University of Colorado Boulder
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Senior Projects - ASEN 4018

Project ODDITY

Optimal Descent Device for In-Situ Turbulence analYsis

Conceptual Design Document

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Customer

Name: Prof. Argrow Email: aeschair@colorado.edu Phone: 303-492-8183

Team Members

Name: Corey LePine Email: Corey.LePine@colorado.edu Phone: (281) 901-2014	Name: Alexander Larson Email: Alexander.Larson@colorado.edu Phone: (603) 502-7905
Name: Stephen Chamot Email: Stephen.Chamot@colorado.edu Phone: (720) 257-4041	Name: Michael McCuen Email: Michael.McCuen@colorado.edu Phone: (610) 955-6889
Name: Thania Ruiz Email: Thania.Ruiz@colorado.edu Phone: (303) 652-7431	Name: Marcus Bonilla Email: Marcus.Bonilla@colorado.edu Phone: (720) 403-5677
Name: Steven Priddy Email: Steven.Priddy@colorado.edu Phone: (303) 990-0801	Name: Emily Riley Email: Emily.A.Riley@colorado.edu Phone: (425) 354-8818
Name: Anders Olsen Email: Anders.Olsen@colorado.edu Phone: (970) 818-6480	Name: Elliott Mckee Email: Elliott.McKee@colorado.edu Phone: (303) 304-7275

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1 Project Description

1.1 Purpose

New developments in hypersonic flight have allowed aircraft to fly farther, faster, and higher. This necessitates a more complete understanding of atmosphere characteristics at higher altitudes, specifically in the region from 20-40 km in altitude.

The CU Boulder Hypersonic Flight In the Turbulent Stratosphere (HYFLITS) research team is currently utilizing weather balloons with sensor payloads (gondolas) in order to carry out gravity wave and turbulence data collection; in addition to other in-situ research in these high altitude regions of concern. This data will be used to aid in the research and design of new vehicles, specifically hypersonic vehicles, that operate in the upper atmosphere.

One of the key measurements in the above system is the quantification of turbulent velocity in the upper atmosphere. The nature of this measurement requires that the measurement (specifically the gondola/-payload) must not be affected by the wake of any bodies; as is the case for a balloon rising through the atmosphere, with payload attached below it. This requires that the balloon must be *descending* in order to make accurate measurements of the desired phenomenon.

The existing system facilitates balloon descent, in the region of interest, by utilizing a servo-operated sealing valve placed in the neck of the balloon. As the balloon approaches the maximum allowable altitude, the valve operates, and the internal pressure of the balloon, due to the elastic strain in the latex envelope, ideally forces helium out of the balloon neck. This decreases the buoyancy of the balloon, and allows for the balloon-payload system to descend; as is required for the accuracy of the desired measurements.

However, this current helium evacuation valve system limits the maximum achievable altitude of the system, due to plastic deformation occurring in the balloon envelope. The current valve system relies only on the elasticity of the balloon to create a pressure difference between the balloon interior and exterior, in order to force out helium. However, the plastic deformation that is experienced above ∼35km causes the balloon to experience permanent stretching; meaning that the balloon will not return to the original size. As a consequence, the elastic force of the balloon canvas itself can no longer create the required pressure differential needed to evacuate helium past a given point. The remaining helium sits at the top of the slack balloon in a so called 'helium bubble'. At this point, the balloon still contains enough helium to prevent the system from descending, and therefore, collecting a complete data set. In order to solve this problem, helium needs to be forcibly evacuated from the envelope, in a more reliable fashion than is currently utilized.

The controlled evacuation of helium from the balloon will allow the sensor system to reliably reach higher altitudes than are currently achievable. This will expand the potential flight envelope for the currently used balloons and allow data to be collected at these higher altitudes. By having an active system instead of the current passive evacuation of helium, the volume of gas released can be increased. If this system is also dynamic, the descent rate can possibly be more accurately controlled to achieve the desired descent rate of 2 - 10m/s [Req. 1.0]. A dynamic system could also be adjusted for different mission profiles. The dynamic system will also allow for a wider range of balloons that can be utilized for a given mission; as the varying elasticity between balloon types will no longer be an issue.

1.2 Objectives

As this project focuses on the re-development of an existing system, there are many goals and objectives that need to be reached in order to improve upon the system as a whole. Speaking to the over all system, it will have to achieve all the following objectives, while staying under a mass allotment of 300 grams, in order to ensure proper balancing of buoyant forces. It shall also be a cheap design, under 200 dollars, so that the system does not have to be recovered after every flight, and can easily be re-fabricated without too much financial loss.

The main objective of this project is to create a sub-system designed to evacuate the helium bubble from the interior of the balloon envelope. It shall do this in such a way that it is able to reach a target altitude of 40km and still be able to reliably descend below 20km at a rate between 2m/s and 10m/s. This valve system shall be able to attach, and also be adaptable to, two different variations of balloon necks (Kaymont - 5cm diameter, Hwoyee - 9cm diameter). Furthermore, it shall be able to attach to the balloon neck before the insertion of helium, and as a result, must facilitate balloon inflation operations.

The RF Communications and Control sub-system shall be another major aspect in this design, as it will provide a wireless communication link to the gondola. This will allow for two way communication between the gondola and the the valve, which will help inform decisions about vent timing, as well as cut-away. Speaking to the cut-away component, the radio communication and control shall allow determination for cut-away time both electronically and remotely. RF Communications sub-systems shall also provide live status updates of the balloon and its vital sub-systems such as cut away and buoyancy control device, *to* the gondola; meaning that the radio communication shall be a two way link.

To accommodate these electronics and other sensitive hardware, insulation and heating will be utilized to ensure reliability and survivability of the system. Environmental testing will be conducted with the selected heating/thermal control methods to ensure the system can survive both the pressure and temperature extremes associated with altitudes between 20km and 40km (between 0.0287 kN/m^2 and 0.5529 kN/m^2; and -22.8°C to -56.5°C respectively).

The overall system shall include a cut-away device to ensure detachment of the gondola from the balloon, so that the balloon may safely rise/pop before entering restricted airspace. This cut-away device shall be paired with software that will achieve three main objectives. The first is to be able to pre-program the cut-away altitude, such that the gondola will be reliably cut-away from the balloon upon descent, at a desired altitude. The second is that the software will include fail safes, in the event of a mission failure (i.e. mechanism malfunction or drift over geo-fence). The final measure that the software will include is a remote cut-away command that would be received from the gondola in case of any other unique circumstance in which the mission must be aborted.

The end product shall come with an assembly guide for ease of reproduction with each flight. This will entail a step by step instruction manual for the device, as well as instructions/documentation for the attachment of the device to the balloon-payload system. Additionally, a list of component providers will also be provided in the case that more materials or components must be acquired. This guide could include writing, pictures, videos or a combination of the three as to best describe to a user, without any detailed knowledge on this project, how to properly assemble and install the ODDITY.

1.3 Critical Project Elements

CPE-1 *RF Communications and Controls System*:

The system shall be capable of 2-way wireless communication with the gondola. The system will also read commands sent by the gondola and output those commands to the other on-board systems as necessary.

CPE-2 *Buoyancy Control System*:

The system shall provide some means to control balloon altitude, such that a descent rate between 2m/s and 10m/s can be maintained. This descent rate is to allow the sensor payload to be within its operating range of vertical velocities.

CPE-3 *Neck Attachment System*:

The system shall have a neck attachment such that it is capable of securely interfacing with multiple brands of high altitude balloon.

CPE-4 *Insulation and Heating System*:

The system shall include thermal control measures to ensure system reliability throughout the range of expected altitudes/conditions.

CPE-5 *Gondola Cut-Away System*:

The system shall be able to cut the balloon away from the gondola for safety at the end of the mission.

1.4 Levels of Success

Levels of Success	Altitude Control	Descent Rates	Balloon Attachment	Communications	Survivability	Cutaway Mechanism
Level 1	The altitude control system is able to extract helium from the balloon in conditions similar to those at 36 km	The altitude control system is able to remove enough helium to theoretically achieve a descent rate between 2m/s and 10m/s	The device shall be able to attach to large Kaymont weather balloons (5 cm Diameter) Before the balloon has been filled with helium	Effectively shares a communication link with the gondola via XBEE radio	Hardware and electronics are able to withstand pressure and temperature of altitudes up to 36 km Battery lasts 6hr	The cutaway mechanism is able to cut the gondola away in testing
Level 2	The Balloon and the Gondola will achieve a target altitude up to 36 km and will descend to 20 km	The Balloon and the Gondola maintain a descent rate of 2 to 10 m/s	The device will be able to attach to large Kaymont weather balloons (5 cm), and is easily adapted to Hwoyee balloons (9 cm) Before the balloon has been filled with helium	Effectively shares a communication link with the gondola via XBEE radio and receives data from gondola	Hardware and electronics are able to withstand pressure and temperature of altitudes up to 40 km and battery lasts 6hr	The cutaway mechanism is able to cut the gondola away at 20 km during a flight
Level 3	The system and Gondola will be able to target an apogee up to 40 km with an accuracy of +/-500m	The Balloon and the Gondola maintain a descent rate between 2 and 5 m/s		Level 1 and 2, and transmits data back to the gondola	Level 1 and 2, and has the ability to abort the mission if conditions become undesirable	The cutaway mechanism can operate successfully an any point throughout the mission

Figure 1: Levels of Success

1.5 Functional Requirements

Req 1.0:

The *buoyancy control system (CPE-2)* shall achieve descent rates between 2m/s and 10m/s from the target altitude until the gondola is cut away.

Req 2.0:

The *system (CPE-1,2,3,4,5)* shall survive until the gondola is cut away from the balloon.

Req 3.0:

The *RF communications and control system (CPE-1)* shall have a communication link with the gondola.

Req 4.0:

The *system (CPE-1,2,3,4,5)* shall not interfere with the data gathering equipment.

Req 5.0

The *system (CPE-1,2,3,4,5)* shall mount to the neck of a standard weather balloon.

1.6 Mission CONOPS

The concept of operations (CONOPS) for the overall mission is shown below. The purpose of this CONOPS is to give a big picture view of what ODDITY will be apart of. Specifically, ODDITY is the red/green box attached to the balloon.

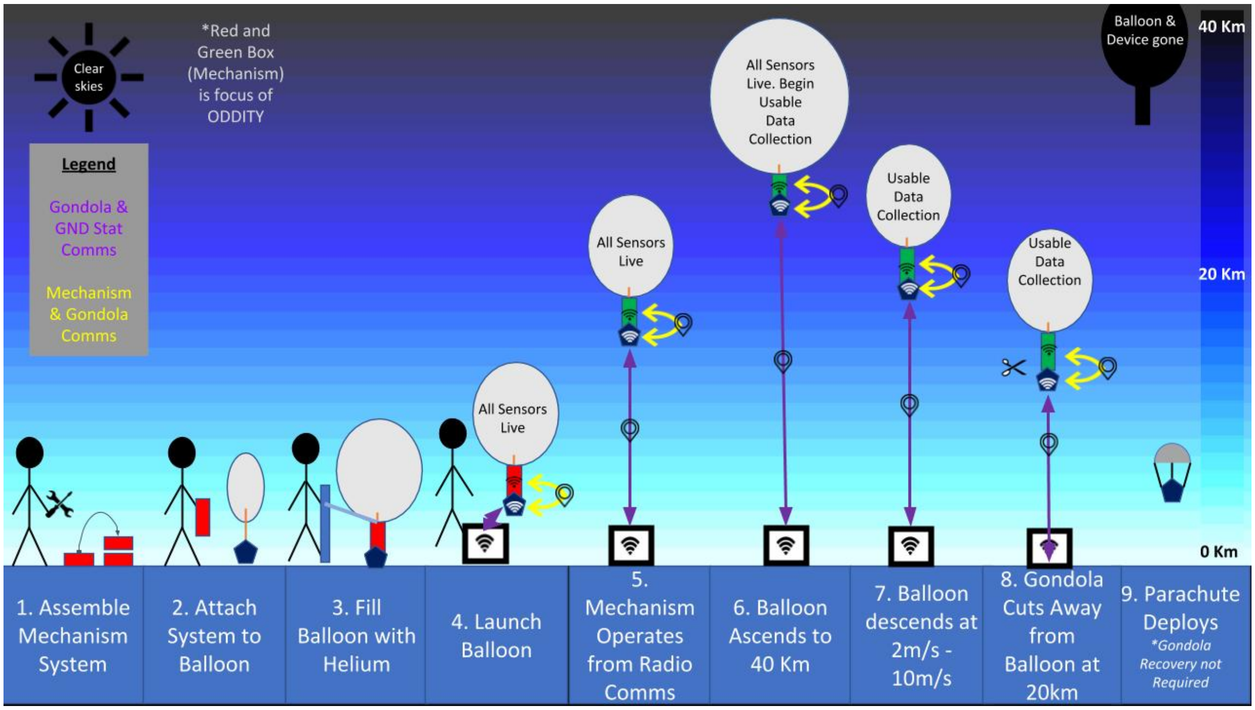

Figure 2: Overall Mission CONOPS

1.7 ODDITY CONOPS

The CONOPS for ODDITY itself is shown below. The purpose of this CONOPS is to pictorially describe the specific functions of the ODDITY unit.

