CanSat 2011 Preliminary Design Review

Team 513

Virginia Tech Team Rocket

Presentation Outline

- **Systems Overview** – George Bacon
- **Sensor Subsystem Design** – Chris Jennette
- **Descent Control Design** – Younes Taleb
- **Mechanical Subsystem Design** – David Pudleiner
- **Communication & Data Handling Subsystem Design** – Chris Stack
- **Electrical Power Subsystem Design** – Chris Jennette
- **Flight Software Design** – Chris Stack
- **Ground Control System Design** – Chris Jennette
- **Cansat Integration and Test** – Stephanie Butron
- **Mission Operations and Analysis** – Younes Taleb
- **Management** – Stephanie Butron

Team Overview

Name	Major	Year
George Bacon	Aerospace Engineering	Junior
Stephanie Butron	Aerospace Engineering	Junior
Chris Jennette	Electrical Engineering	Junior
Aubrey Knight	Aerospace Engineering	Junior
David Pudleiner	Mechanical Engineering	Junior
Moises Seraphin	Aerospace Engineering	Junior
Chris Stack	Computer Engineering	Junior
Younes Taleb	Aerospace Engineering	Junior
Greg Woodhouse	Aerospace Engineering	Junior

Team Organization

- **Team Leaders**
  - George Bacon
  - Stephanie Butron
- **Faculty Advisor**
  - Troy Henderson, Ph.D.
- **Team Mentor**
  - Scott Reedy

- Mechanical Systems & Structures Group
  - **Leader** David Pudleiner
  - Moises Seraphin
  - Younes Taleb
  - Greg Woodhouse
- Computer & Electrical Group
  - **Leader** Chris Jennette
  - Chris Stack
  - Younes Taleb
- Mission Operations & Ground Control Group
  - **Leader** Younes Taleb
  - Chris Jennette
  - Chris Stack
- Systems Engineering Group
  - **Leader** George Bacon
  - Stephanie Butron
  - Aubrey Knight

Acronyms

- **A** - Analysis
- **ADC** – Analog-to-Digital Converter
- **ADR** – Average Descent Rate
- **ALD** – Audible Locating Device
- **API** – Application Programming Interface
- **CDH** – Communication & Data Handling
- **D** - Demonstrate
- **DCD** – Descent Control Design
- **DCS** – Descent Control System
- **DS** – Datasheet
- **EEPROM** – Electrically Erasable Programmable Read-Only Memory
- **EST** – Estimate
- **FIFO** – First in, First out
- **FOS** – Factor of Safety
- **FSW** – Flight Software
- **GCS** – Ground Control System
- **I** - Inspect
- **I2C** – Inter-Integrated Circuit
- **I/O** – Input/Output
- **IDE** – Integrated Development Environment
- **IV** – Initial Velocity
- **MMCX** – Micro-Miniature Coaxial
- **RSSI** – Received Signal Strength Indication
- **S/H** – Shipping and Handling
- **SPI** – Serial Peripheral Interface
- **SSD** – Sensor Subsystem Design
- **T** - Test
- **VM** – Verification Matrix

Systems Overview

George Bacon

Mission Summary

- Launch an autonomous CanSat with a deployable lander containing one large raw hen egg
- CanSat will be deployed from a rocket at an altitude around 1020 meters and start transmitting GPS telemetry
- At 500 meters, the carrier shall release the lander that contains one large raw hen egg
- After separation, the carrier shall have an Average Descent Rate (ADR) of 4 meters per second and the lander shall have an ADR or 5.5 meters per second
- The lander should land without damaging the egg and measure the force of impact with the ground

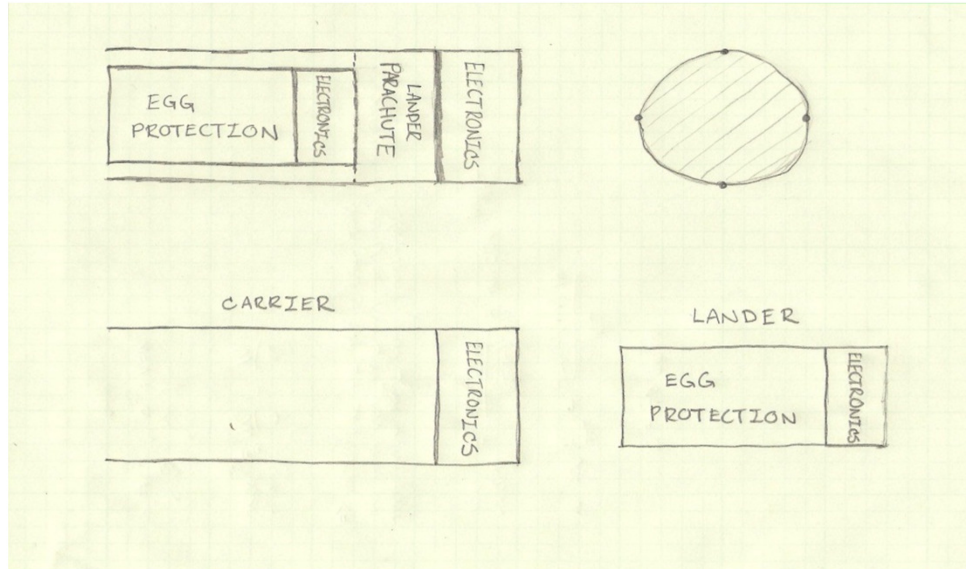
System Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
SYS-01	Total mass shall not exceed 500 g (excluding egg)	Base Mission Requirement	High	None	DCD-01,EPS-03,MS-01		X		
SYS-02	CanSat shall be compatible with the Loc/Precision Forte Rocket as specified in the payload section	Base Mission Requirement	High	None	DCD-02,MS-02		X		
SYS-03	CanSat shall comply with descent and recovery requirement	Base Mission Requirement	Medium	None	DCD-05,DCD-06,DCD-07,CDH-10		X	X	X
SYS-04	CanSat shall comply with communication requirements	Base Mission Requirements	Medium	None	CDH-09, GCS-04, GCS-05, GCS-06		X		
SYS-05	CanSat and associated operations shall comply with all field safety regulations as outlined in Field Section Rules section	Base Mission Requirement	Medium	None			X		
SYS-06	CanSat shall be launched within the assigned launch window	Base Mission Requirement	High	None	None				X
SYS-07	CanSat shall comply with power requirements	Base Mission Requirement	High	None	EPS-07,EPS-08		X		

System Requirements

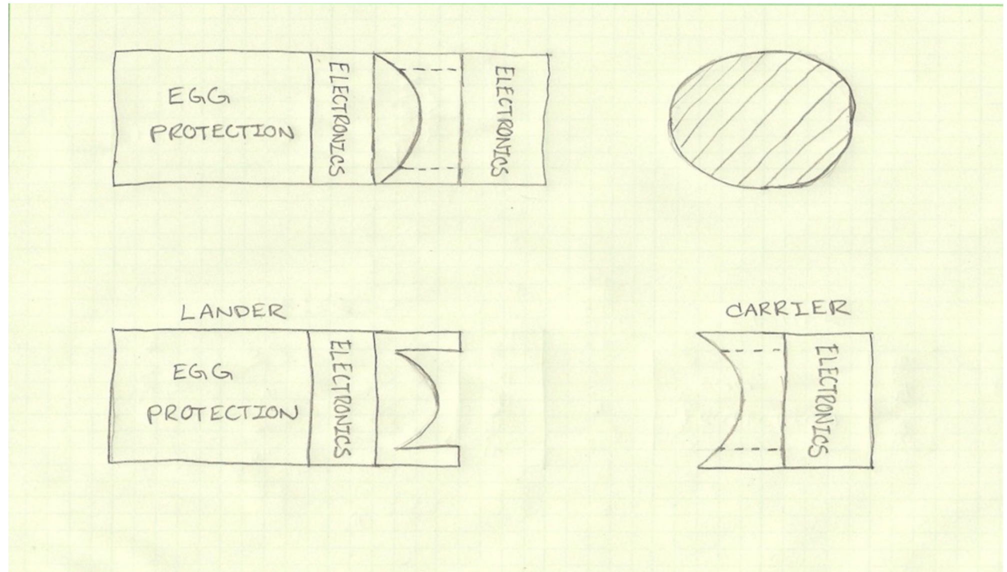
ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
SYS-08	Cost of the CanSat flight hardware shall be under $1000 (Ground support and analysis are excluded)	Base Mission Requirement	Medium	None	None		X		
SYS-09	Each team must use their own ground station and comply with telemetry requirements	Base Mission Requirement	High	None	FSW-07,FSW-08,FSW-09	X	X		X
SYS-10	Lander CanSat shall measure the force of impact with the ground	Selectable Objective Requirements	High	None	SSD-03,SSD-05,SSD-08		X	X	X

- **Nested Design**
  - First design considered
  - Lander is enclosed within the carrier shell
  - At separation, a false bottom will open and the lander will drop out
  - Lander parachute is inside of carrier

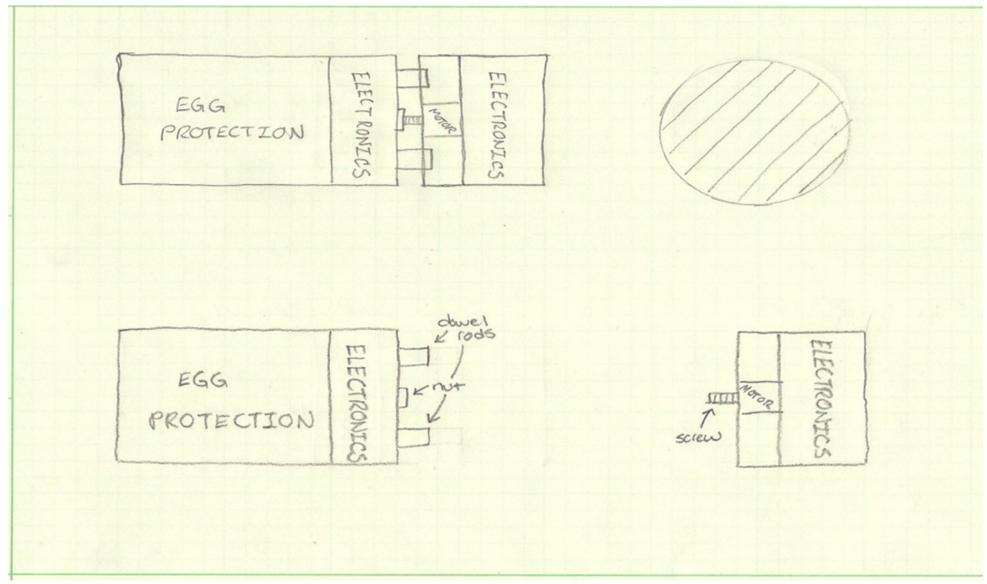


System Level CanSat Configuration Trade & Selection

- **Sliding Design**
  - Second design considered
  - Carrier and lander have the same diameter
  - Lander slides into the carrier
  - At separation, the lander slides out of carrier
  - Lander parachute inside carrier



