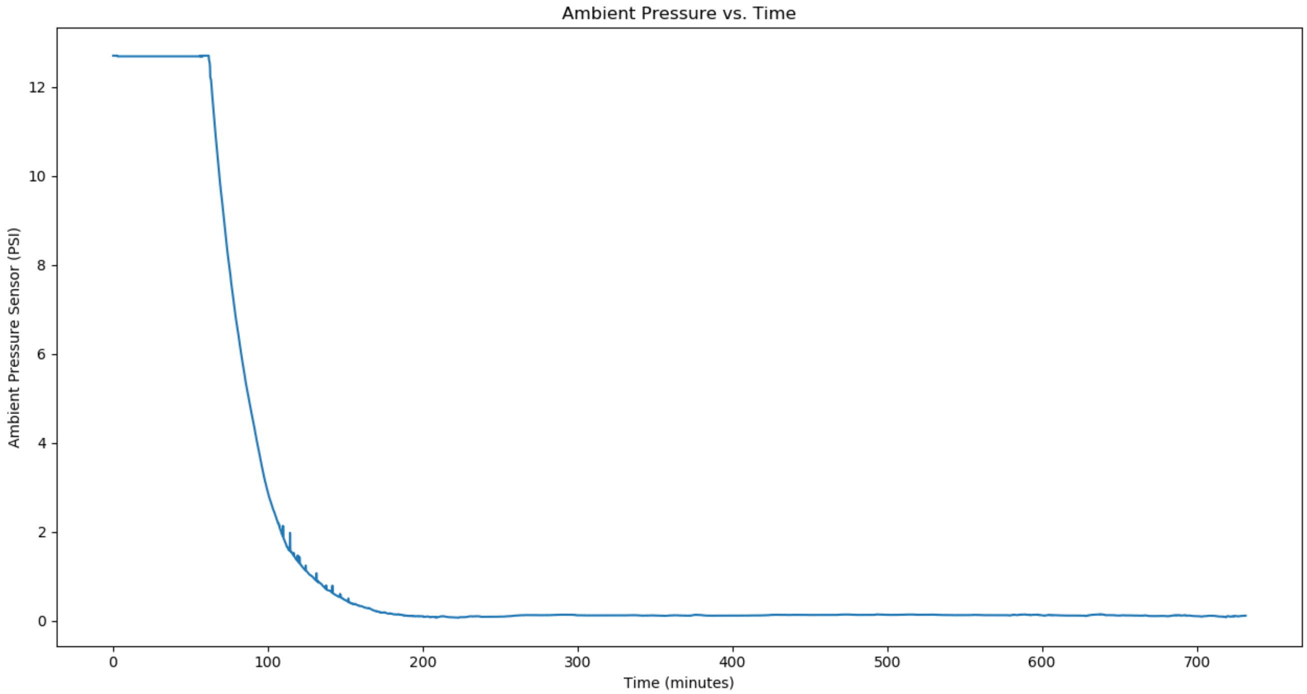


Figure 45: Ambient Pressure versus Time

The pressure data is as expected with a steady decrease until float altitude where it remains constant at an almost vacuum.

