# EML 4551C – Senior Design

# Deliverable #4

# Team 18: CANSAT

**Group Members: Samuel Rustan (EE), Andrew Grant (ME), Andrew Guerr (ECE), Maxwell Sandler (ME), Yasmin Belhaj (ME)**

**Technical Advisors: Dr. David Cartes (ME), Dr. Victor DeBrunner (ECE)**

**Faculty Advisor: Dr. Kamal Amin (ME), Dr. Michael Frank (ECE)**

**Report Submitted: 11-DEC-2012**

# Table of Contents

## Project and CanSat Competition Overview

The CanSat competition is a design-build-fly competition held by AIAA. The competition provides teams with an opportunity to experience the design life cycle of an aerospace system. The CanSat competition is designed to reflect a typical aerospace program on a small-scale implementation. The competition includes almost all aspects of an aerospace program from the preliminary design review to post mission review. The mission and its requirements are designed to reflect various aspects of real world missions including telemetry requirements, communications, and autonomous operation. The competition for 2013 will be held June $7^{th}$ through the $9^{th}$ in Burkett, Texas. Each team is scored throughout the competition on real-world deliverables such as schedules, design reviews, and demonstration flights.

The motivation behind this project is to simulate how a satellite entering the atmosphere of an Earth-like planet gathers flight data and safely delivers a sensor payload to the planet's surface. The two main components of the CanSat are the payload that secures the sensor (a hen egg) and the container that encloses the payload from ascent to initial descent.

The rocket, provided by the competition, will launch the CanSat, then deploy it at an altitude of 670 m, at which point a parachute or streamer will decrease its descent velocity to 20 m/s. At 400 m, the container will release the lander-payload and an aero-braking system will be employed in the safe landing of the lander-payload. In addition to controlling the descent autonomously, the flight software will transmit telemetry data during the flight. This includes altitude, temperature, GPS data and battery voltage. The force of impact will be transmitted upon landing of the lander-payload. The impact force calculation is one of two "selectable objectives" that were required to be selected and implemented in the CanSat design. The other selectable objective is a video camera that would record the descent. The force of impact calculation was selected based on the relative ease of implementation of the impact force calculation and transmission.

A post-flight review will be conducted and taken into account to evaluate the success of the design at the competition. Since the competition will not be held until a month after the end of the semester, the results of the competition design reviews and demonstration flights are taken into account for the purposes of evaluation of this project.

## Design Requirements

The CanSat design requirements are dictated by the 2013 CanSat competition rules[1]. Below is a synopsis of the relevant rules.

- The container must protect the sensor load (egg).
- The telemetry requirements are transmitted in the radio frequency required and all telemetry is accomplished via the XBEE radios series 1 or 2.
- The audible location device is activated and emits a tone of at least 80 decibels and maintains power until found.
- The power delivery system is sufficient to provide electrical power to all relevant components.

- The ground station antenna is at least at a height of 3.5 meters and powered by ground station circuitry.
- The CanSat's total mass must be 700 grams ± 10 grams before the egg is placed inside.
- The CanSat must fit inside a cylinder that is 130mm in diameter and 250mm in length.
- When initially released the satellite may use any passive decent control device to reduce its speed to 20 m/s ±1m/s.
- When the container is below 400 m it cannot free fall or use a parachute or similar device.
- The container cannot have any sharp edges or protrusions that go beyond the envelope.
- The container must be a florescent color.
- No flammable substances may be used.
- All decent control devices, attachments and mechanisms must be able to survive a 30 gee shock.
- The Canister must have an external power control.
- The CanSat cannot use lithium polymer batteries.
- No electronics can be exposed except sensors.
- The CanSat flight hardware must cost less than 1000 U.S. dollars excluding ground support and analysis tools.
- Mechanisms that produce heat must be ventilated.

# Analysis and Design

## Physical Overview

As competition rules mandate, the overall size of the CanSat must fit within a cylinder with dimensions of 130mm in diameter and 250mm in length. A physical representation of the layout can be seen in the figure below.

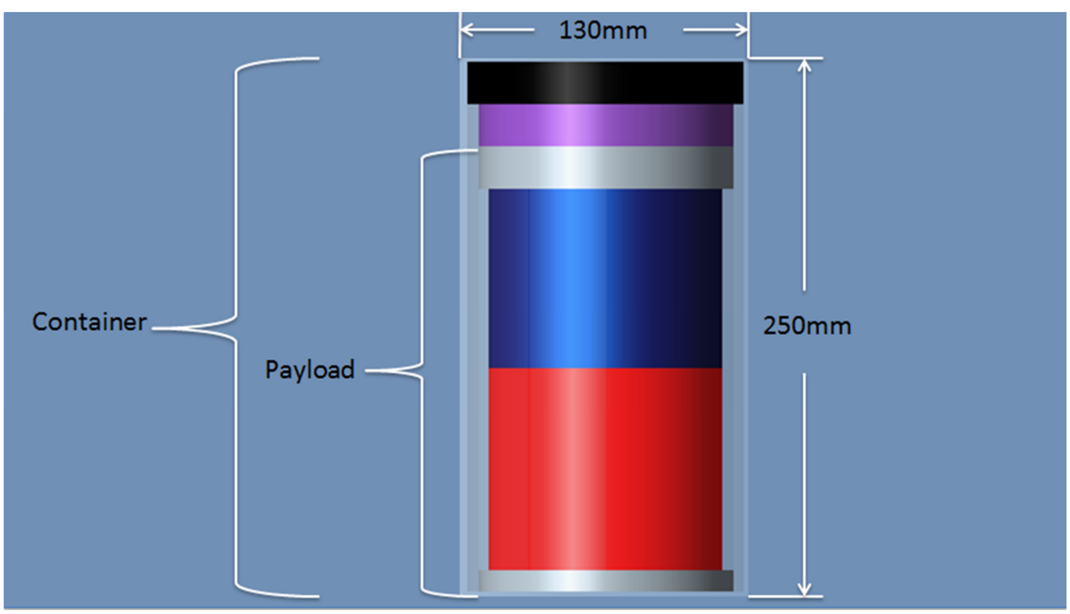



Figure 1: CanSat physical layout

The only other size/shape constraint, as stated in the rules, is there may be no sharp edges that may hinder the release of the CanSat from the rocket upon deployment. Essentially, this means that the intended shape of the CanSat is to be a complete cylinder. Also shown in the figure is the payload situated within the confines of the container. This is exactly how the CanSat will be placed inside of the rocket supplied by AIAA. In the next figure, the payload can be seen separated from the container.

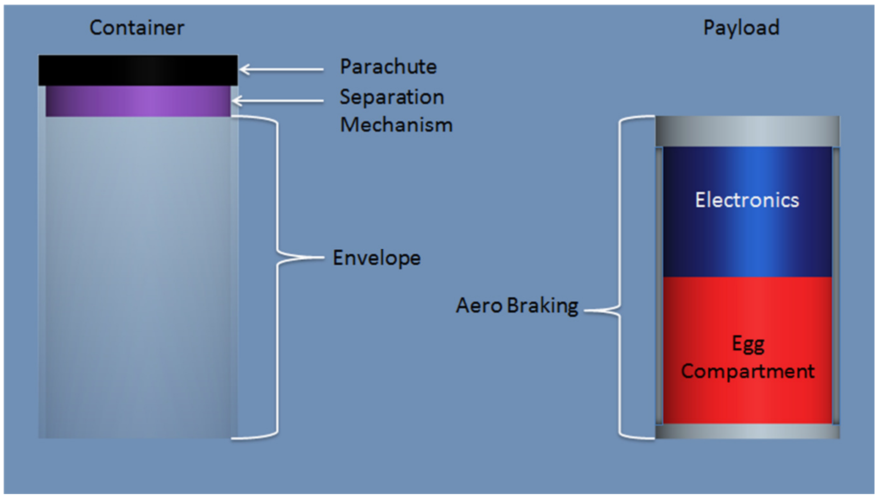



**Figure 2: CanSat physical layout with payload separated from container**

The container's main responsibilities are to offer separation between phase 1 and the payload, as well as, in our case, enclose the payload within the rocket without any protrusions or sharp edges. Other than that, it does not contain electronics or any other items that relate to gathering telemetry data and the phase 2 aero-braking systems. It does, however, contain a subsystem that is used in the separation mechanism.

The payload is the main focus, housing all of the electronics, the aero-braking systems, and the egg enclosed by its protective compartment. Due to our designs, the payload is essentially completely surrounded by the aero-braking system during the time before actuation. The aero-braking must also be without protrusions so that it may slide from the container without difficulty. In the center of the payload the volume is shared by the electronics and the egg compartment. Depending on the size of all the electronics the actual size of the egg compartment is subject to change as long as it is still capable of accommodating a large hen's egg.

## CanSat Material

According to the competition rules, all structural components of the CanSat must be capable of surviving up to 10 g's of acceleration and a 30 g's shock force. In order to do this a strong, fracture resistant material would be preferred. Since the mass and size of the CanSat is defined in the competition rules, it is not difficult to calculate the maximum stress that the CanSat should be designed for. Cost is another important factor for when choosing a material since there is a limit on the total cost the final product. The approximate amount of material required can be calculated based on the dimensions of drawings. With this information, it is possible to calculate the approximate cost and factor of safety for each material based on information given by the manufacturer. Polyethylene is an inexpensive material that is fracture resistant and strong [2]. It will cost only $2-$9 for the material to make the CanSat Structure. While using a 1/16 inch thickness for the material and only 1/10 of the possible area striking the ground, if it does not land flat, the stress that the structure will feel is 3.5 MPa. This is well below the tensile strength of the polyethylene, making it a good candidate. Fiberglass is also a light and strong material. Since it has similar material properties to polyethylene, it could be a good choice as well, but it is much more difficult to manufacture parts, so polyethylene would be a better choice. Carbon fiber would be more than strong enough for this application, but it is very expensive. Since the Cansat has a cost limit on the final product, it would possibly drive the cost of the CanSat too high. Aluminum is a strong, light weight metal. It has a high strength when compared to Polyethylene and fiber glass, so a thinner stock could be used. However Aluminum could interfere with the radio signals that the CanSat uses to communicate with the ground station. For these reasons Polyethylene would be a good choice.

**Table 1: A comparison of different materials for the CanSat structure**

| Material | Cost ($/m^2) | Tensile Strength (Mpa) | Density (kg/m^3) | Pros | Cons |
|---|---|---|---|---|---|
| Polyethylene | 12.20-47.94 | 41.2 | 1040 | Light, Strong, Cheap, Easily Molded | Weaker than Other Options |
| Fiber Glass | 20-40/gal | 42.3 | 1120 | Light | Difficult to Use |
| Carbon Fiber | 300-500 | 3500 | 1330 | Light, Strong | Expensive |
| Aluminum | 69.00-144.77 | 152-310 | 2700 | Strong, Relatively Cheap | Heavier than Other Choices |

## Theoretical Model

In order to assist in the choice of parachute size, a theoretical model showing the descent characteristics was created. Given a target descent rate, a good way to start experimenting with different size parachutes is to know of a close approximation. By doing this, time can be saved without making erroneous decisions and a baseline to start experimenting from can be formed. The model is able to take in a desired terminal velocity and, along with some other initial parameters like altitude, drag coefficient of parachute and container, and the cross-sectional area of the container, output the area of the parachute necessary to meet the constraints.

```
Command Window
Input
Initial Height (m) = 400
Desired Terminal Velocity (m/s) = 20

Output
Area of a streamer for given terminal velocity (m^2)= 0.045956
Area of a parachute for given terminal velocity (m^2)= 0.0085785
Diameter of a parachute for given terminal velocity (m)= 0.10451
Vmax (m/s)= 19.8778
Vmax Height (m)= 273.3553
Time to reach Vmax (s)= 7.758
Time to hit ground (s)= 21.588
fx >> |
```

**Figure 3: Screenshot of Matlab model**

The theoretical model was created using Matlab and a screen shot from the command window can be seen in the figure above. It shows some of the user inputs that are placed in the .m file along with the outputs associated with the desired parameters. The core of the program is based off the fundamentals of Newton's second law,

$$F=ma$$

Along with the basic kinematic equation and its derivatives,

$$s=s_0+v_0t+\frac{1}{2}at^2$$

Another equation used in order to complete the program was the drag equation.

