ODDITY Spring Final Review

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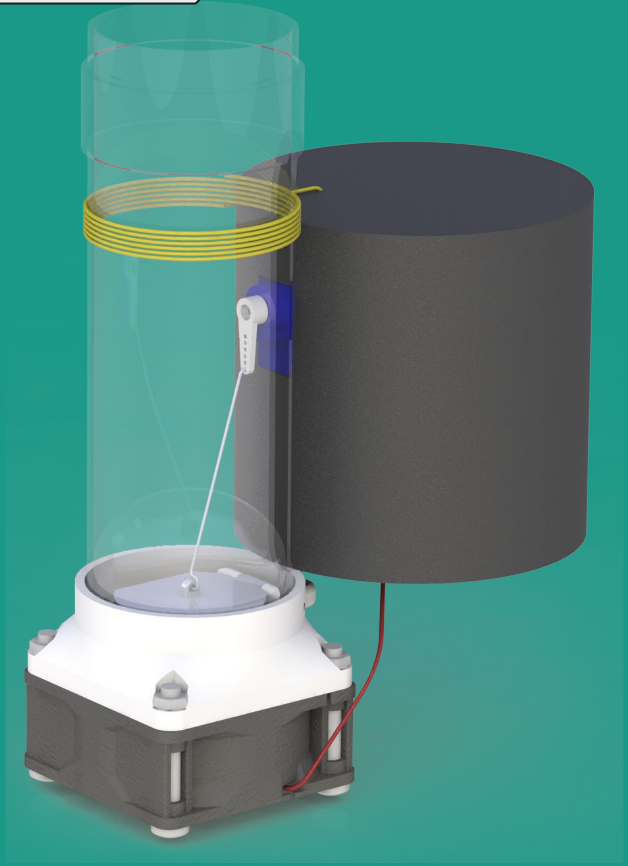
Project Purpose

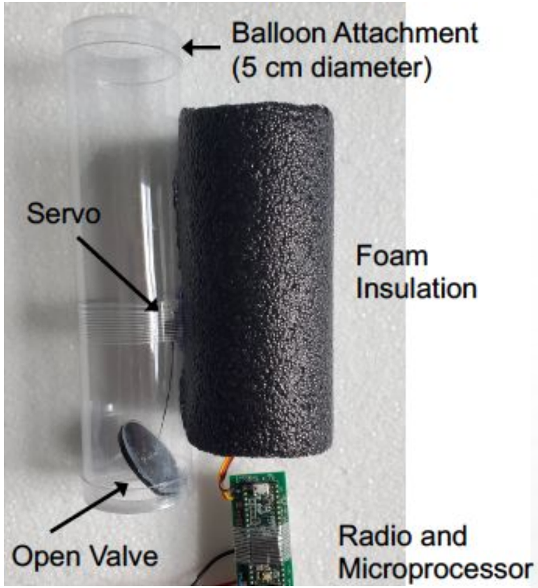


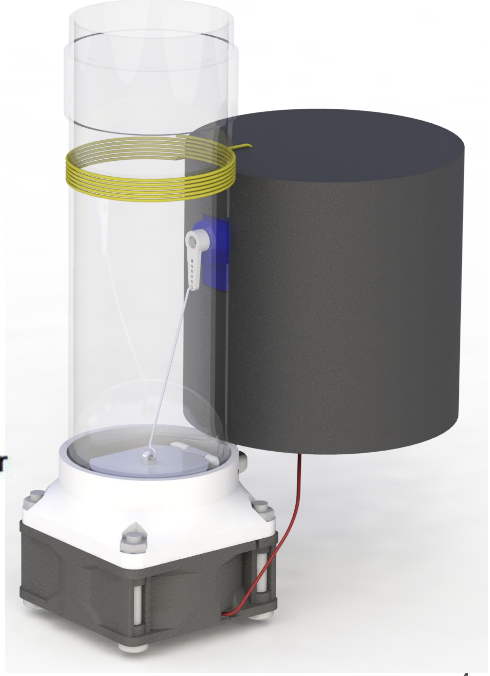
Mission Summary

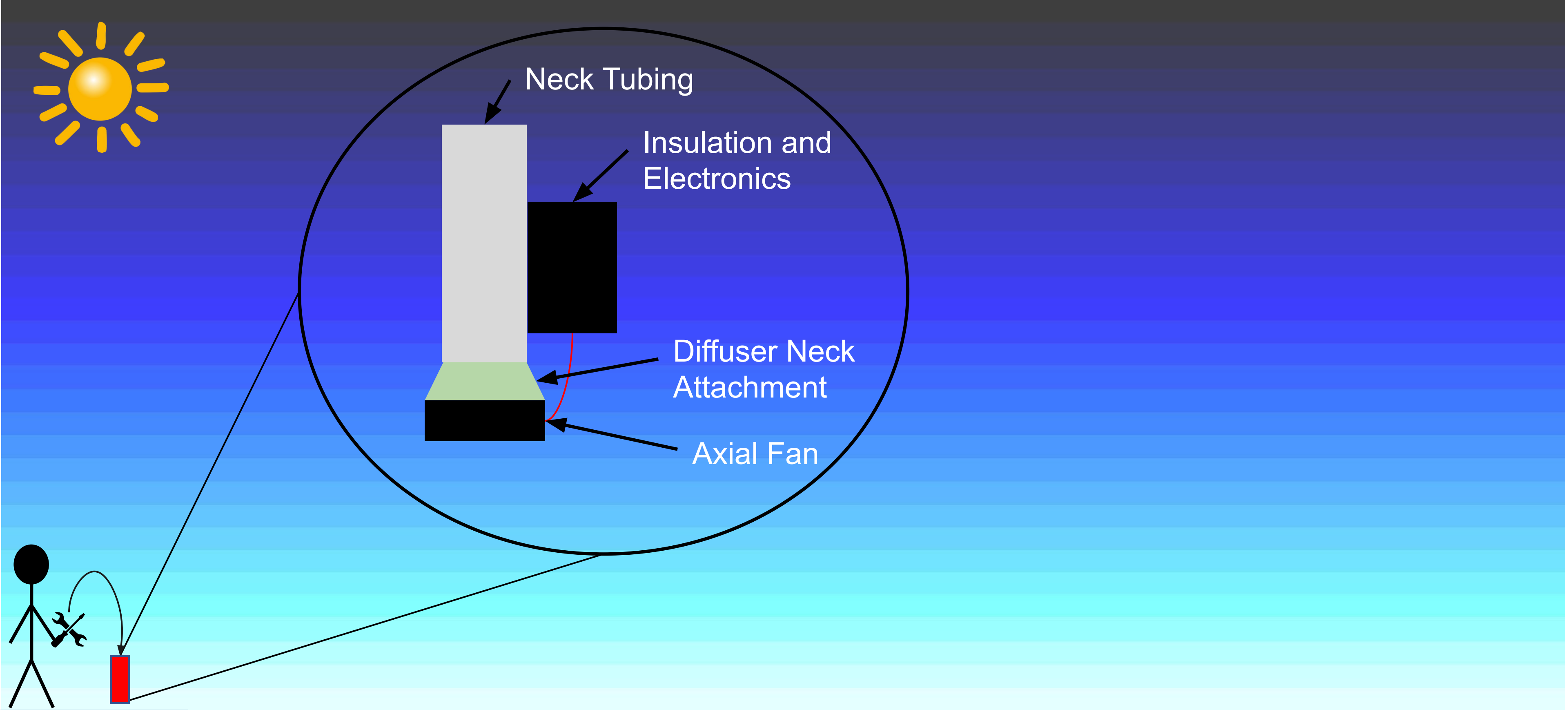
- Turbulence data is required for high altitude hypersonic aircraft design
- Gondola sensor package is used to collect such high altitude data and is provided by HYFLITS group
- Gondola sensor package hangs below the balloon, and must be descending to collect unperturbed air due to the large balloon canopy
- Helium vent allows for helium withdrawal and descent of weather balloon

The Need for a Better Solution

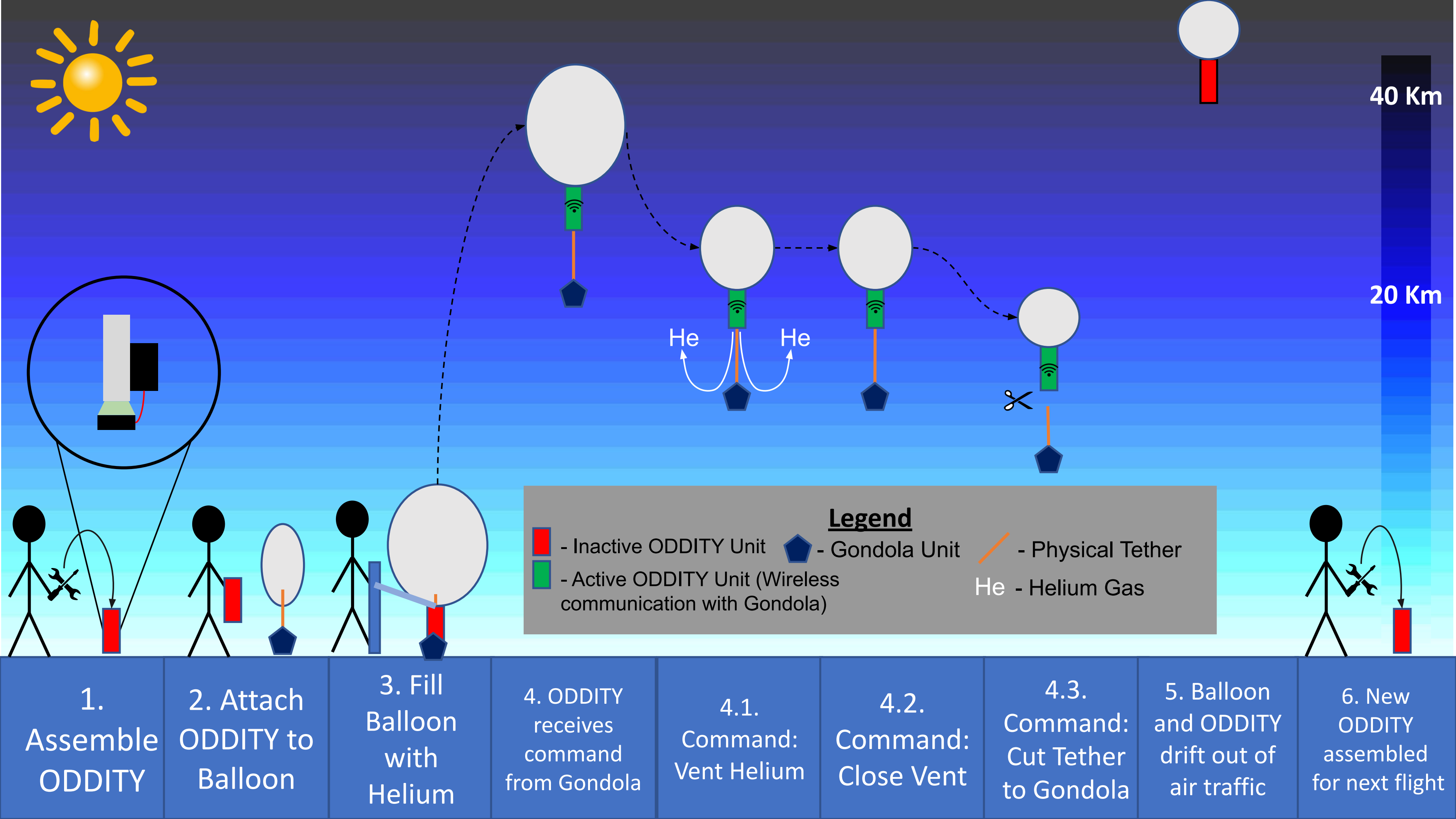
- Legacy device only utilizes passive valve which does not enable helium removal when the balloon has undergone plastic deformation at high altitudes
- This causes slower than necessary descent rates or stops the balloons descent altogether
- The goal is to “upgrade” this existing device so that it can maintain reliable descent rates (2-10 m/s) even at these high altitudes.
- At these high altitudes it is expected that ODDITY will see temperatures down to -60°C
- Finally the ODDITY must be remotely controlled by the HYFLITS gondola sensor package







1. Assemble ODDITY


40 Km
20 Km
He
He
Legend
- Inactive ODDITY Unit
- Gondola Unit
- Physical Tether
- Active ODDITY Unit (Wireless communication with Gondola)
He - Helium Gas
1. Assemble ODDITY
2. Attach ODDITY to Balloon
3. Fill Balloon with Helium
4. ODDITY receives command from Gondola
4.1. Command: Vent Helium
4.2. Command: Close Vent
4.3. Command: Cut Tether to Gondola
5. Balloon and ODDITY drift out of air traffic
6. New ODDITY assembled for next flight

Levels Of Success

	Descent Control	*Balloon Attachment*	*Communications*	*Survivability*
Level 1	System is able to extract helium from balloon in conditions similar to those at 35km	ODDITY is able to attach to a 5cm neck diameter Kaymont balloon prior to being filled	ODDITY shares communication link with the Gondola via XBee radio	ODDITY is able to withstand pressures and temperatures similar to those seen at 35km
Level 2	ODDITY and Gondola will match legacy system performance in flight testing (35km altitude)	ODDITY is able to be installed on 8cm neck diameter Hwoyee balloons prior to being filled	ODDITY is able to receive data and commands from the Gondola	ODDITY is able to survive the temperatures and pressures seen at 35km
Level 3	ODDITY and Gondola are able to reach a target apogee of 40km		ODDITY is able to transmit data to the Gondola	ODDITY is able to survive the temperatures and pressures seen at 40km

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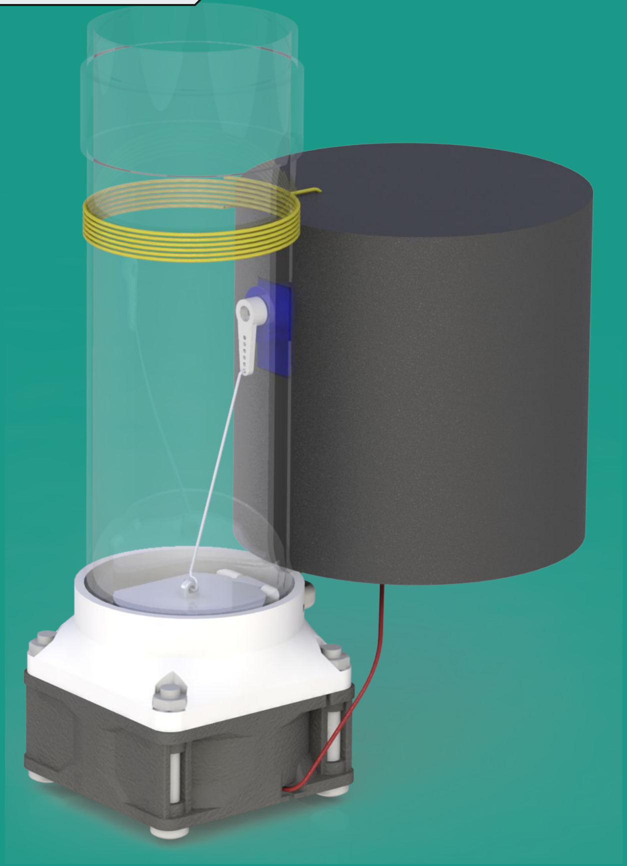
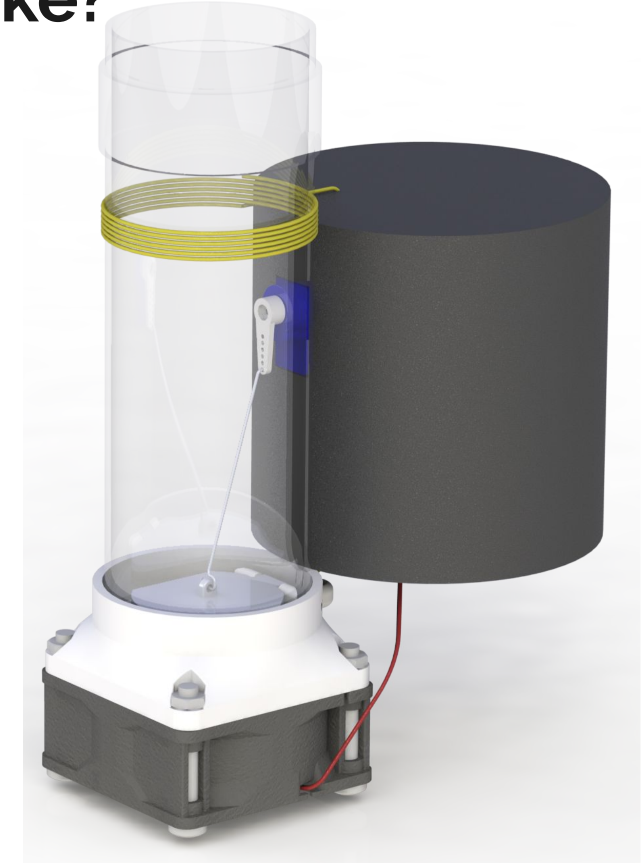
Design Description



What Does ODDITY Look Like?



