Balloon-Based Rocket Launch System

UCI Rocket Project: Structures

Team Leader: Yuan Zhang

Members: Nathan Cox, Ryan Williams, Isaiah Navarro, David Li, Robert Chung

Advisors: Professor Kenneth Mease, Dave McCue

University of California, Irvine

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SAMUELI SCHOOL OF ENGINEERING

UNIVERSITY of CALIFORNIA · IRVINE

Contents

1. Objective

The layer of our atmosphere known as the mesosphere, which spans from altitudes of about 30miles (50km) to about 50 miles (80km), is the least understood layer of our atmosphere. Because the mesosphere lies above the cruising altitude of aircrafts and below the minimum orbital altitude for spacecraft, it is extremely hard to gather data for an extended period of time. In order to effectively take measurements and experiment in this layer of the atmosphere, a cost-efficient and reusable method for sending rockets to the mesosphere must be developed.

For this reason, the UCI Rocket Project Structure team is in the process of designing a rockoon, that is, a rocket that will be launched from an airship held high in the air by balloons. This “airborne launch pad” will be a reusable structure, saving on the costs of the first stages of multiple rockets, and bringing our rockets up out of the dense atmosphere and much closer to the mesosphere at the point of takeoff. This reusable method will enable testing of the mesosphere to be done frequently and cheaply, ultimately leading to a better approach in understanding the mesosphere. If our rockoon concept proves viable, the future goal of the UCI Rocket Project will be to launch a liquid-fuel rocket from the platform carrying a cube satellite.

2. Introduction

The Rockoon Project is a design project with the intent to build and launch a rockoon, a hybrid vehicle that lifts a solid fuel sounding rocket up into the upper atmosphere using a gas balloon and then launches it to the mesosphere. While this concept has been around since the late 1950s, there have not been any recent developments or applications using rockoons. As a result, we decided to research rockoons as a viable alternative to the orthodox sounding rocket, particularly to further research of the mesosphere and other high-altitude levels of the atmosphere.

There are many advantages that make rockoons a worthy technology to research and consider for application, with many of them arising in comparison to the conventional sounding rocket. The major benefit is the cost of the vehicle itself; by replacing the first stage of a two-stage sounding rocket with a space balloon, costs are reduced by a significant factor. For example, the launch cost of ARCAS, a sounding rocket that can bring a 4.5 kilogram payload to an altitude of 52 kilometers, was 2000 dollars in 1960. By taking the inflation into account, the launch cost of ARCAS is around $16,083 in today’s dollars. For another example, to bring a 4 kilogram payload to an altitude of 70 kilometers, the four major aerospace companies in China gave the quotes range from 98,123 dollars to 163,538 dollars. However, if we use rockoon, the launch cost to an altitude of 50-60 kilometers will be the cost of solar balloon (around $90) plus the cost of the rocket fuel. Even if we use the helium balloon, the launch cost still lower than the traditional sounding rocket. The launch cost will be the cost of balloon and helium (around $1,000) plus the cost of the rocket fuel. Since we launch rocket from high altitude, the cost of fuel will greatly lower than traditional sounding rocket. A second advantage is lies with the construction of the vehicles. Because a rockoon only comprises of a single-stage rocket, a platform, and a balloon, it is simpler to construct than a traditional two-stage sounding rocket.

The single-stage rocket portion of the rockoon is also more reliable than a two-stage rocket, as it removes the issue of separating the stages and mid-air ignition. Another distinction a rockoon has is the reusability of the first stage; the launch platform can be recovered easily and prepped for another usage simply by replacing the balloon. Lastly, rockoons are more environmentally friendly than conventional sounding rockets. The removal of the first stage of a sounding rocket comes with fewer emissions and thus a lessened impact on the environment.

However, with these benefits come some notable disadvantages, which we will attempt to remedy in our study of the rockoon vehicle. A major shortcoming is that balloons cannot be steered; thus, neither the direction the launched rockoon will float nor the region where it will fall is easily controlled. Without guidance, a large area must be required to allow the rockoon ample room to land safely. A possible solution to this issue is a guided Ram-air parachute precision landing system, to guide the vehicle on its way down to a designated landing point. Secondly, the launch pad must be kept stable while the balloon rises, especially under wind turbulence in the upper atmosphere. We will attempt to meet this demand using a gyroscopic gimbal that utilizes a low center of gravity to stabilize the rocket without using electrical components that may add weight to the device. Lastly, a rockoon may end up to prove costly when certain design decisions are made. For example, using helium balloons may not result in a worthwhile cost reduction from a conventional sounding rocket, as helium is expensive. To remedy this, we resolved to use a solar hot air balloon, cutting down on costs significantly.

3. Subsystem Final Report

3.1 Solar Hot Air Balloon (Ryan Williams, David Li)

Introduction

A solar balloon is one of the many options available that can pose as a viable and much more cost effective substitute to the first stage of a high altitude rocket. Other viable substitutes include hydrogen and helium filled balloons, which certainly have a wide array of their own advantages and disadvantages. Schools like UCSD and Cornell are currently researching the capabilities of these balloons and their respective payload escorting capabilities, and have achieved varying degrees of success. But what is a solar balloon, and why is it currently the best option available? A solar balloon is a balloon filled with air that makes use of radiation heat energy from the sun to achieve a temperature differential between the ambient, surrounding air and the air within the balloon. As the temperature within the balloon increases, the hot air expands and thus becomes less dense. This is predicted by the ideal gas law, $PV = m\underline{R}T$. When the density differential is high enough and enough air is displaced by the balloon, buoyancy forces drive the balloon and its payload skyward, until the total balloon density achieves that of its surrounding environment. This buoyancy force is the main driving force predicted by Archimedes' principle, and is what the design of the balloon is based on. It 'lifts' the balloon upward, but it is in no means the aerodynamic 'lift' by definition. All further use of the word 'lift' represents the upward motion created by buoyancy forces as depicted by Archimedes' Principle.

Design Approach

The design is based on literation approach. After quite a bit of research, components of the balloon design became clear. In summary, most sources used the approximation that the temperature differential inside and outside of the balloon should be around 15 degrees Celsius for a solar balloon. Additionally, approximations for Balloon 'lift' at different altitudes were offered for solar balloons. The solar and hot air balloon website http://www.brisbanehotairballooning.com.au/faqs/school/97-solar.html offered approximations of 60 grams/m^3 of lift at sea level and 12.6 grams/m^3 of lift at 15,000m. The balloon design requires the achievement of this value of lift in order to carry our payload in addition to the weight of the balloon. We have also written a MATLAB code to help use design solar balloon. The input parameters are volume of balloon, surface area of balloon, payload of balloon, and skin weight of balloon. Output is a plot of ambient air density and total density of Rockoon verse altitude. We can use the point of intersection to get the maximum altitude that Rockoon can reach.

Literation Steps:

1. Specify design goal (payload weight and desire altitude)
2. Use 60 grams/m^3 of lift at sea level and 12.6 grams/m^3 of lift at 15,000m for approximation.
3. Choose shape of balloon (Shape determines surface area and volume relationship)
4. Use payload weight to estimate the volume of balloon.
5. Use volume to get surface area of balloon.
6. Use surface area to calculate balloon skin weight.
7. Use a new weight (equal to lift) that is greater than balloon skin weight plus payload weight to estimate the new volume of balloon.
8. Use new volume to get new surface area and new balloon skin weight
9. Repeat step 7-8 until the lift is greater than the new balloon skin weight plus payload weight.
10. Enter the balloon parameters and payload weight into MATLAB code to check the maximum altitude.
11. If the result is not close enough to design goal change the lift assumption in step 2 and redo the literation until the result is close to design goal.

MATLAB code in Appendix A, code 1

Sample Calculation for Prototype 2:

Parameters:

1) payload: 5 kg
2) Material weight: 17 g per trash bag
3) design goal: reach altitude of 15 km

Material:

1) Black Trash Bags

39 Gallon, .4 mil, 17gram trash bags

Design Approximations:

1) Spherical in shape
2) 12.6 grams/m^3 of lift at 15,000m
3) 15 degree celsius temperature differential between ambient and balloon air

4) 17g of weight compactor bag (at .4 mil thickness) per trash bag
5) Surface area of trash bag: 1.5 m^2

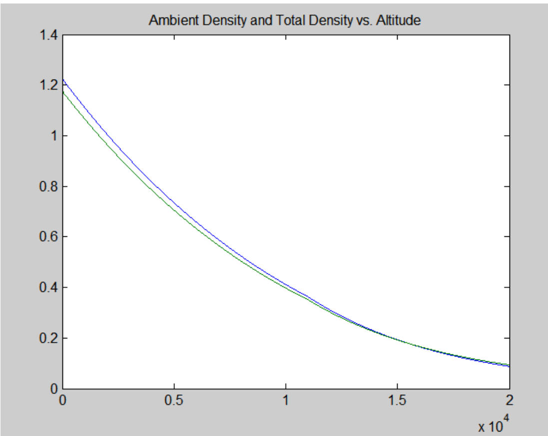
Literation

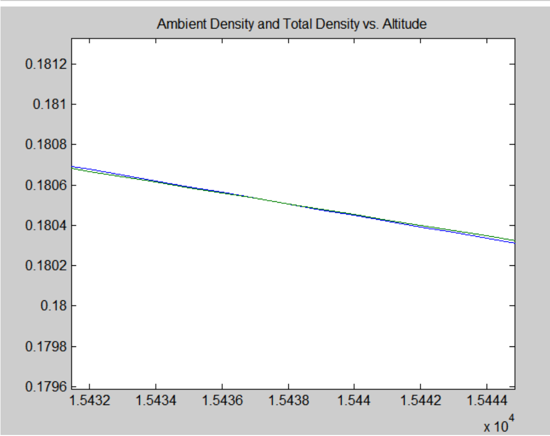
Start from step 4

4. Volume=5000g/ 12.6g/m^3=396.92m^3
5. Surface Area=261.3 m^2
6. Balloon skin weight= 261.3m^2/1.5m^2 *17g=2.961kg
7. New weight= 10.696kg>5kg+2.961kg
  New Volume=848.94m^3
8. New surface area=434.47m^2
  New balloon skin weight=4.923kg

9 lift=10.696kg>4.923kg+5kg

10.





Maximum altitude is around 15.4km, which is close to our design goal 15km.

Fabrication Method and Material Selection:

Refer to *Fly Solar Balloon-Everything You Want to Know About Making and Flying Your Own* by Jonathan Boehme pages 8-26

https://drive.google.com/open?id=0Bz_fOWftUmutV3hkeXBDdnRPTnM&authuser=0

<u>Fabrication Report</u> (Isaiah Navarro)

Manufacturing

Using black trash bags, a solar balloon can be made by seaming the edges of many plastic bags together to create a large balloon with a pre-determined shape. For this project a tetrahedron shape was chosen because it take up less of a span compared to a spherical balloon in order to avoid collision between rocket and balloon (shape seen in first picture). Basically plastic trash bag sheets where taken and lined up so the edges matched each other. Then from there the edges would be seamed in a way that the final shape would be our tetrahedron. From this, a rigging can be made on a corner to attach a line, so the balloon doesn't fly away on us. Alternatively, the rigging can be used for our prototype launch of the rockoon.

At first it became apparent that some type of clamping devices was need to hold the plastic bags in place was the edges were seamed together to keep them from moving. At first tape was used to mount the sheets to the table, but upon removal, would easily tear the material. This not being a desired outcome, cheap plastic clamps where used and held the bags perfectly together as the sheet were being fashioned and were easily movable.

Heat Sealing vs. Tape

The most common method for creating solar balloon is to use tape in order to seam plastic bags together. From this the combined plastic bags will create a larger balloon as opposed to just one bag by itself. For smaller balloons, only a small amount of tape is required to create a complete balloon. However, for larger balloon, many seams are needed to fashion the balloon, increasing the amount of tape needed exponentially and increasing the cost of the solar balloon to fabricate. The alternative method being used for this project will be to heat seal all the seams together using only the plastic bags themselves. Basically melt the seams of the plastics bag together and have them fuse with each other creating the same effect as tape but with a lost less weight and expense.

Heat Seal for Crafting and Bagging

The process to find the right tool in order to heat seal efficiently and make a strong enough bond between the plastic bags was difficult but successful. The original idea was to use a small heat sealing device used to seal two plastic bags, then simply close the clamp on the seam[1]. There was two flaws with this. The first being there was no correct orientation to seal the seams of the bag without sealing another part of the bag not meant to be seam. Basically this design was too small. The second issues was the heat sealers are expensive and a lot of money to spend on a tool.

The next solution was to use a heat sealer[2] found at any given crafting store and then use that to run the length of the seam. It was much cheaper ($3) than the heat sealer used for bagging and could seal the bag easily. The seaming part was basically a small wire about a millimeter in diameter that would heat when compressed against the top of the device, creating a small sealed line. This Crafting heat sealer was not able to make the bond between two different plastic bag sheets strong enough without folding the edge of the bags over a few times. However, this shrank the size of the balloon and used more material. When the crafting seal moved along the edge of the bag, the bag would tear and create holes easily and frequently. From this we would not be able to manufacture effectively with great craftsman ship.

1. Picture from Amazon.com listing

2. Picture from Ebay.com listing

Sealing Iron for model Airplanes

With the crafting sealing iron the main issue was that only a small amount of bagging material was sealed and creates a weaker seal. With a larger surface area to transfer heat to, more surface of the area of the bag can be bonded together, creating a stronger bond. The next approach was to user a Sealing Iron used for making the skin of model airplanes. This however, was not able to reach the melting point of the bag and couldn't fuse any of the material together, even when placed for prolonged periods of time.

Folding of edges of plastic bag. Increases bond of sheets, but decrease volume of balloon

Sealing Iron, photo from Amazon.com listings

Iron (Clothes)

Small balloon made from clothing iron using the folded side method with aluminum. At first it held up, but under greater pressure failed.

Since the sealing iron did not have enough heat to bond the materials together, the idea was that more head was necessary. Irons used to press and unwrinkled clothing was hot enough to melt the plastic bag and has a large surface area that could be used to heat the bag. The main difficulty initially with the iron, was finding the right temperature to use on the bags, too hot and the bag would easily shrivel up and melt. On the other hand too little heat would only semi-bond the bag and would come undone with little

force. The iron was becoming too temperamental and couldn't be used effectively.
Although, with the help of aluminum foil as a semi thermal barrier between the hot iron and the plastic bags, the plastic bags would bond together. Unfortunately, even with the correct bonding of the trash bags, the seam was still not strong enough for use as a solar balloon. After folding the trash bags over once and ironing again with the help of the aluminum foil, the bonding did improved, but was later seen that it still was not flight worthy.

This is when it was noticed that the clothing iron was only melting one side of the plastic bag and leaving the other side how it originally was. Meaning that one side of the bag was bonding itself to the other, but the opposite sheet wasn't bonding to the first sheet of plastic.

Flat Iron (Hair)

From this conclusion a flat iron was chosen as our next tool to seam the bags together. Flat irons are used for straightening long hair and are commonly seen among feminine hair care products. The difference between this and a regular clothing iron was that the flat iron is heated on two different surfaces allowing for the seaming of both sides of the plastic bags. After trial and error in finding the correct setting for a strong seam. It should be noted that like the iron, the flat iron doesn't not display temperature, rather has arbitrary number from 1-25 that have no other meaning than hot and hotter.

On the lowest setting of the flat iron, was able to create a strong seal without the use of aluminum foil and from this solar balloon was created to test using this method. In addition turning the setting on the flat iron to its max and with the use of aluminum foil, an even stronger seam was able to be fabricated.

Flat Iron with aluminum foil

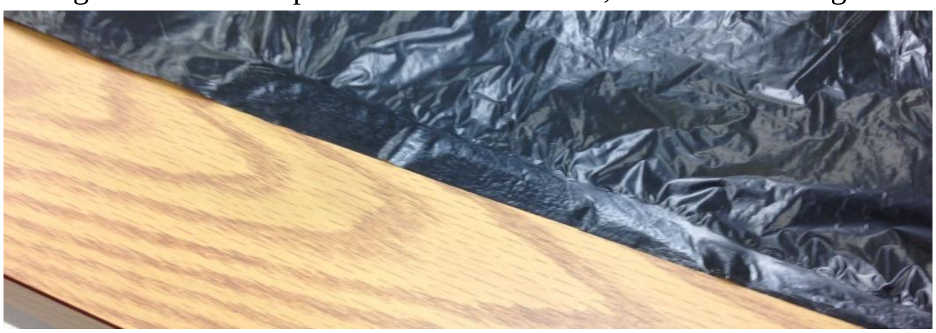
Conclusion

At first testing of the heat sealed seam was done with crafting tools consisting of very a small surface area that produced heat. This resulted in a very small seam that was not strong or for use. From there the hot surface area of the tool was increased and used to seam the edges, resulting in a stronger bond. However, the seams were still not strong enough. It was noted here that only one side sheet was being melt to form the bond, while the other one was untouched. When a heated surface was applied to both sides of the seam was made strong enough, but over heating the bag was very frequent.

The hardest part in the testing of each tool was finding the correct temperature. If it was too hot it would melt the bag and create holes, rendering the seams useless.

Plastic bag that was melted due to too much heat

On the other hand, not enough heat wouldn't melt the plastic and no bond between the sheets would be formed. After many experimentation with temperature, it was found that the hottest setting for the tool coupled with aluminum foil, created the strongest bonds.



The strongest bond resulting from the Flat Iron, Aluminum foil method. Not the increase in reflection, as compared to the rest of the bag, where the seam is.

Solar Balloon Test Report #1

Date: November 26, 2014

Researchers: Yuan Zhang, Isaiah Navarro

Testing time: 9:00-11:00 AM

Result: **Fail**

Testing goal:

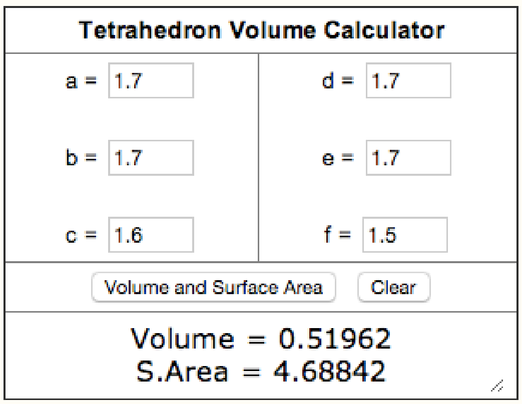
Measure the net lift of our first solar balloon at different temperature gradient.

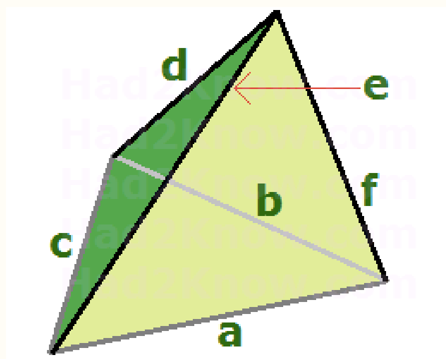
Specs of the balloon:

Shape: Irregular tetrahedron

Total weight: 68g(weight of material of balloon)+ 20g (load tape)=88g

Dimension: (unit: m)





Testing equipment:
1.Infrared thermometer
2. Scale

Data
The inside temperature might be incorrect because the infrared thermometer might detect the surface temperature as inside air temperature.

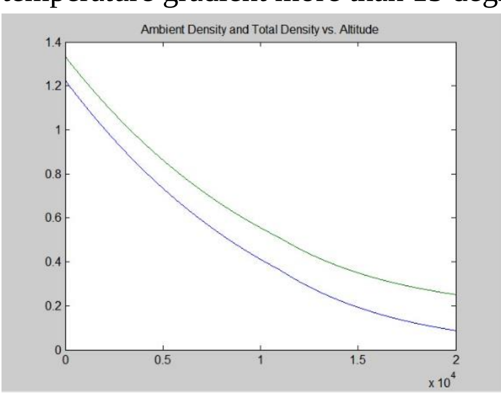
Time	Ambient temperature (Celsius)	Maximum surface temperature (Celsius)	Inside temperature (Celsius)	Temperature gradient (Celsius)	Net lift (g)
9:40AM	17.9	39	24	6.1	N/A
11:40 AM	24	27	25	1	N/A

Result:
The upper part of balloon is floating, but the whole balloon failed to fly.

Failure Analysis.

1. The ambient temperature is too high. From our data in 11:40 AM the temperature gradient is only 1 degree Celsius.
2. We did not fully inflate the balloon. We inflated it to around 90%.
3. We did not seal the opening of the balloon. When the wind is strong, we lost hot air.
4. The load tape and the string are too heavy.

5. Our MATLAB code shows that the balloon cannot fly at temperature gradient of 15 degrees Celsius. We cannot even reach temperature gradient of 15 degrees Celsius. This balloon needs temperature gradient more than 15 degrees Celsius to fly.



Improvement for next test:

1. Fully inflated the balloon.
2. Seal the balloon.
3. Test it at 7am of a cold and sunny day.

4. Place the BMP180 pressure and temperature sensor in the center of the solar balloon to get the real inside temperature.-
5. Reduce the weight of load tape, and use the fishing line.

Solar Hot Air Balloon Test Instruction (Yuan Zhang)
Refer to Appendix B.
Source: *Fly Solar Balloon-Everything You Want to Know About Making and Flying Your Own* by Jonathan Boehme
Saucer Balloon (Nathan Cox)
We have also researched how to make a saucer balloon and how to calculate the volume of saucer balloon. Detail Report refer to Appendix B

3.2 Helium balloon (Nathan Cox)

In order to get the UCI Rocket Project rockoon off the ground and in the air, the Structures team used helium balloons. A prototype launch structure was designed to use four helium-filled weather balloons to carry the weight of the structure and the rocket to a specified alititude. We predicted the amount of helium using the mass of the launch structure and rocket, atmospheric conditions, and Archimedes' Principle for buoyancy.

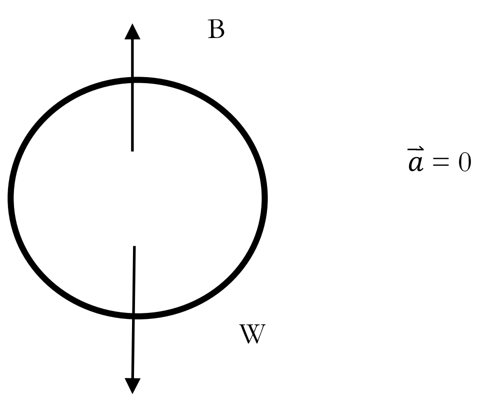
Maximum Altitude Considerations

The buoyancy force is given by Archimedes' Principle:

$$B = \rho_f g V$$

where ρ_f is the density of the fluid in which the object is submersed, and V is the total volume of fluid displaced.

By doing a force balance on a balloon, we can determine the conditions at maximum altitude by setting the buoyancy force equal to the weight with no upward acceleration. Upon liftoff, the buoyancy force must be greater than the weight of the balloon in order to have upward velocity and a rising balloon. At max height, the balloon must be in static equilibrium. The total weight that the balloons will carry is the combined weight of the helium gas, the launch structure, rocket, and balloon skins. A simplified model is shown below, with the buoyant force B representing the total buoyant force caused by all four balloons.



$$B - W = 0$$

$$\rho_{air} gV - (\rho_{He} gV + W_{LS} + W_R + W_s) = 0$$

$$\rho_{He} gV = weight\ of\ helium\ gas$$

$$W_{LS} = weight\ of\ launch\ structure$$

$$W_R = total\ weight\ of\ the\ rocket$$

$$W_s = total\ weight\ of\ the\ four\ balloon\ skins$$

<u>Determining the Required Amount of Helium</u>

Now, by choosing a desired launch altitude, the volume of helium required and weights can be designed for. At any given altitude h above sea level, there will be a certain pressure P and temperature T. Standard atmospheric conditions can be used, or a more refined calculation can be used (such as the equations for the atmosphere given in chapter 5 of *Fundamentals of Flight*, 2nd ed. by Shevell). At the maximum altitude of the balloon, it is assumed that the helium inside of the balloon has the same pressure and temperature as the ambient air. Using the gas constants for both air and helium, the densities of the air and helium can be determined.

$$\rho_{air} = \frac{P}{R_{air} T}$$

$$\rho_{He} = \frac{P}{R_{He} T}$$

Where the gas constants for air and helium are R_{air} = 286.9 J/kg-K and R_{He} = 2077 J/kg-K, respectively.

Now using the total weight and the computed densities, the volume needed for an altitude of h above sea level can be computed:

$$W_{LS} + W_R + W_s = W_{total} = m_{total} g$$

$$(\rho_{air} - \rho_{He}) gV = m_{total} g$$

$$V = \frac{m_{total}}{(\rho_{air} - \rho_{He})}$$

This volume V computed is the total volume displaced by all four balloons at the maximum altitude h. By multiplying by the density of helium at this altitude, the total mass of helium can be computed:

$$m_{He} = \rho_{He} V$$

While the density decreases and the volume increases during the flight, the mass of helium is constant throughout the whole flight of the launch structure, and so this will be the amount chosen to fill the balloons with on the ground.

Balloon Selection

Four the four balloon launch structure design, the amount of helium in each balloon can be determined by dividing the mass of helium computed by four. Also, the burst diameter of the balloons chosen should be greater than the diameter of the balloon at the maximum altitude. The total volume displaced by the balloons was given by V, and the diameter of each balloon can be computed, as below:

$$V_{balloon} = \frac{1}{4} V$$

$$V_{balloon} = \frac{4}{3} \pi R^3$$

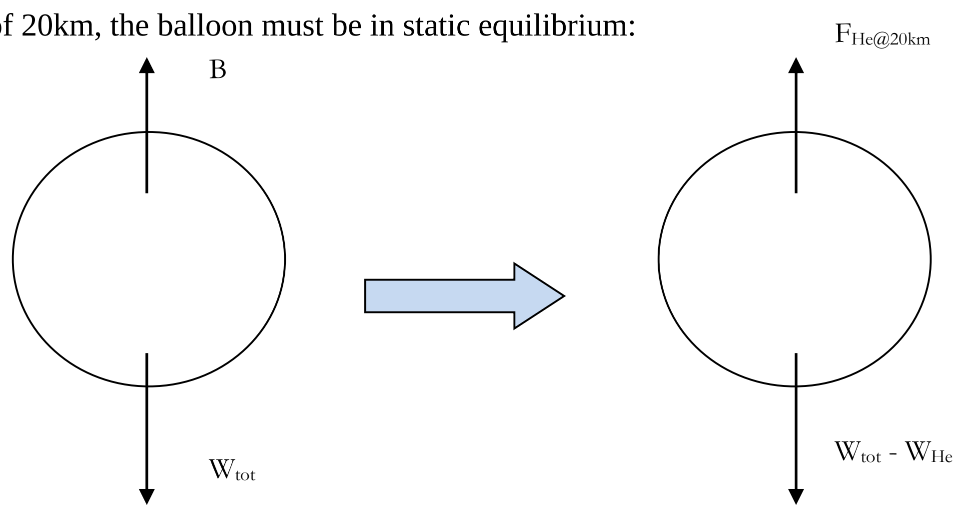
$$R = \left(\frac{3}{4\pi} V_{balloon}\right)^{\frac{1}{3}}$$

$$D = 2R < burst\ diameter$$

If the diameter D of each balloon exceeds the rated burst diameter, a larger balloon should be chosen, which will also increase W_s, the weight of the balloon skins, and the process should be repeated.