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

With the combination of these equations and in conjunction with some algebra and calculus, the model is able to, at some height and some force associated with drag as a function of velocity, output parameters that are necessary to estimate the objects trajectory. With the CanSat being deployed at a height of 670m, this model is essential to estimating the trajectory at a height that cannot be experimentally tested before the competition. The model can also help to estimate how far away from the launch pad the CanSat may land. This is done by taking the total time estimated to hit the ground and multiplying that by the velocity of the wind where it is to be launched. This gives an estimated distance that eases the retrieval of our project.

The theoretical model may also be used for determining the aero-braking surface areas. We start by determining what a reasonable impact speed would be that we may effectively protect our egg from. From this we can obtain the surface area necessary to reach the given terminal velocity. Our final designs may then be drawn up along with impact and actuation testing. The total time of flight will be hard to determine at this point because there is no way of accurately estimating any delay of separation and the aero-braking system engaging. This will be modeled as an instantaneous transition between phase 1 and 2.

## Phase 1

According to competition rules the CanSat's descent velocity must be limited to 20 m/s with a tolerance of 1 m/s for the portion of the descent from apogee to 400 m. In order to do this, a passive aero braking device such as a parachute or streamer may be used. The table below shows the most commonly used aero braking devices in model rocketry:

**Table 2: A comparison of common aero braking systems used in model rocketry.**

| | Drag Coefficient | Pros | Cons | Description |
|---|---|---|---|---|
| Flat Streamer | 0.05-0.4 | Simple, Low Wind Drift | Low Drag Coefficient, Requires Largest Area | Long, Rectangular, One Piece |
| Parasheet | 0.75 | Simple, Inexpensive, Reliable | Possible Wind Drift | Flat, Round, One Piece |
| Round Parachute | 1.5 | Largest Drag Coefficient | Complex, Can be Expensive, Possible Wind Drift | Round, True Dome Shape, Multiple Pieces |

Initially wind drift was a concern due to the high average wind velocity in Burkett, Texas. Figure 4 shows a map of the U.S with a color code indicating the average wind velocities of the area over one year. The black dot shows the approximate position of Burkett, Texas. According to the map the average wind velocity is between 6.5 and 9 m/s in the competition area. These velocities are fairly high and would normally constitute the use of a streamer. Apogee Rockets recomends the use of a streamer if the rocket is 30 g or less or when the rocket will reach an altitiude of 2000 ft or higher[4]. According to competition rules the CanSat must have a mass of 700 g with a tolerance of 10 g, so the Cansat will weigh much more the the recommended mass for a streamer, however, it will appogee at appoximately 670 m (2200 ft). Parachutes are much more commonly used in model rocketry and have been used in prior competitions in the same area with success.

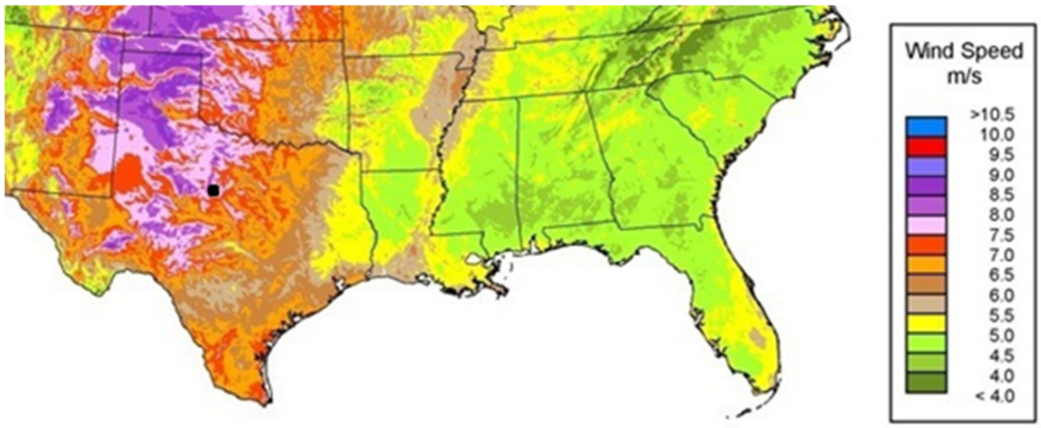



**Figure 4: A map of the U.S showing average wind velocity[3]**

In order to aid in the descision making process, an experiment was performed earlier in the semester. An apparatus shown in figure 5 was chosen because it simulates the approximate size of the canister. The parachutes and streamer were made larger because to reach a velocity of 20 m/s would require too large of a building, the apparatus would most likely break, and it would be harder to accurately measure the time. The parachutes used were two standard size parasheets and the streamer was made from a nine foot long ribbon. The apparatus had a constant mass and was dropped from a constant height making the only change each run the passive aero braking device. The time of the descent was measured by two people each run and five times were recorded for each device.

**Figure 5: A picture of the experimental apparatus**

The data is shown in figure 6, the mean value of the colleted data is shown with its standard deviation. The expected descent time based on a model is shown directly next to it. The data shows that the that the standard deviation of the streamer is larger than the stardard deviation of the parachutes, meaning streamers are less predictible. The experiment also shows that a parachute reduces the descent velocity of the apparatus by a significant amount of time more than the streamer, even though the streamer is 1.4 times larger than parachute 2. According to the model used to predict the falling times, A streamer would have to be over 5 times larger to produce the same results as the flat parachute. The size of a parachute necessary to limit the descent velocity of the CanSat to 20 m/s is 7.5

inches in diameter based on the model. Since the Cansat will have such a high mass and the parachute will be small it is unlikely that wind drift will be a large factor in this portion of the fall. The smallest parachute available is 9 inches in diameter, so a parachute will have to be modified to meet the requirement. Since a round, true dome parachute has a higher drag coefficient, it will be have to be even smaller than a flat parasheet and be more difficut to acquire. For these reasons a parasheet was choosen as the phase 1 aero braking device.

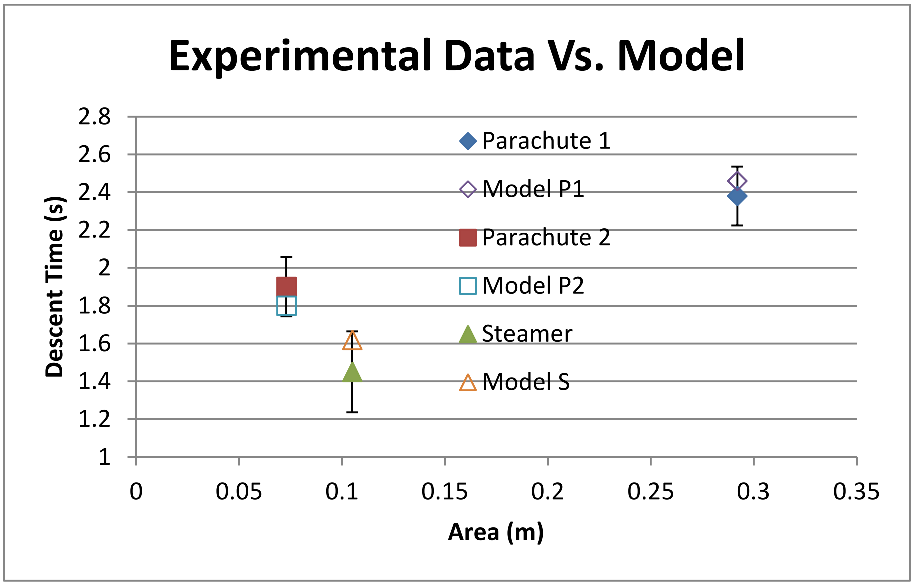



Figure 6: A graph showing descent time vs. effective area of each aerobraking device.

## Separation Mechanism

When the CanSat reaches the 400m mark, the payload needs to detach from the container so that the phase 2 aero-braking system can engage. In order for this detachment to happen a mechanism is necessary to physically separate the container from the payload. Out of three design concepts, one was chosen through a decision matrix in order to obtain the optimal choice.

### Trap door

This concept is essentially what the name implies, a trap door mechanism. The payload sits inside the container sealed on all sides. Upon release, a mechanism opens the floor to the container in order for the payload to simply slip out. The bottom portion of the container will be in two separate pieces, attached to the container via spring loaded hinges. A locking mechanism, comprised of a an electronically actuated device, most likely a solenoid, will hold the doors closed and keep the payload safe inside of the container. Upon the electronic signal and the locking mechanism actuation, the spring loaded hinges will open the doors and the payload will slip out using its own weight.

This design, along with its benefits, has some drawbacks. There will be a possibility of malfunction which would likely result in failure. The rules stipulate that the outermost shell of the CanSat, the one which will be in direct contact with the rocket, may not have any protrusions that may hinder the safe release of the CanSat. This being said, any geometry associated with the trap doors must be on the interior of the container which will therefore limit the diameter of the payload. This constraint will have a larger effect on the payload volume than if the geometry was shortened length wise. And while the CanSat may easily release from the rocket, the payload may have trouble releasing from the container.