- **Screw Design**
  - Final design considered
  - Carrier and lander have same diameter
  - No overlap between carrier and lander
  - Separation is mechanically driven
  - Lander parachute is in the separation mechanism



System Level CanSat Configuration Trade & Selection

Design	Simple Design (1-5)*	Spatially Efficient (1-5)*	Pre-made Materials (1-5)*	Pros	Cons
Nested Design	2	4	1	Simple Design	Separation impractical, Waste of Space, Small egg compartment
Sliding Design	4	3	3	Simple Separation, Large egg compartment	Lander hard to manufacture
Screw Design	3	1	2	Efficient use of space, Large egg compartment	Lander parachute location

*Note: 1 is best, 5 is worst

Configuration chosen – Screw Design

- Configuration has the benefits without many negatives of previous configurations
  - Very efficient use of space
  - Large Egg compartment
  - Can be constructed to be made modular

System Concept of Operations

Pre-Rocket Launch

- Slide components into CanSat
- Insert egg into lander
- Power CanSat on
- Integrate CanSat into rocket payload

Rocket Launch

- Begin ground communications with CanSat
- Receive telemetry

CanSat Deployed

- Carrier parachute opens
- Altitude and pressure data is received by the Ground Control System (GCS)

System Concept of Operations

Separation

- An approximate altitude measurement of 500 meters initiates separation
- Lander is deployed
- Lander parachute opens

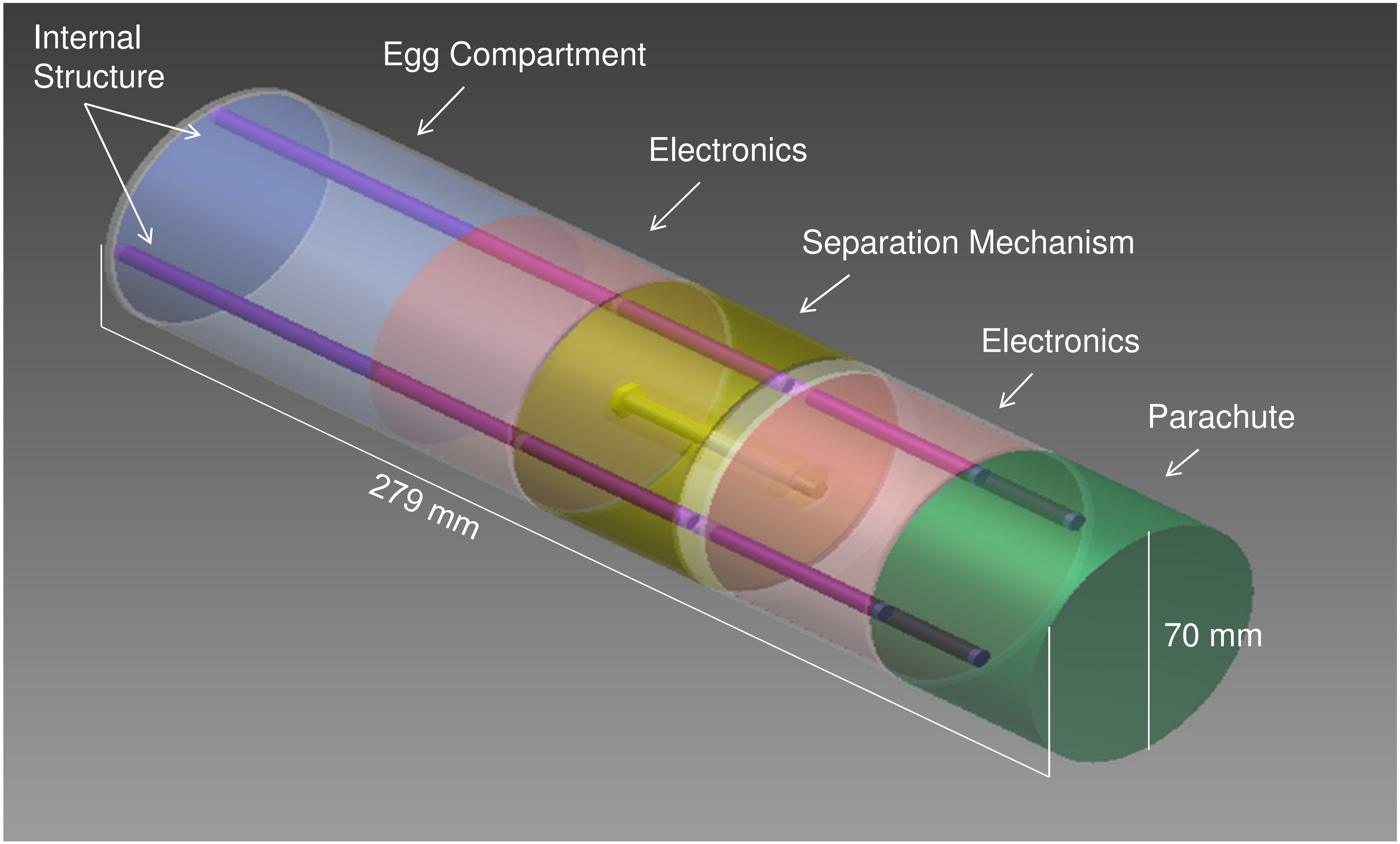
Landing

- Audible beacons activate on both the carrier and lander upon landing
- Impact force recorded by the lander

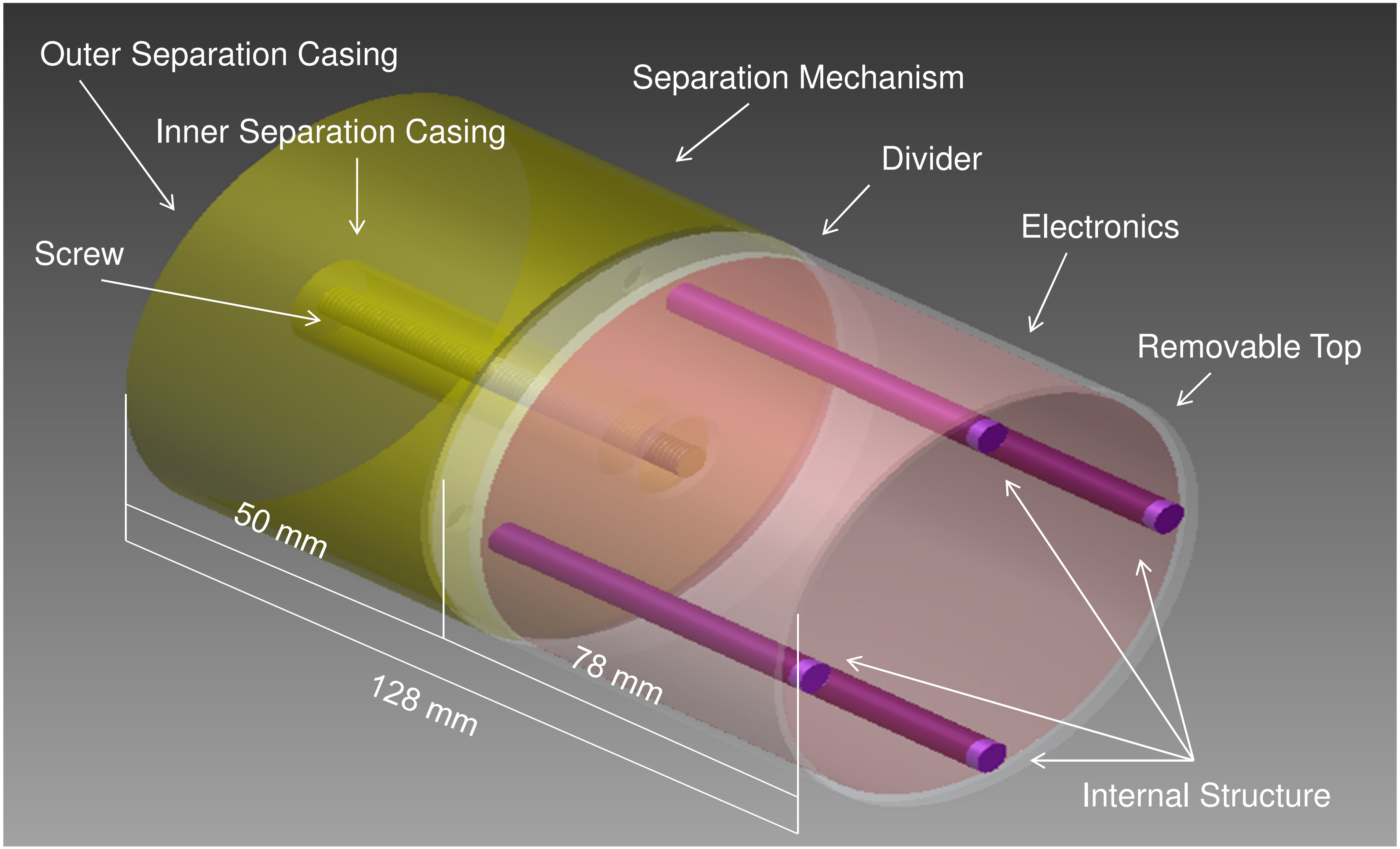
Recovery

- Carrier and lander are retrieved
- Telemetry data is retrieved from the lander via a USB connection