Temperature of Components and Ambient Temperature

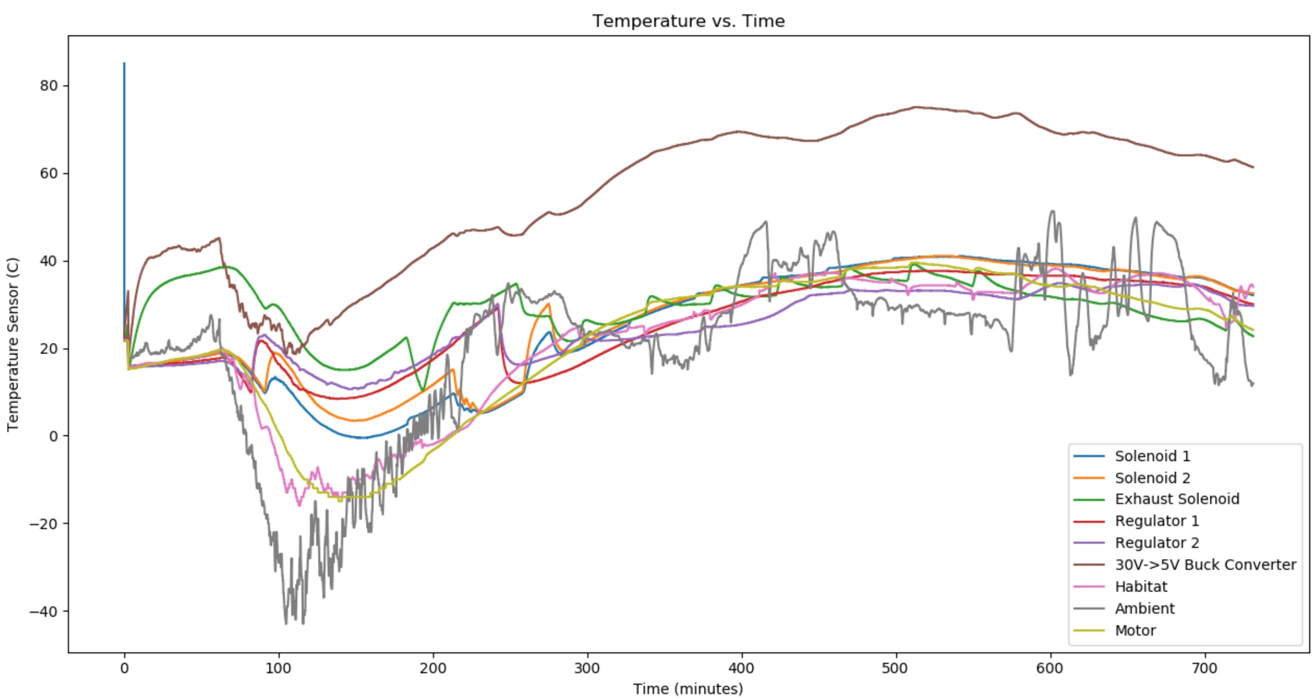


Figure 46: Temperature versus Time

The temperature of the components all remained within their operating rage and behaved as expected. The ambient temperature was generally the lowest while all the other components matched the general trends of increasing and decreasing atmospheric temperature. The buck converter was the hottest component which was consistent with previous testing.