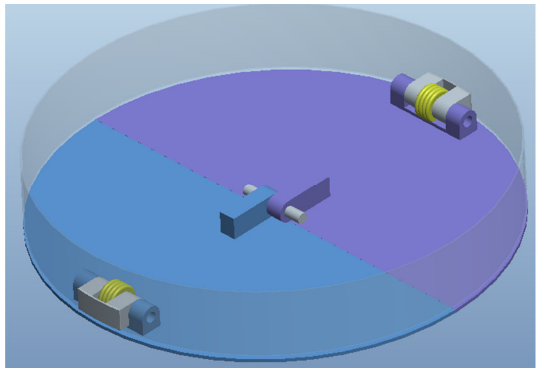


**Figure 7: Trap door isometric view**

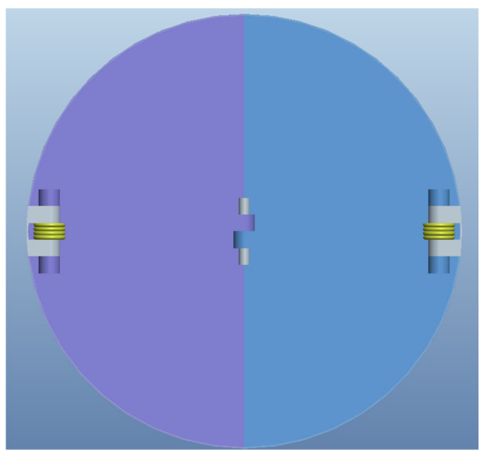


**Figure 8: Trap door top view**

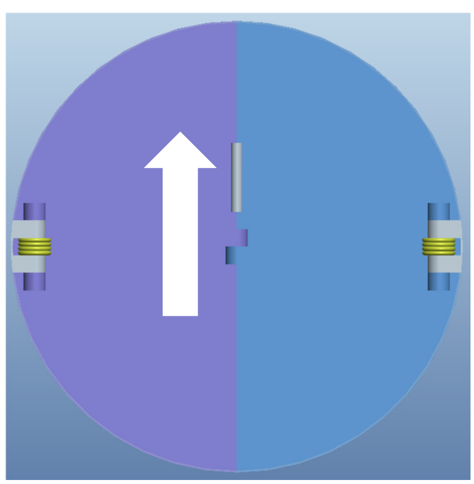


**Figure 9: Trap door top view showing motion of release pin**

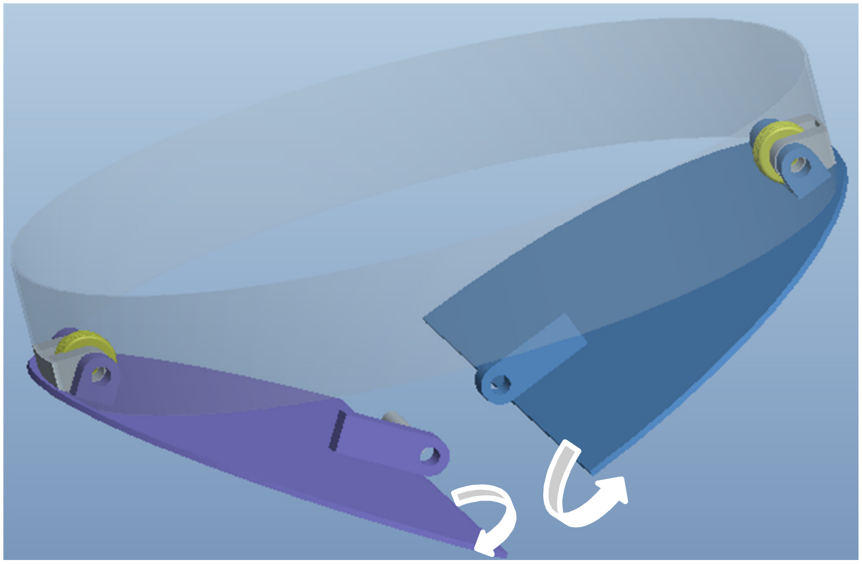


Figure 10: Trap door showing doors opening

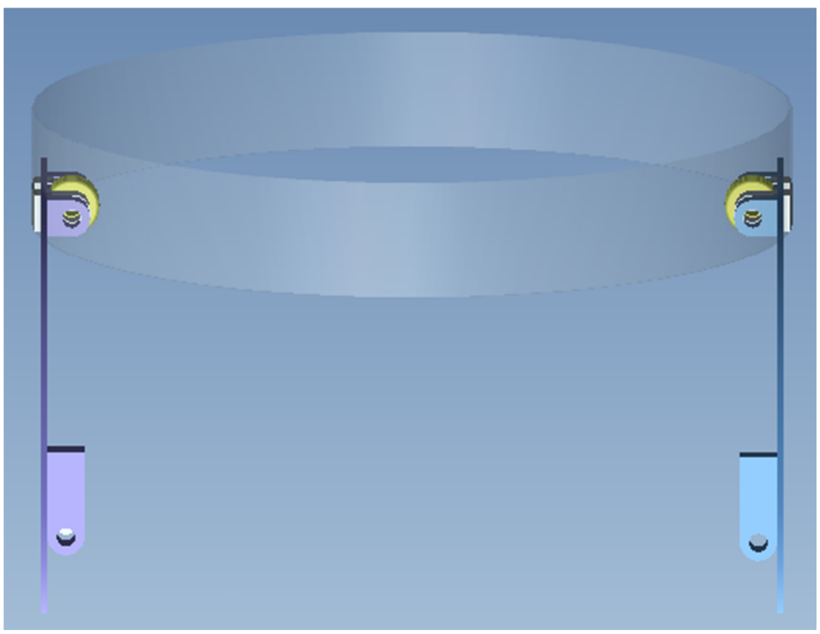


Figure 11: Trap door showing doors entirely open

## Solenoid quick release

This design utilizes a simplistic, pin release mechanism. A pull type, electronic solenoid will be the source of actuation. Upon electronic signal, the solenoid will move the pin in an axial direction. This pin is initially situated through a three piece sandwich comprised of two brackets with holes connected to the payload, and an eyebolt connected to the container. The movement of the pin disconnects the ring from the outer brackets and allows the payload to release under its own weight.

An issue that is associated with using this method is within the solenoid. Solenoids do not offer feedback control. Meaning within flight, under autonomous control, the electronics won't have a way to tell if separation was successful. This could potentially be an ultimate failing point for the project.

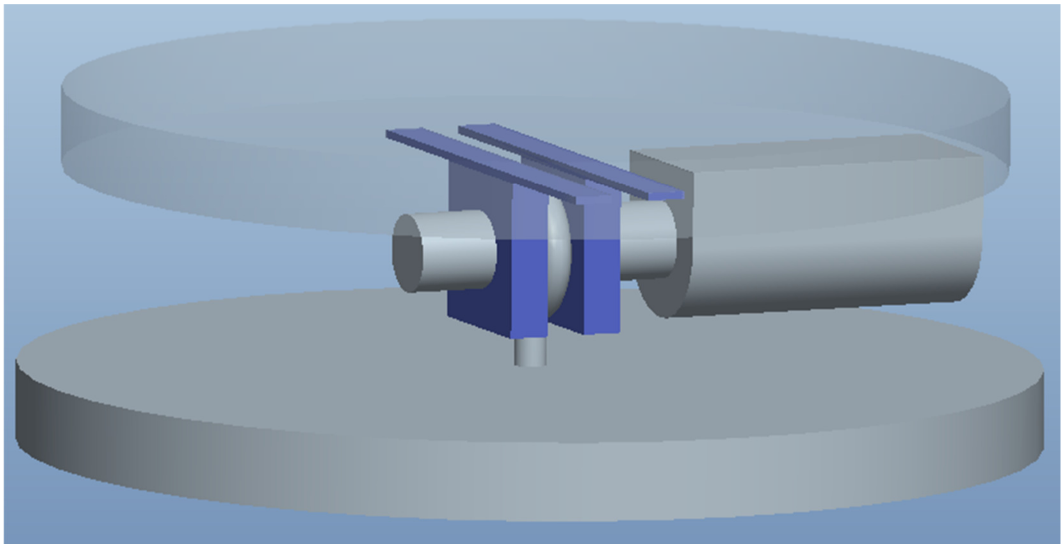


Figure 12: Solenoid quick release mechanical drawing

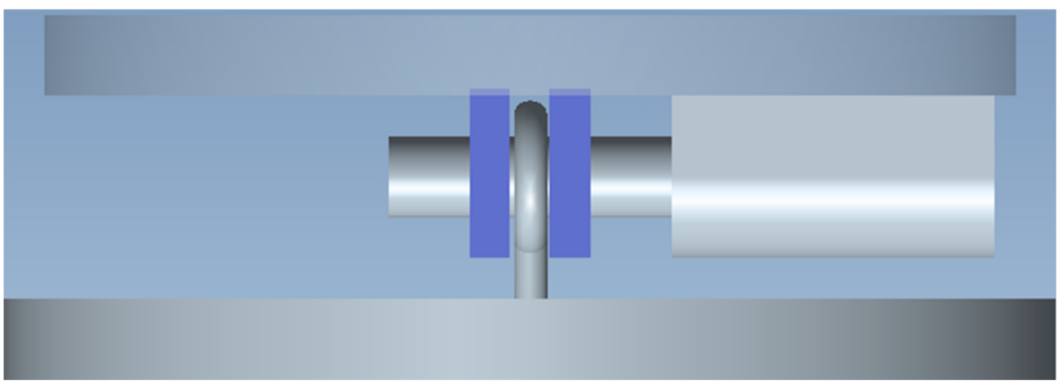


Figure 13: Solenoid quick release pin fully extended

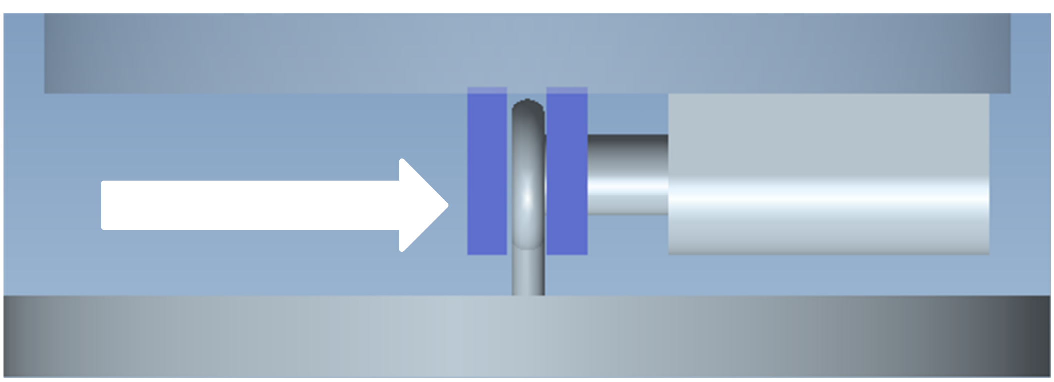


Figure 14: Solenoid quick release pin retracting

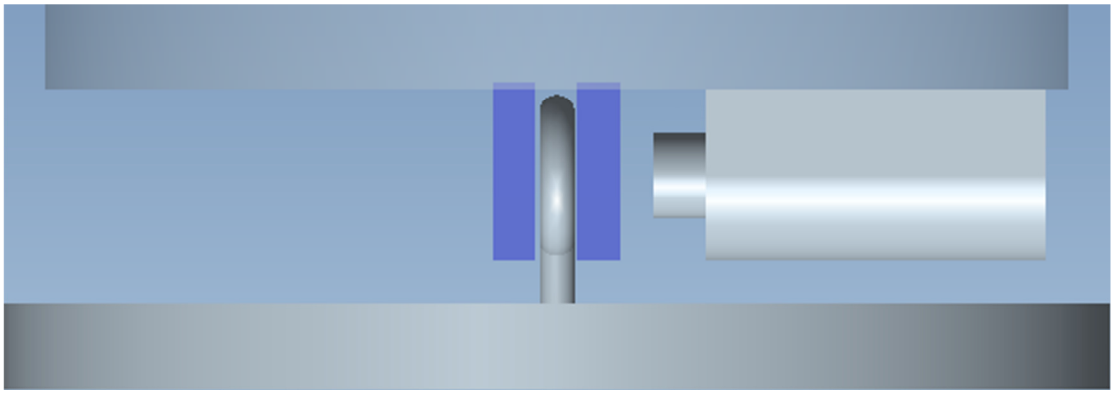


Figure 15: Solenoid quick release pin fully retracted

## Ring Release

This design is very similar to the solenoid mechanism, however, it uses a DC motor rather than a solenoid. The other primary difference between the two is instead of using a pin to separate the eyebolt from the brackets, this uses an un-closed ring that the motor spins, rather than pulls. The main reason for this idea, since it very closely resembles the solenoid method, is that the electronics needed to implement it are simpler than those needed for a solenoid. Another benefit of this method is that if frictional forces are too great, the problem can be easily fixed by increasing the diameter of the ring, raising the mechanical advantage. This solution is simpler in comparison to sourcing a stronger motor that would change size, weight, and electronic constraints. Implementation of a feedback system will be simple as well along with adding to the success rate.

The ability for this method to fail lies within the payload coming out of the container. As long as the motor is supplied with enough power, the feedback control will ensure that the open ring is no longer in contact with the eyebolt. So the only failure point should be from the payload becoming stuck in the container.

