



Weather Balloon Altitude Control System

Senior Design 2014-2015

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Executive Summary

The field of high altitude ballooning is an effective and relatively inexpensive way to deliver scientific payloads to the upper atmosphere for data collection. High altitude balloons can be grouped into two main categories: zero pressure and burst. The burst balloon is designed to ascend constantly until it reaches a certain altitude, at which point it will burst allowing the payload to descend back to the ground. The zero pressure balloon is much larger, and is designed to ascend to a certain altitude, then float until the flight is terminated. The zero pressure balloon is more versatile than the burst balloon as it can float at neutral buoyancy for extended data collection. The burst balloon is significantly less expensive so it is commonly used by facilities that use meteorological sounding packages and university ballooning groups with smaller budgets. The Goal of the altitude control system is to provide the ability to fly the lower cost burst balloon at neutral buoyancy. This will allow users to collect data on a floating platform without the increased expense of a zero pressure balloon.

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Problem Definition

Introduction:

University level ballooning programs and stations that collect meteorological sounding data typically use relatively inexpensive latex weather balloons to transport their payloads to high altitudes. These balloons are made to fly to a high altitude and then burst, providing no control over the duration of flight and the altitude of data collection. For longer duration flights, zero pressure balloons are typically used. These balloons are many times more expensive than latex weather balloons. The goal of this project is to develop a low cost alternative to zero pressure balloons that will still provide neutrally buoyant flight. To accomplish this goal we will develop a valve that is user controlled that can be inserted into the neck of the latex balloon, then can be opened to vent helium and therefore control the altitude and duration of the flight.

The mechanical portion of this project will consist of a flow tube that will be connected to the fill nozzle. This flow tube will feature a mechanical gate vent system to allow Helium to be vented from the balloon during flight. The mechanical valve gate will be located at the bottom of the flow tube. this device will also have a fill port that will interface with the fill station, to allow the balloon to be filled with Helium after attachment to the device. The circular valve gate will actuated by a small motor, which will be controlled by the onboard microcontroller.

The electrical portion of the project will consist of multiple control and wireless communication systems working together to give the user control of the flight and facilitate various in-flight experiments. One control system will be connected to the mechanical valve

assembly which will control the motor which opens and closes the valve, wireless communication with the main command capsule, and reads various sensors. A second control system in the main command capsule will act as the main communication and control hub for the flight system. This module will consist of a microprocessor which will wirelessly control the valve system and interface with the users onboard long range tracking and or communication system. Research will be performed on which microprocessors and wireless protocol will best suit the project. Custom printed circuit boards and supporting electronics will be designed for each module.

Needs Description:

University level ballooning programs and stations that collect meteorological sounding data typically use relatively inexpensive latex weather balloons to transport their payloads to high altitudes. These balloons are made to fly to a high altitude and then burst, providing no control over the duration or altitude for data collection. For longer duration flights, zero pressure balloons are typically used. Zero pressure balloons provide a long flight duration at a near constant altitude. However, these balloons are many times more expensive than latex weather balloons, which puts them out of reach of smaller ballooning groups. This design will seek to develop a system to use burst latex balloons in place of zero pressure balloons. This will be done by developing a valve that can be inserted into the neck of various sizes of latex balloons to vent helium sufficient to achieve neutral buoyance at a user controllable altitude. This will reduce the cost associated with doing experiments that traditionally required a zero pressure balloon.

Currently the only group that has successfully done anything like this is in the past, outside the military, is the BOREALIS program at MSU. BOREALIS has made a prototype to vent helium. The current system requires a wired connection from the vent to the payload, this allows the user to manually open and close the vent. The improvements that need to be made are to adapt this system for traditional 2000 and 3000 gram latex balloon as well as smaller 200 gram balloons used for weather sondes. The main things that need to be improved are making a valve design that can be used for weather sondes and for larger 2000 or 3000 gram weather balloons, wireless communication between the valve and the main payload, and the valve needs to have the ability to autonomously open and close to achieve neutral buoyance at a user selectable altitude. Using a valve will reduce the cost associated with doing experiments that traditionally required a zero pressure balloon. Being able to wireless communicate with the valve will reduce possible complications such as the wire connected to the valve getting tangled with the parachute. Wireless communication between the valve and the main payload will further reduce the weight of the system. Having the valve autonomously navigate to a desired height will reduce human error and the need for communications between the ground and the balloon during flight.

This system will allow for a broader range of experiments at smaller university level ballooning programs to be done at relatively low cost. Particularly this will provide a stable camera platform for the BOREALIS program to record the 2017 eclipse. Another important application of this system will be for use with weather sondes in extreme weather situations, such as hurricanes. This is will be beneficial because it will allow weather sondes to collect data for longer periods of time and at selectable altitude. This will reduce cost and risk of using aircraft to take these measurements.

Stakeholder List:

A low-cost controllable-altitude balloon platform has a diverse group of stakeholders. The stakeholders include the students and campus faculty involved in the program, the Montana Space Grant Consortium, and the atmospheric science community. Each stakeholder has a unique vested interest in the completion of this project as detailed below.

The primary stakeholders are the students and campus faculty directly involved in the program. The students responsible for the project have a vested interest in its completion as it fulfills a graduation requirement for their respective majors. The project also offers them valuable engineering design experience to take with them to their future employer. The campus faculty are also stakeholders in the project's success. Not only are the faculty asked to help guide their students towards successful completion, they are also ultimately responsible for assigning grading marks for the student's work as well. The faculty are also invested in the program to help further Montana State University's reputation of producing excellent engineers.

The Montana Space Grant Consortium (MSGC) BOREALIS program is a stakeholder in this project as they are the organization sponsoring the student's work. MSGC is interested in a controllable-altitude balloon platform for their 2017 total solar eclipse project which hopes to take live images of the total solar eclipse from the stratosphere. A reliable altitude control system for their balloon payload is essential for placing their cameras at the correct altitude to capture the eclipse.

Finally, the atmospheric science community will greatly benefit from this system. Scientists currently use latex weather balloons to measure atmospheric and weather phenomena using measurements obtained as their balloon payload rises through the atmosphere. Once their payload reaches a certain altitude it bursts, terminating their flight and experiment. An altitude control

system (such as that being developed in this project) would allow more measurements to be taken before the flight is terminated as the balloon could loiter at a specific altitude without bursting.

In conclusion, the stakeholders include:

- Students and faculty involved in the project
 - Students directly involved in the design, build and testing of the project
 - Campus faculty supporting and grading the students
- Montana Space Grant Consortium
 - MSGC BOREALIS program requiring a stable camera platform in the stratosphere for their eclipse project
- Atmospheric Scientists
 - Scientists involved in measuring atmospheric conditions

Project Goals:

The main goal of this project is to provide a system that will allow users to fly payloads at neutral buoyancy using latex weather balloons (Burst balloons). This system will be required to vent the correct amount of Helium from the balloon within the time constraints of the balloon mission. This system will also be required to restrict the flow of Helium adequately enough when closed to eliminate variability in the float altitude. The two sub-goals for this project include autonomous vent control, and short range wireless control of the Helium vent. The autonomous vent control will be an electronic function built into the valve itself. It will have a user interface for selection of float altitude, and a microcontroller that will make vent decisions based on the user selection. The short range wireless control will give the user the ability to control the valve manually by using another long range communication system on a different payload container on the same payload chain. For example: the user would send the 'open vent' command through their standard communication system (e.g. amateur radio or satellite modem), the command would be

received by their payload chain attached to their balloon, and the command would be transmitted short range from the communication payload to the valve system.

Project Constraints:

The constraints placed on a high-altitude weather balloon system include project length, cost, weight, density, breaking force, temperature, endurance, size, and communications. A detailed look at these constraints is provided below:

- Time
 - The project must be completed within the two semester Senior Design sequence specified by Montana State University
- Cost
 - The project must be completed within the budget assigned to the student group by MSGC
 - Actual dollar amount is yet to be determined
- Weight
 - Valve and control systems must be as light as possible to allow other systems to utilize the total weight allowed (see below)
 - FAA regulations (FAA Part 101 – (a)(4)(ii) and (iii)) require no more than six pounds per payload, and no more than 12 pounds overall total for multiple payloads
- Density
 - FAA regulations (FAA Part 101 – (a)(4)(i)) specify an upper maximum density of three ounces per square inch to avoid catastrophic aircraft damage should a collision occur
 - Determined by dividing the total weight in ounces of the payload package by the area in square inches of its smallest surface

- Breaking force
 - FAA regulations (FAA Part 101 – (a)(4)(iv)) require that any rope or suspension used for the payload must break free with an impact force of no more than 50 pounds
 - Payload must survive impacts with the Earth once the flight terminates
 - Parachute system must reduce speed to 10-20 feet per second depending on payload / experiment requirements
- Temperature
 - All systems must be able to withstand temperatures from -60⁰C in the upper atmosphere through +35⁰C at the Earth’s surface
 - Mechanical and electrical systems must operate through this range for extended periods of time as indicated in the endurance section
- Endurance
 - Both mechanical and electrical systems must be able to operate for the duration of the mission
 - Typical BOREALIS loiter flights (“zero pressure flights”) last approximately 3 hours
 - Typical BOREALIS flights require that any flight systems are operational 30 minutes before balloon launch
- Size
 - While there are no size constraints directly placed on the valve and control systems, they must conform to the weight, density, and breaking force specifications provided above
- Communications

- Control system must be able to interface and communicate with the current BOREALIS communications payload which includes an NAL Research 9602-LP Iridium satellite modem connected to an Arduino Uno microcontroller
 - Communications protocol / interface can be determined by the designers

Functional Analysis

Introduction:

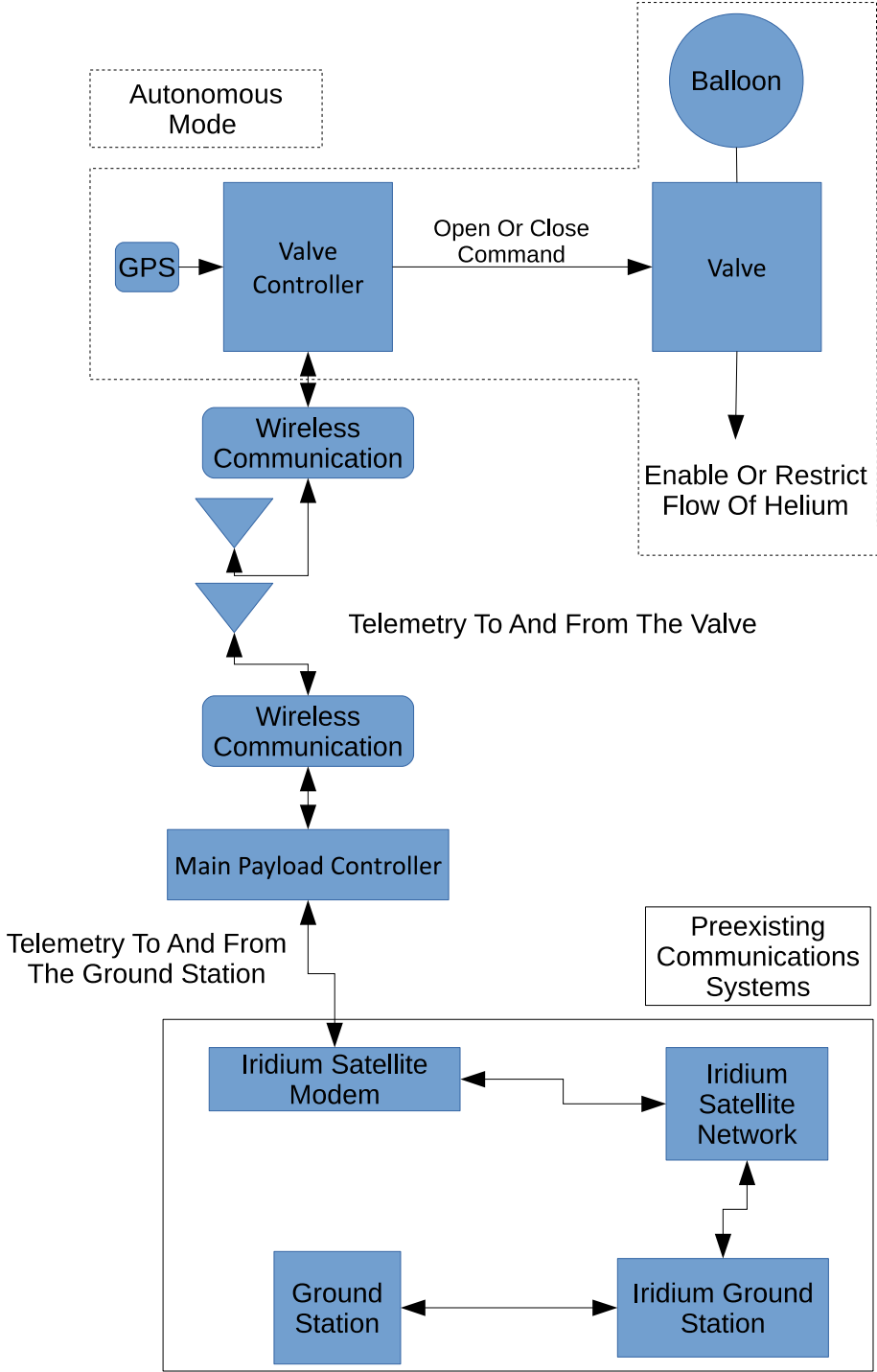
The following functional specification overviews the high level requirements of the valve control system. Very few if any technical details will be provided however the overall function of the system will be detailed. The functional specification starts with a black box model which describes what each individual subsystem does along with a high-level look at how the systems are connected together. The next section is functional specifications. The functional specifications provides a granular look at what each subsystem must do to accomplish the overall goal of the project. Each high level function is broken down into smaller sub functions as needed. Finally the design metrics for the project will be presented. The design metrics are the overall design goals that the end product will be weighed against to determine if the project was successful or not.

