Concept Generation

EML 4551C – Senior Design – Deliverable #4
Team 18: CANSAT

The World's Forum for Aerospace Leadership

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Project Scope and Needs Assessment

The motivation behind this project is to simulate how a satellite entering the atmosphere of a 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, 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 payload and an aero-braking system will aid in the safe landing of the payload. In addition to controlling the descent autonomously, the flight software will transmit data during the flight, including altitude, temperature, and battery voltage. There are two options to include in the CanSat design—either implement a force sensor to measure the landing impact or film the decent of the satellite with a mounted camera. Additional size, weight, material, and telemetry limitations are specified in the needs assessment. A post-flight review will be conducted and taken into account to evaluate the success of the design.

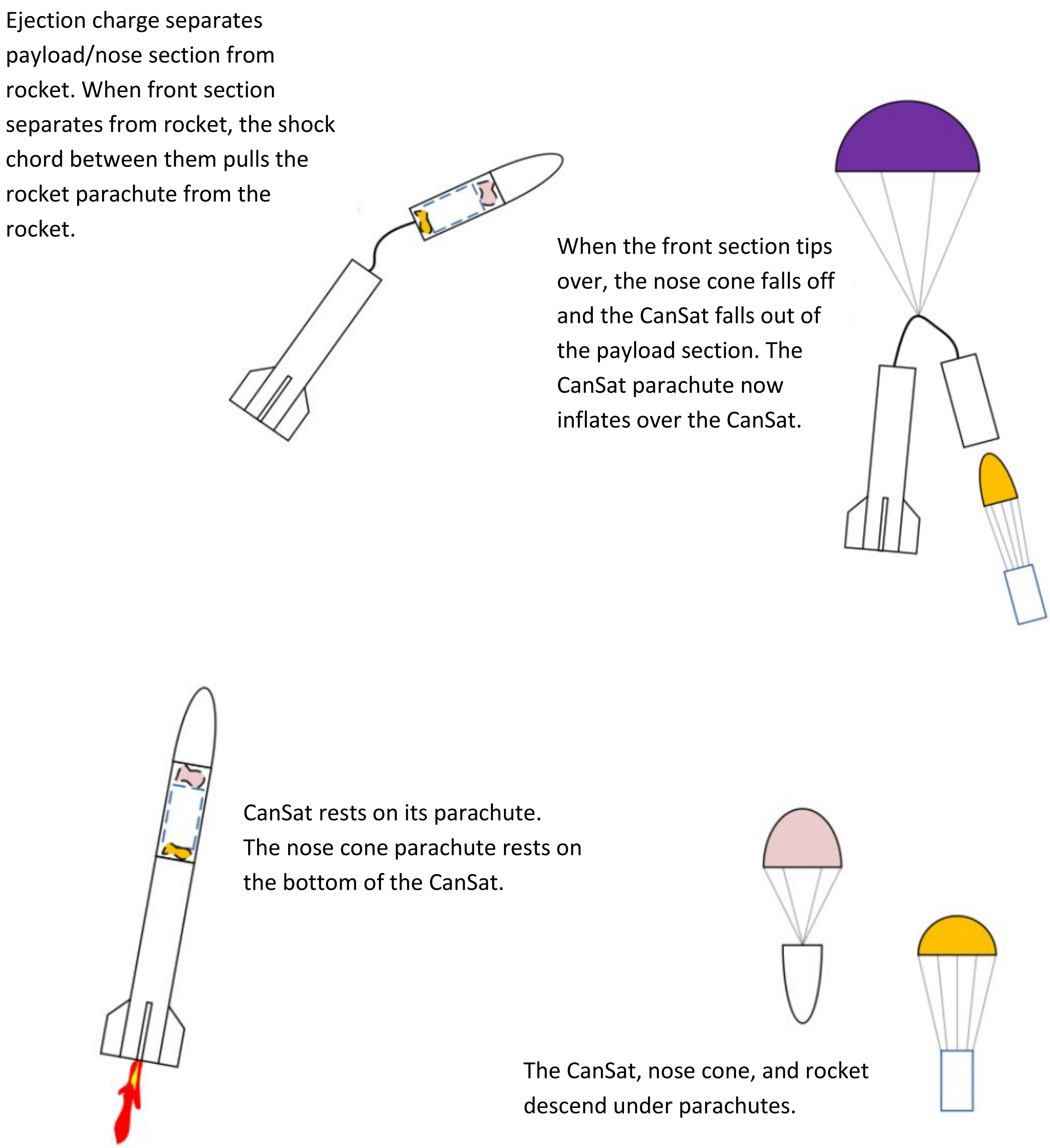

Figure 1. A diagram of the rocket deployment, CanSat detachment, and component descent.

Phase 1: Passive Braking System

Phase 1 is the portion of the CanSat's fall from the point it is released, an altitude of about 670 m, until an altitude of 400 m. During this time the CanSat is allowed to use a parachute or streamer to limit its falling speed to about 20 m/s. There are many types of parachutes and streamers available. In order to decide which option is the best for the project, some of the important characteristics of each choice were compared. These characteristics are drag coefficient, size and weight, how much a crosswind will cause the CanSat to drift (wind drift), complexity and cost. The drag coefficient is important because it affects the amount of material that is used to get the correct amount of drag force. This, also, affects the size and cost of the option that is chosen. The next characteristic to consider is the overall size and weight of each choice. Since there is a limited amount of space and a limit on the mass of the CanSat, it is imperative that the passive braking system be light and small.