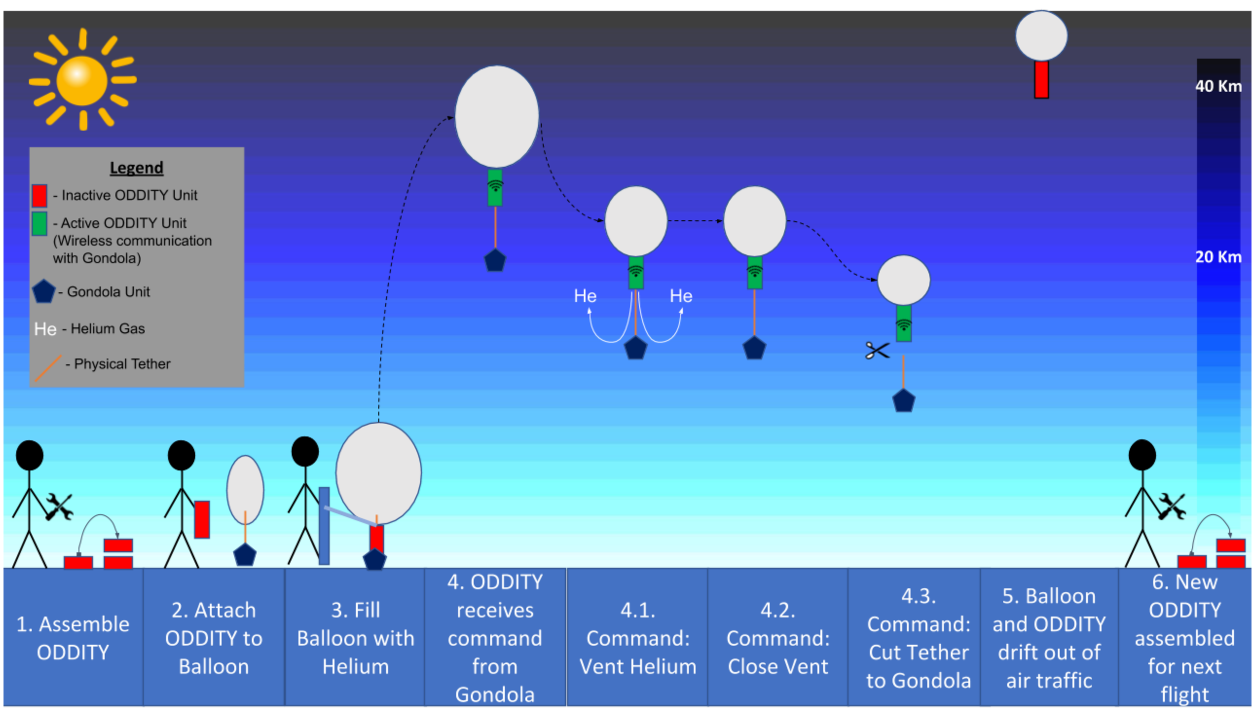

Figure 3: ODDITY CONOPS

1.8 FBD

A major component of this project will be the electronics used to send and receive radio signals and control the overall system remotely. A XBee radio on the gondola will act as a wireless tether between the ODDITY and the ground station, sending data to the ground and facilitating a communication link to the ODDITY itself. Below is a block diagram which details how the electronic systems will work with each other on the ODDITY and also how these components will function within the overall mission itself.

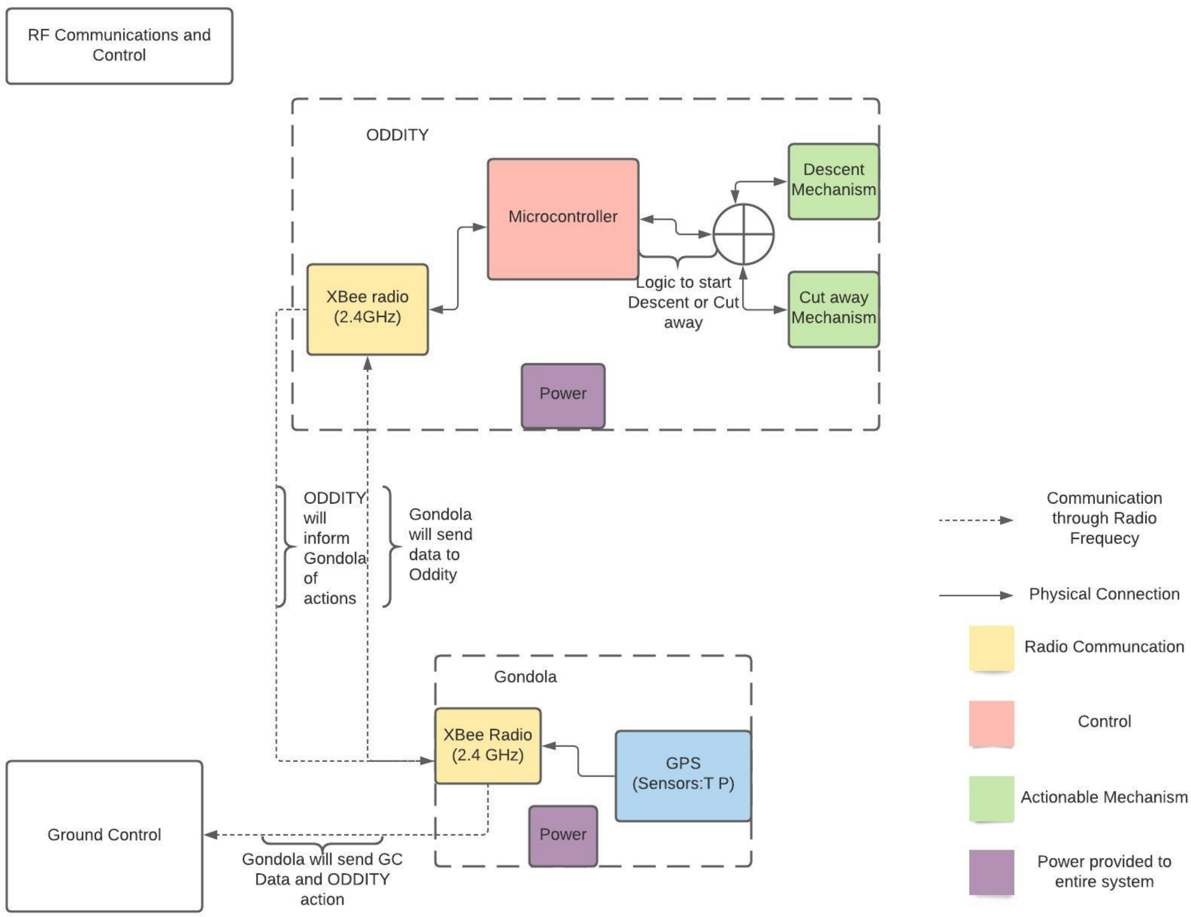

Figure 4: Electronic Block Diagram

As an initial note concerning Figure 4, power systems are supplied in both the ODDITY and the gondola (denoted by the power block in each dotted box), however distinct power flow lines have not been drawn as exact power distribution is unknown at this time. Upon further inspection of Figure 4, one can see that the process will start at the gondola's collection of pressure, temperature and GPS altitude. A command will then be sent based on these data readings via the gondola's XBee radio to the ODDITY. The XBee on board the ODDITY will then send this data via a hard connection to a microcontroller. The microcontroller will then look at one of four commands before sending it to the correct location. The first command is that the balloon has not reached the required altitude, in which case the valve does nothing and the XBee sends the inactive status to the gondola which sends it to the ground. The second and third options are that it has reached required altitude for venting, in which case the controller commands the altitude control system to actuate, or not, depending on the trajectory. This active status information is again sent to the ODDITY XBee and is then sent to the gondola XBee and then to the ground station. The final possibility is that the altitude for cut-away is reached, in which case the microcontroller commands the cut-away mechanism to activate and begin cut-away. It will also send information indicating that the gondola is being cut-away from the balloon down the communication chain.

2 Design Requirements

The design requirements are sub-components of the functional requirements listed above.

2.1 Requirements

The system named in the Functional Requirement will be referred to as system in the sub-requirements unless otherwise noted

1. The *buoyancy control system (CPE-2)* shall achieve descent rates between 2 m/s and 10 m/s from the target altitude until the gondola is cut away.
   Motivation: The controlled descent of the weather balloon is the main motivation for the project, and the customer specified the range of descent rates that would be acceptable.
   Verification: This functional requirement will be verified by GPS velocity data.

   1.1. The system shall evacuate helium from the balloon.
   Motivation: Helium must be removed from the balloon to achieve descent.
   Verification: Helium is evacuated from the balloon when the *buoyancy control system (CPE-2)* is activated.

      1.1.1. The system shall aid in the evacuation of 30 mols of Helium.
      Motivation: Customer driven requirement.
      Verification: 30 mols of helium are evacuated from the ballon envelope, under the existing system.

      1.1.2. The system shall achieve the **desired** descent rate 2500 sec after apogee.
      Motivation: Customer driven requirement.
      Verification: **Desired** descent rate is achieved 2500 sec after maximum altitude, as per GPS data.

      1.1.3. The system's current draw shall be within a range that the battery is able to provide.
      Motivation: The size and type of battery used will dictate the maximum current that the battery can supply.
      Verification: Measure the current draw of the system

      1.1.4. The system shall weigh less than 300 grams.
      Motivation: The entire *system (CPE-1,2,3,4,5)* must weigh no more than 300g.
      Verification: Weigh the system to find the system mass.

      1.1.5. The system shall have power available to operate during at least the venting stage.
      Motivation: The system needs to operate for up to 2500 sec in order to vent the proper amount of helium.
      Verification: Ensure that the battery can supply enough power to operate the system for its required length of time after ascent, at the specified operating conditions.

   1.2. The system shall be controlled by the gondola.
   Motivation: The gondola processes all data and will send commands to the system.
   Verification: The gondola sends commands to the system.

      1.2.1. Controls will be executed following the commands of the gondola (See Req-3).

   1.3. The system shall not damage the balloon prior to or during operation.
   Motivation: Damage to the balloon prior to or during operation could result in mission issues or even failure.
   Verification: Ensure no part of the system has the ability to damage the balloon.

1.4. The altitude and velocity of the system shall be processed by the gondola.
Motivation: The altitude and velocity information is pertinent to the decision of when to begin venting helium and how much helium to vent.
Verification: The code on the gondola requires this GPS data to operate properly and not execute a safety measure.

1.4.1. The processed data shall result in command(s) that are sent to the *buoyancy control system (CPE-2)*.
Motivation: Altitude is a trigger for helium venting.
Verification: Commands to begin helium venting are dependent on altitude information.

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2. The *system (CPE-1,2,3,4,5)* shall survive until the gondola is cut away from the balloon.
Motivation: If the systems do not survive, then there will be a mission failure or a safety issue. This could be due to helium not being evacuated, and the balloon not descending, or due to the gondola not being successfully cut away.
Verification: Systems pass low temperature and low pressure testing with no issues in performance.

2.1. The system shall maintain operational capabilities in the low pressure environment it will be exposed to.
Motivation: The system will be exposed to low pressures and must retain full functionality.
Verification: The entire system will be tested in a low pressure chamber.

2.1.1. The lowest pressure that will be seen during flight is 277Pa as predicted by the US Standard Atmosphere.

2.2. The system shall maintain operational capabilities in the low temperature environment it will be exposed to.
Motivation: The system will be exposed to low temperatures and must retain full functionality.
Verification: The entire system will be tested in a low temperature chamber.

2.2.1. The lowest temperature that will be seen during the flight is -56.5°C as predicted by the US Standard Atmosphere.

2.2.2. The *RF communications and controls system (CPE-1)* shall maintain a system temperature of at least -40°C
Motivation: The radio and microcontroller have a lower operational temperature limit that needs to not be crossed.
Verification: The radio and microcontroller remain above their lower temperature bound during cold temperature testing.

2.2.2.1. This shall be the responsibility of the *insulation and heating system (CPE-4)*.

2.3. The *system (CPE-1,2,3,4,5)* shall be disposable.
Motivation: The system will not be recovered and must not pose a hazard after the mission is complete.
Verification: The system meets FAA guidelines.

2.3.1. The system shall not contain hazardous materials.
Motivation: Environmental issues stemming from hazardous materials.
Verification: Does not contain any hazardous materials.

2.3.2. The system shall be less than $200.
Motivation: Customer specified requirement.
Verification: Material cost for one final, complete system is less than $200.

2.3.3. The system shall not pose a hazard after the mission is complete by following FAA Part 101.
Motivation: Weather balloons must follow certain rules so that they are not hazards to aircraft.
Verification: Abides by FAA Part 101.