Black Box Model:

This project consists of four main subsystems, the preexisting long range communication system, an Iridium satellite modem, a controller in the main payload to interface to the Iridium satellite modem, a controller up on the valve with a GPS unit, and the a valve to vent helium. Currently the MSGC BOREALIS program is using an Iridium satellite modem to communicate with the balloon payload other ballooning groups commonly use amateur radio DTMF. This project will entail designing a main payload controller that can interface to an existing communications system be that a satellite or amateur radio DTMF. This controller will then via a wireless connection communicate with a controller up on a valve closer to the balloon. This valve controller will then directly control a valve that is inserted into the neck of a balloon which will open and close enabling or restricting the flow of helium out of the balloon to achieve neutral buoyance. The valve controller will also have the functionality to operate autonomously, venting helium to achieve neutral buoyance at a preprogrammed attitude. It will do this be implementing an algorithm to interpret

GPS data and determine when and for how long the valve should be opened to achieve the user selected altitude.

Valve Control System



Functional Specifications:

The purpose of the valve system is to allow users of latex high altitude balloons to fly them at neutral buoyancy. This will be accomplished by venting a certain amount of helium out of the balloon during flight to affect the amount of lift produced by the displaced air. This will allow users to extend the duration of their flights, and allow them a degree of control in flight duration and altitude.

The electronics package will consist of two functional subsystems: a control subsystem and a valve subsystem. The control subsystem will reside within the main payload container that the end user supplies. The control subsystem is responsible for interfacing with the end user's tracking and command system (Iridium satellite modem, amateur radio, etc.) The interface protocol will need to be well documented for easy integration with the end user's existing payload. The interface will allow for remote control of the valve and its various functions. The control subsystem must wirelessly communicate with the valve subsystem. The control subsystem must have an endurance of 6 hours.

The valve subsystem interfaces directly with the valve mechanics and is responsible for actuating the valve as required. A wireless connection must be established between the control subsystem and the valve subsystem if required. The valve subsystem must also have a autonomous mode which works independently of the control subsystem if activated. The autonomous mode will use internal logic and various sensors to determine when to actuate the valve mechanics. In either mode the valve subsystem must be able to wirelessly send status updates and sensor readings to the control subsystem.

Specific design requirements for this project are as follows:

- The valve system will be required to have a sufficiently high flow rate to allow the user to bring the balloon to float (Neutral buoyancy) within 15 minutes of being open. Due to the ascent rate of the average high altitude balloon flight, the time window for venting is limited to a maximum of 15 minutes. If the vent time takes longer, the balloon may burst at high altitude due to excessive volume.
- The valve system will be required to achieve float at a pre-specified altitude to within a 10% degree of accuracy. This design requirement is aimed at making this product marketable to institutions that collect meteorological sounding data that will require altitude control that is acceptably accurate.
- The valve system will be required to operate inside the temperature range of -60 C to 40 C. This is the average operating temperature range from ground level to 100,000 ft.
- The valve system will be designed for use with 300 gram Kaymont brand balloons. Future designs may include a design that is compatible across other brands or sizes of balloons, but this project will be designed for a balloon commonly used for meteorological data collection.
- The total weight of the valve system cannot exceed 8 oz. The 300 gram balloons commonly lift a 2 lb. payload, and the addition of a valve system weighing more than 8 oz. becomes unreasonable compared to the average payload weight.
- Communication specification for interfacing the valve system with the end user's payload
 - The valve system is not required to control or track the end user's payload, however a data link protocol is provided to interface with the user's system if desired. The protocol specifies the method of communication the valve system expects from the external control system such as baud rate, serial protocol, timing, etc.
- Battery endurance of 6 hours

- The complete valve system must operate for a minimum of 6 hours, however no particular power usage specification is required as long as the other functional specifications are still met (temperature range and weight would likely be most affected). The valve system design must determine how best to achieve this goal through efficiency of operation, battery capacity, DC/DC converter requirements, sleep states of the microprocessor, etc. The 6 hour requirement is based on the intended use of the end product.
- Cost per unit less than \$100 for 100 units.
 - Due to the average cost of weather sounding packages, it would be unreasonable to expect a customer to pay more than \$100 for the neutral buoyancy upgrade.
- The valve system will be required to provide flight termination for the balloon by venting a significant volume of Helium to cause the balloon to descend back to ground level.
- The valve will be required to have an in-line fill system that will allow the user to attach the balloon to the valve prior to fill, then inflate the balloon with Helium through the valve. This system will also require a fill station that will interface with the Helium tank regulator.
- This project will be required to be accomplished within 3 test flights and 1 demonstration flight due to budget and time requirements.

Design Metrics:

The design metrics for the project are the most important project goals that must be met for the project to be a success. These specifications are the most important high level goals as they are the specifications given to the project group by the end user. If these design metrics are not met the end user will not only be displeased, they may proceed with another company's product.

The design metrics for the project are specified as follows:

- The valve mechanics must be simple to connect the latex weather balloon to and also hold onto the balloon so it does not disconnect in flight.
- The valve mechanics must allow for inline fill of the latex weather balloon.
 - Inline fill allows the end user to attach their latex weather balloons to the valve mechanics and then connect their helium supply to the valve. The valve system must not be cumbersome to connect or interface with.
- A float altitude between 30,000-60,000 feet within a 10% tolerance must be achievable with the system.
 - This altitude range encompasses the altitude regions in which the end user would typically utilize such a system, and an acceptable tolerance level at those altitudes.
- The valve must weigh no more than 1/2 pound.
 - If the valve system is heavier than that specified the end user will lose valuable payload weight for their experiments.
- The entire system must cost no more than \$100 per unit in 100 unit quantities.
 - To be competitive or desirable with the intended market the entire valve system must not cost more than the cost of a typical weather balloon (\$100).
- Up to three test flights and one final flight may be used to test the project design.

Alternatives Evaluation

Introduction:

This section of the report will cover the design alternatives proposed by the Capstone group. These design alternatives are a group of ideas that could possibly be used to accomplish the functional requirements. This report will discuss the design alternatives in detail, then rank them based on operational criteria proposed by the Capstone group. This report will also discuss the user operation requirements for the project. These can include ergonomics, setup, maintenance, and correct operation of the product.

Design Alternatives:

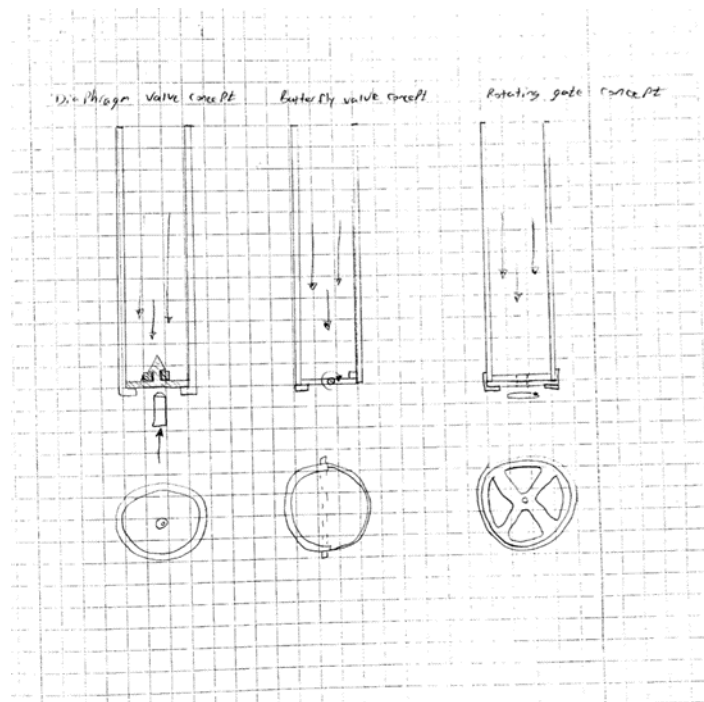
The design alternatives area is where you will be explaining the top design selections that you have come up with. Here, about a 1 – 1 ½ pages for each design idea along with sketches needs to be produced so the reader can get a good understanding of what the concept is. The sketches don't have to be perfect. You can make copies of the ones in your journal and scan them in.

Mechanical design alternatives:

Diaphragm valve: This design alternative will obstruct the flow of Helium through the vent tube with a flexible rubber disk trapped against a ridge internal to the flow tube. Venting will be accomplished by an armature pushing on the diaphragm from the outside, temporarily compromising the seal and allowing the Helium to vent.

Butterfly Valve: This design alternative will use a disk of rigid material connected through the center axis by a rotating connection point. The inside of the flow tube will have a sealing ridge on half of the circumference, and have an identical sealing ridge on the outer opposite side. The flow would be obstructed by having the disk rotated about the pin until it contacts the stops. Helium flow will be allowed by rotating the disk in the opposite way.

Circular gate Valve: This design will use two circular disks of rigid material that lay flat against one another and cap off the end of the flow tube. Each disk has as identical and symmetrical hole pattern such that when the openings are lined up, gas is allowed to flow through the openings. By rotating the top disk, the openings are misaligned, and the flow opening is closed. The two disks will use a high viscosity lubricant at their interface. This will help make the seal gas tight, as well as prevent the two surfaces from wearing on one another.

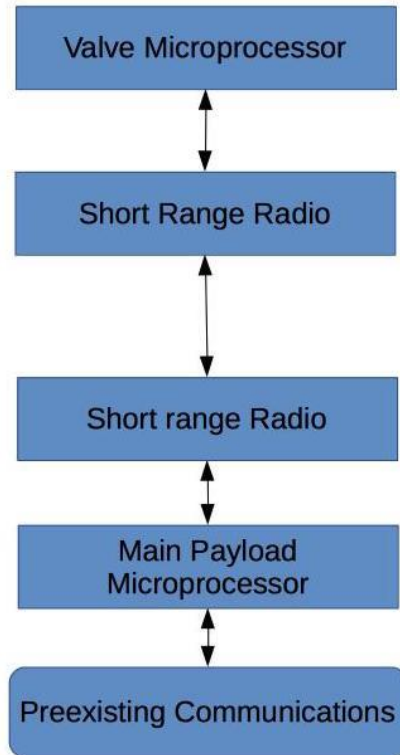


Electrical Design Alternatives:

Design Alternative 1: Microprocessor with external short range radio.

This alternative is using a microprocessor with an external short range radio module, such as an Xbee ZigBee module.

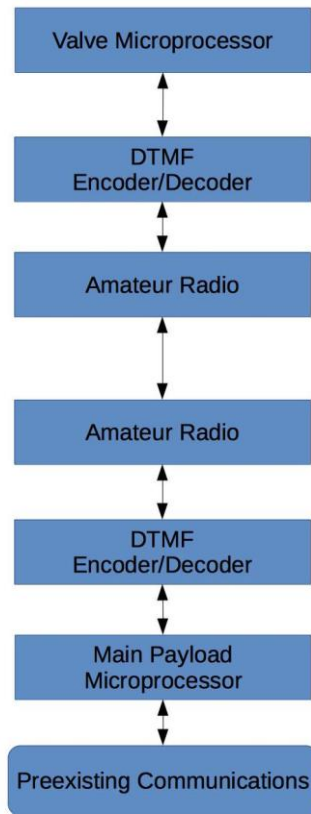
Microprocessor With Amateur Radio Link



Design Alternative 2: Microprocessor with amateur radio link.

This is probably the most commonly used solution to this design challenge however there are a lot of things to interface together and it is somewhat complicated.

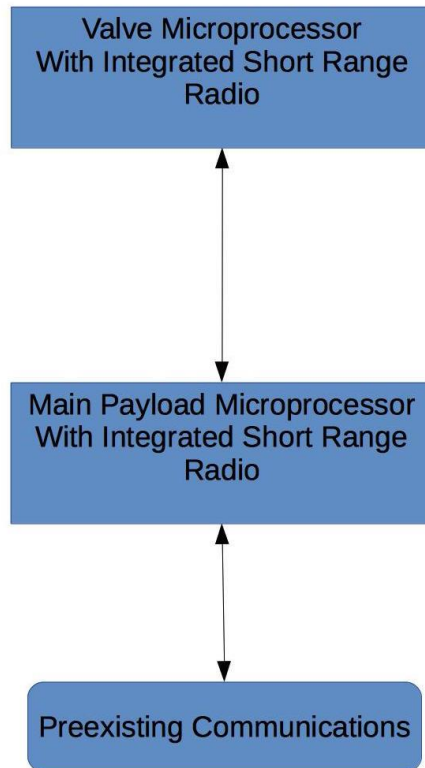
Microprocessor With
Amateur Radio Link



Design Alternative 3: Microprocessor with integrated short range radio.

There are some microprocessors that have integrated radios similar to ZigBee modules. This system will have the least amount of components

Microprocessor With Integrated
Short Range Radio



Client/User Operation:

The client and user operation of the valve has both mechanical and electrical considerations and will be explained in detail individually.

Proper operation of the physical valve and related components is vital to the end user successfully deploying the system. There are complexities associated with integrating the system with the end user's tracking and communication system as well as with connecting and filling the necessary weather balloon. Easy to follow instructions and methods to reduce incorrect usage will be vital for preventing errors and avoiding unnecessary confusion and frustration.

The valve system will require an interface on the outside of the flow tube that will allow the user to easily and quickly connect the specified balloon type to it. This will be either a surface that provides enough friction to retain the balloon nozzle, or a latching system that will capture it.

The valve system will also need an in-line fill system that will allow the user to fill the balloon with Helium through the valve system after it has been connected. A unique fill nozzle that can interface on one end with the Helium tank regulator, and on the other end with the valve, will need to be created. This will allow the user the most efficient launch procedure, instead of having to fill the balloon then attach to the valve.

The electrical and computer user interfaces are also important components of the valve project. The electrical operation considerations will be detailed separately from the computer user interface. Electrical operation includes the specification for interfacing the end user's communications equipment with the valve microprocessor. The computer user interface is used to select the valve's operating mode as well as for downloading sensor and operation data.

The user interface for the electrical system describes how the end user will interface their communications system with the microprocessor within the valve system. Because the valve system must interface with a wide range of tracking and communication systems, a protocol standard must be developed and documented. This document will specify how to physically interface with the valve microprocessor, electrical specifications for logic levels, and how data is expected to be sent and received. The specifications for the physical connection with the device must include port pin-out diagrams, special handling requirements (such as static electricity precautions), and where to find the ports on the printed circuit board. The electrical specification must include maximum and minimum electrical ratings, supported logic levels, and timing requirements. Finally the protocol which is used to communicate data to and from the valve microprocessor must be detailed (such as how and when to acknowledge a data byte).