Another potentially important consideration is wind drift. This parameter's importance is based on the area where the competition takes place because average wind speed varies depending on what part of the country you are in. If the wind speed is high then the CanSat could be carried off by the wind and move out of range of the receiver. Figure 2 shows a map of the average wind speed across the U.S. The black dot on the map is Burkett, Texas, where the competition will be held. This map shows that the wind speed in the area averages between 7 and 9 m/s. Since the average wind speed is high in the area, wind drift could be a significant problem. Complexity of the system is to be taken into account as well. If the system is more complex, then it could take more time and resources to design and produce. The last parameter to take into account is cost. There is a limit put on the total cost of the CanSat, so having a low cost option is preferred.

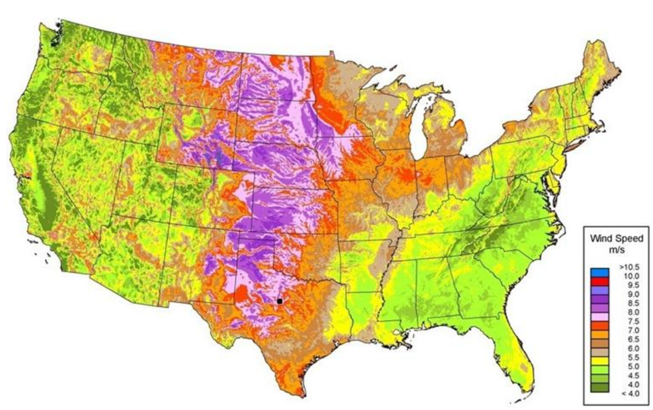

Figure 2. A map of the average wind velocity in the U.S. with Burkett Texas marked on the map.

Option 1: Round Parachute

Figure 3. A true dome shape round parachute on the left and a round parasheet on the right.

One of the most well-known types of parachutes is the round parachute shown on the left of the above figure. A round parachute with a true dome shape has a high coefficient of drag. This type of parachute is not difficult to make and is good for situations were a slow fall rate is desired. However, this type of parachute is susceptible to wind drift. A round parasheet, shown on the right of the above figure, is similar to a round parachute but, instead of having a true dome shape, it is a flat sheet. This type of braking system has a lower drag coefficient then a true dome shape parachute but, is easier to make. It is, also, susceptible to wind drift. These types of passive braking systems are used when the payload must fall at low speed and when wind drift is not a problem.

Option 2: Streamer

Figure 4 shows a rocket using a streamer to slow its decent.