2.4. The system shall be powered by an included battery.
Motivation: Power cannot be drawn from the gondola.
Verification: System is powered fully by separate battery than gondola.

2.4.1. The battery shall last for at least 6 hours.
Motivation: System will be powered on for multiple hours, encompassing ascent, descent, and all activities during those phases.
Verification: Battery lasts for 6 hours under expected load.

2.4.2. The battery shall be able to supply a sufficient amount of current during maximum power draw.
Motivation: All electrical components of system draw current.
Verification: All systems shall be able to operate simultaneously off of battery supply.

2.4.2.1. Maximum current draw is when the *buoyancy control system (CPE-2)*, the *gondola cutaway system (CPE-5*, and the *RF communications and controls system (CPE-1)* are all operating at maximum useful power.

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3. The *RF communications and controls system (CPE-1)* shall have a communication link with the gondola.
Motivation: A link is needed between ODDITY and gondola to complete the communication chain to the ground station.
Verification: XBee radio is paired to channel and ID of existing XBee system and data link is confirmed

3.1. The system shall be able to receive commands from the gondola.
Motivation: This will enable active control of the ODDITY if circumstances necessitate it.
Verification: The communication link from ground to gondola to ODDITY will be tested on ground using mock data packets

3.1.1. The gondola shall be able to command the *buoyancy control system (CPE-2)*.
Motivation: If for any reason the system must be shut off or on for a unique or critical reason
Verification: Test commands on the ground will be sent to the gondola to relay to the ODDITY and respective actions will be observed.

3.1.2. The system shall be able to actuate the *gondola cutaway system (CPE-5)*.
Motivation: The gondola needs to be cut away as a safety measure.
Verification: The system sends a successful cut away command and the gondola is cut away.

3.1.3. The communications link from the gondola to the system shall have a data rate of at least 2400 bits/sec.
Motivation: The amount of information that the system needs to receive from the gondola stipulates a required minimum data rate.
Verification: The data rate from the gondola to the system is at least 2400 bits/sec.

3.1.4. The RF transmitter shall be able to transmit at least 10m.
Motivation: The gondola will be approximately 10m from the balloon.
Verification: Communications system is able to transmit that this distance.

3.2. The system shall be able to send data to the gondola
Motivation: Would allow for information on the system's current state to be downlinked to the gondola.
Verification: System is able to send data to the gondola.

3.2.1. The system shall report back state information from to the gondola.
Motivation: Allows the gondola to see if there is a problem with the system.
Verification: State information is transmitted to the gondola.

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4. The *system (CPE-1,2,3,4,5)* shall not significantly interfere with the data gathering equipment.
Motivation: Interference with the data gathering equipment will result in bad data, negating the usefulness of the mission.
Verification: Data gathering equipment (fine wire temperature and velocity sensors, and optical particulate sensor) accuracy remains within 90% of the accuracy of a control system.

4.1. The *insulation and heating system (CPE-4)* shall not emit enough heat to affect the data gathering equipment.
Motivation: Heat output can effect atmospheric sensors and thus needs to be mitigated.
Verification: There shall be a temperature change of 1°C or less 10m away from ODDITY.

4.2. The *RF communications and controls system (CPE-1)* shall have a gain of +8 dBm.
Motivation: Ensure no disruption in the gondola's data downlink.
Verification: System gain is calculated to be +8 dBm.

4.2.1. The RF transmitter shall emit no more than 6.31 mW of power.
Motivation: Ensure no disruption in the gondola's data downlink and no interference with data collection systems.
Verification: The rated power of the RF transmitter shall be equal to or less than 6.31 mW.

4.3. The *RF communications and controls system (CPE-1)* shall operate on a frequency band between 2.405 GHz and 2.480 GHz.
Motivation: Ensure no encroachment of different frequency bands.
Verification: RF Bands available for communication shall be within specified range.

4.4. The *buoyancy control system (CPE-2)* shall not disrupt data collection.
Motivation: Data disruption may cause inaccuracies in the data, negating the usefulness of the mission.
Verification: Data gathering equipment (fine wire temperature and velocity sensors, and optical particulate sensor) accuracy remains withing 90% of the accuracy of a control system.

4.4.1. Vibration from the *buoyancy control system (CPE-2)* shall not affect sensor measurement.
Motivation: Vibrations may transfer through connections to the gondola, effecting the data gathering equipment.
Verification: Sensor accuracy shall remain within 90% accuracy to the control.

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5. The *neck attachment system (CPE-3)* shall mount to the neck of a standard weather balloon.
Motivation: The neck is the only part of the balloon that is sturdy enough to mount to.
Verification: System mounts to the balloon neck.

    5.1. The system shall fit a standard 5cm weather balloon.
    Motivation: 5cm balloons are one of the two balloon variants that are used.
    Verification: System fits a standard 5cm weather balloon.

    5.2. The system shall be adaptable to fit a standard 9cm weather balloon.
    Motivation: 9cm balloons are one of the two balloon variants that are used.
    Verification: System is adaptable to standard 9cm weather balloons.

    5.3. The system shall support the weight of the *RF communications and controls system (CPE-1)*, the *buoyancy control system (CPE-2)*, the *neck attachment system (CPE-3)* itself, the *insulation and heating system (CPE-4)*, and the *gondola cutaway system (CPE-5)* in addition to the sensor gondola and its attachment hardware.
    Motivation: The *neck attachment system (CPE-3)* is the only interface between hardware and the balloon, therefore, it must bear the weight of all systems.
    Verification: System can support 150% of total system weight.

    5.4. The system shall not compromise the integrity of the balloon.
    Motivation: Compromised balloon integrity may lead to mission failure.
    Verification: The system does not compromise the balloon's structural integrity.

    5.5. The system shall allow the balloon to be inflated after the system is attached.
    Motivation: Customer stipulated requirement.
    Verification: Balloon is able to be filled after the system is attached.

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3 Key Design Options Considered

In this section, different design options for some of the key system elements were explored. First, the most pivotal system of the ODDITY, the Buoyancy Control Mechanism (CPE-2), will be investigated. Here, many creative solutions were available. Conventional systems such as a fan and pump were discussed at length about how they might achieve evacuation of the helium bubble. However, more innovative and creative ideas were also discussed; specifically, puncturing a hole in the balloon, placing a hoop on the balloon to constrict volume, and turning the balloon upside down so that the helium may vent naturally through the top.

For the electrical control (CPE-1) portion of the ODDITY, two different name brand microcontroller manufacturers, Adafruit and Arduino, were investigated. Within these two companies, several chips were closely inspected as to compare the different specifications of each. Each chip was found to have its own set of strengths and weaknesses which are discussed in this section, and then more at length in the corresponding Trade Study section below.

Next, options for the cut-away mechanism (CPE-5) were discussed. A hot wire system was considered first based off of the work that had been done in the legacy device to the ODDITY. The next two innovations that were considered were sharp-edge wire cutter and a quick-release tether system. While these last two were helpful ideas to consider, upon investigation they did not quite fit the needs of our project given the weight and cost restraints.

The next set of options that were considered fall under the thermal control (CPE-4) category. Here, the main objective consists of keeping the microcontroller, radio, and the electronic systems required for the function of the aforementioned components, under safe operating conditions. The primary objective of this task involves heating the battery/batteries so that they may remain effective throughout the flight, as these components are very sensitive to temperature changes. Some material solutions for insulation were considered, as well as more active components that could be introduced to the ODDITY to keep the battery/batteries, as well as other sensitive components, safe. Furthermore, the possible combination of these two approaches was investigated, and how they might benefit each other in what configurations.

Finally, the hardware made for interfacing with the neck of the balloon (CPE-3) was discussed. This is not a major design element and therefore did not warrant a full trade study; however a discussion was still helpful for making future decisions. The main two possibilities investigated in this section involved having one cohesive piece that fits together, to adjust for two possible balloon neck sizes, or fabricating two separate pieces for the two different balloon neck sizes.

3.1 Design Options for Buoyancy Control Mechanism

The critical task of this project element chiefly consists of more reliably evacuating helium from the balloon envelope. The previous system has experienced issues where the balloon fails to evacuate a sufficient amount of helium; likely due to the plastic deformation that occurs once the balloon expands past a given radius, at a certain altitude. Furthermore, the Buoyancy Control Mechanism must be able to control the balloon-payload system to ensure a 2 - 10m/s descent rate. Additional concerns for the Buoyancy Control Mechanism consist of: overall system complexity, weight, power consumption, manufacturability, installation complexity, cost, and volumetric flow rate.

3.1.1 Fan

The most straightforward buoyancy control design option consists of attaching a component to a tube in the neck of the balloon, similar to the current system, but which creates an additional pressure differential between the inside of the balloon and the surrounding atmosphere. This means attaching a fan in conjunction with a sealing valve (similar to legacy hardware) to control the evacuation of helium.

This design option consists of attaching a fan to the existing system, in order to vent helium when the latex balloon canvas fails to provide the adequate pressure required for helium evacuation. Fans tend to move a relatively large volume of fluid, with a low pressure difference relative to that of a mechanism such as a compressor or pump. The performance of such fans are specified traditionally by the *Static Pressure* rating of the fan. This value represents the operating pressure differential between the inlet and outlet of a given fan. An additional performance characteristic of a given fan is the volumetric flow rate. This, as the name suggests, denotes the volume of air that a given fan will move, in a given time period. This value is frequently specified in m^3/hr or liters/min. It should be noted, however, that the test conditions specified on the datasheets from the manufacturers of such devices will likely be much different then the operating conditions that the current system will be experiencing; in terms of temperature, pressure, fluid density, and composition.

Many of the fans that have been investigated are standard axial cooling fans, similar to those commonly used in computer/server chassis'. Such fans come in a variety of different sizes and types, and often can have their rotation rate be controlled by something like a microcontroller, most commonly via PWM. In addition to nominal values of mass flow rate, operating temperature, nominal static pressure, etc., the data sheets for such devices also often provide a graph of volumetric flow rate versus static pressure graph. These plots show that fans behave such that the volumetric flow rate decreases with the increase in adverse static pressure (blowing air *into* a higher pressure region) across the fan. While this behavior should be noted, preliminary research shows that the pressure difference between the interior and exterior of a standard latex balloon is very small; on the order of 100's of Pascals. More importantly, this pressure gradient is favorable to the function of the fan; helping to evacuate helium until the interior and exterior pressures are matched. Only at this point will the static pressure of the fan be *required* in order to vent further helium from the balloon.

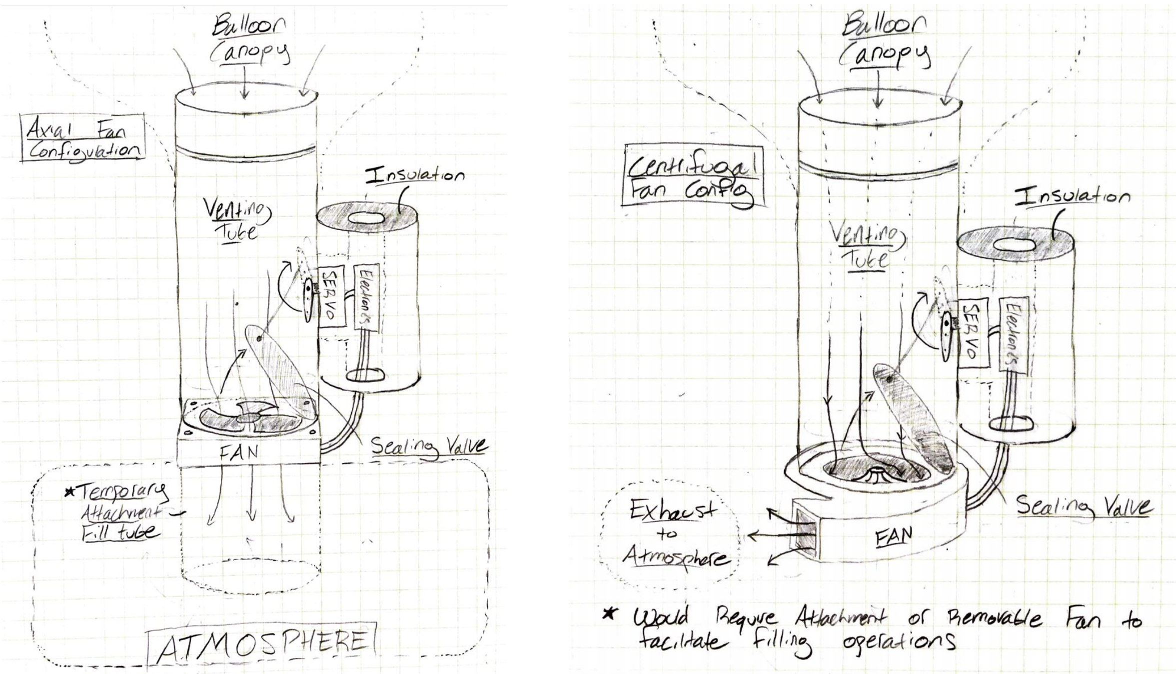
There are different types of fans available in the sizes required. In addition to the more common, axial flow fans discussed above; there are also blower style, or centrifugal fans. Blower style fans utilize a centrifugal impeller design, which accelerates air radially outward from the fan hub. This requires the airflow to be deflected by 90 degrees. Such fans do generally, have larger pressure ratios and flow rates when compared to their axial flow counterparts.