Habitat Pressure

5.2 Pressurization Cycles

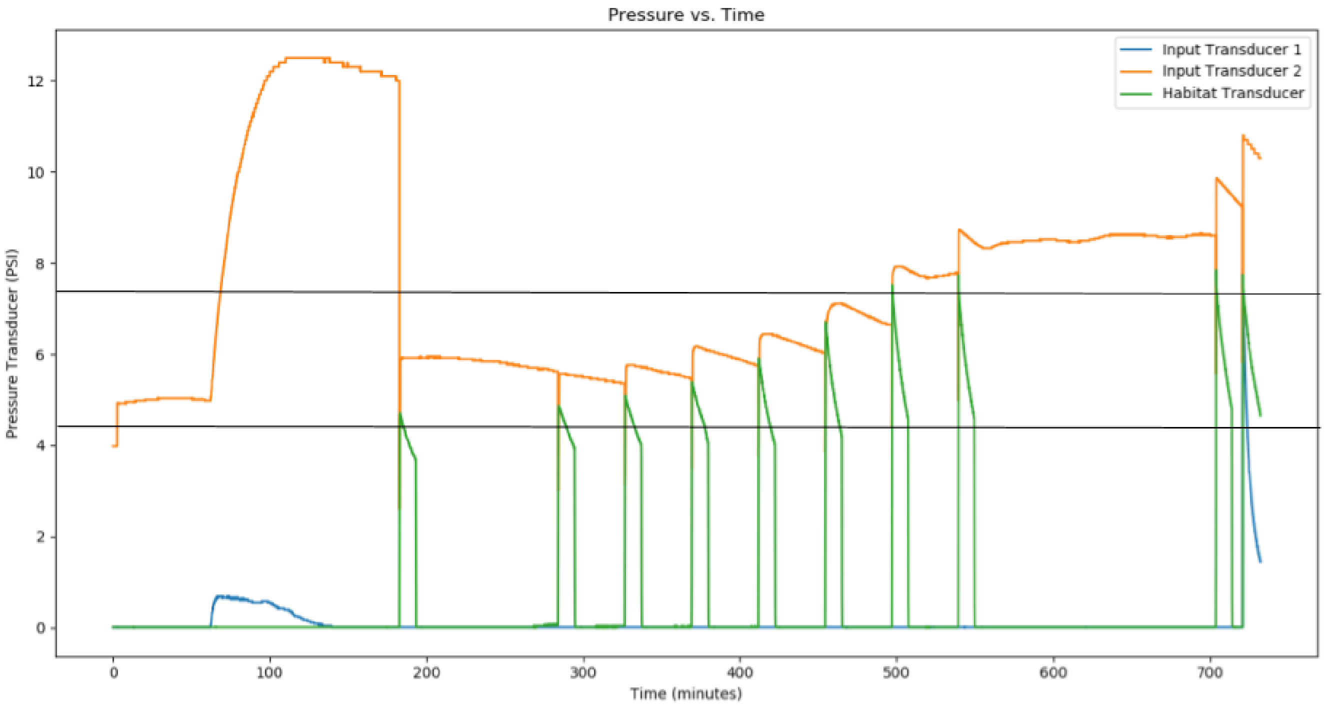


Figure 47: Pressure System Pressure versus Time

To achieve complete mission success, each pressurization cycles was to remain between 7.5 psi and 4.4 psi. In testing, the regulators were shown to exponentially increase pressure as the canisters depleted. To counter this effect, the regulator was only set to 5 psi as it was expected to increase with each cycle and as the ambient pressure decreased. However, this trend did not cause an effect on the regulators as quickly as expected so the first 6 pressure cycles did not fill to 7.5 psi. The habitat was designed so it could only meet the leak rate requirement if it the initial pressure was at least 7.5 psi. However, once the regulator reached the target initial pressure the habitat met leak rate requirements for the last two complete cycles.