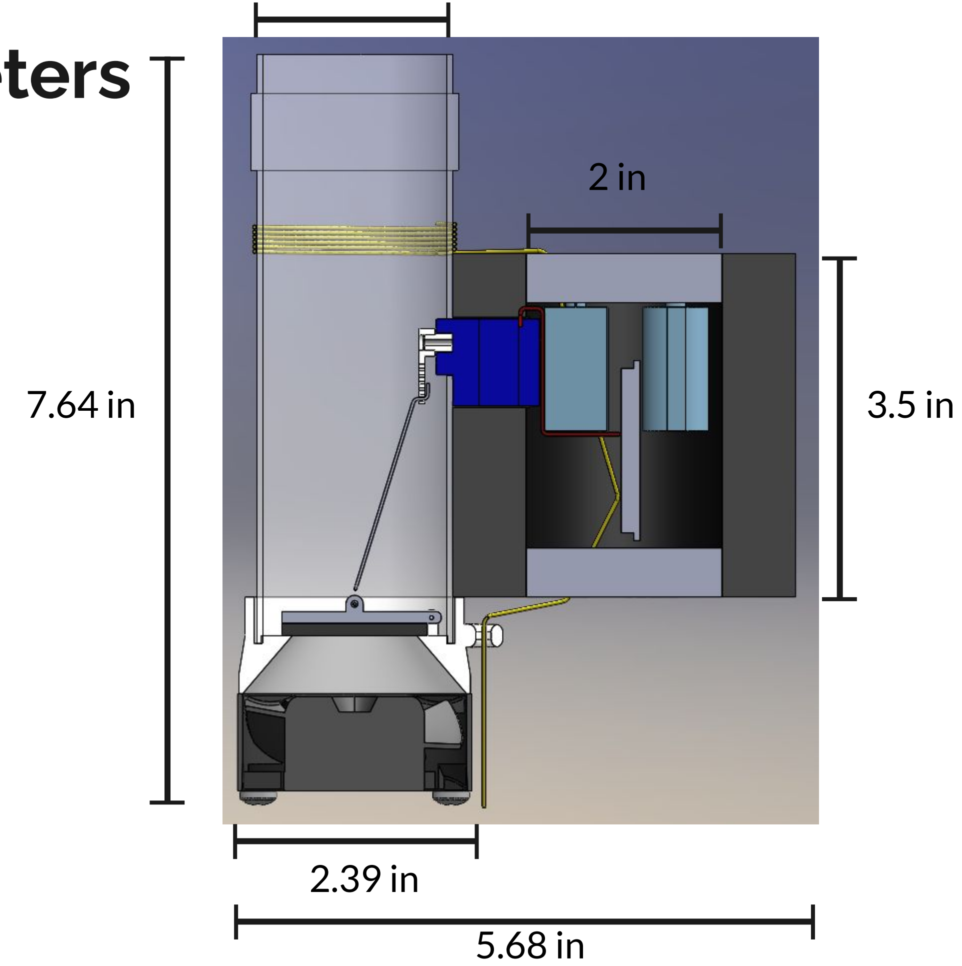
Key ODDITY Parameters

Mass
- 253.5 g

Unit Cost
- $179.21

Dimensions
- Total length - 7.64in
- Insulation tube attachment - 4in x 3.5in

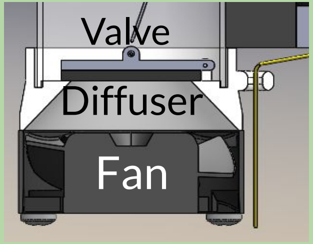
RF Parameters
- 2400 baud to support comms to and from gondola
- API packets to send and receive commands
- ISM 2.4 GHz Frequency Band



Main Subsystems of ODDITY

Descent Mechanism

- Mechanism is comprised of
  - A valve & servo combination
  - An axial fan
  - Diffuser section connecting the two



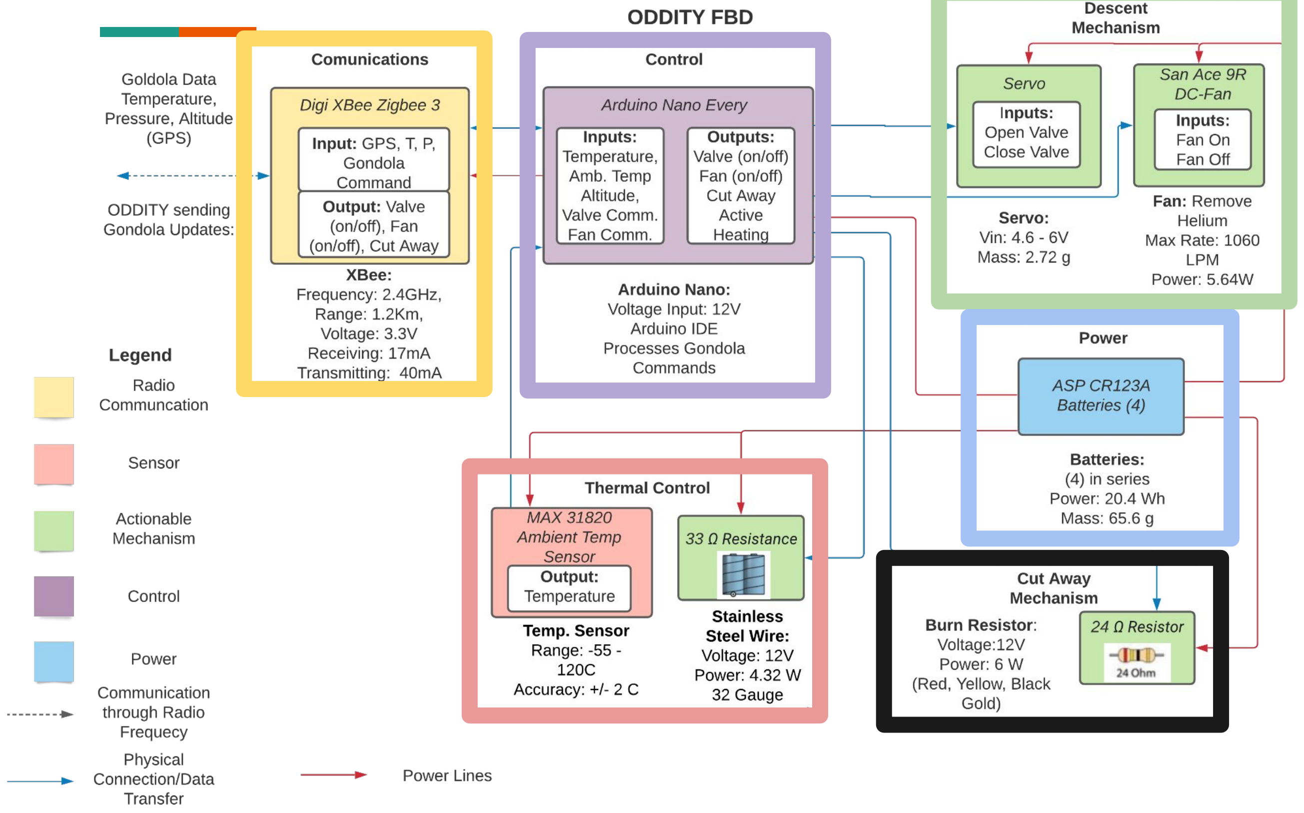
Electronics

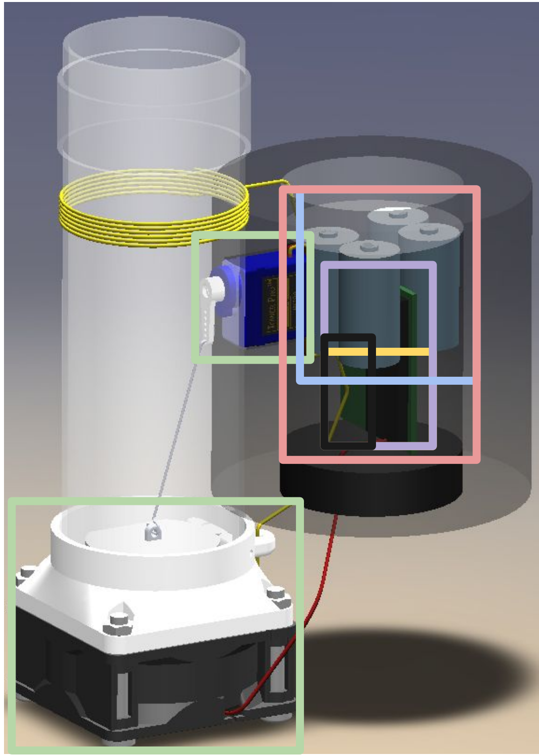
- Custom PCB was designed to include
  - Microprocessor (Arduino Nano Every)
  - Radio communications chip (XBee Zigbee 3)
  - Tether cutaway hardware

Thermal Control

- Thermal control was made using both a passive and active control component
  - Insulation tubing for passive control
  - Stainless steel wire w/ heat dissipation for active control

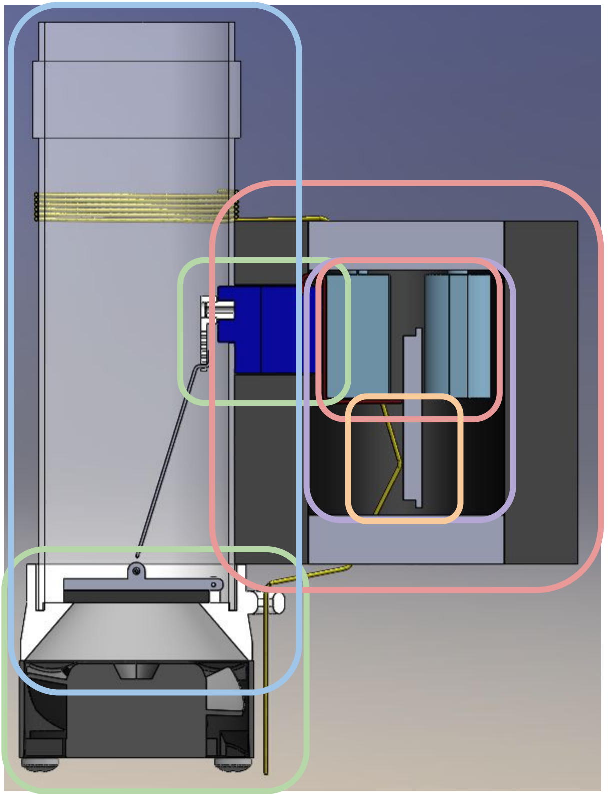
Functional Block Diagrams





Critical Project Elements

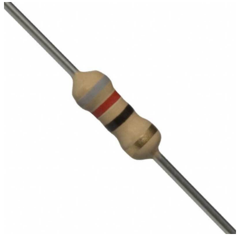
- CPE 1.0 - Descent Mechanism
  - This ecompasses all components that ensure helium is removed reliably from weather balloons at pressure conditions expected between 30 and 40km.
- CPE 2.0 - Comms, Power and Control
  - This includes all components of the project that enable a wireless communication link with the gondola sensor package, the control mechanisms needed to process and execute commands and the power required for the unit
- CPE 3.0 - Thermal Control
  - This CPE covers all components and subsystems of the project that allow control over the temperature experienced by an ODDITY unit
- CPE 4.0 - Neck Attachment
  - The project element includes the mechanical mounting of other CPE's and how they attach to the neck of high altitude weather balloons
- CPE 5.0 - Cutaway Mechanism
  - This final CPE accounts for the components needed to enable cutaway procedures at the end of every flight



Changes to Design from TRR

Thermal

- Heating Resistor to Heating Wire
  - 32 Gauge Stainless Steel Wire: 3 ft per battery cell
  - Approximately 33 Ohms, 10 loops around batteries
  - Allowed for better thermal control due to low air density and therefore low convective heat transfer
- Power Dissipation
  - From 1.5 W to 4.32 W
  - Allowed for thermal system to better “keep up” with ambient temperature drop

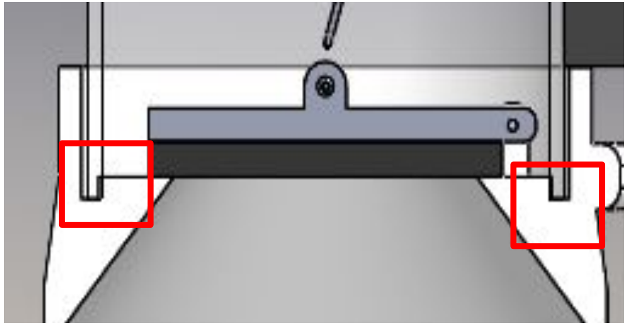


PCB Revisions

- Simple voltage divider was added to circuit
  - This allows for the Arduino to calculate the remaining battery voltage over time
  - This battery voltage is reported back down to gondola and ground station

Descent Control

- Circular slot
  - Tube sits deeper in diffuser section
  - Tight seal on the diffuser and tube



Test Overview

Descent Control Levels of Success

Low Pressure Testing

Survivability Levels of Success

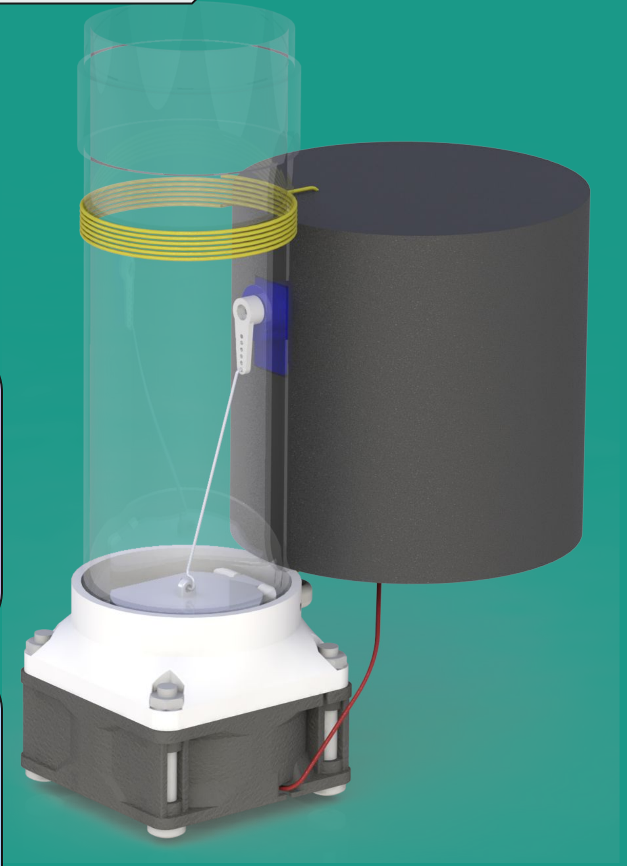
Low Temperature Testing

Communications Levels of Success

Two-Way Communication Testing

Mixed Levels of Success

Flight Testing



Low Pressure Fan Flowrate Testing

The ability of our system to maintain a desired descent rate, is reliant on our ability to remove helium at altitude.

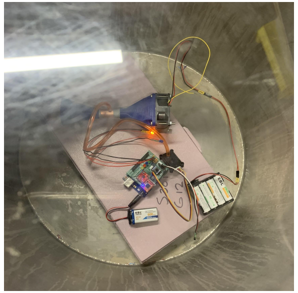
- **Low pressure chamber** testing of a **modified ODDITY configuration** was conducted to **verify CFD flowrate modelling**, quantify flowrate trends
  - **Functional Requirement: 1**
  - **Descent Control Level of Success: 1**

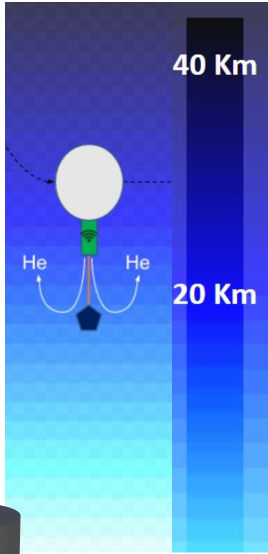
Testing Goals:

- To quantify fan performance trends at simulated flight altitudes.

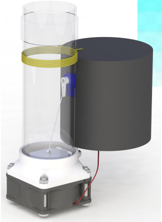
Validation:

- Our **flowrate modeling**, which was primarily accomplished using **CFD**, due to the extreme flight altitudes, and lack of available predictive data in literature.

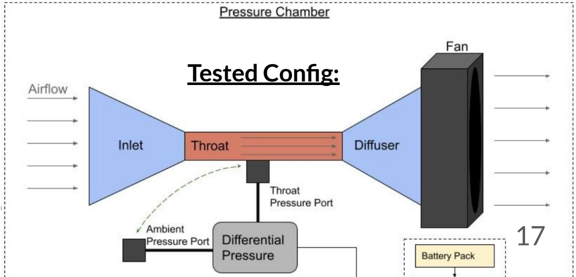




Flight Config:



Tested Config:



Low Temperature Testing

The ability of our system to be maintained within nominal functional temperatures during flight.