The computer user interface will be used to both upload operating information to the valve microprocessor and for downloading data stored in its onboard storage. A graphical user interface should be used to easily perform these actions which can be run from either a software application or a specially crafted webpage. If any features are not self-explanatory a user manual or electronic help document should be present to guide the end user through the operation. The interface will allow the end user to select modes of operation such as fully autonomous mode, a desired altitude ceiling, what sensors to record data from, and/or if the valve should expect commands from the end user's own communication equipment mid-flight. The interface must also allow for downloading flight information after the flight has concluded. The user interface must present this data in an easy to work with file format such as comma separated values within a text file.

Decision Matrix:

Using a design matrix the best solution for the design challenge can be selected via quantifiably criteria. In a design matrix on the left the different design alternatives are listed and then along the top of the matrix the different design criteria are listed. Then the design alternatives are systematically scored on a scale, in this case we are using a scale from 1 to 5 with 5 being the best, against the selected criteria. For this design the selected criteria are power usage, cost effective, ease of integration, durability, ease of use, and overall effectiveness. Power usage is probably the most important criteria for this project. This is because low weight is a critical requirement for the ballooning payload. More power usage means more batteries which translates into more weight. Cost effective was chosen as a criterion because the final design needs to cost less than \$100 per unit for 100 units. Ease of integration with the rest of the system and ease of use for the end user are obviously important because if it is too difficult to use no one will want to buy or use the product. Durability of the design also translates to the lifetime of the product. A longer product lifetime increases the value for the end user. The design alternatives were also scored for

overall effectiveness in meeting the design requirements for this project. The design matrix generated is shown below with total scores for each design alternative in the far right column.

Criteria Scale: 1-5 With 5 Being the Best	Power Usage	Cost Effective	Ease of Integration	Durability	Ease of Use	Overall Effectiveness	Total
Design Alternatives							
Wireless System							
Microprocessor and Short Range Radio Separate	3	3	5	3	5	5	24
Microprocessor And Amateur Radio With DTMF	1	1	3	3	4	5	18
Microprocessor With Built In Short Range Radio	5	5	2	5	1	5	23
Mechanical System							
Diaphragm valve	N/A	5	2	1	3	1	12
Butterfly Valve	N/A	3	3	4	4	3	17
Rotating Gate Valve	N/A	4	5	5	5	5	24

From the above design matrix the winning design alternatives for the electronics system is microprocessor with a separate short range radio module, and for the mechanical system the

rotating gate valve. These designs are superior to the other alternatives when compared with the selected criteria.

Project Planning:

Introduction:

This report will detail the Project planning for the Weather Balloon Altitude Control system currently being designed. This report will contain risk analysis information that covers the severity and probability of the failure modes possible for this system. Next, plans for mitigating risk items above the design threshold will be detailed. A brief breakdown of the work structure for the project will also be included. This will cover high level tasks that need to be completed for the project. The responsibility matrix will assign various design goals to certain members of the design team. Finally, the report will be concluded with a project schedule that will include a timeline for project goal completion.

Risk Analysis:

- Open failure: The valve could fail to open on command, resulting in the balloon to rise to a terminal altitude and burst, causing the project to fail the mission parameters and potentially become lost.
- Flow failure: the valve could fail to vent an adequate amount of Helium to satisfy the mission requirements.
- Close failure: The valve could fail to close after the venting cycle is completed, causing the balloon to become negatively buoyant before float is achieved resulting in mission failure.
- Mechanical Failure: The mechanical linkage between the balloon and payload could fail, resulting in the payload descending before mission completion.

- **Communications Failure:** The wireless link between the main payload and the valve controller could fail and the ability to control the valve could be lost. This could result in the balloon gaining excessive altitude and bursting if control is lost before burst, if control is lost after neutral buoyance was achieved the balloon could go derelict, or if control is lost when the valve is open the balloon could vent excess helium and land before intended.
- **Autonomous valve algorithm failure:** If the algorithm to come to neutral buoyance fails the balloon will either never vent helium and gain excessive altitude and burst of, vent too much helium and land early, or the valve may open and close undesirably.
- **Code failure:** Any type of infinite loop which may occur in the code would effectively terminate the microcontroller's ability to control the valve or make other decisions.
- **Electronics failure:** the power system which runs the electronics could fail or short and draw more current than intended. This could cause the microcontroller to reset, damage to the power system or electronics, or reduced battery life.

0=lowest severity, probability

10=High severity, probability

Risk Item	Severity	Probability
Open Failure	3	2
Close Failure	2	2
Flow Failure	1	3
Mechanical Failure	5	1
Communications Failure	5	1
Autonomous Valve Algorithm Failure	5	3
Code Failure	5	2
Electronic Failure	5	1

Mitigation Strategy: (it was determined that none of the risk factors were unacceptable, so mitigation strategies were created for each one, independent of a trend line)

- Open failure: This problem can be solved by appropriate tolerancing of mechanical components, and correct execution of the autonomous vent code.
- Flow failure: This problem can be solved by increasing the effective flow area of the valve.
- Close failure: This problem can be solved by appropriate tolerancing of mechanical components, and correct execution of the autonomous vent code.
- Mechanical Failure: This problem can be solved by applying appropriate safety factors to all mechanical components in the system.
- Communications Failure: Thorough testing will the full system to insure there is no interference or other unforeseen problems that would result in communications failure.
- Autonomous valve algorithm failure: In order to mitigate the risks associated with the algorithm rigorous simulation and testing will be done to assure that the algorithm performs as intended.
- Code failure: Full systems testing will mitigate most common code failure modes. Watchdog timers can be used to prevent total system failure if unforeseen infinite loops occur.

Recursion

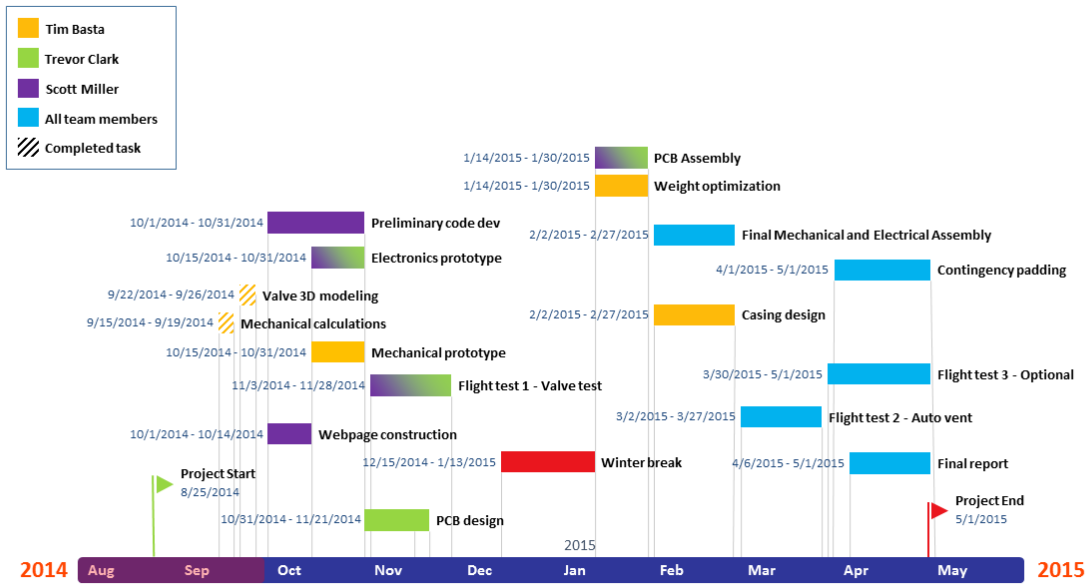
- Electronics failure: Full systems testing will mitigate any issues experienced with the electronics design or power system. Current draw during different modes of operation will be measured and analyzed to ensure the power system can perform as required.

Environment testing can be performed in the BOREALIS lab vacuum chamber.

Responsibility Matrix and Work Breakdown Structure:

Task	Tim Basta	Trevor Clark	Scott Miller
Valve 3D Modeling	x		
Mechanical Calculations	x		
Order Mechanical Components	x		
Order Electronic Components		x	x
Electronic Prototyping		x	x
Mechanical Prototype	x		
Casing Design	x		
Code Development			x
PCB Design		x	x
PCB Assembly		x	x
Website Construction			x
Final Mechanical Systems Assembly	x		
Final Electronic Systems Assembly		x	x
Testing	x	x	x
Documentation	x	x	x

Project Schedule:



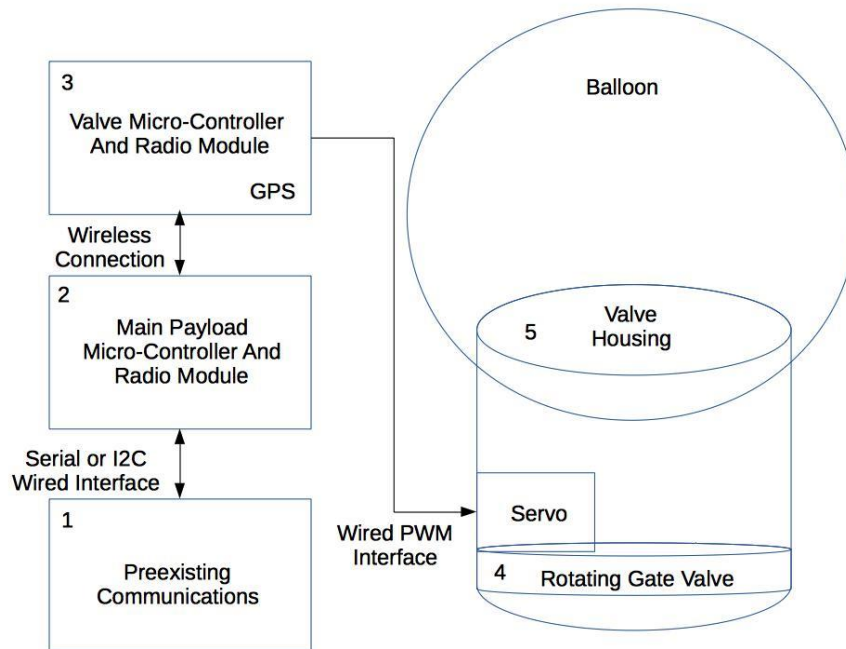
Concept Development

Introduction:

The design alternative that was chosen from the decision matrix is a micro-controller with an integrated radio and a rotating gate valve. Now that these design choices have been selected above the others they will be further explained and developed. The individual components will be explained in greater detail along with how they integrate with the other components in the overall system. In order to make the best overall product a number of interviews were performed to get some feedback on how the current design could be improved and if there should be any additional features added. In accordance with the feedback that is received the design will be potentially changed or added to. Even though the seemingly best design has been chosen there is some potential for some design choices to fail. In order to prepare for this possibility a contingency plan is developed and presented here.

Concept Design:

In order to achieve the goal of developing a weather balloon high altitude control system a number of alternatives were evaluated. The designs that scored highest in the decision matrix were a microprocessor with a built in wireless receiver and transmitter and a valve with a rotating gate. This is shown below.



The following is a detailed explanation of the different components of the chosen design.

1. Preexisting Communications - This is not part of the design but is something the design will interface with, so it is helpful to understand its function. The BOREALIS program at Montana State University uses an iridium satellite modem for communications between a ground station and the balloon during a flight. The ground station communicates with the modem by sending an email to the Iridium company who then sends it via satellite to the modem on the balloon payload. The modem has a serial connection and three digital pins that can be interfaced with. Other ballooning groups use a variety of different options for communicating with the balloon. Traditionally one of the most common has been using amateur radio with a DTMF encoder and decoder which usually have a serial interface. The goal of this design is to have a system that can be easily interfaced to whatever a given group is using for their ground to payload communications. This will be accomplished by having available Serial, I2C, and digital pins available.

2. Main Payload Micro-Controller And Radio Module - A micro controller that is compatible with Arduino and a separate radio module will be used to relay commands from the consumer's preexisting communications to the valve controller. As was mentioned in the Preexisting Communications section this micro-controller will have serial, I2C and digital pins available for interface with whichever ground-to-payload communication is being employed. This will allow the customer the flexibility to use whatever method of communication they choose. The micro-controller will receive and information sent from the ground and will then be able to transmit that information to the valve controller wirelessly via its integrated radio. The wireless feature will prevent any tangling or other complications associated with using a wired connection between the main payload and the valve.
3. Valve Micro-Controller And Radio Module - A second microcontroller and radio module will be used to control the valve servo using a wired PWM signal. This micro-controller and radio module will be the same one that is used in the main payload. The Valve controller will receive commands from the main payload via its integrated radio and then according to the received command send a PWM signal to the servo opening or closing the valve gate. Another one of the goals for this design is to have the ability to have the valve operate autonomously. What is meant by this is for the valve to open and close in order to come to neutral buoyance, or float, at a preselected altitude. In order to accomplish this the valve controller will be interfaced to a GPS unit so that it can read altitude data. Using this altitude data in an algorithm the controller, based on rise rates, will determine when and for how long to open the valve in order to achieve the selected altitude.
4. Rotating Gate Valve - The method by which the Helium will be vented from the balloon will be a rotating circular gate valve. This valve will be constructed from milled polycarbonate

sheet 0.056 inch thick. The valve will consist of two circular parts that will be overlaid. The outer and larger of the two circles will have four triangular holes placed symmetrically about the inside of the circle, with one #6 hole at its center. This outer circle will be secured to the end of the vent tube by a cylindrical tube cap, also milled from polycarbonate sheet. The inside circle will be the negative of the outer ring, meaning that when the two rings are overlaid and rotated to the correct alignment, the triangular hole in the outer ring are closed off. This inner circle will also have a #6 hole at its center. The inner ring will have a 1/8 inch long #6 diameter pin secured to its center hole with adhesive. A four point servo horn will be centered and secured to the opposite side with adhesive also. The servo horn will attach to a sub-micro servo, and the servo along with a low powered compression spring will be closed inside of the two halves of the servo casing, which will allow the compression spring to press the servo and inner circle assembly forward, ensuring an adequate seal between the inner and outer gate circles. The two gate circles will also be coated with white lithium grease for lubrication, and to improve the seal made by the two circles in contact.

5. Valve Housing - The valve housing, or main body tube, will be made from polycarbonate tube I.D. 1 inch, wall thickness 1/16 inch. This will be cut in an 8 inch section, and have a rectangular section removed from the lower end to allow for the servo casing to be attached. The gate cap will then be secured, compressing the compression spring slightly. The body tube will also have a balloon retention ring secured around the top to ensure that the balloon will not come off during flight. The body tube will also feature an electronics enclosure on the outside, with dimensions still to be determined.