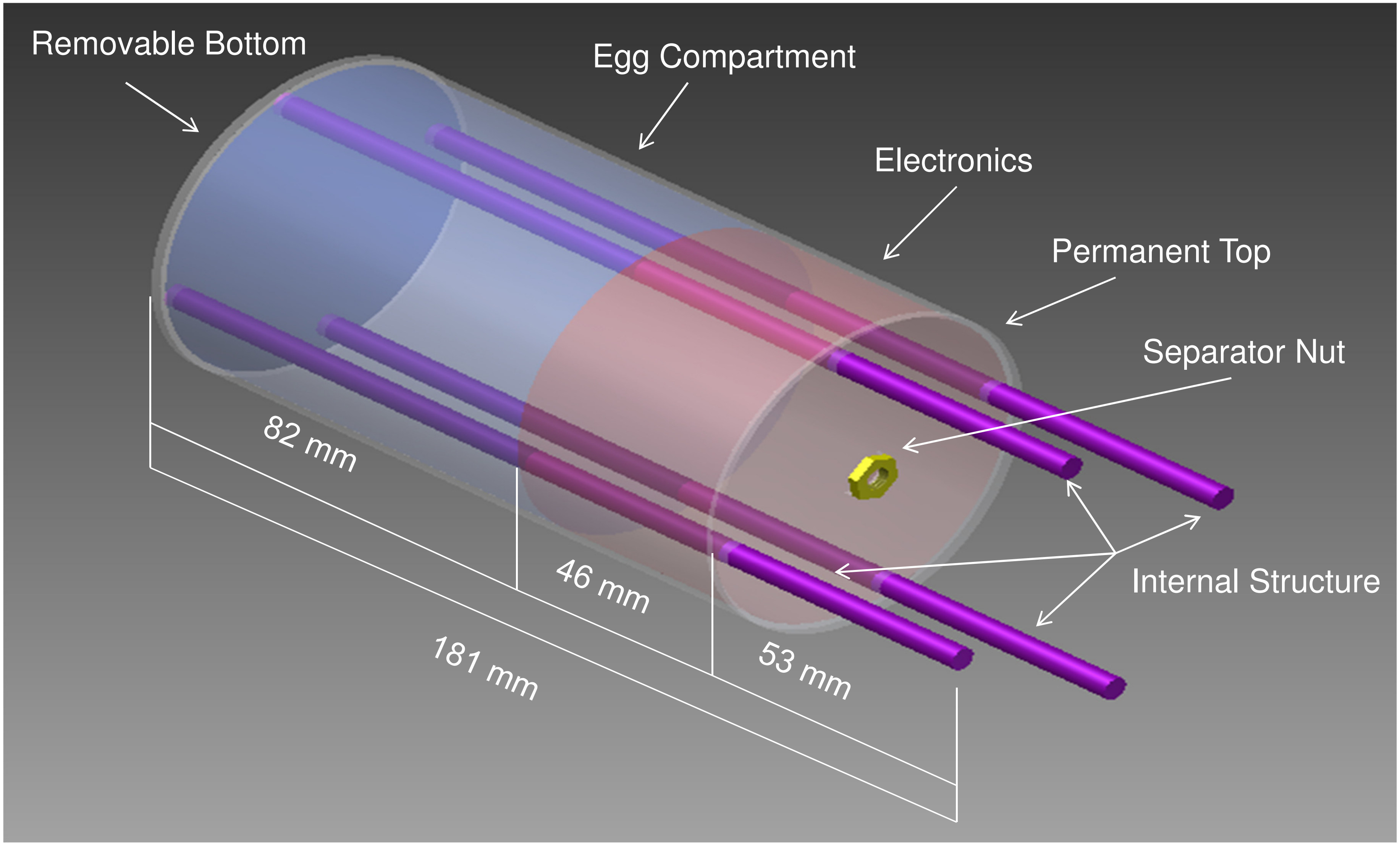
Physical Layout - CanSat



Physical Layout - Carrier

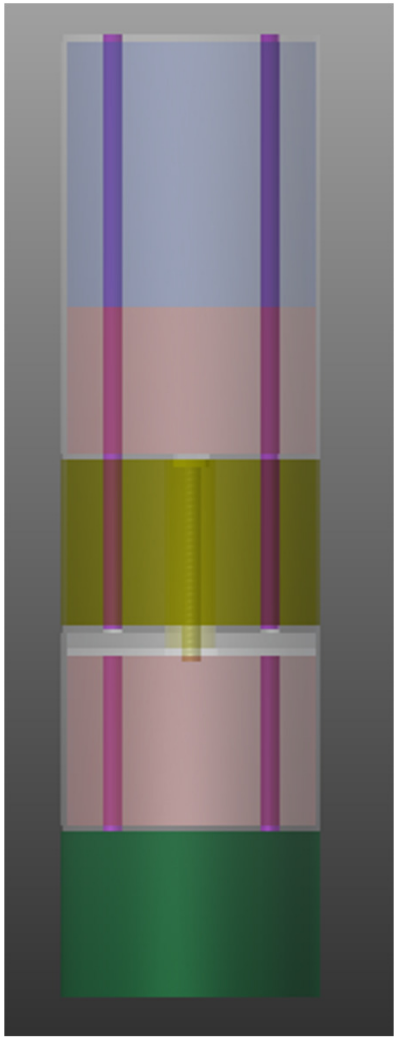


Physical Layout - Lander



Launch Vehicle Compatibility

- **CanSat will be placed upside-down in rocket payload**
  - Deployment from rocket will correct orientation
- **Rocket payload dimensions**
  - Height: 279mm
  - Diameter: 72 mm
- **CanSat dimensions**
  - Height: 279 mm
  - Diameter: 70 mm
- **Payload compatibility verification will take place during pre-launch checks with a pre-built rocket payload model**



Sensor Subsystem Design (SSD)

Chris Jennette

Sensor Subsystem Overview

Sensor Type	Model	Purpose	CanSat use
Pressure	BMP085 Breakout	Altitude, velocity, and temperature measurements	Carrier, Lander
GPS	32 Channel LS20031 GPS 5 Hz Receiver	Position, altitude, and velocity measurements	Carrier, Lander
Accelerometer	ADXL345	Triple axis measurement of impact force of lander	Lander

Sensor Subsystem Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
SSD-01	All sensors used must be operable at 3.3V or lower	Arduino microcontroller operates at 3.3V	Medium	None	None		X		X
SSD-02	GPS sensor must sample UTC time, latitude, longitude, mean sea level altitude, and number of satellites tracked	Base mission requirement	High	None	None	X	X	X	
SSD-03	All sensors must be able to sample data at a rate of at least 1 Hz	Base mission requirement	High	SYS-10	FSW-02		X	X	
SSD-04	Pressure sensor shall measure altitude with accuracy of at least 0.5 hPa	Base mission requirement	High	None	None		X	X	
SSD-05	Accelerometer shall measure impact force at rate of at least 100 Hz	Base mission requirement	High	SYS-10	None		X	X	
SSD-06	Sensors shall have serial or I2C connection interface.	Required to connect to Microcontroller	Medium	None	None		X		
SSD-07	Pressure Sensor shall measure temperature with accuracy of at least 1 °C	Base mission requirement	High	None	None		X	X	

Carrier GPS Trade & Selection

GPS Unit	Price	Current Draw (mA)	Weight (g)	Accuracy (m)	Start (Cold/Hot)	Dimensions (mm)
32 Channel LS20031 GPS 5 Hz Receiver	$59.95	41	14	3	36/2	30 x 30
20 Channel EM-406A SiRF III Receiver	$59.95	44 or 70	16	10	42/1	30 x 30 x 10.5
20 Channel EM-408 SiRF III Receiver	$64.95	44 or 75	20	10	42/8	35 x 36

GPS module chosen – LS20031

- Low weight
- Accurate to 3 m
- Small
- Fast activation time
- Widely used GPS receiver – many guides available

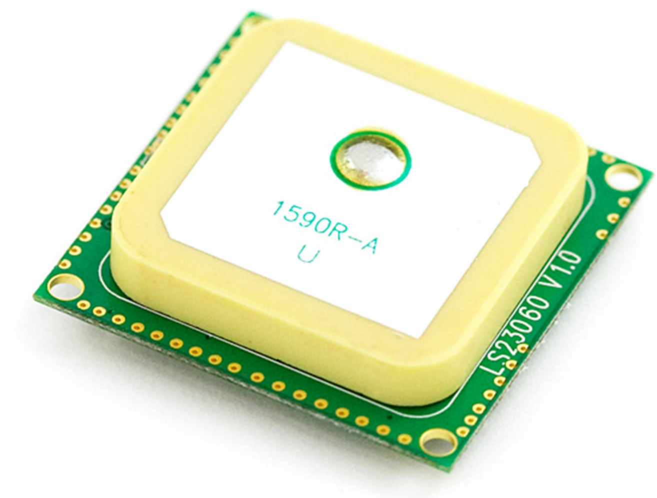


Photo courtesy of http://www.sparkfun.com/products/8975

Carrier Non-GPS Altitude & Temp. Sensor Trade & Selection

Part	Price	Weight (g)	Resolution (bits)	Connection Type	Size (mm)	Sample Rate (Hz)
BMP085	$19.95	2	Pressure – 17 Temp. – 16	I2C	16.5 x 16.5	1
SCP1000	$34.95	2	Pressure – 17 Temp. – 14	SPI (with onboard clock)	19.8 x 19.8	Up to 9

Pressure sensor chosen – BMP085

- Meets required sample rate (0.5 Hz)
- Low cost
- Accurate pressure (±0.2 hPa) and temperature (±0.5 ℃) measurements
- Used for both Lander and Carrier

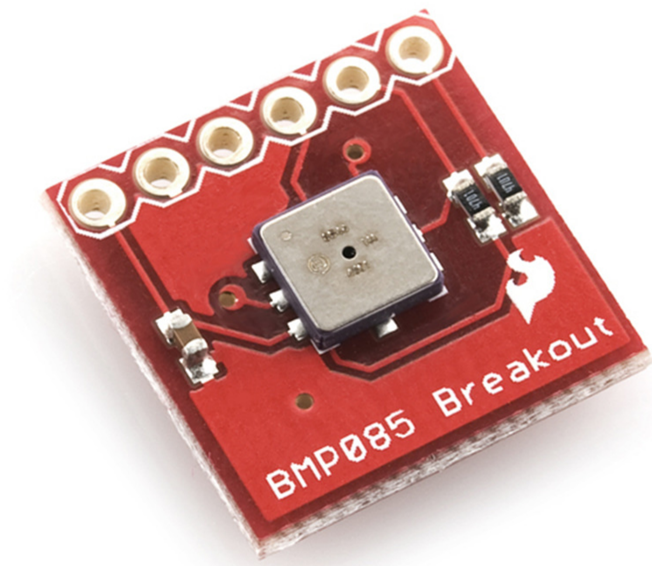


Photo courtesy of http://www.sparkfun.com/products/9694

Lander Impact Force Sensor Trade & Selection

Part	Price	Weight (g)	Current Consumption (µA)	Connection Type	Size (mm)	Additional Features
ADXL345	$27.95	2	145 (0.1standby)	I2C and SPI	3.05 x 5.08	16g res., 3200Hz sample rate
BMA180	$29.95	2	650-975 (0.5 standby)	I2C and SPI	3.05 x 3.05	16g res., 2400Hz sample rate

Accelerometer Chosen – ADXL345

- Selectable sample rate (6.25 to 3200 Hz)
- Flexible range (2 g to 16 g)
- FIFO mode makes data storage simpler

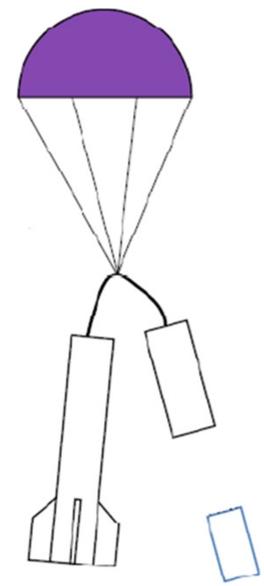
Photo courtesy of http://www.sparkfun.com/products/9156