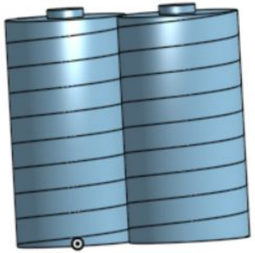
- The thermal control system must be able to maintain the electronics at approximately 20 C for optimal battery voltage
- Functional Requirement: Lowest Functional Temperature: - 20 C (Batteries)

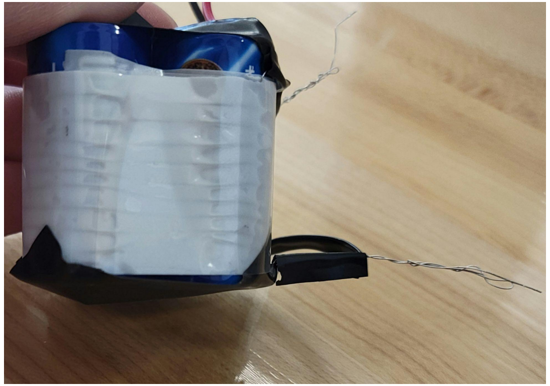
Testing Goals:

- To quantify the ability of the system to heat the insulation housing
- Confirm that the batteries can supply enough power to the system throughout the expected flight time.
- Validate thermal models

Tests Performed:

- Full System Thermal Chamber
- Full System Dry Ice





Communications Testing - Overview

The ability of our system to communicate with the HYFLITS Gondola

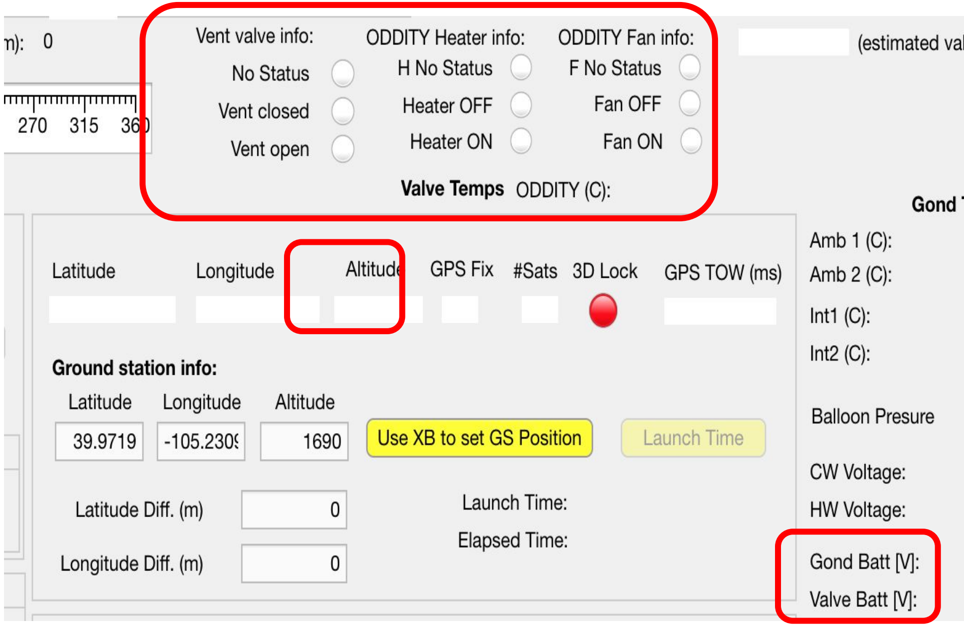
- ODDITY must enable a wireless communication link to the gondola sensor package

Testing Goals:

- Verify ODDITY can receive command packets from the gondola
- Verify ODDITY can send data packets to gondola

Validation:

- Utilize MATLAB GUI and Xbee XCTU Software to analyze API packets to and from ODDITY



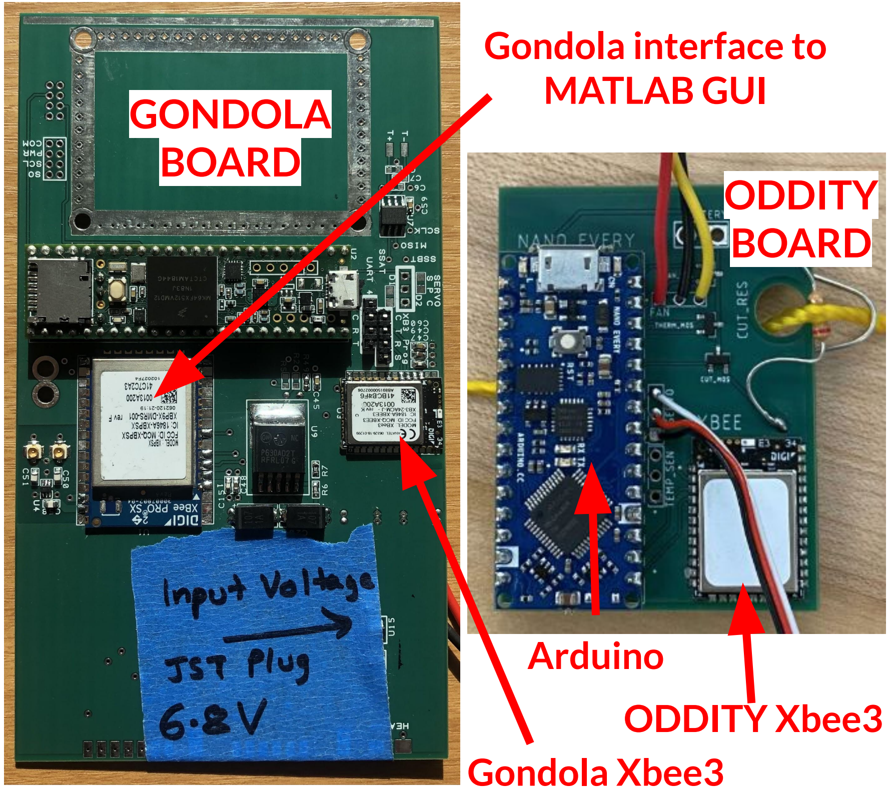
Communication Testing - Simulated Flight

Test Setup:

- Fully assembled ODDITY unit
- Gondola board
  - Xbee 3 Zigbee
  - Xbee Pro
- Xbee Pro connected to PC

Procedure:

- Gondola simulates flight by using preset ascent/descent rates instead of using GPS
- Based on simulated altitude, gondola will send commands to ODDITY
- Analyze gondola packets using MATLAB GUI to verify communication link between gondola and ODDITY



Flight Test - Overview

The ability to test full functionality of ODDITY and test modified control logic in Gondola code

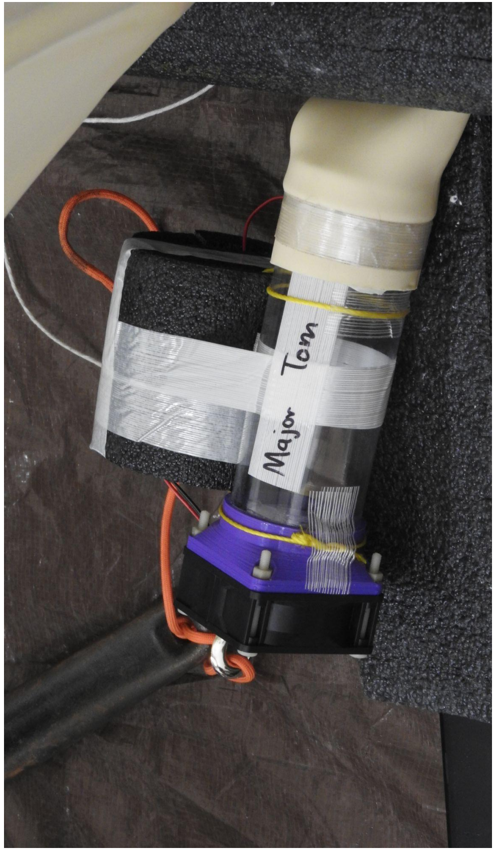
- ODDITY must turn on various components based on received command packets

Testing Goals:

- Verify ODDITY meets functional requirements and compare descent rates to legacy flights

Validation:

- Utilize Ground Station data packets from Gondola



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Test Results

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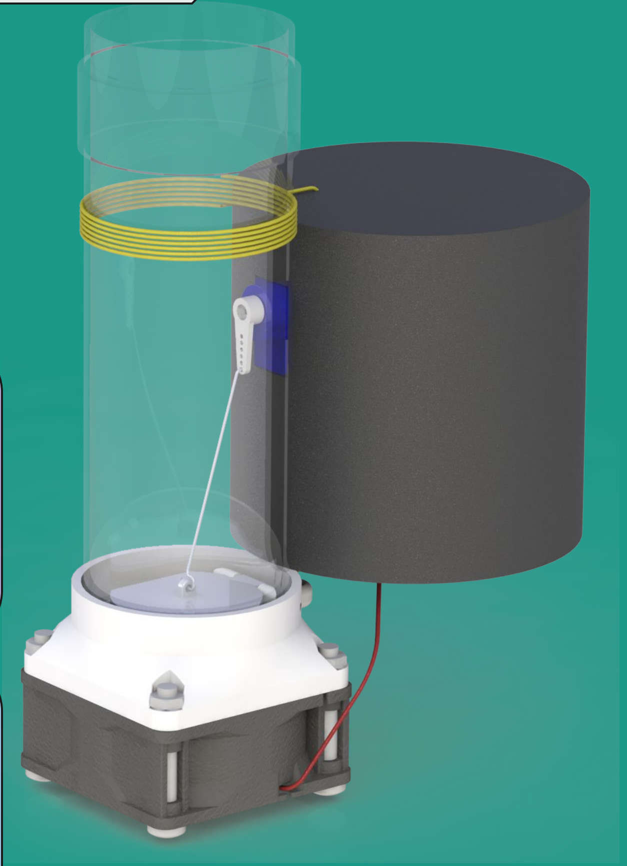
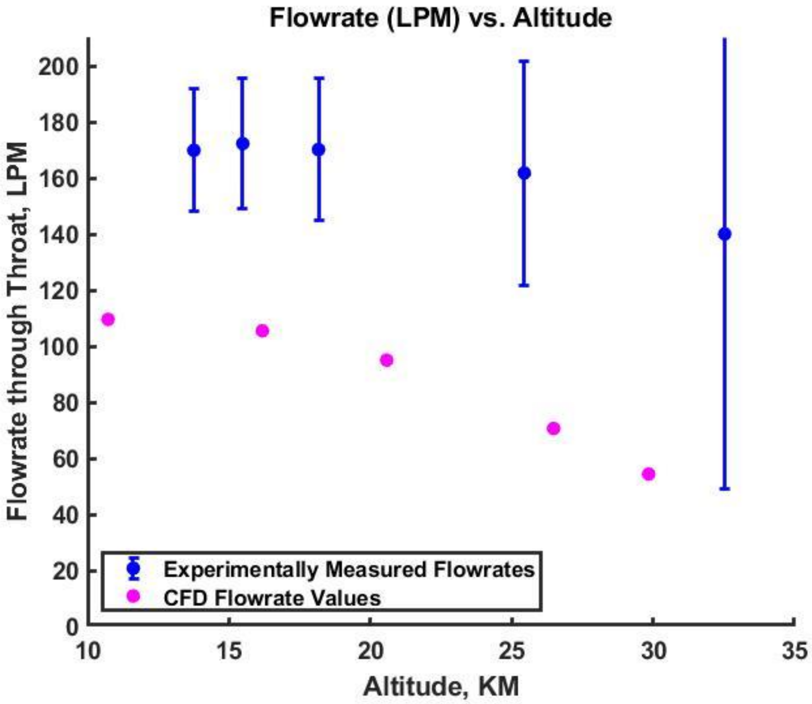


Low Pressure Testing- Flowrate

In general, our experimental flowrate results outperformed what we expected from the CFD modelling performed. Similar trends seen throughout.

1. The experimental calculation assumes a constant cross-sectional flow velocity
   - $V_{throat, centerline} * A_{throat, nominal}$ = **Flowrate**
   - due to **B.L.'s and Flow Constriction,** the effective flow area is less than the nominal throat area utilized in the above equation



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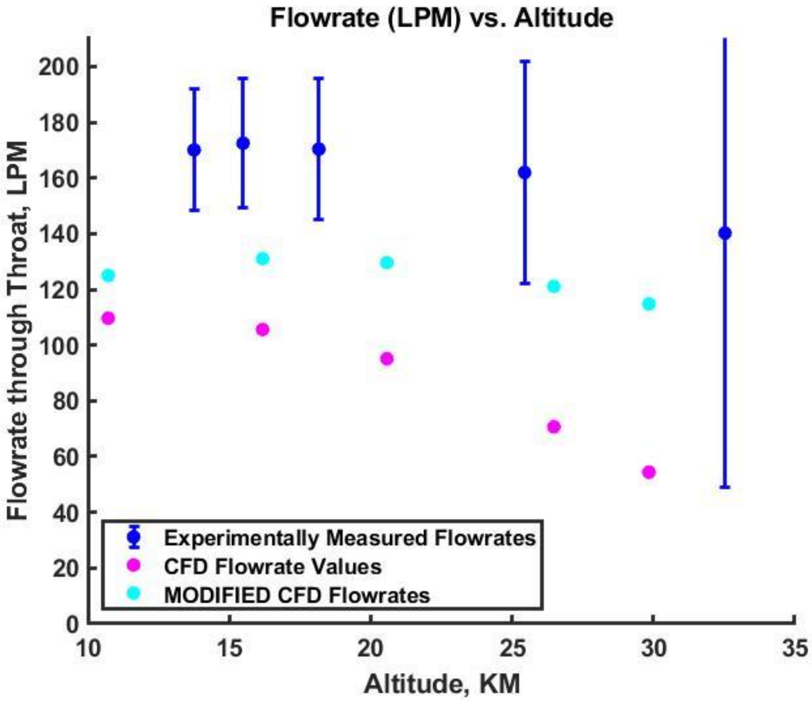
   - due to **B.L.'s and Flow Constriction,** the effective flow area is less than the nominal throat area utilized in the above equation
   - If we use the above, simplified calculation w/ CFD data, we see higher flowrates. (SHOWN IN CYAN)
   - **~20% discrepancy if we account for this calculation assumption**



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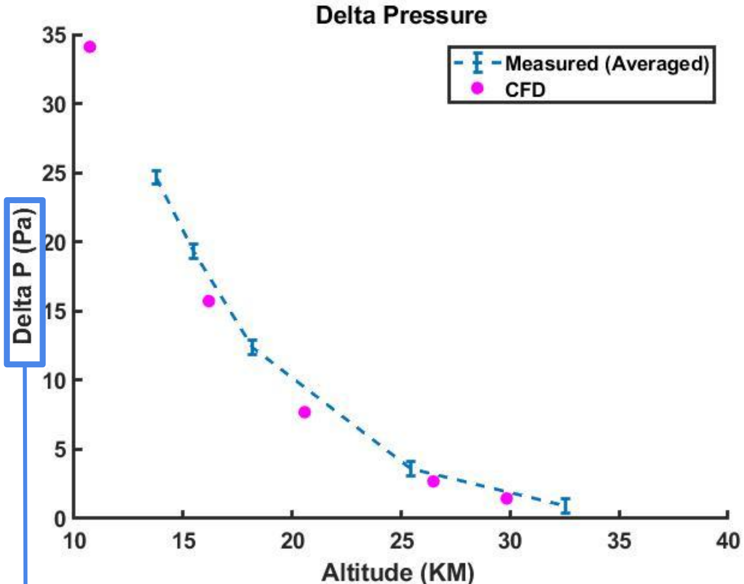
Low Pressure Testing- ΔP Data

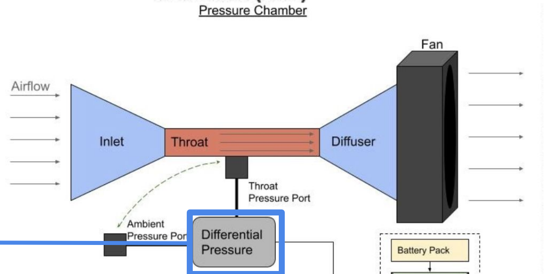
Distilling down to comparing the measured and simulated ΔP's between the Venturi throat and chamber ambient **removes any assumptions associated with the calculated values**

In the plots show, we see strong agreement between the **measured** ΔP's, and the ΔP's given from **CFD**.