Design of a Helium Balloon to carry a 5kg Payload to 20km. (Prototype 2)

At a height of 20km, the balloon must be in static equilibrium:



The weight of the helium must be subtracted from the total weight when using the net lifting force of the balloon, since the weight of the helium is already factored into the derivation of the value of the net lifting force $F_{He@20km}$. Therefore, the mass to be lifted by the balloon is just the payload mass plus the mass of the balloon material itself:

$$m = m_{payload} + m_{balloon}$$

The mass of the payload will be $m_{payload}$ = 5kg. At static equilibrium the two forces will balance each other, and by setting them equal to each other we can determine the diameter the balloon must have at an altitude of 20km.

$$F_{He@20km} = W_{tot} - W_{He}$$

$$F'_{He@20km} \cdot V = mg$$

Since the mass of the balloon material is really a function of the diameter (as a larger diameter balloon will require more material for the balloon and thus more weight), an educated approximation of the balloon mass is used. After finding the value of the diameter, this assumption can be checked and modified as necessary. We will estimate the mass of the balloon at $m_{balloon}$ = 1000g. The equation now becomes:

$$F'_{He@20km} \cdot \left(\frac{\pi D^3}{6}\right) = \left(m_{payload} + m_{balloon}\right) \cdot g$$

Using 9.75m/s2 as the value of the acceleration due to gravity at 20km and plugging in the values, the diameter D can be solved:

$$D = \left(\frac{6mg}{0.709\pi}\right)^{\frac{1}{3}} = \left(\frac{6 \ \cdot (6kg) \cdot 9.75\, m/s^2}{0.709\, N/m^3 \cdot \pi}\right)^{\frac{1}{3}} = 5.40m = 17.72ft$$

A 20ft burst diameter weather balloon has a mass of about 600g. Therefore, our estimation of the mass of the balloon is a valid assumption for a 20ft diameter weather balloon. The volume of helium that would be needed to put in the balloon down at sea level can be determined by:

$$Volume\ at\ 20km\colon\ V = \frac{4}{3}\pi R^3 = \frac{\pi D^3}{6} = 82.45m^3$$

$$Mass\ of\ Helium\colon\ m_{He} = \left(\frac{0.0123kg}{m^3}\right) \cdot (82.45m^3) = 1.014kg$$

where the density of helium is 0.0123kg/m^3 at an altitude of 20km and the volume is the volume of the balloon at that altitude. Since the mass is constant, we can determine the volume of helium we need to put in the balloon at sea-level by dividing the mass of helium by its density at sea-level, 0.166 kg/m³.

$$V = \frac{m_{He}}{\rho_{He}} = \frac{1.014kg}{0.166kg/m^3} = 6.11m^3$$

In conclusion, in order to lift a 5kg payload to an altitude of 20km, four weather balloons each with a burst diameter larger than 5.40m (17.72ft) is needed. A 600g, 20-ft burst diameter balloon is available for around $69.00 from Aether Industries. The helium cost to go in the balloon is around $120.

20 FT. DIA. PROFESSIONAL WEATHER BALLOON, 600G (WHITE)

Product Details: Diameter at release: (1.8 m) Diameter at burst altitude: (6.1 m) Nominal Lift: 3.8 lb (1,700 g) Maximum Lift: (5,450 g) Burst altitude: 100,000 ft (30,500 m) Product Description: 600g Professional Meteorological Weather Balloon, Aether Industries brand. Great fo ...Read more

$68.90 **each**

$62.01 **per unit for buying at least 10**

Product Details:

- Diameter at release: (1.8 m)
- Diameter at burst altitude: (6.1 m)
- Nominal Lift: 3.8 lb (1,700 g)
- Maximum Lift: (5,450 g)
- Burst altitude: 100,000 ft (30,500 m)

Product Description:

600g Professional Meteorological Weather Balloon, Aether Industries brand. Great for tethered and free-floating aerial photography projects. Take pictures like the ones shown using this balloon and a camera.

Technical Details:

- Volume at release: 113 cu ft (1.42 cu m)
- Neck diameter: 2.8 in ()
- Neck length: 9 in ()
- Ascent rate: /min (5 m/s)
- Material: Latex Rubber

<u>MATLAB Code for Helium Balloon Launch Design.</u>

We have developed two MATLAB code to help us design. FindV3() function predicts volume of helium needed to lift payload of mass m to a desired altitudes in meters. This code is based on 4-balloon launch structure design. FindPL3() function predicts payload mass that can be carried by 4-balloon launch structure design. These two codes can give us a more acculturate results. For example, we used FindV3() to design helium balloon for prototype 2. The result is.

```
>> FindV3(5, 20000,1500,6,84300)

Required Volume: 7.0104 m^3
Recommended Balloon Diameter: 20ft burst diameter
```

It requires more helium than our calculation in previous section because this code takes the extra balloon skin weight and launch site altitude into consideration.

FindV3() refers to Appendix A code 2
FindPL3() refers to Appendix A code 3

<u>Final Helium Balloon Design for Prototype 2</u>

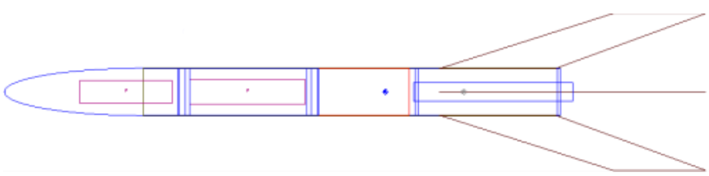
Goal: 5kg payload to 20km
Result: Four 600g, 20-ft burst diameter balloons

3.3 Prototype 2 Rocket (Isaiah Navarro)

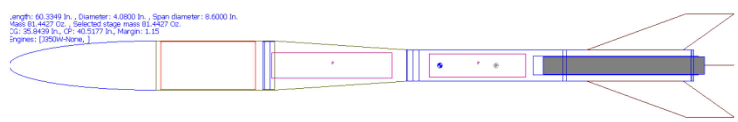
The point of Prototype 2 is to be launching a rocket from a balloon platform from a high altitude (65,500ft). Therefore the rocket for Prototype 2 has to meet certain design requirements. A major requirement was to decrease the weight of the rocket and the whole system altogether because of the Federal Aviation Administration weather balloon regulations. So a rocket with a minimized weight, length and span is desired. Not only will this allow for compliance with the FAA, but also decrease the cost of launch (helium) and materials. Probably the biggest factor to take into account besides the weight is the ability to carry the avionics systems of the rocket that will take flight data and ignite its motor. Before designing the rocket, we had to know the dimensions and weight of the avionics payload. This way we can know the approximate size of the motor and the diameter of the body tube needed to be able to launch the avionics and house the avionics bay. After the designing of the avionics, it was noticed that only a 3 inch diameter rocket was required for our needs. At an altitude of 65,500 ft. as opposed to ground level, different environmental conditions must be taken into account. Here the air is .05 atm. in pressure, -57 degrees Celsius and the pull of gravity is a little less (this was such a small difference it was negligible). The less dense atmosphere will allow the rocket to achieve a higher apogee than being launched from the standard 1 atm. at sea level. Fortunately, all of these factors can be taken into account in the RockSim program, where the Structures Team can design the rocket and simulate launches.

Initially a J sized solid bi-propellant motor was chosen because of our familiarity with the motor. This motor was thought to be used prior to receiving our budget. Upon receiving the amount of funds we were allocated to build this rocket, a cheaper and lighter motor was chosen. The new motor was to be a H sized solid motor and most of the rocket was designed for this motor. However during the simulations done in RockSim, the burn time of the motor was too short, giving to high of an acceleration (105g's) for the avionics to handle. Thus a different motor of the same length and weight was chosen (I sized) with a longer burn time accounting for a maximum of 29g's. The accelerometer on the avionics would saturate to its highest value of 16g's, but would not break or undergo permanent damage from too much force being applied.

The easiest design would be a rocket with the same diameter body tube from the end of the nose cone to the end of the rocket. With this simple the design, in order to achieve stable flight, the semi span of the fins would have to be very large. A major goal for the rocket was to have a little span was to allow for a smaller gimbal system, less material, less weight and less cost. Sweeping the fins could increase the stability for a smaller semi span, but was too thin to withstand large amounts of force. Therefore right after the avionics bay, a transitional piece was added from a larger 3 in. body tube that housed the avionics bay, to a smaller 2.6 in. body tube. This allowed for grossly smaller fins that gave the same amount of stability. An accidental advantage of adding a transitional piece would be reduction of sized need for the avionics bay. Originally a small camera was going to be added and a wind shield attached to the body tube. The windshield would have been hard to mount and decreased stability. With the transition, the camera could be added and not interfere with the avionics by simply being placed on the inner wall of the transitional piece and faced looking down the rocket.



(Left) This was a design for a traditional rocket. Note the large span of the fins as oppose to the smaller one bellow. Both rockets are about the same length.

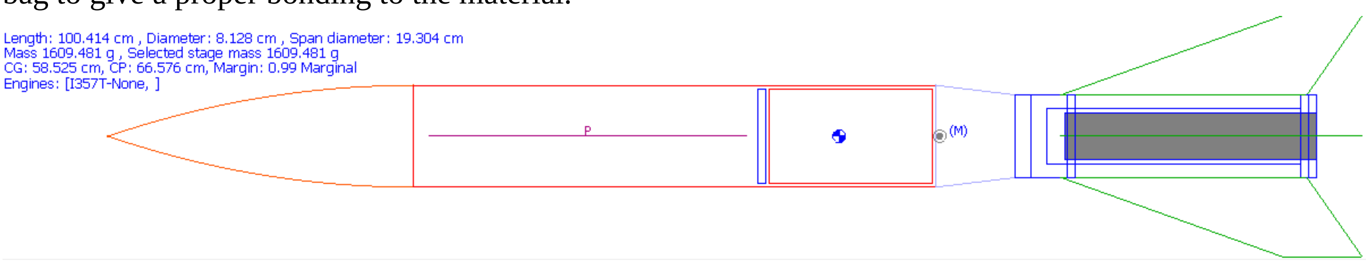


Concern of deployment of the parachute was raised on whether or not it would even be able to inflate at 65,500 ft. Extensive research was done and concluded that it would inflate at this high altitude, but due to the dramatic decrease in air density, would cause the rocket to descend at a fast rate. The large speed at this altitude did not matter as much as the speed when the rocket lands. With this in mind a four foot rocket was chosen that has a large coefficient of drag (1.8) and can return the rocket to the ground with a safe speed when the rockets impacts the ground. The parachute itself was made from rip-stop nylon, was easily packed into a rocket and extremely light. At first the parachute was paced behind the avionics bay, but the GPS doesn't work upside down and without it, the rocket will be lost along with all the data it had acquired. For this, the parachute is added to the front of the rocket so when it deploys, the GPS is facing upright.

The nose cone was not a major factor in the structures team achieving its goals or mission objectives, thus less work went into the design of it. Upon research of nose cones with the highest performance at large speed, an Ogive nose cone was chosen. Its curvature is given by a hack series and gave optimal performance when its length was three times the size of its diameter.

The cold however will be issues for working with certain materials. At this temperature materials become more brittle and some cannot be used because of this. The original idea was to use fiberglass composite to reinforce the cardboard and other materials used. It was thought of for the high tensile strength to weight ratio and the inexpensive cost. However, at -57 degrees Celsius fiberglass becomes too brittle to use and splinter under a large of enough force. Instead carbon fiber composites can be substituted to still endure this low temperature range. Unfortunately, carbon fiber material is approximately 4.6 times more expensive than the same amount of fiberglass. This was trade off was unavoidable though. A similar situation was met with the thermoset polymer (epoxy). The epoxy usually used for the university projects is the #105 Resin and #205 Hardener, from Western Systems. It was questionable whether the epoxy would withstand at this temperature. Upon consulting the manufacturer, I was assured the epoxy could be used for this application (even though it was never tested) and that carbon fiber composites with this epoxy where used for dog sled teams in arctic regions. There is a more flexible epoxy (G-Flex) that would be more suitable for this application but budgetary constraints did not allow this.

Due to the large amount of thrust produced by the I sized motor, all parts need to be made with composite materials to increase their strength and keep weight low. In order to keep costs down, parts where only reinforced with carbon fiber rather made from pure carbon fiber. Members of the Structures Team had prior experience in working with composite materials and were able to implement a vacuumed bagging system. Where a part was wrapped in carbon fiber and laid up with epoxy, then wrapped in peal ply and breather, then left to cure in a vacuumed bag to give a proper bonding to the material.



Above is the picture of the final design of the rocket.

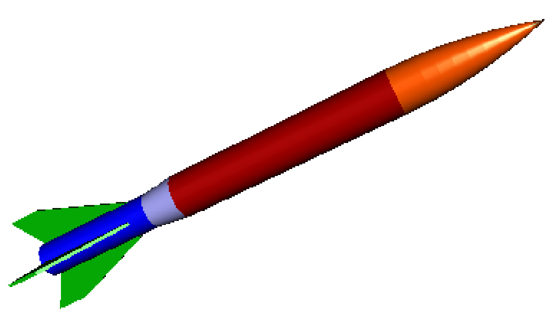
The body tubes were the least difficult to manufacture, with having a standard mailing tube and wrapping the outside of the tube in three layers of bi-directional carbon fiber. Prior to the lay-up process, the tubes were cut to size and sanded for a rough surface to allow the epoxy to have stronger bond to the cardboard. Due to the lack of funds, proper squeegees used to spread and squeeze out epoxy in the carbon fiber were not used. Instead spent gift cards and old library cards were used and just as effective.

The manufacturing of the fins was the most difficult to plan. The idea was to test a new way of manufacturing fins. In prior years, balsa or some other heavier wood was cut in the shade of the fin, then re-enforced with fiber glass. This was effective, but parts turned out to be very heavy for rocket. Here the new design was to have an inner foam core wrapped in bi-directional carbon fiber. The result would be light weight and sturdy with only two layers of carbon fiber. The Rocket Project, however, does not have a way to cut foam easily. Thus UCI's Human Powered Airplane project let the team use their CNC foam cutter. This allowed for the fins to be made accurately with respect to each other. After the fins were cut out, the leading and trailing edges were rounded off along with the tip cord for decrease in drag. Then the same lay-up process was used as in the case with the body tubes. A couple months after manufacturing the fins, an AIAA article was published in their magazine showing how the US Army is using the same design for rotor blades on their Black Hawk helicopters.

The Nose cone and transitional pieces were both 3D printed, but both were too large for the printer available. Thus they had to be printed in separate pieces and glued together with epoxy. Then both were wrapped in two layers of carbon fiber for re-enforcement. Both are to be hollowed out the reduces weight, but are still very strong for their size and weight due to the carbon fiber. The 3D printer did have issues printing the tip of the nose cone, so the tip was cut off and epoxy clay put instead. Once cured, the epoxy clay was sanded down to the proper point to give the right shape.

The bulk separating the parachute from the avionics bay as seen in the final design of the rocket bellow was made from birch wood and mounted with epoxy. The epoxy however was filled with small individual fibers of carbon fiber for added strength and technically are considered an epoxy. All pieces after this are mounted with fibers added as filler when the epoxy is mixed.

The motor mount was made from thick cardboard tubing and centered using Rocket wood centering rings. The fins when attached were mounted to the motor mount tube and slots cut into the tab of the fins, not exposed to the outside of the rocket. This allowed for the fins to slide over the centering rings. A thrust plate was made that the motor will push against causing the plate to push against the fins which in turn will apply the force against the body tube, propelling the rocket forward. Two metal clips were added to run parallel with the length of the motor mount and fastened using epoxy to retain the motor. There may not be a need for a retainer during flight of the rocket, but without these metal clips, the motor could fall out during deployment of the parachute.



Fact Sheet

Structure

Length: 40.85 inches

Diameter: 3.2”

Span: 7.6”

Mass= 1587 grams, 55.98 oz

Margin of Stability: 1.04

Parts

Nose Cone: Length: 9.6”; Diam. 3.2”

3D printed plastic, Wrapped in 2 Layers of Carbon Fiber composite

Larger Body Tube: Diam. 3.2”; Length: 17”

Cardboard Tubing, Wrapped in 2 Layers of Carbon Fiber composite

Smaller Body Tube: Diam. 2.6”; Length: 10”

Cardboard Tubing, Wrapped in 2 Layers of Carbon Fiber composite

Fins: Root Chord: 7.75”; Tip Cord: 2.5”; Semi-Span: 2.5”; Thickness: 0.25”; Sweep: 7”

Foam Core, Wrapped in 2 Layers of Carbon Fiber composite

Transitional Piece: Forward Diam.: 3.2”; Rear Diam.: 2.6”; Length: 2.5”

3D printed plastic, Wrapped in 2 Layers of Carbon Fiber composite

Motor

Motor Name: I357T (T marks that it burns blue)

Casing Size: 38/360

Length: 193 mm

Burn Time: 1.1 second

Total Impulse: 342.8 N-s

Total Thrust: 432.8 Newtons

LAUNCH SIMULATION (simulates launch from 65,500 ft.)

Altitude: 65,500 ft

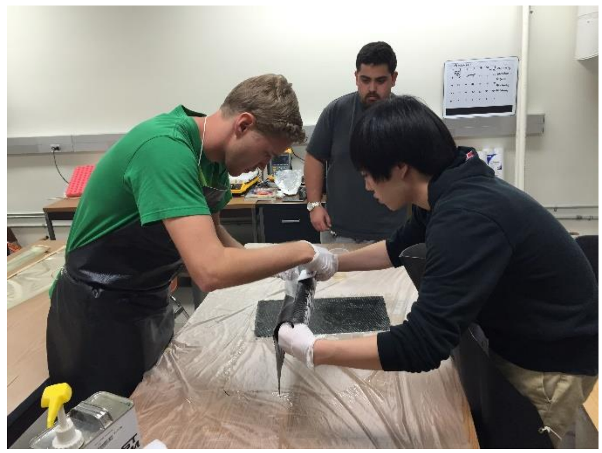
Temperature: -63 F, -52.78 C

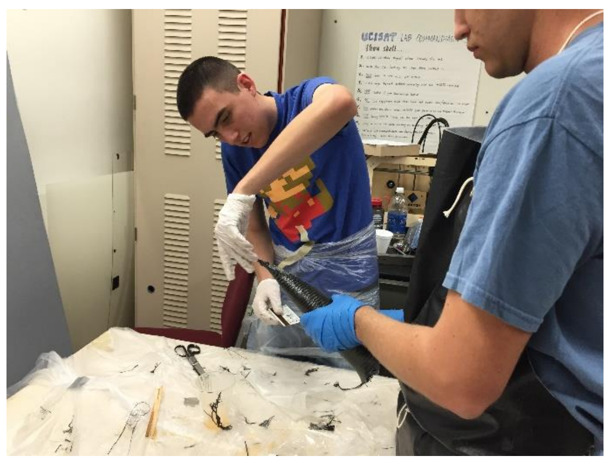
Atmospheric Pressure: 5,000 Pa, 0.050 Bar

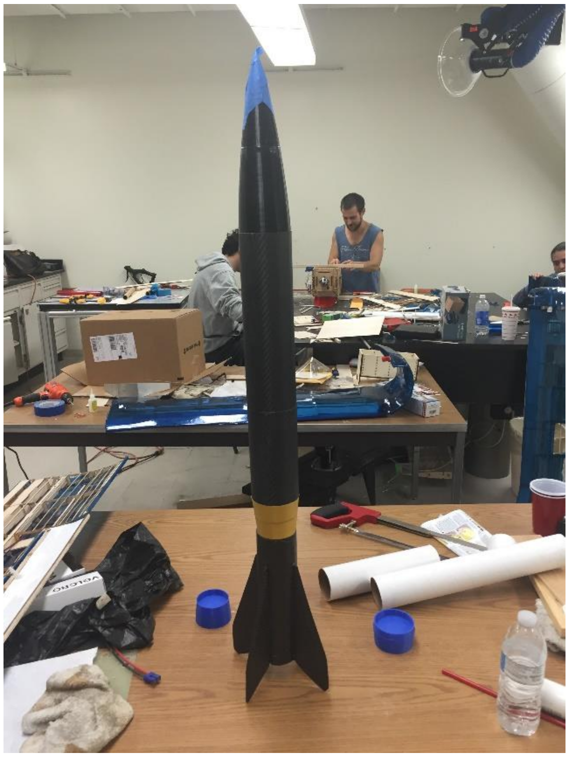
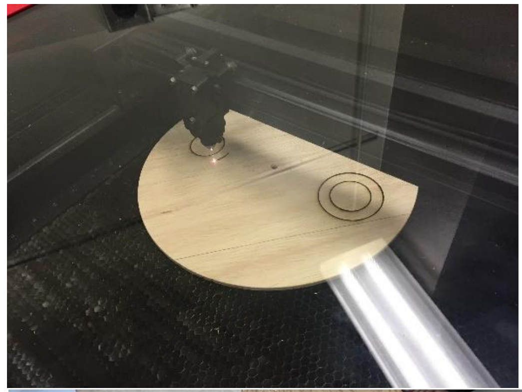
Approximate Apogee: 8200 ft.

Max Velocity: 708 ft/s

Max Acceleration: 929 ft/s^2




3.4 Rockoon Platform (Yuan Zhang)

We have two versions of the rockoon. The first rockoon version uses solar balloons, and the second version uses helium balloons. The solar balloon version is the best choice due to the extremely low cost and simple structure. However, the use of a solar balloon is highly restricted by area. We can only use the solar balloon method in an area that is cold and has a lot of sunshine. For example, the South Pole is the best place to use the solar balloon method. In order to use the rockoon in other areas, we also designed a helium balloon version, which is more expensive and complicated, but the launch cost is still lower than traditional launch method.

Design Approach

First of all, for both versions, the balloon connects to the platform directly without using strings because using strings causes the platform less stable. This is our experiment to show the influence of using strings:

https://www.youtube.com/watch?v=wUktgJpzvhc&feature=youtu.be

This is the video of same design without using strings.

https://www.youtube.com/watch?v=yxC_Ntc5odM&feature=youtu.be

The rest of the design choices of the Rockoon platform are single balloon, multiple balloons, fixed launcher, launcher with gimbal and launcher with string.

The next thing to determine is the number of balloons to use for each version. A multiple balloon system might have a tilt problem caused by unequal buoyancy force in each balloon. A single balloon system does not have tilt problem, but it needs to incorporate the use of a launcher in the system. We used latex weather balloons for the helium balloon version. A latex balloon is elastic and has a small neck. It is impossible to incorporate a launcher for the latex weather balloon. Therefore, the helium balloon version must use a multiple balloon design. For the solar balloon version, we used a trash bag to make a solar balloon. It is easy to incorporate the launcher for the solar balloon, so we used a single balloon for the solar balloon version.

Last thing is to find a suitable launcher design for each version. We have conducted experiments to compare each choice.

For a solar balloon version, we compared a launcher with gimbal and a fixed launcher. This is the video of launcher with gimbal:

https://www.youtube.com/watch?v=S3W4KGLyZhE&feature=youtu.be

This is video of fixed launcher:

https://www.youtube.com/watch?v=-d8vhSfO49Y&feature=youtu.be

From these videos, it is clear that the fixed launcher is more stable than the launcher with the gimbal. Therefore, we used a fixed launcher for the solar balloon version.

For the helium balloon version, we compared a fixed launcher, a launcher with the gimbal and a launcher with string. This is the video of the fixed launcher:

https://www.youtube.com/watch?v=YXQpnbYN34c&feature=youtu.be

This is the video of the launcher with the gimbal:

https://www.youtube.com/watch?v=yxC_Ntc5odM&feature=youtu.be

This is the video of the launcher with string:

https://www.youtube.com/watch?v=pPBHBEcinZw&feature=youtu.be

From these videos, the launcher with the gimbal is the most stable design.

Therefore, we choose the launcher with the gimbal for the helium balloon version.

Conclusion:

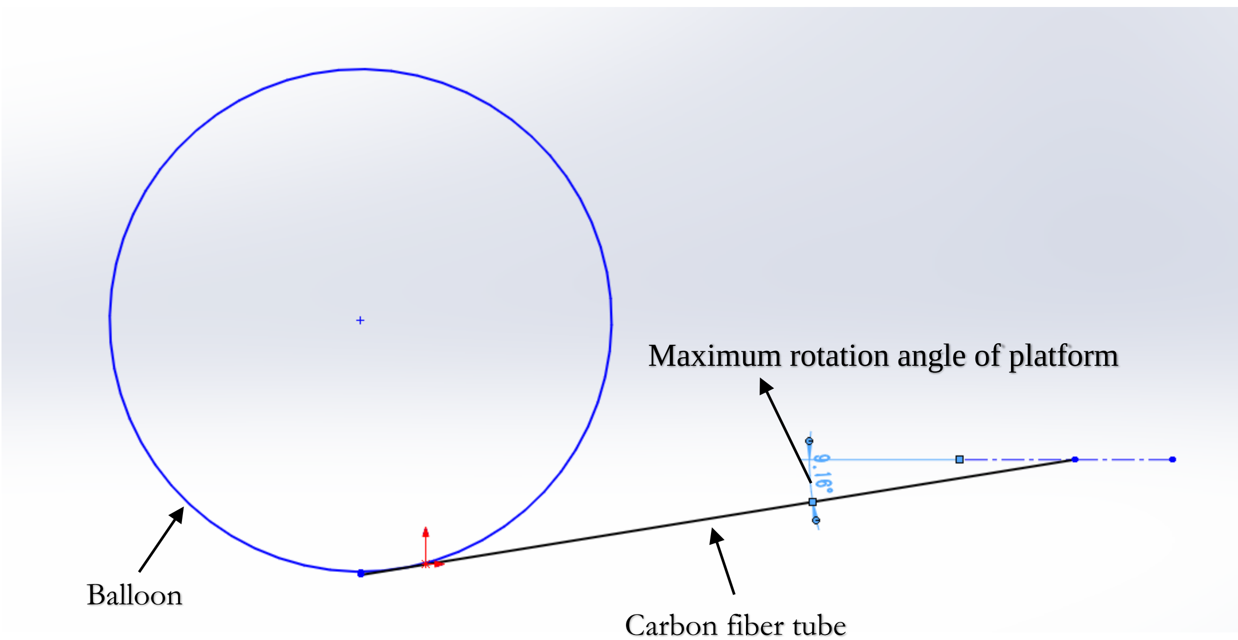
Solar balloon version: A single solar balloon with fixed launcher.