Pressure Stages

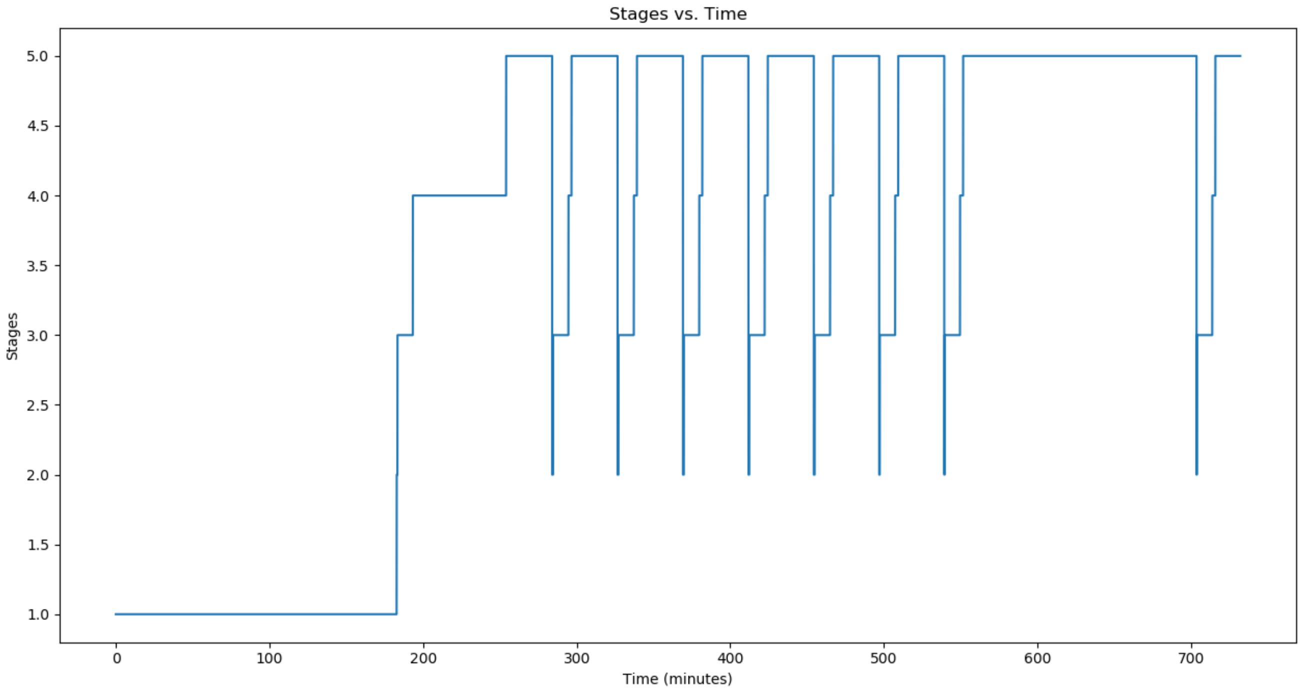


Figure 48: Stages of Pressurization Cycle versus Time

As the pressure cycles were run, the current stage was tracked to understand whether the habitat was in ascent (1), inflation (2), sustention (3), retraction (4), or stowed (5). Since this plot matches the time and events noted in the habitat pressure graph it can be concluded that the cycles were run according to the designated time steps. The large break in the graph is the time were cycles were paused to allow the habitat to increase temperature in an attempt to meet thermal requirements. It is also shown that there were no power disruptions that would have caused the Raspberry Pi to reset.

5.2.1 Retraction

Retraction was confirmed by visual images taken by the two cameras on the payload.

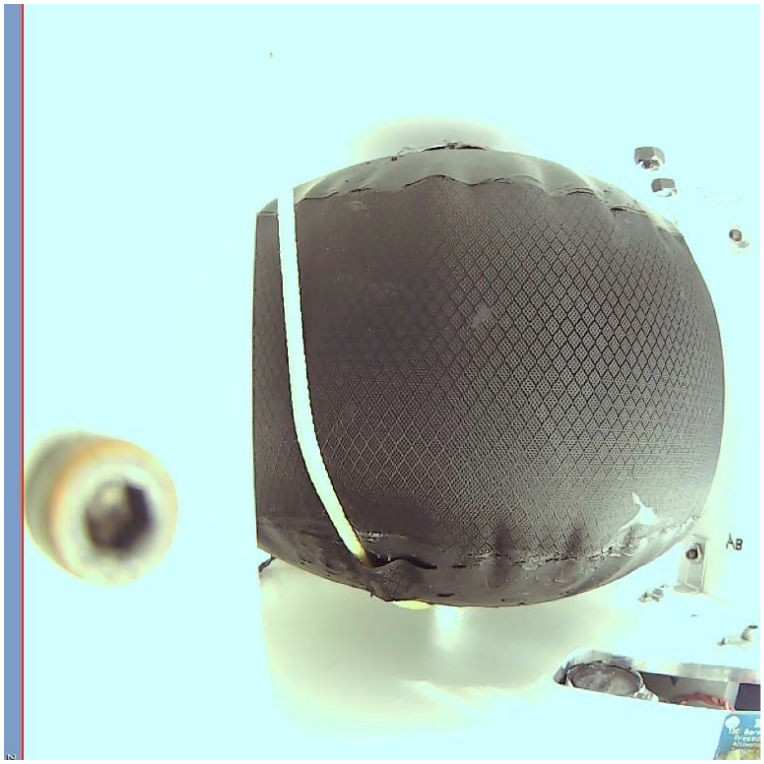


Figure 49: Habitat in Stage 3 - Sustention

Photos from all pressurization cycles were accounted for which confirms the data presented in both the habitat pressure and stage graphs.