Of the discrete CFD pressures tested, the **maximum relative error seen was 11.3%**

- Uses interpolated experimental data
- Largest error at lowest chamber pressure, with largest relative error from pressure sensor experimental measurement
- **Nearly within margin of error from pressure sensor at all points**

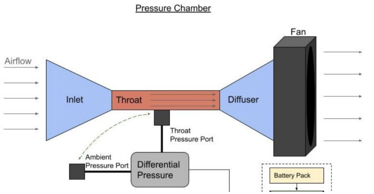


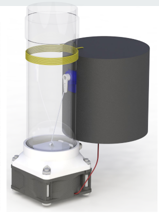


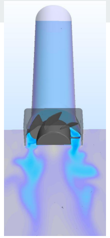
<u>**Removal of calculation assumptions showed strong agreement between models and experimental results.**</u>

- More direct verification of the CFD modelling utilized

Low Pressure Testing- Conclusions







Testing of a flight configuration inlet was not possible, due to pressure sensor resolution limitations

Low pressure testing of a modified version of our Helium removal system provided an estimate of fan performance trends with altitude, and a point of comparison for the CFD modelling methodology being utilized

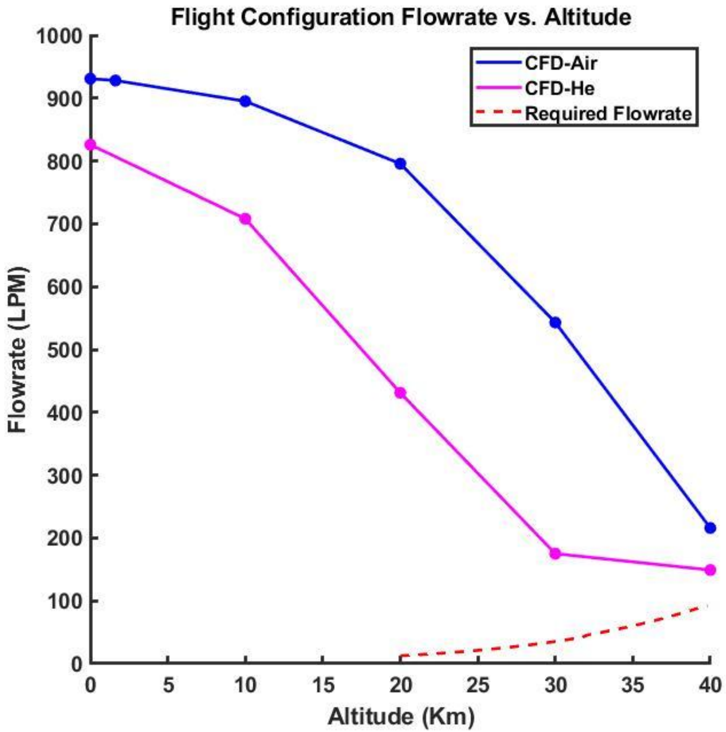
- Afforded more confidence in the CFD modelling of our actual flight configuration. *(modelled as congruously as possible)*

Our CFD modelling of the flight configuration showed acceptable flowrates, in order to achieve the descent rates desired.

- Flowrate requirements determined from balloon dynamics modelling
- Nearly **~200% Margin** across all altitudes expected in flight

Thus, this testing served to help verify our models for the descent control system's ability to remove helium across the range of flight altitudes.

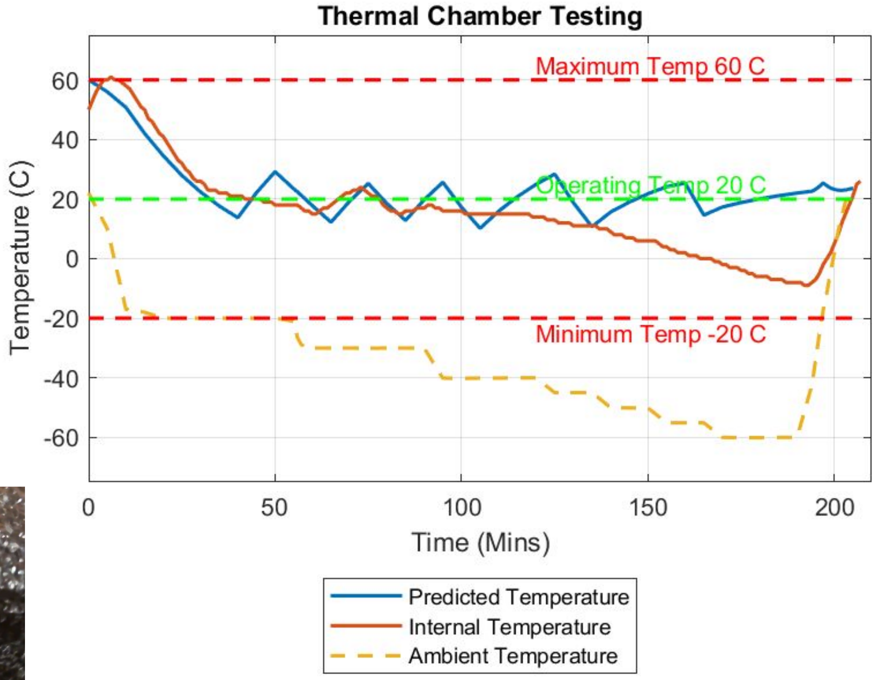
- Used to validate Descent Control Levels of Success

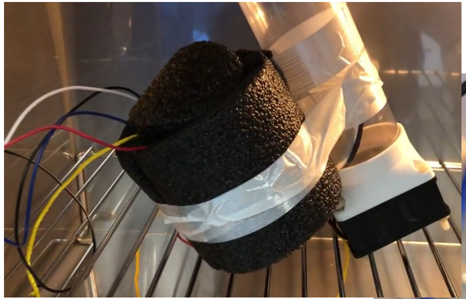


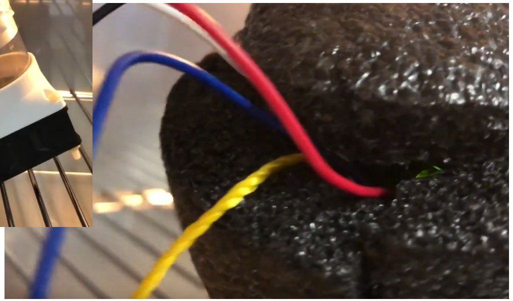
Thermal Chamber Test Results

Results:

- Insulation plug was ajar
- There was a short at the beginning
    - Heated the inside to 60℃
- Internal Temperature: -9℃
- Voltage: 5.86 V
- Heater not sufficient







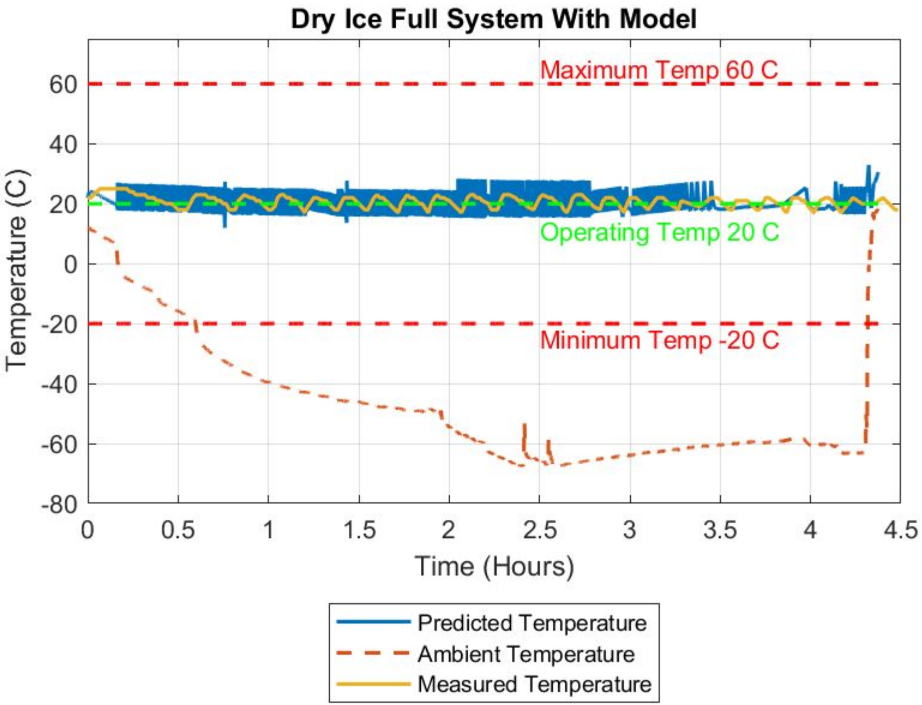
Full System Dry Ice Test Results

Results:

- Ambient temperature dropped as low as -60℃ to -70℃
- Internal temperature: 18-22℃ +/- 2℃
- System operated for the full flight duration (fan, servo, and heater)
  - Cutaway did not cut the tether
- Battery voltage was maintained around 11 V
  - Minimum of 9 V (rounded down)
- Model Prediction:
  - Temperatures: 12-32℃

Takeaway:

- Satisfies the system survival requirement
- Satisfies Level of Success 1 for Survivability
  - Survive conditions similar to 35 km



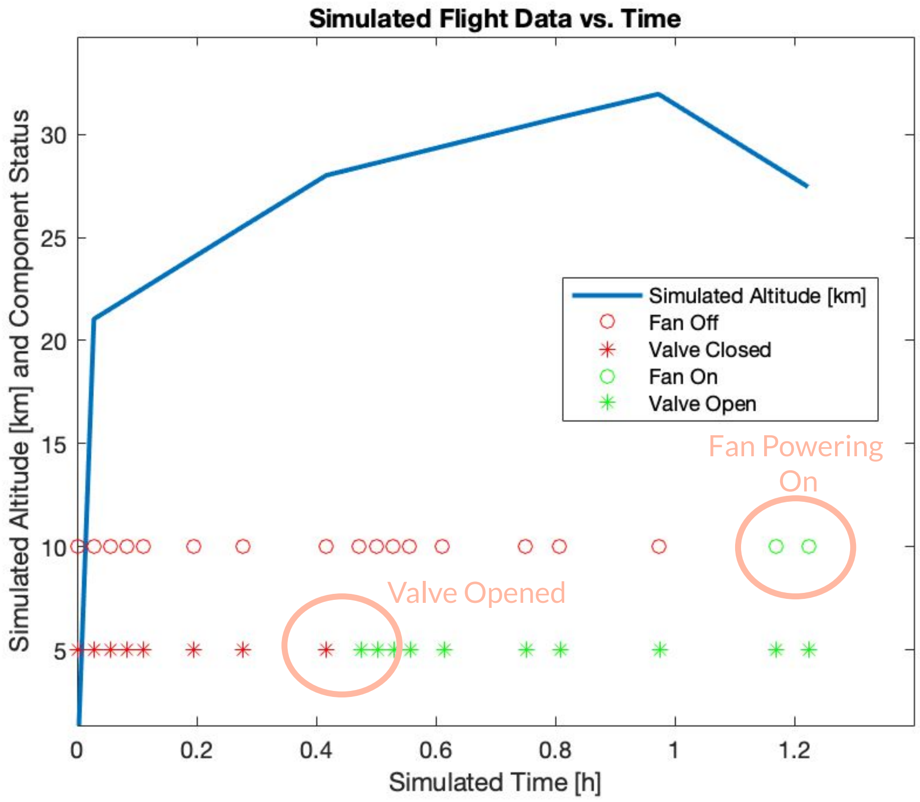
Communication Testing Results

Results:

- Successful communication link between ODDITY and the Gondola
- Successful interpretation of command packets from Gondola
- Verification of ODDITY components powering on and off based on commands from Gondola

Takeaway:

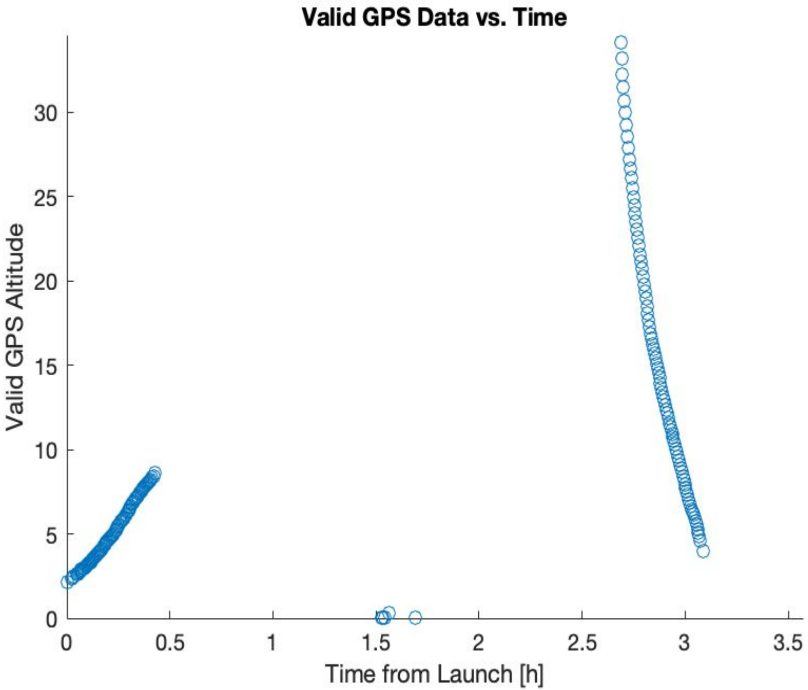
- Satisfies the communication link level of success 1-3
  - Shares a communication link w/ gondola, data received by ODDITY and data sent by ODDITY
- Valve opened at specified altitude (25 km)
- Fan powered on at apogee (31 km)



Test Flight Results (1)

Results:

- GPS on board the Gondola failed at 9 km
  - Gondola has a GPS check flag that prevents faulty control
  - Team ODDITY was not responsible for the GPS on Gondola
- Antenna pointing was not able to update based on GPS location of gondola
  - Caused splicing of downlinked packets (instrument and gondola)
- Antenna was manually pointed based on previous flight trajectories later in flight



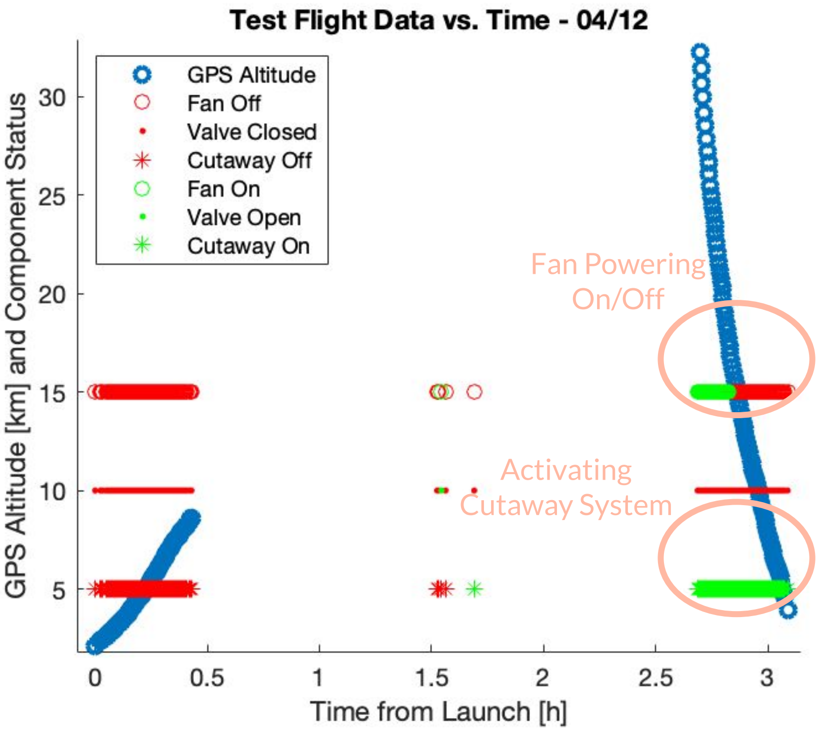
Test Flight Results (2)

Results:

- Verified ODDITY survival throughout flight
- Verified fan status was updated during descent portion of flight
- Cutaway mechanism did not cut through tether

Takeaway:

- Modified control logic for gondola was successful
- System survival level of success 2
- Fan performance was not able to be tested
- Cutaway system did not work potentially due to unforeseen forces from balloon burst