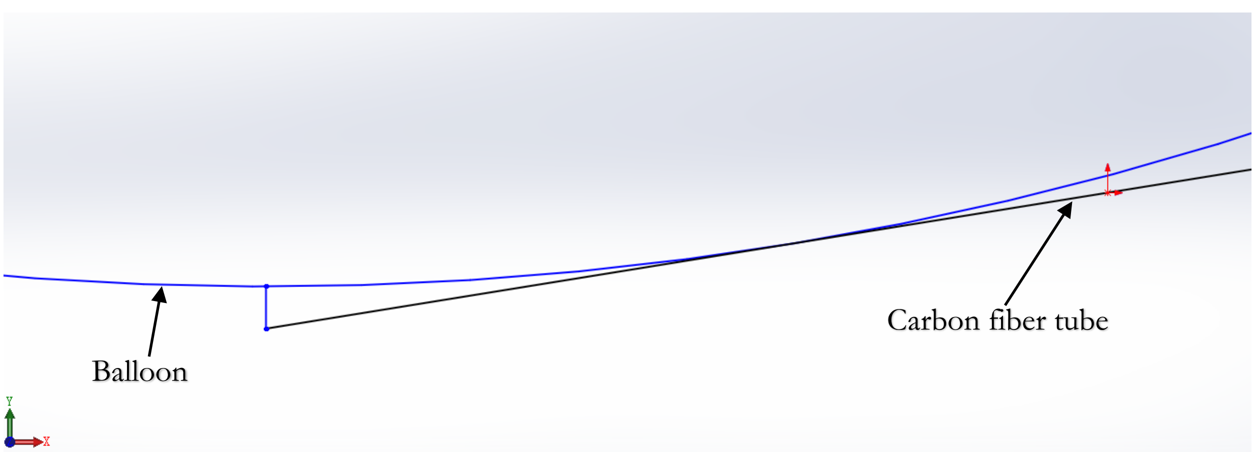
Helium balloon version: Multiple helium balloons with a gimbal system.

Helium Balloon Version Design

We can also see that if the buoyance force in each balloon is not equal, the platform will tilt until the smaller balloon hits the carbon fiber tube from the previous video. The angle at this situation is the maximum rotation angle of the platform. However, if the gimbal is placed at the point where the total moment at that point is zero, the platform will not tilt. This is a video to show this situation: https://www.youtube.com/watch?v=ctnoumMKaHE&feature=youtu.be

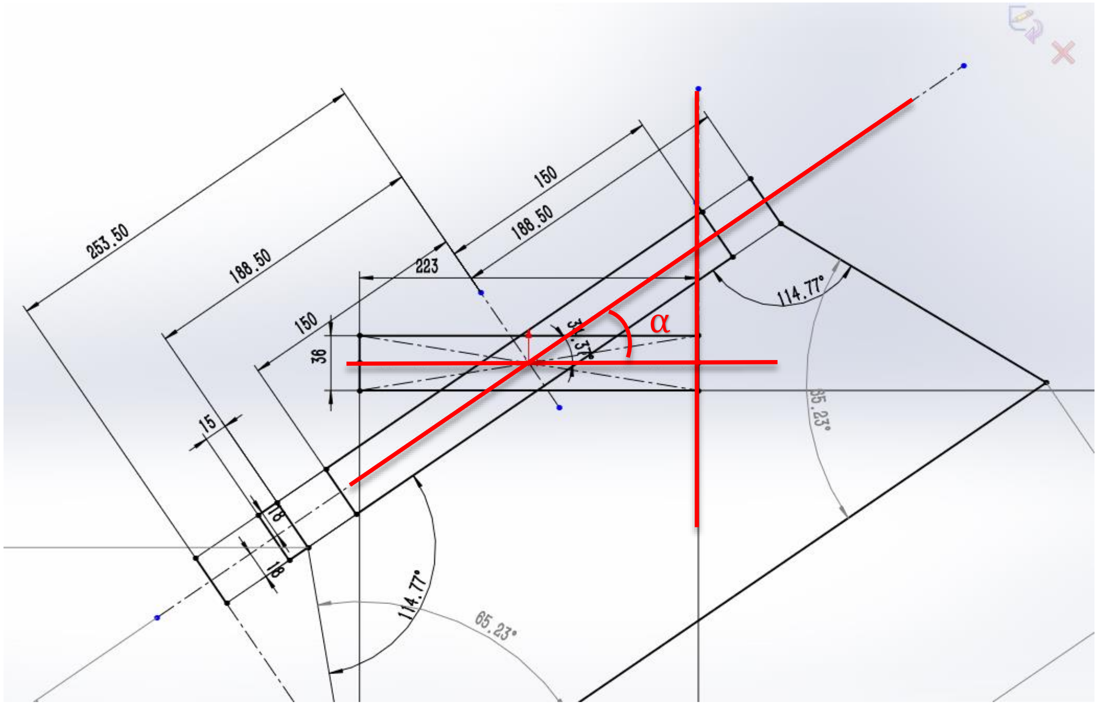
In our rockoon design, it is not feasible to move the gimbal to equilibrium position because the space above the launcher must be cleared. Therefore, we need to try our best to make sure the buoyance force is equal in each balloon. If the difference in buoyance force is small, the friction in gimbal system can provide a moment to make the total moment at the gimbal location be zero. If the difference is too large, the platform will tilt until it reaches the maximum angle. Therefore, gimbal system must be able to keep the launcher face up and launch rocket safely at the maximum rotation angle of platform. As reflected below in the pictures, the platform is at its maximum rotation angle. This situation occurs when the balloon skin makes contact with the carbon fiber tube.





Gimbal System

The most important design parameter of the gimbal system is the maximum rotation angle of the gimbal. This angle must be greater or equal to the maximum rotation angle of the platform. The maximum rotation angle of the gimbal occurs when the inner edge of the inner ring is perpendicular to the inner edge of the middle ring. The picture below shows this situation.



To simplify our design we used the same size of bearing, bolt and nut for all three rings. We also used the same thickness, height and spacing for all rings. In the equal spacing situation, the maximum rotation angle of the gimbal only relates to the inner and middle ring. We can use the geometry relationship to derive the way to design a gimbal system. In our design, the inner diameter of the inner ring is determined by the span of the rocket and the thickness of the nuts. The inner radius of the inner ring must satisfy the following equation.

$$r_1 = span\ of\ rocket + 2h_n + safety\_length$$

$$h_n: thickness\ of\ nut$$

The height and thickness (outer radius minus inner radius) of the gimbal can be determined by the bearing size. The size must be large enough to fit the bearing. With the information above, we can use the geometry to derive the expression of the inner radius of middle ring.

$$r_2 = \frac{r_1}{cos\alpha} + \frac{sin\alpha}{cos^2\alpha} \times \frac{h_g}{2}$$

$$r_1: inner\ radius\ of\ inner\ ring$$

$$r_2: inner\ radius\ of\ middle\ ring$$

$$\alpha: deisre\ maximum\ rotation\ angle\ of\ gimbal$$

$$h_g: height\ of\ gimbal\ ring$$

There is also a constraint of the thickness of the nut. The maximum allowable thickness of the nut at a given maximum rotation angle can be calculated by:

$$h_{n\_max} = tan\alpha \frac{h_g - d_n}{2}$$

$$h_{n\_max}: maximum\ allowable\ thickness\ of\ nut$$

$$d_n: outer\ diameter\ of\ nut$$

Then we can calculate the required length of the bolt.

$$l_b = r_2 - r_1 + h_n + w$$

$$l_b: length\ of\ bolt$$

$$w: thickness\ of\ gimbal\ ring$$

However, this length of the bolt might not be available in the market. We need to choose the closest and larger bolt length to continue the design. Then use the new length of the bolt to check whatever the spacing between the rings is greater than the drive size of bolt. Next, find the new$r_2 - r_1$, and then find the new r_2. Using r1 and new r2 to get the real maximum rotation angle. This angle will be larger than our desired one, but it is ok. The last step is to use the new spacing to find the inner radius of all three rings. We have developed a Matlab code to design the gimbal system.

$$\Delta r_{new} = l_{b_{new}} - h_n - w$$

$$\Delta r_{new}: new\ r_2 - r_1$$

$$s_{new} = \Delta r_{new} - w$$

$$s_{new} > D_h$$

$$s_{new}: new\ spacing\ between\ gimbal\ ring$$

$$D_h: drive\ size\ of\ bolt$$

$$l_{b_{new}}: new\ length\ of\ bolt$$

$$r_{2_{new}} = \Delta r_{new} + r_1$$

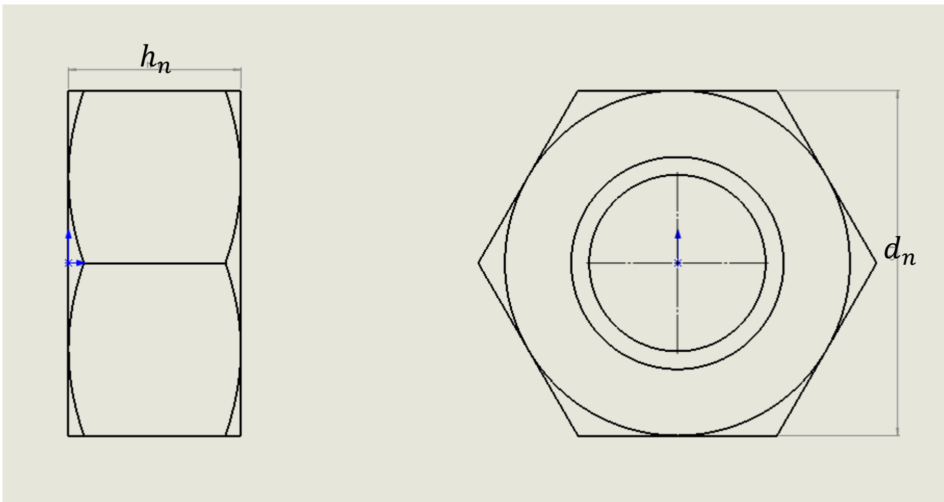
$$r_{2_{new}}: new\ inner\ radius\ of\ middle\ ring$$

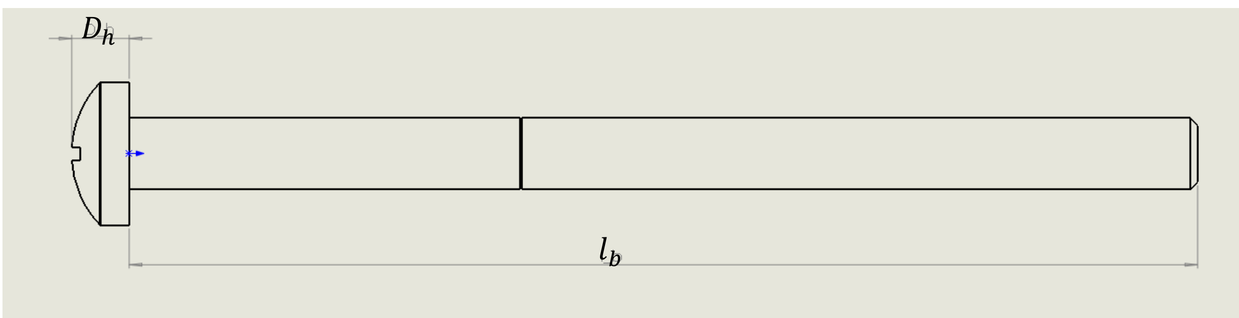
Solve for α_{new}: $r_{2_{new}} = \frac{r_1}{cos\alpha_{new}} + \frac{sin\alpha_{new}}{cos^2\alpha_{new}} \times \frac{h_g}{2}$

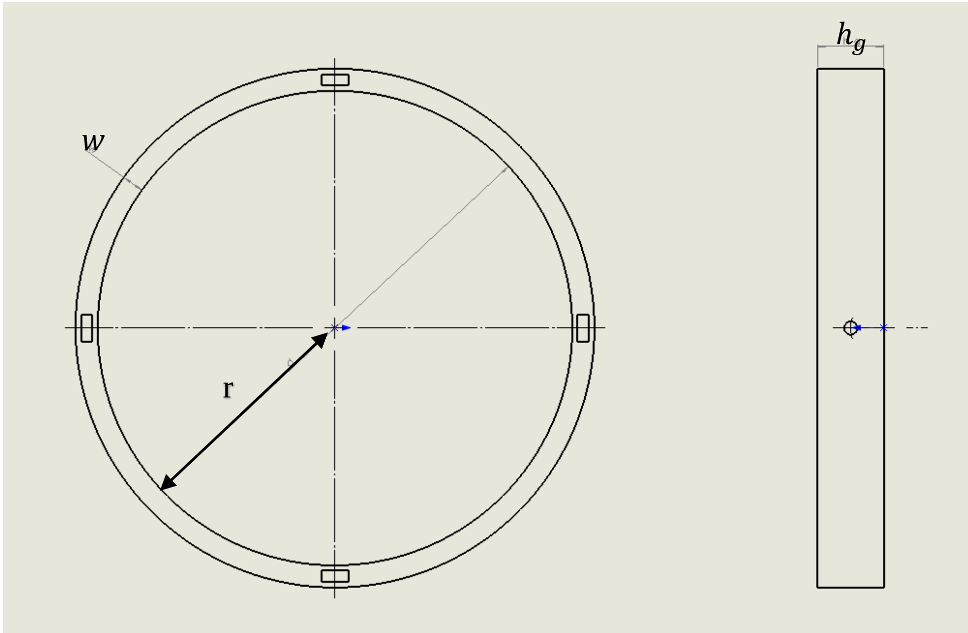
$$\alpha_{new}: new\ maximum\ rotation\ angle$$

$$r_3 = r_{2_{new}} + \Delta r_{new}$$

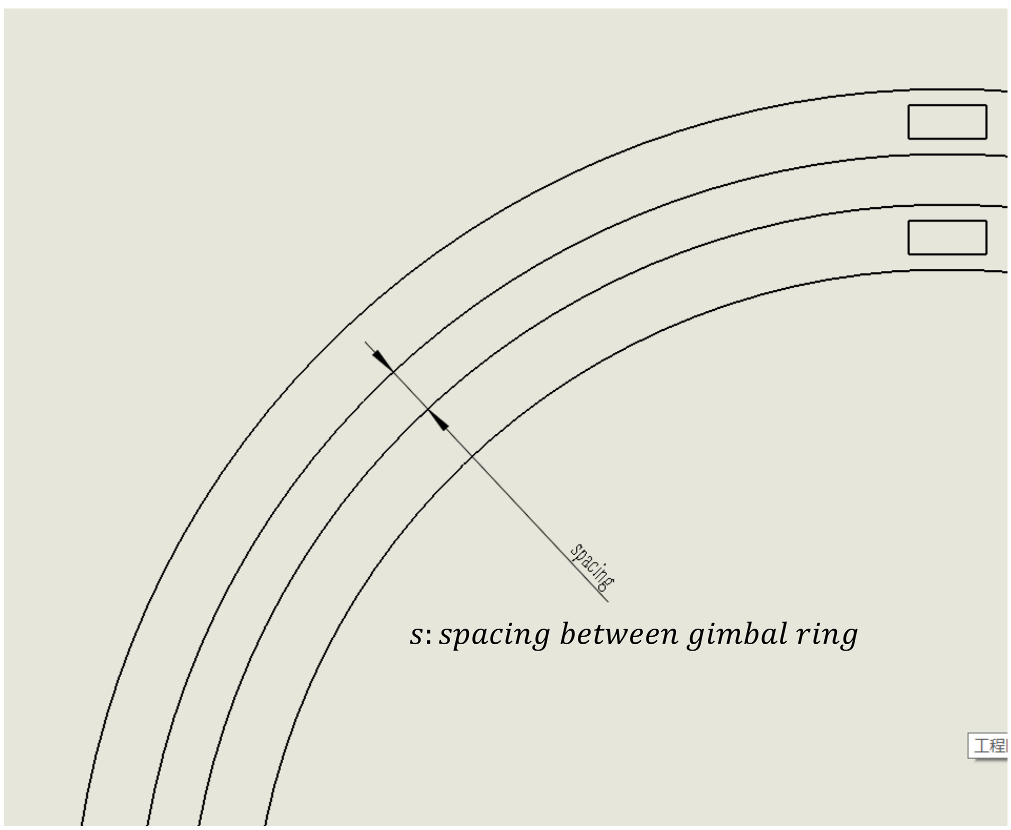
$$r_3: inner\ radius\ of\ outer\ ring$$







h_g
w
r



spacing
s: spacing between gimbal ring

Gimbal calculation code refer to Appendix A code 7.

The following are the design results for prototype 2:

α : Desire maximum rotation angle: 30 degrees

h_n: Thickness of nut (mm):6.5

d_n: Diameter of nut (mm): 13

w : Thickness of gimbal ring (mm): 15

h_g: Height of gimbal ring (mm): 36

r1=111.5mm

r2=150mm

r3=188.5mm

α_{new}: Real maximum rotation angle: 34.37

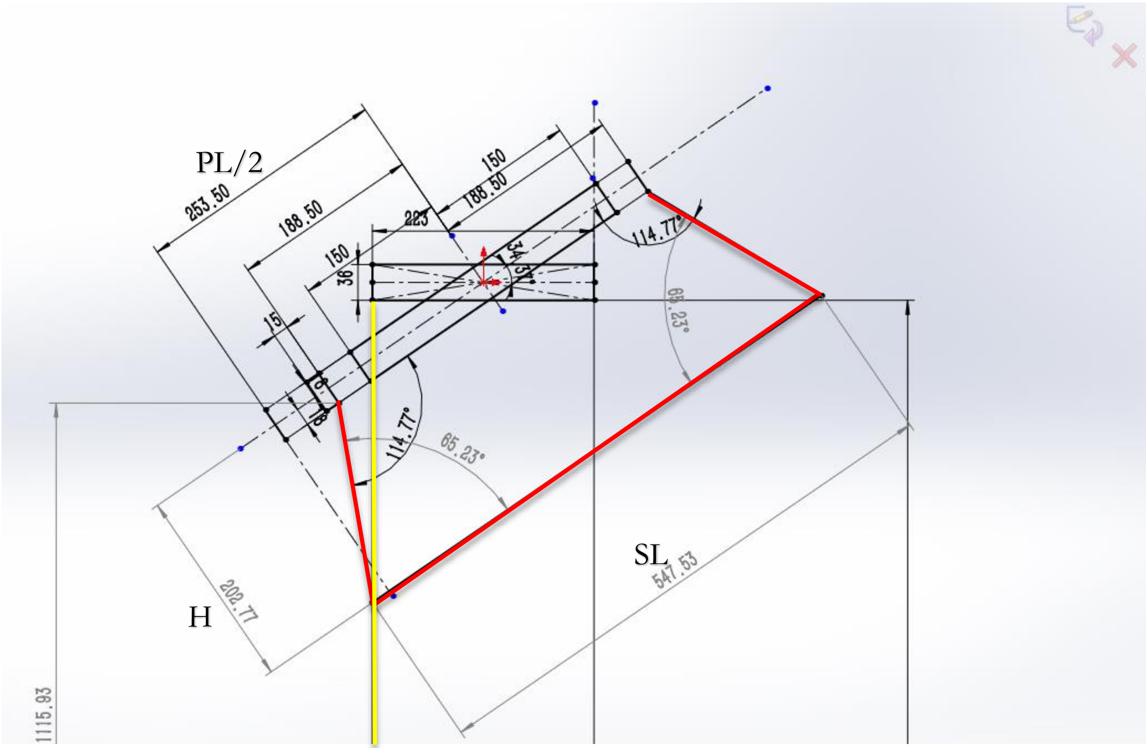
$l_{b_{new}}$: Bolt length (mm): 60

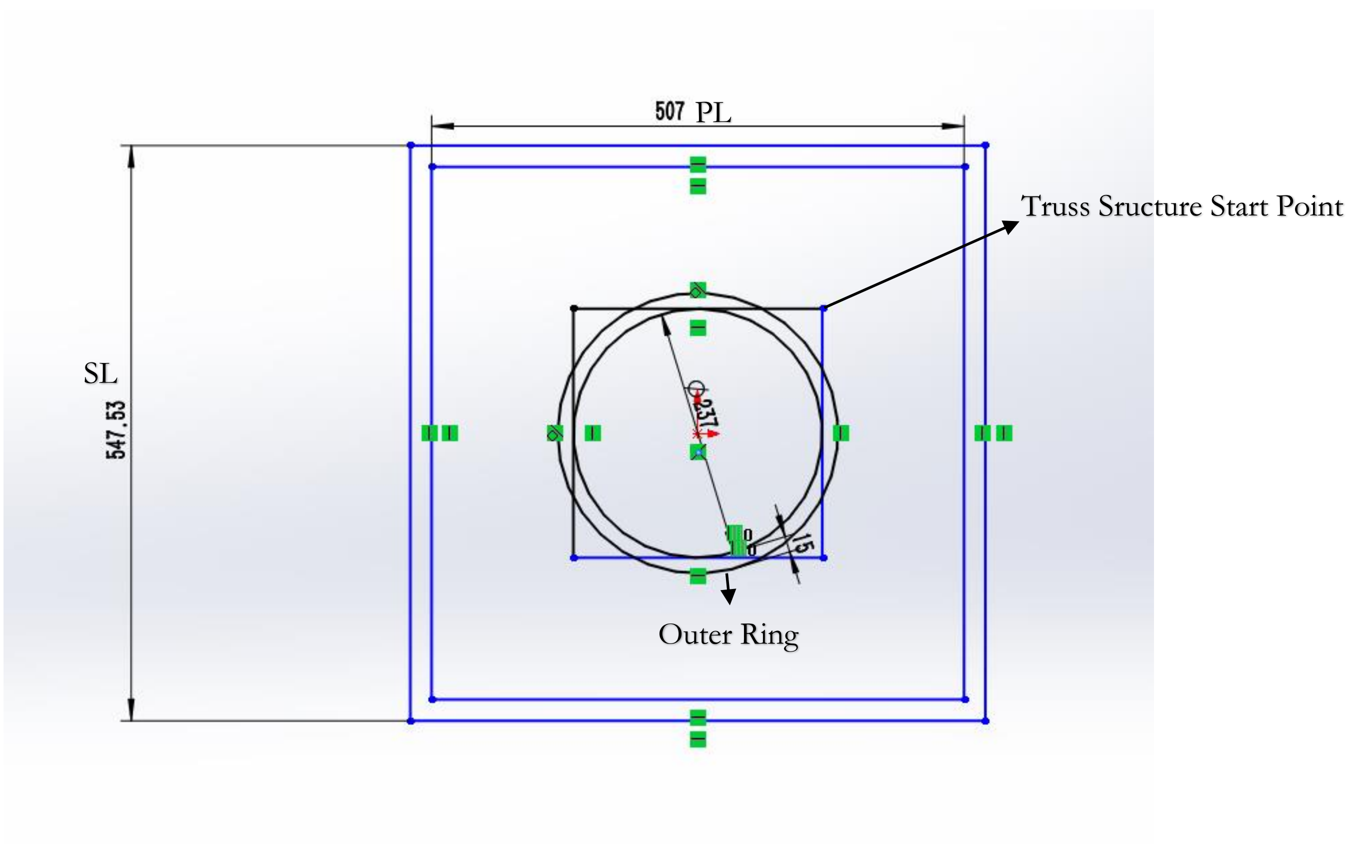
Truss Structure

The beam that connects to the balloon must be extremely long, thus a huge bending moment will occur in the beam. We need to design a truss structure to reduce the bending moment on the beam. This truss structure also can limit the rotation of gimbal at its maximum rotation angle. We used a finishing line to reduce the bending moment at beam. We need to ensure the finishing line will not fail, and the beam can survive when all finishing line fail. Because the design is based on literation, we have developed a code to help us design.

Truss structure calculation code refer to Appendix A code 8.

First thing is to decide the geometry of the square plate that holds the gimbal and beam. In order to have space for avionics and the beam, the side length of square plate (PL) should be equal to 507mm for our prototype 2. Then we need to use Solidworks to draw the situation that angle between the centerline of the inner ring and middle ring is equal to real maximum rotation angle (α_{new}). The outer ring is parallel with middle ring, and the truss structure starts from the inner edge of outer ring. The following two pictures shows this situation. Start literation by drawing a line start from inner edge of outer ring to any point in the extension line of inner edge of ring. The truss structure is highlighted in red. The extension line of the inner edge of the inner ring is highlighted in yellow. From the below situation, we get that the span of the truss structure (SL) is equal to 547.53mm. Next, we used Solidworks to measure the height of the truss structure (H). From the picture, we can see that height is equal to 202.77mm. SL and H are the parameters that we have to change each time in literation. We redid the above process until the results from the code were close to our desired safety factor, and in the emergency situation, the carbon fiber tube will not fail. In our design, we used a safety factor of 2.





The code algorithm is as follows. All data are from prototype 2.

First we need to know the maximum force that the string can tolerance (F_{max}), total weight of prototype 2 (W), desired safety factor (SF), length of the carbon fiber tube (RL), length of the carbon fiber tube that is inserted into the square plate (IN), inner diameter of the carbon fiber tube (ID), outer diameter of the carbon fiber tube (OD), tensile strength of the carbon fiber (T), number of carbon fiber tube (n_c), and the number of strings (n_s).

Second, we started to calculate the emergency situation that all finish lines fail. In this case, the carbon fiber tube had its maximum bending moment. We needed to make sure in this situation that the carbon fiber tubes would not fail.

$$Outer\ radius\ of\ carbon\ fiber\ tube$$

$$r_o = \frac{OD}{2}$$

$$Inner\ radius\ of\ carbon\ fiber\ tube$$

$$r_i = \frac{ID}{2}$$

$$Moment\ of\ inertia$$

$$\mathrm{I} = \frac{\pi}{4} \times (r_o^4 - r_i^4)$$

$$Effective\ length$$

$$l_{eff} = RL - IN$$

$$Bending\ Moment$$

$$M = \frac{W \times l_{eff}}{n_c}$$

$$\mathrm{Stress} = \frac{M \times r_o}{I}$$

$$\mathrm{Stress} < \mathrm{T}$$

Third, we wanted to ensure the string in certain truss structure designs had a safety factor that is greater or equal to 2.

First, we find the vertical (z) component of force of each string

$$F_z = \frac{W}{n_s}$$

Then, find the maximum force that is allowed in each string.