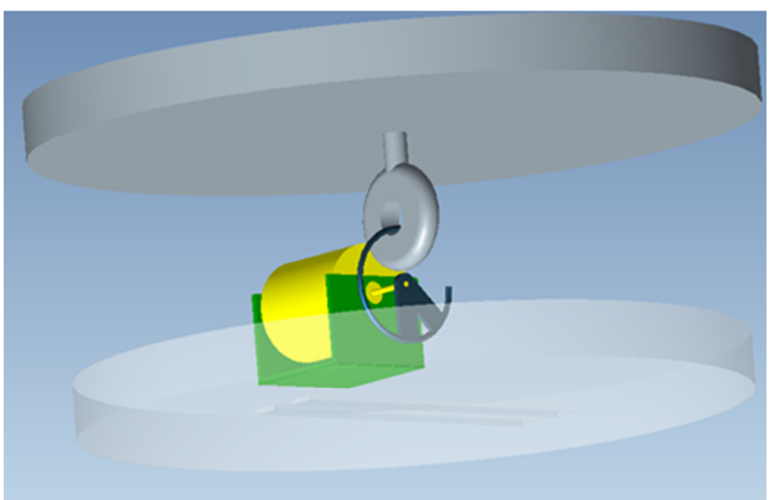


Figure 16: Ring release drawing

Table 3: Release mechanisms pros and cons

| | Pros | Cons |
|---|---|---|
| Trap Door | Solenoid offers instant Release<br>Container Completely encloses Payload | Solenoid requires additional voltage supply<br>Multiple moving parts, more fail points<br>Solenoid does not offer feedback control<br>Comparatively heavier<br>More parts, more money<br>Payload has potential to get stuck |
| | | |
| Solenoid Quick Release | Solenoid offers instant release<br>Container bottom open, safe release<br>Small amount of parts | Solenoid requires additional voltage supply<br>Solenoid does not offer feedback control |
| | | |
| DC Motor Quick Release | Inexpensive<br>Used with existing voltage supply<br>Container bottom open, safe release<br>Small amount of parts<br>Offers feedback control | Slower actuation<br>Open ring is hard to manufacture |

Table 4: Release mechanism decision matrix

| | Failure | Weight | Cost | Additional Accomodations | Simplicity | Manufacturability | Total Rating |
|---|---|---|---|---|---|---|---|
| Weight | 0.27 | 0.24 | 0.23 | 0.17 | 0.06 | 0.03 | |
| Trap Door | 3 | 5 | 5 | 1 | 3 | 6 | 3.69 |
| Solenoid Quick Release | 4 | 8 | 7 | 1 | 9 | 9 | 5.59 |
| DC Motor Quick Release | 9 | 8 | 9 | 8 | 8 | 9 | 8.53 |

*Category weights determined by comparing categories to one another on a 1-9 scale 9 being the best, then solving for weights to add to 1 with this correlation*

## Phase 2

After container-payload separation, which occurs at 400 m, the CanSat will deploy an aero-braking structure to reduce the descent rate. The following designs were developed to meet competition requirements and limitations regarding the use of certain chemicals and pyrotechnics, structural material properties, geometry, weight, and size. Details of the design constraints can be seen in the competition manual and the Needs Assessment provided on the team website.

In a NASA technical brief, an aero-braking structure is defined as a method of increasing the drag of a spacecraft by increasing the effective area by at least 5 times without significantly contributing to the structure's mass. Since parachutes, streamers, para-foils, and similar devices were unacceptable methods to use for the Phase 2 descent, the following designs were developed.

### Option 1: Spring-loaded Rods

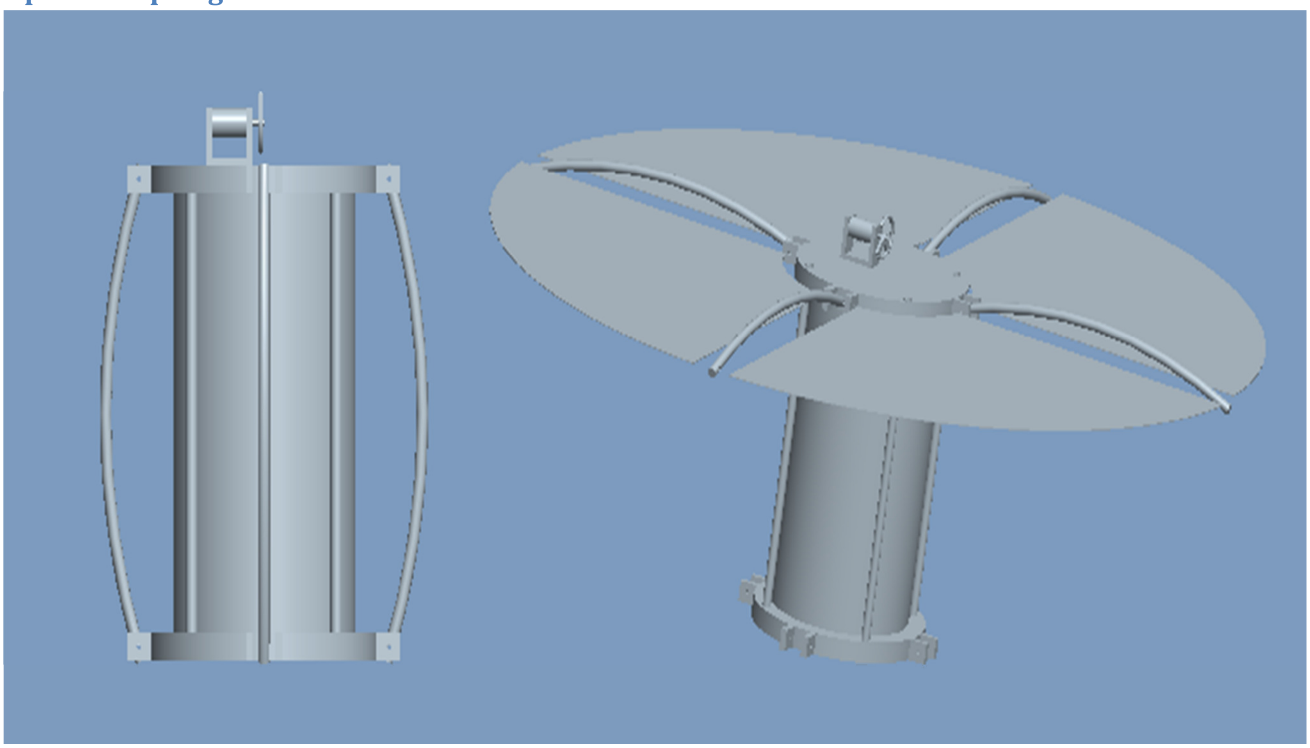


Figure 17: Spring loaded rods mechanical drawing, left closed, right open

This schematic shows an enclosure containing the payload. Support rods are used to secure the payload to the aero-braking structure and provide the rigidity necessary to withstand the specified impact. Essentially, the aero-braking structure is composed of rods with fabric in between, which deploy at 400 m to increase the effective area. Though not modeled in figure 17 above, durable fabric (such as a kite textile) is secured at the top portion of the structure and the bottom ends of each rod. The motor on the top of the design is used as the separation mechanism, mentioned previously. Torsional springs located at the top inner portion of the rods are held in compression at the bottom of the enclosure. A release mechanism, such as a contractible pin, a heating element to release a wire, or other similar concept may be used to release the stored mechanical energy in the springs.

### Option 2: Deployable Exterior Panels

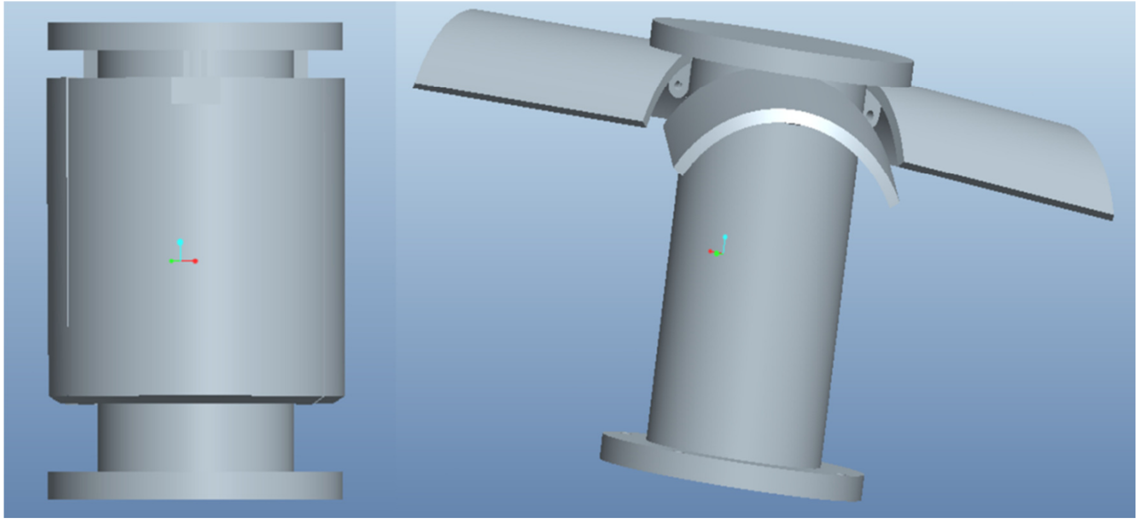


Figure 18: Deployable exterior panels mechanical drawing, left closed, right open

This second concept operates by having rigid panels on the payload open to create needed drag during the descent. The panels are geometrically constrained at the top of the enclosure, limiting the maximum angle they can open. The advantage of having rigid panels is a more durable aero-braking structure, at the expense of power needed to open the panels. Though a motor would be an effective method of deployment, it would be costly both for a mass and a power budget.

### Option 3: Telescoping Arms

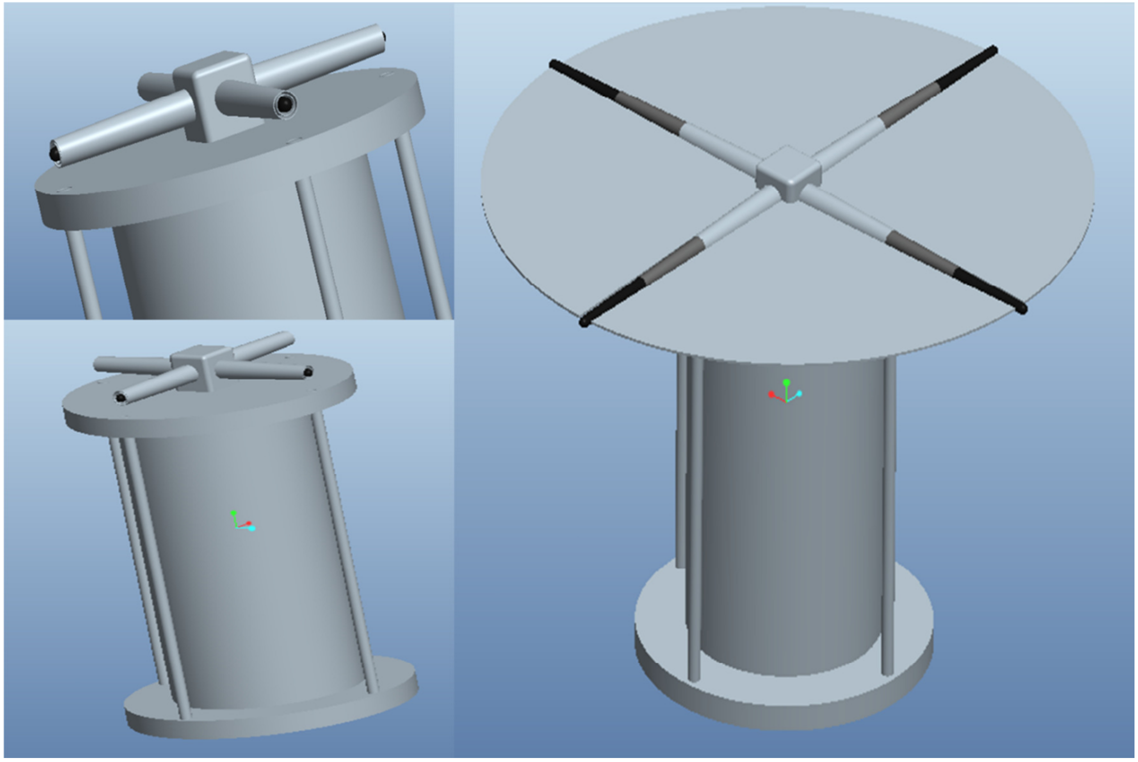


Figure 19: Telescoping arms  mechanical drawing, left retracted, right extended

Fabric, not seen in the two left images, is folded in between arms, attached at the center point and the tips of the last arm. As the telescoping arms extend, the fabric does as well. This design is easily customized to fit larger effective area ratios by adding longer arms. However, as the arms decrease in diameter, strength needed to withstand the drag force also decreases. The complexity of this design is in the method of extending the arms. A linear actuator can accomplish the task, but the time it would take to reach the fully extended position may be too far into the payload's descent to be effective.