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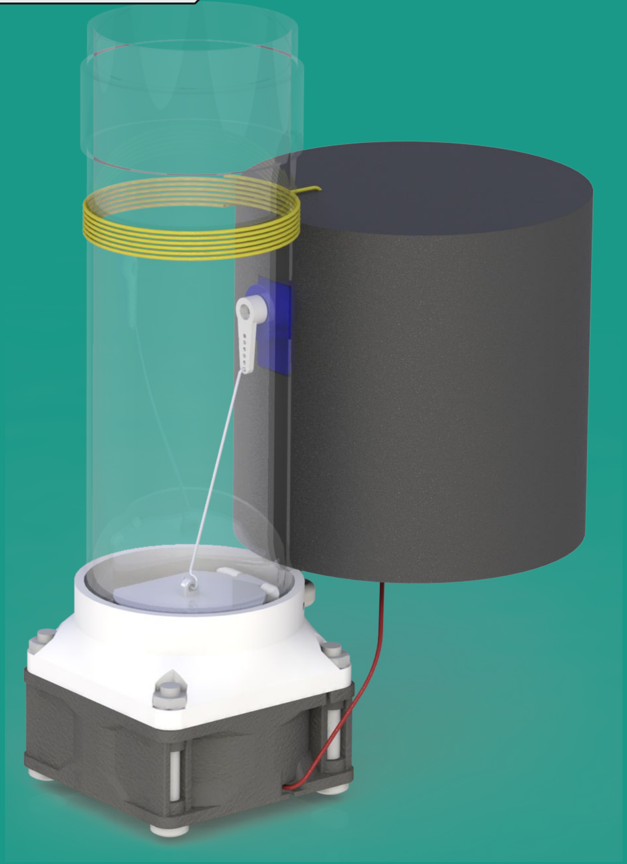
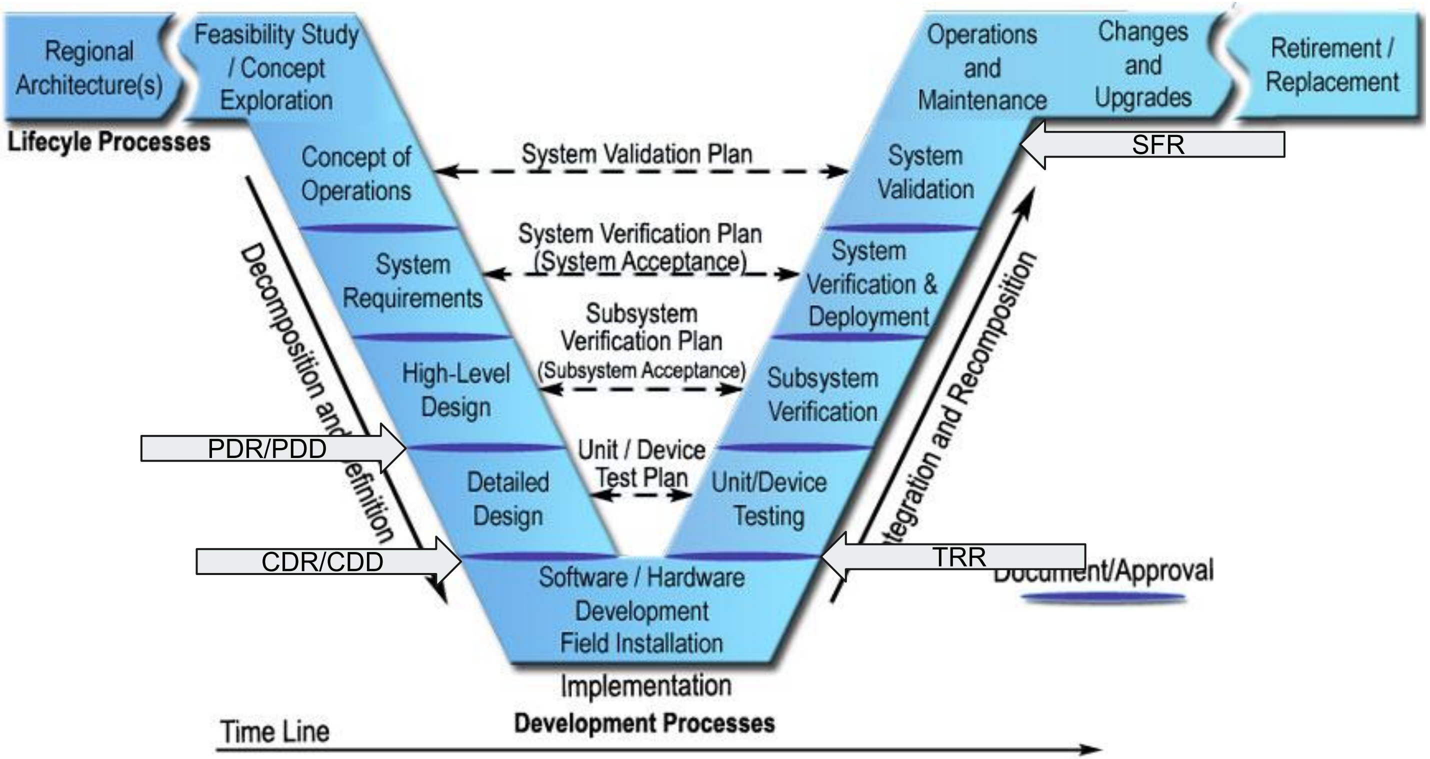
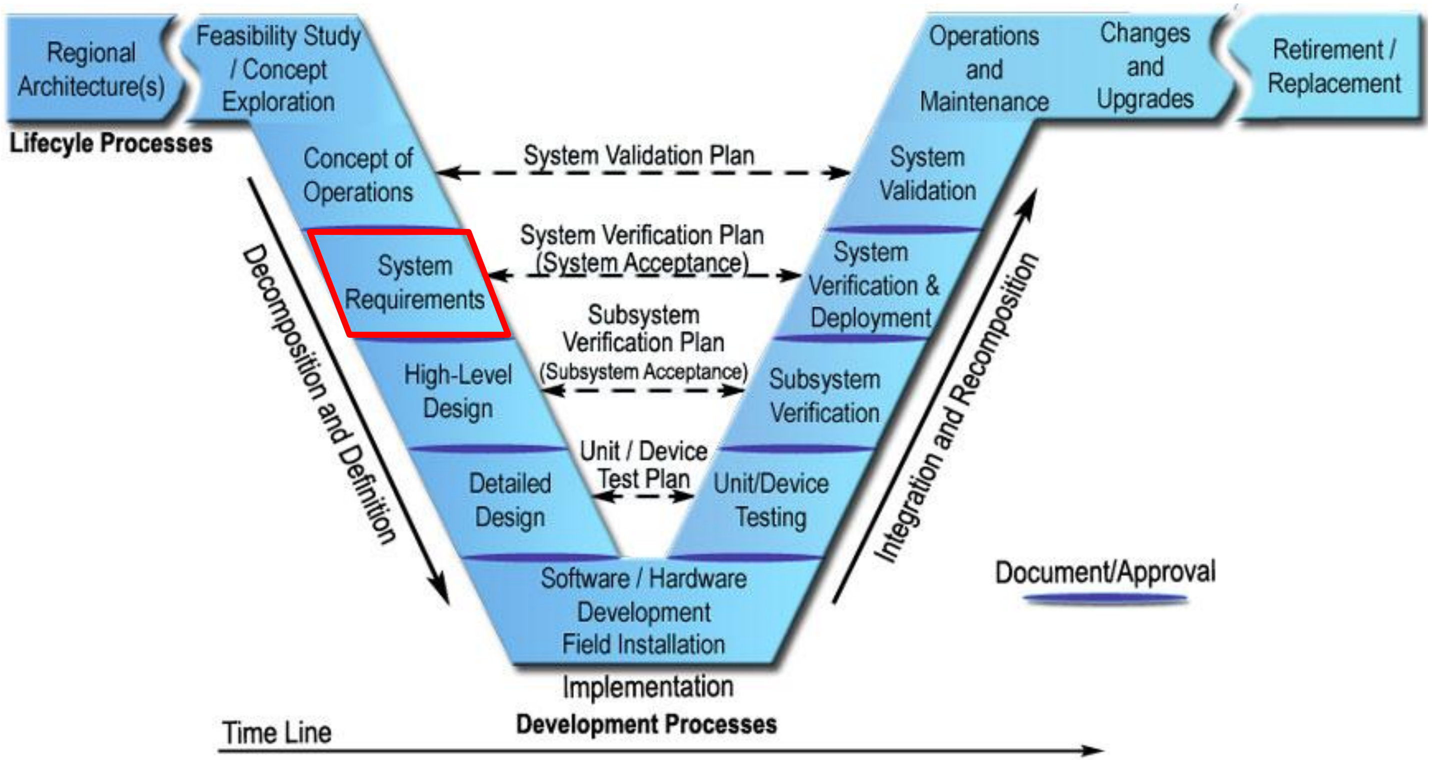
Systems Engineering



Systems Engineering "V"



Systems Engineering "V"

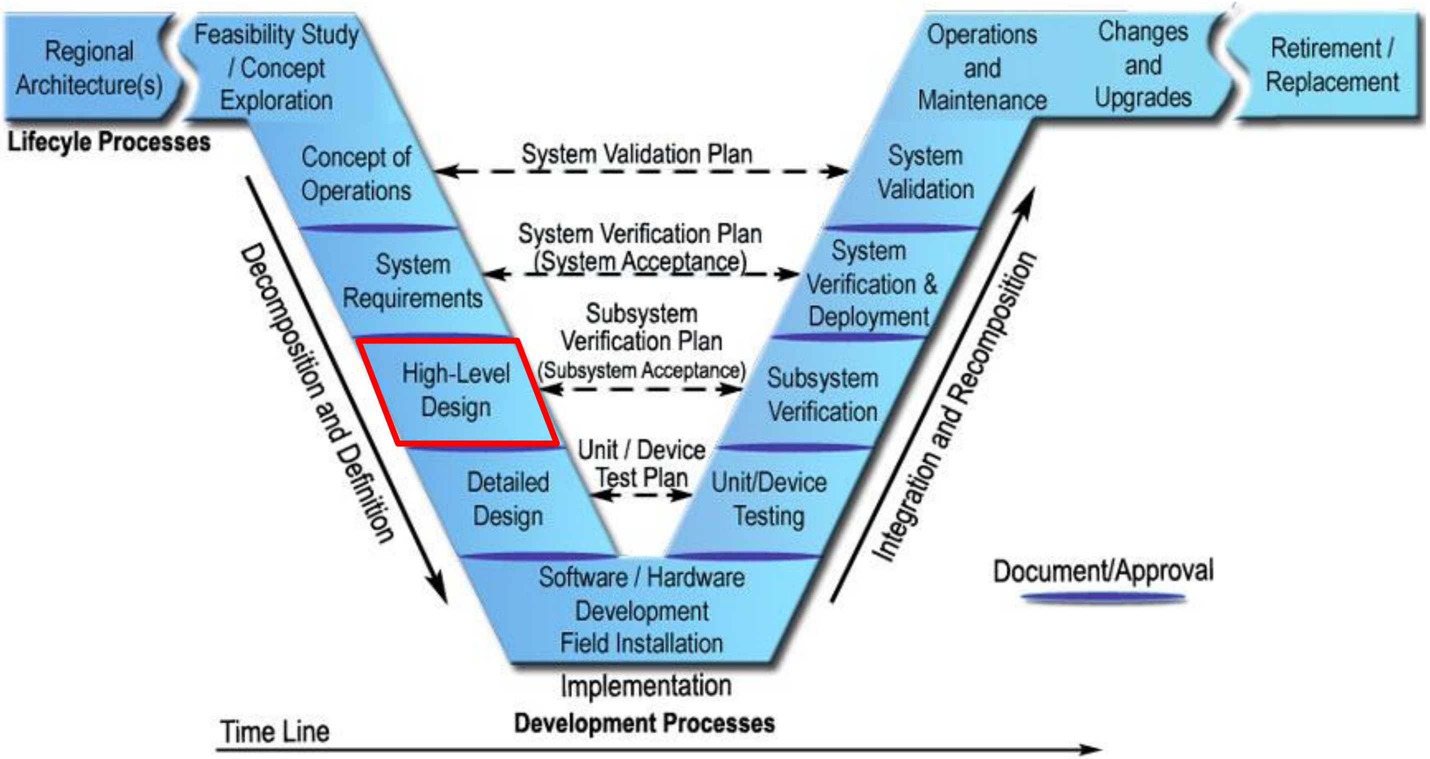


Requirements Flow-Down

Customer wants a system that removes helium from from a weather balloon to facilitate controlled descent of the balloon.

- This requirement lead to the development of 5 main functional requirements
  - **FR1:** ODDITY shall achieve a descent rate between 2m/s and 10m/s from the target altitude until the gondola is cut away.
  - **FR2:** ODDITY shall survive until the gondola is cut away from the balloon.
  - **FR3:** ODDITY shall have a communication link with the gondola.
  - **FR4:** ODDITY shall not significantly interfere with the data gathering equipment on the gondola.
  - **FR5:** ODDITY shall mount to the neck of a standard weather balloon.

Systems Engineering "V"



Key Trade Studies

Descent Control Mechanism

- Seeks to answer the question, "What is the best method to remove helium from the balloon envelope?"
- **Results:** The *Axial Fan* design was chosen as the active descent control system

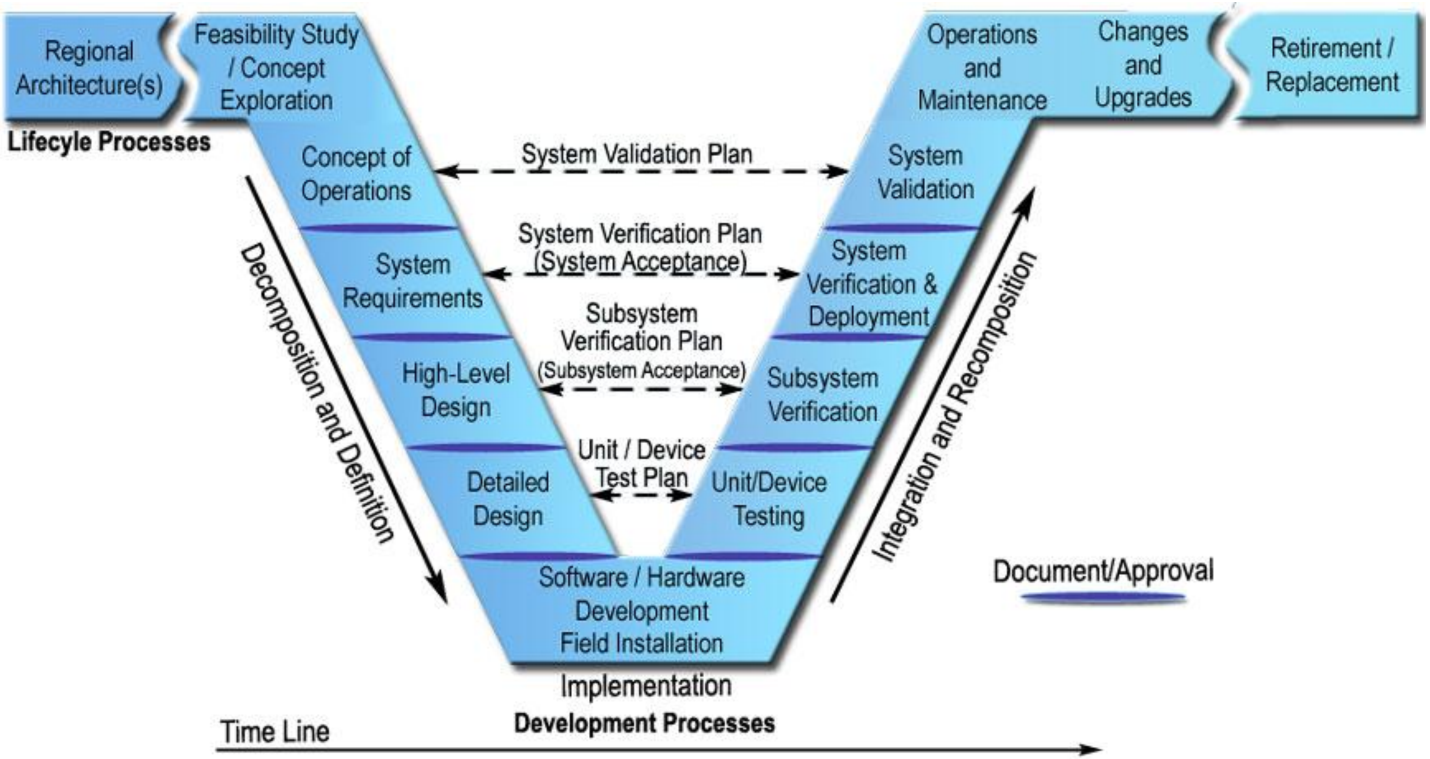
	Axial Fan	Pump	Hoop	Upside Down Balloon
Metric (Weight)	*Score*	*Score*	*Score*	*Score*
Mass (25%)	4	3	1	1
Cost (10%)	5	5	5	1
Volumetric Flow Rate (25%)	3	1	3	5
Current Draw (15%)	5	5	3	5
Complexity/Feasibility (25%)	2	5	1	1
Weighted Score	3.5	3.5	2.2	2.6

Electronics Insulation

- Seeks to answer the question, "What material will best insulate the electronics while being light and cost effective?"
- **Results:** *Polyethylene* was chosen to insulate the electronics

	Expanded Polystyrene	Polyiso-cyanurate	Extruded Polystyrene	Armaflex Polyethylene
Metric	*Score*	*Score*	*Score*	*Score*
Density (35%)	3	4	5	3
Thermal Conductivity (35%)	2	5	4	3
Temperature Range (20%)	2	5	1	5
Cost (10%)	1	4	5	5
Weighted Score	2.25	4.55	3.85	3.6

Systems Engineering “V”



How Risks Were Assessed

Level	*Likelihood*	*Impact*
5	Certain	**Catastrophic:** The entire flight will be rendered useless due to risk
4	Highly Likely	**Severe:** Very little useable scientific data is able to be used from flight
3	Likely	**Major:** Some data is able to be gathered, uncertain data accuracy
2	Improbable	**Minor:** Issues prevent all data gathering, but still overall successful
1	Extremely Improbable	**Minimal:** Mission is still able to be accomplished with minimal issues

*Score (Impact * Likelihood)*	*Level of Risk*
1 - 5	Low
6 - 14	Medium
15 - 25	High

Primary Project Risks

Risk	Before Mitigation	After Mitigation	Was it an Issue?
COVID-19 Closures	*Impact:* Severe *Likelihood:* Highly Likely	*Impact:* Severe *Likelihood:* Likely	Slight Issue
Test Flight does not happen	*Impact:* Minor *Likelihood:* Likely	*Impact:* Minor *Likelihood:* Improbable	Not an Issue
Fan cannot remove helium fast enough	*Impact:* Major *Likelihood:* Likely	*Impact:* Major *Likelihood:* Improbable	Not Expected to be an Issue
Insufficient battery power	*Impact:* Major *Likelihood:* Improbable	*Impact:* Major *Likelihood:* Extremely Improbable	Not an Issue
Batteries get too cold	*Impact:* Major *Likelihood:* Likely	*Impact:* Major *Likelihood:* Extremely Improbable	Not an Issue

Systems Engineering Challenge:

Difficulty getting access to parts we needed to interface with.