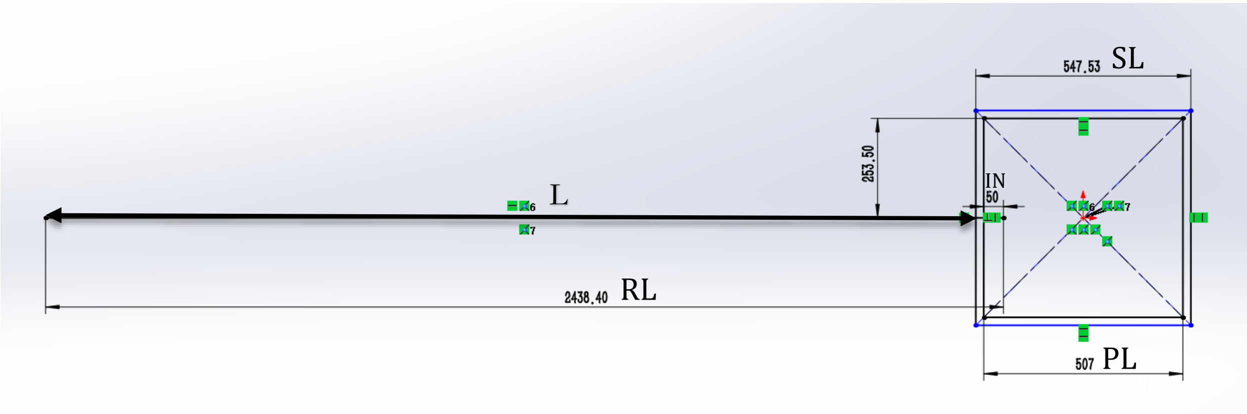
$$F_{SF} = \frac{F_{max}}{SF}$$

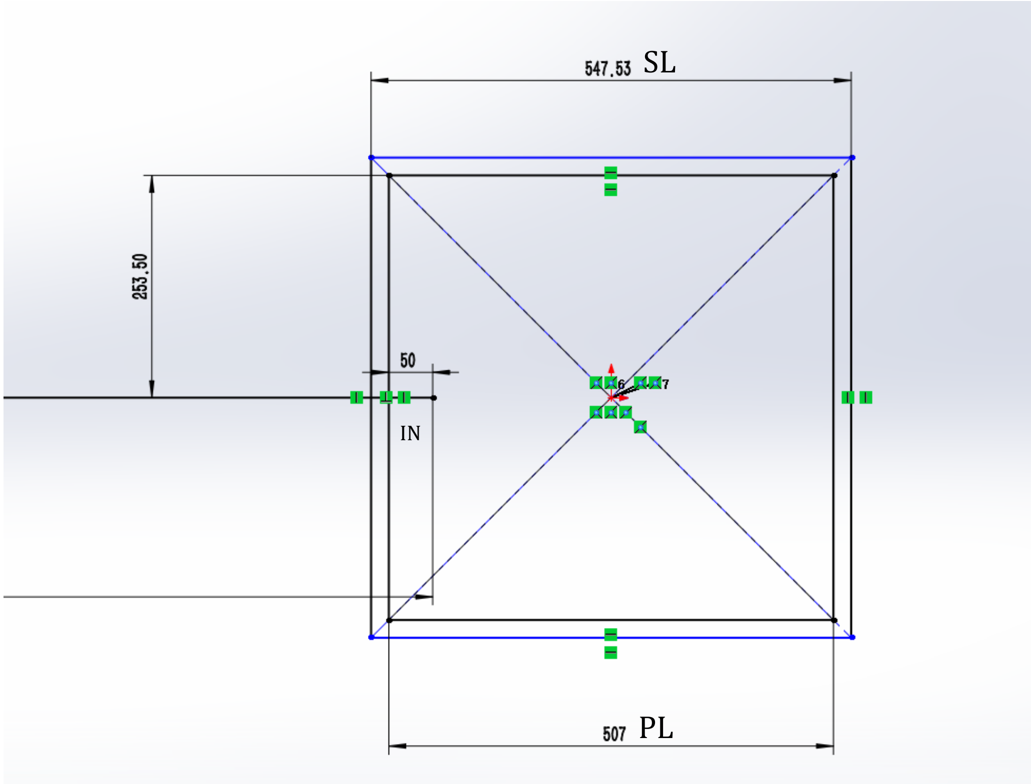
Next, we compute the length of each fishing line.

$$\mathrm{L} = \mathrm{RL} - \frac{SL - PL}{2} - IN$$

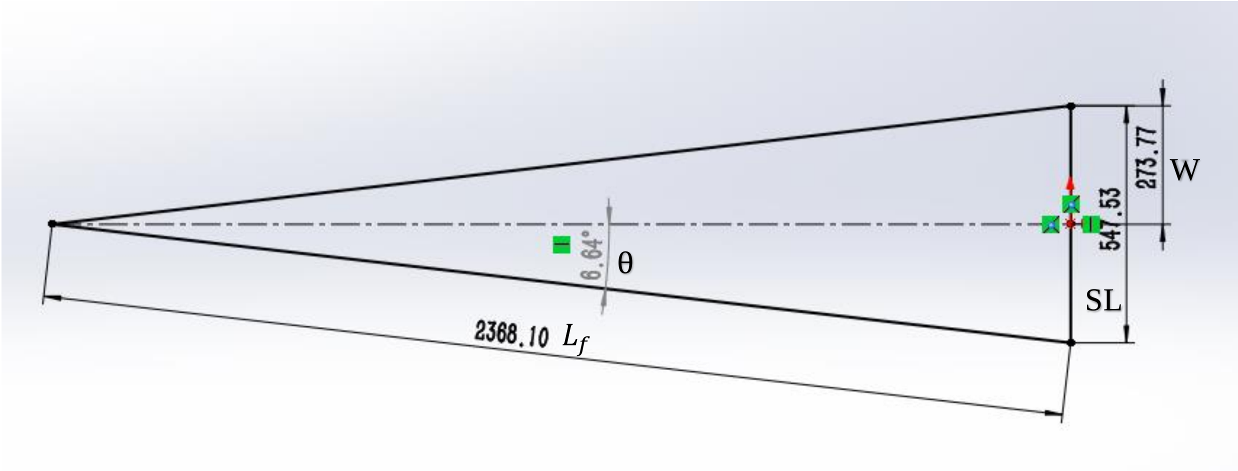
$$\mathrm{W} = \frac{\mathrm{SL}}{2}$$

$$L_f = \sqrt{L^2 + W^2 + H^2}$$



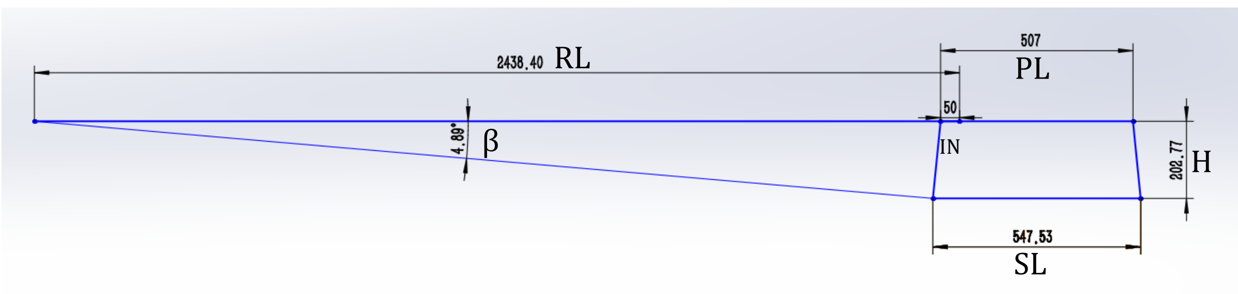


We need to find the angles to decompose the force in the fishing line to x, y, and z direction. First, using L_f and W to find the angle that decomposes the force to x direction and y-z plane.



$$\theta = sin^{-1}(\frac{W}{L_f})$$

Second, we find the angle that decompose the force to the y and z direction.



$$\beta = tan^{-1}(\frac{H}{L})$$

Lastly, we can use these angles and F_z to find the force in the fishing line.

$$F_{yz} = Fcos\theta \qquad F_x = Fsin\theta$$

$$F_z = F_{yz}sin\beta = Fcos\theta sin\beta$$

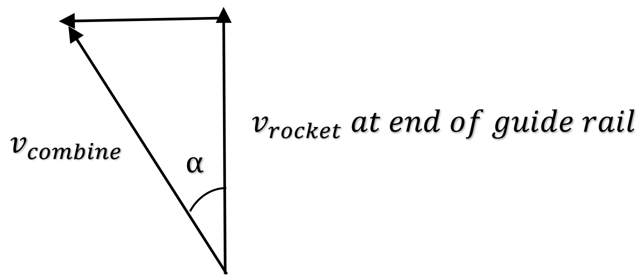
$$F = \frac{F_z}{cos\theta sin\beta} < F_{SF}$$

$$SF_{actual} = \frac{F_{max}}{F} \geq SF$$

<u>Guide Rail</u>

We have to find out the length of the required guide rail. The length is decided by the engine specification, maximum angle of attack after leaving the rail, and maximum wind speed.

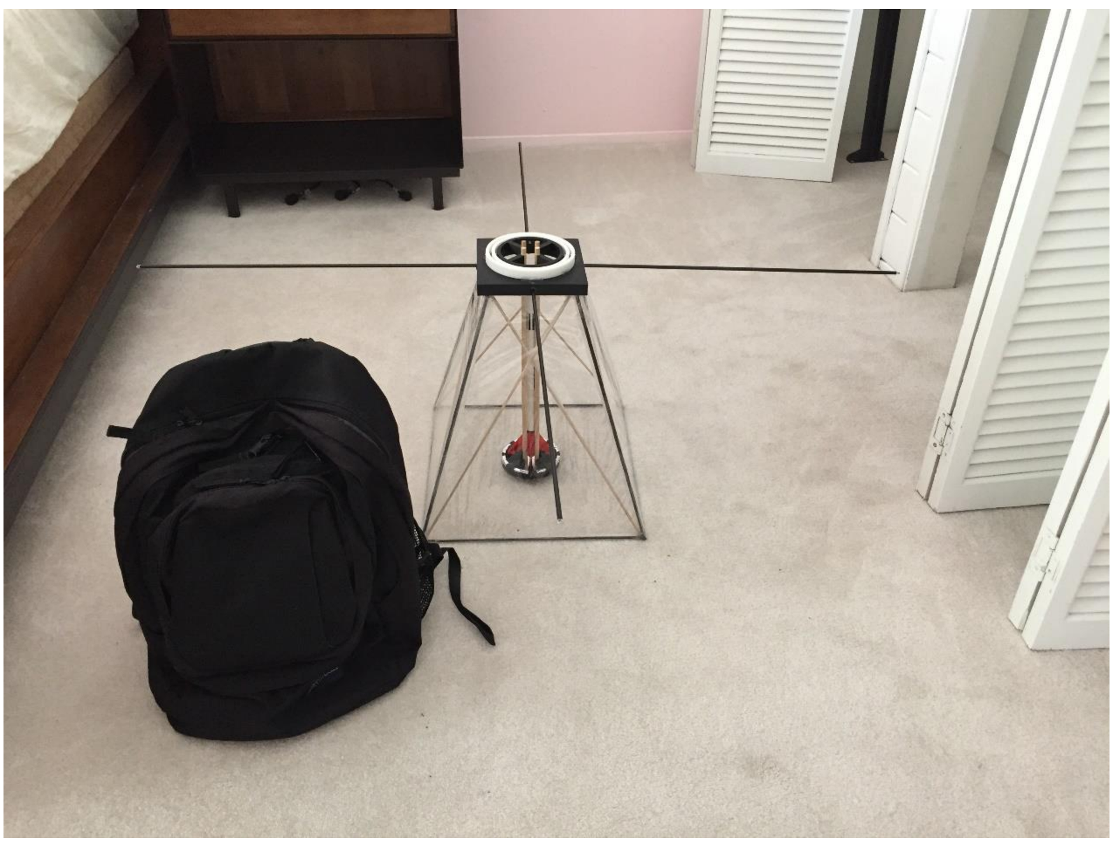
For example, in our prototype 2 design, we wanted the rocket to be launched safely at the maximum wind speed of 5mph. At this wind speed, the maximum angle of attack should be 5 degrees. The angle of attach is the angle between the combined velocity of wind and the rocket velocity. By using simple vector calculation, we know the safety velocity that the rocket should attain at the end of guide rail. Then we used a simulator to find at what altitude the rocket will reach that speed, and that altitude is the length of the guide rail. For our prototype, the velocity of the rocket at the end of the guide rail should be equal to 25m/s and from the simulator the length should be 1.123m.

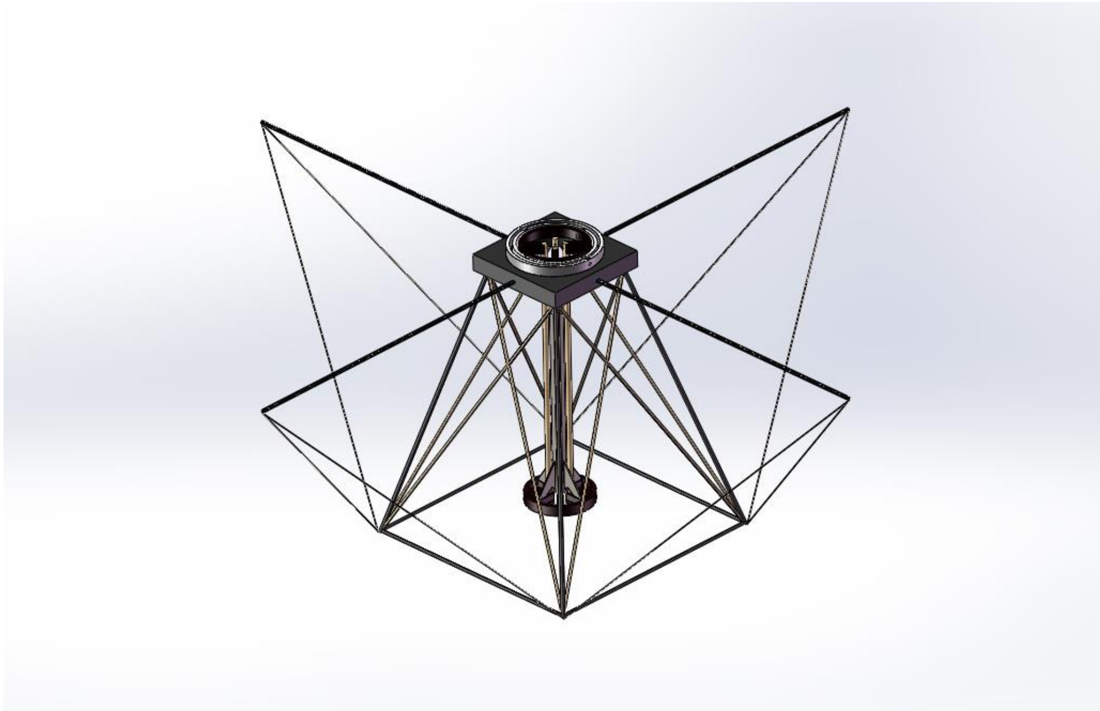


α: angle of attack

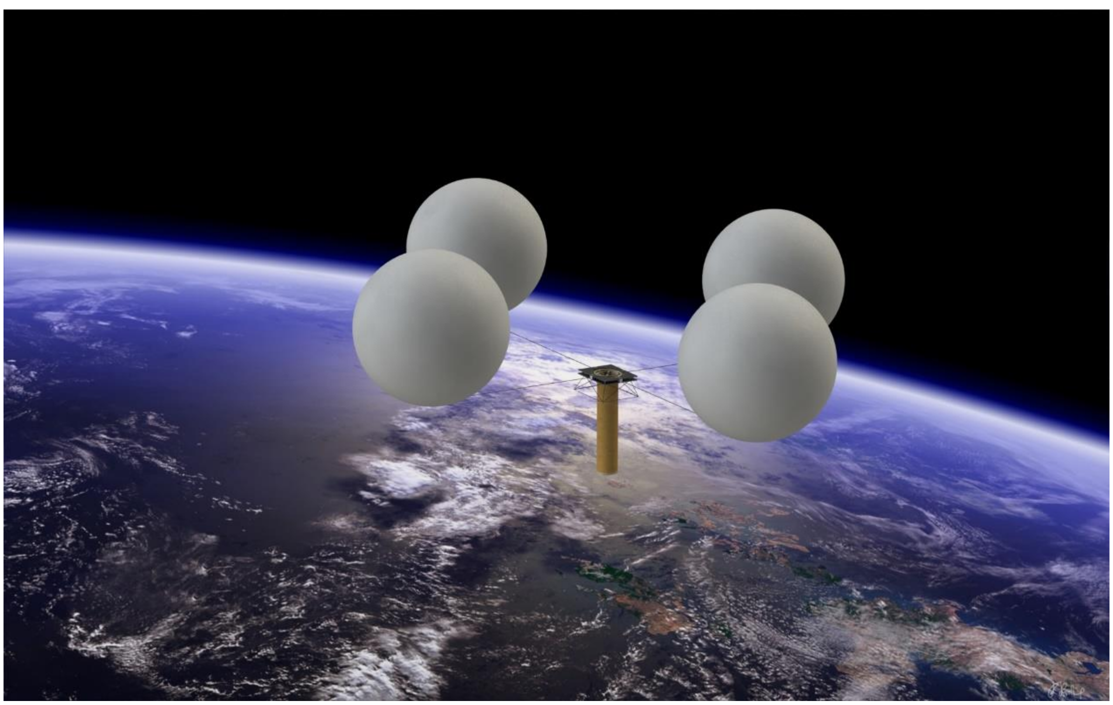
$$v_{rocket} \text{ at end of guide rail} = \frac{v_{wind}}{\tan\alpha}$$