Evaluation Criteria:

In order to make a more desirable product for the customer. A number of interviews with potential customers were performed with the following questions.

Interview Questions

1. Our engineering team is designing a \$100 microprocessor-controlled helium valve system which will allow latex weather balloons to maintain a set, pre-selected altitude in the atmosphere. This will allow a scientific payload to remain airborne for up to six hours. Would your team be interested in such a product and how would the increased flight duration be beneficial to you compared with your current flight system?
2. The helium valve being developed will be easy to attach to the industry standard Kaymont latex weather balloons. All mechanics and electronics will be unobtrusive, light weight, and rugged. How important is ease of use for a system such as this, and what concerns would your team have about integrating a valve such as this into your existing flight system?
3. Our design will allow for fully autonomous operation or manual control using your existing flight communications system (or both) to reach the desired altitude. Would your team prefer one mode over the other?
4. Wireless communication is used to communicate between the valve assembly and the main command and control payload. This avoids having to run external cabling which can become tangled or damaged during flight. If wireless communication could also be extended to your other payload electronics to facilitate wireless communication would you be interested in such a feature? Do you have any concerns about the use of wireless communication?
5. Are there any other features your team would like to see incorporated into this product? If so what features?

The interviewees consisted of Berk Knighton, Randy Larimer, Angela Des Jardins, and Jen Fowler. They provided feedback for how the product could be improved and features they would like to see incorporated. This diverse group of potential clients includes educators, product engineers, and field scientists. Through their unique perspectives we can determine if our plan is converging with a perceived need that is currently underserved in the market we hope to enter.

Dr. Des Jardins' Response:

1. "I can think of several experiments that would benefit from a longer exposure to the space-like environment as well as benefit from more time to collect data. Also, a longer flight affords more control for landing in a preferred area."
2. "Ease of use and reliability are certainly key. At this time, we simply tie the balloon closed and let it burst, so adding a complicating factor would be a big step for us. If instructions and information are very clear, I would feel more confident about using the valve. Other concerns for integrating: we don't have a method for cutting down our balloon – we just let it pop. We would need some reliable way of terminating the flight at the time we wanted if we were to have a valve. Also, we currently do basic flight predictions with an on-line program that does not have extended flight time available. I would need help in finding out how to predict how long to let the balloon float at what altitude, how long to vent the balloon to get there, and in how to know when I should terminate the flight. Finally, we are thinking about making the transition to hydrogen because it is so much less expensive. You mention that this is a helium valve. I would want to make sure it would be okay for me to use this valve using hydrogen as a lifting gas."
3. "It seems to me that the only autonomous part of our current flights is that the balloon will pop. Without that, it seems like each flight is so different, I can't imagine how an autonomous flight would work. That being said, in order to use manual control, I'd need

lessons on how to know how much to vent and when to get my desired float time and altitude. Also, in order to use manual control, I'd have to have some way of communicating with the valve, right? We don't currently have any capability for sending commands, so we'd need that additional piece (and complication) to our set up."

4. "Reducing tangling sounds great. We don't currently have any communication going between payloads (as mentioned above) – we just store the data and retrieve it – but if we did have that capability, I could see it being useful."
5. "I already mentioned the most important features that might be incorporated – a termination mechanism, communication to the payloads, and flight predictions. Can't think of any others right now."

Randy Larimer's Response:

1. "Yes a cost effective solution to spend more time in a radiation filled environment would be beneficial for testing redundant computing systems. Since the cost is reasonable more flights could be conducted compared to sounding rockets or larger NASA balloon flights."
2. "A simple to use system would be beneficial since my team has limited ballooning experience. Can the balloon be filled easily as helium is expensive if we mess up? Is it easy to tell when the system is powered on and working from a distance? We do not want to fiddle with the system."
3. "Fully autonomous would allow my team to set the altitude and forget it, focusing on our real time data at float altitude. I guess having a backup manual mode would be good if things go bad during the flight. What commands and how do I send them to the valve would be a concern. Is there a format for the commands that I must follow?"

4. "Wireless communication between multiple payloads would be great! What command format would I use to send and receive data on this wireless link? Will the wireless link interfere with any of my other wireless products such as GPS or iridium communication? Will it function next to a noisy GoPro camera or other high speed devices? How many hours of service can I expect from this wireless link? Will it last the entire time?"
5. "Some type of test feature to determine that the wireless communication is working between payloads...LED's or audio? Some type of addressing for multiple payloads so I know who I am talking to? Cut down or easy fill options would be great!"

Dr. Knighton's Response:

1. "I can see some potential applications for such a device. Since we are in the business of flying radiosondes on routine basis, several hundred a year, it seems unlikely that we would find use in our standard application where we are simply interested in collecting vertical profile data. Severe weather events are times when extended flight times at a specified altitude are desirable and we would definitely find your system useful for this application. "
2. "It's got to be easy to use and robust. Even though we launch often, our group doesn't allocate much time to the process. Because we see this as a special application we are willing to tolerate a bit more fiddling, but we are certainly interested in a device that interfaces well with our existing equipment."
3. "Autonomous operation for sure. We will know ahead of time what altitude level we will want to study. Our data retrieval system is totally automated and so not having to have a dedicated operator is very important."
4. "Sounds great for academic ballooning programs, but we don't have any need for communication between our measurement payload and the valve."

5. "Since we do not anticipate recovering the system cost is critical as is ease of use. Setting the altitude and powering the system needs to be easy. System status lights for power, GPS lock and altitude set point acknowledgement are important features so that we know that it is ready to fly. The ability to be able set the altitude manually or through a smart phone will be helpful. We don't want to have to use a computer to initialize the valve system."

General trends in the responses of our interviewees will be covered in the Converge Plan section.

Convergence Plan:

To build a convergence plan it is important for our team to take into account the feedback received during our interview process (with potential customers) to determine if any changes need to be made to our final design. This ensures that we are correctly gauging the needs of the intended market and that we are providing a product that serves to resolve a need which (we feel) is currently lacking in this market space. Incorporating this feedback also shows that our engineering team is aware of the importance of our client's needs which will help build loyalty between our design team and our clients.

The response from all interviewees was generally positive on all fronts and confirms that our product fits into a very niche market. In the following paragraphs the feedback will be evaluated for each interview question and how that feedback will help us converge our engineering plan towards a completed product.

The first interview question was to gauge overall interest in our overall product from several different perspectives, including academia, meteorology, and engineering. The overall response was positive in confirming that a device such as ours would be accepted and desired. Dr. Des Jardins suggests that the currently available flight prediction software in this sector cannot predict landing zones when the balloon floats/hovers during the flight. As landing prediction is a

major component of traditional weather balloon flights we may need to develop our own flight prediction software which can handle our flight profile or find products on the market which have this capability already. Dr. Knighton indicated that he did not see a need in the market for vertical profile radiosondes, however he noted that scientists studying extreme weather would be interested. The potential academic clients were interested in how our product could allow for more advanced, long duration flights for student experiments. Mr. Larimer also mentioned several engineering specific use cases which could benefit from our system such as radiation tolerant computing. From this feedback we note that in general our plan converges with the client's interest in the capabilities it provides to their work. No changes would be required based on this section, however the new areas of interest mentioned by our interviewees may indicate that we have not fully investigated all of the potential uses for our product. It will be important for us to continue conducting market research to find other niche applications for the helium vent.

The second interview question attempts to determine if our proposed design will be easy to use and durable in the eyes of our potential clients. The question also opens the door for any concerns the interviewees have about integrating the valve into their current system. The overall response indicated that there was a slight hesitance to add additional complexity to existing systems. Another common theme was that the system had to be as easy to use as possible to ensure the device is actually used and to prevent errors. This does converge with several of our stated design choices, including reducing external wiring by using wireless data transmission, integrating a fill nozzle into the valve, and designing towards compatibility the industry standard latex balloon. This also indicates that our team needs to potentially spend additional time on the documentation and software design to ensure it is easy to use and configure our product. Finally, Dr. Des Jardins inquired about our system being compatible with hydrogen gas. The industry may start to move towards hydrogen gas as a buoyant gas since helium's price is highly dependent on oil production. As hydrogen is explosive while helium is not this would present an additional engineering challenge

and likely also change the procedures for using the valve. While we will likely not change our design plan to accommodate hydrogen at this phase, it will be very important for us to continue to watch the market for helium to ensure our product is viable for the future. Our team must also ensure that sufficient warning is provided to the clients to avoid using hydrogen gas with our product.

The third question is meant to determine how involved the end user will be in the operation and control of the valve. Our team is currently planning to have two main modes: autonomous and fully manual. The autonomous mode attempts to reach a preselected altitude with no input from the user other than initially inputting the altitude. Manual mode would turn off any automatic control functions and would rely on the end user having a method to control the valve midflight, such as another microcontroller or satellite uplink. The feedback received from our interview sessions overwhelmingly suggests that autonomous mode will be the stand out, and preferred, mode of operation. This suggests that we need to invest a significant portion of our development into the code performing the autonomous decisions. We will also need to focus on very thoroughly documenting the proper use of this mode as some clients were apprehensive about how complicated this process may be. There was some interest in the manual control mode but mainly for contingency reasons. A standard protocol document which explains how the end user will interface with and control the valve in manual mode will need to be thorough in scope. The feedback received from these interviews suggests that our current engineering plan will converge with the needs of our clients.

The fourth question asked of our interview panel was used to determine if the wireless communication that we plan to implement would be a useful feature to the clients. Specifically we currently plan to use wireless communication between the valve mechanism and the main control system microcomputer which resides in a command payload below the valve (approximately 20 feet away). An additional feature our engineering team is planning on implementing is a general

wireless communication spec which would allow the clients to send data between payloads. This would rely on wireless expansion modules that we would package in with our product. The majority of those interviewed felt the wireless communication with the valve is a great idea that they would like to see implemented. The wireless expansion modules sparked interest for those in academic settings. As with most of our features, the interviewees wanted to know exactly how these modules would work and how they would implement them into their current systems. This suggests again (as a common theme) that we must have very thorough documentation which describes the details required for using these more advanced features. Dr. Knighton suggests that the radiosonde community would not see as much value in wireless communication. Our team will need to determine if this suggests we need to explain the virtues of the wireless capabilities with these groups more thoroughly, or if we need to market the other features of the valve to this specific market (radiosonde meteorological community). The feedback received suggests that our current engineering plan for this feature will converge with the requirements of our academia clients, and our overall system will still be beneficial to the meteorological community.

The fifth and final question was open ended in an attempt to gather any other general feedback the potential clients had to offer. The common themes mentioned were ease of use, confirmation of proper operation, and low cost. Ease of use has been a common theme throughout our interviews which again suggests our documentation needs to be thorough. The overall system must also have features to indicate proper operation and status. LED status indicators were mentioned several times as a way to confirm operation. This was not previously something the engineering team considered so we must implement this feature to converge our plan with our client's needs. Dr. Knighton mentioned cost as a main metric by which our system would be evaluated to the meteorological community. Referencing his suggestions to question four, this may suggest that a second model of our valve could be developed with cost as main design factor. Removing extra features such as wireless communication may result in an inexpensive product

which is more desirable to that community. If we implement these suggested features our plan will converge on a product which our clients would be interested in using.

Contingency Plan:

There is some chance that our design choices will not work. In order to minimize the impact on the end product it is necessary to make a contingency plan. Two potentially problematic design choices are the valve design (it may not allow for the necessary amount of air flow), and the selected microcontroller configuration (it might not interface as well as we would like or it might consume too much power during operation).

If the microcontroller configuration selected does not work for various reasons the contingency plan is to use the next design alternative that scored the next highest in the decision matrix. If it is required we could select a low power, less powerful micro-controller for our design. Also a more commonly used microcontroller could be selected, one that has been previously used with a radio module for something similar to this application and has example code available.

There is a question as to whether or not the gate valve will have a high enough flow rate to provide the user with neutral buoyancy within the specified vent time window. The gate valve currently utilizes approximately 45% of the flow area available within the geometry of the flow tube. If the flow rate ends up being inadequate, the butterfly style valve will be used. This valve will allow an estimated 75% of the effective flow area provided by the inner geometry of the flow tube.

System Architecture

Introduction:

This Report will detail the system Architecture for the Weather Balloon Altitude Control Project. The report will first explain in detail the system architecture plan for the project, covering the major interfaces, their position in the assembly, and their function. This includes The flow tube, the gate valve, the nozzle of the balloon, the main payload microcontroller, and the valve servo. This section will be divided into mechanical and electrical groups to clarify the nature of each system and its respective interfaces. The next section will cover the system interfaces together in a block diagram. This representation will provide better insight into the different sections, and how they interface. The next section will detail the sub-system interfaces. This includes the valve controller, any third party communication payload, and the commands uploaded by the user during flight. For this project, these are entirely electrical, and are explained below in more detail. Finally, the report will cover the user interface for this project. this will include any setup, handling or operational interfaces the user may encounter while using this system. For this project, user interface includes attaching the balloon to the valve, filling the balloon through the valve using the fill station, attaching the payload to the bottom of the valve, programming the microcontroller, and interfacing the user's existing communications payload to the valve controller.

System Architecture Plan:

Mechanical:

The mechanical portion of the valve project will have 3 interface connections. The first will be an interface with the Helium fill station nozzle. This nozzle, when connected, will press a limit switch connected to the microcontroller. this controller, after reading the switch as being pressed, will activate the servo, and open the gate of the valve. this will allow for Helium to pass through the

tube of the valve into the balloon, which is the second interface. The flow tube of the valve has been sized such that the nozzle of the balloon will fit over it snugly. The retention ring (a raised portion on the balloon end of the valve tube) causes the latex of the balloon nozzle to stretch, ensuring a gas tight seal between the valve and the balloon nozzle. The third interface on the valve project is the interface between the servo and the microcontroller. This allows the microcontroller to open or close the valve when its logic is instructed to do so.