There are benefits and drawbacks to both types of fans. While axial fans generally have lower static pressures and flow rates, they are also generally lighter; as they do not require the substantial housing of blower-style fans. More investigation would have to be done in order to determine which type is more optimal from a flow rate-per-mass standpoint; as total system mass is a strong driving factor in the overall system design.

Finally, most of the fan systems investigated utilize Pulse Width Modulation (PWM) in order to control the fan's speed. This is a very common standard, therefore many microcontroller boards have the capability of outputting the required PWM signal. This allows the fan to be controlled across the entire spectrum of operating speeds if desired.

Preliminary system design sketches are given below in Fig. 5a & 5b, showing how the implementation would look if either style (axial or centrifugal) fan design were to be selected.

Figure 5: Design Option: Fan Design Sketches



(a) Axial Fan Configuration

(b) Centrifugal Fan Configuration

The above diagram shows a high-level overview of how the implementation of adding a fan, either axial or centrifugal, would interact with the rest of the system. This option, as it stands, leverages many aspects from the legacy hardware implementation. A main venting tube is attached to the balloon envelope via friction, where additional friction is provided by tape wrapped around the balloon- where it is attached to the venting tube. Mounted to the side of the venting tube is a hollow foam cylinder, which houses the electronics to provide valve and fan control, as well as communication with the gondola. This also houses a servo, which is used to operate the sealing valve; which is a main component of the legacy design. This servo is attached to a small disc, which acts as a sealing valve, via a thin wire. This wire can push down and pull up on the valve, as the servo is operated. This disk/valve initially rests on an inner concentric lip/ledge, which is smaller than the overall tube diameter, such that the disc/valve remains securely within the venting tube. When the valve is closed, the disc rests on this ledge; sealing the exit, and ensures no helium escapes. When helium venting is desired, the servo is operated, pulling upwards on the sealing valve/disc, allowing helium to pass around it, outward to the surrounding atmosphere.

Directly below this valve, is where either the axial or centrifugal fan would be located. This fan would create the additional pressure difference to assist in the evacuation of helium from the balloon. The sealing valve is still required, in this case, as the fans themselves do not provide any way of sealing the helium inside the balloon. These fans would intake helium from inside the balloon canvas and exhaust it to the surrounding atmosphere, either directly, or through an exhaust tube if more efficient.

Both cases would require an attachment point such that the balloon can be filled with helium, while the device is attached. There are many possible ways of facilitating these fill operations, which will be discussed further in the design phase. For the axial fan configuration, a preliminary idea for such a system, would be adding another tube section, either removable or permanent, below the fan, so that the existing fill nozzle will attach to the system and allow for filling. For the centrifugal fan, it is likely that the fan will have to be able to be installed after the balloon is filled, or that a new fill nozzle/adapter will have to be investigated.

A possible limitation of this approach, is that it is likely that the fan will be used outside of its rated operational environment. From investigating products across multiple common electronics suppliers; the lowest operational temperature rating on a fan was found to be -40 C. Upon comparison with the US Standard Atmosphere [9], the coldest temperature, assuming a standard day, that the system is likely to experience is -55 C; which is lower than the rated temperature of any of the fans found. This likely means that either additional testing will have to be conducted in order to verify the operation of the fan at such temperatures, or additional thermal management will have to be implemented.

More importantly, it is unknown if the fan will be effective at pulling helium out of the balloon; due to the low pressures and densities. Little to no information about the performance of fans at the expected altitudes can be found; besides that the fan performance *will* degrade with altitude, due to lower air density. Determining if the fan can provide the mass flow rate required, at the desired altitudes, is key in determining the feasibility of this design option.

Pros	Cons
High* + Controllable Flow Rate	Effectiveness at Low Densities/Pressures
Leverages Legacy Design	Power Draw
Inexpensive	Complexity (Fan+Sealing Valve)
Data Readily Available	Environmental Concerns

Table 1: Design Option: Fan Pros and Cons

**: At Sea Level Standard Conditions*

3.1.2 Pump

Another proposed solution, is the use of a fluid/gas pump in order to extract helium from the balloon envelope. Specifically, a positive displacement type fluid/gas pump was proposed. Such pumps function by trapping, and then exhausting, a certain volume of gas/fluid. Due to their nature, such positive displacement pumps provide volumetric flow rates which are nearly independent of exhaust pressure, or operating pressure differential.

The performance of such devices is normally categorized by the free flow rate, and the maximum vacuum that it can pull. The free flow rate is a measure of how much volume the device can pull (usually stated in m^3/hr or liters/min), while operating across a zero pressure differential. These devices do tend to see decreased volumetric flow rate once a pressure differential in either direction is present. However, due to the very small differential pressure between the interior of the balloon envelope and the atmosphere, the loss in performance will likely be small for the desired implementation. Additionally, we will not be pulling anywhere near the maximum vacuum value, so we will not likely run into any issues due to the maximum vacuum limitation.

The control of such devices will be similar to that of the fan configuration. Of the pumps that have been considered, many utilize a simple DC motor to provide the rotational work needed to capture and expel the working fluid. As such, many of the devices seen have the capability to have varied speed, and therefore, flow rates; either by changing the input voltage into the motor, or by using PWM (Pulse-Width Modulation).

There are many different types of positive displacement gas pumps; but based on preliminary research, the main ones that would satisfy our given mass constraint are likely to be diaphragm-type pumps. Many of these type of pumps are available in masses less than 100 grams, and can be powered by a DC voltage source.

One of the most significant drawbacks of using a positive-displacement pump is that the volumetric flow rates for such devices is relatively low, especially for pumps of the required size/mass. From the research that has been conducted, the volumetric flow rates for DC powered diaphragm-type pumps of a reasonable mass are on the order of 4-10 liters per minute. In preliminary analysis, it is expected that this alone would likely not be able to vent the required helium to achieve neutral buoyancy during the ascent under the given time constraints.

However, the proposed solution serves to augment the standard sealing valve design by removing helium once the original servo-operated valve can no longer vent. The pre-existing valve hardware will be utilized during ascent in order to reach the target altitude at neutral buoyancy. Once the valve has been utilized to its full extent, the valve will close and the positive displacement pump will turn on. This will allow more helium to be expelled from the balloon, resulting in a previously unachievable descent rate.

The proposed implementation of such a system is illustrated below in Fig. 6.

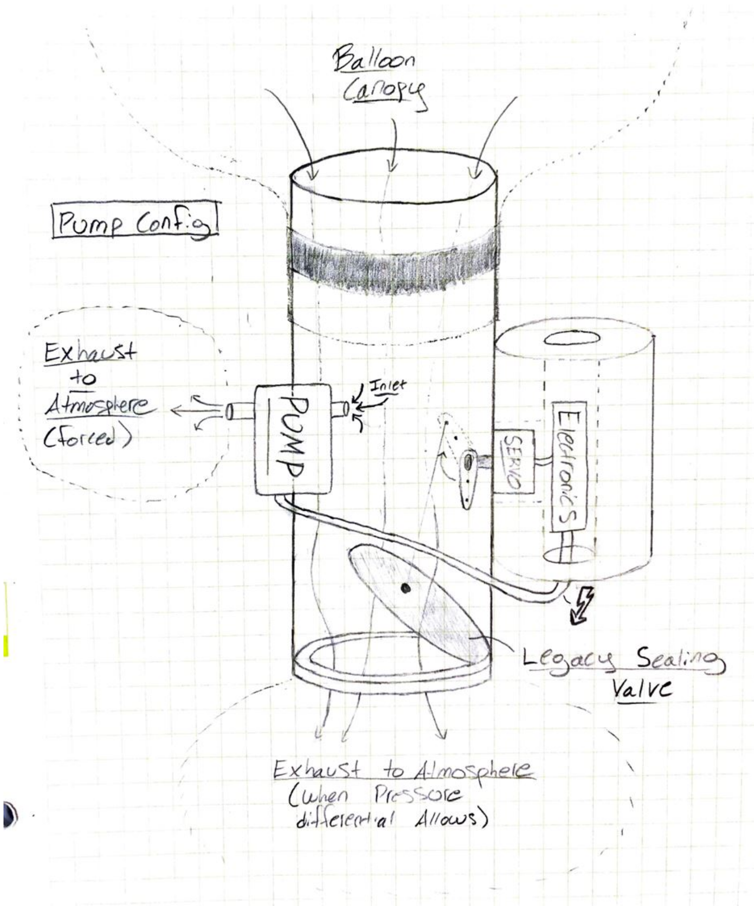


Figure 6: Proposed Pump Design Option

Note: This shows the conceptual design. This is not likely accurate to a the proposed physical system, as this pump inlet/outlet configuration has not been seen, as well as environmental/mounting reasons.

As stated before, this proposed solution utilizes the previously existing valve hardware. It utilizes the main sealing valve to achieve a desired altitude ceiling. This valve consists of a valve in the venting tube that is actuated by a servo attached to the side on the tube itself. As the servo is actuated, the sealing valve moves up and down within the tube. This seals helium in when in the bottom position, and releases helium once lifted up.

As stated previously, this system fails to remove any helium from the balloon once the pressures on the interior and exterior of the balloon have equalized. This occurs somewhere during the descent phase of flight. Once this occurs, the pump, which is also placed in the side of the venting tube, can be utilized to help the balloon to continue venting helium, when the original valve cannot. For the pump to function effectively, the original valve must be closed to prevent the system from sucking air from the atmosphere back into the balloon or into the pump itself.

The biggest challenges that are likely to be faced with this approach have to do with; flowrate, mass, and environmental concerns at altitude.

The flowrate of the pump is significantly lower than that of a fan at standard sea Level conditions. This system, as stated before, likely cannot be the only source for venting helium effectively within time constraints.

Similar to the fan option presented above, this approach will likely present operational environment challenges due to the low temperatures experienced at the desired altitudes. None of the pumps that have been found, in the correct form factor, possess rated operating conditions anywhere near those seen at altitude. It is likely that these operational temperature values have some wiggle room though, as many of the pumps seen are rated for 1,000's of hours of operational lifetime, under the rated operating conditions.

Despite this, thorough testing or thermal control will be required in order to ensure effective operation under the expected conditions.

Pros	**Cons**
Controllable Flow Rate	Flow Rate
No Pressure Diff. Required	Power Draw
Data Readily Available	Mass
Leverages Legacy Design	Complexity
	Environmental Concerns

Table 2: Design Option: Pump Pros and Cons

3.1.3 Popping a hole

A more creative method of reducing the buoyancy of the balloon would be to pop or cut a hole in the balloon. Helium would escape through the hole, reducing the balloon's volume, and thus reducing the overall buoyant force on the balloon. Ideally, the puncture would be made at the top of the balloon to allow for helium to escape even in the absence of elastic force in the balloon envelope. A hole at the top would cause helium to vent even if the balloon is plastically deformed, as the 'helium bubble' always seeks to rise upward.

A possible method of creating a puncture would be to launch a small projectile up the neck of the balloon where it would punch a hole in the upper part of the balloon envelope. This projectile could be a small metal or plastic sphere, similar to an airsoft or BB pellet. The projectile could be launched using a spring system which could be compressed before flight. As shown in Fig. 7, the spring would sit in a cylinder held in the center of the balloon neck above the existing valve. Once the command is received a servo motor would pull out the latch holding back the spring, firing the projectile into the balloon envelope. One issue that could arise from this is that the projectile could create unpredictable hole sizes, depending on the state of the balloon envelope.