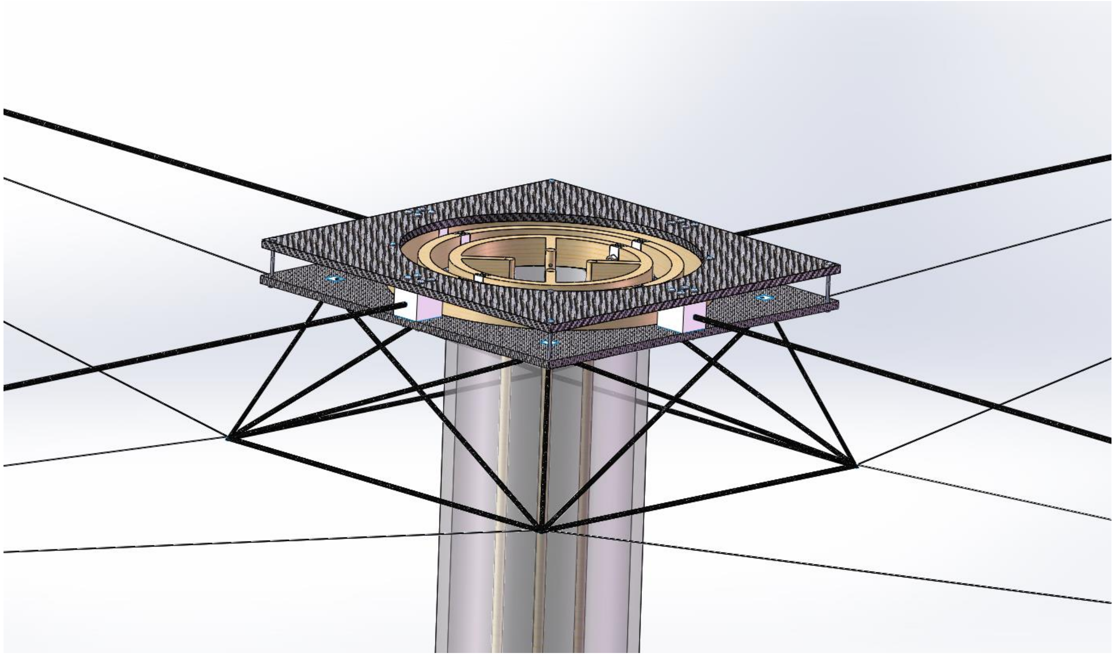
Helium Balloon Version Prototype 1

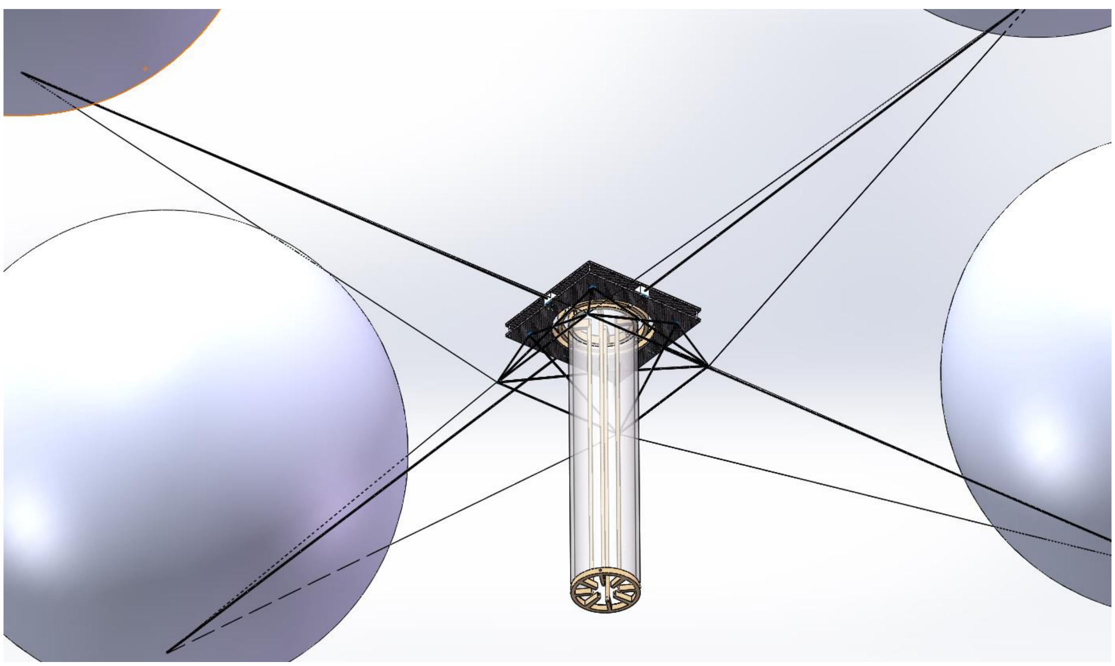


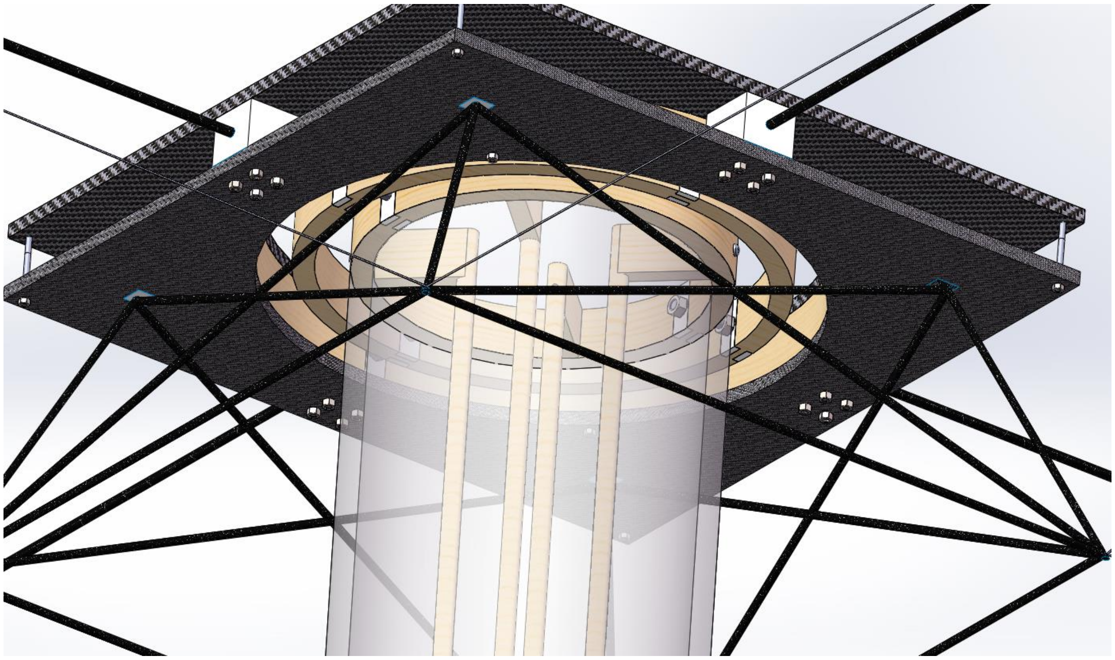


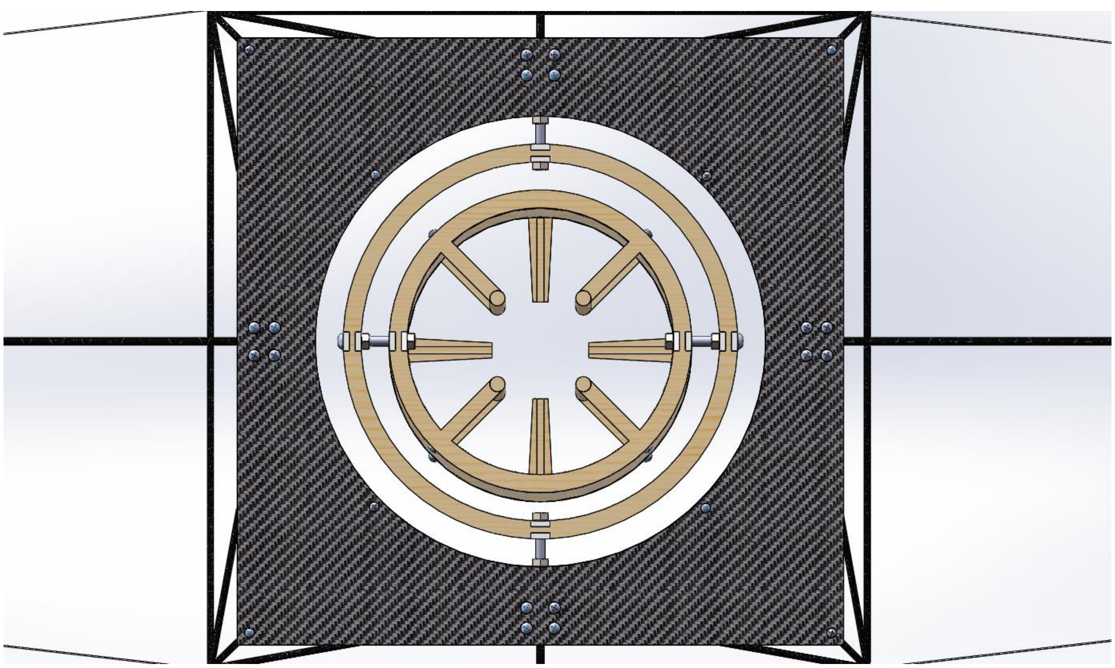
Helium Balloon Version Prototype 2

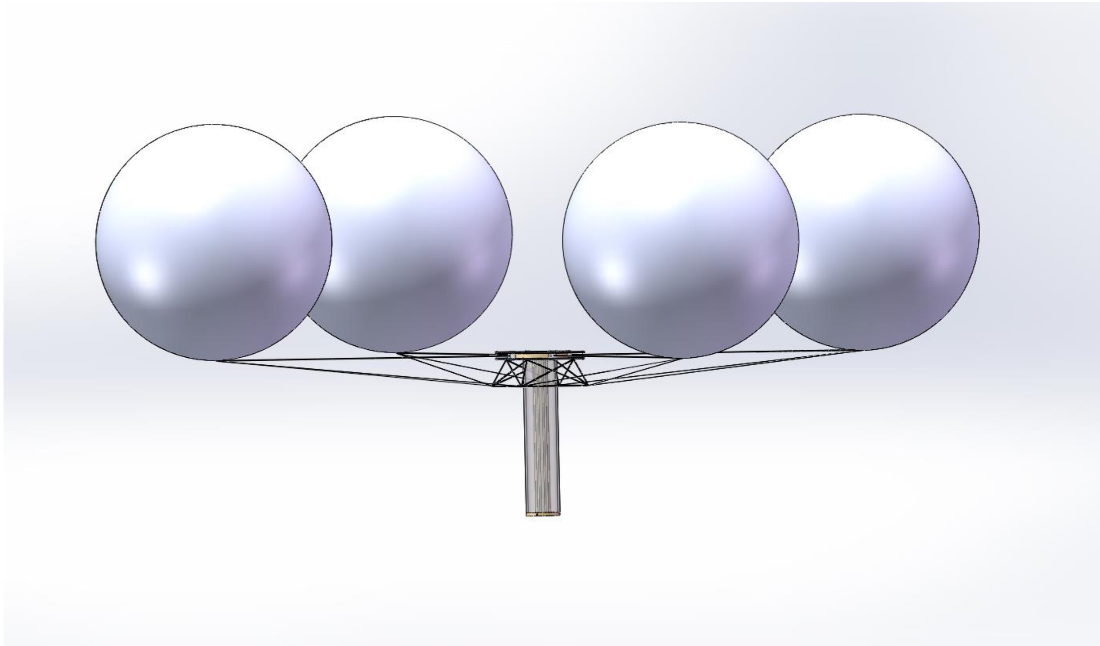






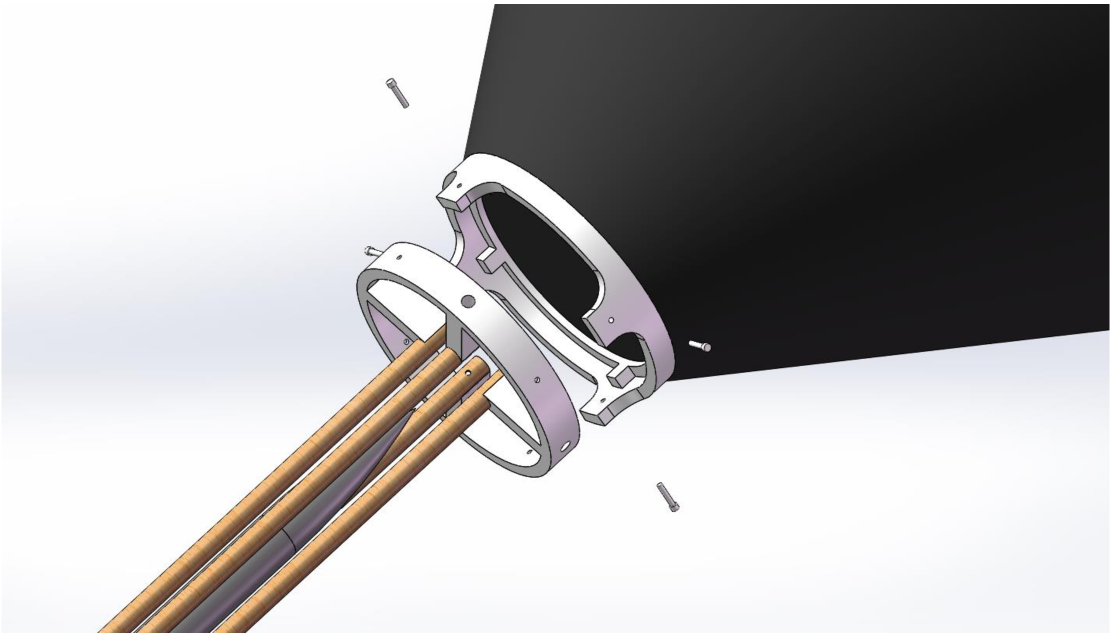


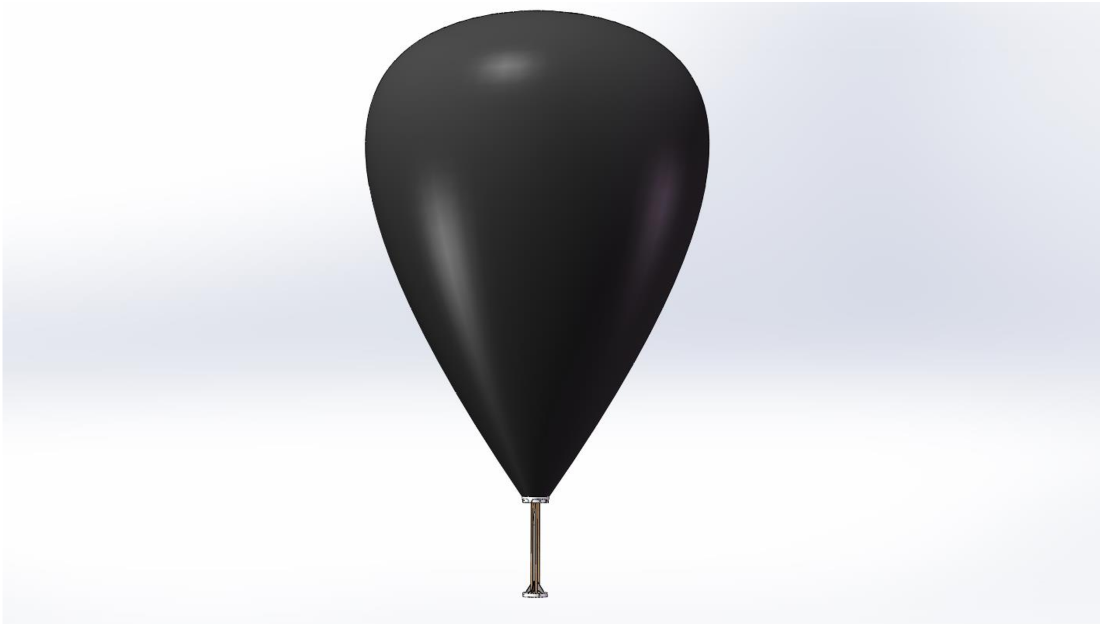


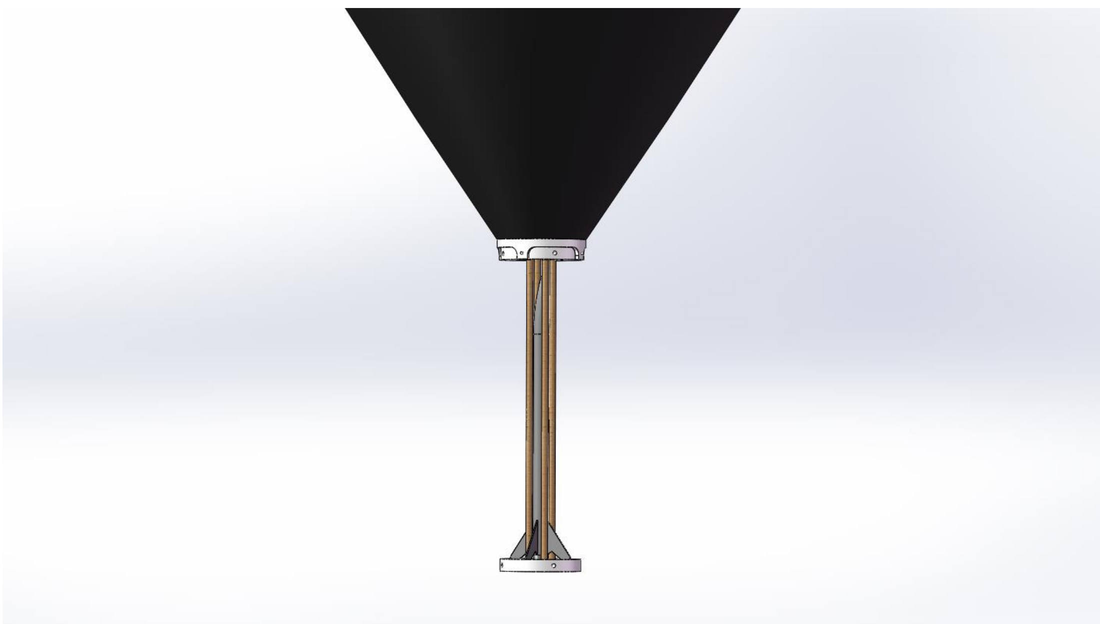


Solar Balloon Version Design

We only needed to design a connection part for the solar balloon version. The connection part will be taped in the balloon.

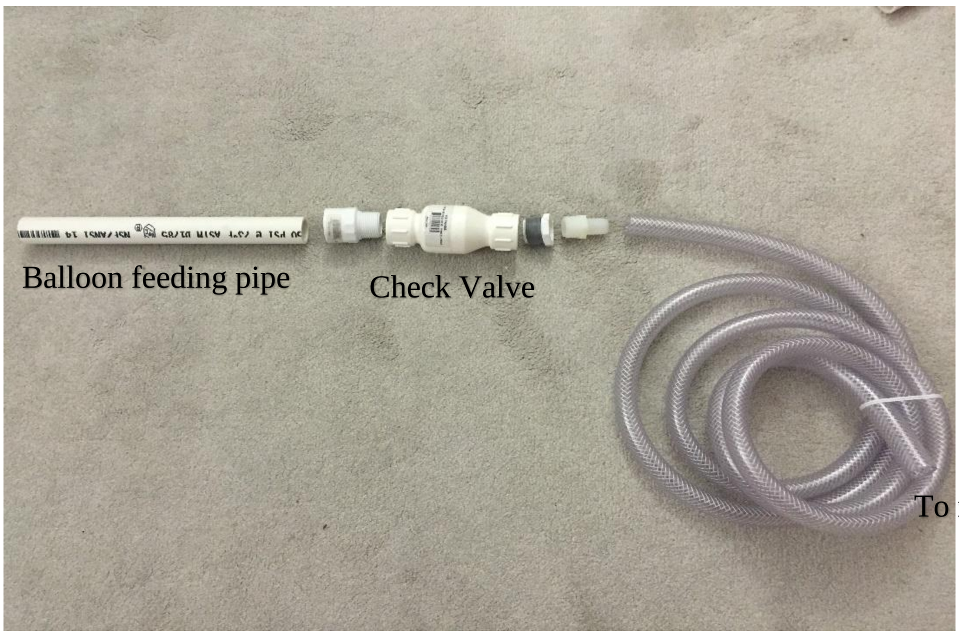


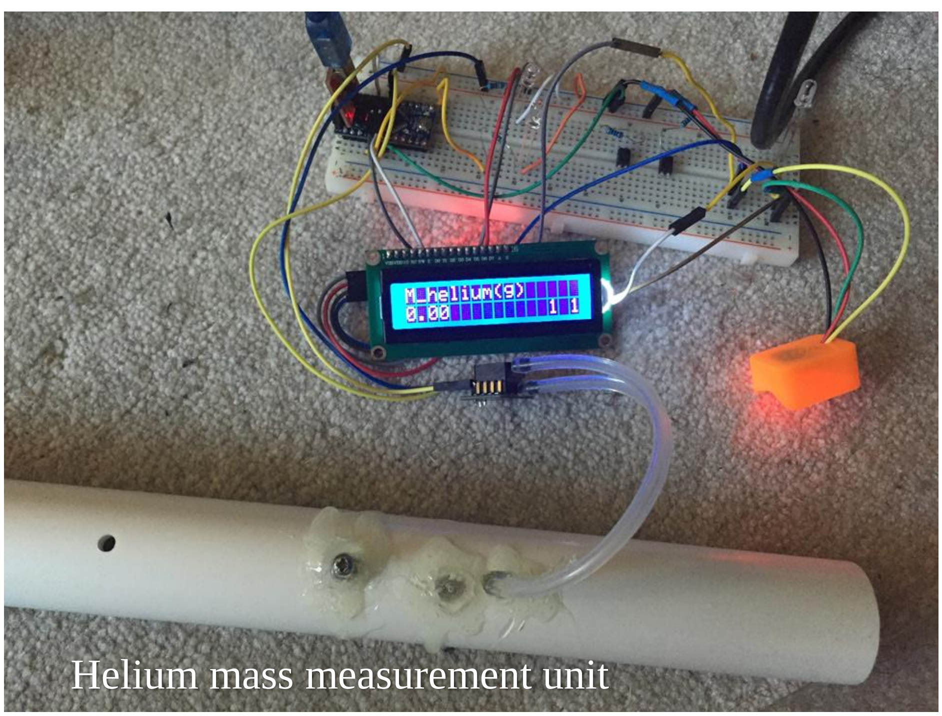




3.5 Helium Balloon Filling System (Yuan Zhang)

From the prototype 1 test, we found out that a system that can measure the mass of helium filled in the balloon is necessary. This system should also help us measure the lift generated by the balloons. Helium first runs into the helium mass measurement unit. It is a PVC pipe with Pitot tube, temperature and barometric sensors installed. By using those devices and fluid mechanics, we can get the mass of helium that has passed through the unit. Then helium runs through a check valve (one way valve). Finally, helium goes into balloon. We can stop the filling at any time and measure the lift without removing the balloon. If the lift is not enough, we can continue filling. The following pictures show the system design.





Design Approach

Design Goal

We want the system to be able to fill the balloon that has a size of 2.57 cubic meters in 3 minutes. I assume the pressure is 1 atm and temperature is 20 degree Celsius for all design approaches. Using the density of helium at this condition, the required mass of helium is 428.52g. The required mass flow rate is 2.38g/s

$$\rho = \frac{P}{RT}$$

$$\dot{m} = \frac{m}{t}$$

Ideal Situation

For the best accuracy, we want the following conditions to be satisfied.

(1) Incompressible flow: M<0.3
We want to use Bernoulli equation, so the flow must be incompressible.

$$M = \frac{V_{average}}{\sqrt{\gamma RT}}$$

Where R is specific gas constant, and it is independent from pressure and temperature. For helium, R=2077J/kg·K. Helium is monatomic gas, so C_p and C_v are constant. Since $\gamma = \frac{C_p}{C_v}$, γ is also a constant. For helium, $\gamma = 1.667$.

(2) Laminar Flow: $\mathrm{Re} < 2100$
For laminar flow in the pipe, there is only the component of velocity, so the estimation of volume flow rate by using the centerline velocity detected by a Pitot tube will be more accurate.

$$\mathrm{Re} = \frac{V_{average}D}{\nu}$$

(3) Fully developed laminar flow: $l_e \le l$

$$l_e = 0.06\mathrm{ReD} < \mathrm{l}$$

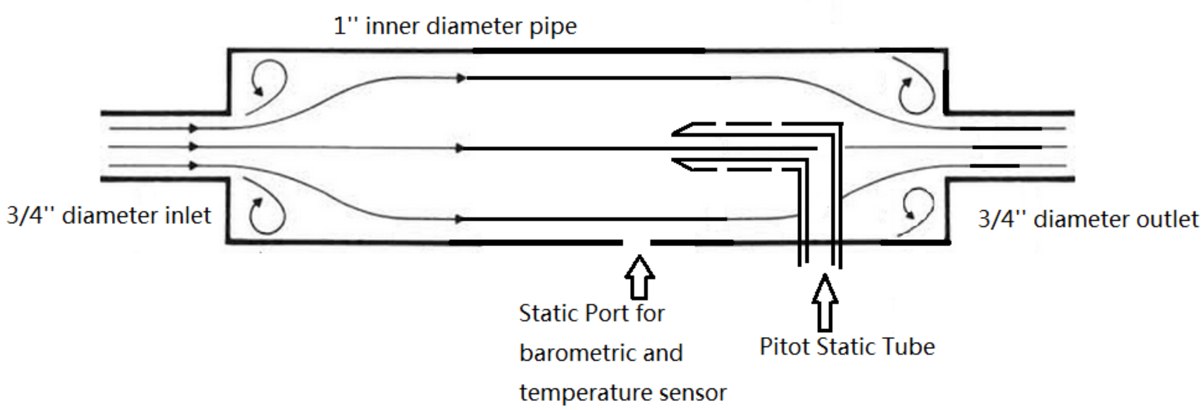
In order to get an accurate volume flow rate, we want the accurate $V_{average}$ in the tube. In fully developed laminar flow, the average velocity is equal to half of the centerline velocity. Therefore, if we place the Pitot tube at the centerline to measure the centerline velocity and the flow is a fully developed laminar flow, we can get an accurate $V_{average}$.

$$V_{average} = \frac{V_{centerline}}{2}$$

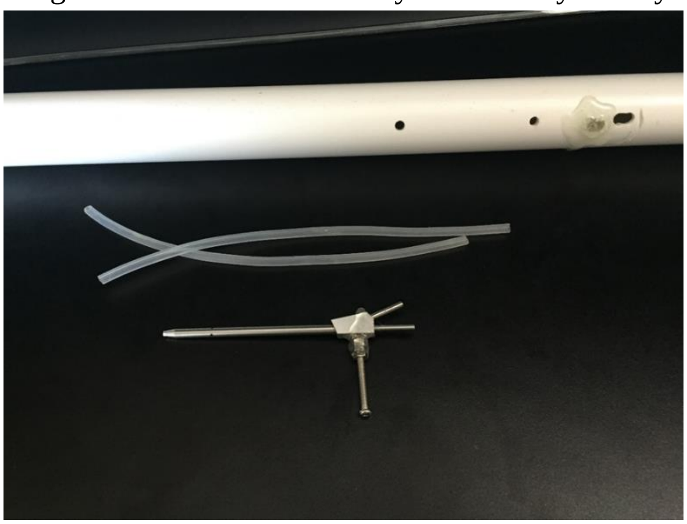
$$\mathrm{Q} = \mathrm{A}V_{average}$$

Helium mass measurement unit specification

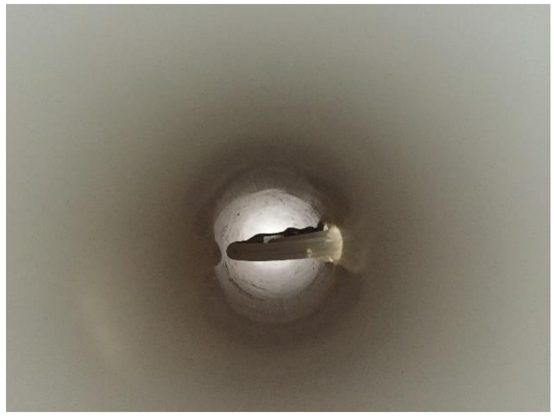
2ft (60.96cm) PVC pipe with 1 inch (0.0254m) inner diameter.
3/4 inch inlet and outlet.
Distance from inlet to the entrance of Pitot static tube: 0.5m
Tube length before helium mass measurement unit: 3m



Because there is a sudden expansion in the inlet and a sudden contraction in the outlet, streamline near the inlet and outlet will not be straight. In order to get a reliable reading. I place the entrance of Pitot static tube near the middle of helium mass measurement unit, and the static port is drilled right before the tip of pitot static tube. At that position, the streamline is most likely to be straight and the flow most likely has velocity in only one direction.



Pitot Static tube



Pitot static tube mounted in the unit.

Situation that meets the design goal

$$\dot{m} = \rho V_{average} A$$

$$V_{average} = \frac{\dot{m}}{\rho A} = 28.227\text{m/s Incompressible flow}$$

$$\text{Re} = \frac{V_{average} D}{\nu} = 6113 > 4000\ Tubrblent\ flow$$

$$Entrance\ length\ for\ turblent\ flow: l_e = 4.4(Re)^{\frac{1}{6}} D = 0.478m$$

$$l = 0.5m > l_e\ Fully\ developed\ turblent\ flow, Incompressible$$

Therefore, if we use this system to attain the design goal, the flow must be fully developed turbulent flow. We cannot have the best mass approximation for current design goal because we cannot have a good $V_{average}$ approximation due to the property of turbulent flow. We have to reduce the mass flow rate in the system to achieve the laminar flow or, at least, transition flow.

The design goal cannot be reached by this system in ideal situation. Next step is to find out what is the ability of this system.

Maximum mass flow rate at laminar condition

The maximum mass flow rate in laminar flow condition occurs when Re=2100.

$$V_{\text{average\_max}} = \frac{Re \cdot \nu}{D} = 9.7m/s\ \text{Incompressible flow}$$

$$\dot{m} = \rho V_{\text{average\_max}} A = 0.82\text{g/s}$$

$$\text{t} = \frac{m}{\dot{m}} = 8.7\ \text{min}$$

$$l_e = 0.06\text{ReD} = 3.2\text{m}$$

If we assume the tube before the helium mass measurement unit is a straight pipe, then the length from entrance to Pitot static tube is 3m plus 0.5m. 3.5m>l_e, therefore, we can have the fully developed laminar flow at Reynold number of 2100. **<u>The approximation is reliable for mass flow rate of 0 to 0.82g/s and Reynold number of 0 to 2100.</u>**

Maximum mass flow rate at transition flow condition

The maximum mass flow rate in transition flow condition occurs when Re=4000.

$$V_{\text{average\_max}} = \frac{Re \cdot v}{D} = 18.47\ m/s \text{ Incompressible flow}$$

$$\dot{m} = \rho V_{\text{average\_max}} A = 1.56 \text{ g/s}$$

$$\text{t} = \frac{m}{\dot{m}} = 4.57 \text{ min}$$

Our algorithm is not very accurate in transition flow condition, but it is still a good approximation. By increasing the Reynold number to 4000, we reduce the balloon filling time to an acceptable region.

Conclusion:

Fully Developed Laminar Flow

0<Re<2100

0< $\dot{m}$<0.82g/s

t>8.7min

Helium Mass Approximation is most accurate

Transition Flow

2100<Re<4000

0.82g/s < $\dot{m}$<1.56g/s

4.57 min<t<8.7 min

Helium Mass Approximation is acceptable

Code Algorithm

Helium Balloon Filling System code refers to Appendix A code 9

The temperature and pressure inside the pipe might change, and thus the density and viscous might change. The system must be able to self-adjust this change. Pitot static tube sensor can only provide the centerline velocity. Thus, I drill a static pressure port before the tip of pitot static tube and added a BMP180 barometric and temperature sensor on it. By getting the static pressure and temperature, the density at any given time can be calculated as well as the dynamic viscous.

$$\rho = \frac{P}{RT}\ , \nu(T)$$

From the Pitot static tube sensor, we can get the centerline velocity. In a fully developed laminar flow, average velocity is half of the centerline velocity. In transition flow condition, it is an acceptable assumption.

$$V_{average} = \frac{V_{centerline}}{2}$$

We can get the instant mass flow rate from the average velocity.

$$\dot{m} = \rho V_{\mathrm{average}} A$$

From a very short time, the change in mass can be approximated by using the following equation.

$$\Delta \mathrm{m} = \dot{m} \Delta t$$

By adding a change in mass continuously, we can know the mass of helium that we have filled in the balloon.

In order to show the accuracy of the measurement, the system can also output the current flow type and the compressibility.

$$\mathrm{Re} = \frac{V_{average} D}{\nu}$$

$$M = \frac{V_{average}}{\sqrt{\gamma R T}}$$

3.6 Avionics (Yuan Zhang)

This year we have finished the prototype 2 rocket avionics system design and finished the code for subsystem and precision landing system. We will finish the entire avionics system in 2015 summer.

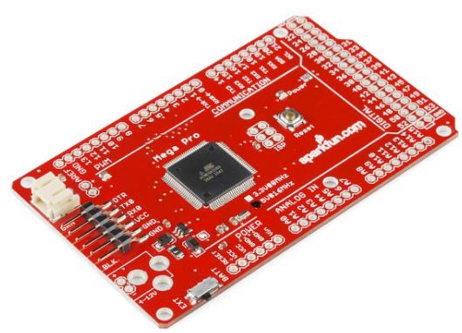
Prototype 2 rocket Avionics

(1) Electronics selection:

1: Battery: 3 of 3.7V 500mAh battery for UDI U818A RC Quadcopter
Unit weight: 17g
Unit capacity: 500mAh
Total weight: 51g
Total capacity: 1500mAh
Maximum safe continuous discharge current: 20A

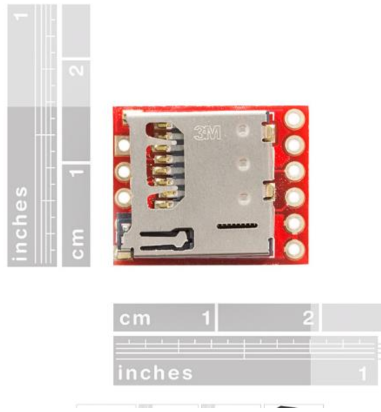
Reason: the rocket avionics system needs to work for at least 6 hours, so the battery capacity should be large. The GSM module needs 1A continuous current, and the avionics needs to ignite the motor. The requirement for the electric match is 12 V, so I used three batteries connects in series to provide 11.1V for the electric match. The resistance of electric match is low (usually1-2 ohm), so during the ignition, the current will be very large (around 11A). The battery with high continuous discharge is required.

2. Microcontroller: Sparkfun Mega Pro 5V



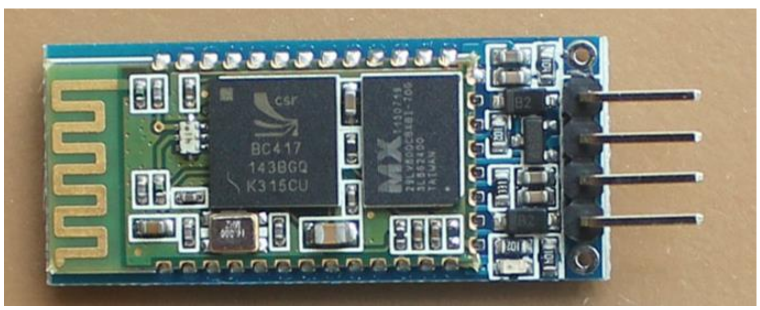
Reason: the avionics system has five components that need to use UART communication. Only the Arduino Mega 2560 has four hardware serial ports. By using the software serial library, the Arduino Mega 2560 can provide 5 serial communication ports. The traditional Arduino Mega 2560 is too heavy and big. Mega Pro 5V from Sparkfun has the same features as the traditional one, but it is smaller and lighter.

3. Data logger: sparkfun openlog



Reason: The SparkFun OpenLog is a serial logger, which means I only need to use the Serial.print() function in the arduino to write in the data. The traditional micro SD logger requires a special library, and the library might conflict with the library for other sensors, and it will consume the computation power.