Descent Control Design (DCG)

Younes Taleb

Descent Control Overview

- **The Descent Control System (DCS) is composed of a parachute for the lander and carrier.**
  - Purchased parachutes will be modified to optimize weight.
  - Parachutes will include spill holes and shroud line swivels to improve stability and maintain attitude
  - DCS will be rigorously tested through drop testing to simulate weather conditions



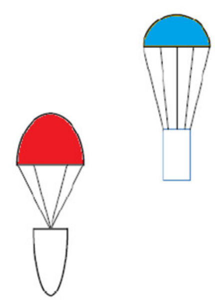


Photo courtesy of CanSat competition guide

Descent Control Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
DCD-01	The parachutes must fit inside the 72 mm diameter cylinder	Base Mission Requirement	High	SYS-02	None		X		
DCD-02	The parachute shall not exceed a packing depth of 70 mm	Allow for sufficient space allocated to the rest of the systems.	High	SYS-02	None		X		
DCD-03	Both parachutes must be reasonably light (under 30 g)	Keep the weight budget from exceeding 500 g	High	SYS-01	None		X		
DCD-04	Parachute shroud lines must be able to support the force of deployment	Prevent shroud lines from breaking or tearing the parachutes	High	None	None				X
DCD-05	Parachute must be designed to avoid tangling of shroud lines.	Prevent tangling during descent that could lead to a failed recovery	High	None	None				X
DCD-06	Average Descent Rate (ADR) of the CanSat carrier after deployment of the lander shall be 4±1 m/s	Base Mission Requirement	High	SYS-03	None		X	X	
DCD-07	ADR of the CanSat lander after deployment shall be 5.5±1 m/s	Base mission Requirement	High	SYS-03	None		X	X	
DCD-08	Decent Control System (DCS) shall not use flammable or pyrotechnic devices	Base Mission Requirement	High	SYS-03	None		X		

Descent Control Strategy Selection and Trade

Manufacturer	Price	Diameter (cm)	Shape	Weight (g)	Pre-installed swivel	Descent rate (m/s)
SkyAngle	$22.00	50.8	Round	28.3	yes	3.93
Dynastar	$11.11	61.0	Hexagon	24.9	no	4.3
Top flight	$9.25	61.0	Hexagon	31.2	no	3.9

Parachute chosen - SkyAngle Classic II 20

- Appropriate for both the lander and carrier
- Low weight
- Designed for stability
- Includes a pre-installed swivel
- Low porosity
- Strong suspension lines

Photo courtesy of: http://www.apogeerockets.com/parachutes.asp

Descent Rate Calculation

- **The governing equations relating area of the parachute to terminal velocity are:**

$$S = \frac{\pi d^2}{4} \quad \text{and} \quad S = \frac{2W}{\rho\, C_d\, V^2}$$

W = weight of the CanSat
ρ = air density at deployment altitude
$\boldsymbol{C_d}$ = coefficient of drag (Provided by SkyAngle)
V = desired descent velocity
d = diameter of the parachute

*** Assuming no weather perturbations, buoyancy effects, or change in density*

Descent Rate Estimates

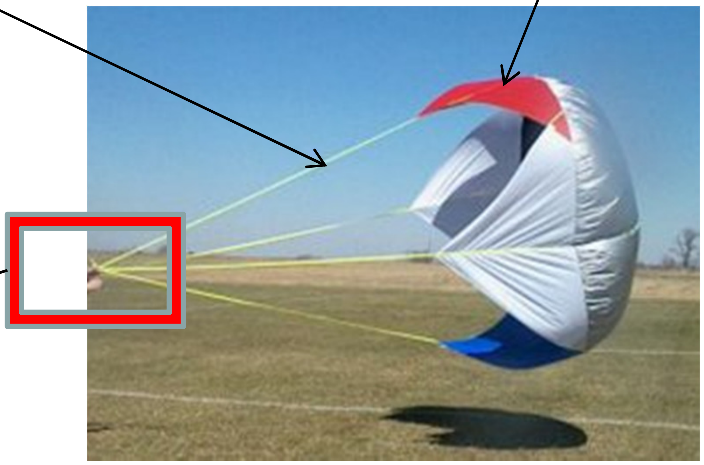
Configuration	Weight (g)	Descent rate (m/s)
Carrier & Lander (pre-separation)	500	10.2*
Carrier (post-separation)	181.4	3.93*
Lander (post-separation with no egg)	318.6	5.21*
Lander (post-separation with egg)	374.2	5.65*

*Using a C_d of 0.8 provided by the manufacturer and http://www.aerospaceweb.org/question/aerodynamics/q0231.shtml

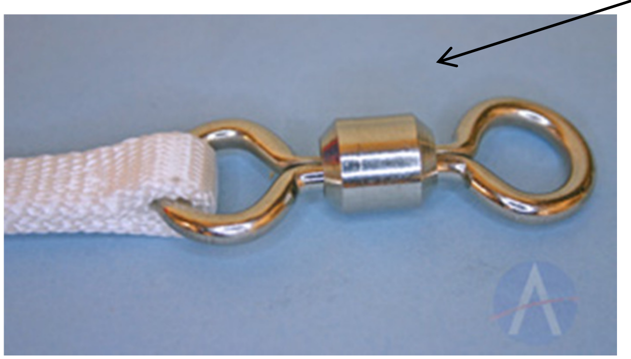
Parachute Diagram

Parachute

Shroud lines



Swivel



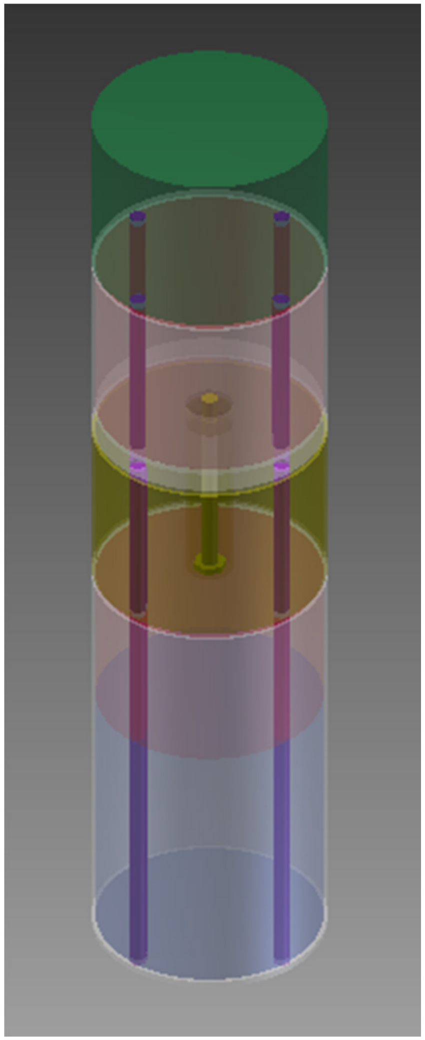
Photos courtesy of: http://www.apogeerockets.com/parachutes.asp

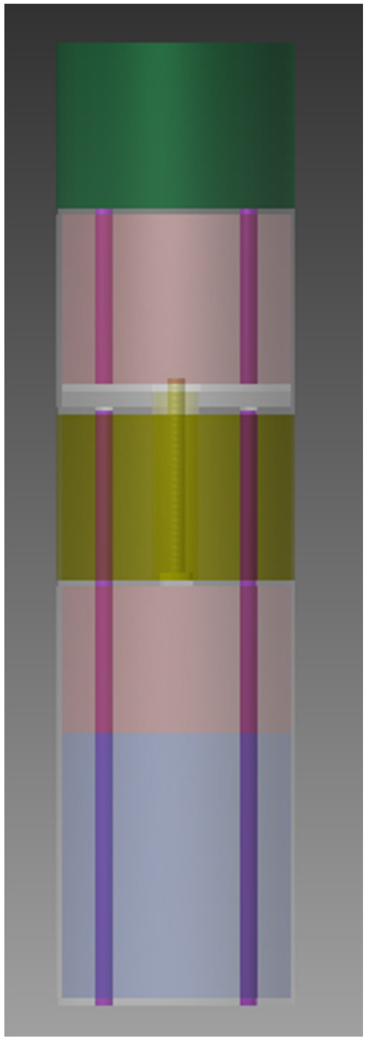
Mechanical Subsystem Design

David Pudleiner

Mechanical Subsystem Overview

- **Structure**
  - Wooden skeletal rods
  - Plastic exterior shell
- **Electronics**
  - Battery and circuitry allocated in the top the lander and in the carrier
- **Egg Compartment**
  - Rubberized foam surrounding the egg in the bottom of the lander
- **Separation Mechanism**
  - Screw and nut based design
  - Houses lander parachute





Mechanical System Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
MS-01	Total mass of CanSat (without egg) shall not exceed 500 grams	Base Mission Requirement	High	SYS-01	None		X		
MS–02	CanSat shall fit within 72 mm diameter and 279 mm long payload bay	This is the maximum space that the payload of the rocket will permit	High	SYS-02	None		X		
MS-03	Internal structure shall support electronics during flight and impact	Certain electronics must continue to work after landing	High	None	None			X	
MS-04	Use of metal components should be limited in size and number	Metal interferes with radio signal	Medium	None	None		X		
MS-05	CanSat shall deploy lander from carrier at 500 m	Lander Requirement from Competition Guide	High	None	None			X	
MS-06	Egg shall not break from impact from landing	Need to preserve precious cargo during impact	High	None	None			X	

Egg Protection Testing

Trial Number	Egg Orientation	Cushion Material	Details	Drop Height (m)	Impact Velocity (m/s)	Survival?
1	Vertical	Egg Crate Foam	2.54 cm of material surrounding egg, sharp side	6.7	11.5	Yes
2	Vertical	Pipe Insulation Rubber	2.54 cm of material surrounding egg, bubble packed, sharp side	6.7	11.5	Yes
3	Vertical	Egg Crate Foam	2.54 cm of material surrounding egg, dull side	6.7	11.5	No
4	Vertical	Egg Crate Foam	2.54 cm of material surrounding egg, sharp side	6.7	11.5	No
5	Vertical	Pipe Rubber	2.54 cm of material surrounding egg, bubble packed, sharp side	6.7	11.5	Yes