- Made it difficult to integrate the ODDITY system with the sensor carrying gondola
  - Integration was not able to be fully verified until just recently when we were given a new gondola control board to work with
- Full and verified integration was a key step towards being able to do a test flight
  - The ability to have a test flight was a primary risk the group was monitoring
  - Mitigated the risk through the excellent overtime work of Steven Priddy ensuring ODDITY was integrated with the gondola

Systems Engineering Challenge:

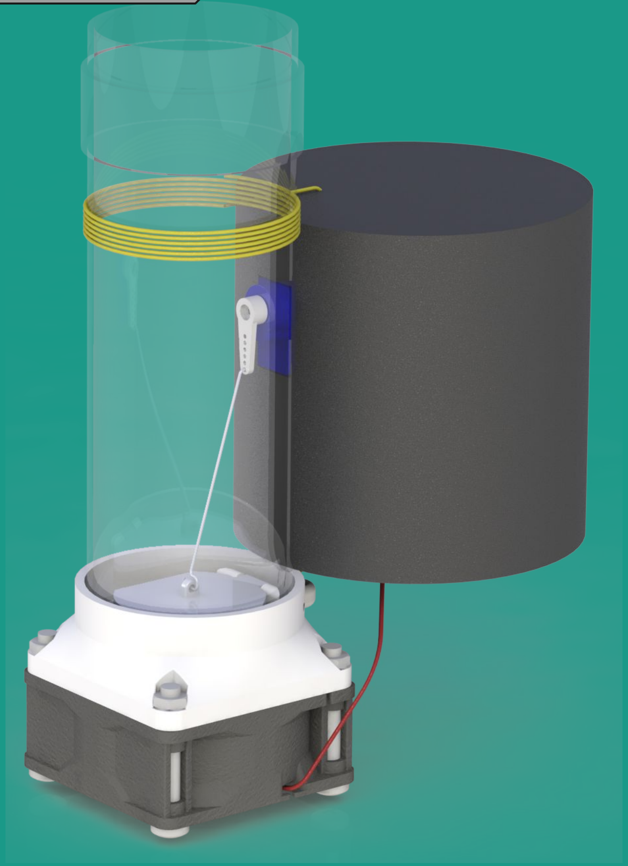
What does an assembly guide and user manual need to include?

- A customer requested deliverable for ODDITY is an assembly guide and user manual document
  - No one in ODDITY had experience developing either an assembly guide or a user manual
    - Customer provided the group with the assembly guide for the legacy system
  - Unsure of how detailed the instructions need to be based on the given legacy guide
    - Erring on the side of too much detail to ensure ODDITY is replicable
  - User manual instructions are difficult to develop
    - Have to constantly remember that what is intuitive to the group may not be to the end user

Key Systems Engineering Lessons Learned

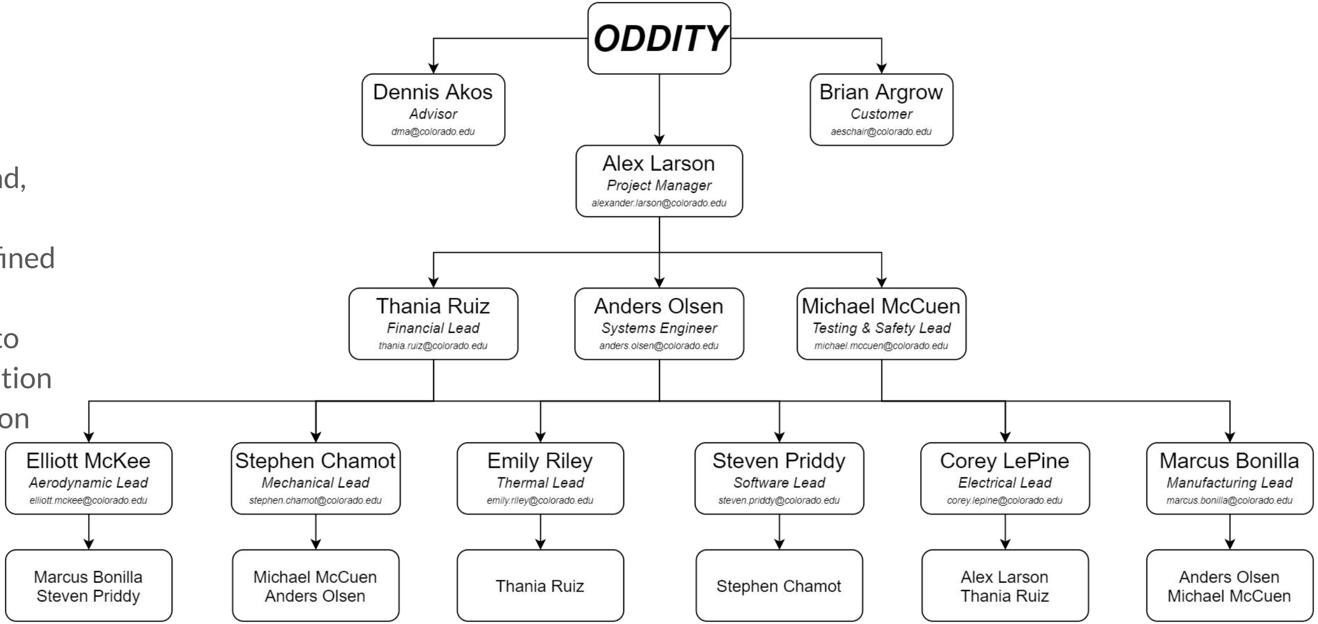
- Developing requirements is a difficult but important task
  - Requires good communication between customer and group hired to complete the task
  - Must be done early on so that there is minimal scope/requirement creep in the project
  - Must be thorough to prevent either side from misunderstanding expectations
- Risk tracking and management is fluid
  - New risks must be identified as early as possible
  - Current risks must be monitored continuously
    - Mitigation is a constant process to ensure the best chance at success

Project Management



Management Summary

- Customer provides problem to be solved which creates need for coordinated project
- PM provides vision for project, project deliverables and project timelines
- Vision flows down to Financial Lead, Systems Engineer and Testing and Safety Lead where the vision is refined and task breakdown is defined
- Task's to achieve vision then flow to appropriate sub-teams for completion
- Sub-teams formed with emphasis on personnel cross over to enable seamless and frequent cross communication and collaboration between teams



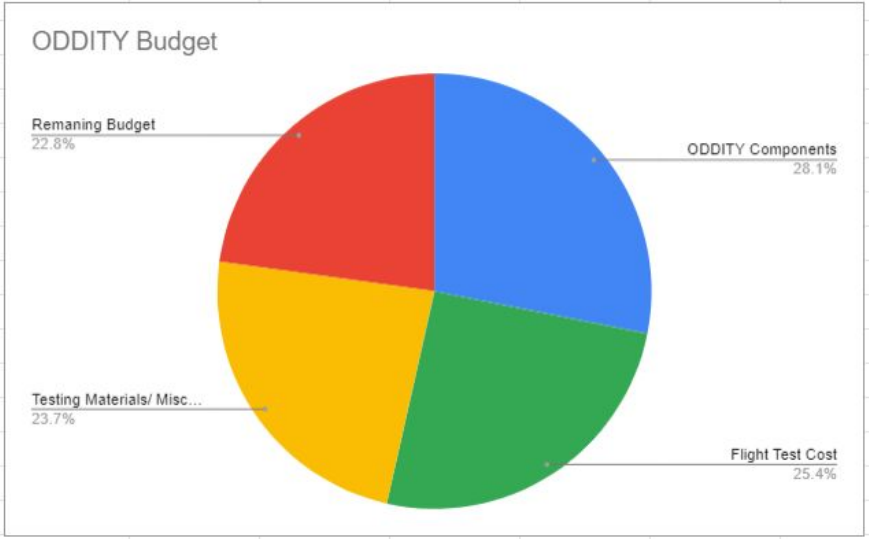
Successes and Lessons Learned

- Successes
    - Frequent communication between sub-teams was achieved, enabled a strong support system and team wide understanding of project vision and direction
    - Sub-team crossover in personnel allowed for flexibility in task completion
    - Lead roles lent themselves well to the different critical project elements, created natural leads and support systems for individual CPE's
- Lessons Learned
    - Remote work requires longer turnaround and margin time in project plan then first expected
        - Incorporate longer turnaround and margin in almost all task operated in a 'not in person' environment
    - Sub-team crossover in personnel could lead to individual's work loads filling up quickly
        - Establish more frequent sub-team meetings so schedules and work loads could be better managed incrementally
    - Due to critical path, varying workloads from sub-team to sub-team was difficult to balance in certain portions of the project
        - Created a check-in system or document where sub-teams and their personnel reported their weekly workload so resources could be more easily managed as far as workload distribution

Project Budget

ODDITY Parts	Quantity	Cost	Total	Uncertainties
Electronics			$99.68	$6.42
Arduino Nano	1	$12.90	$12.90	$3.52
Xbee Zigbee 3	1	$16.21	$16.21	$1.60
ASP CR123A Batteries	4	$1.90	$7.60	$1.00
Transistors	4	$0.45	$1.80	$0.00
Temperature Sensor Resistor	1	$0.06	$0.06	$0.10
Voltage divider Resistors	3	$0.31	$0.93	$0.00
Solder Flux	**1**	**$26.99**	**$26.99**	**$0.00**
Current Limiting Resistors	1	$0.19	$0.19	$0.20
Printed Circuit Board	1	$33.00	$33.00	$0.00
Thermal Control Parts			$33.50	$3.00
Insulation (6ft)	**1**	**$19.20**	**$19.20**	**$2.00**
Active Stainless Steel Wire	**1**	**$8.65**	**$8.65**	**$0.00**
Thermal Tape	10	$0.37	$3.70	$0.00
Temperature Sensor	1	$1.95	$1.95	$1.00
Descent Control Parts			$33.53	$4.50
Servo	1	$7.98	$7.98	$0.50
Sealing Valve	1	$2.00	$2.00	$1.00
Foam Tape	**1**	**$12.23**	**$12.23**	**$0.00**
Axial Fan	1	$11.32	$11.32	$3.00
Cut Away Mechanism Parts			$0.50	$0.10
Burning Resistor	1	$0.50	$0.50	$0.10
Balloon Attachment			$12.00	$7.00
Nylon Bolts	**1**	**$27.99**	**$27.99**	**$0.00**
Sealing Glue	**1**	**$4.75**	**$4.75**	**$0.00**
Mounting tape (3ft)	**1**	**$6.99**	**$6.99**	**$0.00**
Diffuser Neck Attatchment	1	$2.00	$2.00	$3.00
Balloon Neck Plastic Tube (5 cm)	1	$4.00	$4.00	$2.00
Balloon Neck Plastic Tube (8 cm)	1	$6.00	$6.00	$2.00
		Total	$179.21	$21.02

Customer Requirement: $ 200.00
Project Cost at CDR: $129.22
Project Cost now: $179.21



Remaining Budget: $1141.52

Project Labor and Estimated Industry Cost

- Fall semester total labor hours
  - 704.5 hours (recorded) + 635 hours (estimated for first 7 weeks of undocumented hours) = 1339.5 hours
    - Estimated hours was derived by averaging weekly total hours across both semesters and multiplying by 7 for the amount of undocumented weeks
- Winter break total labor hours
  - 37 hours
- Spring semester total labor hours to date
  - 1099.5 hours
- Project total labor hours comes out to 2476 hours
  - Approximate equivalent labor cost of entry level aerospace engineer ($31.25/hour) comes out to be $77,375
  - Incorporating approximate overhead costs of 200%, total estimated cost reaches $232,125
- Materials cost to date has reached around $3,900, which puts the grand total of an “industry equivalent” project to:

$236,025

Team ODDITY would like to thank

Dr. Brian Argrow

Dennis Akos

The PAB

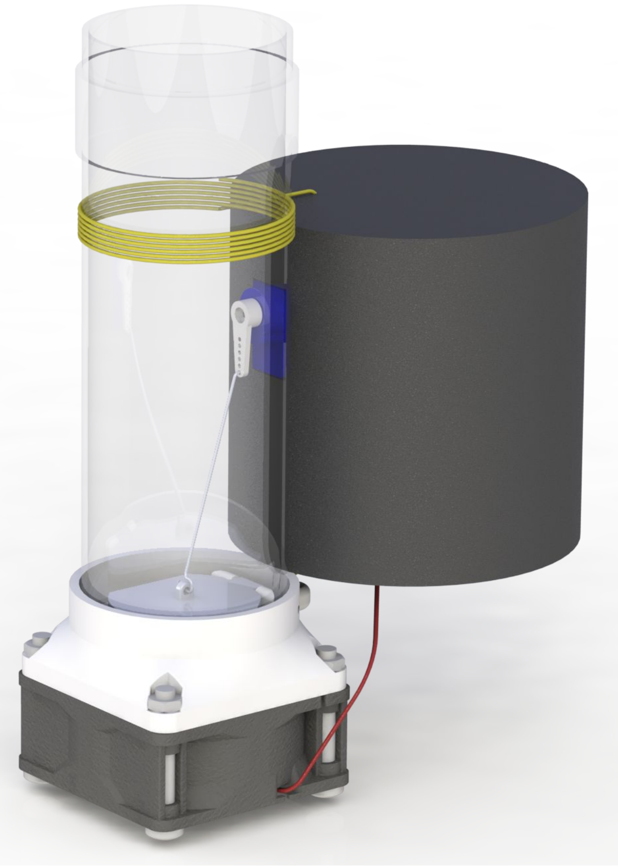
Special Thanks to

Devesh Sharma

Dr. Dale Lawrence

ODDITY

Any Questions?