4. Bluetooth: HC06 Bluetooth module.



Reason: the Bluetooth module is used for short distance communication. Only the platform avionics has real time long-range communication system, so if we need to send command to the rocket, we need to send the command to the platform avionics, and the platform avionics uses Bluetooth to communicate with rocket avionics.

5. GPS: NEO-6M with 28dB path antenna.

Reason: high gain antenna is good. NEO-6M can work up to 50km.

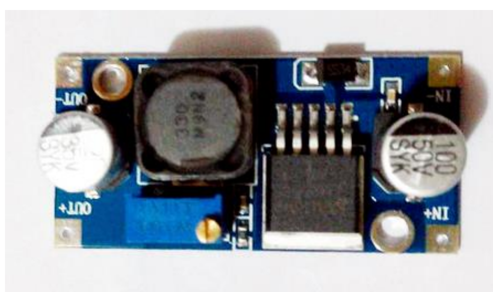
6． GSM Module: SIM900

Reason: Long range communication module, it can send the GPS coordinate to your phone through text message. This module can only be used when the rocket lands due to the regulation.

7. Buzzer: 12V high power buzzer

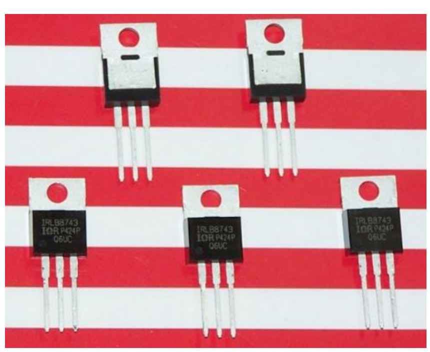
Reason: high power buzzer is very loud and easy for recovery.

8. Power module: DC-DC converter.



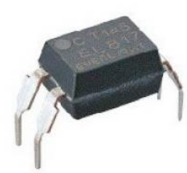
Reason: 5V supply from the Arduino cannot supply enough current for the GSM module, so we need to use the power converter. It can output the 1A current at 5V and generate heat. The heat can help keep the avionics bay warm.

9. MOSFECT: IRLB8743PBF



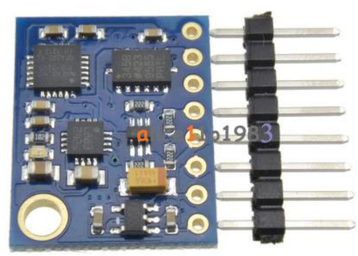
Reason: this is logic level mosfect, which means the 5V output from the Arduino can fully open the mosfect. Vgs(th) is less than 1.5V.

10. Optoisolator: SHARP PC817 Optoisolator



Reason: Optoisolator can allow the microcontroller to control the mini DV.

11. IMU module: 9DOF 9axis degree of freedom IMU sensor ITG3200/ITG3205 ADXL345 HMC5883L Module

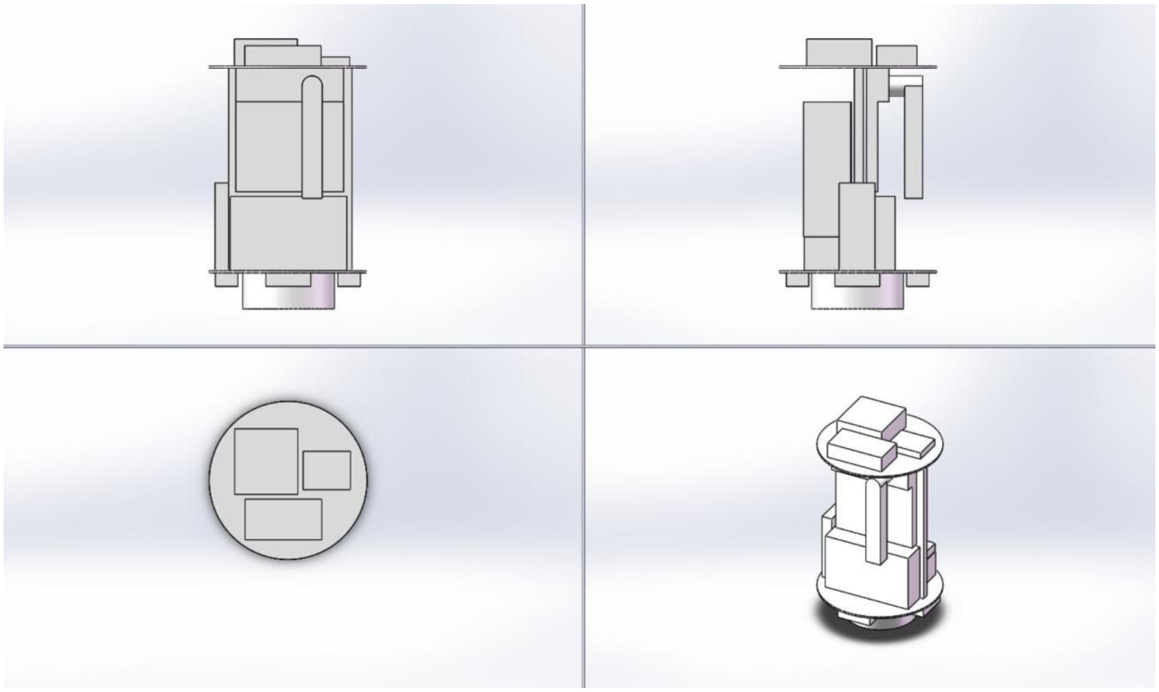


Reason: I find an open source code for this module. (Razor-9DOF-AHRS-MASTER in Github) It can output accurate yaw, pitch, and raw data. This module will connect to an Arduino pro mini, and the pro mini will process the data and output the data to the Mega Pro 5V.

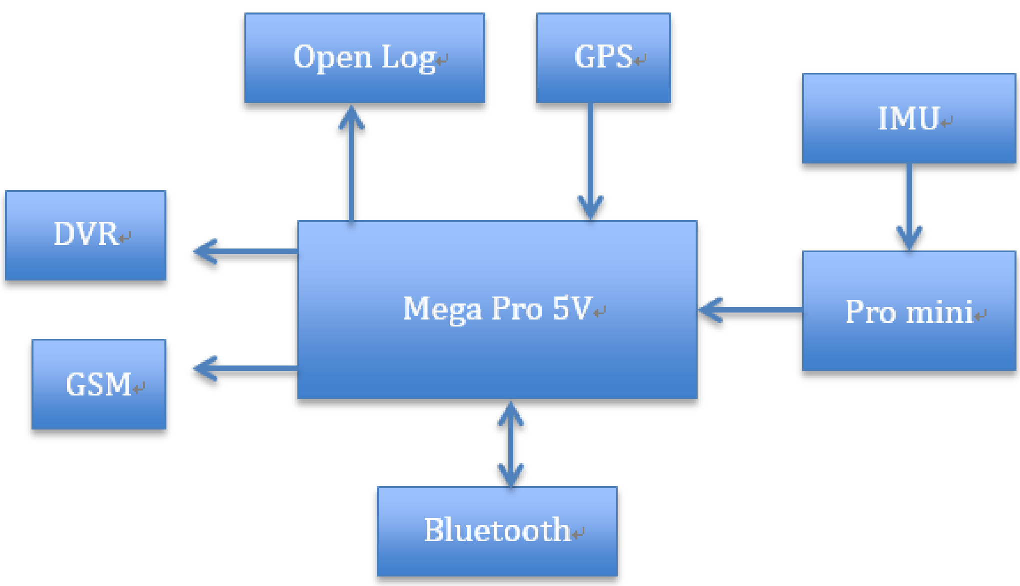
12. Mini DV: Mini DVR 808 #16 V3 -Lens D Car Key Chain Micro Camera HD 720P Pocket Camcorder.

Reason: 720P resolution with extend lens, and the battery can work for 40 minutes. It is only 17g.

(2) CAD of avionics bay
Height: 12.06cm
Diameter: 7cm



(4) Design

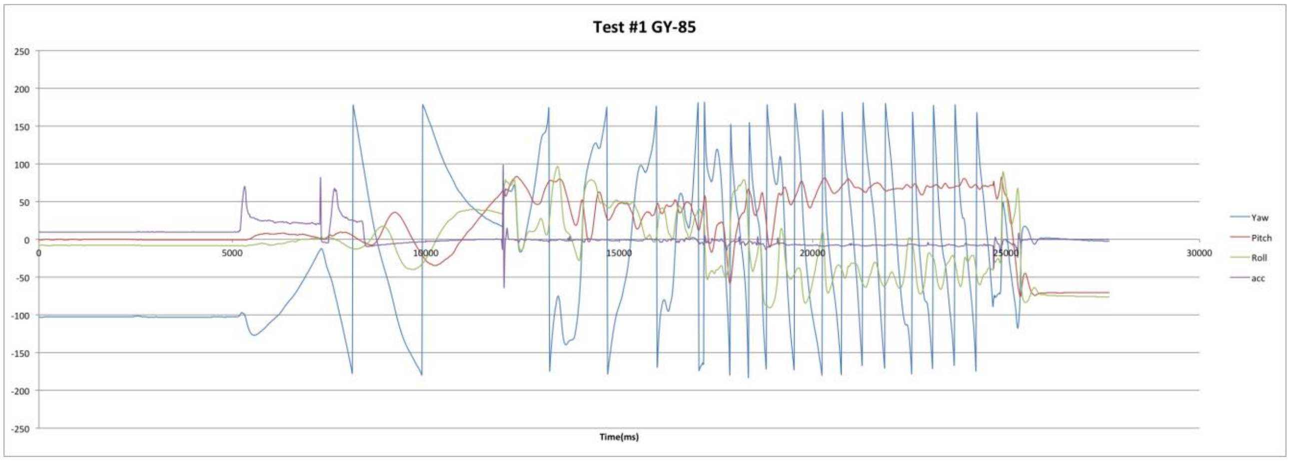


(4) Code

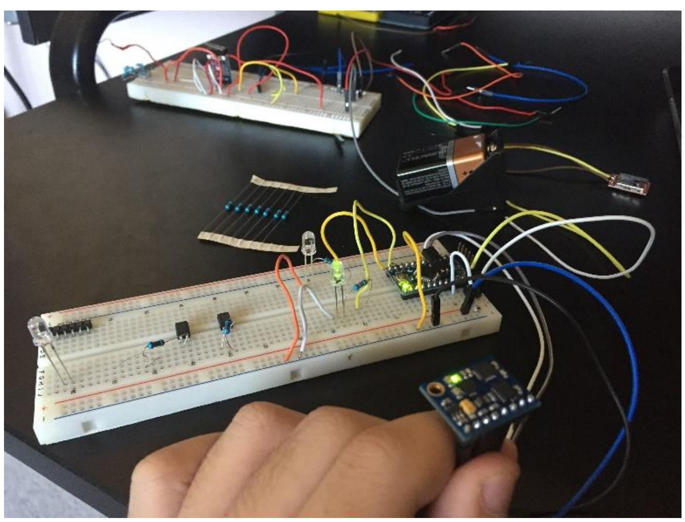
Flight Control System

Due to the limited time, we only finished the code for the subsystem. We have finished the flight control code and recovery code. Flight control code can use acceleration to check the launch status of the rocket. It can also use attitude data to eject the parachute near the apogee. It also has a fail-safe function to deal with emergency situations. These situations include ignition fail, motor fail, and apogee detection fail. We will finish the rest of the part during the 2015 summer.

The following plot is from the flight control system test.



Flight control system code refer to Appendix A code 4



Recovery System

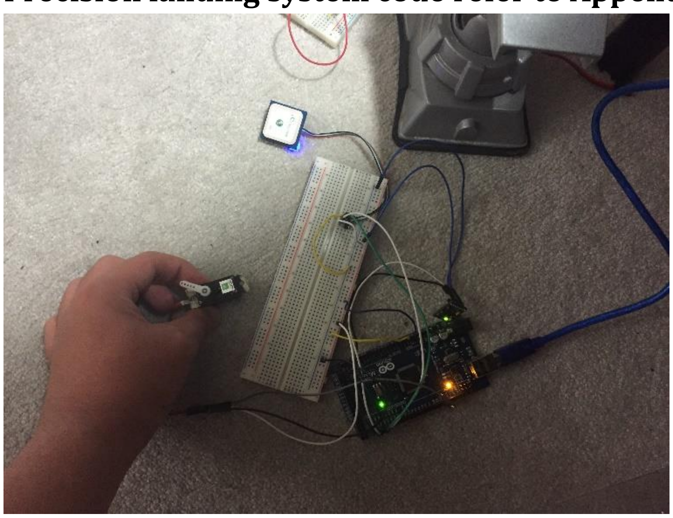
The recovery system includes GPS and SIM module. When the rocket lands, it will automatically send a text message that includes its GPS coordiantes. We can aslo send text messgage “#01” to the recovery system, in which the recovery system will reply a text message that include coordinates.

Recovery system code refer to Appendix A code 5

Precision Landing System

The precision landing system includes a digital compass, GPS, and servo. The GPS can calculate the heading angle and the distance to the target point. The digital compass can obtain the current heading angle. A simple feedback control system will control the servo to steer the ram-air parachute.

Precision landing system code refer to Appendix A code 6



3.7 Helium Balloon Version Prototype 1 Test Report

UCI Rocket Project: Structures

Helium Balloon Version Prototype 1 Test Report

Introduction (Prepared by Yuan Zhang)

On April 19th, 2015, the UCI Rocket Project Structures Team conducted a test for its prototype 1 rocket at Lucerne dry-lakebed. The main goal of this test was to examine the efficacy of our structure design, the helium balloon version (truss structure and gimbal system), and two kinds of IMU (Inertial measurement unit).

Reasons for conducting this test:

1. The gimbal system has proved to be able to always keep the launcher face up, but whether it can fully function as a stable and reliable launcher remains unknown.
2. The reason of using a gimbal system is to solve the tilt problem of the multiple balloons design. We needed to conduct a test to prove our new gimbal-incorporated structure (shown in Figure 1) can actually solve the tilt problem in mid-air.
3. From the previously conducted two-stage rocket launch, we found that the reason for ignition failure was caused by incorrect roll data during high speed ascent. This was caused by the malfuncation of the onboard IMU (our previous IMU cannot be used at high speed). In order to positively confirm that this was the reason and find a possible soulution, we made a small avionics system that includes two kinds of IMU and inserted it in a small 2-stage model rocket to test them (shown in Figure 2). By doing this test we can finish the faliure analysis of two stages rocket and finding a reliable IMU for Prototype 2 rocket.

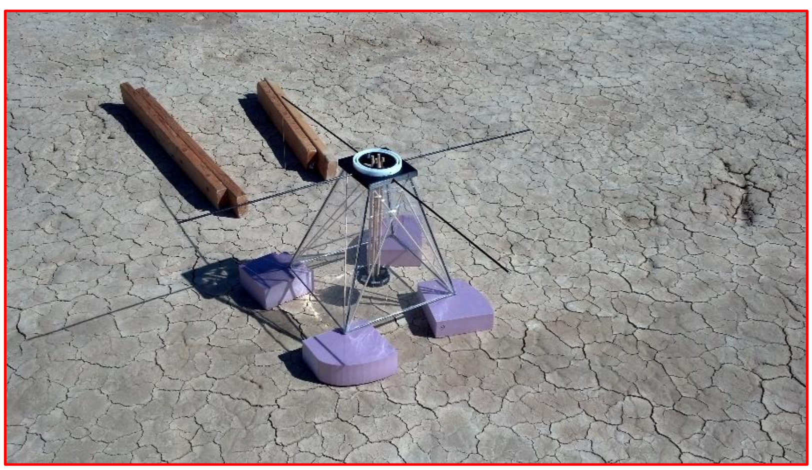


Figure 1. Gimbal-Incorporated Structure with Wind Shield

Figure 2. IMU Installed in a 2-stage Rocket

Test Plan

Test Sequence (8 launches):

#1 IMU test rocket
#2 P1 with blast deflector plate, ground test
#3 P1 with blast deflector plate, 2m test
#4 P1 with blast deflector plate, 20m test
#5 P1 without blast deflector plate, 1.5m test.
#6 P1 without blast deflector plate, ground test.
#7 Isaiah's rocket
#8 IMU test rocket test 2

Rocket Engines Selection:

Prototype 1 rockets: ESTES A3-4T motor.
IMU Test rocket: ESTES C6-0 for first stage, ESTES B6-4 for second stage.

Both ground and airborne tests for prototype 1 would be executed. The ground test was used to determine whether or not the gimbal system could function as a stable launcher. Because our analysis involved a high-speed rocket, we needed to use high-speed cameras to capture the necessary videos and photos. Tests on the ground would be able easier to record while mid-air launches would be more challenging. In addition, the test results would be more accurate on the ground because all cameras would be fixed by tripods. Airborne tests were necessary to test whether the gimbal system could solve the tilt problem. The biggest problem of airborne tests is that it is very hard to use a fixed camera to shoot the necessary high-speed video. Therefore, we planned to use string to fix the platform at around altitude of 2 meters. By fixing the platform, we can still use a fixed camera. The blast deflector plate is a design variable in our gimbal design. Because the prototype 1 rocket is much lighter than the gimbal system, the center of gravity is not low enough to maintain the stability of the launcher. We decided to add a blast deflector plate to increase the stability during the launch. High-speed gas from rocket engine would produce a force in the blast defector plate and then increase the stability during the launch.

Procedures (Prepared by Robert Chung)

In order to achieve our goals in a safe and reliable manner, we followed many protocols and constructed basic procedures to follow.

Preparation:

1. Pack up all the necessary gear we would need before heading out.
2. Make sure to leave by 7:30 a.m. so we can get to the launch site by 9:00 a.m.
3. Find flat, leveled ground away from people.
4. Wear sunblock and wear protection for the sun.
5. Set up gear under a large canopy for shade.

Test #1 (IMU Test):

1. For the first test, bring out the following gear: The 2–stage rocket with the IMU installed, support rail, all cameras/go-pros, multiple igniters, electric match and controller, water.
2. Set the support rail on a flat surface.
3. Make sure the rocket is properly arranged and attach an igniter connected to an electric match.
4. Slide the rocket onto the launch rail.
5. Prepare the cameras and go-pros around the rocket/structure so that all angles are properly recorded.
6. Position the team away from the rocket but within range for the wireless controller to be effective.
7. Launch the rocket and retrieve all parts.
8. Make sure the IMU is not damaged.

Test #2 (P1 ground test):

1. For the second test, bring out the following gear: Prototype 1 rocket, gimbal support structure, foam supports/wood, all cameras/go-pros, multiple igniters, electric match and controller, water.
2. Assemble a support system using the foam and wood.
3. Attach the igniter to the rocket as well as the electric match.
4. Make sure the deflector plate is attached and insert the rocket into the structure.
5. Place the gimbal structure with the rocket inside on top of the support system so that the rocket can freely swing.
6. Set up the cameras.
7. Position the team away from the rocket but within range for the wireless controller to be effective.
8. Launch the rocket and retrieve all parts.
9. Check for any damages on the structure.

Test #3&4 (P1 mid-air test):

1. For the third test, bring out the following gear: Prototype 1 rocket, gimbal support structure, balloons, helium tank, tape, string, all cameras/go-pros, multiple igniters, electric match and controller, water.
2. Fill up the balloons with Helium to the desired size.
3. Tape the balloons to the tip of each carbon fiber rods.

4. Repeat steps 3-7 from Test #2
5. Attach a 2m long string (20m for test 4) to the bottom of our structure to keep it from flying away.
6. Launch the rocket and retrieve all parts.
7. Check for any damages on the structure.

Test #5 (P1 mid-air test minus deflector plate):

1. Repeat steps from Test #4 but take the deflector plate out.

Test #6 (P1 ground test minus deflector plate):

1. Repeat steps from Test #2 but take the deflector plate out.

Test #7 (Isaiah's Rocket):

1. Follow Isaiah's directions and launch his rocket.

Test #8 (New IMU Test):

1. Repeat steps from Test #1, replacing the old IMU with the new one.

Actual Test and Last-Minute Modifications

We soon learned that not everything will go according to the procedure and schedule. There were many set-backs and elements that we did not consider and therefore prepare for; however, we learned much from our mistakes.

During the entire test day, we conducted only 4 tests due to problems during the test.

1. Sensor test rocket launch #1 (Old and New IMU)
2. Prototype 1 Ground test with blast deflector plate
3. Prototype 1 Airborne test with blast deflector plate
4. Sensor test rocket launch #2 (Old and New IMU)

We started with the sensor test rocket launch. It was successful and only took around 10 minutes to finish. Everything went according to the procedures with Test #1.

However, we started to have problems when we reached the prototype 1 ground test. We had a remote control controller to ignite the rocket engines, but it failed to work. In order to find out the problem, we had to disassemble the ignition unit and test it. We attached the electeric match to controller, and then pressed the ignition buttion. We saw the electric match burned. This concluded that the remote controller and electric match were working properly. As a result, the problem was that the effective distance was too short. We reassembled the ignition unit and used the remote control from a very short distance. The second try was successful, but the entire ground test took around 1 hour.

Next, we started the prototype 1 airborne test. We had the most problems in this test. A more detail-oriented report of the problems is listed in the Test Launch Review section of this report. The prototype 1 airborne test took our 2 hours, and we ultimately had to abandon the original plan. We could not get enough lift, so we had to not only remove the remote control ignition unit and use the wire ignition system, but we also had to attach smaller balloons to the structure to create additional lift. We also found out that due to the strong wind, it was hard to fix the platform to the wire ignition system without it strongly drifting away. We also had to place the cameras on hand to shoot the high-speed videos which was not optimal as it was not as steady as fixed cameras.

After we finished the prototype 1 airborne test, it was around 13:00. The wind was strong and we lost balloons during the test. Since we had finished the most important tests and we had not enough balloons to finish the other tests, we decided to do one more sensor test rocket launch and call it a day. We left the Lucerne dry lakebed at 13:30. We concluded that we should leave earlier next time to avoid harsh winds and extreme sunlight.

Test Launch Review (Prepared by Nathan Cox)

Helium for Launch Structure (4-balloon Design)

After running the original MATLAB codes (FindV, FindPL), we decided we would need about 1 cubic meter of helium distributed between all four balloons to make our balloon neutrally buoyant at about 10 meters above the ground. This test was just a low altitude test, so we were conservative on the height and amount of helium we would need, so that it would not be too expensive. While the test was overall a success, we encountered two significant problems with the helium balloons during the test. The first was that we did not have a method for determining the amount of helium we were putting into each balloon, except for a ruler and a rough eyeball estimate of the diameter of the inflated balloons. The second was that the total volume of helium predicted by the code was slightly off; the balloon would rise for a second but float slowly down to the ground, so we were not getting enough buoyancy.

The balloons were unequally filled with helium, which prevented the launch structure from floating level. While the gimbal system was designed to ensure a vertical launch, the structure, with all four balloons attached, had already exceeded the maximum rotation angle of the gimbal. We attempted to correct this problem at the launch site by filling up smaller balloons with helium and placing them as far away from the gimbal as possible in order to produce a large correcting moment. This quick fix seemed to work well enough for the test, but with the addition of each balloon came increased weight from the balloon skin and helium itself. While minor weight additions, it was still extra weight that needed to be lifted into the air by the other 4 balloons.

The amount of helium we used was slightly off as well. The launch structure was not quite able to lift off of the ground. The balloon MATLAB codes were written originally as a preliminary estimate, and were written before the 4-balloon rockoon structure design was finalized. The codes considered the weight of the structure and rocket in the mass input, and not the weight of the balloon skins. The original codes predicted the weight of a single balloon skin, but our design had 4-balloons, which increased the weight somewhat and caused an error in the calculation. Also, the launch day was very hot, which lowered the ambient air density of the launch site, reducing the neutral buoyancy height of the balloon. The original codes considered a standard atmosphere approximation, which would have given us a higher desired height and a lower required helium volume

Solutions to Problems

To ensure that all four balloons are properly filled with an identical amount of helium in each balloon, a flow meter or similar device should be used to measure the exact amount of helium that enters the inflated balloon. This should prove to be a better method for filling up the balloons, since before we had no specific way of measuring the helium in the balloons except for a rough estimate using a yard stick and our best guesses.

The helium codes have now been altered to be specifically for the 4-balloon design, which are FindV3 and FindPL3. The additional weight from all four balloon skins is now taken into account by the code, and it also had additional inputs for the elevation, temperature, and ambient pressure of the launch site to account for non-standard atmospheric conditions at the launch site. By inputting the data for the day we launched, the new code shows that we needed about 20% more helium than what we had originally considered.