A streamer is a simple passive braking system for model rockets. This option tends to have a low coefficient of drag. The coefficient of drag can be increased by using paper or other material that holds it shape when folded and folding it in a zigzag pattern. This type of passive brake is used when there is a high cross wind to reduce wind drift because a parachute tends to carry the payload off. However, streamers tend to allow the objects to fall faster and potentially requires more material to make than a round parachute.

Option 3: Square Parachute

Figure 5 shows a square parachute commonly used by skydivers.

A square parachute is another commonly used type of parachute. This type of parachute has a high drag coefficient. This type of chute is commonly implemented when the user want to have control over the area that they want to land in. This option is susceptible to wind drift.

The decision matrix attached in Appendix A shows that the flat and folded streamers are the best for our application. This makes sense because the CanSat is permitted to fall at a fairly high velocity and the area where the competition will be held tends to have high average wind velocities. To confirm that the decision matrix is correct, an experiment will be conducted to test each option.

Phase 2: Active Braking System

The second phase of the CanSat deployment consists of a system that actively controls the descent of the payload through aero-braking. After the CanSat descends below the 400 m mark, an altimeter triggers a mechanism that separates the container from the payload enabling phase 2. The aero-braking must be done as an active system, meaning the use of a parachute or streamer at this point is prohibited. Satellites use a form of aero-braking when changing their position in Earth's orbit. This is done by immersing their solar panel wings into the atmosphere to create drag. Computers in the satellite take into account multiple parameters and properties of the atmosphere to accurately control its deceleration.

The amount of active aero-braking systems that could possibly be implemented in the CanSat design is of limited quantity. However, some ideas may be taken directly from existing structures i.e. a satellite. For instance, deployable flaps can be utilized to increase drag so that the payload is not in free-fall. Deployable rotors may be used to either cause an autorotation[1] effect, as seen in helicopters, or may even be used to generate lift using a motor, just like in a helicopter. A propulsion system could be used at the tip of the rotors as opposed to a motor so that the payload itself would not spin as much. Due to the limitations of the competition rules, the fuel for a propulsion system is very limited. A form of combustible fuel with a high energy to density ratio would be ideal, however, rules state that no combustible materials or chemicals may be used.

Option 1: Fixed, Rigid Aero-foils

The first idea proposed is to use a propulsion system to generate upward thrust, slowing down the payload. Large flaps would be deployed in order to induce more drag as well as give a slight spin to the payload to increase stability. Thrusters, powered by onboard compressed Co2, can be mounted along the flaps to slow down the decent rate. A drawback of using compressed gas is the amount need in order to sustain a constant active system through its entire flight. Large tanks could increase weight dramatically as well as cost and also limit the amount of space inside the payload where other things need to be. While this may give a very good amount of control to the system, the cons will far outweigh the pros.

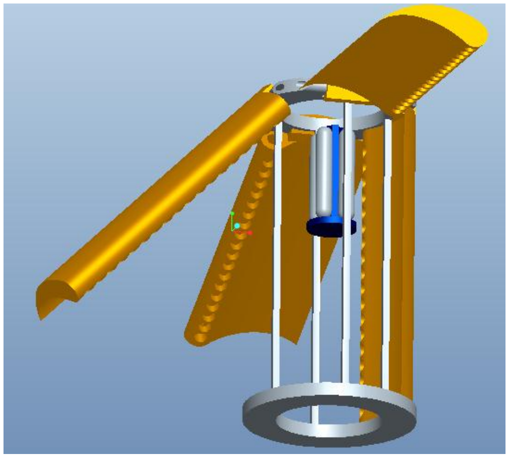

Figure 6. In gold are the deployable flaps that will house nozzles along their Leading edges. These Nozzles will be powered by the Co2 canisters located in the center.

[1] Autorotation is induced by air flow across a helicopters rotor that has been disconnected from the engine.

Option 2: Rotational, Semi-rigid Aero-foil

The second idea proposed is to use a system very similar to that on a helicopter. When the payload disconnects from the container, semi-rigid wings will deploy and under constant electric motor control, it will be able to land the payload to the ground at a very controllable rate. By using this technique, implementation is much simpler due to the ease of manufacturing the wings and where the weight/cost can be kept low as well. In comparison to compressed gas thrusters, the difference in complexity is enormous. A single motor can be used to run the system. This idea will be the better option in regards to the constraints that apply to the CanSat.