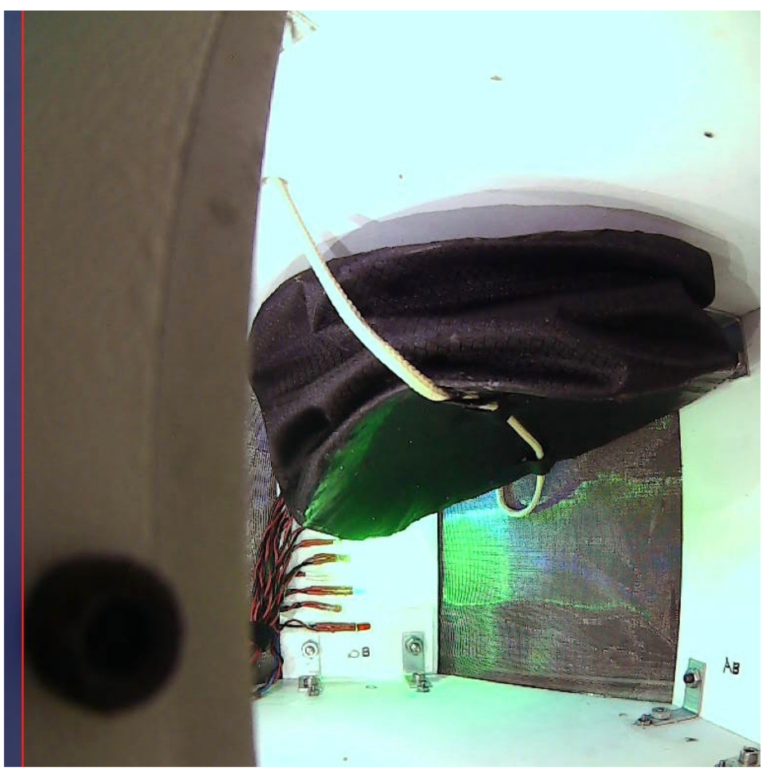


Figure 50: Habitat in Stage 5 - Stowed

5.3 Failure Mode

There was only one notable failure on flight, which was that one of the cameras did not record visual data over the course of the flight.

5.3.1 Root Cause Analysis

This failure was not due to design, but instead due to the fact that the integration team did not plug in the USB connection between the camera and the Raspberry Pi.

5.3.2 Failure Analysis

To prevent future failures similar to this camera failure, more rigorous adherence to integration procedures with initials for verification at each step shall be implemented. This failure was due to negligence, which is remedied by more strict procedures.

5.4 Habitat Resilience

5.4.1 Post-Flight Visual Inspection

There was no visual indication the habitat had withstood any damage during flight. Through analysis of the pressure data the last cycle the habitat was still holding pressure so there was no indication of leaks or punctures in the material.

6 Conclusions and Discussions

6.1 Mission Objectives

All levels of success are scaffolding, meaning that a Level 2 success also requires all Level 1 and Level 0 criteria to be fulfilled.

Level 0 Mission Success: Payload does not pose a safety hazard to any people, the HASP platform, or other payloads on the platform.

- Pressure regulators and solenoids remain within rated operating temperatures for the duration of flight
- Mesh caging is secured around habitat housing as well as regulator housing
- 1cm thick aluminum plates surround pressure piping system in the upper housing as well as the solenoids and transducers
- A safety release valve vents pressure above 15 psi in the pressure piping system
- At the end of float, all pressure will be vented from the canisters using commands to open inlet and exhaust solenoids at the same time, transducer data will confirm that pressure is no longer present in the system
- Extensive testing has been carried out to characterize the behavior of the system in flight environments as well as when overpressurization has occurred, and all of this testing has supported the conclusion that the payload will be safe

Level 1 Mission Success: Payload pressurizes the habitat to 7.5 psi at least two times

- Code cuts off inlet solenoid at 7.5 psi
- Successful exhaust occurs and, following stow, another pressurization occurs

Level 2 Mission Success: Payload retracts payload at least once following a successful pressurization and sustains 7.5 psi for 10 minutes at least once

- Motor activates following 10 minutes of sustention
- 10 minutes of sustention at 7.5 psi on a pressure cycle in which there is an unrelated error (i.e. motor not functioning) will still be considered a success

Level 3 Mission Success: Payload remains between 10°C and 20°C for at least the duration of one sustension.