Appendix

Future Flight Test

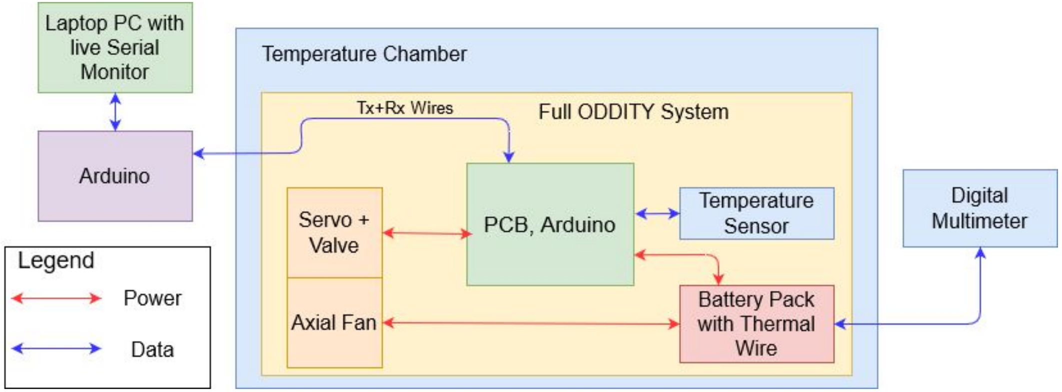
Low Temperature Testing - Thermal Chamber

Test Setup:

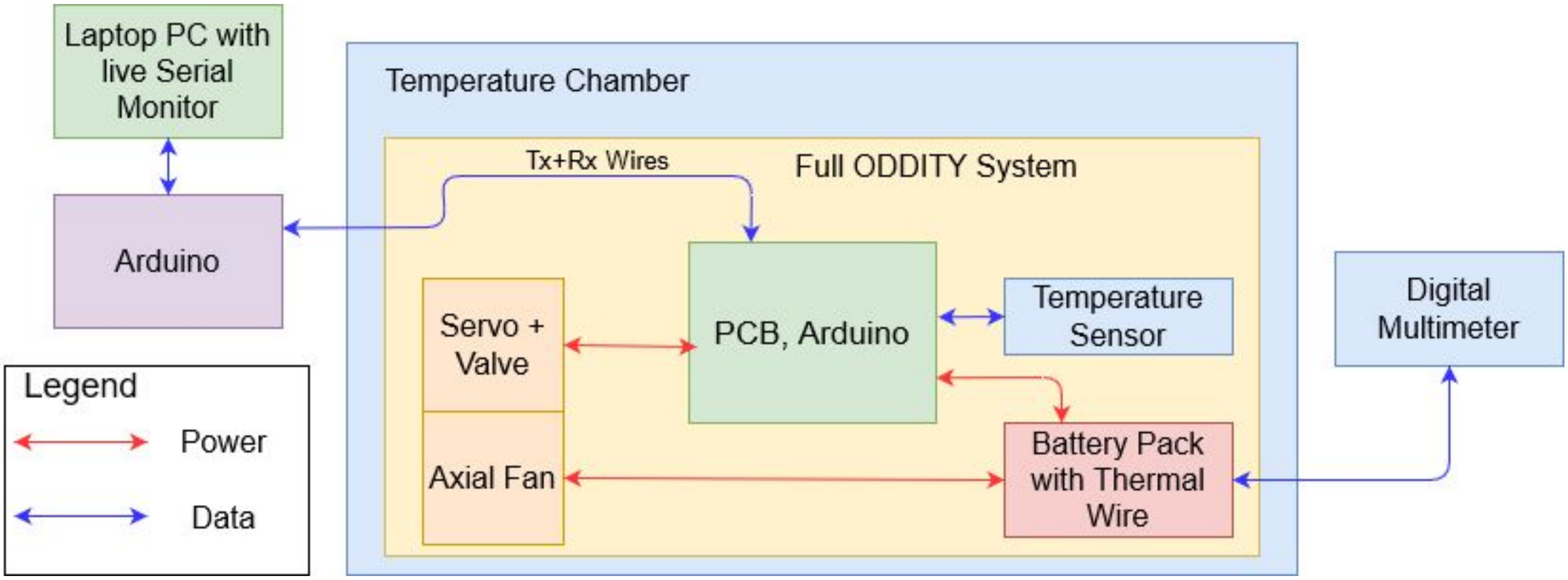
- Low temperature thermal chamber
- Send commands through Rx+Tx
- Measured voltage using multimeter
- Heater bounds from 15-25°C

Procedure:

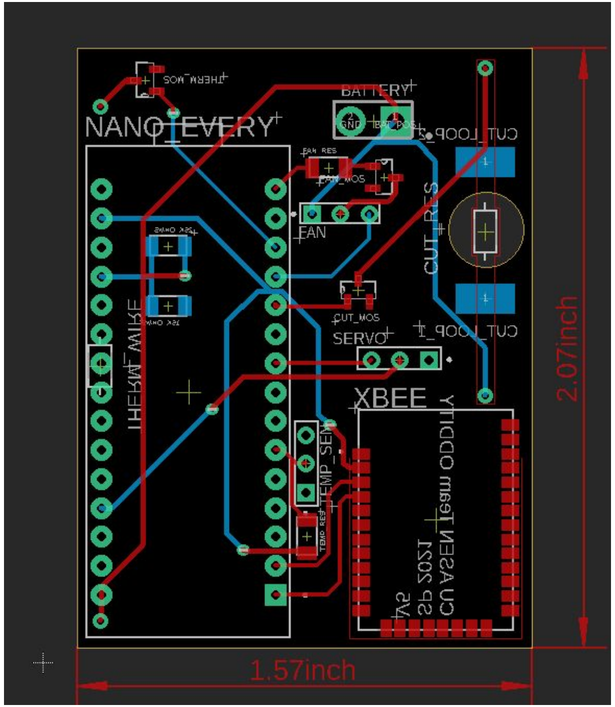
- Step down chamber temperatures in intervals of 10 °C
- Allow system to operate over full flight time.

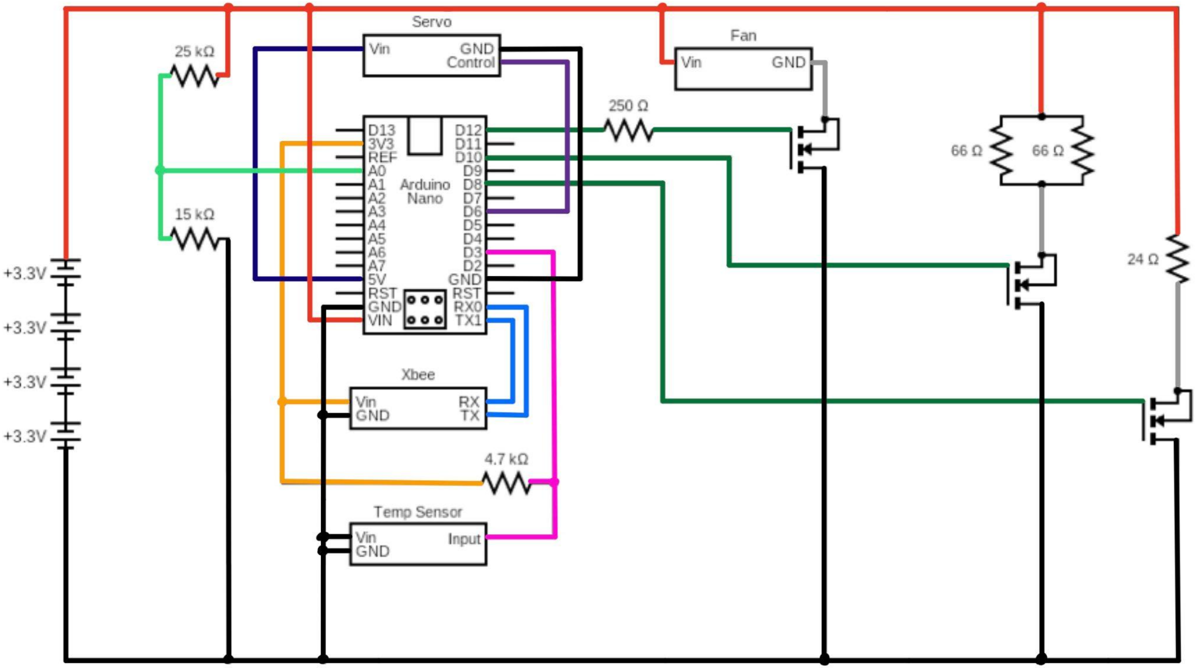


Extra Slide: Cold Chamber Test Diagram

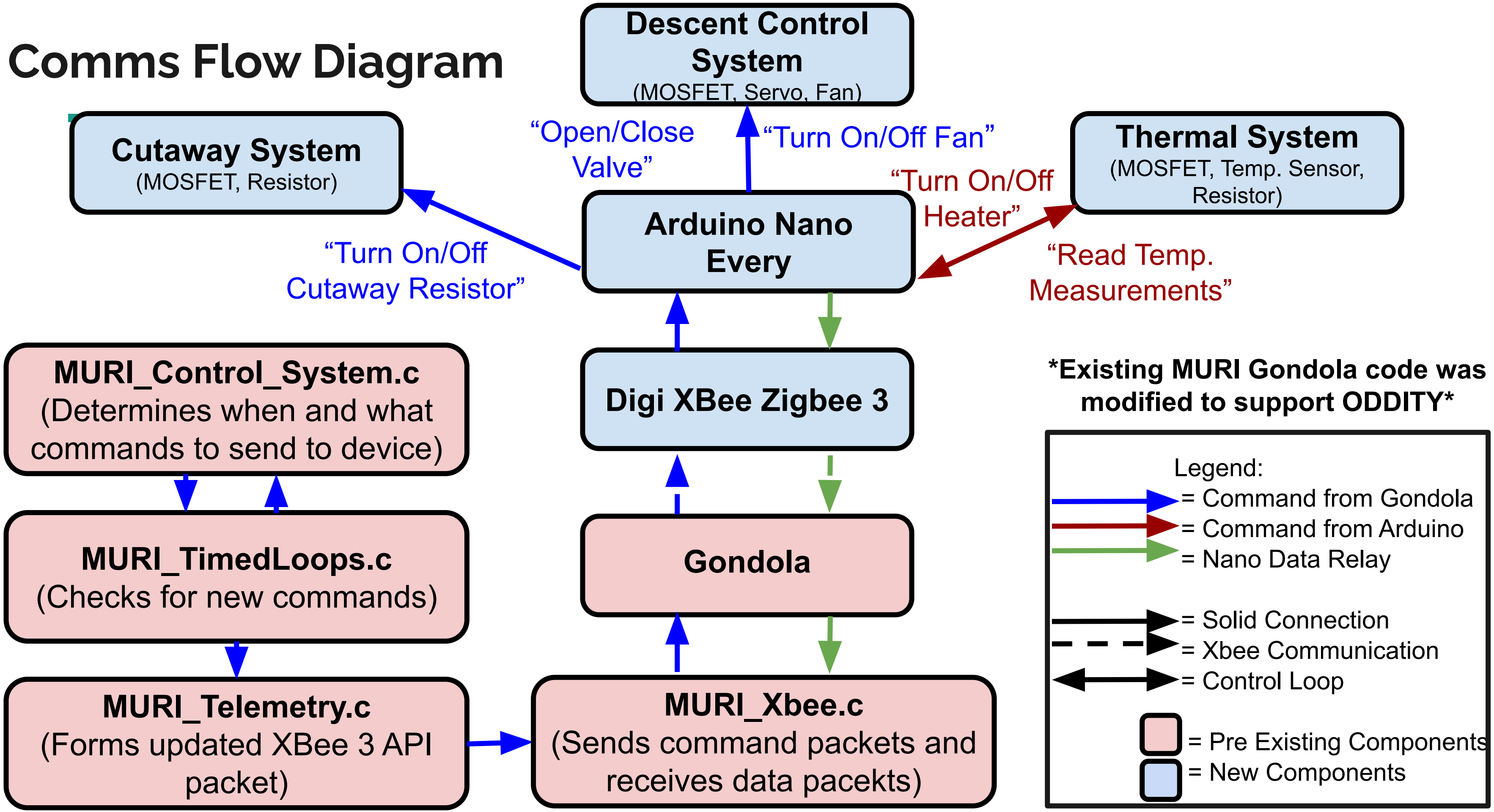


ODDITY PCB and Electrical Schematic





Comms Flow Diagram



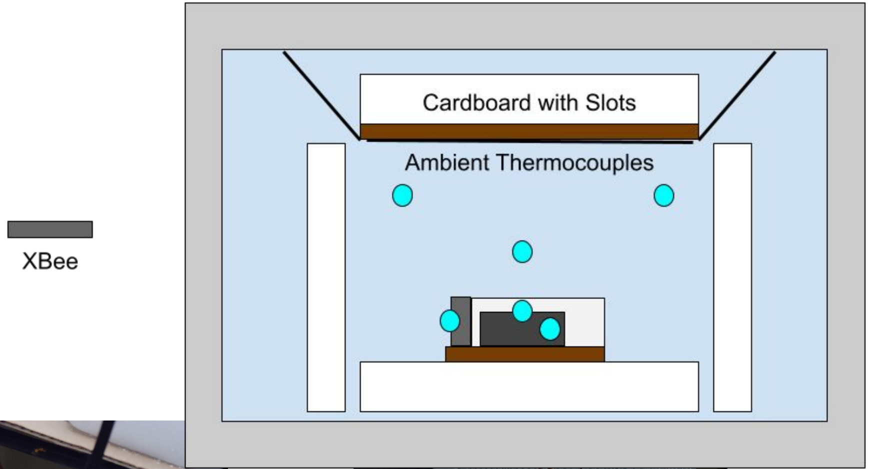
Low Temperature Testing - Dry Ice

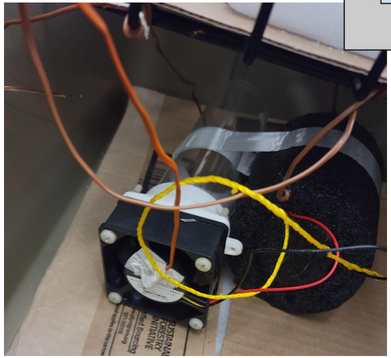
Test Setup:

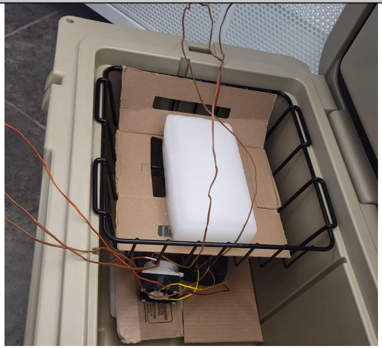
- Dry-ice in Yeti cooler
- 3 thermocouples as ambient
- 1 thermocouple in insulation
- 1 thermocouple near servo
- 1 thermocouple on fan motor
- Heater bounds from 18-22℃

Procedure:

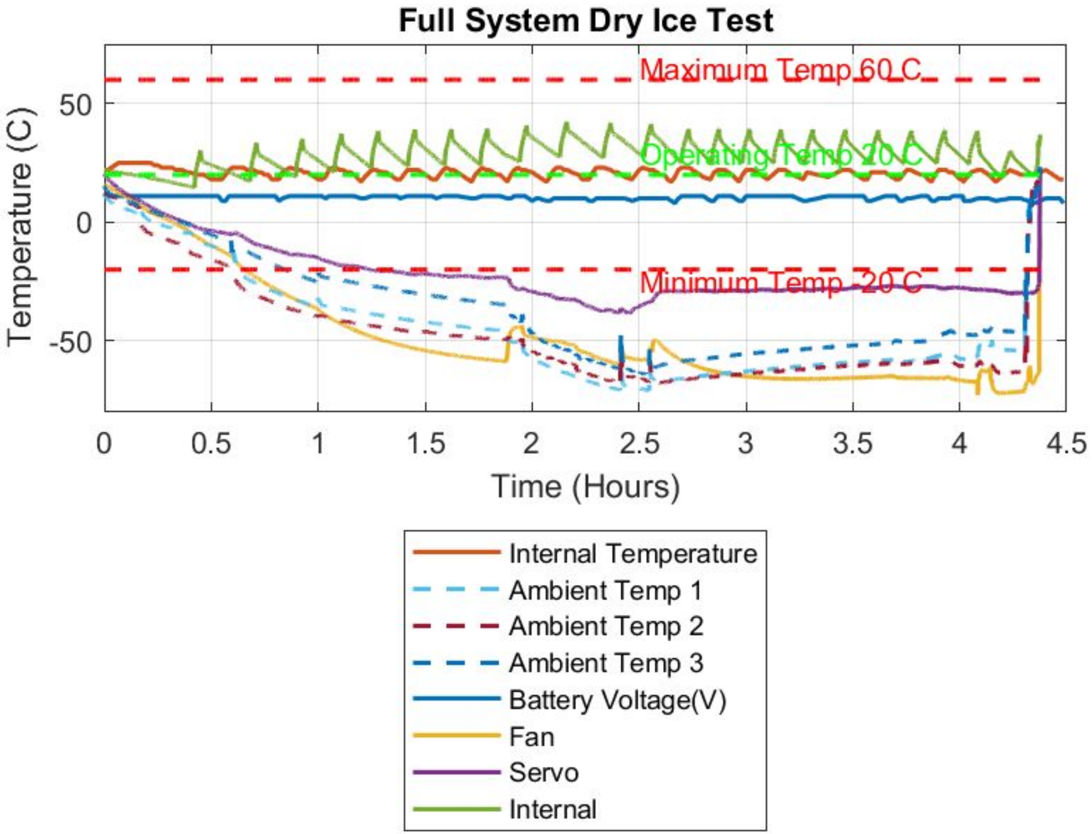
- Simulate expected temperature profile by adding or removing ice
- Allow system to operate over full flight time.