New Code (FindV3) prediction of helium volume:

Lucerne Valley Test Site (4/19/15):

Elevation: 869m

Temperature: 32°C

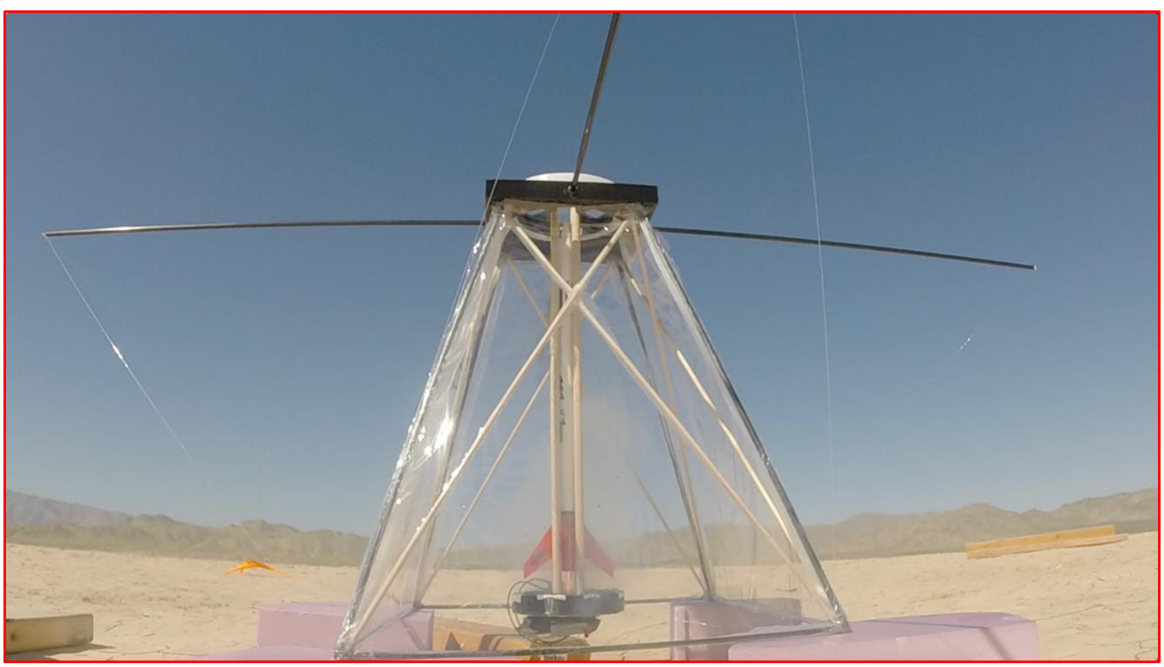
Pressure: 98.21 kPa

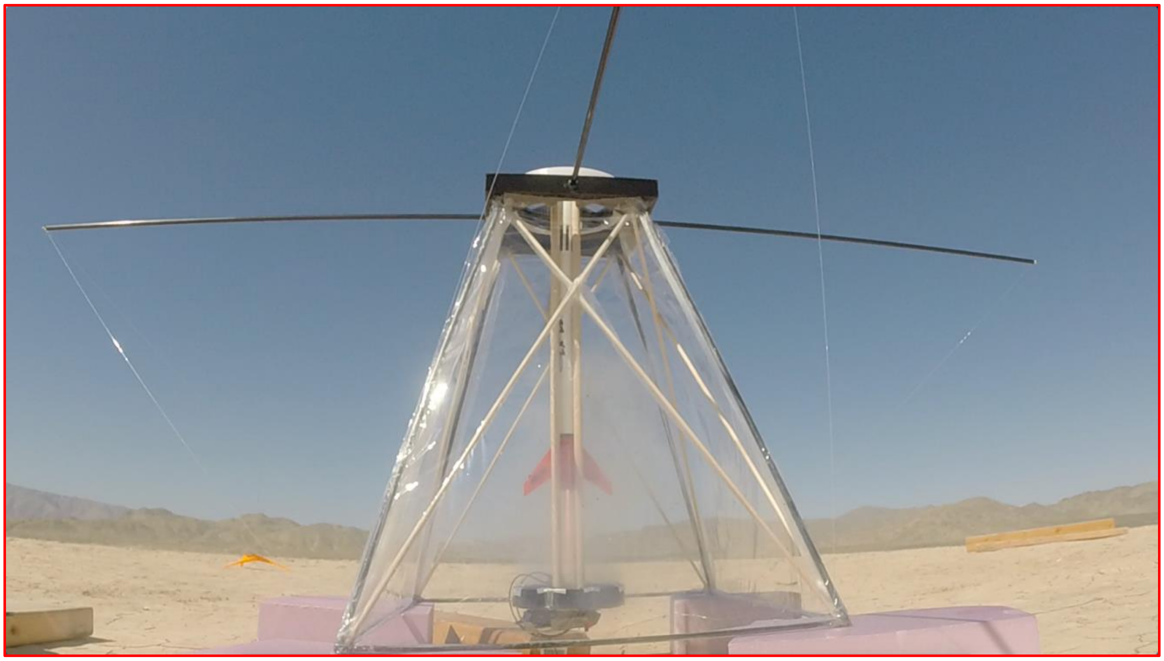
```
EDU>> FindV3(.7,879,869,32,98210)

Required Volume: 1.2316 m^3
Recommended Balloon Diameter: 5ft burst diameter

EDU>>
```

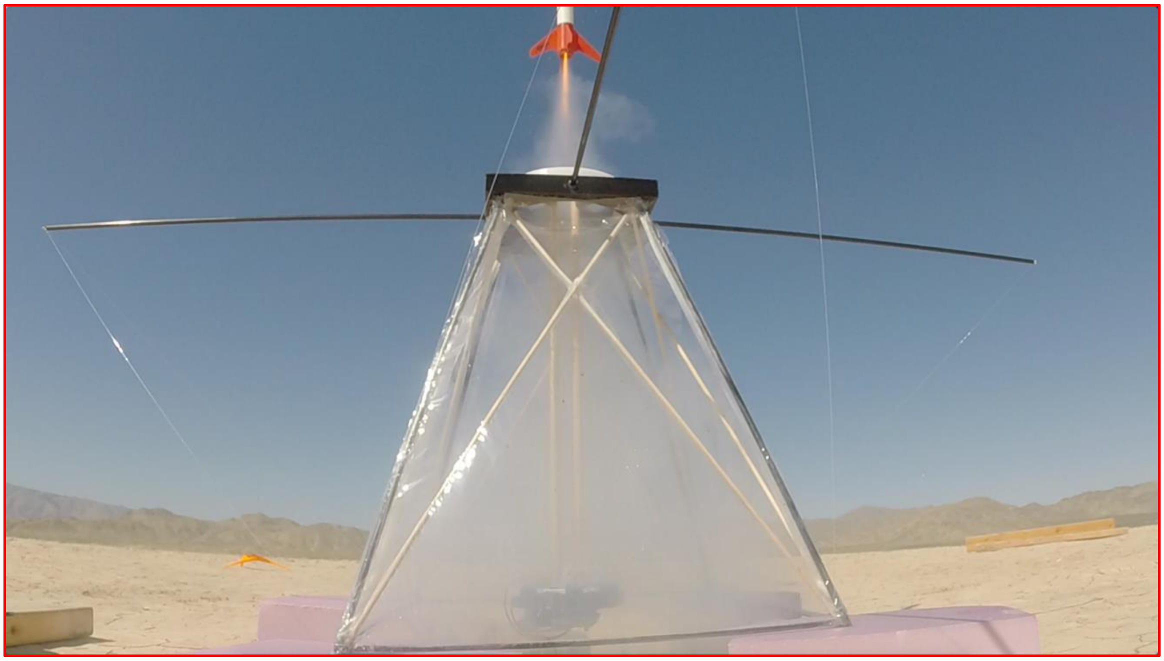
Analysis (Prepared by Yuan Zhang)

Test Video: https://youtu.be/ZmPrAegVZCY

Analysis of Ground Test:







From this set of screenshots of ground test, it is clear that the launcher remains fixed during the entire launch. Therefore, the gimbal system can function as a stable launcher.

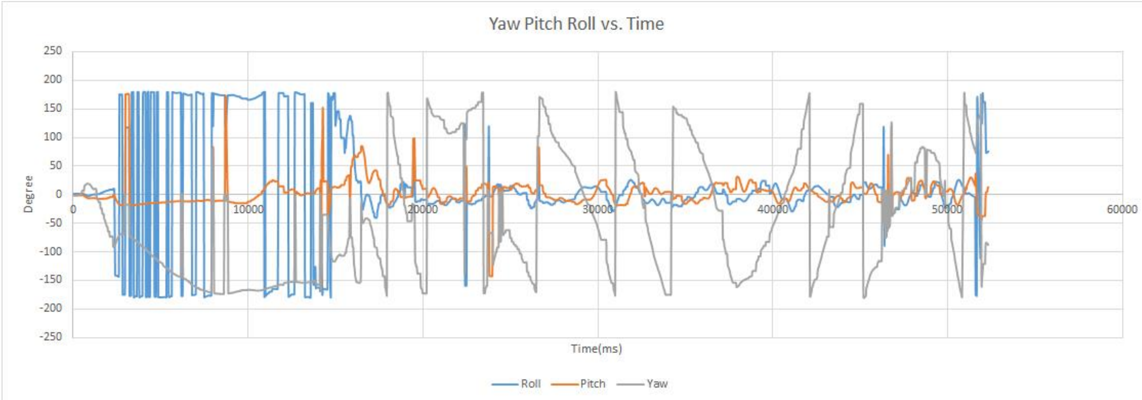
Analysis of Airborne Test:

From this set of screenshots, it is clear that the launcher remains fixed during the entire launch. However, the platform was tilted. The launcher might have hit the windshield rendering the results unreliable. In order to determine whatever the launcher hit the windshield in this set of screenshot or not, we conducted a small experiment. We tried to recur this situation and see if the launcher hit the windshield.

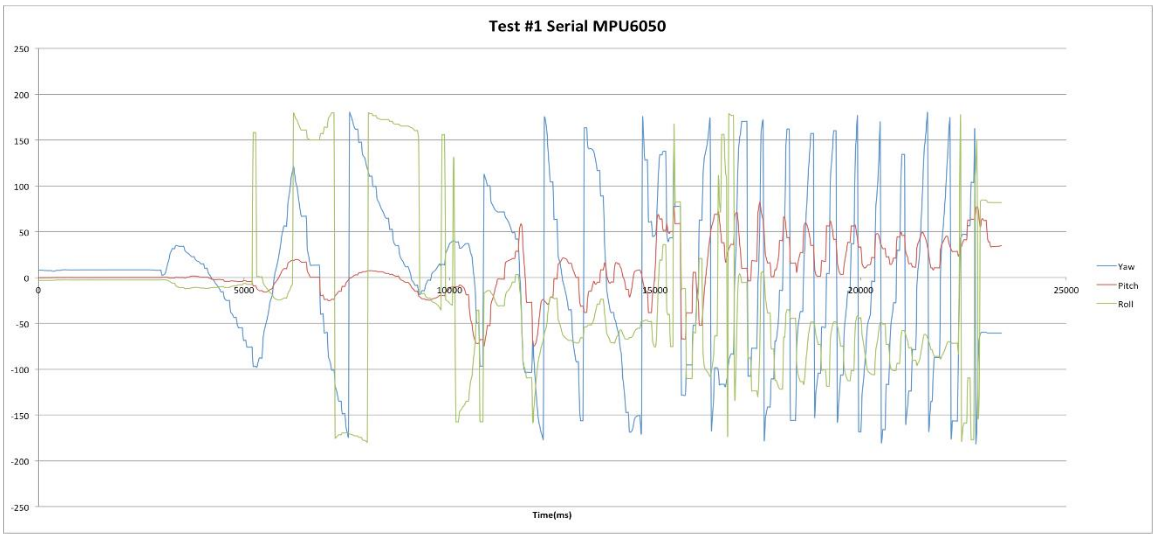
From this experiment, we have proofed that the launcher did not hit the windshield. Our result is reliable.

Analysis of IMU:
Serial MPU6050 is the IMU that I used in two stages rocket.
GY-85 is the new IMU.

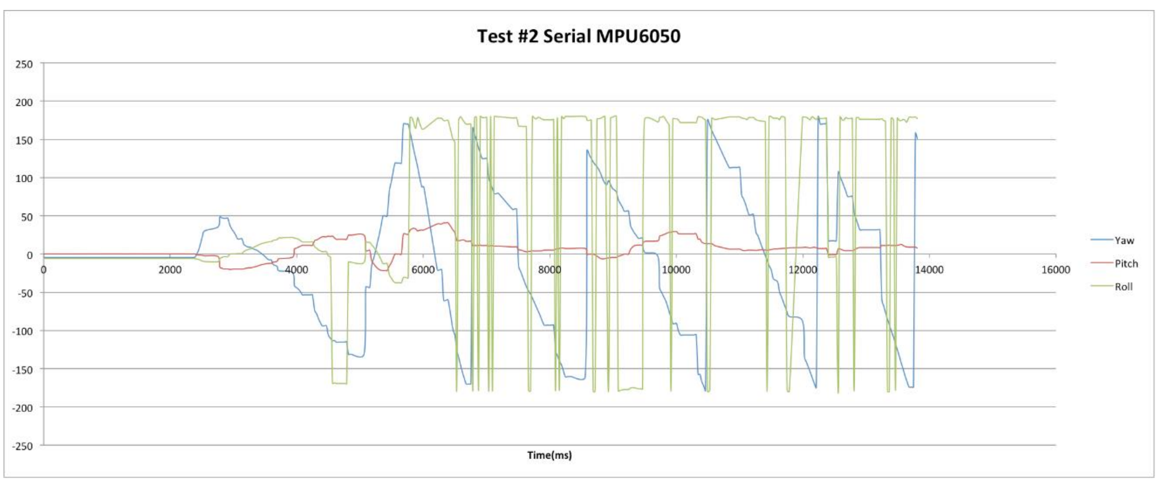
Coordinate System



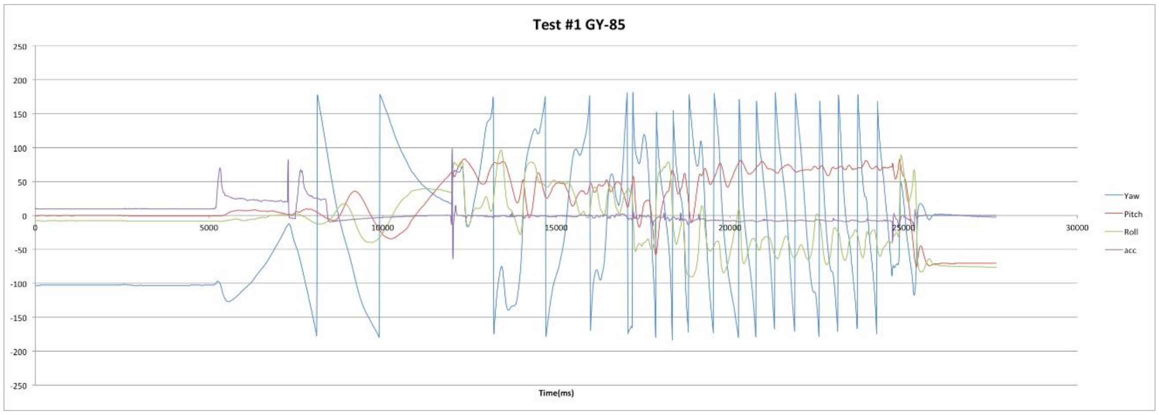
This is data from two stages launch. The Roll data was incorrect. IMU is serial MPU6050.

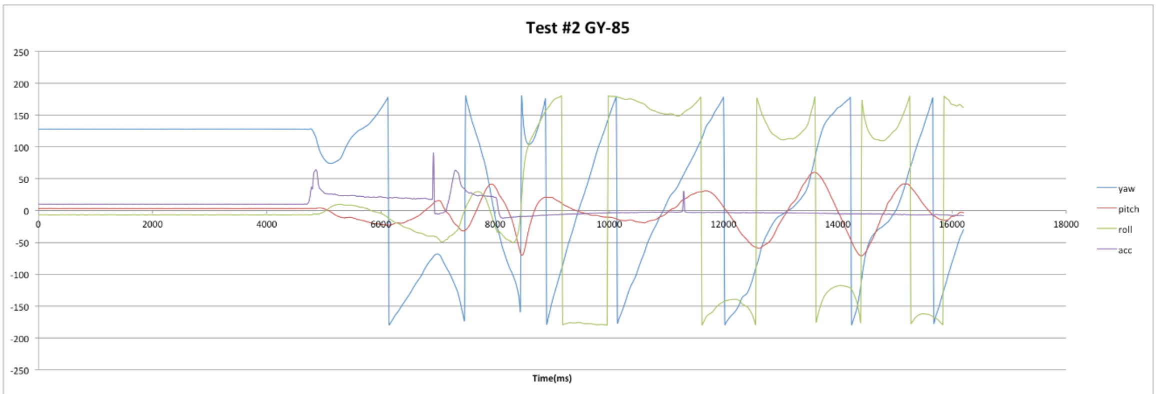


This is the data from sensor test rocket launch #1. During the high speed ascent, the roll data was incorrect as well.



This is the data from sensor test rocket launch #2. The roll data was incorrect as well.
From the above three plots. We can draw a conclusion that. Serial MPU6050 cannot be used in a high speed situation.





These two plots are data from the new IMU. The data looks correct. From test #1, the parachute was ejected when the pitching angle neared 90 degrees, which is desirable. From the acceleration data, it is easy to see the first stage ignition and separation as well as the second stages ignition and parachute ejection. We can conclude that this IMU can be used in the prototype 2 rocket.

Test Results:

1. **The Gimbal System can function as a stable launcher.**
2. **The Gimbal System can solve the tilt problem.**
3. **The IMU that is used in the two stage rocket cannot be used in a high speed situation. The new IMU can work properly at high speed.**

Notes for Future Launches (Prepared by Isaiah Navarro)

For the testing of Prototype 1, the Structures Team of UCI's Rocket Project went to Lucerne Valley. With this experience certain notes should be highlighted to as to be more prepared for future testing. First to be mentioned would to leave at an earlier time to make it to the launch site. The team arrived around 9am and already the sun was bright and wind starting to rise. In the desert especially during the summer, winds can act up and heat uncomfortable. To avoid such conditions, testing in the morning is preferable. For test requiring a large amount of time, maybe camping out the night before and getting an early start with the rising of the sun might be able to optimize working hours of morning.

Due to the absence of shade and constant sunshine, protection against the sun must be considered. Sunscreen is a must to avoid sun burns and an "Easy Up" canopy would be useful. While working in the field it was hard to assemble last minute items and prepare for launch. A portable and foldable datable should be brought along.

Due to the extreme dry conditions in the desert water should be brought along as well as food. The team brought an abundance of water with and was well prepared in that regard. Since we did not leave until lunch time it was necessary to stop for food on the return trip. Snacks will be able to extend the time in the field. Another thought to consider would being able to relief oneself. This time there was portable toilets. In the future this may not be an option. Prior planning must be taken.

Certain tools, materials and supplies needed to make a quick repair need to be brought along. For example tape, quick curing epoxy and sandpaper should be brought along just in case. Without this, the two hour drive from UCI to Lucerne Valley may be in vain. During the last test, we were well prepared in the material we brought.

For transportation of all these prior accommodations and testing equipment must be able to fit in the vehicles as well as the rocket team members going to the test sight. For this launch, two cars were taken carrying all necessary testing rocket and equipment as well as four members. This arrangement was adequate; however a single large SUV could have been used instead. An SUV would have been advantageous in the rough terrain of Lucerne. Luckily both cars were able to barely make it across the dry lake beds rough terrain. An SUV would be desirable if the terrain is to get rougher. Also there was a notice that during the winter snow would fall. Testing could still occur in these conditions but a better terrain vehicle would be a requirement.

Structures Team Group Photo

4. Bill of Materials

Product	Unit Cost	Quantity	Total
Balloon Time Helium Tank, Fills 50 Balloons	$43	3	$129
XBee-PRO XSC S3B	$42	2	$84
SparkFun XBee Explorer Regulated	$10	1	$10
Mega Pro 5V	$45	2	$90
SparkFun OpenLog	$25	4	$100
Temperature Sensor - TMP36	$1.5	5	$7.5
SparkFun XBee Explorer Dongle	$25	1	$25
Heating Pad - 5x15cm	$5	3	$15
Heating Pad - 5x10cm	$4	6	$24

Polymer Lithium Ion Battery - 400mAh	$7	2	$14
Kevlar- 281 part# 281-38	$24.55	3	$73.65
Carbon Fiber	$30	1	$30
Resin 206 #318386	$21.99	1	$21.99
Vacuum Bag Sealant Model# 128340	$15.49	1	$15.49
Hardener 105 # 323733	$46.99	1	$46.99
Scissors item # 375667	$5.99	2	$10.98
Permanent Marker item# 553248	$5.49	1	$5.49
Orange Spray Paint Model# 249095	$23.22	1	$23.22
Foam insulation Model# 36L	$33.95	1	$33.95
Metal Ruler Model# 306-36	$3.95	1	$3.95
Extension Cord Model	$9.97	1	$9.9 7
Duck Tape Model# 392875	$2.7	1	$2.7
Parachute 4'	$40	1	$40
Masking Tape Model# 5142-18E	$0.79	2	$1.58
Cardboard Tubing	$10.5/ 4 tubes	1	$ 10.50
Parachute 30" part # 29127	$12.99	4	$ 51.96
3D printing fee	$40	1	$ 40.00
Midwest Carbon fiber tube .21OD*0.132ID*40in	$8.5	4	$34.0
I-motor	$60	1	$60.00
Carbon fiber tube	$10	6	$60.00
Grand Total			**$1074.92**

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6. Appendix A

Code 1: Solar Balloon Calculation
Code Instruction:

Assumptions:

1) Ideal Gasses (both air inside and ambient)
2) Compressible (changing density) gases
3) Balloon Volume is fixed
4) Static equilibrium: Pressure inside the balloon is equivalent to the pressure outside the balloon or the ambient Pressure
5) The temperature within the balloon is 15 degrees Celsius greater than the Temperature of the ambient air
6) The maximum height is achieved when the Buoyant force of the ambient air on the balloon is equivalent to the weight of the balloon and its payload
7) The designed balloon will be operating in the conditions determined by the characteristics of the Troposphere and Stratosphere
8) Standard Atmosphere is assumed and models for standard atmosphere are followed, allowing for a quantitative assessment of ambient air Pressure, Temperature, and Density variations with altitude
    a. Pressure is modeled differently between the Troposphere and the Stratosphere
    b. The Troposphere exists between Sea Level and 11000 km in elevation

c. The Stratosphere exists between 11000 km and past 20000 km in elevation
d. Temperature in the Troposphere follows this model:
with a Beta value of .0065
e. Temperature in the Stratosphere is constant and equivalent to approx. -56.5 degrees Celsius

9) Archimedes principle can accurately model the location of maximum altitude of a balloon

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```
%%Physical Equations and Constants and assumptions
R = 286.9; %Ideal Gas Const for air, assume constant for all elevations
g = 9.81; %gravity, assume constant within elevation of 20 km (check)
T_a = 288.15; %Kelvins, Sea Level temp
P_a = 101.33*1000; %Pascals, Sea Level pressure
B = .00650; %Kelvins/meter
P_b = P_a*((1 - B*11000/T_a).^(g/(R*B))); %Pascals, Pressure at 11000 meters
%z1 = linspace(0,11000); %elevation from 0 meters to 11000 meters
%z2 = linspace(11000,20000); %elevation from 11000 meters to 20000 meters
%z3 = linspace(0,20000);
T_s = 216.65; %Temp of Stratosphere in Kelvins (Constant)
D_s = 1.225; %density of air at sea level, kg/m^3

%Balloon Modeling for a Tetrahedron (input Parameters) *************
%A1 = ; %surface area of balloon's bottom surface
%A2 = ; %surface area of balloon's sides
%A3 = ; %surface area of balloon's top surface
%alpha = ; %angle that the side surface makes with the horizontal
%delH = ; %height of the balloon, measured from the bottom surface to the top
surface
TotalArea = 4.69; %A1+3*A2+A3; %total surface area of balloon in m^2
V = .5192; %volume of balloon, m^3

%Total Load
m_pl = 0; %payload mass, kilograms
m_bal = TotalArea*1/(1.35)*17/1000; %17/1000 kg per trashbag, 1.35 m^2 per
trash bag assumption => mass of the balloon
%note: our calculations will be more accurate if we weigh the balloon
%instead of relying on the previous calculation for balloon mass

m_load = m_pl+ m_bal; %mass of the payload plus the mass of the balloon (Not
including mass of the air inside of the balloon)
D_load = m_load/V; %Density of the combined payload and balloon (Not
including air inside the balloon)

    %Pressures acting on balloon's surfaces
%P_1 = ; %Net Pressure on bottom surface of balloon
%P_2 = ; %Net Pressure on the top of the ballon
```

```
%P_3 = 4*(P1-P2)*sin(pi/2-alpha); %Net Pressure on sides of the balloon in
the upward direction
    %Forces acting on balloons surfaces
%F_1 = P_1*A1;
%F_2 = P_2*A2;
%F_3 = P_3*A3;

%Atmosphere Modeling

%Troposphere, Temp varies with elevation, elevation range from 0<z<11km
%T = T_a-B*z1; %Linear Variation of Temperature with elevation (Kelvins)
%P_t = P_a*((1 - B*z1/T_a).^(g/(R*B))); %Troposhpere pressure variation
elevation
%D_t = P_t/(R*T);

%Stratosphere, assume Temp const (T_s) from 11km to 20km
%P_s = P_b*exp(-g*(z2-11000)/(R*T_s)); %Pressure of Stratosphere in Pascals
%D_s = P_s/(R*T_s);

%plot check
%plot(z1,P_t,z2,P_s)
%plot(z1,D_t,z2,D_s);

%Matrix Equations and iteration values
n = 1; %may need to create indices for matrix so I can change n value to get
more accuracy
h_max = 20000;
h_matrix = zeros(h_max/n,1); %altitude matrix
Pmatrix = zeros(h_max/n,1); %pressure matrix of atmosphere
Dmatrix = zeros(h_max/n,1); %density matrix of atmosphere
D_ins_matrix = zeros(h_max/n,1); %density matrix of air within the balloon
D_tot_matrix = zeros(h_max/n,1); %density matrix of total configuration
max_alt = 0;
min_alt = 1000000;

for z = 0:n:h_max
    if z <= 11000 %troposhere
        %atmosphere modeling
        h_matrix(z+1) = z;
        T = T_a-B*z;
        P_t = P_a*((1 - B*z/T_a).^(g/(R*B)));
        Pmatrix(z+1) = P_t;
        D_t = P_t/(R*T);
        Dmatrix(z+1) = D_t;
        %balloon modeling
        D_insT = P_t/(R*(T+15)); %density of the air within the balloon
(Troposhpere)
        D_ins_matrix(z+1) = D_insT;

        D_totT = D_load + D_insT; %total density of the entire balloon, the
air within, and the payload as a single unit (Troposphere)
        D_tot_matrix(z+1) = D_totT;

        if  .999995*D_t <= D_totT && D_totT <= 1.000005*D_t

            if max_alt < z
                max_alt = z;
            end
            if min_alt > z
```

```
                min_alt = z;
            end

        end
        %disp(P_t);

    elseif 11000 < z <= 20000 %stratosphere
        %atmosphere modeling
        h_matrix(z+1) = z;
        P_s = P_b*exp(-g*(z-11000)/(R*T_s));
        Pmatrix(z+1) = P_s;
        D_s = P_s/(R*T_s);
        Dmatrix(z+1) = D_s;
        %disp(P_s);
        %balloon modeling
        D_insS = P_s/(R*(T_s+15)); %density of the air within the balloon
(Troposhpere)
        D_ins_matrix(z+1) = D_insS;

        D_totS = D_load + D_insS; %total density of the entire balloon, the
air within, and the payload as a single unit (Troposphere)
        D_tot_matrix(z+1) = D_totS;

        if .999995*D_t <= D_totT && D_totT <= 1.000005*D_t

            if max_alt < z
                max_alt = z;
            end
            if min_alt > z
                min_alt = z;
            end
        end
    end
end
disp (min_alt);
disp(max_alt);

%z = 0:n:h_max;
%disp (z);
%disp (h_matrix);
%disp(Pmatrix);

%subplot(2,2,1)
%plot(h_matrix,Pmatrix);
%title('Ambient Pressure vs. Alitutde')
%subplot(2,2,2)
plot(h_matrix,Dmatrix,h_matrix ,D_tot_matrix);
title('Ambient Density and Total Density vs. Altitude')
%subplot(2,2,3)
%plot(h_matrix,D_ins_matrix);
%title('Inside Air Density vs. Altitude')
%subplot(2,2,4)
%plot(h_matrix,D_tot_matrix);
%title('Total Config. Density vs. Altitude')
%plot(z,Pmatrix);
```

Code 2: FindV3()

Important: This is for 4-balloon launch structure design.