Table 5: Phase 2 aero-braking mechanism decision matrix

| | Strength | Simplicity | Light Weight | Cost Effective | Spatial Efficiency | Total |
|---|---|---|---|---|---|---|
| 1: Spring Loaded Rods | 2 | 3 | 3 | 3 | 3 | 14 |
| 2: Deployable Exterior Panels | 3 | 3 | 1 | 3 | 2 | 12 |
| 3: Telescoping Arms | 2 | 1 | 2 | 2 | 3 | 10 |

The decision matrix above represents the top requirements of the aero-braking structure, as noted in the competition guidelines. The rules specify that the design must be able to withstand 30 gees of shock, which is denoted by the strength category. Mass, cost, and size restrictions are explicitly given. Simplicity incorporates ease of manufacturing, implementation, and deployment. Ranked on a simple 1 to 3 scale, 1 being low, 2 medium, and 3 high, numeric values are given. The category names are manipulated such that a high score achieves the objective.

Based on the results of the decision matrix, the final design chosen is Option 1. A more detailed drawing is provided below.

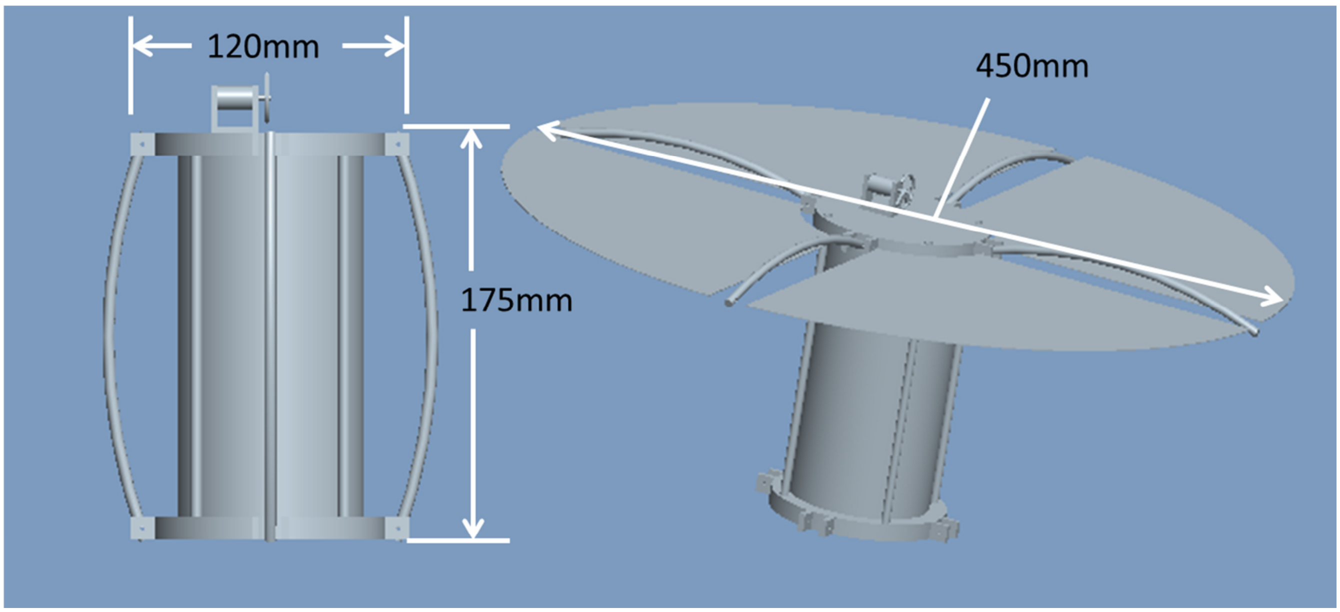



**Figure 20: Spring loaded rods drawing with measurements**

As seen above, the specified dimensions are well within the allotted diameter and height of the container, which is constrained by the competition guidelines. Further development of the design is in progress, including the deployment method, materials, purchasing, and fabrication.

## Phase 3

One major priority of the mission is to protect the "sensor", an egg, during the fall and impact with the ground. To do this the egg will be completely enclosed in a soft, flexible material. Table 7 shows the possible materials that are currently being considered. Memory foam is a low density material that will conform to the shape of the egg. This will hold the egg in place as well as significantly increase the area that a force is felt over the egg. Memory foam can be bought for a relatively inexpensive price, but higher quality memory foam may have better properties than low quality memory foam. Dough could be an inexpensive option but some extra research must be done to find an appropriate recipe. A light, airy dough could possibly be an acceptable choice, but it will be necessary to consider how the dough's properties will change over time. This option has been used in the past with successful results.

Polystyrene beads (Styrofoam) will also be considered. The density of a single bead is much higher than the density of memory foam, but there will be air between the beads while inside the container which will lower the relative density [6]. The beads can fill the space around the egg to prevent any movement of the egg and increase the area over which the egg will feel the impact force. In order to aid in the decision between these choices, an experiment will be performed early next semester. This experiment will involve dropping the egg while wrapped in each substance from a standard height so that the egg will hit the ground at a good testing velocity. Since the average acceptable velocity for a model rocket to hit the ground is from 3 to 5 m/s, a good testing velocity would be two to three times that to ensure the survival of the egg upon impact. If multiple materials make the egg survive the decision will be made based on cost and mass requirements.

Table 6: A comparison of different materials for sensor protection.

| Material | Density | Cost | Details | Pros | Cons |
|---|---|---|---|---|---|
| Memory Foam | 48-80 kg/m^3 | $20-150/ Mattress Topper | Rectangular Foam 1.5 in Thick | Soft, Light | Susceptible to heat |
| Dough | Unknown | $2-10 | Organic Material with Air Pockets | Cheap | Difficult to obtain consistent properties |
| Polystyrene Beads | 1050-1120 kg/m^3 | 12-15¢/ Liter | Expanded Soft Beads | Cheap, Light | May get Loose in Container |

## Electrical Power System

The battery management will be accomplished using a simple voltage divider and an analog to digital converter (ADC). The voltage divider is used to limit the current flow to the ADC and also to provide a known voltage to base the measurements from. The following figure shows a simple schematic of a possible configuration.

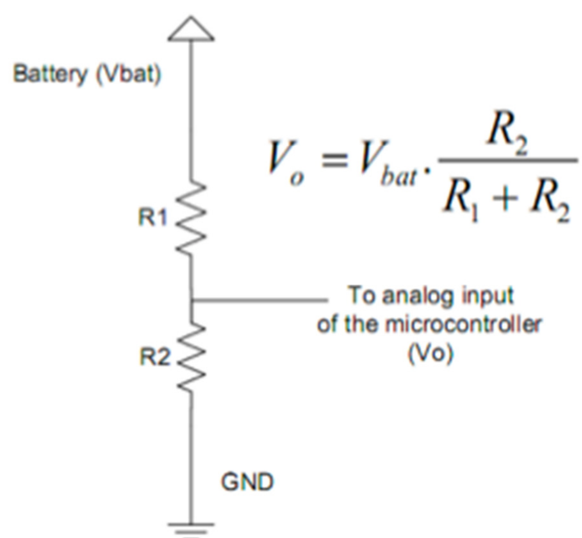



Figure 21: Voltage divider

$R_1$ and $R_2$ are high valued resistors (e.g. 100 kΩ and 270 kΩ respectively), this would make the ratio of the voltage measured to the actual battery voltage about 0.73.

The following table shows a power budget based on the current designs and interpretation of the competition requirements.

**Table 7: Current CanSat power budget**

| Component | Current [mA] | Voltage [V] | Power [mW] | Expected duration [min] | Total energy [mWh] |
|---|---|---|---|---|---|
| Microprocessor | 50 | 5 | 250 | 10 | 41.7 |
| I/O Pins | 40 | 5 | 200 | 10 | 33.4 |
| GPS* | 41 | 3.3 | 136 | 10 | 11.8 |
| BMP085 | 0.01 | 3.3 | 0.2 | 10 | n/a |
| XBEE Tx | 250 | 3.3 | 825 | 10 | 137.8 |
| XBEE Rx | 55 | 3.3 | 181.5 | 0.1 | 18.2 |
| Actuator* | 600 | 3.3 | 1980 | 0.1 | 198.0 |
| Buzzer* | 8 | 3.3 | 26.4 | 180 | 79.2 |
| Total | | | | | 520.1 |

* Values are estimated based on data obtained from previous competitions.

The power budget is currently an estimate because not all components have been selected and there are some remaining decisions that need to be made. Examples are the separation mechanism and the GPS.

Based on the required energy from the power budget in the previous table a minimum of 520.1 mWh would be needed for the operation of the CanSat under normal conditions. A typical package type-A lithium-ion battery has a high enough energy density to provide enough energy while limiting the mass added to the overall mass budget constraint.

## Telemetry

The CanSat 2013 competition guideline states that upon receiving activation command, the CanSat shall transmit the telemetry data. The format of the telemetry data that is transmitted shall be in packets of comma-separated fields followed by a carriage return character in the following format. The telemetry data shall be transmitted every 2 seconds.

```
CANSAT,<TEAM_ID>,<MISSION_TIME>,<GPS_TIME>,<GPS_LAT>,<GPS_L
ONG>,<GPS_ALT>,<GPS_SAT>,<ALT_SENSOR>,<TEMP>,<BAT_V>,<STATE
>[,<CUSTOM>[,<CUSTOM>]]
```

Where,

- CANSAT = the fixed string "CANSAT";
- <TEAM_ID> = the four digit team number that will be assigned;
- <MISSION_TIME> = the mission time maintained by the flight; software in integer format. The time will be measured in seconds;
- <GPS_TIME> = the local time output by the GPS module. The format of the GPS time will be "HH:MM:SS";
- <GPS_LAT> = the GPS latitude from the NMEA format output. This will include the cardinal direction N or S, and output in the following format: "DDMM.mmmmN"
- <GPS_LONG> = the GPS longitude from the NMEA format output. This will include the cardinal direction W or E, and output in the following format: "DDMM.mmmmW"
- <GPS_ALT> = the altitude measured by the GPS module; in meters above sea level; obtained from the NMEA output;
- <GPS_SAT> = the number of GPS satellites being tracked ; from the NMEA output;
- <ALT_SENSOR> = the altitude in meters as measured from the non-GPS sensor with a precision of 0.1 m above sea level
- <TEMP> = the measured air temperature in degrees Celsius with a precision of 1 degree resolution.
- <BAT_V> = the carrier battery voltage in volts with a precision of 0.1 volt resolution
- <STATE> = an integer value indicating the state of the flight software; the state of the flight software corresponds directly to the state of flight of the CanSat; the <STATE> output may include non-flight states such as "Boot" and "Debug" to indicate the CanSat is in a test mode.
- [,<CUSTOM>[,<CUSTOM>]] = these may be used for additional telemetry fields, or a custom output as needed;

The telemetry for the entire mission shall be saved on the ground station computer as a comma-separated value (.csv) file that shall be delivered to the competition judges for examination. This file must be provided to the judges via a USB drive. The telemetry data shall be named using the following format

CANSAT2013_TLM_<TEAM_ID>_<TEAM_NAME>.csv

The <TEAM_ID> is provided by the competition and the team chooses the <TEAM_NAME>. The team name for our group is the "Fighting Mongooses" so our output file should be

CANSAT2013_TLM_<TBA>_<FIGHTING_MONGOOSES>.csv

## Sensory Subsystem

The sensory subsystem shall take all the required measurements per the competition Telemetry requirements. (COMP_REQ-3.3) The data will be processed and transmitted in the proper format to the Ground Control Station. The Sensory Subsystem is composed of the Altitude, Temperature, Force sensor, and GPS module. All sensors must be able to be sampled at a rate no less than 0.5 Hz; i.e. every 2 s. All sensors must be able to interface with the microprocessor using standard protocols. Examples of protocols are serial TTL, UART, $I^2C$, SPI, and analog voltage. All electronic components were researched using distributors and manufacturer websites to obtain data-sheets and other resources related to the device.