Note: Level 3 mission success has been descoped. This is because the team realized in early July that some parts of the mission were unrealistic to achieve with the resources and timeframe available for the project, and the mission success criteria had originally been decided when the team was unfamiliar with the scope and scale of the tasks involved.

In the interest of having something accomplished by the flight rather than spread efforts too wide and end up with an unsafe or unreliable payload, the team aimed to fulfill all Level 2 success criteria by integration in Palestine at the end of July.

6.2 Requirements

Level 0	Requirement	Rationale	Derived
0.1	Miura II shall expand, sustain, and contract.	Mission Statement	0
0.2	The payload shall document the state of the habitat.	Data for downlink and post-flight analysis.	0
0.3	The habitat shall be pressurized.	Mission Statement	0
0.4	The payload shall comply with all requirements set forth by the HASP Call for Payloads 2018.	Must be met for flight in September	0
0.5	The payload shall comply with all safety requirements set forth by HASP and the NASA Office of Safety and Mission Assurance.	Must be met for integration in July	0

Level 1	Requirement	Rationale	
0.1.1	The habitat shall fully expand.	Ensure no mechanical errors hinder the extension of the structure.	0.1
0.1.2	The habitat shall complete a cycle every 45 minutes with a 5 minute allowance.	Ensure no mechanical errors hinder the extension of the structure.	0.1
0.1.3	The habitat shall return to a compact state.	Make sure no mechanical errors hinder the extension of the structure.	0.1
0.2.1	The payload shall collect visual data of habitat at least once every five seconds.	Visually analyze the folding structure.	0.2
0.2.2	The payload shall collect and downlink the height, temperature, and pressure of the payload and habitat at least once every 0.2 seconds.	Monitor critical functionality of systems.	0.2
0.3.1	The pressure within the habitat shall remain above 4.4 psi while in sustention.	Maintain pressurized system.	0.3
0.4.1	The payload shall not exceed the physical constraints of a large payload space.	HASP 2018 Requirements	0.4
0.4.2	The payload shall be built to withstand the entire duration of a High Altitude Student Payload flight.	HASP 2018 Requirements	0.4
0.4.3	The payload shall interface with HASP power and telemetry connectors.	HASP 2018 Requirements	0.4
0.5.1	The habitat shall be designed to withstand over-pressurization at 300% of flight pressure.	Prevent burst of pressure vessel with a factor of safety of 3.	0.5
0.5.2	The payload shall be capable of containing fragments in the case of a pressure failure.	Maintain safety in case of reservoir burst	0.5
0.5.3	The payload shall demonstrate a Factor of Safety of three.	Prevent interference with HASP platform in case of failure.	0.5

Level 2	Requirement	Rationale	
0.4.1.1	The payload shall weigh no more than 20 kg.	HASP 2018 Requirements	0.5.1
0.4.1.2	The payload shall not exceed the dimensions of 38 cm x 30 cm x 30 cm.	HASP 2018 Requirements	0.5.1
0.4.2.1	The payload shall remain intact attached to the mounting plate during 10g vertical and 5g horizontal shocks.	HASP 2018 Requirements	0.5.2
0.4.2.3	All electronic components shall remain within their respective operating temperature range.	HASP 2018 Requirements	0.5.2
0.4.2.4	The payload shall be functional at external pressures of 5 to 10 mbar (0.5 to 1 kPa).	HASP 2018 Requirements	0.5.2
0.4.3.1	The payload shall use no more than 30 VDC.	HASP 2018 Requirements	0.5.3
0.4.3.2	The payload shall draw no more than 2.5 A at 30 VDC.	HASP 2018 Requirements	0.5.3
0.5.3.3	The payload shall convert the provided VDC to voltages necessary for operating the payload.	HASP 2018 Requirements	0.5.3
0.5.3.4	The power system shall utilize the provided 20 pin EDAC 516 connector.	HASP 2018 Requirements	0.5.3
0.5.3.5	The payload shall communicate with the HASP platform via a 4800 baud serial port.	HASP 2018 Requirements	0.5.3
0.6.1.1	Any pressure vessels shall not be a structural components.	CSBF Vessel Flight Certification, less likely to collapse	0.6.1

6.3 Mission Success

The project is considered a level two success. Three sustentions were carried out during flight which satisfied all pressure and leak rate requirements, and there were no critical failures which impeded function of the payload.