Egg Protection Testing

Trial Number	Egg Orientation	Cushion Material	Details	Drop Height (m)	Impact Velocity (m/s)	Survival?
6	Horizontal	Pipe Rubber	1" of material surrounding egg, bubble packed	6.7	11.5	Yes
7	Horizontal	Bubble Wrap	1" of material surrounding egg	6.7	11.5	No
8	Horizontal	Pipe Rubber	1" of material surrounding egg	6.7	11.5	Yes
9	Horizontal	Pipe Rubber	1" of material surrounding egg, bubble packed	6.7	11.5	Yes
10	Horizontal	Pipe Rubber	1" of material surrounding egg, bubble packed, +IV	6.7	< 15	Yes

•Bubble packed indicates that bubble wrap was used to fill in any extra space on the side of the container for increased protection
• Sharp and dull refer to the two differently shaped poles of an egg
•Conducted to provide a FOS of 2 relative to impact velocity

Egg Protection Trade & Selection

Material	Example	Cost	Details	Density (g/cm^3)	Pros	Cons
Foam Rubber	Pipe Insulation Rubber	$3 per meter (approx. 5 cm in outer diameter)	Cylindrical Rubberized foam 1.25 cm thick	0.15	Easy to manipulate, Perfect diameter for the egg	Heaviest of the three
Bubble Wrap	Bubble wrap from Staples	$6.49 for 2.32 square meters	Small air bubbles, approx. 0.50 cm thick	0.05	Widely available, Packs well	Hard to package egg consistently, Bubbles pop
Foam	Egg Crate Foam	$19.93 for 0.55 square meters	Rectangular foam block, approx. 2.54 cm thick	0.024	Extremely light weight	High strain, More volume required

Egg Protection Trade & Selection

- **Material Chosen – Rubberized Foam & Bubble Wrap**
  - Provided best protection
  - Minimal space occupied
  - Light weight material
  - Easy and reliable to package
  - Egg protection on all sides

*Top and bottom rubber removed for picture

Mechanical Layout of Components Trade & Selection

Material	Example	Cost	Tensile Strength (MPa)	Density (g/cm^3)	Pros	Cons
Plastic (Polyethylene)	Tennis Ball Can	$3.00 (per can)	55-75	1.40	Low cost, Water-proof, Sufficient strength, Light	Melts under high heat
Fiberglass	Shell/Circular plates	$45.95 (86.4 cm tube)	55	1.53	Water-proof, High strength, Light	Hard to manufacture
Carbon fiber	Shell/Circular plates	$44 per kg	>1000	1.49	Good structural integrity, Light weight	Expensive, Rare
Cardboard	Pringles can	$1.25 (per can)	23-51	0.60	Low cost	Not water-proof, Relatively weak
Aluminum	Soda can	$1.00 (per can)	125	2.70	High strength, Water-proof	Radio interference

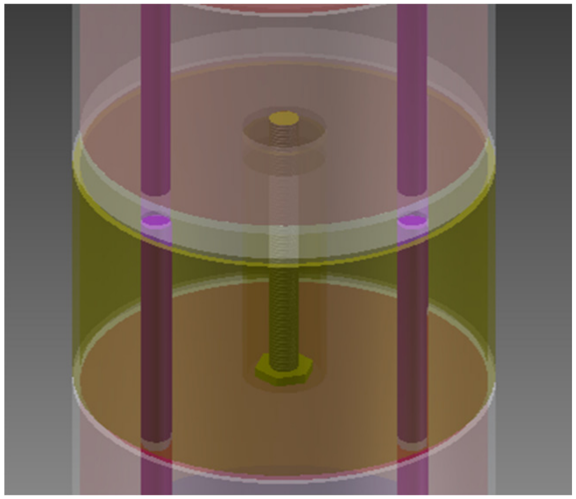
Mechanical Layout of Components Trade & Selection

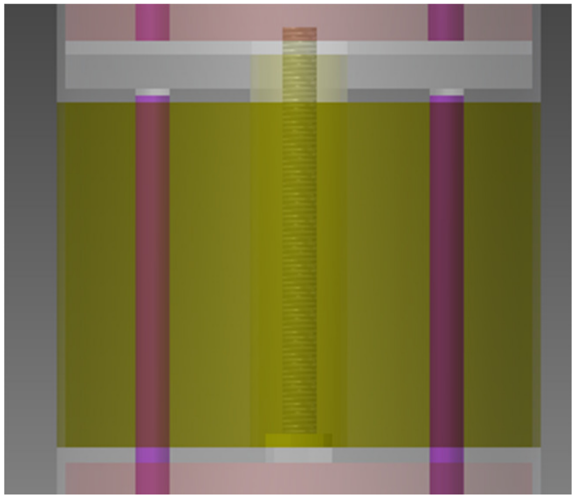
- **Material chosen – Plastic**
  - Low cost
  - Lightweight
  - Common
  - Water-proof
  - Easy to modify

Photo Courtesy of: http://www.recommsports.com/store/kenko-soft-tennis-ball-starter-set.html

Carrier-Lander Interface

- The basic principle will be a screw and nut design
- Motor will rotate the screw for separation
- Four fixed supports ensure no unwanted torque on the screw
- Parachute will be packed inside the device with a rip cord attached to the carrier to ensure proper deployment
- Motor and screw will be shielded to prevent tangling with the parachute





Motor Trade & Selection

Model	Price	Load Current (mA)	Operating Voltage (V)	No Load Speed (rpm)	Size (mm)	Weight (g)	Torque (g-cm)
Parallax Continuous Rotation Servo	$12.99	190 no load (> 1 A load)	1.5 - 6	60	40.5 X 20 X 30.8	45	3,400
56:1 Mini Metal Geared Motor	$18.99	550	1.7 - 5	480	12 X 10 X 24	7.8	800
100:1 Mini Metal Sealed Gear Motor	$19.75	612 (Stall)	1.5 - 6	240	14 X 14 X 33	11.1	1526

Motor Selection - 56:1 Mini Metal Geared Motor

- Extremely lightweight
- High torque output
- High RPM for fast separation

Photo courtesy of: http://www.robotmarketplace.com/products/0-GM11A.html

Mass Budget

Lander

Component	Mass (g)	Source
Frame	50	Estimate
Parachute	80	Estimate
Separation Module Bottom	25	Estimate
Exterior Shell	30	Estimate
BMP085 Pressure Sensor	2	Data Sheet
Arduino Pro Mini 328 - 3.3V/8MHz	2	Estimate
Li-Ion 14500 Battery	20	Data Sheet
Buzzer 668-1028-ND	6	Data Sheet
GPS sensor	14	Estimate
EEPROM	2	Estimate
Egg Protection Material	20	Estimate
Accelerometer ADXL345	2	Data Sheet
Motor	7.8	Data Sheet
Lander Total	260.8	

Carrier

Component	Mass (g)	Source
Frame	40	Estimate
Parachute	80	Estimate
Separation Module Top	25	Estimate
Exterior Shell	20	Estimate
BMP085 Pressure Sensor	2	Data Sheet
Arduino Pro Mini 328 - 3.3V/8MHz	2	Estimate
Li-Ion 14500 Battery	20	Data Sheet
Buzzer 668-1028-ND	6	Data Sheet
GPS sensor	14	Estimate
RF Module Laird AC4790-200A	21	Data Sheet
Carrier Total	230	

CanSat Total = 490.8 g

Communication and Data Handling (CDH) Subsystem Design

Chris Stack

CDH Overview

- **Lander**
  - Data from the voltage divider, accelerometer, and barometer is received by the Arduino Pro Mini and stored on external EEPROM
  - Retrieved later through external connection from the Arduino
- **Carrier**
  - Data from the GPS, barometer, and voltage divider is received by the Arduino Pro Mini and transmitted by the AC 4790 transceiver to the GCS

CDH Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
CDH-01	Shall transmit or store all subsystem data	Base Mission Requirement	High	None	None	X		X	X
CDH-02	Microcontroller will allow I^2C and serial communication. (2 pins needed for I2C and 4 pins for serial)	All subsystems use either of these two protocol.	High	None	None		X		
CDH-03	Microcontroller shall operate at high enough frequency to manipulate data and still output at 0.5 HZ (at least 1MHZ)	Data from all sensors must be integrated into one packet	Medium	None	None		X	X	
CDH-04	External memory for lander shall store at least 24 Kb	Data from descent and impact will be at least this large	Medium	None	None		X		X
CDH-05	Shall store and transmit all data using Hexadecimal encoding	Using Hexadecimal encoding will lower the number of bytes needed to be stored and transmitted	Low	None	None		X		
CDH-06	Communications radio shall be Laird AC4790-200	Base Mission Requirement	High	SYS-04	None		X		
CDH-07	Communications shall use the Laird AC4790 packet format	Base Mission Requirement	High	SYS-04	None		X		
CDH-08	Radio must not use the broadcast mode	Base Mission Requirement	High	SYS-04	None		X		

CDH Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
CDH-09	CanSat shall autonomously terminate telemetry transmissions within 5 minutes of landing, verified by GCS	Requirement set by CG	High	SYS-04	None		X		
CDH-10	Audible locating device s(ALD) hall activate upon	Base Mission Requirement	Medium	SYS-03	CDH-10a,CDH-10b,CDH-10c		X		X
CDH-10a	ALD shall not be activated during launch and launch activities	Base Mission Requirement	Medium	SYS-03,CDH-10	None				X
CDH-10b	ALD shall operate for at least 1 hour following activation	Base Mission Requirement	Low	SYS-03,CDH-10	None				X
CDH-10c	ALD shall be at least 95 dB	Needs to be loud enough to hear from a distance	Low	SYS-03,CDH-10	None		X		

Processor Trade & Selection

Microcontroller	Input Voltage (V)	Current (mA per pin)	Clock Frequency (MHz)	Digital Pins	Analog Pins	Flash Memory (kb)	EEPROM (bytes)	Weight (g)	Dimensions (mm)	Price
Arduino Uno	9	40	16	14	6	32	1024	32	85.58 x 53.34	$29.95
Arduino Pro Mini 328	9	40	8/16	14	6	16	512	1	17.8 x 33.02	$18.95
Arduino Pro 328	9	40	8/16	14	6	32	1024	11	53.34 x 52.07	$19.95

Microcontroller Selection - Arduino Pro Mini 3.3V

- Advantages
  - Capable of Serial, I^2C, and SPI communication
  - Small
  - 3.3 V operating voltage
- Disadvantages
  - 8 MHz clock speed for 3.3 V version
  - No onboard USB
  - Less memory