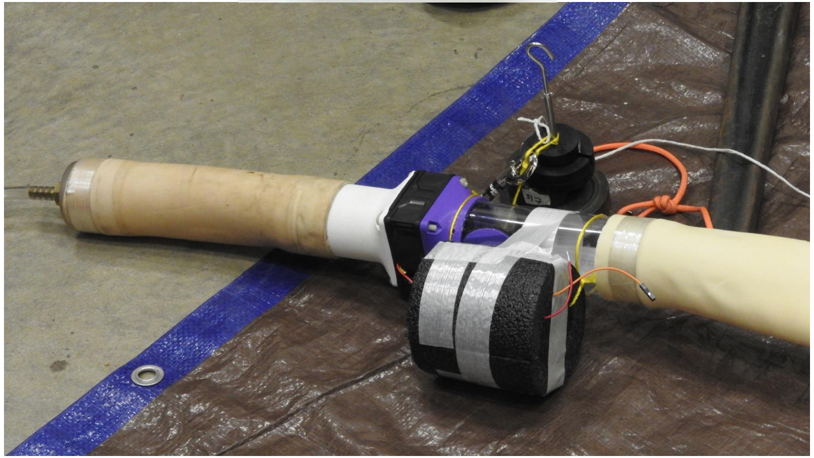
Low Temperature Testing - Dry Ice



Helium Filling Method

3D Printed Fill Adapter

- HYFLITS uses a balloon neck as an adapter for the legacy model
- The same bolts and nuts that connect the fan and diffuser are used to connect the Fill adapter
- Command ODDITY to open the Valve and commence filling

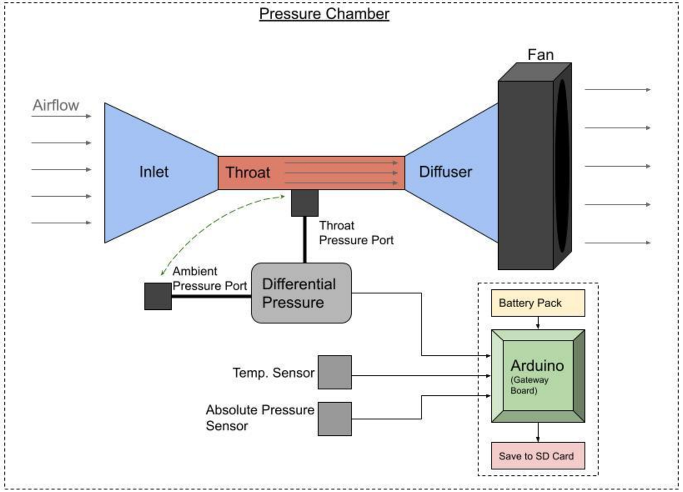


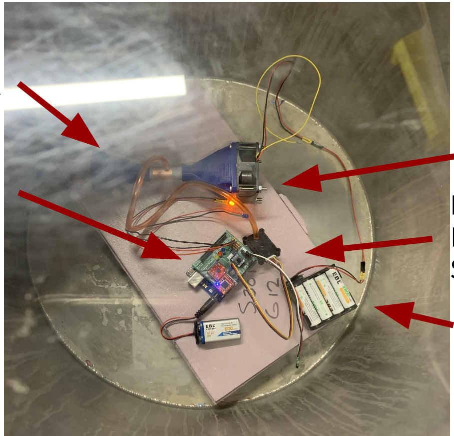
Low Pressure Testing- Concept

A **Low Pressure Chamber** (AERO) was used in order to simulate the extreme altitudes experienced in flight.

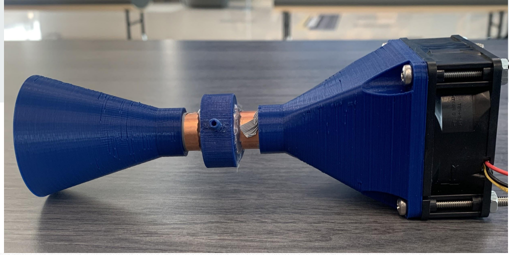
A **measurement of the dynamic pressure** of the flow was made, to **determine the flow velocity** in the throat.

- Because of the low air densities and flowrates, the dynamic pressure readings expected were extremely small in magnitude.
- As such, a **"Venturi tube" was used, in order to accelerate the flow, such that the differential pressure measurement was large enough to be measurable.**
- A **differential pressure sensor** measured the difference between the chamber ambient pressure (*assumed total*), and the static pressure at a port inside the Venturi tube throat section; effectively the **dynamic pressure**, assuming no losses
    - Allows for the calculation of flow velocity at that point. Assuming uniform velocity, we can then estimate the volumetric flowrate, given the known throat area.





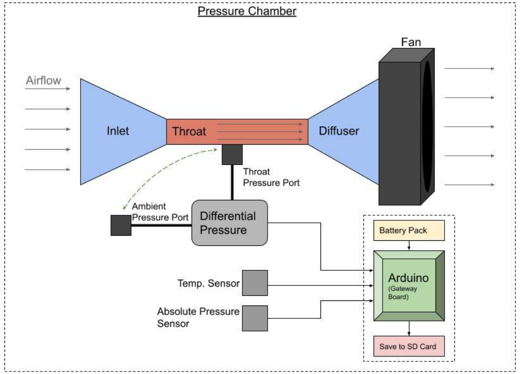
Low Pressure Testing- Setup/Procedure

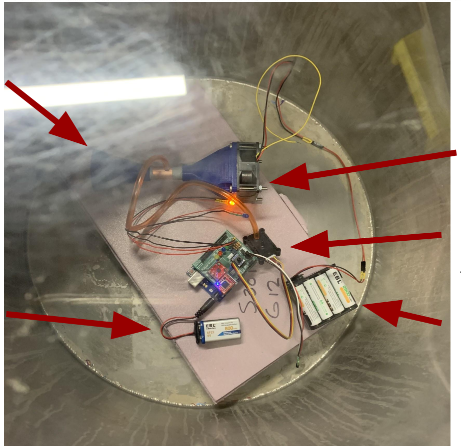


Facilities Required:
- Low-Pressure Chamber
  - Available in AERO via Matt R.

Test Equipment:
- Arduino & Gateway to Space Cape
  - Also provided by Matt R.
- 9V Arduino Battery
- Fan with Venturi assembly
  - 3D Printed Inlet/Diffuser
  - Press Fit Copper Tube w/ drilled holes
- High-Res Differential Pressure Sensor
  - Tubing
- 12V Fan Battery Pack

Procedure:
1. Insert SD-Card to Arduino
2. Power Arduino + Fan
3. Place entire set up into test chamber
4. Seal Low Pressure Chamber
5. Pump down Chamber to desired simulated altitudes
   a. Hold pressure for >30s, to ensure steady state has been reached
6. Once all pressures tested, slowly depressurize chamber.
7. Un-seal pressure chamber once pressures equalized
8. Remove Test Apparatus
9. Power off Arduino
10. Remove SD Card and save data.





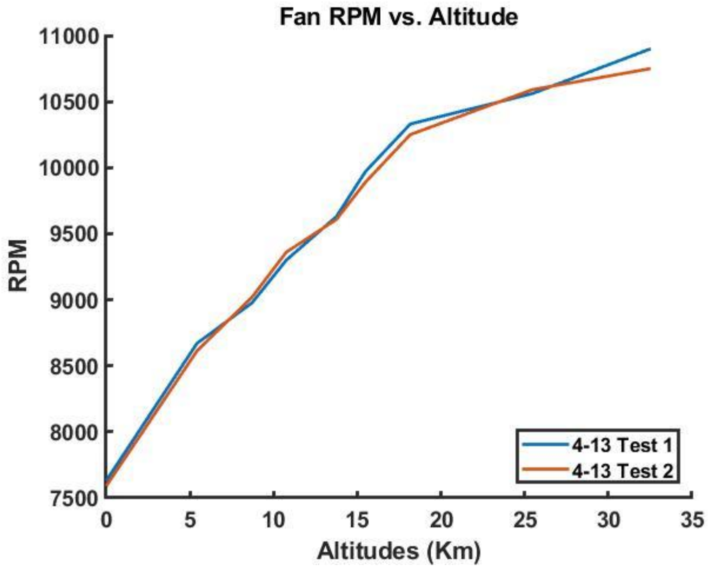
Low Pressure Testing- RPM Testing & Results

It was expected that the Fan RPM would increase due to the thinner air at altitude

The previous testing methodology also allowed for a tachometer to be mounted in the pressure chamber

Allowed to quantify the increase in fan RPM with altitude

Results were included to update the fan flowrate vs. altitude analysis



Testing confirmed that the fan RPM did increase significantly at higher altitudes.

- Nominal, **Sea Level**: **7,600 RPM**
- Measured, **35 KM**: **~10,500RPM**

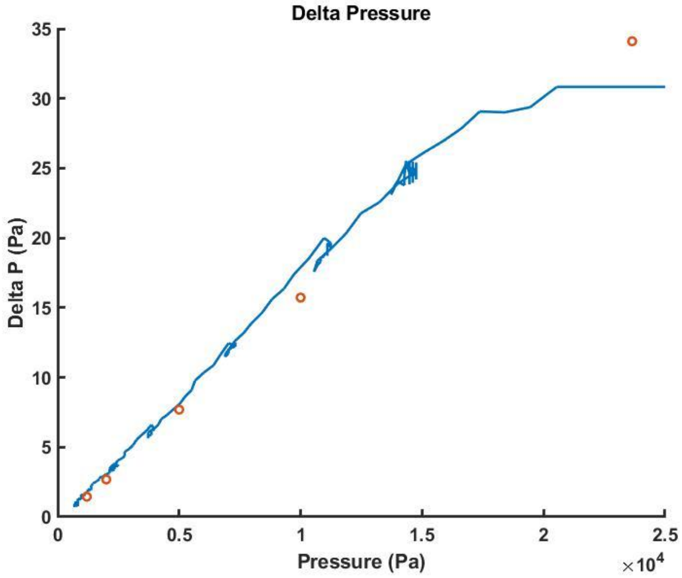
Low Pressure Testing- Delta P Data

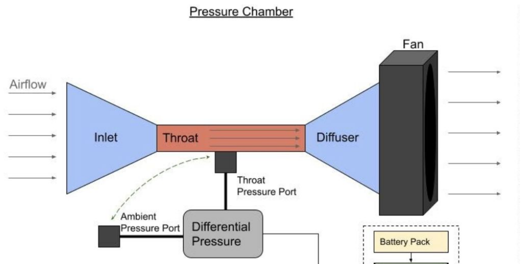
Distilling down to comparing the Delta Pressure measured between the Venturi throat and chamber ambient **removes as many assumptions associated with the calculations**

In the plots show, we see strong agreement between the measured ΔP's, and the ΔP's given from CFD.

Of the comparable points, the **maximum relative error seen was 11.3%**

-Uses interpolated test data





Ann and H.J. Smead
Aerospace Engineering Sciences
UNIVERSITY OF COLORADO BOULDER

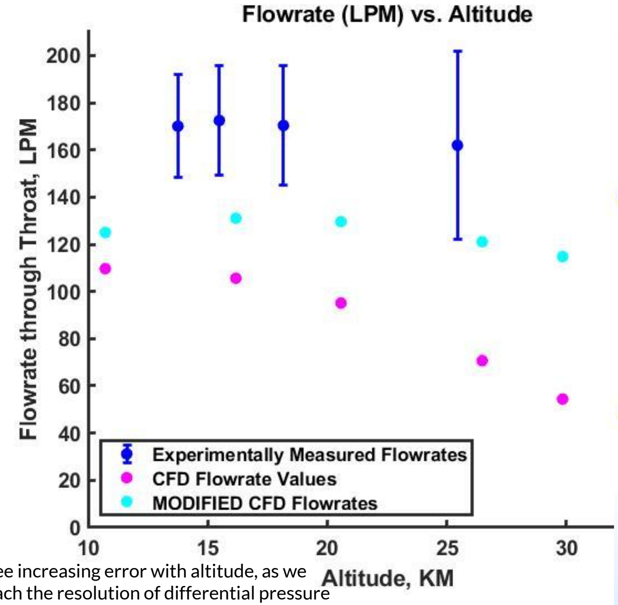
Low Pressure Testing- Additional Discrepancies

In general, our experimental results outperformed what we expected from the CFD modelling performed. Similar trends seen throughout.

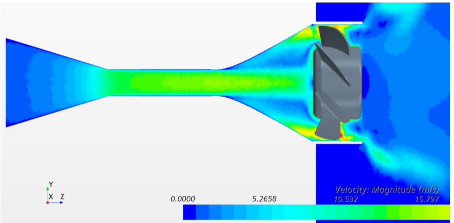
1. The experimental calculation assumes a constant cross-sectional flow velocity

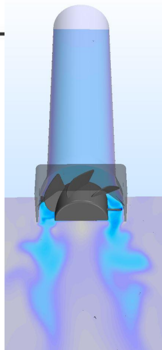
2. RPM measured in dataset used was higher than modelled in CFD
   - Result of Battery Voltage
3. Slightly larger throat inner diameter in experiments
   - Less Restriction
4. Unknown turbulence behavior
   - Because of extremely low Reynolds numbers, turbulence was suppressed in the inlet+throat.
     i. If turbulent, due to 3D printed roughness, flow-tripping on inlet-throat interface, etc., could lead to more constriction, and higher centerline velocities
5. Other CFD modelling limitations/assumptions

Many suspected discrepancies are magnified from using the constricted throat venturi tube



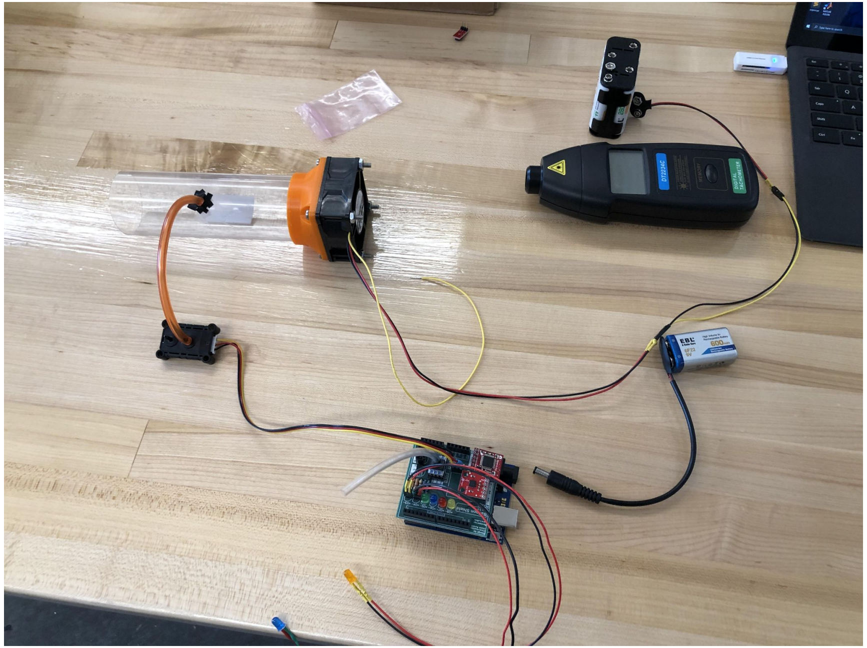
*We see increasing error with altitude, as we approach the resolution of differential pressure sensor



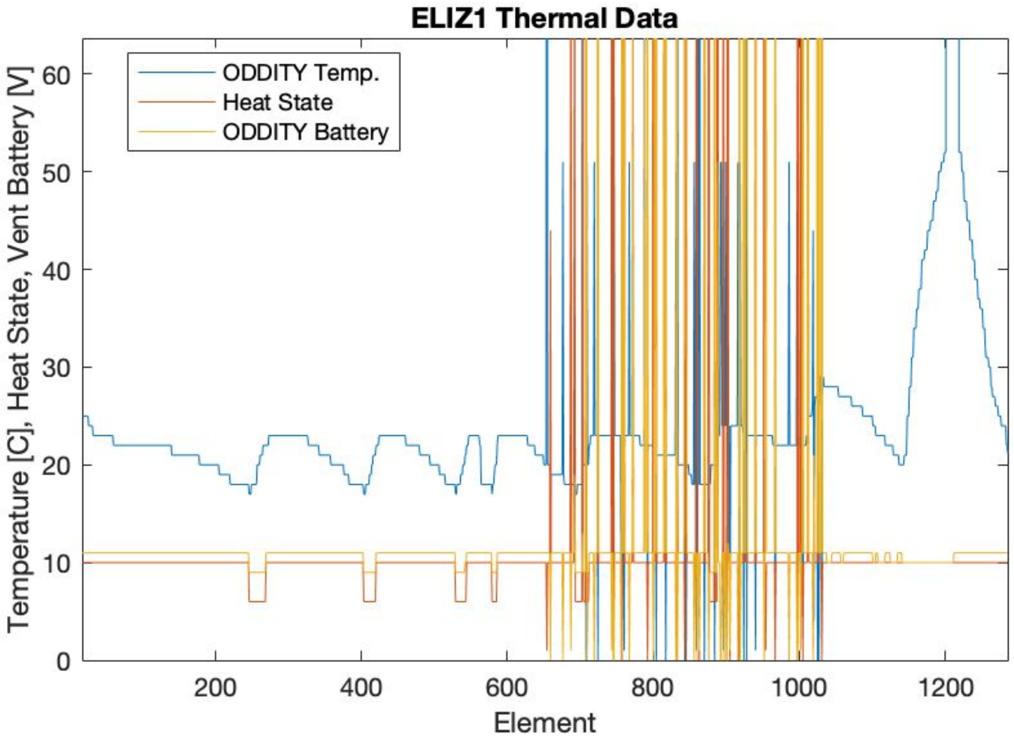


Boulder Altitude Testing

- 800 LPM measured relative to 1000 LPM nominal
- Low battery voltage, additional valve constriction



Test Flight Results (3)



ODDITY Demo Video