```
function [] = FindV3(m,h_des,h_g,T_g,P_g)
%Predicts volume of Helium needed to lift payload of mass m to a desired
%altitude in meters. Launch structure is 4-balloon design.
%Payload mass does not include the mass of the balloon skins.
%
%m = mass of the launch structure (kg) *less mass of balloon skins*
%h_des = desired launch altitude above sea level (m)
%h_g = elevation of launch site above sea level (m)
%T_g = temperature of launch site (degC)
%P_g = pressure of launch site (Pa)
%
%For weather info @ Lucerne, visit
%http://www.wunderground.com/weather-forecast/US/CA/Lucerne_Valley.html


%standard values at sea level
g0 = 9.81; %m/s2
Psl = 101315; %sea level pressure (Pa)
Tsl =288.16; %sea level temp (K)
rhosl = 1.225; %sea level density (kg/m3)
R=287.05; %gas constant (J/kg-K)
Rhe = 2077;  %gas const. of helium (J/kg*K)
rhoHeSL = Psl/(Rhe*Tsl); %sea-level density of Helium (m^3)
RE = 6378000;  %radius of earth (m)

%Atmosphere Characteristics (Taken from Shevell - Fund. of Flight, Ch.5)

a = -0.0065; %lapse rate in K/meter
T_g=T_g+273; %convert C to K

if h_des<11000 %desired altitude in the gradient region (Troposphere)

    T_des = T_g+a*(h_des-h_g); %temperature at desired altitude

    P_des = (P_g)*((T_des/T_g)^(-g0/(a*R))); %pressure at desired altitude

    rho_des = P_des/(R*T_des);  %density at desired altitude


elseif h_des>11000 && h_des<25100 %desired altitude in isothermal region
(Stratosphere)

    T11 = T_g+a*(11000-h_g); %temp at 11km
    T_des = T11;      %desired temp = temp at 11km

    P11 = (P_g)*((T11/T_g)^(-g0/(a*R))); %pressure at 11km
    P_des = P11*(exp((-g0/(R*T_des))*(h_des-11000))); %pressure at desired
altitude

    rho_des = P_des/(R*T_des); %density at desired altitude
end

g= g0 /((1+(h_des/RE))^2);       %variation in gravity w/ altitude

rhoHe_des = P_des/(Rhe*T_des);  % ideal gas law for helium; determines
density
```

```
Fnet = (rho_des - rhoHe_des)*g;      % net force up per unit vol of filled
balloon
                                     % at altitude h [N/m^3]

W_pl = m*g; %weight without balloon skin

Vol_1 = (W_pl/Fnet)/4;   %required volume per balloon obtained from force
balance
                         % static equilibrium at max height

D_b1 = (((6*Vol_1)/pi)^(1/3))*3.28084;   %burst diameter in feet to be used
to recommend balloon size

sizes = [5, 8, 20, 30, 40] ;  %typical balloon burst diameters
(ProjectAether.com, Amazon.com)
masses = [.150, .300, .600, 1.2, 2] ; %masses of balloon skin corresponding
to balloon sizes

I = find(sizes>D_b1);
xtraM = 0;

if isempty(I)==1
    fprintf('\nDiameter of Balloons > 40ft.\n')
    return
else
    xtraM = 4*masses(I(1));
end

W=(m+xtraM)*g; %adds extra weight from balloon skins into final weight calc;

Vol2 = W/Fnet; %total volume needed to lift weight of W

Vol2_b = Vol2/4; %volume per balloon
D2 = (((6*Vol2_b)/pi)^(1/3))*3.28084; %required diameter of balloons

J = find(sizes>D2);

balloon = 0;
if isempty(J)==1
    fprintf('\nDiameter of Balloons> 40ft.\n')
    return
else
    balloon = sizes(J(1));
end

VHeSL = Vol2*(rhoHe_des/rhoHeSL); %volume of Helium needed (sea level value)
                                  %taken from mass balance for Helium

fprintf(['\nRequired Volume: ',num2str(VHeSL),' m^3'])
fprintf(['\nRecommended Balloon Diameter: ', num2str(balloon),'ft burst
diameter\n\n'])
end
```

Code 3: FindPL3()

Important: This is for 4-balloon launch structure design.

```
function [] = FindPL3(vol, h_des, h_g, T_g, P_g)
%Predicts payload mass that can be carried by 4-balloon lauch structure
%design. Payload mass does not include the mass of the balloon skins.
```

```
%
%vol = (sea level) volume of helium available (m^3)
%h_des = desired launch altitude above sea level (m)
%h_g = elevation of launch site above sea level (m)
%T_g = temperature of launch site (degC)
%P_g = pressure of launch site (Pa)

%standard values at sea level
g0 = 9.81; %m/s2
Psl = 101315; %sea level pressure (Pa)
Tsl =288.16; %sea level temp (K)
rhosl = 1.225; %sea level density (kg/m3)
R=287.05; %gas constant (J/kg-K)
Rhe = 2077;  %gas const. of helium (J/kg*K)
rhoHeSL = Psl/(Rhe*Tsl); %sea-level density of Helium (m^3)
RE = 6378000;  %radius of earth (m)

%Atmosphere Characteristics (Taken from Shevell - Fund. of Flight, Ch.5)

a = -0.0065; %lapse rate in K/meter
T_g=T_g+273; %convert C to K

if h_des<11000 %desired altitude in the gradient region (Troposphere)

    T_des = T_g+a*(h_des-h_g); %temperature at desired altitude

    P_des = (P_g)*((T_des/T_g)^(-g0/(a*R))); %pressure at desired altitude

    rho_des = P_des/(R*T_des);  %density at desired altitude


elseif h_des>11000 && h_des<25100 %desired altitude in isothermal region
(Stratosphere)

    T11 = T_g+a*(11000-h_g); %temp at 11km
    T_des = T11;      %desired temp = temp at 11km

    P11 = (P_g)*((T11/T_g)^(-g0/(a*R))); %pressure at 11km
    P_des = P11*(exp((-g0/(R*T_des))*(h_des-11000))); %pressure at desired
altitude

    rho_des = P_des/(R*T_des); %density at desired altitude
end

g= g0 /((1+(h_des/RE))^2);       %variation in gravity w/ altitude

rhoHe_des = P_des/(Rhe*T_des);  % ideal gas law for helium; determines
density
                            % of helium at altitude h_des, assuming P and T
                            % are same for helium in balloon as for
                            % the surrounding air. This assumption is based
                            % on force & energy balances between balloon
                            % and surrounding air.


Fnet = (rho_des - rhoHe_des)*g;      % net force up per unit vol of filled
balloon
```

```
                                         % at altitude h [N/m^3]

vol_alt = (rhoHeSL/rhoHe_des)*vol; %volume in balloon at altitude (mass
balance between He @ sea level and desired altitude)

netforceup = Fnet*vol_alt; %net force up at desired altitude (N)

Mass = netforceup/g; %mass of balloon payload + balloon skin

vol_b = vol_alt/4; %volume per balloon in 4-balloon design launch strucutre

D_b = (((6*vol_b)/pi)^(1/3))*3.28084; %diameter of each balloon in feet


sizes = [5, 8, 20, 30, 40] ;  %typical balloon burst diameters
(ProjectAether.com, Amazon.com)
masses = [.150, .300, .600, 1.2, 2] ; %masses of balloon skin corresponding
to balloon sizes

I = find(sizes>D_b);
xtraM = 0;
balloon = 0;

if isempty(I)==1
    fprintf('\nDiameter of Balloons > 40ft.\n')
    return
else
    xtraM = 4*masses(I(1)); %estimated extra mass from balloon skins
    balloon = sizes(I(1));  %size of balloons to be used
end

MPL =  Mass-xtraM; %payload mass (total mass less skin mass)

fprintf(['\n\nMaximum Payload Mass: ', num2str(MPL),' kg\n', 'NOTE: Does not
include mass of balloon skins\n'])
fprintf(['\nRecommended Balloon Diameter: ', num2str(balloon),'ft burst
diameter\n\n'])

end
```

Code 4: Flight control system code
https://drive.google.com/open?id=0Bz_fOWftUmutfnprSE5XVGVRVUJhd01UNHgzRzB2cFQtM19mS1drOGZWX08tQ0hDZkU5TWs&authuser=0

Code 5: Recovery system code
https://drive.google.com/open?id=0Bz_fOWftUmutfmhrTGJpa0NfaTNYaGZpazFUOVRIUW94OVFUSVRzU2k3R0JnOTJXcGpSNDg&authuser=0

Code 6: Precision landing system code
https://drive.google.com/file/d/0Bz_fOWftUmutNGxHQjUyd3owVkE/view?usp=sharing

Code 9: Helium Balloon Filling System code https://drive.google.com/open?id=0Bz_fOWftUmutWklMcEFacERPaUk

Code 7: Gimbal Calculation

```
clear,clc

selection=input('1:enter d1 2. enter span:');
if selection==1

r1 = input( 'Input inner diamteter of inner ring (mm):')/2;
end
 if selection==2
  span=input('Input the span of rocket(mm)£º');
safetylength=input('input safety length(mm):');
    end
size=[10,12,16,20,25,30,40,50,60,70,80];
a = input( 'Input dsired max roatation angle(deg 0-90): ');
while a>90 || a<0
    a = input( 'Error! reinput dsired max roatation angle(deg 0-90): ');
end
hg = input( 'Input height of gimabl (mm):');
hn = input( 'Input height of nut (mm):');
dn = input( 'Input diameter of nut (mm): ');
w = input( 'Input width of gimbal ring (mm): ');
Dh=input('Input drive size(mm):');
% calculate maximum height of nut and to make sure the nut height is safe
hn_max=tand(a)*((hg-dn)/2);
if hn>hn_max
    disp('height of nut is too large');
  return
end
if selection==2
r1=(span+2*hn+safetylength)/2;
end
% calcualtion of delata r
r2=(r1/cosd(a))+(sind(a)/((cosd(a))^2))*(hg/2);
delta_r=r2-r1;
lp=delta_r+hn+w;
if lp>max(size)
    disp('no suitable bolt');
    return
end
% calculation of available bolt length
matrix1=size-lp;
 m=min(matrix1(matrix1>0));
 index=find(matrix1==m);
 lp_new=size(index);
 % calculation of new delta r
 delta_r_new=lp_new-hn-w;
 spacing=delta_r_new-w
 if delta_r_new-w<Dh
     disp('drive size too big');
     return
 end
 r2_new=r1+delta_r_new;
```

```
 syms x
eqn = (r1/cos(x))+(sin(x)/((cos(x))^2))*hg/2==r2_new;
a_new=radtodeg(abs(solve(eqn,x)));

r3=r2_new+delta_r_new;
% output
disp(['    r1    r2    r3'])
disp([r1,r2_new,r3])
disp(['Maximum rotation angle'])
disp(a_new)
disp(['bolt length'])
disp(lp_new)
disp(['Height of Gimbal ring'])
disp(hg)
disp(['Width of Gimbal ring'])
disp(w)
disp(['Height of nut'])
disp(hn)
disp(['Diameter of nut'])
disp(dn)
```

Code 8: Truss Structure Calculation

```
clear,clc
F_max=  147 ;                 %STRING MAX LAOD (N)
SF=  2      ;               % SAFETY FACTOR
F_max_new=F_max/SF;
WEIGHT=  49;  % PAYLOAD WEIGHT (N)
Fz=WEIGHT/8; % 8 string
RL= 2438.4 ;   % mm
IN= 50;
PL= 507;
SL=547.53;
H=202.77;
OD=0.0064516 ;  %m
ID=0.0040132;  %m
max_tensile=1.72*10^9; %(Pa) tensile strength
r2=OD/2;
r1=ID/2;
I=(pi/4)*(r2^4-r1^4);
if PL>SL
    disp('wind shiled length should be larger than square plate length');
    return
end
L=RL-((SL-PL)/2)-IN;
W=SL/2;
LF=(L^2+W^2+H^2)^(1/2);
THETA=asin(SL/(2*LF)); % RAD
BETA=atan(H/L);  % RAD
F=Fz/(cos(THETA)*sin(BETA));
M=(WEIGHT/4)*((RL-IN)/1000);
stress=(M*r2)/I
max_tensile
if stress<max_tensile
    disp('stress safe with safety factor:');
    disp(max_tensile/stress);
end
if F<F_max_new
    disp('safe');
```

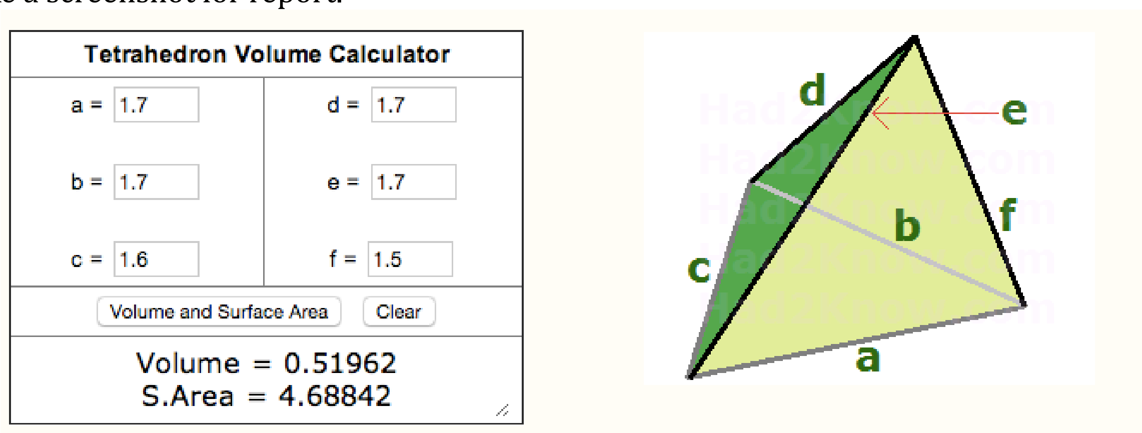
```
else
    disp('unsafe');

end
disp('difference from current maxmimum');
disp(F_max_new-F);
disp('current safety factor');
disp(F_max/F);
```

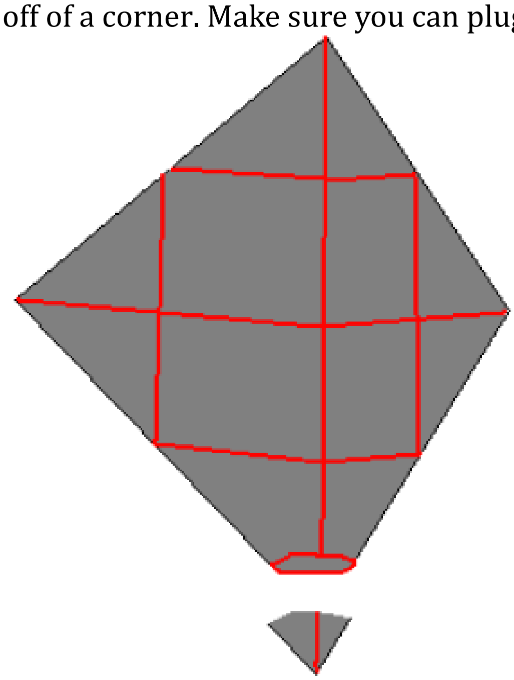
7. Appendix B

Solar Balloon Test Instruction

Step 1: Measure the dimension of the solar balloon. Use the link below to calculate the volume and surface area of the balloon
http://www.had2know.com/academics/tetrahedron-volume-6-edges.html
Take a screenshot for report.

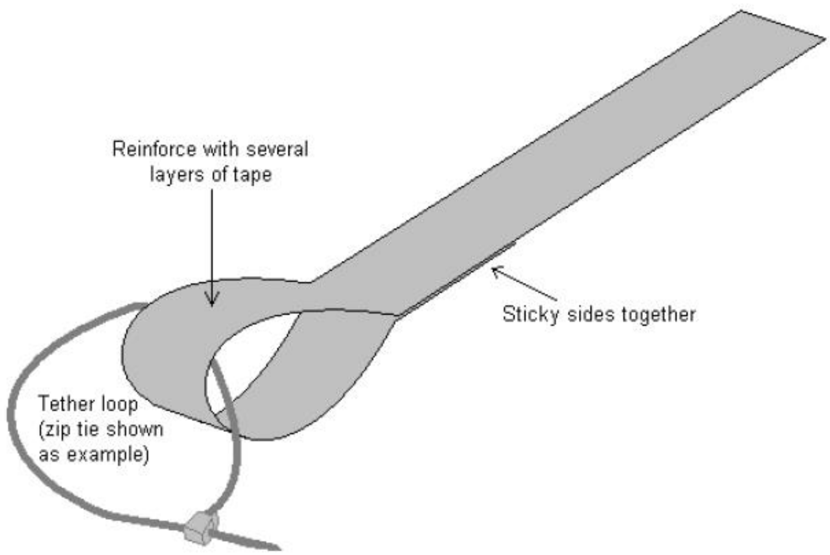


Step 2: Cut a few inches off of a corner. Make sure you can plug in the tube for filling.

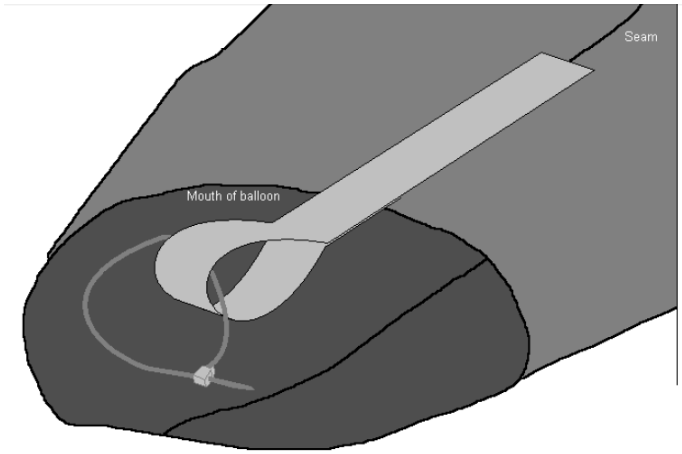


Step 3: Attaching the Tether

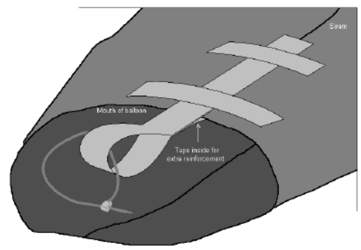
You will need to attach your tether to the balloon securely, so it does not tear away from the balloon during gusts or hard pulls. A rule of thumb for good, secure tether attachments is to distribute the tension a short distance up the length of the balloon to avoid focusing all the strain on one point. (Do not use too much tape)



When your loop is securely attached to the load tape, stick the tape directly on a seam, as shown below. The seam is a strong point on the balloon; it's important to attach your tether to a strong point. This keeps the tether from tearing away a portion of the mouth if the balloon is pulled excessively hard.



Reinforce the tape to ensure its security and to prevent it from tearing off.



Step 4: Measure the total mass of the balloon, and measure the mass of weight

Step 5: Plug in the tube and use heat gun or hair dryer to fully inflate the balloon.

Step 6: Place the probe of thermometer inside the balloon. Try to fix the probe in the middle of the balloon

Step 6: Seal the opening of balloon

Step 7: Attach the fishing line to the loop. Attach the other end of fishing line to the weight.

Step 8: When the balloon starts to fly, place the weight in the scale. Record the ambient temperature, inside temperature, and scale reading.

Step 9: Fill out the information below during the testing. Remember to take photo of each step, and take photo when balloon is flying. If possible, take a group photo with balloon.

Date:

Testing time:

Dimension of balloon: (unit: m)

[Screenshot here]

Total mass of balloon (balloon+ load tape):

Mass of the weight:

Time	Ambient temperature (Celsius)	Inside temperature (Celsius)	Temperature gradient (Celsius)	Mass of the weight (g)	Scale Reading (g)	Net lift (g)

Step 10: Write the testing report. Similar to my report, but replace the table with above one.

Source: *Fly Solar Balloon-Everything You Want to Know About Making and Flying Your Own* by Jonathan Boehme

Saucer Balloon

Ideas on Approximation of Shape:

1. n^th root graph
2. Oblate spheroid

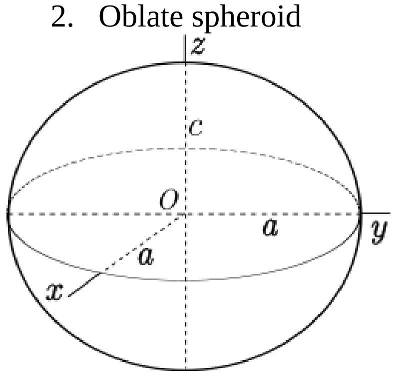


Figure 1. Oblate spheroid

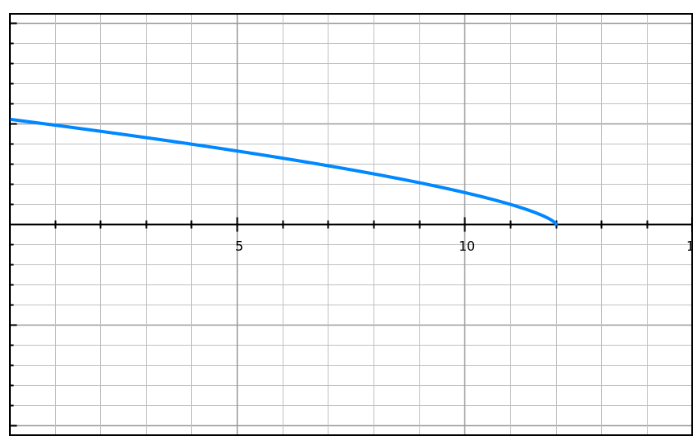


Figure 2. n^th root graph

1. nth root graph to estimate volume of saucer balloon

$$y = (R - x)^{\frac{1}{n}}$$

Balloon is symmetric about x-axis.
Using an axis of revolution and an integral:

$$V = 2\pi \int_0^{\sqrt[n]{R}} (R - y^n)^2 dy$$

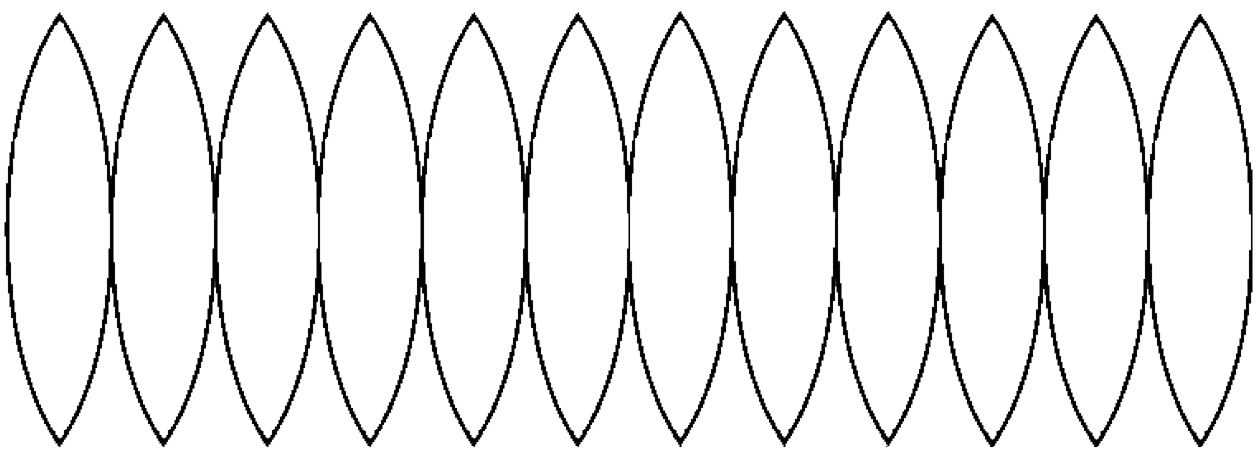
$$V = 2\pi\left[\frac{2n^2}{2n^2+3n+1}\right]R^{2n+1/n}$$

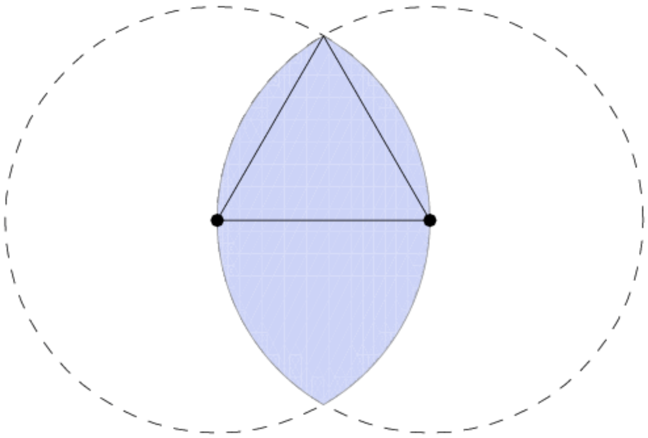
2. Volume of Oblate Spheroid

$$\frac{x^2}{a^2}+\frac{y^2}{a^2}+\frac{z^2}{c^2}=1$$

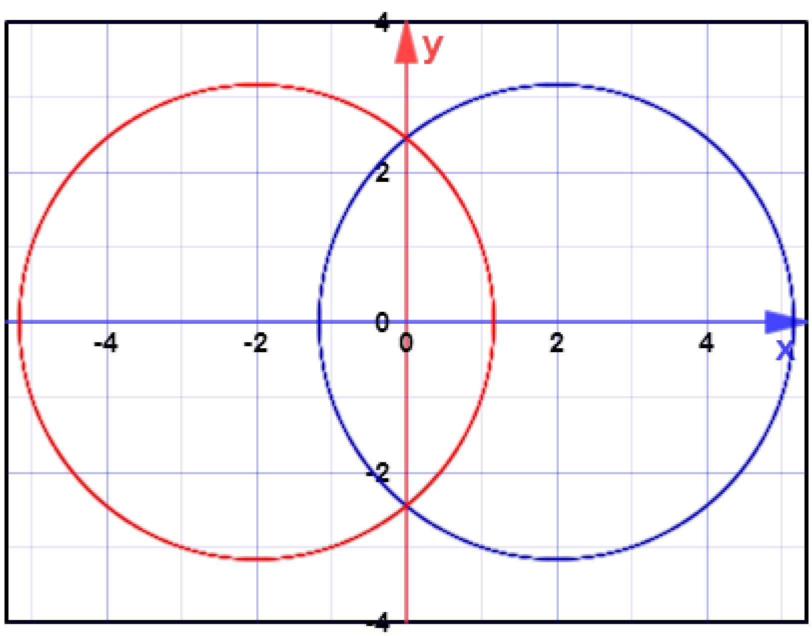
$$V=\frac{4}{3}\pi a^2 c$$

To make balloon





Intersection of 2 circles
d= distance of center from origin:



Height of each piece: $h = 2\sqrt{R^2 - d^2}$

Width of each piece: $w = 2(R - d)$

Radius of Curvature: R centered at a distance d from the vertical axis