6.4 Habitat

6.4.1 Habitat Performance

For the scope of this mission, the habitat design was successful, but it does not represent a scalable model. While it met the requirements for leak rate and pressure containment, the habitat does not comprehensively demonstrate the theory behind the mission. For a full scale habitat that could be used for human activity in space the material selection would need to be of much higher quality and durability. Ideally there would be multiple layers of airtight material for redundancy as well as managing the effects of radiation and insulation. A full scale model would require much more precise design and engineering which was not within the scope of this mission. However, the demonstration of technology in terms of mission requirements was successful.

To improve upon the habitat that was flown, more layers could have been added to reduce leak rate and thermal control system could have been implemented. Mission success greatly depended on the environment so making a more autonomous system that is insulated would create a more realistic design of a space activity module.

6.5 Overall System Functionality

In conclusion, the system worked extremely well. It met all habitability and re-usability requirements for a Level 2 success, which was the maximum possible level of success after descoping. Each subsystem functioned as expected from testing, and good data was downlinked which gave the team a clear understanding of what happened.

7 Lessons Learned and Recommendations

7.1 Science

The transition between the design and manufacturing stages posed the most amount challenges for the science team and proved to be the largest learning curve. Making a habitat that met mission requirements took several design iterations to understand the material properties and raise the quality of the manufacturing method. The process to make an airtight vessel was much more challenging than anticipated so the mission had to be descoped to a lower flight pressure and simpler design in order to keep up with deadlines.

Beyond design challenges, the science team learned how to formulate and execute a comprehensive testing plan. The habitat and retraction method needed to be tested in several different conditions and through that process the team discovered new problems and unknown properties of the system.

7.2 Structures

The biggest lesson learned from this mission was learning to translate the designs made in SolidWorks to the actual structure. CAD is very nice for designing things exactly the way the structure should look, with holes for screws and bolts, but when machining, it is often hard to maintain the tolerances. However, when multiple people were working on machining of the structure, it was easier to find mistakes and correct them.

Another issue was not using a cloud based CAD system. With multiple people working on the CAD, it was hard to figure out which files were the most recent. While the structures team never switched to using a cloud based CAD system, a shared folder was made for each edit of the design, so the members of the team knew which file was the current design.

7.3 Flight Software

It is difficult to do testing on the code when the rest of the team has not met deadlines on time. Using flat-sat tests is very valuable in the case that system-level testing must be done but the payload is not integrated. Additionally, declaring variables for requirement guidelines instead of hard-coding numbers will save you during testing. For our payload, the pressure requirement was initially hard-coded, and that was a headache when the target pressure had to change.

7.4 Electrical and Power Systems

The most difficult challenge for the EPS team was designing a comprehensive working PCB that met all of the changing requirements of the project. Several iterations of Miura II's PCB were made after realizing errors were made in connectivity of lines, or simply missing connections. During the final weeks before integration, sections of the main PCB were damaged by re-heating solder joints, or simply did not work, so an additional PCB was constructed.

These mistakes could have been remedied by more communication with other teams so as to decide on all requirements earlier, and to not rush on the design or checking of the PCB.

7.5 Systems Engineering

The most important thing to do as a systems engineer is to document your work. Ultimately, none of the testing that you do is worth anything if you cannot communicate it to other people. Make sure that you have an organized filing system, so that if someone asks you for the temperature tolerance of a component or the results of the testing the command and data handling interface with the science payload, you can find that information quickly.