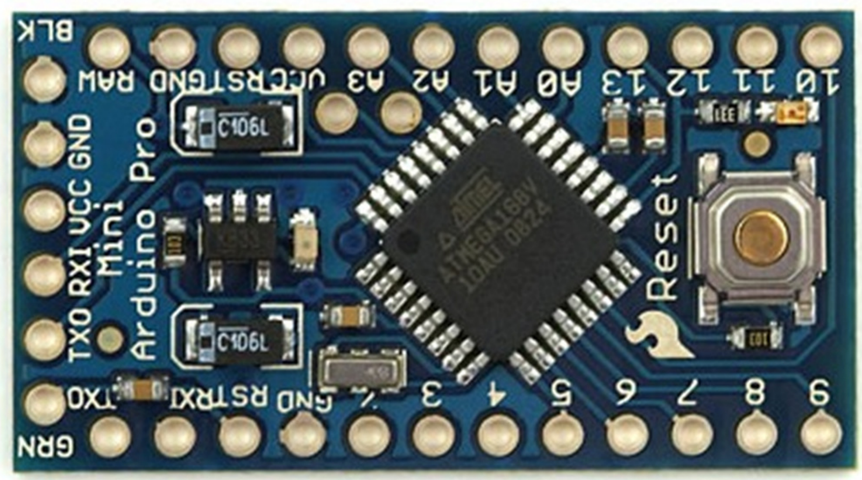


Photo courtesy of: http://arduino.cc/en/Main/ArduinoBoardProMini

Memory Trade & Selection

Memory Unit	Price	Input Voltage (V)	I^2C Clock Frequency (kHz)	Current Draw (mA)	Protocol	Memory (kb)
Microchip 24LC256	$1.95	2.5-5.5	400	3	I^2C	32
Microchip 24LC512	$1.94	2.5-5.5	400	5	I^2C	64

Microchip 24LC512 EEPROM

- Advantages
  - Easy to use protocol
  - Well documented
  - Large Size
- Disadvantages
  - Uses more power

Photo courtesy of: http://cdn.sigma.octopart.com/308656/image/Microchip-24LC512-I/P.jpg

Carrier Antenna Trade & Selection

Antenna	Price	Type	Gain (dB)	Length (cm)	Interface
gigaAnt Integrated Antenna	$1.35	Micro strip	-0.5	3	N/A
A09-QRAMM	$12.00	¼ wave monopole	1.9	7.62	MMCX
S467FL-5-RMM-915	$14.64	½ wave dipole	2.0	17.8	MMCX

Antenna Chosen – gigaAnt

- Integrated into transceiver module to reduce amount of space
- Able to position it in multiple ways
- Approved for use as noted in data sheet

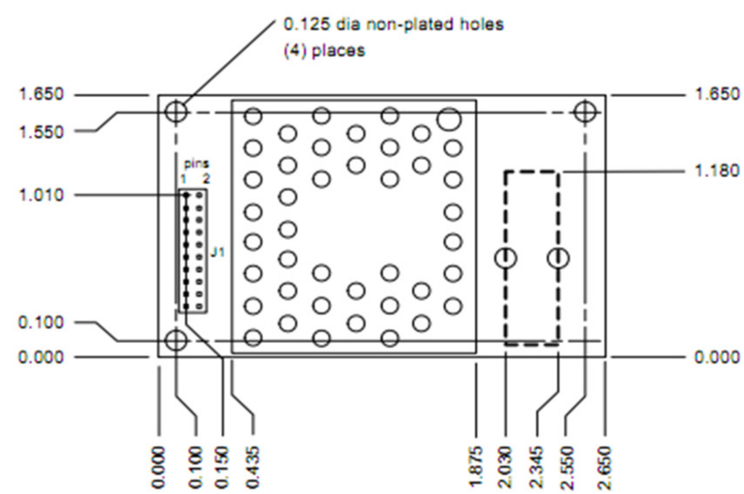


Photo courtesy of Laird 4790 Radio Users Guide

Communications Configuration

- **Mission Guidelines require that we must use the AC4790 transceivers in API mode to reduce interference**
  - On transmission, the FSW will write the API header, payload data length, session count refresh, transmit retries, destination MAC and payload data to the transceiver in that order
  - The GCS will receive the data in the following format: API header, payload data length, instantaneous RSSI, validated RSSI, and the payload data

Carrier Telemetry Format

- **Data included in Carrier Transmissions:**
  - From GPS: UTC time, latitude, longitude, altitude, and satellites tracked
  - From barometer: pressure and temperature
  - From voltage divider: battery voltage
- **76.8 kbps data rate**
- **Tentative Format:**
  - All values in hex
  - 38 characters including parity

Data Packet Definition

Original characters	Number of characters after encoding	Definition
Hhmmss.sss	7	UTC time – hours, minutes, seconds, fraction of a second
Ddmm.mmmm	7	Latitude
Dddmmm.mmmm	7	Longitude
hhhhh.h	5	GPS altitude
xx	1	Satellites tracked – max of 12
ppppp	4	Absolute value of pressure difference from barometer
tt.t	3	Air temperature
vv.vvvv	3	Battery voltage

Autonomous Termination of Transmissions

- Change in pressure is constantly monitored by the Arduino
- When pressure is constant for 5 minutes transmission will be terminated
- Ground station will verify end of transmission by displaying the message “Lost Contact”

Locator Device Trade & Selection

Part	Price	Loudness (dB)	Size (mm)	Weight (g)	Power Req.
AI-2429-TWT-R	$4.51	100	23.8 (Dia.) x 16	6	8 mA 3-20 VDC
AI-4228-TF-SP-LW145-R	$7.87	98	41.8 (Dia.) x 16	15	10 mA 3-20 VDC
AI-4228-TF-LW140-3-R	$4.76	106	41.8 (Dia.) x 16	15	10 mA 3-20 VDC

Device chosen – AI-2429-TWT-R

- Smaller size and weight to fulfill space requirements

Method used for enabling/disabling

- Activated when pressure is constant for 30 seconds
- Can be turned off by external power switch on CanSat

Photo courtesy of http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail&name=668-1028-ND

Electrical Power Subsystem (EPS) Design

Chris Jennette

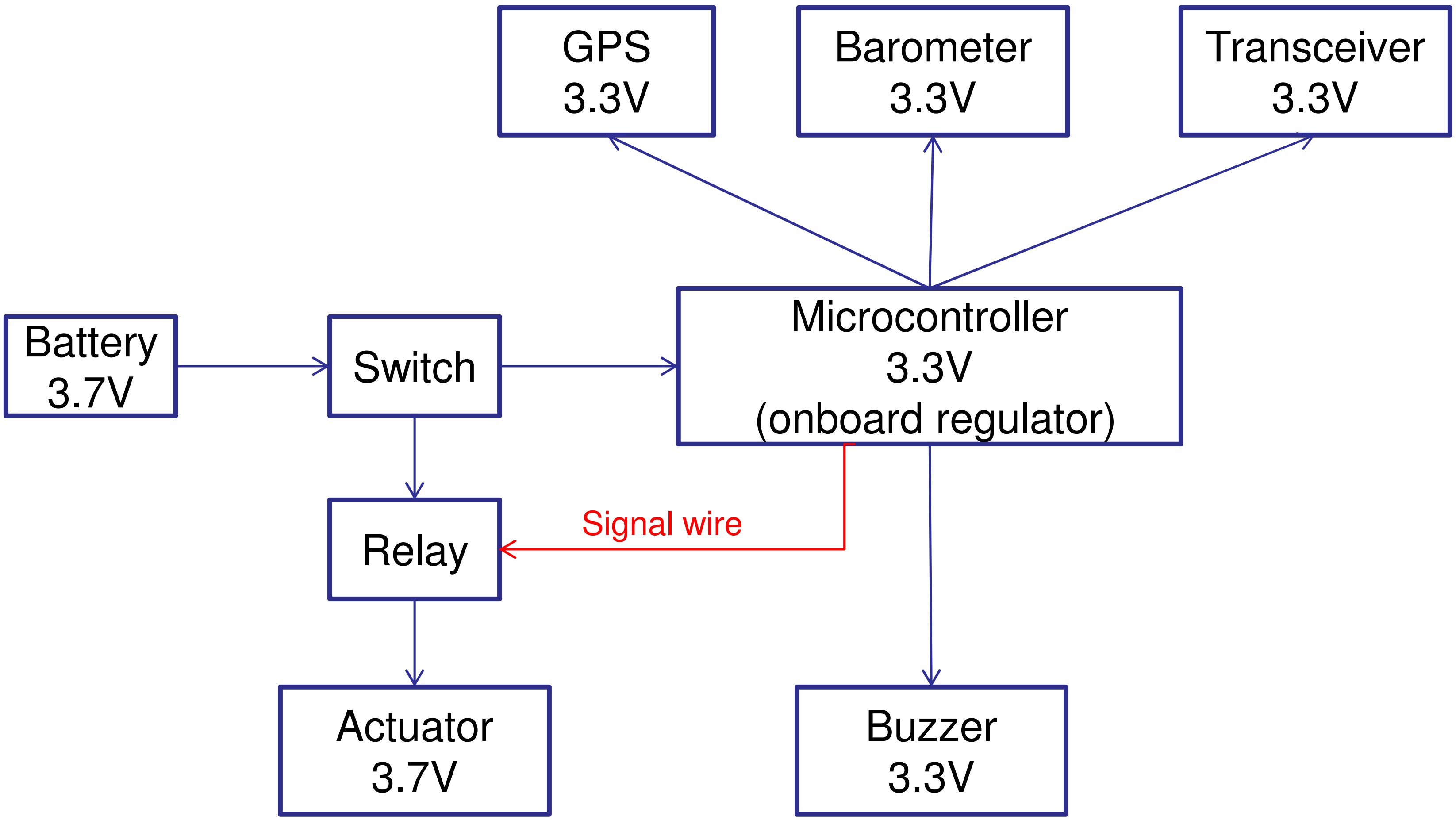
EPS Overview

Part	Purpose
Li-Ion 14500 Battery	Powers all components within carrier and lander
Slider Switch	Controls power from battery to main circuit
Relay (Transistor)	Allows power to flow from battery directly to actuator when signal from Arduino is detected
LED	Used to show CanSat carrier and lander power is on
Voltage Divider (resistor circuit)	Scale down total power to measure voltage using Arduino ADC