- Interface between the bottom of the valve and the Helium fill nozzle
- Interface between the top of the valve and the balloon nozzle
- Interface between the valve gate servo motor and the microcontroller

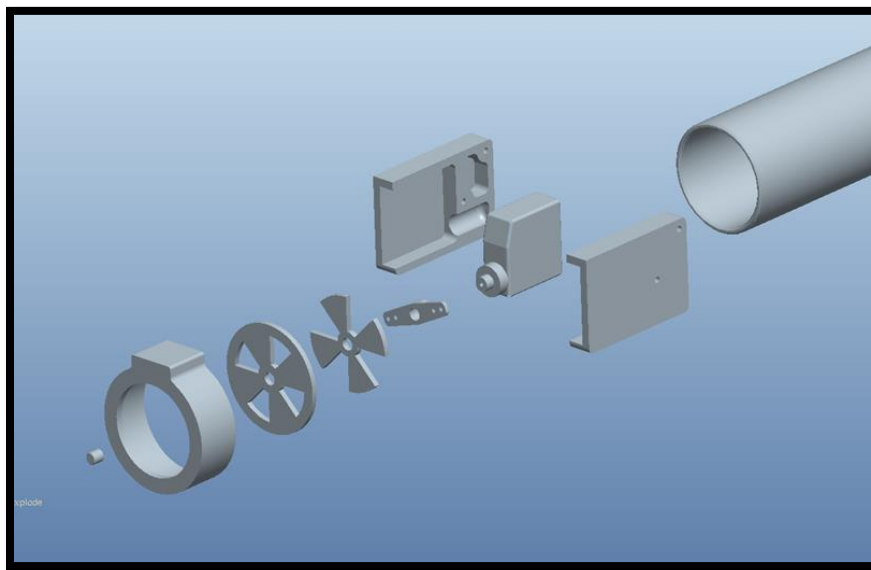


Figure 1: Exploded CAD model of the Valve geometry

Electrical:

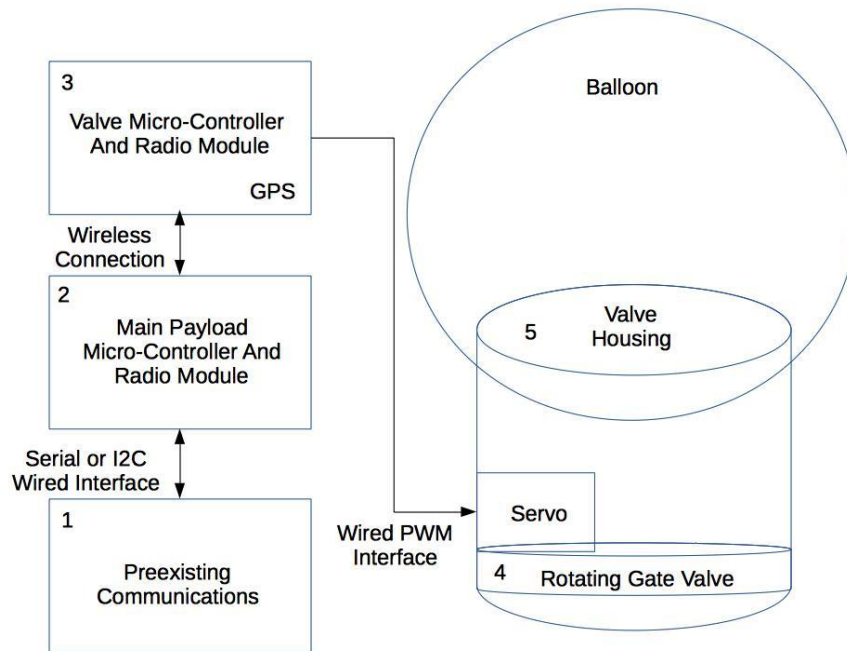
The electrical portion of this project will consist of interfaces between electrical components, mechanical components, and the user. The first interface will be the interface between the customer's communications system and the microcontroller in the main payload. This interface will have user-selectable options: serial, I2C, and or some digital control lines. The user

will be able to send commands and receive data via these this interface. The next interface is the interface between the main payload micro-controller and the micro-controller on the valve. This interface is going to be a wireless connection. This is achieved with a radio module controlled by a micro-controller. Next the valve microcontroller interfaces to the servo that controls the valve gate with a pulse width modulated signal. The user will interface with the microcontrollers by connecting the microcontroller to a computer via USB cable and uploading their desired code.

- Interface between the user's communication system and the main payload micro-controller
- Interface between the main pay load and the valve micro-controller
- Interface between valve micro-controller and the valve servo
- Interface between the user and the microcontrollers

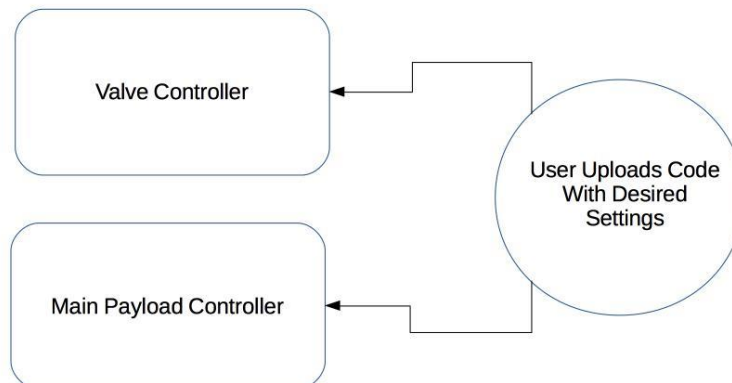
System Interfaces:

The following figure shows the different components of the system and how they interface together.

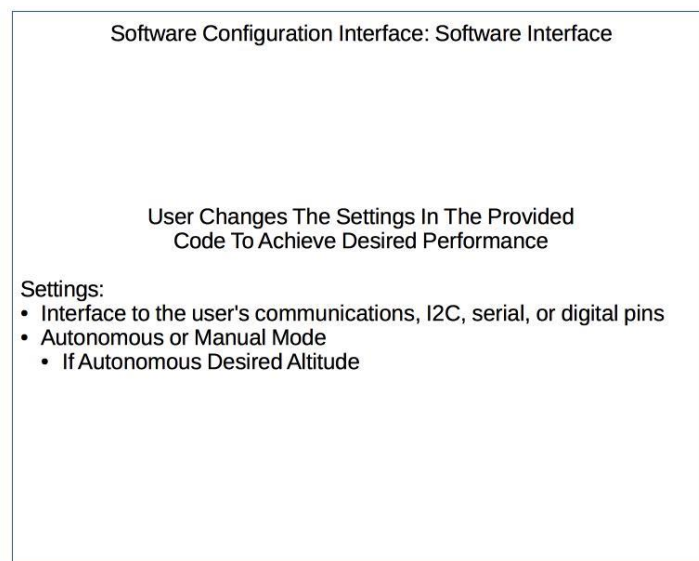


Sub-System Interfaces:

Software Configuration Interface: Physical Interface

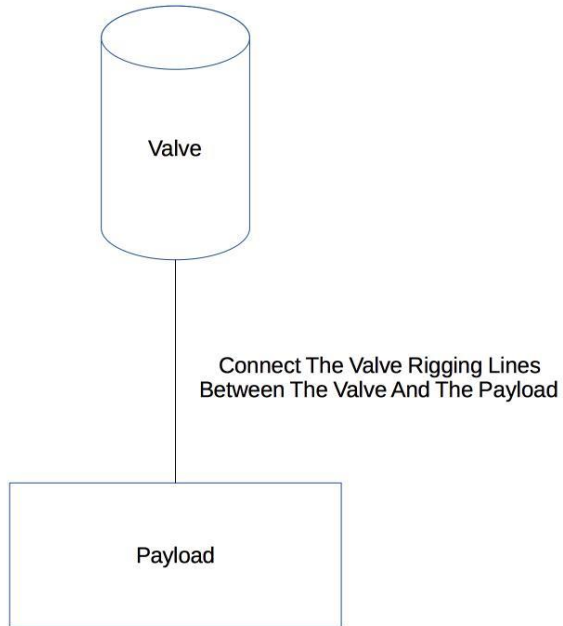


Software configuration interface: physical interface - The physical interface of the software configuration interface describes the electrical connection of the programming cable with the main payload controller. The user must plug a USB cable into their computer and connect the other end with the main payload microcontroller, and then with the valve microcontroller. A label or graphic will guide the user to the correct location for the programming cable. Then the settings outlined in the user manual will be changed by the user according to their preference.



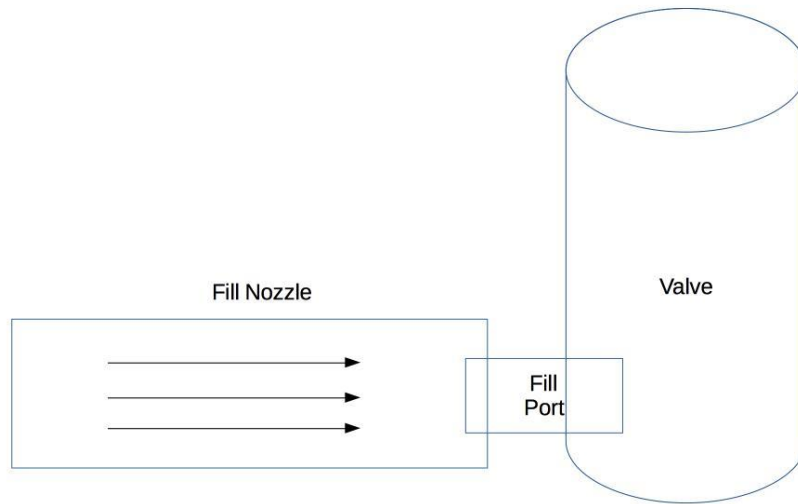
Software configuration interface: software interface - The software configuration interface is used to program the main payload and valve controllers with the settings selected by the user. This interface consists of a graphical user interface running on the customer-provided computer and any setup or installation required to get the software running. The user must interact with the software to select their desired settings.

Mechanical Interface - Connecting Rigging Lines To The Valve And Main Payload



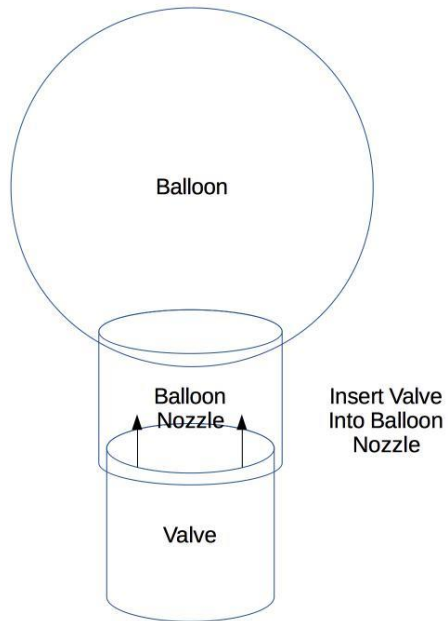
Mechanical interface: connecting rigging lines to the valve and main payload - The mechanical interface between the valve and main payload requires the user to physically couple their payload to the helium valve hardware. The rigging lines used will be provided by the customer however our product will provide hard mounting points to securely attach these lines to the valve.

Mechanical Interface - Attaching Helium Fill Nozzle To The Valve Fill Port



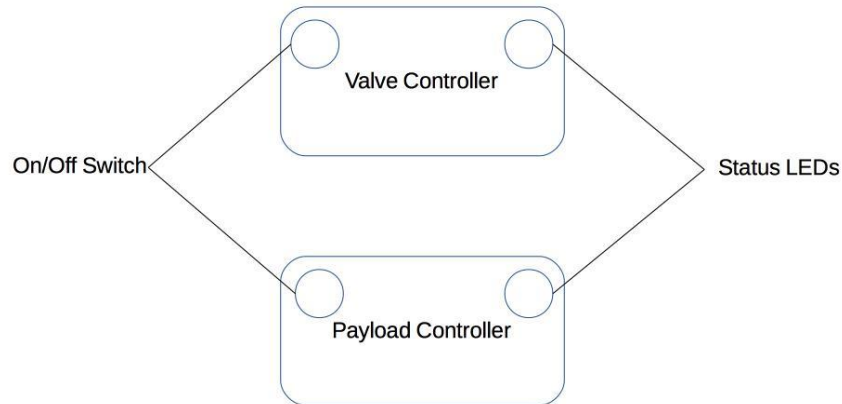
Mechanical interface: attaching helium fill nozzle to the valve fill port - The mechanical interface between the fill nozzle and fill port requires the user to physically connect a fill nozzle from their helium tank and regulator to the fill port of the valve assembly. The user must then operate their helium filling equipment to fill the latex weather balloon as needed.

Mechanical Interface - Inserting Valve Hardware Into Latex Weather Balloon



Mechanical interface: inserting valve hardware into latex weather balloon - The mechanical interface between the customer's latex weather balloon and the valve assembly requires the user to mechanically insert the valve sub-assembly into the balloon nozzle. Once the valve has been inserted to a reference mark the customer must secure the valve to the balloon using zip-ties or other similar means.

Mechanical Interface - Turning On The Valve Electronics And Verifying Status



Mechanical interface: turning on the valve electronics and verifying status - The valve electronics require a mechanical interface between the user and the product activation switches. The user must physically actuate the power switch to turn on the valve electronics. Once the electronics have powered up the user must verify proper operation using status LEDs located on the valve hardware.

User Interfaces:

The user interfaces for the balloon valve system consist of two main components: the mechanical assembly and construction of the valve with the balloon, and the electrical connections and configurations required to operate and program the system. This section will describe the human factors required for proper operation of both components. This will include any part of the valve system which a human must touch or interact with to properly operation our product.

The first main component of the user interface will be those related to the mechanical and physical valve assemblies. First the valve housing assembly user interface will be detailed (which connects to the latex weather balloon), then the main payload subsystem interface (which is used to interface with the customer's tracking system) will be detailed.

The valve housing assembly will likely have the most human contact over all other systems in our product. The valve housing assembly has three main sub-interfaces: connection of the latex weather balloon to the valve, attaching or detaching the helium fill nozzle, and turning the system on and verifying operation.

Attaching the latex weather balloon will be a critical step requiring the user to physically insert the valve into the balloon nozzle. As we are designing the valve hardware to fit within a standard Kaymont weather balloon this operation should not require heavy exertion by the user. The user must hold the latex weather balloon nozzle in one hand, and guide the valve assembly into the balloon nozzle with the other hand. Once the valve is inserted far enough into the latex balloon (indicated by a reference mark) they will need to secure the balloon to the valve using zip-ties to ensure the balloon does not slip off during use. The user must then physically couple their main payload to the valve using their own rigging materials. The valve will provide hard mounting points which the user may use to affix nylon rope (or similar) as required.