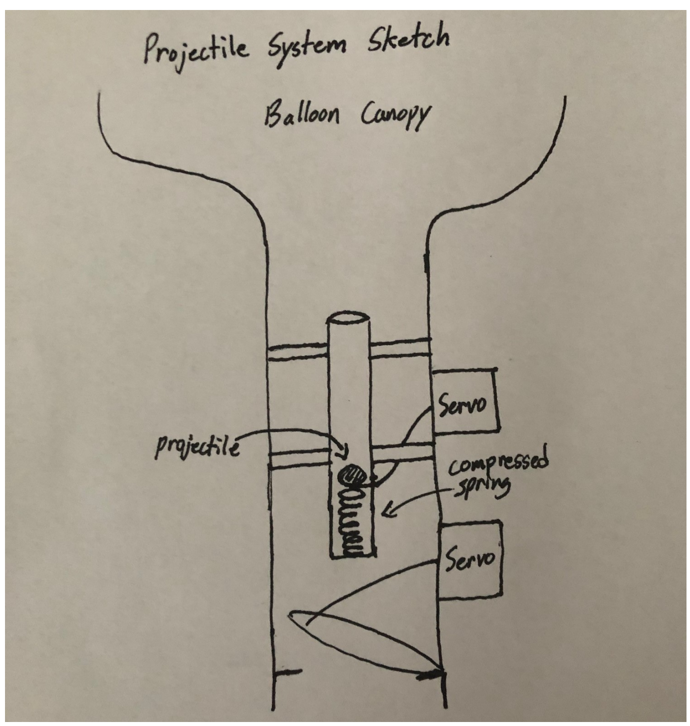


Figure 7: Simple Sketch of Projectile Puncturing Conceptual Solution

There are several issues with this approach, the largest of which being the problem of how to create a hole in the balloon without the balloon being destroyed completely. When a weather balloon bursts at high altitude, the envelope of the balloon is stretched extremely thin, resulting in the balloon shredding upon burst. This happens because any small crack in the balloon will quickly propagate across the entire envelope. If the system used to puncture the balloon causes the balloon to be destroyed, the flight will be a failure; as the system will no longer be able to maintain a 2-10 m/s descent rate. Something must be done to insure the integrity of the balloon when it is punctured. If the puncture is made when the balloon is in the plastically deformed, 'helium bubble' state, the balloon with likely respond differently than when stretched thin during a typical burst. The lack of tension in the balloon envelope could prevent cracks from spreading as easily. Given the fragility of the balloon envelope, it would be too risky to attempt to puncture the balloon before it reaches the 'helium bubble' state. Even then, given the lack of existing research, it would be difficult to ensure the balloon would be successfully punctured reliably, without compromising the overall structural integrity of the balloon.

Another problem with this approach is the fact that there would be no way to dynamically control the helium venting. Once a hole is made, there would be no way to stop the helium from venting. On one hand this is good because the venting system would not require power as the helium is escaping. On the other hand, if the helium is venting too quickly, there would be no way to slow it down, should the descent rate become to great.

Due to the lack of background research and the lack of dynamic control capability, puncturing the balloon is likely not a feasible solution to meet the requirements for ODDITY. A more reliable solution, that is dynamically controllable would be a better fit for ODDITY. Something dynamic would be more adaptable, allowing the customer to make adjustments for different mission profiles and balloon sizes. Because of this, as well as the aforementioned structural concerns, puncturing the balloon will not be analyzed in the trade study.

Pros	**Cons**
Simple	Damages balloon
Low Current Draw	Uncontrollable
Helium Naturally Vents Upward	Unpredictable
	Lack of Research/Prior Knowledge

Table 3: Design Option: Popping a Hole Pros and Cons

3.1.4 Putting a hoop on the balloon

Another proposed design to control the amount of helium stored inside the balloon is to add some sort of device to restrict the shape of the balloon envelope. The option proposed consists of a constricting hoop on the balloon. The hoop would work as an external force on the balloon envelope, as it is wrapped around the envelope, circumferentially. At launch the balloon will be attached to the hoop as a loose fit but when the balloon rises in altitude, the balloon's volume will increase and the hoop will begin compressing the balloon. A visual representation can be shown on Fig. 8. Before the balloon's material reaches the altitude at which plastic deformation would occur, a valve in the neck will open, similar to the legacy design, removing the desired amount of helium, to cause the desired descent rate. This predetermined amount of helium mass flow will be determined so that the decent rate of the whole system is 2-10 m/s. A preliminary consideration for the material of the hoop would be a nylon rope. A rope is simple and adjustable for the volume increase that takes place in the balloon.

A possible limitation with this design option is that the balloon will pop before reaching the ideal apogee altitude of 40km. An obvious reason for this is the volume of the helium will expand too much and the hoop will put too much pressure on the balloon, causing it to pop. From previous launches the balloons diameter started at 2m at launch and when it reaches an apogee of 35km the diameter increased to approximately 6m. The other consideration that plays into the volume increase is the material of the balloon and how much stress it experiences with the volume of helium it is able to hold. While being stretched any sort of additional external stress experienced on the balloon will cause the balloon to pop.

Another limitation is the placement of the hoop. Knowing that the diameter increases three fold, the hoop needs to account for the increase in circumference depending on where in the balloon it is placed. The trade off with the placement is that the higher the hoop is placed, the more pressure it is able to put on the helium, but it is more likely to cause the balloon to pop.

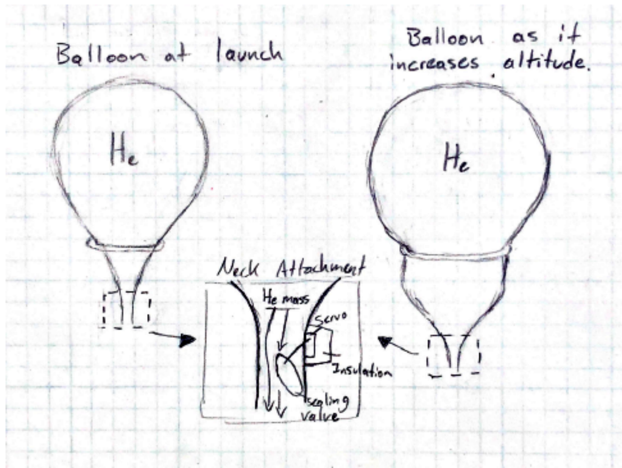


Figure 8: Hoop Design Option

Pros	Cons
Able to squeeze helium out as soon as volume increases	External hoop force on the balloon can cause it to pop
Easy to manufacture	The hoop could fall or get destroyed
No power required	May cause the Balloon to plastically deform sooner
Lightweight	

Table 4: Design Options: Hoop Pros and Cons

3.1.5 Upside-Down Balloon Configuration

Another design option for buoyancy control is to have an upside-down balloon configuration. In this configuration, the balloon neck would be faced upwards. When plastic deformation occurs in the balloon and the neck is facing downward, the helium is unable to expel because it is trapped at the top of the balloon. If the neck was faced upward, a valve system can be utilized to expel the trapped helium that would normally be stuck at the top of the balloon. This method is appealing because it doesn't require an active mechanism besides a servo valve to control helium expulsion; the valve in the balloon neck would simply open when helium expulsion is desired and closed when it is not. The complication of this design option is the attachment to the gondola; a tether would still be needed to connect to the gondola. Since the gondola is required to be in freestream airflow, it still needs to be located under the balloon. Therefore, an attachment that travels from the neck of the balloon to the bottom of the balloon will be needed to connect the tether and gondola to. An option for accomplishing this is streaming four polyethylene strips down the balloon surface and hoisting the tether and gondola below the balloon. Assuming a maximum balloon diameter of 10 m, the required length for each polyethylene strip to stream down the balloon would be around 15 m; the strips would meet below the balloon and would connect to the tether and gondola. This design option has little to no research, so implementing it in ODDITY would introduce several challenges. As the balloon gets larger as its altitude increases, the polyethylene strips would apply a force on the balloon which could potentially burst the balloon. One of the only methods of testing this configuration would be flight testing it, which would be more expensive than other design testing choices. Also, the polyethylene strips would weigh a considerable amount relative to the 300g limit. A diagram of the upside-down configuration is shown in Figure 9.

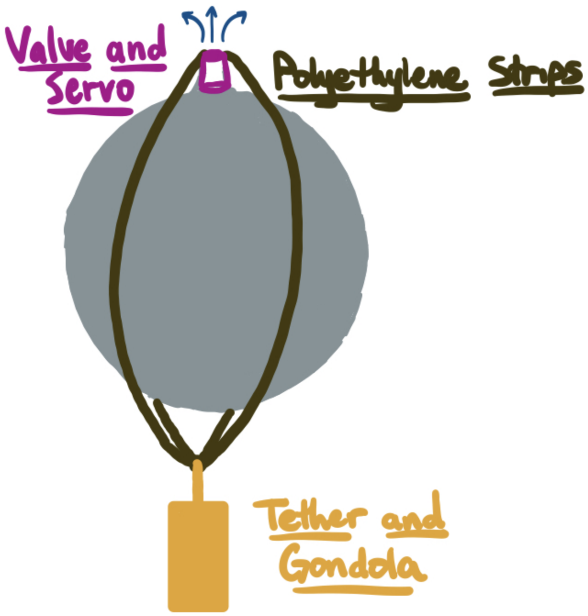


Figure 9: Upside-Down Configuration Design

3.2 Design Options for RF Communication and Control

The major options to be considered for this element are mainly the microcontrollers that will help electronically control the system. As the overall balloon system and gondola already utilize XBee radios, our RF communication system will do the same as to easily interface with the current system. With this in mind, two different brands of microcontrollers were considered, Arduino and Adafruit. Both brands are known to be compatible with XBee radios and all microcontrollers researched are compatible with a XBee radio.

3.2.1 Adafruit Microcontroller

The first brand of microcontroller, Adafruit, for all intents and purposes is a company that appears to be a copy company to Arduino. All of their chips are compatible with Arduino IDE and therefore can be programmed in the same fashion that an Arduino can be programmed. In many aspects these microcontrollers are very comparable to more mainstream alternatives, the Adafruit Metro and Adafruit Metro Mini themselves are almost identical. The main difference comes from the mass and size of each microcontroller, rather than their capabilities, which will prove to be large considerations when choosing a final design. The other major difference is the power required to operate each board. This is also a large component to consider as required power influences the choice of battery/battery size. A larger battery will add additional mass to the system, so an in depth consideration must be made here, in order to lower the required power, and therefore, required battery mass.

3.2.2 Arduino Microcontroller

The last brand of microcontroller that was investigated was Arduino. All Arduino microcontrollers are inherently capable of being programmed with the Arduino IDE, which is the software ODDITY will use. The four Arduino microcontrollers proposed for ODDITY include the Arduino Nano, Arduino Every, Arduino Micro, and the Arduino Uno. The key differences between the Arduino microcontrollers stem from mass of the board, size of the board, and operational power ranges. All of these differences in conjunction with the number of pins and clock speed are key factors in determining the optimal microcontroller for ODDITY.

Similar to the Adafruit microcontrollers, Arduino microcontrollers will need a battery to function which implies a deeper layer of analysis with the microcontrollers proposed.

3.3 Design Options for Cut-Away System

An important aspect of the project is to cut away the balloon and the buoyancy control mechanism from the provided gondola payload. A cut-away system is required in order to follow the Federal Aviation Administration (FAA) guidelines, as well as to make sure the balloon system does not travel in a restricted area. Without the cut-away system, the gondola will drift as far as the balloon will drift; which is problematic if gondola recovery is desired. Therefore, the cut-away system can aid in recovery of the gondola, based on where the tether is cut. Various design options were investigated to determine the ideal cut-away system for ODDITY.

3.3.1 Hot-Wire Mechanism

A common cut-away system in ballooning missions is the use of a hot-wire system. A hot-wire system has a wire attached to a tether connecting the balloon payload. The hot-wire system is connected to a micro-controller and is powered by a battery. Once activated, the low resistance of the wire causes the wire itself to heat up, which allows the hot-wire to burn through various types of tethers.

A hot-wire mechanism is simple, light-weight, and small; which are all desired qualities for use in ODDITY. ODDITY will already have a micro-controller, so the hot-wire mechanism can be connected to it without additional hardware. A downside of a hot-wire cutter is that it needs constant, significant current on the order of multiple seconds. As the cut-away mechanism will be actuated near the end of the balloon flight, power will have to be saved throughout the flight in order to ensure the function of the cut-away mechanism.

An example of a existing, yet still somewhat inexpensive hot-wire system is the Nichrome burn wire release mechanism. The mechanism consists of a two saddle design that has compression springs to apply a force to the nichrome wire and thermally burn through a tether. The mechanism can burn through a tether as quick as five seconds, depending on the material type and diameter of the attached tether [2]. The nicrhome release mechanism was designed to work consistently in air and vacuum environments, which covers the environment the balloon will be subject to. A diagram of the nichrome mechanism is shown in Figure 11.

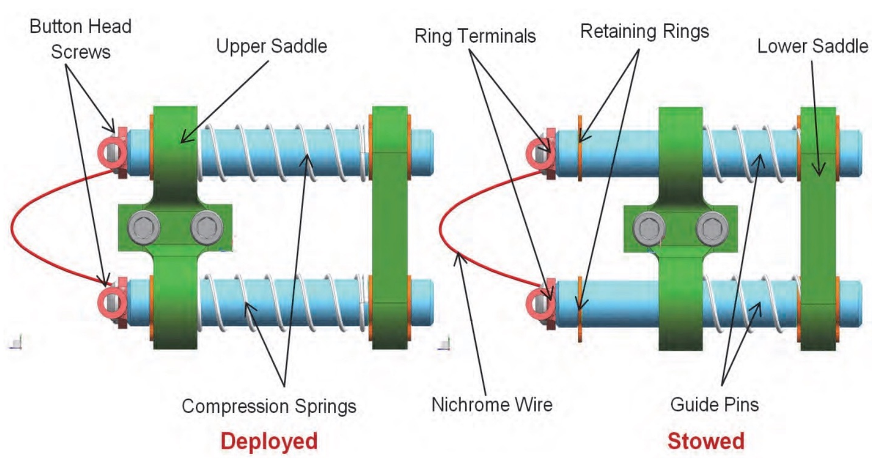


Figure 10: Source: "41st Aerospace Mechanisms Symposium.", NASA

An even simpler approach to this hot-wire release mechanism has been utilized during previous HYFLITS balloon missions. The current system currently uses small resistance resistors, in order to burn through the tether. This system functions by converting electrical energy to thermal energy, through the resistor; in sufficient quantities to burn through the existing tether. Specifically, the resistor can be wrapped around the tether and the heat energy will be used as the burn source. This method is simplistic and only requires a single circuit consisting of a power source and a resistor.