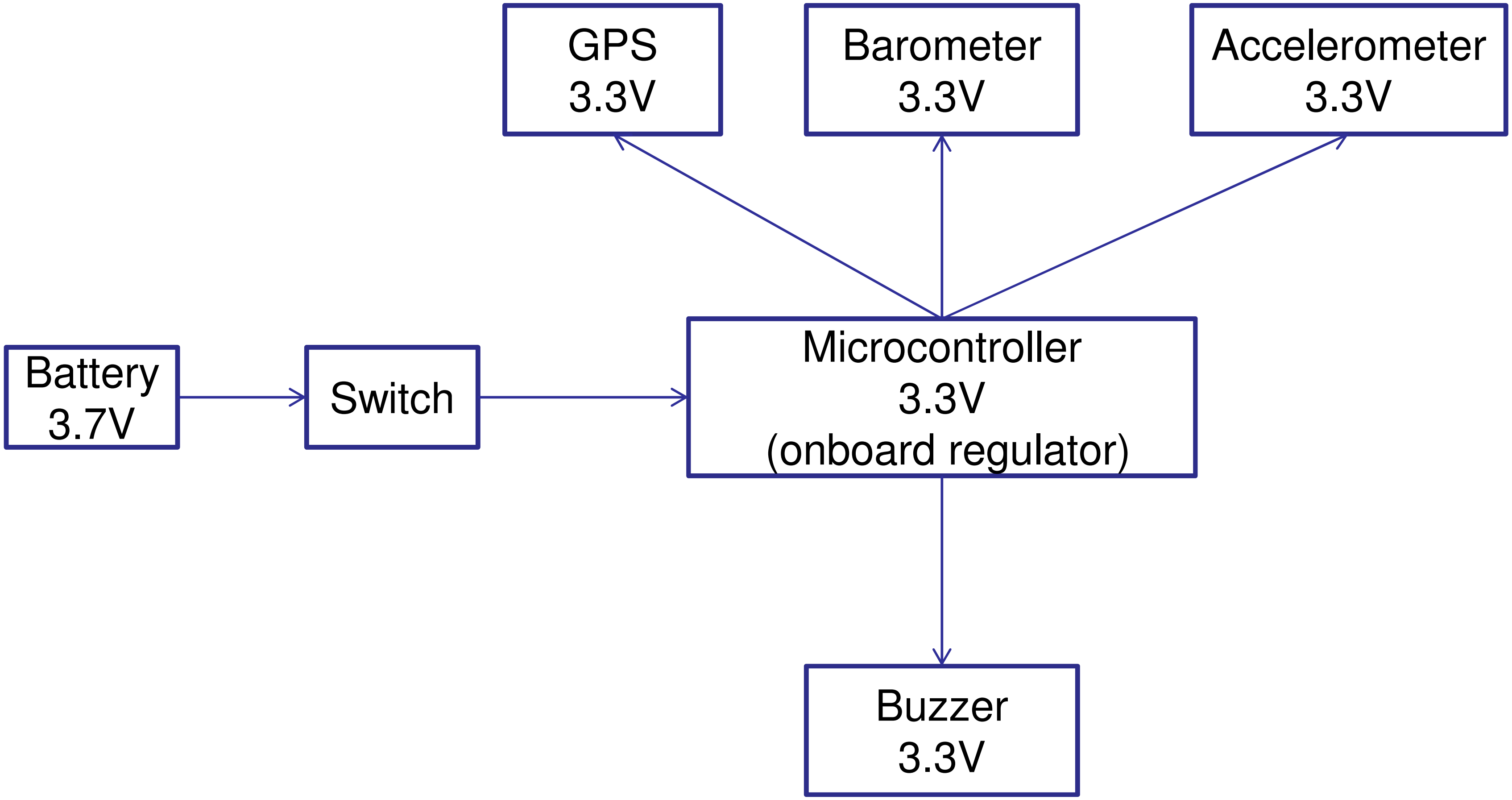
EPS Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
EPS-01	Battery shall output at least 3.3 V for duration of flight	Arduino requires a 3.3 V input	High	None	None		X	X	
EPS-02	Battery shall be able to discharge a peak of 900 mA	When actuator is in use, current drawn will spike	Medium	None	None		X	X	
EPS-03	Battery shall be adequately light (less than 50 g at least)	Weight is a limiting factor in our design choice	Medium	SYS-01	None		X		
EPS-04	Battery shall have a high enough capacity to last the duration of the mission (350 mAh)	CanSat needs power for duration of mission	High	None	None		X		X
EPS-05	Will use Arduino's ADC to measure battery voltage with resolution of 10 bits (3.2 mV)	Base Mission Requirement	Medium	None	None		X		X
EPS-07	Carrier and lander shall have an external power control switch that turns on and off	Base Mission Requirement	High	SYS-07	EPS-07a		X		
EPS-07a	On-off switch shall be connected directly to battery	To cut off carrier power	Medium	SYS-07, EPS-07a	None		X		
EPS-08	Cannot use lithium polymer (LiPo) batteries	Base Mission Requirement	High	SYS-07	None		X		

Carrier Electrical Block Diagram



Lander Electrical Block Diagram



Carrier Power Budget

Component	Current (mA)	Voltage (V)	Power (mW)	Expected Duty Cycle (Time on in min.)	Uncertainty (±%)	Total Energy Consumed* (mWh)	Source
Arduino	25	3.3	82.50	60.00	20	82.50	EST
Arduino I/O pins	120	3.3	396.00	5.00	10	33.00	DS
GPS	41	3.3	135.30	5.00	10	11.28	DS
Barometer	0.007	3.3	0.02	5.00	10	0.00	DS
Transceiver	108	3.3	356.40	5.00	10	29.70	DS
Actuator	550	3.7	2035.00	0.20	30	6.78	DS
Buzzer	8	3.3	26.40	60.00	10	26.40	DS
Total						**189.66**	
Available (mWh)						2775.00	
Margin (mWh)						2585.34	

**Total Energy Consumed has been calculated as the* $Total\ Energy * (1 + Uncertainty)$

Lander Power Budget

Component	Current (mA)	Voltage (V)	Power (mW)	Expected Duty Cycle (Time on in min.)	Uncertainty (±%)	Total Energy Consumed* (mWh)	Source
Arduino	25	3.3	82.50	60.00	20	82.50	EST
Arduino I/O pins	160	3.3	528.00	5.00	10	44.00	DS
GPS	41	3.3	135.30	5.00	10	11.28	DS
Barometer	0.007	3.3	0.02	5.00	10	0.00	DS
EEPROM	0.4	3.3	1.32	5.00	10	0.11	DS
Accelerometer	0.145	3.3	0.48	5.00	10	0.04	DS
Buzzer	8	3.3	26.40	60.00	20	26.40	DS
Total						**164.33**	
Available (mWh)						2775.00	
Margin (mWh)						2610.67	

**Total Energy Consumed has been calculated as the* $Total\ Energy * (1 + Uncertainty)$

Power Source Trade & Selection

Part	Price	Type	Capacity (mAH)	Weight (g)	Voltage (V)	Size (mm)
RA-H2/3A4I2TB	$9.95	NiMH	1200	83	4.8	17 x 34 x 60
Li-ion 18650 Cylindrical	$5.95	Li-ion	2200	47	3.7	18.4 (diameter) x 64.9
Li-ion 14500 pre-wired with PCB	$9.95	Li-ion	750	20	3.7	18 (diameter) x 54

Battery Chosen – Li-ion 14500

- Lightest and smallest
- Meets required voltage and capacity
- Integrated protection circuit
- Used for carrier and lander

Photo courtesy of http://www.batteryspace.com/li-ion14500battery37v750mah277whbatteryprewiredwithpcb3alimit.aspx

Battery Voltage Measurement Trade & Selection

- We will be using the Arduino's ADC to measure the voltage, which has a resolution of 10 bits.
- Will use high valued resistors (for low current drain) to make a simple voltage divider and bring the voltage down from 4.2V max to 3V max
- Resistor values will be 100 kΩ and 250 kΩ
- Will calculate battery voltage using the ratio:

$$\frac{V_{meas.}}{V_{battery}} = \frac{250k\Omega}{100k\Omega + 250k\Omega} = \frac{5}{7}$$

Flight Software Design (FSW)

Chris Stack

FSW Overview

- **Basic FSW architecture**
  - Runtime loop: monitors time and requests updates at a rate of 0.5 Hz, builds data string and sends it back to ground station, monitors altitude and initiates separation as well as disabling of radio
- **Programming languages**
  - C/C++
- **Development environments**
  - Arduino IDE

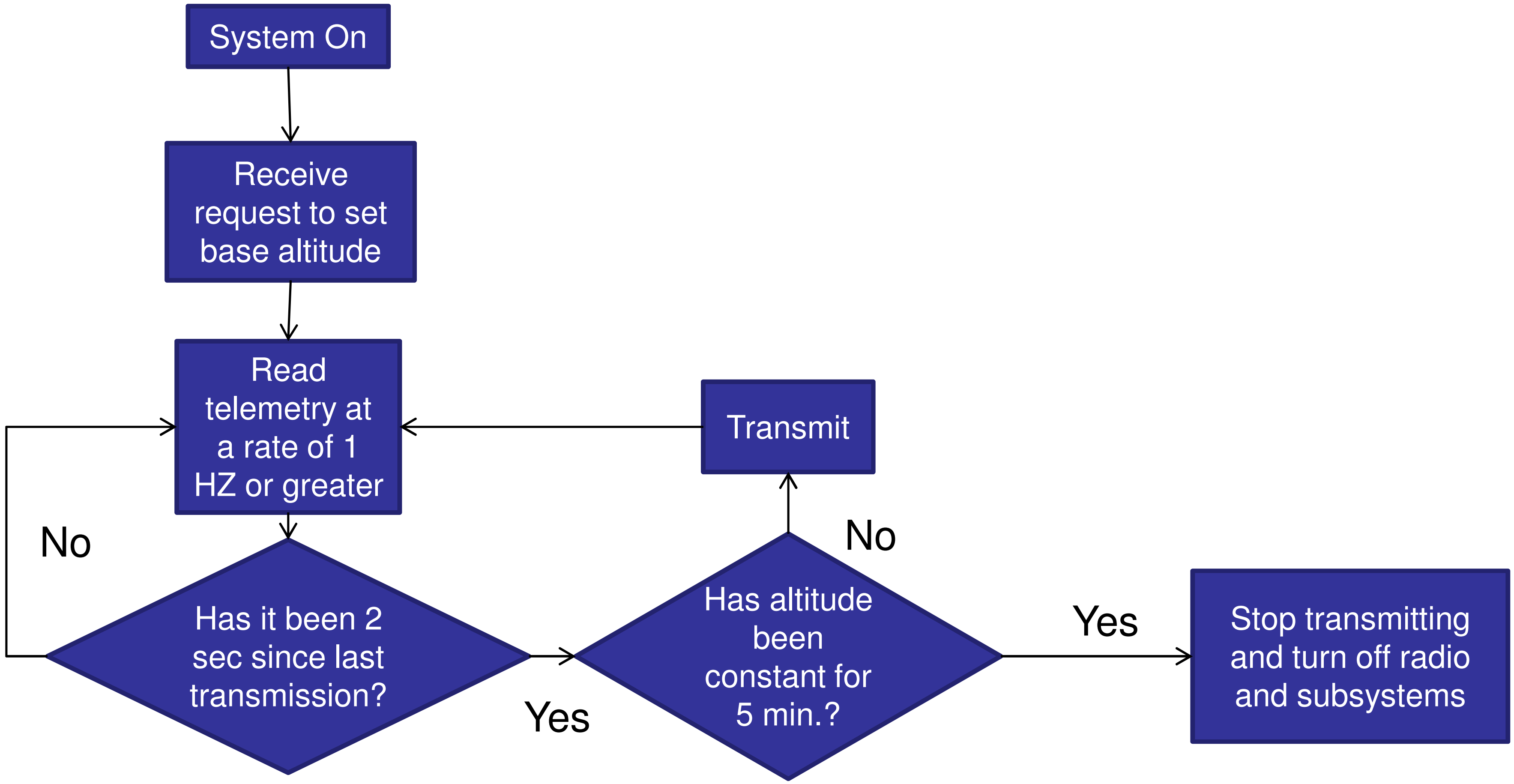
FSW Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
FSW-01	For testing sample programs will be made to simulate significant events such as the need for separation and approaching ground to ensure the appropriate action is taken	Our separation mechanism and other things like it need to be tested before actual drop testing.	High	None	None			X	X
FSW-02	Data will be sampled for all subsystems except for accelerometer at rate of at least 0.5 Hz	Transmission must occur every 0.5 Hz so this will ensure new data for all subsystems	Medium	SSD-03	None		X		X
FSW-03	Baud rate of 57600 bps	This is the optimal baud rate for both the GPS and transceiver.	Low	None	None		X		
FSW-04	Data will be stored using an external memory module through I^2C protocol	The Arduino microcontroller does not have enough on-board memory so we have selected an external module.	Low	None	None		X	X	
FSW-05	The carrier will interface with the ground station through transceiver uplink.	Base Mission Requirement.	Low	None	None		X		X