The second mechanical interface will be between the helium fill nozzle and the valve (which has already been inserted into the latex balloon). This consists of attaching a helium fill tank (which the user must supply and know how to operate) to the valve such that the balloon may be inflated. As the valve itself starts in the closed position the user will be able to fill the latex balloon with the valve assembly already assembled. Our product will supply a fill nozzle or adapter which will connect to the customer's helium tank using industry standard hardware. The user must physically couple the helium fill tube (connected to their helium tank and regulator) to the valve assembly and

ensure it is connected securely before turning on the helium flow through the regulator. Once the balloon has been filled to customer specifications the user will then need to decouple the helium fill tube from the valve assembly.

The third and final mechanical interface will be turning on the system and verifying it is operational. Both the main payload controller and the valve assembly will have electronics which must be activated prior to use. The product will have a switch or other method used to turn on each device and status LEDs which indicate proper operation. Activating the system will require that the user manipulates the activation mechanism and also observes the status LEDs which appear.

The electrical connections and software configurations are the other primary interface with our product. These components will be used to configure the microcontroller for proper operation and ensure the customer's systems can properly communicate data with our product.

The electrical connection is the physical coupling of the main payload controller with the client's tracking and communication system. The main payload controller will contain data ports or screw terminals which the user must electrically connect to their system (if this functionality is to be used by the client). This may involve the user providing their own cables and tools (such as screwdrivers) to mechanically couple these devices. A protocol datasheet will be provided with the product which will describe how the user must communicate (through their tracking and communication system) with our product. The user must be able to interpret this protocol and configure their own equipment as needed for this data link.

The second electrical and configuration user interface will be the software graphical user interface used to configure the product to the user's requirements, in this case the Arduino programming IDE and the Xbee configuration software, XCTU. This software must be executed on the user's computer by downloading it from a location we specify. The software will provide meaningful labels or instructions guiding them through the process of configuring the valve

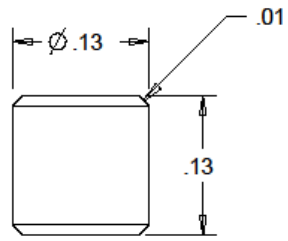
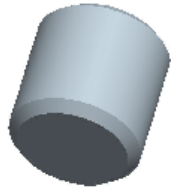
electronics. The user will select or enter various settings into the software according to their needs, such as manual or autonomous mode and the desired float altitude. Once all settings have been entered the user will connect a USB cable to their computer (which is provided with the valve system) and the other end of the cable into the main payload controller. This will start the software programming of the user selected configurations onto the microcontroller of the main payload controller. Labels or other indicators will be present on the main payload controller which will help the user select the correct port to plug the programming cable into. A graphical alert will instruct the user when the programming process is complete, after which they may unplug the programming cable. Status LEDs will provide some low level indication of configuration and operating status.

Detailed Design

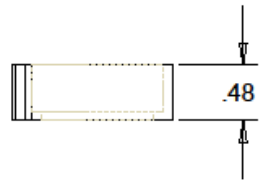
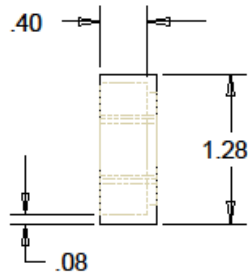
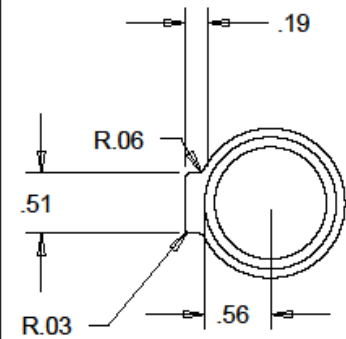
Introduction:

This section outlines the materials required for this design and their specifications. This product can be divided into two sections, the mechanical or valve section and the electrical or controller section. The valve section will require numerous custom and off the shelf pieces of hardware to produce. The electrical section requires microcontrollers, a GPS unit, various circuit elements, and two custom made printed circuit boards. There are some possible production issues that need to be kept in mind when designing and getting ready to produce this product, such as a shortage of the items required to build this product. A potential customer will want to know how the product will perform and what its expected lifetime is, for instance the fact that this product is designed to for one use, but could potentially last much longer should the consumer choose to retrieve and reuse it.

Layout Drawings:



TOLERANCE: $\pm .001$ MATERIAL: STEEL MEASUREMENTS: INCH	MSU MECH. ENG. DEPT>		
	PIN		
10/25/14	A	PART: 1	Drawing 1
TIM BASTA	SCALE: 10:1		



TOLERANCE:
±.001
MATERIAL:
POLYCARBONATE
MEASUREMENTS:
INCH

MSU MECH. ENG. DEPT>

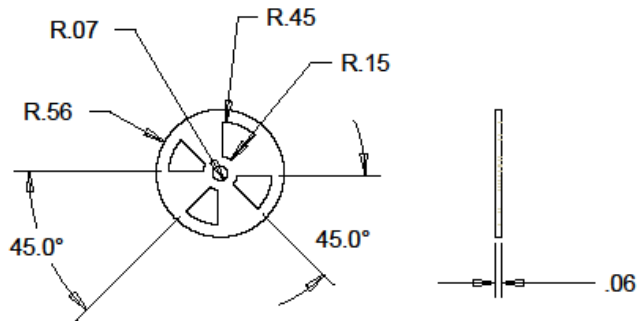
GATE CAP

10/25/14

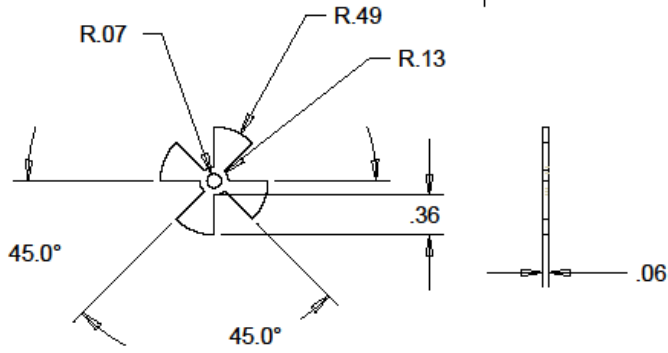
A	PART: 2	Drawing 2	
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TIM BASTA

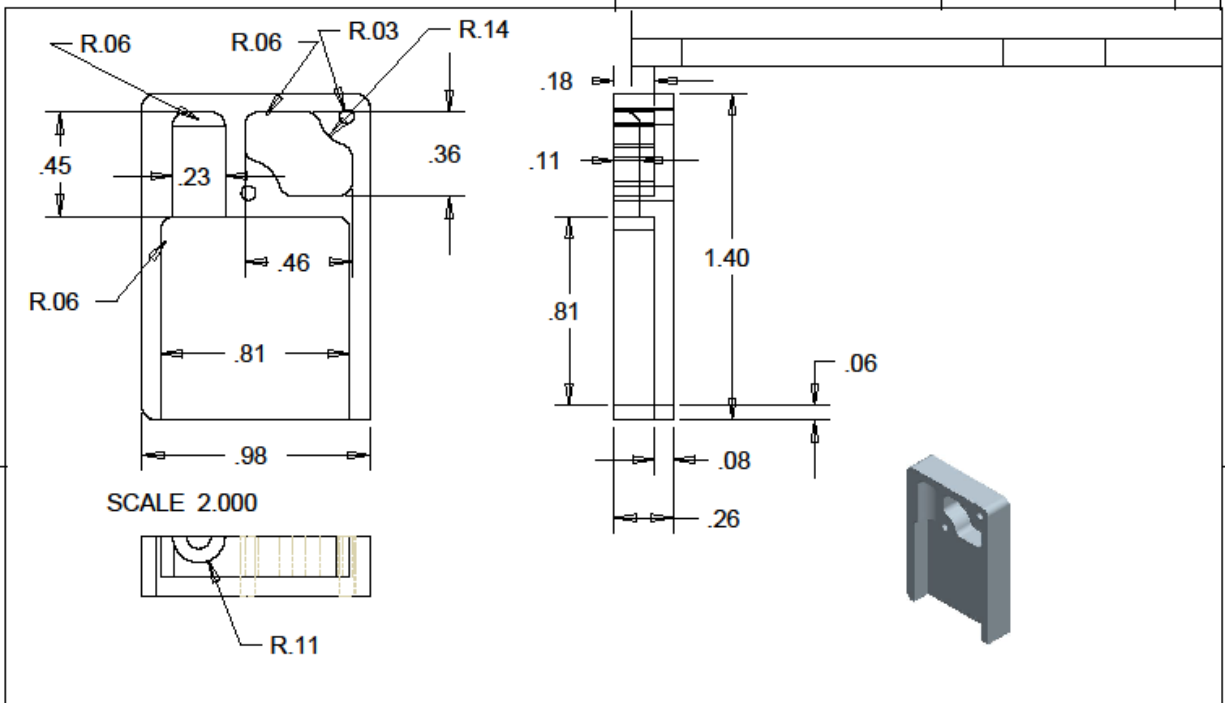
SCALE: 1:1



TOLERANCE: $\pm .001$ MATERIAL: POLYCARBONATE MEASUREMENTS: INCH	MSU MECH. ENG. DEPT>		
	GATE VALVE OUTER		
10/25/14	A	PART: 3	Drawing 3
TIM BASTA	SCALE: 1:1		



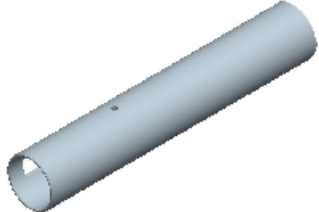
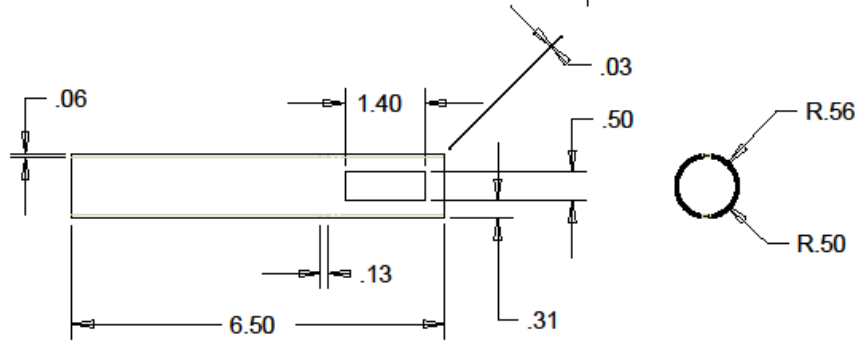
TOLERANCE: $\pm .001$ MATERIAL: POLYCARBONATE MEASUREMENTS: INCH	MSU MECH. ENG. DEPT>		
	GATE VALVE INNER		
10/25/14	A	PART: 4	Drawing 4
TIM BASTA	SCALE: 1:1		



SCALE 2.000

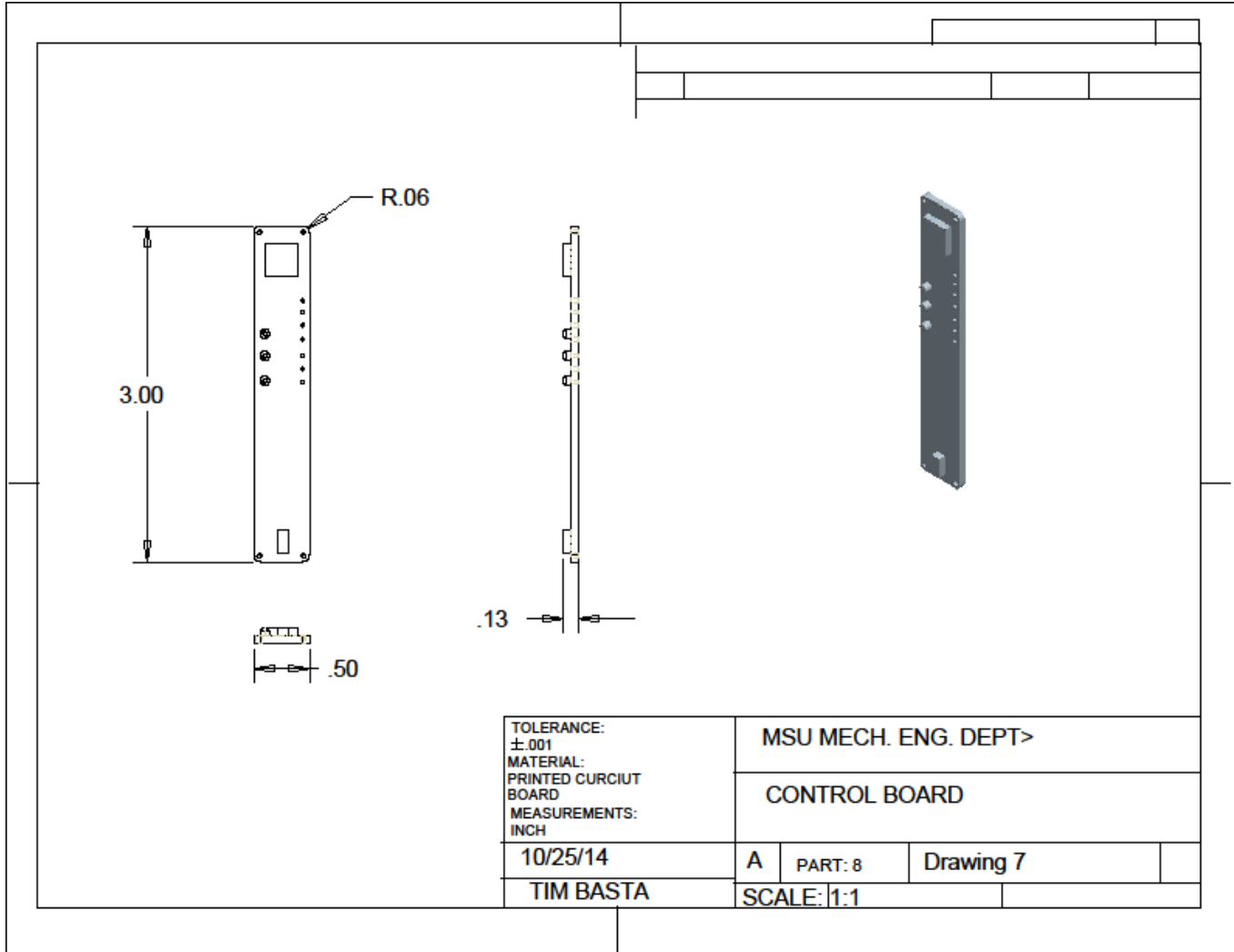
NOTE:
RIGHT AND LEFT HALVES HAVE IDENTICAL
DIMENSIONS, BUT MIRRORED GEOMETRY

TOLERANCE: ±.001 MATERIAL: POLYCARBONATE MEASUREMENTS: INCH	MSU MECH. ENG. DEPT>		
	SERVO CASE, RIGHT AND LEFT		
10/25/14	A	PART: 5, 6	Drawing 5
TIM BASTA	SCALE: 1:1		