3.3.2 Sharp-Edge Mechanism

Another cut-away option is to cut the attached tether using a sharp-edge mechanism. This mechanism is designed to press a sharp edge through the tether to cut it, similar to scissors or a box cutter. However, this method is generally not used in weather balloon missions. This design consists of a sharp-edge and a mechanism to move the sharp-edge, which will be powered by a battery. It will also have to be connected to a micro-controller in order to activate the mechanism at a desired time. Overall, a sharp-edge mechanism will weigh more than the hot-wire mechanism, since a mechanism is needed to force the sharp-edge through the tether. It is also more complex than a hot-wire mechanism because there needs to be a mechanism to physically move the sharp edge through the tether. An example of a sharp-edge mechanism is shown below. A motor rotates circular gears to force a sharp edge through a tether; the red components in the figure are the sharp-edge.

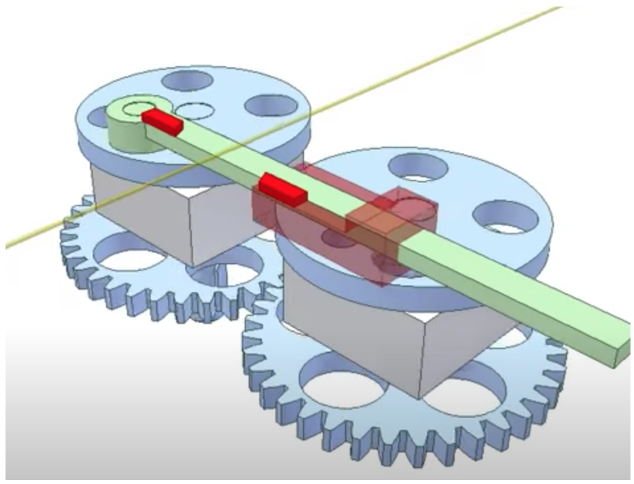


Figure 11: Source: "Wire-cutting mechanism 1", May 2020

3.3.3 Quick-Release Mechanism

A quick-release mechanism can potentially be used for the cut-away system in ODDITY. A quick-release mechanism would consist of a Snap Shackle connecting the balloon and ODDITY to the tether connected to the gondola. The Snap Shackle would release the tether when the pin in the device gets pulled out. From this, a mechanism will be needed to release the pin from the the Snap Shackle to disconnect from the tether; this increases the complexity of the cut-away design. Since the cut-away system also requires a mechanism to pull the pin, the mass of this design is considerably larger than the hot-wire design. It is desirable for the cut-away mechanism to be as lightweight as possible so more mass can be allocated to the other systems of ODDITY. Therefore, the quick-release mechanism does not show promise.

3.4 Design Options for Thermal Control and Heating

As the balloon ascends to the target altitude, ODDITY will experience temperatures as low as -56.60 °C around altitudes of 15-20 km [10]. The average minimum discharge temperature for most battery types is approximately -20°C, while the minimum operating temperatures for microprocessor cores is around -25°C. The goal of the thermal control system is to ensure that these minimum operating temperatures are met throughout the duration of their operation. Though these are the listed minimum temperatures for operation, achieving higher temperatures than the minimum required will allow for more efficiency; especially in the case of the batteries, which lose a majority of their efficiency below temperatures of 20 °C [6]. Other considerations for thermal control include the heat output of the electronics themselves.

There are two types of thermal control systems that will be considered in order to ensure that the thermal requirements of the electronics and batteries within the system are met. The use of passive, or a combination of passive and active thermal control systems can be utilized. Passive thermal control consists of controlling the temperature within the system without utilizing components which are actively controlled/powered. This means focusing on choosing materials based on their thermal properties. An active thermal control system consists of equipment that may be powered to control the heat and heat flow within a system; such as heaters, fans, etc. Based on these definitions, a purely active thermal control system is not included as a design alternative because it would not be practical to retain sufficient heat without use of insulators.

3.4.1 Passive Thermal Control

The first design option is a purely passive thermal control system. This consists of an insulation material which encases the elements that need to be protected. It will also trap the heat emitted from the electronics in order to maintain the operating temperatures of the equipment. Further research will need to be conducted to determine how much heat is dissipated by the electronics that are chosen. A diagram of this is shown in Fig.12. Research shows that common types of insulators used on payloads for weather balloons is different types of foam, including Styrofoam and other foams such as pipe insulators. The four main types considered for ODDITY are expanded polystyrene, polyisocyanurate, extruded polystyrene and Armaflex polyethylene. This is due to their light weight, low thermal conductivity properties, and low cost. Some systems also incorporate a reflective material such as emergency blanket to prevent further leakage of the internal heat. The pros and cons for the purely passive system are listed in Table 5.

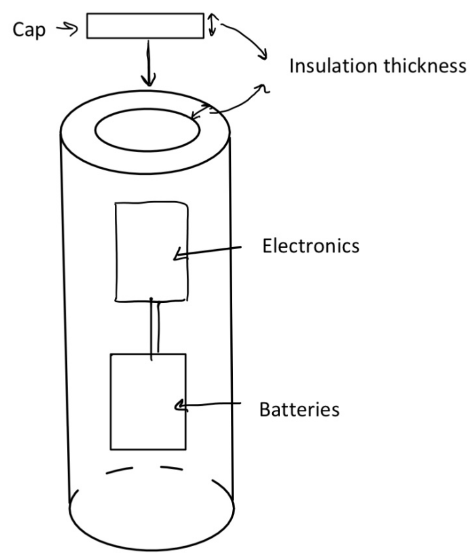


Figure 12: Diagram of Passive Thermal Control System

Pros	Cons
Light Weight	May require insulation thickness that is bulky
Easy to manufacture and replicate	If manufactured incorrectly, may have leakage
No power required	May not trap enough heat to provide the ideal temperature

Table 5: Passive Thermal Control Pros and Cons

3.4.2 Active Heating with Passive Thermal Control

Another consideration is a combination of passive and active heating thermal control systems. An active thermal control system consists of elements that require outside energy sources like a heating system. A common heating system on weather balloon payloads consists of a resistor or series of resistors to add additional heat to the system. The thermal control system of the legacy balloon mechanism utilizes this method by coiling a wire resistor around the batteries to heat them during the flight. This requires additional power supply to provide enough heating throughout the duration of the mission. A diagram of this configuration is shown in Fig. 13. Common types of resistors used for these types of heating systems are ceramic and aluminum wire clad resistors. Using this method may reduce the thickness of the insulation required, but will require its own supply of batteries which will add extra weight to the system. The pros and cons for the active system are included in Table 6.

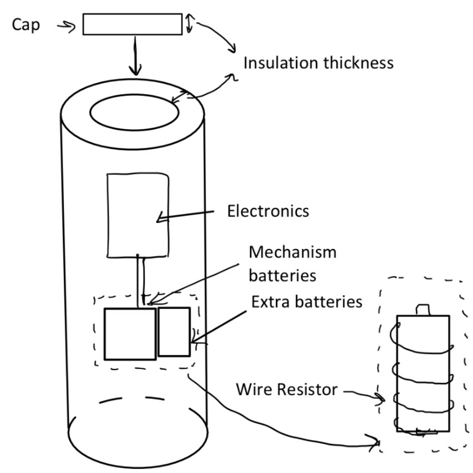


Figure 13: Diagram of Active Heating with Passive Thermal Control System

Pros	**Cons**
May reduce thickness of insulation required	Will require power supply
Simple circuit design	Will require more weight for batteries
Can provide temperature control ability	Heating elements may have higher risk of failure

Table 6: Combination of Active and Passive Thermal Control Pros and Cons

3.4.3 Inactive Heating with Passive Thermal Control

Another design alternative is using a heating element that does not require battery power such as a hand warmer. Disposable hand warmers are often used in weather balloon payloads to heat electronics in conjunction with an insulation material to trap heat. Disposable hand warmers operate using an exothermic oxidation reaction and do not rely on a power supply. They are also inexpensive and light weight and would simply be placed next to the elements that require heating. Disposable hand warmers claim to last up to 10 hours at an average temperature of 57°C when stored and used in ideal conditions. However, the weather balloon will be rising to altitudes greater than 20 km where the concentration of oxygen is less than at sea level due to lower pressures. One Near Space Adventure weather ballooning team conducted an experiment that measured the temperature of a hand warmer throughout an hour long balloon flight that reached an altitude of 24 km. Their results showed that the temperature of the hand warmer began at 65°C and slowly decreased to 11°C by the time the balloon hit apogee and burst [7]. Further testing or research may be needed to ensure that using hand warmers would be reliable at higher altitudes for a longer duration mission. Table 7 shows the pros and cons for this design.

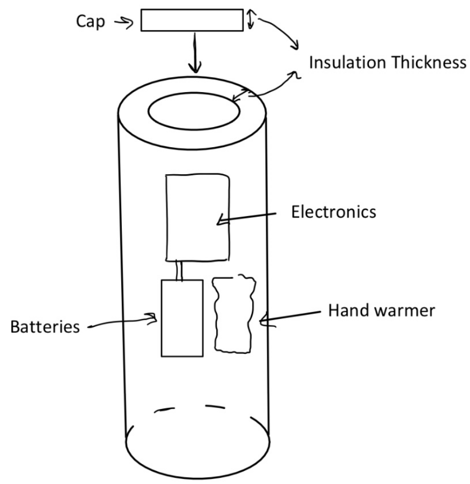


Figure 14: Diagram of Inactive Heating with Passive Thermal Control System

Pros	**Cons**
Does not require power supply	May not operate efficiently at higher altitudes
Light weight	May not last for the duration of the mission

Table 7: Combination of Hand Warmers and Passive Thermal Control Pros and Cons

3.5 Design Options for Neck Attachment

A main constraint of this project is the system must work with two different types of balloons. The balloons are a Kaymont balloon with a neck diameter of 5 cm and a Hwoyee balloon with a neck diameter of 9 cm. The main objectives of this sub system are the ability to be attached to the two different neck sizes (5 cm and 9 cm) on the balloon and to be compatible with the Buoyancy Control Mechanism. Additionally, when the balloon is filled with helium, it must be able to seal the helium in the balloon.

3.5.1 Neck attachment with valve

The current legacy neck attachment system uses a plastic cylinder attachment with a servo controlled valve that controls the flow of helium out of the balloon. The main neck attachment is a cylindrical transparent hollow tube with a valve. The valve is opened and closed with a wire and a servo that pushes the valve up and down. All of the pieces of this neck attachment can be seen in Fig. 16 and Fig. 15. Preparing the legacy design for launch, the latex balloon mounts on top of the neck attachment with plastic clear tape. Then to fill the balloon, a latex 5cm tube attachment is temporally placed on the bottom of the neck attachment where the helium is pumped into. The balloon is then pumped until the whole system has a lift force of 5 pounds. At that point the valve is shut and the balloon is ready for a launch release.

A limitation with this design is that the neck attachment is only fit for the 5cm Kaymont balloon and it restricts the use on the Hwoyee model balloons.

A possible limitation with this design is the servo, microprocessor, and foam insulation are all attached to the neck attachment. The servo is glued on to the neck attachment while the foam insulation and microprocessor are taped on to the neck attachment. Although this system has been proven to be successful for about 15 flights, the connection could possibly be improved upon to not strain the servo and not get in the way of it operating.