### Altitude Sensor (non-GPS)

The competition guidelines require that data from a non-GPS altitude sensor be included in the telemetry. The barometric pressure and temperature sensor is a commonly used method for measuring height above sea level. The components shown in the following table were obtained by using the following criteria:

- Output resolution of 0.1 m
- Sample rate of at least 0.5 Hz
- Operate on $I^2C$, SPI, or serial LV TTL protocol
- Nominal operating voltage no higher than 5 V
- Low weight, low cost
- Preferably connected with breakout board

Table 8: Altitude Sensor Comparison

| MFG P/N | Sample Rate [Hz] | Resolution [m] | Interface / Protocol | Operating Voltage [V] | Weight [g] | Cost of Component [$US] |
|---|---|---|---|---|---|---|
| BMP085 | 1 | 0.1 | $I^2C$ | 3.3 | 5 | 19 |
| SCP-1000 | 1 to 9 | 0.15 | SPI, $I^2C$ | 3.3 | 5 | 30 |
| MS5607 | 10 | 0.1 | SPI, $I^2C$ | 5 | 5 | 30 |

Based on the criteria above, the BMP085 was found to be the most desirable for the purposes of non-GPS altitude sensor. The BMP085 has been used successfully in similar projects. This is made very clear when reviewing past competition documents and performance reviews, as well as rocket hobbyist and design/build shops that implement these devices regularly and can verify the validity of the output data. The BMP085 is shown in the following image.

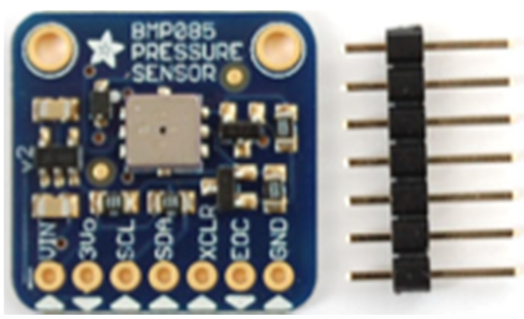



Figure 22: BMP-085, Pressure/Temperature sensor with breakout board

The output of this sensor includes a temperature measurement with a resolution of 0.1 degrees C. It is a low noise (0.1 m), low power device that has a current drawn of only 5 µA at 1 sample/sec and operates at 3.3 V.

Using the $I^2C$ interface, only 4 pins are required for connection to the microcontroller: $V_{CC}$, GND, SDA, and SCL. It is available, as shown; with a breakout board that allows for quick integration to the main processing board or the device itself can be integrated into a custom PCB. The decision to implement the telemetry devices via breakout or a custom PCB has not been made as of this time.

This device requires calibration on start-up. The data is stored on the BMP085 on-chip, so it is a calibrated device.

The altitude is determined by the equation (obtained from the data sheet)

$$altitude = 4430 * \left[1 - \left(\frac{p}{p_0}\right)^{\frac{1}{5.255}}\right]$$

Where $p$ is the measured pressure and $p_0$ is the pressure at sea level. A range of about 0 to 1000 m corresponds to a change in $p$ of about 100 hPa. A pressure change of 1 hPa corresponds to 8.43 m at sea level.

Typical application of the BMP085 is shown in the following figure

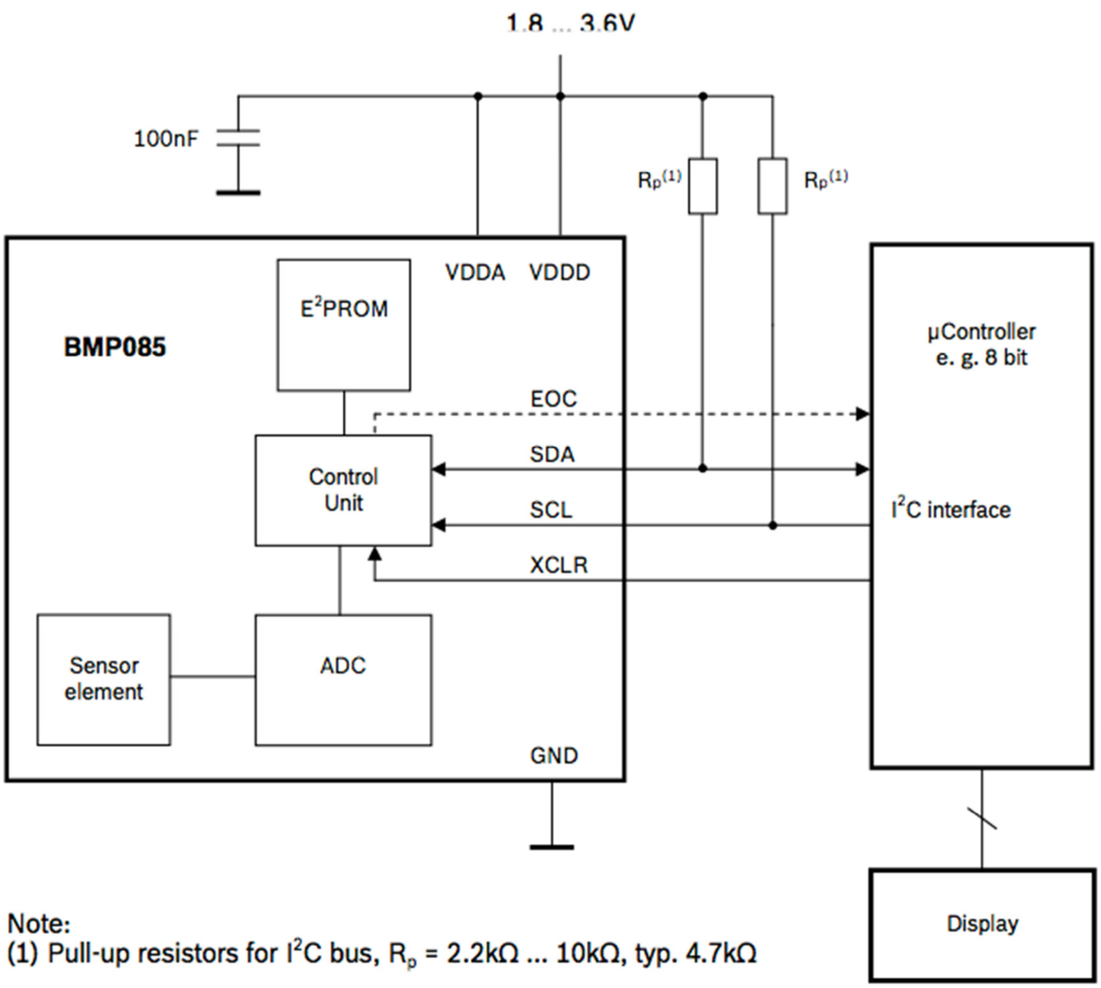



Figure 23: BMP085 Application Diagram

## Force Sensor

For the force of impact selectable objective the competition requires that the force of the CanSat's impact with the ground be measured and recorded. To accomplish this we will use an accelerometer to measure the deceleration on impact and multiply that by the known mass of the CanSat.

The components shown in the following table were obtained by using the following criteria:

- Sample rate of at least 100 samples/second
- Operate on $I^2C$, SPI, or serial LV TTL protocol
- Nominal operating voltage no higher than 5 V
- Low weight, low cost
- Preferably connected with breakout board

**Table 9:Accelerometer comparison**

| MFG P/N | Sample Rate [Hz] | Resolution | Interface / Protocol | Operating Voltage [V] | Weight [g] | Cost of Component [$US] |
|---|---|---|---|---|---|---|
| ADXL 345 | 3200 | 16g | $I^2C$, SPI | 3.3 | 2 | 19 |
| LSM303-DLHC | 2400 | 8g | SPI, $I^2C$ | 3.3 | 2 | 30 |
| BMA180 | 2400 | 16g | SPI, $I^2C$ | 5 | 2 | 25 |

Based on the criteria above obtained from the manufacturer datasheets, the ADXL345 was found to be the most desirable for the purposes of the obtaining an acceleration to be input to the impact force calculation. The ADXL345 has a proven track record for reliability and has been used successfully in similar projects. This is made very clear when reviewing past competition documents and performance reviews, as well as rocket hobbyist and design/build shops that implement these devices regularly and can verify the validity of the output data. The ADXL345 and breakout board is shown in the following image.

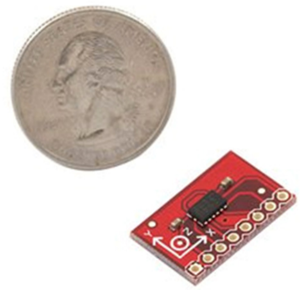


Figure 24: ADXL345 with breakout board compared to quarter

The ADXL345 is a complete 3-axis acceleration measurement system with a selectable measurement range of ±2 *g, ±4 g, ±8 g,* or ±16 *g.* It measures both dynamic acceleration resulting from motion or shock and static acceleration, such as gravity, which allows the device to be used as a tilt sensor. The nonlinearity of the device is, as a percentage of full scale, ±0.1%. This should be a negligible concern for the output to our force of impact calculations.

The sensor is a polysilicon surface-micromachined structure built on top of a silicon wafer. Polysilicon springs suspend the structure over the surface of the wafer and provide a resistance against acceleration forces.

Deflection of the structure is measured using differential capacitors that consist of independent fixed plates and plates attached to the moving mass. Acceleration deflects the beam and unbalances the differential capacitor, resulting in a sensor output whose amplitude is proportional to acceleration. Phase-sensitive demodulation is used to determine the magnitude and polarity of the acceleration.

The output resolution is 10-bit for each axis (x,y,z) with a typical sensitivity of 32 LSB/g and a scale factor of 31.2 mg/LSB. The sensitivity due to temperature is ±0.01 %/degree C. The noise performance for a data rate of 100 Hz at 10-bit full resolution is less than 1.5 $LSB_{RMS}$ for the z-axis. The bandwidth is user selectable from 6.25 to 3200 Hz.