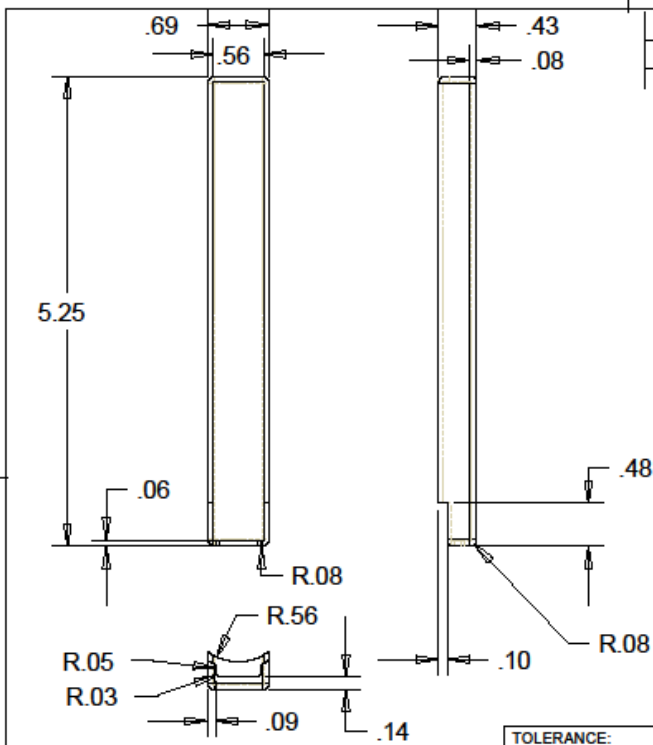


SCALE 0.500

TOLERANCE: $\pm .001$ MATERIAL: POLYCARBONATE MEASUREMENTS: INCH	MSU MECH. ENG. DEPT>		
	MAIN TUBE		
10/25/14	A	PART: 7	Drawing 6
TIM BASTA	SCALE: 1:2		



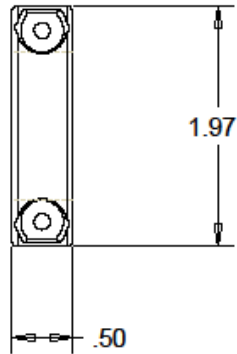
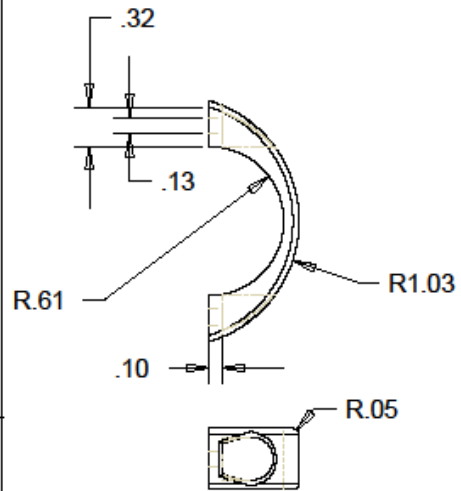
TOLERANCE: $\pm .001$ MATERIAL: PRINTED CURCIUT BOARD MEASUREMENTS: INCH	MSU MECH. ENG. DEPT>		
	CONTROL BOARD		
10/25/14	A	PART: 8	Drawing 7
TIM BASTA	SCALE: 1:1		



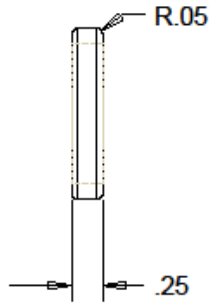
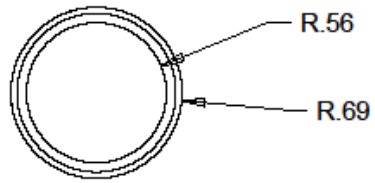
SCALE 0.750

SCALE 0.750

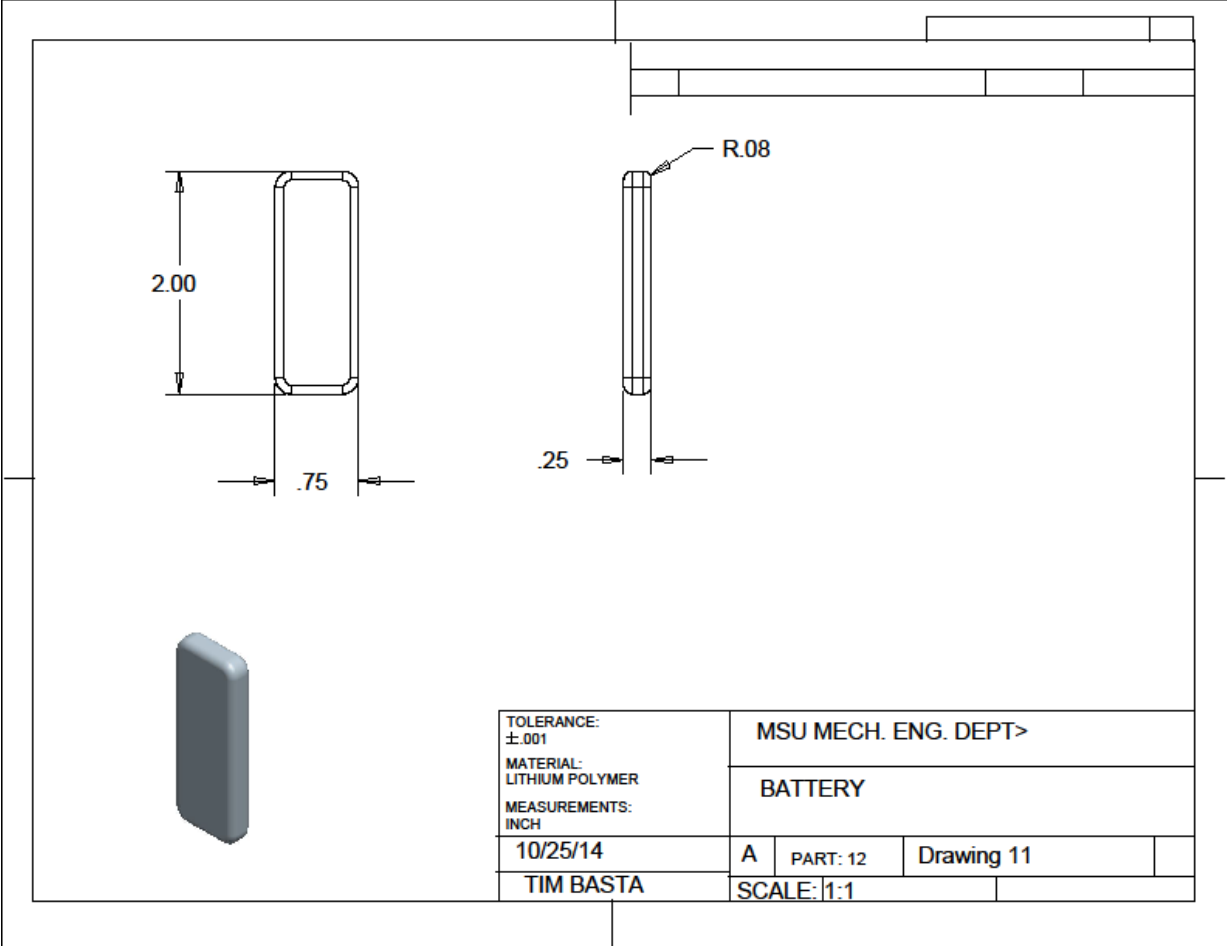
TOLERANCE: ±.001	MSU MECH. ENG. DEPT>		
MATERIAL: POLYCARBONATE	VALVE CAP		
MEASUREMENTS: INCH	10/25/14	A	PART: 9
TIM BASTA	SCALE: 1:1		Drawing 8

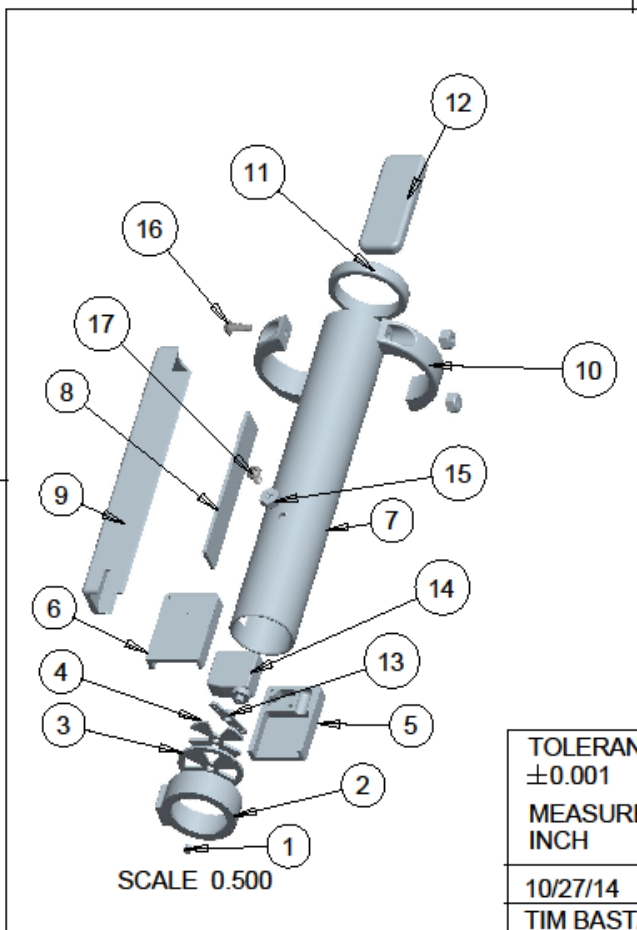


TOLERANCE: $\pm .001$ MATERIAL: POLYCARBONATE MEASUREMENTS: INCH	MSU MECH. ENG. DEPT>		
	NOZZLE CLAMP		
10/25/14	A	PART: 10	Drawing 9
TIM BASTA	SCALE: 1:1		



TOLERANCE: $\pm .001$ MATERIAL: POLYCARBONATE MEASUREMENTS: INCH	MSU MECH. ENG. DEPT>		
	RETENTION RING		
10/25/14	A	PART: 11	Drawing 10
TIM BASTA	SCALE: 1:1		





#	Description	Qty.
1	Alignment Pin	1
2	Gate Cap	1
3	Gate Outer	1
4	Gate Inner	1
5	Servo case Left	1
6	Servo case Right	1
7	Main Tube	1
8	Control Board	1
9	Valve Case	1
10	Nozzle Clamp	2
11	Retention Ring	1
12	Battery	1
13	Servo Horn	1
14	Sub-Micro servo	1
15	6-32 Nylock Nut	4
16	6-32 x 3/8" Machine Screw	2
17	6-32 x 1/4" Machine Screw	2

TOLERANCE: ±0.001 MEASUREMENTS: INCH	MSU MECH. ENG. DEPT.		
	VALVE ASSEMBLY, B.O.M.		
10/27/14	A	PARTS: 1-17	DRAWING 10
TIM BASTA	SCALE 1:2		

Bill of Materials

#	Description	Qty.
1	Alginment Pin	1
2	Gate Cap	1
3	Gate Outer	1
4	Gate Inner	1
5	Servo Case Left	1
6	Servo Case Right	1
7	Main Tube	1
8	Control Board	1
9	Valve Case	1
10	Nozzle Clamp	2
11	Retention Ring	1
12	Battery	1
13	Servo Horn	1
14	Sub-Micro Servo	1
15	6-32 Nylock Nut	4
16	6-32 x 3/8" Machine Screw	2
17	6-32 x 1/4" Machine Screw	2
18	Main Payload Micro-Controller (ATmega328)	1
19	Valve Micro-Controller (ATmega328)	1
20	GPS MTK3339	1

21	Miscellaneous discrete electronics parts (to be determined)	NA
22	Xbee Radio Modules (XB24CZ7RIS-004)	2

Purchased Component Specifications		
#	Description	Qty.
13	Servo Horn	1
14	Sub-Micro servo	1
15	6-32 Nylock Nut	4
16	6-32 x 3/8" Machine Screw	2
17	6-32 x 1/4" Machine Screw	2
18/19	Micro-Controller - ATmega328	2
20	GPS Unit - MTK3339	1
21	Electronic Components TBD	NA

Specifications -

GPS Unit - MTK3339

- -165 dBm sensitivity, 10 Hz updates, 66 channels
- Ultra low power usage: 20mA current draw while tracking
- 3.3V operation,
- RTC battery-compatible
- Built-in datalogging
- PPS output on fix
- We have received reports that it works up to ~32Km altitude (the GPS theoretically does not have a limit until 40Km)
- Internal patch antenna + connection for optional external active antenna
- Fix status output
- Ultra small size: only 16mm x 16mm x 5mm and 4 grams

Micro-Controller -ATmega328

- 16 MHz
- Arduino compatible
- I2C
- SPI
- UART

Xbee Radio Modules (XB24CZ7RIS-004)

- 60m Indoor/Urban Range
- 1200m Outdoor/RF Line-of-Sight Range
- Transmit Power - 3.1 mW (+5 dBm) / 6.3 mW (+8 dBm) boost mode
- Receiver Sensitivity (1% PER) - 100 dBm / -102 dBm boost mode
- Data Rate - RF 250 Kbps, Serial up to 1 Mbps
- Configuration Method - API or AT commands, local or over-the-air
- Serial Data Interface - UART, SPI
- Frequency Band - ISM 2.4 GHz
- Dimensions (L x W) and Weight - 0.87 in x 1.33 in x 0.12 in (2.20 cm x 3.40 cm x 0.30 cm);
1.40 oz (40.00g)