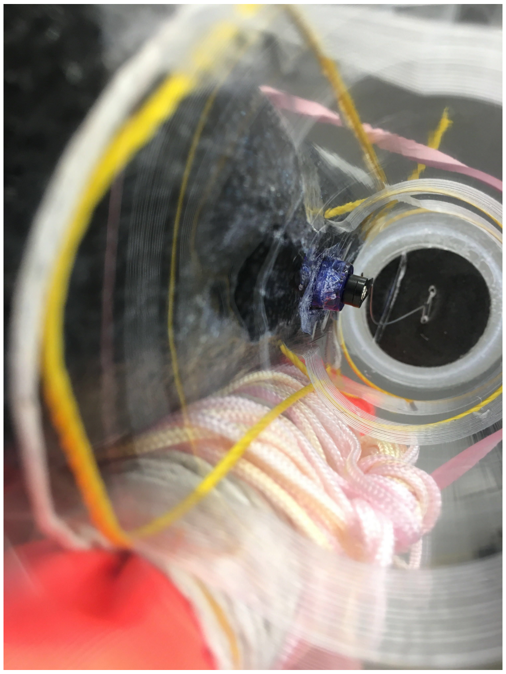


Figure 15: Legacy Neck Attachment

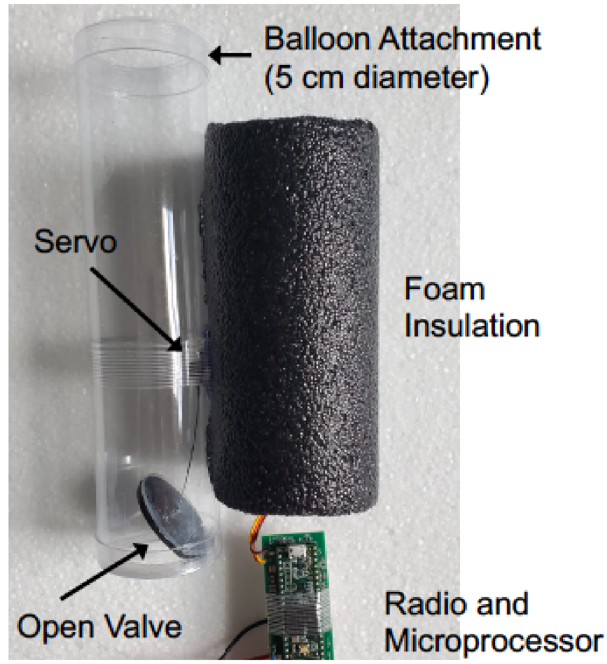


Figure 16: Top View Of Neck Attachment

3.5.2 Funnel

This design addresses the different neck sizes constraint by using one main neck attachment for both the Kaymont and Hwoyee balloons. The main neck attachment would be the same one used for the legacy project that was described above in Section 3.5.1. This neck attachment of 5cm diameter would fit perfectly on to the Kaymont balloon neck. For the Hwoyee 9cm balloon, a cylindrical funnel from 9cm to 5cm would be used in between the balloon and the main neck attachment, shown in fig 17. This design option would ensure that there is one main neck attachment that is interchangeable between the different balloons. Another thing that makes this design favorable is the mass flow calculations through the neck attachments would be the same due to the same minimum cross sectional flow area.

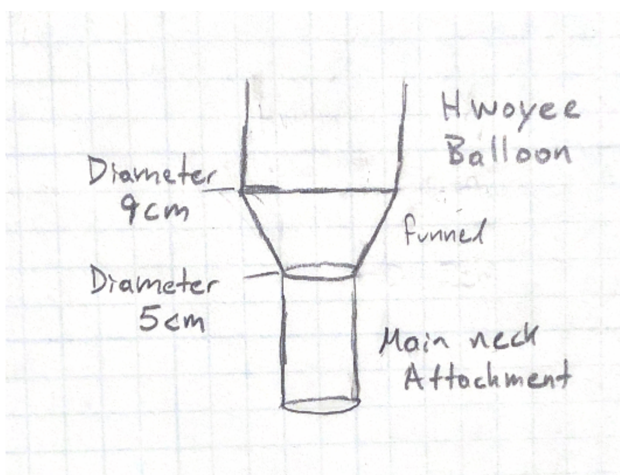


Figure 17: Funnel Design Option

Pros	Cons
One main neck attachment is needed	Funnel connections might break
Same mass flow for both balloons	Helium bleed though the connections
Same complex system	Mass

Table 8: Design Options: Funnel Pros and Cons

3.5.3 Two different sized attachments

This design also addresses the different neck sizes constraint, by utilizing two similar cylindrical neck attachments. One attachment will have a diameter of 9cm specifically for the Hwoyee balloon and the other will have a diameter size of 5cm for the Kaymont balloon. The benefit of going this route is that the necks will be made specifically for the corresponding type of balloon and will allow the system to be a truly closed system from the neck. This design option also benefits from lower mass than the funnel system. This is due to the lack of need for a funnel/adapter to be used for the 9cm Hwoyee balloon.

A limitation with this design option is the need to make two separate complex systems instead of one. This necessitates more testing due to having separate systems and it also makes mass production more difficult.

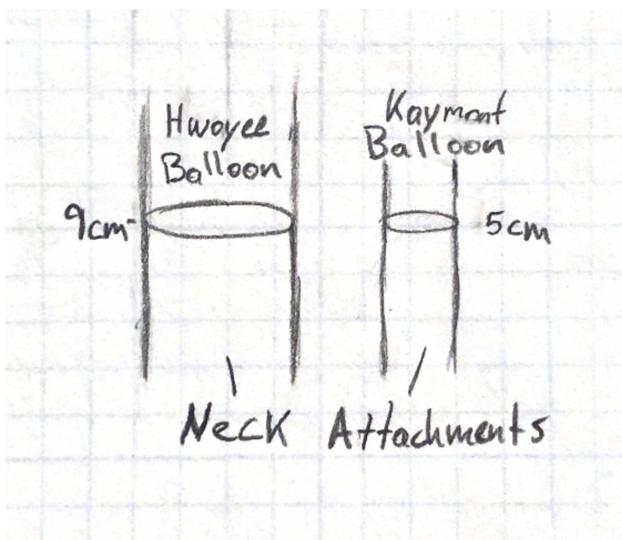


Figure 18: Separate necks Design Option

Pros	Cons
Tight fit for each balloon	Designing two neck attachments
Higher mass flow rate for larger balloons	Cost

Table 9: Design Options: Separate Systems Pros and Cons

4 Trade Study Process and Results

4.1 Buoyancy Control Mechanism

4.1.1 Criteria

Mass: Mass is a significant metric that needs to be taken into account, as any mass increases will reduce the maximum height of the balloon. Specifically, added mass increases the amount of lifting force required, which uses more helium, which will cause the balloon to rupture at lower altitudes. Taking into account that the overall Buoyancy Control system must not exceed 300g, the mass shall be weighted as 25% of the score for the following trade study.

Mass:	*150g or More*	*100-150g*	*50-100g*	*25-50g*	*25g or Less*
Score:	1	2	3	4	5

Table 10: Buoyancy Control Mass Scoring

Cost: Cost is a parameter that comes up in every part of this project. The customer wants the payloads to be disposable; as tracking and recovering each overall system after a flight is impractical. Furthermore, the customer has required that the overall system to cost less than $200. The cost shall be weighted as 10% for the trade study.

Cost:	*$200 or more*	*$150-$200*	*$100-$150*	*$50-$100*	*$0-$50*
Score:	1	2	3	4	5

Table 11: Buoyancy Control Cost Scoring

Volumetric Flow Rate: Volumetric flow rate can be used as a direct measure of how much gas can be removed from a space per unit time. ODDITY will use the Volumetric flow rate as a parameter to determine the rate at which helium can be evacuated from the balloon. This is an important metric to quantify, as it allows us to estimate the time it will take to vent the required amount of helium from the balloon. Additionally, higher volumetric flow rates also allow the system to react more quickly to outside factors such as vertical wind. The volumetric flow rate shall be weighted as 25% for the trade study.

Volumetric Flow Rate:	*0-5LPM*	*5-50LPM*	*50-100LPM*	*100-200LPM*	*200LPM or More*
Score:	1	2	3	4	5

Table 12: Buoyancy Control Volumetric Flow Rate Scoring

Current Draw: Current draw is an important design factor because this subsystem will likely be the largest source of current draw in the system. The current draw will need to remain within a value that can be supplied by the power system that is chosen. Thus, the buoyancy control actuator selected will have a significant influence over the power requirements of the system. The larger the current draw of the actuator, the larger the battery will have to be to power it, leading to a higher overall system mass. This has lead the group to prefer lower current draw designs over high current draw ones. The current draw shall be weighted as 15% for the trade study.

Current Draw:	*10A or More*	*7-10A*	*5-7A*	*3-5A*	*0-3A*
Score:	1	2	3	4	5

Table 13: Buoyancy Control Current Draw Scoring

Complexity/Feasibility: Complexity and feasibility are not easily quantifiable. However, they are very important to consider in design. These scores will be assigned by general consensus within the Buoyancy Control subteam. Complex designs may be able to perform a role more efficiently or effectively, but this is often at the cost of more weight, complexity, and cost. Complexity also often leads to lower reliability for the system. Feasibility consists of the amount of literature/previous work that exists for a given design; as well as the overall perceived risks associated with a given design option. These factors have lead the group to favor simpler and less complex solutions over more complex ones. The system complexity and feasibility shall be weighted as 25% for the trade study.

Complexity/Feasibility:	*Highly Complex*	*Complex*	*Average*	*Simple*	*Very Simple*
Score:	1	2	3	4	5

Table 14: Buoyancy Control Complexity Scoring

4.1.2 Fan Scoring:

An axial fan was considered when evaluating the merits of the different buoyancy control system designs. Axial fans are very commonly used to pull air out of a confined space. This is done currently in computers and HVAC systems, as well as other common applications. Because of their widespread use today, implementing a fan is expected to be a low cost, straightforward option for an active helium removal system. In addition to this, these fans are often made of plastic and incorporate all necessary electronics into one package. This allows for them to be very low weight. The volumetric flow rate of fans is also quite promising because of their simple and efficient design. This efficiency also yields low current draws by the fan motor. The feasibility of a fan, however, is questionable for this project. The efficiency and ability of a fan to create a pressure differential at the extreme altitudes that will be seen in flight needs to be, and will be explored by the group further. Because of this, the Complexity/Feasibility score for the axial fan was low.

4.1.3 Pump Scoring:

A positive displacement pump was evaluated when exploring different options for the buoyancy control system. Positive displacement pumps operate by capturing a fixed volume of gas and forcing it into an exhaust. This means that a positive displacement pump is able to move the same volume of air per cycle independent of the ambient pressure. This independence from ambient pressure helped the pump to score well in feasibility because of its ability to operate predictably at high altitudes in low pressure. However, the constant volume displacement results in generally low volumetric flow rates and thus a low score for volumetric flow in Fig. 19. The pump that was used to perform the trade study was also relatively heavy at 69g, resulting in a score of 3 based on the requirements in Table 10. The current draw for the pump is low due to the small size and low volumetric flow rate. The cost of the positive displacement pumps is low as well due to the widespread use of them in industry.

4.1.4 Hoop Scoring:

This design option seemed to be one the simplest, but from the scoring trade study in Fig. 19 the score turned out to be the least favorable mechanism to be used. The material that was considered as reference for the hoop design option was nylon rope; due to its adjustable size and the softness of the material. The cost of this material was tied to the amount of mass that would be required to wrap around the balloon. Not knowing where exactly the hoop would wrap around, the calculations for mass and cost were estimated using the lower third of the balloons total diameter; 6 meters. This resulted in a estimate of about 50$ for about 300g of 6mm diameter nylon rope for for a length of 15m. Since the volumetric flow rate and the current draw were unknown they were both rated with an average score of a 3. Lastly, in the category of complexity and feasibility this design option rated a 1 because it had a lot of concerns about actually functionality, structural concerns, and overall mass required. All together, this design option ranked last with a weighted total of 2.2 points.

4.1.5 Upside Down Balloon Scoring:

This design idea was an innovative yet simple one. In theory it would not require any additional active systems to draw the helium from the balloon; since any nozzle would be situated on top of the balloon. This made it an ideal candidate in terms of overall current draw for the system. It also would achieve high volumetric flow rates. Because the helium would naturally exhaust out of the of the valve at the top, it would only be restricted by size of the exit valve. However, this is where this design option begins to struggle in terms of the project requirements. The hardware required to support this system, for example, straps to the gondola, coupled with any other necessary balancing hardware, would add a considerable amount of mass to the system. The cost of straps that would not adversely affect the material of the balloon would be a bit too high for the $200 constraint. And finally, the complexity and feasibility of this design option also ranked low. Not enough is known about the interaction between polyethylene straps and balloon side walls to confidently employ this as a reliable design. Furthermore the turbulence experienced at this altitude would offer many dynamic problems to the stability of the balloon and the gondola payload.

4.1.6 Comparison of Designs:

	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

Figure 19: Trade Study of Buoyancy Control Options

It can be seen in Fig. 19 that there was a tie between the Axial Fan and the Pump. Because of this, both options will be evaluated further to determine what the final system will use. While the fan has a significantly higher volumetric flow rate; a characteristic which is highly desirable for this project, its functionality at high altitudes has yet to be properly explored. This will be explored and presented on in future documents and presentations.

4.2 RF Communications and Control

For this critical element of the project, there are two major components; the radio for communications and the microcontroller for control. For the radio, the XBee brand of radio is being used in the overall mission, and therefore is what the ODDITY will be using as well. However, the microcontroller that will be utilized is more of an open ended question, so the trade study in this section will focus on different microcontrollers, their capabilities, and how they would interface with the project as a whole.