Table 10: ADXL345 maximum ratings table

## ABSOLUTE MAXIMUM RATINGS

**Table 2.**

| Parameter | Rating |
|---|---|
| Acceleration | |
| Any Axis, Unpowered | 10,000 *g* |
| Any Axis, Powered | 10,000 *g* |
| $V_S$ | −0.3 V to +3.6 V |
| $V_{DD\,I/O}$ | −0.3 V to +3.6 V |
| Digital Pins | −0.3 V to $V_{DD\,I/O}$ + 0.3 V or 3.6 V, whichever is less |
| All Other Pins | −0.3 V to +3.6 V |
| Output Short-Circuit Duration (Any Pin to Ground) | Indefinite |
| Temperature Range | |
| Powered | −40°C to +105°C |
| Storage | −40°C to +105°C |

## GPS

The competition requires information from a GPS be included in the telemetry transmission, specifically, data from the the NMEA GGA sentence shown below.

```
$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47

Where:
     GGA          Global Positioning System Fix Data
     123519       Fix taken at 12:35:19 UTC
     4807.038,N   Latitude 48 deg 07.038' N
     01131.000,E  Longitude 11 deg 31.000' E
     1            Fix quality: 0 = invalid
                               1 = GPS fix (SPS)
                               2 = DGPS fix
                               3 = PPS fix
                               4 = Real Time Kinematic
                               5 = Float RTK
                               6 = estimated (dead reckoning) (2.3 feature)
                               7 = Manual input mode
                               8 = Simulation mode
     08           Number of satellites being tracked
     0.9          Horizontal dilution of position
     545.4,M      Altitude, Meters, above mean sea level
     46.9,M       Height of geoid (mean sea level) above WGS84
                      ellipsoid
     (empty field) time in seconds since last DGPS update
     (empty field) DGPS station ID number
     *47          the checksum data, always begins with *
```

The components shown in the following table were obtained by using the following criteria:

- Sample rate of at least 1 Hz
- Operate on $I^2C$, SPI, or serial LV TTL protocol
- Output NMEA GGA Sentence
- Low weight, low cost

Table 11: GPS comparison

| MFG P/N | Sample Rate [Hz] | Accuracy | Interface / Protocol | Operating Voltage [V] | Cost of Component [$US] |
|---|---|---|---|---|---|
| LS20031 | 5 | 3m | Serial | 3.3 | 60 |
| Copernicus II | 1 | <4m | Serial | 3.3 | 45 |
| Linx RXM-GPS-SR-B | 1 | 5 | Serial | 3 - 4.3 | 44 |

At this time the final GPS selection has not been made.

## Radio Communications

The CanSat 2013 competition guideline states clearly that all telemetry and all radio communication must use an “XBEE” type “Series 1 or Series 2” radio transceiver. Some assumptions, based on simple kinematic equations and physical reasoning, of the flight geometry suggest that for line-of-sight communications to be maintained a minimum range of approximately 700 m will be required. Since environmental factors, primarily wind, must be considered, the estimated maximum range of the radio will be approximately 1.4 km.

**Table 12: XBEE-PRO series 1 Key Specifications**

| Specification | |
|---|---|
| Outdoor, Line of Sight Range | 1600 m |
| Transmit output power | 63 mW |
| RF Data Rate | 250 kbps |
| Serial Interface rate | 1200 bps to 250 kbps |
| Receiver Sensitivity | -100 dBm (1% packet error rate) |
| Operating Frequency | 2.4 GHz |

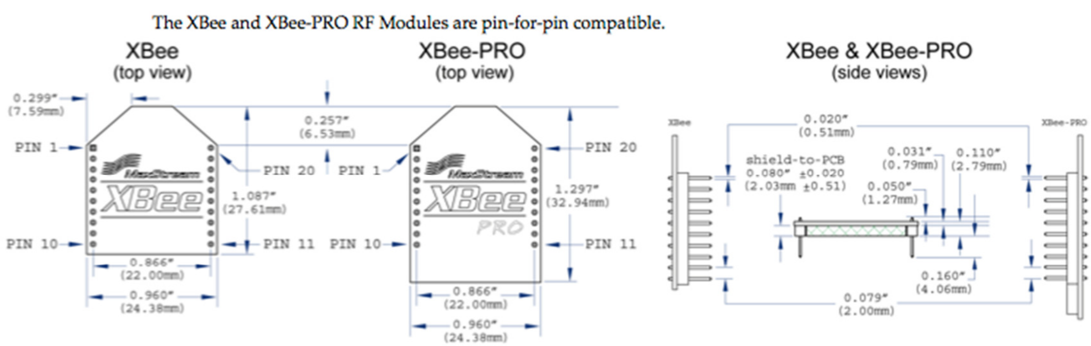



**Figure 25: XBEE Mechanical Drawings**

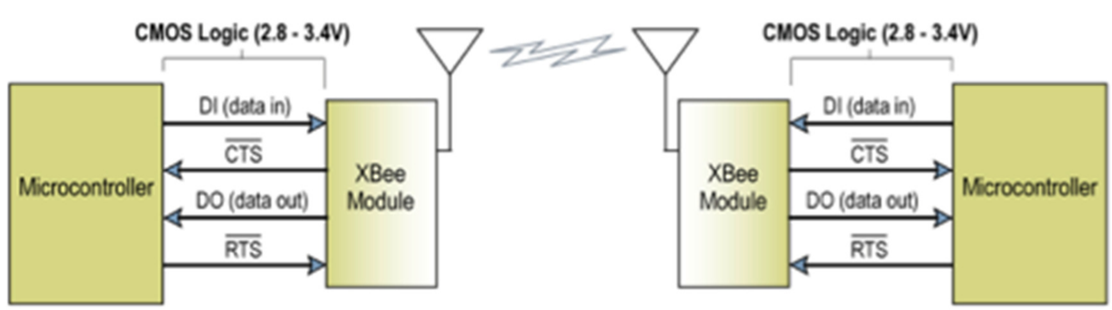
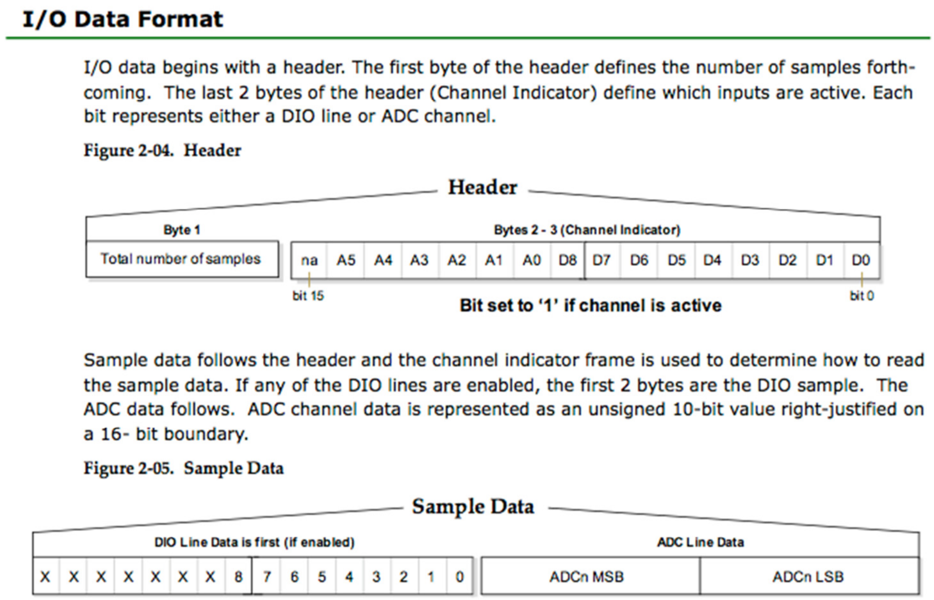



**Figure 26: System Data Flow Diagram in a UART interfaced environment.**



**I/O Data Format**

I/O data begins with a header. The first byte of the header defines the number of samples forthcoming. The last 2 bytes of the header (Channel Indicator) define which inputs are active. Each bit represents either a DIO line or ADC channel.

**Figure 2-04. Header**



Sample data follows the header and the channel indicator frame is used to determine how to read the sample data. If any of the DIO lines are enabled, the first 2 bytes are the DIO sample. The ADC data follows. ADC channel data is represented as an unsigned 10-bit value right-justified on a 16- bit boundary.

**Figure 2-05. Sample Data**



Figure 27: I/O Data Format

## Microcontroller

The microcontroller will run the flight software and interface with all of the sensors, the radio, the separation mechanism, and the stage 2 aero braking mechanism. The microcontroller was selected using the following criteria.

- Low cost
- Small Size
- Able to interface with all needed components
- Sufficient memory to run program
- Easy development

Table 13: Microcontroller comparison

| Microcontroller | Clock Speed [MHz] | Memory | Communication Interfaces | Operating Voltage [V] | Size | Cost [$US] |
|---|---|---|---|---|---|---|
| Arduino Uno | 16 | 32k | Serial, $I^2C$, SPI, A2D | 5 | 2.7 x 2.1 in | 30 |
| Arduino Pro Mini 328 | 16 | 16k | Serial, SPI, $I^2C$, A2D | 5 | 0.7 x 1.3 in | 19 |
| FEZ Cerberus | 168 | 300k | SPI, $I^2C$, UART, A2D | 5 | 2.25 x 1.85 in | 30 |

From the options the Arduino Uno was chosen because it had the capability of interfacing with all the needed components and because it was the easiest to work with and develop for. It has a sufficient number of pins to connect everything and is capable of handling the protocols used by the components. Arduino has a very simple development environment and good community support. Many components already have example code and libraries written for them, so development will be much simpler than with other microcontrollers.

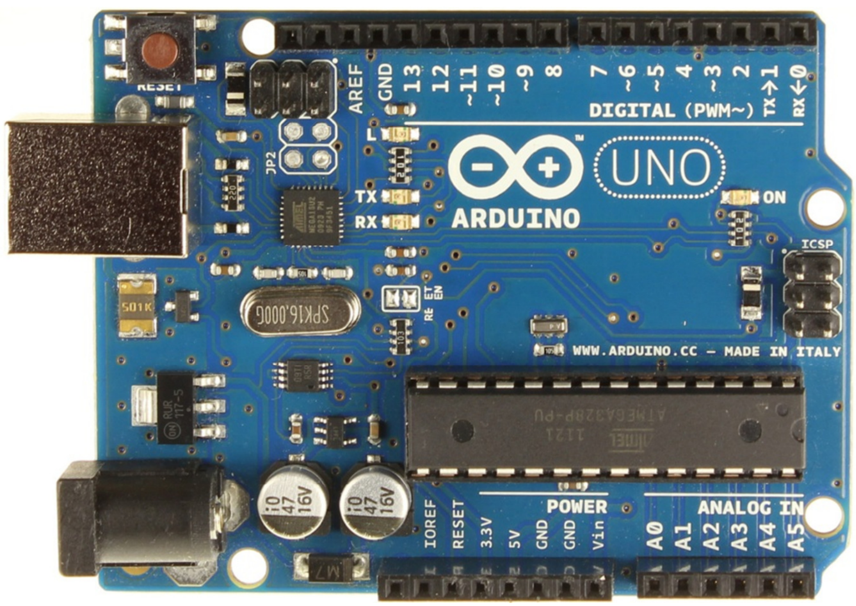



Figure 28: Arduino Uno

Table 14: Arduino Uno component interface

| Arduino Uno Interface | | | |
|---|---|---|---|
| | Component | Interface/Protocol | Pins |
| Radio | XBEE Series 1 | Serial | 0, 1 |
| Altimeter | BMP085 | I2C | A4, A5 |
| Accelerometer | ADXL345 | SPI | 10 - 13 |

## Software

### Flight Software

The flight software will run on the microcontroller and will control the reading of sensors, transmission of telemetry, deployment of the stage 2 aero braking system, impact force calculation, and starting the locator beeper on landing. The software will be written in the Arduino programming language, a simplified version of C/C++. According to the competition rules the software must wait for a signal from the ground station before beginning telemetry transmission, it will receive this signal while on the launch pad. After that it must gather information from the sensors and transmit the telemetry every two seconds. It must also keep track of what state it should be in even in the case of a processor reset. Because the software state is determined both by the altitude and direction of motion of the CanSat this will be accomplished by checking the current altitude and comparing it to the last taken altitude measurement. If it is higher the CanSat is ascending, if it is lower the CanSat is descending, if they are the same the CanSat is landed.