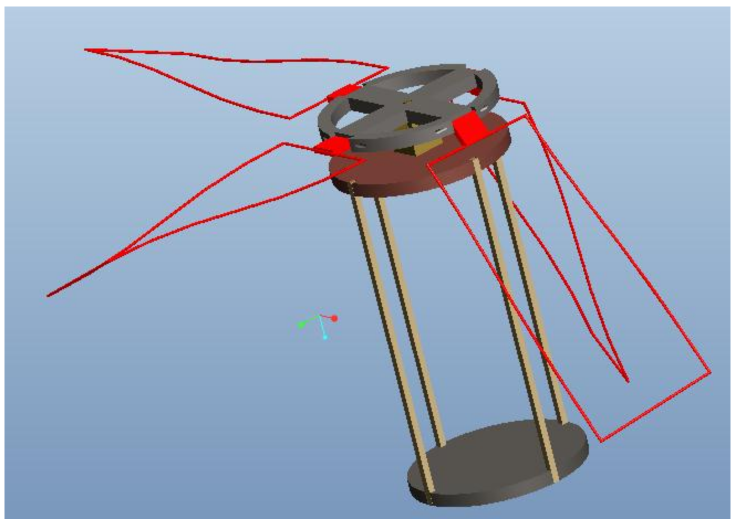

Figure 7. In red are semi-rigid, wire frame rotors. They are attached to a rotating assembly in dark gray at the top.

Phase 3: Impact

Option 1: Dough

Dough could be used to do dampen the blow of an impact. The gluten molecules in the dough can act as springs to help absorb the force the egg will experience during landing. Completely enclosing the egg in dough allows it to be protected from all directions. Bread dough is very cost effective and can be experimentally tested prior to implementation in the design. This could have a significant weight contribution due to its density.

Option 2: Memory foam

Memory foam, developed for commercial retail bedding, has properties that can conform to odd shapes as well as off a soft, yet firm feeling. This material could be used in order to safely deliver the payload to the ground while absorbing every bump along the way. This could be implemented by simply taking a cube of the material, slightly larger than most large hen eggs, and cutting a core out from the center. The “payload” could then be fitted inside of the empty core region for a nice, snug fit. This method would also offer a nearly entire enclosure surrounding the egg, due to its form fitting nature, making it a very effective method of protection. This material also has a very low density making it ideal for our lightweight CanSat. A drawback however, is that depending on the properties we calculate our memory foam to need, some sources could be at quite some expense.

Option 3: Flexible Membrane Clamp

Another option for keeping the egg restrained when descending and protecting the egg on impact is a clamp that utilizing a flexible membrane. This could be accomplished with two rigid ring structures with latex or rubber bands as a flexible membrane that fills the inner space of the circle. The egg is then place in the center of one of the membranes and the other membrane is pressed on top.

Selectable Objective

Option 1: Camera to record descent.

One option for the selectable objective is to place a camera on the bottom of the CanSat to record its descent. This could be accomplished with a Go Pro camera, which is relatively light and capable of enduring stress. However the weight is still a significant fraction of the total allowable weight and integrating the camera into the system could present difficulties.

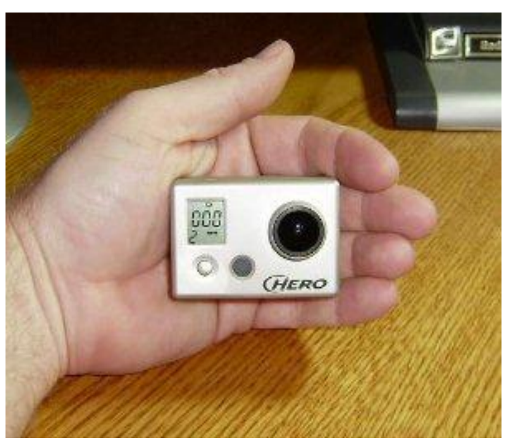

Figure 8 shows a Go Pro Hero video camera relative to the size of person’s hand.