4.2.1 Criteria

Mass: As with any component in this project, the mass is an extremely important factor because the overall system must not exceed 300g. In the case of the microcontroller, they are all rather small, as the name implies. However, even the smallest of differences will matter when dealing with a weight constraint of 300g; so this is an aspect that should be heavily weighted when grading each microcontroller. With this in mind, mass was awarded a weight of 25% on the overall grading criteria, and the following table gives the mass range which corresponds to the grade given in this trade study.

Mass:	*20g or More*	*16-20g*	*11-15g*	*6-10g*	*1-5g*
Score:	1	2	3	4	5

Table 15: Microcontroller Mass Scoring

Required Power: With any electrical component comes the necessity for power, and as such any microcontroller will need a power allotment to support it. To provide this power allotment the ODDITY will need to be equipped with a battery of some sort which carries it's own mass. As stated in the previous criterion, mass is a major consideration throughout this project so it will be important to consider the needed power so that the mass of the system can be extrapolated. One can assume that a lower power required will imply a smaller battery, so that is the assumption that the grades for this criterion will be based off of. Since required power is so closely tied with mass of the system it was also assigned a weight of 25%. The following is a table showing the different power requirements and their corresponding grade values.

Min Operating Voltage:	*10V*	*9V*	*8V*	*7V*	*6V*
Score:	1	2	3	4	5

Table 16: Minimum Operating Voltage Scoring

Shape/Size: The next criterion is the physical dimensions of the microcontroller. While this is not nearly as big of a study point as power required and mass; it is a worthwhile investigation, as it must fit on the device nicely and be treated with some sort of thermal control surface. A smaller microcontroller will also give more space for the XBee radio, and will help ensure the component is not cumbersome to the rest of the ODDITY system. As this is a smaller concern than the last two criteria, shape/size was awarded a weight of 18%, and the following table relates each size to a corresponding grade value.

Size	*1.5 in^2 or More*	*1.4-1.49 in^2*	*1.3-1.39 in^2*	*1.2-1.29 in^2*	*Below 1.2 in^2*
Score:	1	2	3	4	5

Table 17: Size/Shape Scoring

Number of Pin Outs: This characteristic speaks to the number of pin out's each microcontroller has. Each pin is typically designated as an analog or a digital pin for use, with some pins reserved for power in, ground and other special cases. Essentially this value will dictate how many things you can have hooked up to your microcontroller at one time. However in the case of the ODDITY project this will not matter too much as there will only be a handful of connections made. In light of these facts this criterion was only weighted 18%, and the corresponding grades to number of pin outs can be found below.

# of Pins	*20*	*22*
Score:	4	5

Table 18: Pin Out Scoring

Clock Speed: This final criterion is the speed of which the processor of the microcontroller completes a processing cycle. Meaning it is the measure of how fast the controller can process data sent to it. This is not a massive concern as the data being sent will likely be at a much slower rate than the clock speed of most modern processors. However it is something to take into account because higher clock speeds allow for quicker commands sent to other subsystems and overall better reaction time of the system. For these reasons clock speed was given a weight of 14%, and the following grades for the varying clock speeds.

Clock Speed	*16 MHz*	*20 MHz*
Score:	4	5

Table 19: Clock Speed Scoring

4.2.2 Adafruit Microcontroller Scores

In the evaluation of the two different Adafruit microcontrollers, Adafruit Metro and Adafruit Metro Mini the Adafruit Metro Mini easily surpassed its counter part. The Adafruit Metro was fairly mediocre across the board, comparable to an Adruino of the same size, but a bit lacking in some of its specs. The Adafruit Metro Mini on the other hand excelled in almost every category. Landing 5's in mass, required power and size/shape and receiving 4's in every other category. Not only is this microcontroller the best for the applications provided by it's carrier, but it performed well enough to stand up to other Arduino alternatives.

4.2.3 Arduino Microcontroller Scores

Four different Arduino microcontrollers were investigated for this trade study, the Arduino Uno, Arduino Micro, Arduino Nano Every and a Arduino Nano. For the most part every microcontroller was solid in their own right and clearly could lend themselves to many projects, but for the purposes of our project one stood out among the rest. The Uno and Micro are not ideal candidates due to their large mass and size, receiving a total score of only 2.71 and 3.57, respectively. Next was the Nano which did very well, receiving a 4 in every category except number of pins in which it got a 5. Similar to the Nano, the Nano Every had at least a 4 in every category and received 5's in mass and clock speed as well as pin number. This put the Nano Every in very close terms with the Adafruit Metro Mini and required a detailed evaluation of each to determine the chip best suited for the ODDITY.

4.2.4 Scoring Summary

Below is a figure (Fig. 20) depicting the detailed breakdown of every microcontroller in relation to each criterion, and their total overall score.The weighted scores are normalized to 5.

	Adafruit Metro 3	Adafruit Metro Mini	Arduino Nano	Arduino Nano Every	Arduino Micro	Arduino Uno
Metric	*Score*	*Score*	*Score*	*Score*	*Score*	*Score*
Mass	2	5	4	5	3	1
Required Power	4	5	4	4	4	4
Shape/ Size	1	5	4	4	3	1
Pin #	4	4	5	5	4	4
Clock Speed	4	4	4	5	4	4
Weighted Score	2.9	4.68	4.18	4.57	3.57	2.71

Figure 20: Microcontroller Trade Study Results

As one can see from figure 20 the Adafruit Metro Mini and the Arduino Nano Every were very evenly matched, but the Adafruit Metro Mini had a slight edge given it's low power requirement. It is also worth noting that the Metro Mini microcontroller is the lowest cost option considered that also happens to work well.

4.3 Insulation and Heating

Concerning the insulation and heating of critical elements; a trade study was conducted on the type of insulation, and research was conducted to help choose between passive or active heating on the system. As mentioned in Section 3.4, the system will be experiencing very low temperatures. A trade study for the insulation material was conducted to assure the electronics of the system would remain within functional operational temperatures. This trade study was conducted because all design alternatives require the use of insulation. However, if the insulation cannot maintain the electronics within functional temperature, a heating element must be utilized to increase the temperature to an acceptable range.

Four types of insulation foams were researched and considered in this trade study. These include; Expanded Polystyrene, the type of styrofoam that disposable coffee cups are made from, Polyisocyanurate, a common rigid thermal insulator, Extruded Polystyrene, another common insulator, and Armaflex, which is a type of Polyethylene commonly used for pipe insulation.

4.3.1 Criteria

Density: As with all the critical elements mass is a factor that always must be taken into consideration. The density of the insulation material directly correlates to the mass and size of the material. Thus to minimize the density of the insulation the weight given in the trade study for the density of the material was chosen to be 35%.

Density:	*60kg/m^3 or More*	*50-59kg/m^3*	*40-49kg/m^3*	*30-39kg/m^3*	*20-29kg/m^3*
Score:	1	2	3	4	5

Table 20: Insulation Density Scoring

Thermal Conductivity: Insulation materials are generally chosen due to their low thermal conductivity. With a low thermal conductivity, heat transfer and the heat loss out of the system is minimized. In this case, the heat produced by electronics can be conserved and the outside cold temperatures dissipate this heat less. Given that conserving the heat from the electronics/heating elements is critical for overall system functionality, the thermal conductivity is weighted highly at 35%.

Thermal Conductivity:(W/mK)	*0.05 or More*	*0.04-0.049*	*0.03-0.039*	*0.02-0.029*	*0.01-0.019*
Score:	1	2	3	4	5

Table 21: Thermal Conductivity Scoring

Temperature Range: As the system will be traveling through a large range of altitudes, there will also be a large range of temperatures the system will experience. However, given that the low temperatures affect functionality of the electronics, it was verified throughout the trade study that the insulation material must also function at these low temperatures. The lowest temperature that the system will experience at the high altitudes is approximately -60° C. Looking at the different types of insulation materials, some were not manufactured to experience extremely low temperatures. The minimum temperature for each insulation material needed to be confirmed to function at the lowest temperature experienced by the system thus this criterion was given a weight of 20%.

Temperature Range:	$T_{min} > -60^\circ C$	$T_{min} \leq -60^\circ C$
Score:	1	5

Table 22: Temperature Range Scoring

Cost: As mentioned before the customer of this project would like it to be disposable given that recovery of the system is difficult. To minimize cost of the overall project the cost of materials is also minimized thus giving the weight for the cost of insulation of 10%. To directly compare the prices, it was decided to compare the cost of material per meter squared.

Cost/m^2:	*$20 or more*	*$14-$18*	*$9-$13*	*$5-$8*	*$0-$4*
Score:	1	2	3	4	5

Table 23: Insulation Cost Scoring

4.3.2 Insulation Scoring Summary

Figure 21 shows the breakdown of every insulation material that was considered and it's scores based on the criterion mentioned previously. This trade study shows that the polyisocyanurate scored the highest with high scores across the board.

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

Figure 21: Insulation Trade Study Results

5 Selection of Baseline Design

5.1 Baseline Buoyancy Control Mechanism

Referencing the trade study that was conducted in the previous section (Section 4.1 Fig. 19), the fan and the pump designs were tied for the baseline design. Therefore, both the fan and pump will proceed to be considered as our baseline design for the buoyancy control mechanism. Both of these designs scored favorable in the current draw, cost and mass. The three important categories that need to be considered in order to achieve our customer requirements. Although there are some specifications from the trade study that make the pump better than the fan and vise versa, there needs to be further analysis between the two designs. Further research about pump and fan need to be done on their operating functionality at the desired altitude range of 20 - 40 km and detailed findings on the volumetric flow rate on different models both design options. These two considerations will help ODDITY find the best design option for the buoyancy control mechanism this project.

5.2 Baseline RF Communications and Control

Based on the trade study conducted in Section 4.2 for RF communications and Control (figure 20), the Adafruit Metro Mini microcontroller was selected for the baseline design. This chip will fulfill the projects needs best based on mass and minimum power requirement (3g and 6V respectively) [4], but also achieves high scores in every other criteria. It has 20 i/o pins, six of which are analog and six digital pins built with PWM's for easy data conversion. As the name implies it has quite small dimensions (17.78mm x 43.18mm), and has a fairly comparable processor to boot (16MHz clock speed) [4]. The chip's processor also has a wide thermal range for operating efficiency, between -40°C and 125°C, which will also be helpful in meeting our survivablility requirements (CPE-2.1).

5.3 Baseline Cut Away Mechanism

While there were several alternative cut-away device designs in comparison to the legacy device (hot wire system), it was found that this system did not require any improvements. Furthermore, the design options that were explored for this system did not fit the project requirements nearly as well as the current design with respect to weight and required power. So based on these facts, it was decided that a simple hot-wire system similar to the current system will be used in ODDITY. The system will most likely have a wire-resistor connection around the tether, acting as the burn source for the cut-away system. If this is not sufficient for ODDITY, a Nichrome tether system can be utilized, as discussed in Section 3.3.1. The Nichrome hot wire cutter has not been tested directly in this mission application but has been tested in other similar NASA missions. It has been confirmed to work under the high altitude conditions faced in this mission, and has been proven to facilitate the tether burn-through relatively quickly. Future investigation will take place to see if a simple resistor-wire connection is sufficient for ODDITY, and if not, another hot-wire system such as the Nichrome device will be used.

5.4 Baseline Insulation and Heating

The insulation that scored highest during this trade study was the polyisocyanurate, which should serve as an effective baseline insulator for any of the heating designs. It scored highest in the thermal conductivity and effective temperature range, as well as scoring high with a low density and low cost. Based on this trade study it scored significantly higher than the alternatives which makes it the best choice going forward.

The legacy device utilizes a powered heating system which suggests that a thermal system comprised of purely insulation may not be enough to ensure adequate operating temperatures of the batteries and electronics. After some research on the batteries currently being used, the data-sheet shows that the discharge rate decreases tremendously at a temperature of -20°C [6]. To assure steady continuous discharge rate, research was conducted on whether a hand-warmer (passive), or a hot wire heating element (active) worked better for this system. As mentioned before, reference [7] showed that hand-warmers are heated by a chemical reaction, and thus require oxygen in order to increase heat. However, given that in this project, the system will operate in high altitude where oxygen is sparse; the functionality of hand-warmers could be diminished.

Thus, hand-warmers need more testing to determine the longevity of the warmers themselves, as well as to how well they function in high altitude.

The current system uses a hot wire to heat the batteries when needed. After weighing the option between the hand-warmers and a hot wire, shown in table 7 it was decided that the hot wire heating element is the more suitable option.

5.5 Baseline Neck Attachment Design

Although there was no trade study done for the neck attachment, ODDITY will keep the legacy 5 cm neck attachment due to its practicality and the success rate from 15 previous launches. The approach that ODDITY will be implementing, is the addition of a funnel to address the requirement of utilising both the Hwoyee and Kaymont balloons. This decision was made out of simplicity and uniformity. Utilising the same 5cm neck attachment can help ODDITY determine the same mass flow rates out of the valve, regardless of what balloon is being used. The other reason is the practicality/simplicity of manufacturing multiple 5 cm neck attachments, which allows us to leverage the design of the legacy hardware.

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