Printed Circuit Boards

- Two Printed Circuit Boards:
 - One to accommodate the main payload controller
 - One to accommodate the valve controller and a GPS unit

- Designed with a minimal footprint
- F Antennas for the IEEE 802.15.4 radios will be designed into the printed circuit board

Detailed Design:



Valve Assembly, 10/27/14

Flowrate Calculations For Large Valve with 2000 g. Balloon

Neutral Buoyancy:

$$W_{\text{Balloon}} = W_{\text{AirDisp}}$$

$$W_{\text{Balloon}} = W_{\text{He}} + W_{\text{Latex}} + W_{\text{Payload}}$$

$$W_{\text{Latex}} = 2 \text{ kg}$$

$$W_{\text{Payload}} = 5.44 \text{ kg}$$

$$\text{Lift} = 1.1 \text{ kg}$$

$$\rho_{\text{AirBaseMan}} = 1.025 \frac{\text{kg}}{\text{m}^3}$$

$$\rho_{\text{HeBaseMan}} = 0.1418 \frac{\text{kg}}{\text{m}^3}$$

$$\rho_{\text{Air84000ft}} = 0.364 \frac{\text{kg}}{\text{m}^3}$$

$$\rho_{\text{He84000ft}} = 0.05 \frac{\text{kg}}{\text{m}^3}$$

$$V_{\text{dispBaseMan}} = \frac{(W_{\text{Latex}} + W_{\text{Payload}})}{(\rho_{\text{AirBaseMan}} - \rho_{\text{He84000ft}})} = 7.294 \text{ m}^3$$

Volume displaced at 84000 ft with lift:

$$V_{\text{disp84000ftWL}} = \frac{(W_{\text{Latex}} + W_{\text{Payload}} + \text{Lift})}{(\rho_{\text{Air84000ft}} - \rho_{\text{He84000ft}})} = 271.975 \text{ m}^3$$

$$V_{\text{burst}} = \left(\frac{35 \cdot ft}{2}\right)^3 \cdot \pi \cdot \left(\frac{4}{3}\right) = 635.693 \text{ m}^3$$

$$\frac{1000 \text{ ft}}{\text{min}} = 5.08 \frac{\text{m}}{\text{s}}$$

$$12 \text{ lb} = 5.443 \text{ kg}$$

$$3 \text{ lb} = 1.361 \text{ kg}$$

Non-Commercial Use Only

Volume displaced at 84000 ft without lift:

$$V_{\text{disp84000ft}} = \frac{(W_{\text{Latex}} + W_{\text{Payload}})}{(\rho_{\text{Air84000ft}} - \rho_{\text{He84000ft}})} = 236.943 \text{ m}^3$$

Change in Volume at 84000 ft necessary to achieve neutral buoyancy

$$\Delta V = V_{\text{disp84000ftWL}} - V_{\text{disp84000ft}} = 35.032 \text{ m}^3$$

Flowrate:

$$Q = \frac{\Delta V}{600 \cdot s} = 0.058 \frac{\text{m}^3}{\text{s}}$$

$$Q = C_f \cdot A_0 \cdot \sqrt{(2 \cdot \Delta P) \cdot \rho_{\text{He84000ft}}}$$

$$A_0 = .000444 \cdot \text{m}^2$$

- .1
- .12
- .125
- .3
- .4
- .5
- .6
- .7
- .8
- .9

$C_f =$

$$\Delta P = \frac{\left(\frac{Q}{C_f \cdot A_0}\right)^2 \cdot \rho_{\text{He84000ft}}}{2} = Pa$$

- [4.323 · 10³]
- [3.002 · 10³]
- [2.767 · 10³]
- 480.347
- 270.195
- 172.925
- 120.087
- 88.227
- 67.549
- [53.372]

$\Delta P =$

- [0.627]
- [0.435]
- [0.401]
- [0.07]
- [0.039]
- [0.025]
- [0.017]
- [0.013]
- [0.01]
- [0.008]

psi

Non-Commercial Use Only

$$P_1 := 2549 \cdot \frac{N}{m^2} + \Delta P = \begin{bmatrix} 6.872 \cdot 10^3 \\ 5.551 \cdot 10^3 \\ 5.316 \cdot 10^3 \\ 3.029 \cdot 10^3 \\ 2.819 \cdot 10^3 \\ 2.722 \cdot 10^3 \\ 2.669 \cdot 10^3 \\ 2.637 \cdot 10^3 \\ 2.617 \cdot 10^3 \\ 2.602 \cdot 10^3 \end{bmatrix} Pa$$

$$G_g = 0.138 \quad T_1 = 221.4 \text{ K}$$

$$C_v := .9 \cdot .000444 = 3.996 \cdot 10^{-4}$$

Guess Values	$\Delta P := .001 \cdot P_a$
	$Q = C_v \cdot P_1 \cdot \left(1 - \frac{2 \cdot \Delta P}{3 \cdot P_1}\right) \cdot \sqrt{\frac{\Delta P}{P_1 \cdot G_g \cdot T_1}}$
Constraints	
Solver	$x := \text{find}(\Delta P)$

Non-Commercial Use Only

$$C_v = \frac{Q}{P_1 \cdot \left(1 - \frac{2 \cdot \Delta P}{3 \cdot P_1}\right) \cdot \sqrt{\frac{\Delta P}{P_1 \cdot G_g \cdot T_1}}} = \begin{bmatrix} 1.39 \cdot 10^{-5} \\ 1.499 \cdot 10^{-5} \\ 1.528 \cdot 10^{-5} \\ 2.769 \cdot 10^{-5} \\ 3.561 \cdot 10^{-5} \\ 4.374 \cdot 10^{-5} \\ 5.198 \cdot 10^{-5} \\ 6.028 \cdot 10^{-5} \\ 6.862 \cdot 10^{-5} \\ 7.699 \cdot 10^{-5} \end{bmatrix} \frac{m^3 \cdot s \cdot K^{\frac{1}{2}}}{kg}$$

$$\frac{C_v}{A_0} = \begin{bmatrix} 0.031 \\ 0.034 \\ 0.034 \\ 0.062 \\ 0.08 \\ 0.099 \\ 0.117 \\ 0.136 \\ 0.155 \\ 0.173 \end{bmatrix} \frac{m^2 \cdot s \cdot K^{\frac{1}{2}}}{kg} \quad kJ = 1000 \cdot J$$

Non-Commercial Use Only

Flowrate Calculations for Mini Valve

Test at ambient conditions: Bozeman Altitude

$T_{test} = 298 \text{ K}$	Ambient temperature at test condition
$P_{test} = 100 \cdot kPa$	Ambient Pressure at test condition
$\Delta P_{test} = 1 \cdot kPa$	Differential Pressure between the inside of the balloon and ambient
$C_f = 5$	Flow Coefficient
$A_v = 1 \cdot m^2$	Effective Flow Area
$Q_{test} = 1 \cdot \frac{m^3}{s}$	Volumetric Flow rate
$R_{He} = 2.0771 \cdot \frac{kJ}{kg \cdot K}$	Gas Constant for Helium
$\rho_{He, test} = \frac{P_{test}}{R_{He} \cdot T_{test}} = 0.162 \cdot \frac{kg}{m^3}$	Density of Helium at test conditions
$Q_{test} = C_f \cdot A_v \cdot \sqrt{\frac{(2 \cdot \Delta P_{test})}{\rho_{He, test}}}$	
$C_f = \frac{Q_{test}}{A_v \cdot \sqrt{\frac{(2 \cdot \Delta P_{test})}{\rho_{He, test}}}}$	$C_f = 20.243$

Non-Commercial Use Only

Valve Flow-rate Calculations. Note: Final flow-Rate for Valve will be calculated pending results of flow-rate experiment.

Weather Balloon Altitude Control System:
Stress Analysis

Assumptions: non-linear elastic material behavior. Material geometry is a thin-walled tube, but stress analysis is done by analyzing a 1/2 inch wide coupon of the material.

Polycarbonate:

$W_{payload} := 2 \text{ lb}$ "Weight of payload"
 $P := 4 \cdot \text{lb}$ "Estimated maximum dynamic loading"
 $n := 2$ "Safety Factor"
 $d := 0.134 \cdot \text{in}$ "Hole diameter"
 $W := .5 \cdot \text{in}$ "Width of material"
 $t := .063 \cdot \text{in}$
 $S := 1$ "Average stress"
 $\sigma := 8000 \cdot \text{psi}$ "Tensile strength"
 $k_t := 2.7$ "Stress concentration factor"

$\frac{d}{W} = 0.268$

$S = \frac{\sigma}{k_t}$ $S = \frac{P}{((W-d) \cdot t)}$

$\sigma := \frac{P}{((W-d) \cdot t)} \cdot k_t \cdot n$ $\sigma = 936.768 \frac{\text{lb}}{\text{in}^2}$

Analysis: The resulting stress on the 1/2 inch of material surrounding the hole is 936.768 psi with a safety factor of 2. The tensile strength of the polycarbonate is 8,000 psi. The material choice and geometry are acceptable for this application.

Valve Mechanical calculations

Micro Controller Interface and Wireless Communications:

The two microcontrollers, one in the main payload and one on the valve, will communicate via a 2.4 Ghz radio module using the Zigbee protocol. These radios are designed for short range communications.. The typical distance that these microcontrollers will need to communicate over will be approximately 4 meters. These radios should be more than capable to transmit and receive over this distance. The interface between the main payload microcontroller and the consumer's preexisting communications system can be I2C, UART, or some digital control lines.

Product Lifecycle :

This product is designed to be a single use item, much like traditional radio sondes. The product will be something the consumer has to buy prior to each flight. Unfortunately due to the nature of ballooning once the balloon is launched it is generally not recovered so recycling is not applicable and the final disposal of the product is it being left out in the environment. Most components utilized in the design are inert or non-toxic which should prevent environmental contamination. Should the consumer choose to recover the product it will be reusable. The lifetime of the product should the consumer choose to recover it could potentially be tens of uses. To reuse the product all the consumer would have to do is recharge or replace the battery and if necessary upload new software to the microcontrollers.

Production issues could cause delays in the shipment of the product to our clients. Most of the parts produced for the valve system will require machining of raw materials for the physical construction of the valve. Any delay in acquiring these raw materials could cause the production to slow or stop especially if an outside machining service is used. That being stated none of the raw materials are exotic and are easily procured locally or through a supplier. The main printed circuit boards will not be manufactured in-house and as such will be vulnerable to any production delays at the manufacturer. The discrete components used to populate the printed circuit board are not exotic and it is not expected that a shortage or delay would be incurred in ordering them. Several major component suppliers (DigiKey, Jameco, etc) can supply these components in abundance.

From production to the end of the life of the product the timespan will probably be a couple of months at a minimum and if the consumer reuses the product it could be as long as a couple years. This really depends on the consumer and how they choose to use the product.

Analysis and Test

Introduction:

Failure Modes and Effects Analysis:

Potential Failure	Effect	Prevention
Balloon disconnects from Valve assembly	Premature descent of the payload, Potential to lose payload.	Locking clamp assembly on the neck of the valve
Valve Fails to vent adequate Helium	Premature descent of the payload, Potential to lose payload.	Ground testing and design to ensure adequate flow rate
Mechanical Failure	Premature descent of the payload, Potential to lose payload.	Mechanical components designed with an appropriate safety factor
Balloon reaches neutral buoyancy and passes out of control range	Loss of payload	independent timer failsafe that will open the vent after the mission clock has expired
Communications Failure	loss of control, and potential loss of payload.	Extensive testing to make sure that under normal operating conditions the communications link will be on.
Autonomous Valve Algorithm Failure	potential loss of payload.	Extensive testing and simulation.
Code failure	loss of control, and potential loss of payload.	Extensive testing and simulation.
General Electronics Failure	loss of control, and potential loss of payload.	Testing of electronic components to make sure they are working properly.

Physical Testing:

A flow rate test for the vent gate of the valve will be conducted as soon as possible. This will be a physical test of the mechanics of the system to determine their effectiveness at ambient conditions. this test will also provide a value for the flow coefficient used in the flow rate calculations, which is currently unknown. This test will also provide a mechanical tension test of the valve structure, as it will be stressed in the same way as it will be in actual operation.

While preparing for the critical subsystem demo it was discovered that the selected design for the microcontrollers and the 2.4 GHz was not going to work for this application as well as had been expected. It was going to be far too complicated for customers and students who didn't have a lot of experience with programming to configure and customize the product to their specific application. This caused a reevaluation of the decision matrix to rescore the ease of use design metric. This resulted in changing designs from the micro-controller with a build in radio to an Arduino compatible microcontroller and a separate radio module. This will be much simpler for the user to customize and configure the product.

Cost Analysis:

Component	Qty.	Raw Matl. Cost (per 100)	Fabrication Cost	Assembly Cost	Testing Cost
Alignment Pin	1	0.03	0	0	0
Gate Cap	1	0.80	0	0	0
Gate Outer	1	0.05	0	0	0
Gate Inner	1	0.05	0	0	0
Servo Case Left	1	0.80	0	0	0
Servo Case Right	1	0.80	0	0	0
Main Tube	1	3.14	0	0	0

Valve Case	1	2.00	0	0	0
Nozzle clamp	2	.80	0	0	0
Retention Ring	1	1.60	0	0	0
Battery	1	10.00	0	0	0
Sub-Micro Servo	1	8.00	0	0	0
6-32 Nylock Nut	4	0.04	0	0	0
6-32x3/8" Mach. Screw	2	0.10	0	0	0
6-32x1/4" Mach. Screw	2	0.10	0	0	0
GPS MTK3339	1	16.33	0	0	0
Xbee Radio Modules (XB24CZ7RIS-004)	2	22.85	0		0
Micro Controller (ATmega328)	2	5.20	0	0	0
PCB	2	20	0	0	0
Misc. Electronic Components	~	~5	0	0	0
Total Valve Assembly		97.69	0	0	\$300/ Test

Once a working prototype has been fabricated and numerous tests and simulations have been done test flights on actual balloons will have to be conducted. Currently there are 3 test flights and then one final demonstration flight allotted for this project. Each flight will cost approximately \$300. These flights are critical in making sure everything operates as intended.