Option 2: Sensor to Measure Force of Impact.

The other option is to include a sensor in the CanSat that measures the force of impact at landing. This can be implemented using an accelerometer since the mass of the payload will be known. An accelerometer can be purchased relatively cheaply and its size and weight are negligible. An accelerometer could easily be integrated with the microcontroller making implementation much simpler than the camera.

Figure 9 shows and accelerometer compared to the size of a quarter.

Telemetry, Sensors and Communications

The CanSat 2013 competition rules state the requirements of the telemetry such that concept generation for some aspects is limited. The competition states clearly that for all radio communications that an “XBEE” type transceiver will be employed, however there are a few models and varieties of XBEE transceivers. 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 range of the radio will be approximately 1.6 km. This gives more than twice the minimum range. The XBEE 802.15.4 has been vetted and selected for testing based partly on the decision matrix in Appendix A. The driving factor for its selection was based on the overall cost of procurement and implementation.

Competition rules require that a non-GPS method for measuring the altitude of the CanSat be employed. The barometric pressure sensor is a commonly used method for measuring height above sea-level. The BMP085 allows for both readings from a single device. The primary consideration for this device is its accuracy (+/- 0.25 m) and its relatively low cost.

The GPS module is still under consideration due to its relatively high cost. The primary consideration is its cost versus its accuracy. The greater the accuracy, the greater the cost of the device. However, regardless of cost or accuracy the GPS module will output standard NEMA data that will then be interpreted by the onboard microcontroller and sent to the XBEE for transmission to the ground station.

The force sensor will be accomplished using Newton's 2nd Law: F = ma. An accelerometer is a device that determines the acceleration applied to it. That acceleration data with the total mass data will allow for the resultant force due to impact to be calculated and transmitted immediately upon impact. Considerations driving the selection of an accelerometer are cost and the capability of the device to measure "DC" i.e. the "zero" acceleration at the point of impact. This is a non-trivial consideration since the accuracy of the measurement (regardless of the resolution) is completely dependent on that characteristic.

Since the CanSat must operate autonomously after launch, a microcontroller will be used to support a flight software that will communicate with all on-board sensors, perform the necessary calculations and data formatting, and send that data to the XBEE for transmission. Currently, experiments with the Atmel Atmega256 microcontroller and the Arduino development environment are being done to determine if this will meet the requirements of the telemetry and software. The driving factor of this selection is the familiarity of this chip and IDE with the team's electrical and computer engineers. The flight software (FS) will be written in C/C++ due to the native integration to the Arduino IDE and the educational background of the engineers. The flight software will be stored on-board the CanSat and on the local ground station laptop for communications and data acquisition.

The battery (batteries) will need to provide enough power for all electrical/electronic components for an estimated duration of about 20 minutes, except for the audible device which must remain live for at least 3 hours. The battery type that fits most cost/energy profiles for the required components is the Litium Ion batteries. These will most likely be of the standard AA or AAA cylinder type. The power analysis has not yet been done, due to possible use of electromechanical devices that may be used for mechanical actuation. (Solenoid, switch, motors) The batteries will have to meet the energy requirement based on the power consumption of each device. The energy is calculated by taking the power consumption and multiplying it by the duration of expected power draw.

Conclusion and Future Work

The overall goal of the mission statement of the competition is to safely deliver the sensory payload to the planet's surface within the limitations imposed by the competition guidelines. In order to ensure that the mission statement be executed successfully, each concept will be subject to extensive testing and experiment. The tests will demonstrate the concept's efficacy, ability to be effectively implemented and further the understanding of the student engineers.

Each air-braking system will undergo a stress evaluation defined here as a drop-test. The drop-test will be implemented by dropping the component from a suitable height so that the component can demonstrate the desired behavior. The force sensor may be subject to this test as well as an electronics bench test. The altimeter will be evaluated during these tests, since the height of a building can be accurately measured and compared to the altimeter readings.

All electronics and sensors will be given a test vector that the device will be tested and compared to. The flight software will be used to test the sensors as the software will include a test mode that can be enabled at any time.