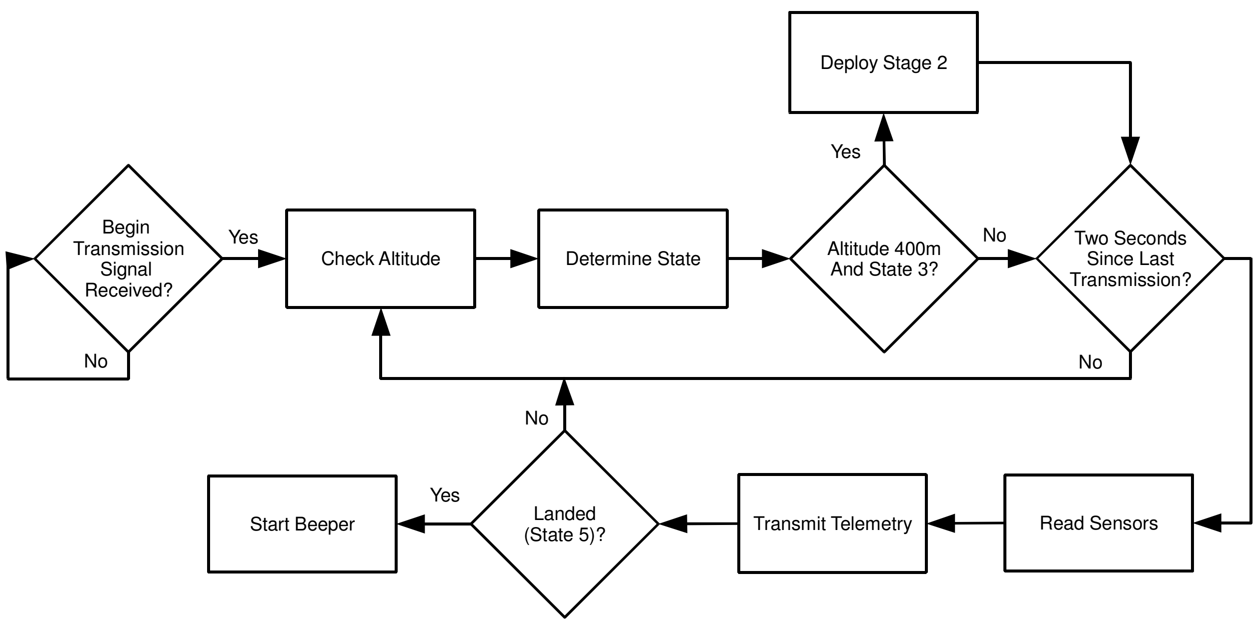



Figure 29: Flight software flowchart

Table 15: Flight software state descriptions

| Flight Software State | Description |
|---|---|
| 0 | Software Initialization |
| 1 | Launch Pad |
| 2 | Ascending |
| 3 | Descending to 400m |
| 4 | 400m to Landing |
| 5 | Landed |

### Ground Control Software

The ground control software will run on a laptop and communicate with the CanSat through an XBEE radio. It will send a signal to the CanSat telling it to begin telemetry transmission, receive telemetry, display and plot the telemetry data in real time, and save the data to a .csv file.

## Funding

Since this project is self-funded, it was necessary to find sponsors. The ECE department donated $200 to the project, $750 was obtained from two private donors, $250 was obtained from State Farm through one of the private donors and $1000 was obtained from Dr. Shih. The current funding and expenses are shown in the table below.

Table 16: Funding and expenses

| Income and Expenses | | | | |
|---|---|---|---|---|
| Sponsor Name | Funds Received | Funds Pending | Equipment Purchased | Cost |
| ECE Department | 200.00 | 0.00 | 2 xbee radios | 84.81 |
| Private Donation | 750.00 | 0.00 | 2 rocket parachutes | 4.28 |
| Dr. Shih | 1000.00 | 0.00 | Can of Oats, Fishing Line, Ribbon | 8.75 |
| State Farm | 250.00 | 0.00 | Can of Oats | 3.39 |
| Total Funding | 2200.00 | 0.00 | Total Expenses | 101.23 |
| Total Available Funds | 2098.77 | | | |

The expected cost of the trip to is $1424. This leaves $766 to construct the Cansat.

# Conclusion

## Risk Assessment

The most challenging aspects of this project are the actuation of the non-parachute at the 400 m mark and the control of the "Phase 2" decent. There are inherent risks associated with the protection of the egg, but this is a well-studied experiment with many sources to drawn upon. The descent using the aero-braking system ultimately leads to the success or failure of the egg protection, since if the lander/payload is traveling at too high a velocity and cannot slow down due to failure of a "Phase 2" system, then there will be little that can help reduce the excessive g-forces that will cause the ultimate failure of the broken egg.

There seems to be little risk of failure involving the telemetry and data handling aspects other than the failure of the electrical power systems. The energy capacity of the batteries has been considered to be so critical that given the mass budget and energy density of the Li-Ion batteries; the batteries should be able to deliver about twice the estimated power required by the CanSat. However, the separation mechanism design has not yet been finalized and only an estimate of the power requirements have been made, so this will have to be taken into consideration before moving into the final design draft work.

Risks associated with the XBEE radio and communication with the ground station include, in addition to the power failures, interference and transmission error. The model of XBEE selected has a considerably low transmission error rate and the chance of an error occurring is extremely low. Interference from water towers, radio towers or other large structures is almost non-existent due to the location of the competition being selected so that all radio communication is line of sight and far from sources of interference from structures. Interference from the radios and antennae of other teams could possibly be a source for interference. Effective communication between teams will be necessary, though it should be noted that each team is responsible for addressing sources of radio interference.

## Final Statement

As mentioned prior, Phase 1 is tested and complete. Due to the results of the experiment and research, a parachute will be used as the passive aero braking system. Phase 2 and 3 are under development, with experiments and finalizations to be made early next semester. When these portions of the designs are complete, an accurate mass budget and an updated monetary budget can be produced. The electronic components have mostly been chosen and once they have been received can be integrated with the hardware and software.

## Time Line

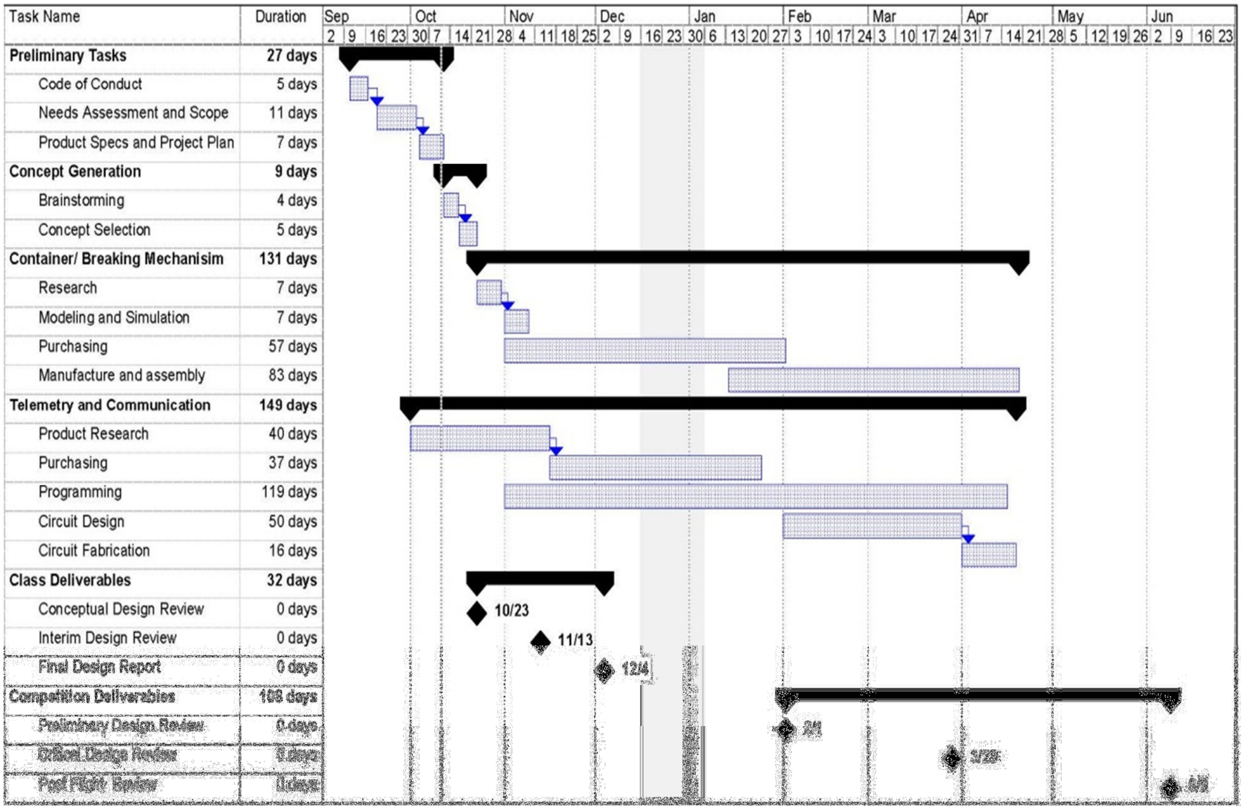


Figure 30: CanSat team Gantt chart

As seen in the timeline above, first semester milestones have been completed and reviewed. Phase 1 of descent has been tested, designed, and preliminary components have been purchased. The Phase 2 design has been chosen and it is currently being developed. Phase 3 tests have been designed and will be conducted prior to the new semester. Thus, the container/braking mechanism is on track for completion as shown above.

Most of the electronics component selection has been completed and ordering parts is on track for the end of this year to the beginning of next year. Initial programming work has been done and once components have been received early next semester integration and testing can begin.

## References


[1] American Astronautical Society and American Institute of Aeronautics and Astronautics . CanSat Competition. 6 September 2012. Web. 11 December 2012 <http://www.cansatcompetition.com/Mission_files/competition_guide_alt1_120710_r8.pdf>.

[2]"General Purpose ABS SP-9010 ." *www.usplastic.com*. Spartech. Web. 26 Nov 2012. <http://www.usplastic.com/catalog/files/specsheets/SP-9010 ABS.pdf>.

[3] Harvey, Hal. "Council on Jobs and Competitiveness Report." *http://energyinnovation.org*. Energy Innovation, 18 Jan 2012. Web. 10 Oct 2012. <http://energyinnovation.org/2012/01/council-on-jobs-and-competitiveness-report/>.

[4] Van Milligan, Tim. "Using Streamer Recovery Instead of Parachutes." *Apogee Peak of Flight News Letter*. 20 2004: 1-5. Print. <http://www.apogeerockets.com/downloads/newsletter128.pdf>.

[5]"Density and Softness." *www.bedinabox.com*. BedInABox. Web. 14 Nov 2012. <http://www.bedinabox.com/memory-foam-mattress-density-and-softness.html>.

[6]"Polybead Polystyrene Microspheres: Frequently Asked Questions." *www.polysciences.com*. Polysciences, 18 2009. Web. 14 Nov 2012. <http://www.polysciences.com/SiteData/docs/TDS 238/2a58421679f9dd8736aa9d6b660e7ebd/TDS 238.pdf>.