8 Moving Forward

8.1 Future HASP Mission Recommendations

As Miura II was the second iteration of Colorado Space Grant Consortium's Miura missions, a successive mission offers many opportunities to improve on the habitat design and integration. The habitat can be improved by adding multiple structural layers as well as implementing a thermal control system to regulate temperature for day and night. The effects of radiation can also be investigated by testing different types of shielding or understanding how soft shell materials degrade from radiation exposure.

A more complex retraction method would decrease the volume of the habitat while stowed and increase the durability of the contracted state. Having a retraction method that is better integrated with the habitat design would offer a more realistic model of a space grade activity module. The retraction method could be implemented between the layers of the material or include a frame to control the way the habitat would fold in contraction.

9 Acknowledgements

The Miura II team would like to thank all the mentors of the project including Brian Sanders, Dawson Beatty, and Alex Paquin. Another special thanks is due to Nichole Ela and The High Altitude Observatory to allowing the team to test the payload in their thermal vacuum chamber.

The team would also like to thank the sponsors of the project; the Colorado Space Grant Consortium, the Undergraduate Research Opportunity Program, and the Engineering Excellence Fund.

Thank you especially to the HASP program and Dr. Guzik for allowing the opportunity to fly and for all the mentorship throughout the entire process.

The team would like the acknowledge the work and dedication of Project Manager Conner Shaver who lead the team through the entire mission and has been instrumental in the great success of the project.

Figure 51: Miura II Team in front of Big Ben at launch

References

[1] "BEAM," Bigelow Aerospace, 2017, Accessed: 14 November 2017. Available: http://bigelowaerospace.com/pages/beam/.

A Publications

Shaver, Anderson, and Lin (April 2017). Project Miura II. Presentation and Paper. *Colorado Space Grant Symposium.*

B Team Demographics

Name	Role	Status	Race	Ethnicity	Gender	Disabled
Conner Shaver	Project Manager	Undergrad	Caucasian	Non-Hispanic	M	No
Shu-Yu Lin	Systems	Undergrad	Asian	Non-Hispanic	F	No
Jaret Anderson	Systems	Undergrad	Caucasian	Non-Hispanic	M	No
Lucas Zardini	CDH Lead	Undergrad	Caucasian	Hispanic	M	No
Charles Puskar	CDH	Undergrad	Caucasian	Non-Hispanic	M	No
Srikanth Venkataraman	CDH	Undergrad	Asian	Non-Hispanic	M	No
Raymie Fotherby	EPS Lead	Undergrad	Caucasian	Non-Hispanic	F	No
Tristan Schoeman	EPS	Undergrad	Caucasian	Non-Hispanic	M	No
Ashkan Bafti	EPS	Undergrad	Caucasian	Non-Hispanic	M	No
Nick Bearns	Structures Lead	Undergrad	Caucasian	Non-Hispanic	M	No
Griffin Van Anne	Structures	Undergrad	Caucasian	Non-Hispanic	M	No
Mary Hanson	Structures	Undergrad	Caucasian	Non-Hispanic	F	No
Madisen Frie	Science Lead	Undergrad	Caucasian	Non-Hispanic	F	No
Lindsay Cobb	Science	Undergrad	Caucasian	Non-Hispanic	F	No
Lewis Redner	Science	Undergrad	Caucasian	Non-Hispanic	M	No
Jason Magno	Science	Undergrad	Asian/Caucasian	Non-Hispanic	M	No

C Previous CU Boulder HASP Member Career Trajectories

Name	Degree	Current Employer
Paige Arthur	BS Aerospace May 2017	JPL
Ryan Cutter	BS Aerospace May 2017	Lockheed Martin
Cooper Benson	BS Electrical Engineering May 2017	AMP Robotics
Brandon Boiko	BS/MS Mechanical Engineering	High Precision Devices, Inc
Becca Lidvall	BS Aerospace Engineering May 2017	Ball Aerospace
Flor Gordivas	BS Electrical and Computer Engineering May 2017	Lockheed Martin

Table 1: List of previous CU Boulder HASP members who graduated within the last year