Upon conclusions of these tests prototyping and more detailed simulations and models of the mechanical components can be done. The electronics and flight software will then be bench-tested by prototyping, “bread-boarding” and programming test.

References

Culp, Randy. "Parachute Decent Calculations."*rocetmime.com*. 24 Aug 2008. Web. 10 Oct 2012. <http://www.rocketmime.com/rockets/descent.html>.

"Parachutes." *Parafauna.com*. Web. 10 Oct 2012. <http://www.parafauna.co.uk/para_shapes.php>.

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/>.

Cooke, Bill. "How to Calculate Streamer Size."*www.sunward1.com*. Sunward. Web. 10 Oct 2012. <http://www.sunward1.com/images-tarc/Streamer Calculations (Cooke) (Jun 09).pdf>.

Sources for ECE (used to source datasheets)

http://www.digi.com/xbee/

http://www.digikey.com

http://www.adafruit.com

http://sparkfun.com

Appendix A

Phase 1

	Drag Coeffecient (0.2)	Small Size (0.1)	Low Wind Drift (0.3)	Low Complexity (0.2)	Low Cost (0.2)	Total	
Flat Streamer	1	1	5	5	4	3.6	out of 5
Folded Streamer	2	2	4	4	5	3.6	out of 5
Parasheet	3	3	3	3	3	3	out of 5
Round Parachute	5	5	1	1	1	2.2	out of 5
Square Parachute	4	4	2	2	2	2.6	out of 5

Phase 2

Idea	Cost	Size	Weight	Effectiveness	Design Ease	Complexity	Manufacturability		Total
Thrusters	0	0	0	1	0	0	0		1
Helicopter	1	1	1	0	1	1	1		6

Selectable Objective

Comparison of Selectable Objective Options				
Option	Base Cost	Battery Life	Weight (no case)	Weight (with case)
HD Hero Go Pro Camera	$130	2.5 h	94 g	167 g
Impact Sensor (Implemented with accelerometer)	$30	Negligible power use	Negligible	Negligible

Radio Decision Matrix

Description	Range (nom) [m]	Power (max) [mW]	Cost [$US]
XBEE-Pro 802.15.4	1600	63	32.00
XBEE-Pro SMT	3200	63	36.00
XBEE-Pro DigiMesh	3200	100	48.00

Altimeter (Pressure and Temperature Sensor) Decision Matrix

Description	Sample Rate [Hz]	Weight [g]	Cost [$US]
BMP085	1	2	8
SCP-1000	1 to 9	2	35.00
MS5534-CM*	5000	negl	42.10

*module chip only

GPS module Decision Matrix

Description	Current draw (mA)	Weight [g]	Accuracy [m]	Cost [$US]
LS20031	41	14	3.0	50
EM-406A	44	16	10	60
EM-408	44	20	11	65

Accelerometer (Force Sensor)

Description	Force Resolution	Weight [g]	Sample Rate [kHz]	Cost [$US]
ADXL345	16 g	2	3.2	28
BMA180	18 g	2	3.2	30

Appendix B

Round Chute Calculations

$$C_d = 1.5$$

$$F_D = \frac{1}{2}\rho_{air} A C_D V^2$$

$$F_w = F_D$$

$$mg = \frac{1}{2}\rho_{air} A C_D V^2$$

$$A = \frac{2mg}{\rho_{air} C_D V^2}$$

$$A = \frac{2 * 0.772kg * 9.81\, {}^{m}/_{s}}{1.22\, {}^{kg}/_{m^3} * 1.5 * (20\, {}^{m}/_{s})^2}$$

$$A = 0.021m^2$$

$$D = .162m$$

Parasheet

$$C_d = 0.75$$

$$A = .041m^2$$

$$D = .230m$$

Flat Streamer

$$C_d = 0.14$$

$$A = 0.222m^2$$

$$t = 0.04m$$

$$L = 5.5m$$

Folded Streamer

$$C_d = 0.4$$

$$A = 0.078m^2$$

$$t = 0.04m$$

$$L = 1.94m$$