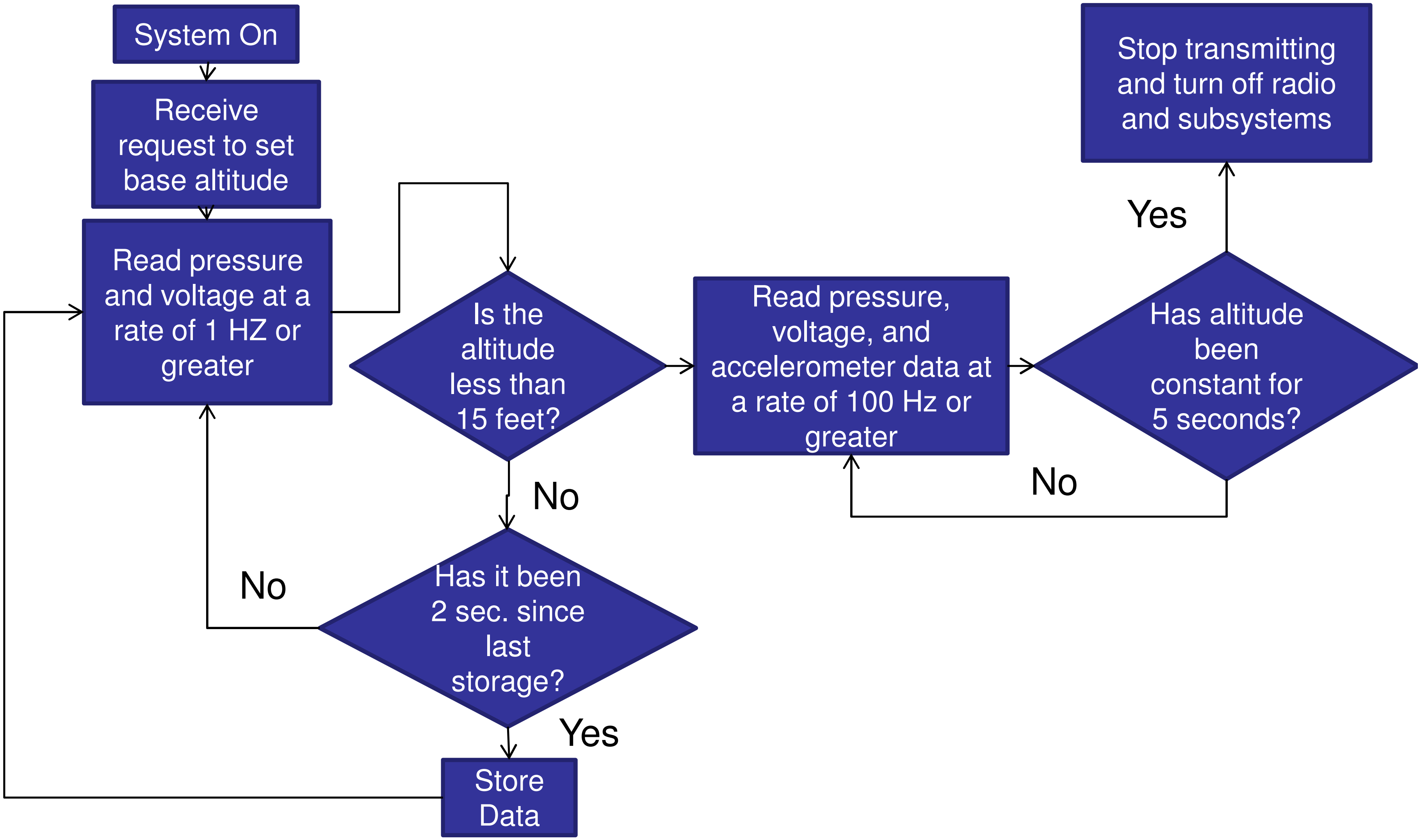
FSW Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
FSW-06	The lander will interface with the GCS through FTDI USB cable.	This is the standard protocol for accessing data from an Arduino without USB.	Low	None	None		X		X
FSW-07	All telemetry data shall be displayed in real-time during launch and descent	Base Mission Requirement	High	SYS-09	None	X			
FSW-08	All telemetry data shall be displayed in engineering units	Base Mission Requirement	High	SYS-09	None				X
FSW-09	Shall plot data in real-time during descent	Base Mission Requirement	Low	SYS-09	None	X			

Carrier CanSat FSW Overview



Lander CanSat FSW Overview



Ground Control System Design

Chris Jennette

GCS Overview

1. Antenna receives signal from carrier
2. Received by transceiver
3. Data transferred to computer from transceiver over an FTDI cable
4. Data processed, displayed, and stored by GCS

GCS Requirements

ID	Requirement	Rationale	Priority	Parent(s)	Child(ren)	VM			
						A	I	T	D
GCS-01	GCS must be able to parse and graph data from carrier and lander.	Mission requirement to display real-time data.	Medium	None	None				X
GCS-02	Antenna must be free of interference.	Interference would cause signal loss and could cause loss of communication	Low	None	None				X
GCS-03	Antenna will be placed to aim in the direction the wind is blowing to ensure coverage during entire flight.	Current selection of a directional antenna means more care needs to be taken in antenna placement.	Low	None	None	X	X		X
GCS-04	GCS antenna shall be elevated a minimum of 3.5 m from the ground level	Base Mission Requirement	High	SYS-04	None		X		
GCS-05	GCS will verify that transmissions have stopped from the carrier 5 minutes after landing	Base Mission Requirement	High	SYS-04	None		X		
GCS-06	Must have own ground station	Base Mission Requirement	High	SYS-04	None	X			X

GCS Antenna Trade & Selection

Antenna	Price	Type	Gain (dB)	Beam Width (degrees)
A09-Y11NF	$70	Yagi	9	Vert. - 55 Hor. - 65
SG101N-915	$52	Omni-Directional	5	Hor. - 360 Vert. - drops at 90 and 270
0600-00025	$14	½ wavelength dipole	2	Hor. - 360 Vert. - drops at 90 and 270

Chose Omni-Directional SG101N-915

- CanSat could drift as much as 1500m during descent, requires wide antenna coverage
- Antenna will be angled away from launch site to account for drop in coverage at 90°

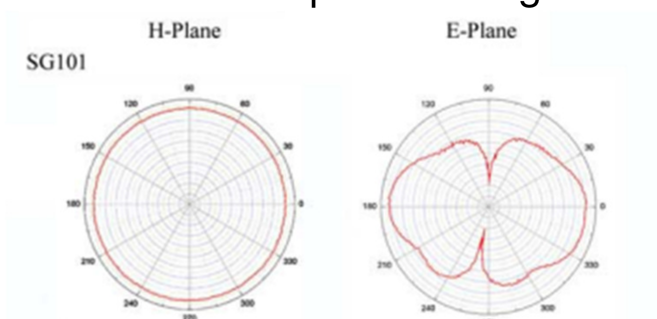
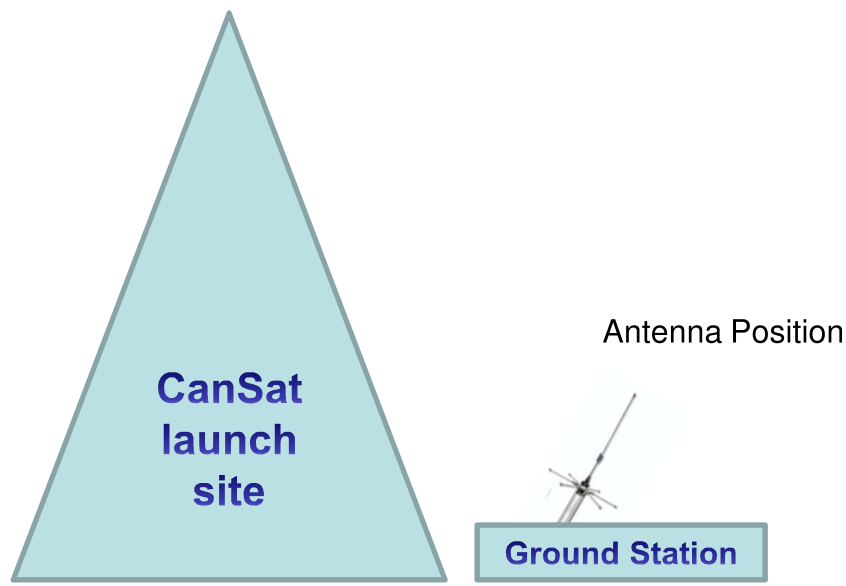


Photo Courtesy of http://media.digikey.com/pdf/Data%20Sheets/Nearson%20PDFs/SG%20Series.pdf



CanSat Integration and Test

Stephanie Butron

Integration & Testing

- **Mechanical**
  - Lab test of the separation mechanism while under load
  - Egg drop testing with integrated CanSat
    - Egg protection will be refined and optimized to reduce volume
  - Drop test from sufficient altitude to ensure correct operation of the separation mechanism in flight
    - This will require a helium balloon or similar method to deliver the CanSat to high altitude, and a large, open field for safety

- **Decent Control**
  - Low altitude drop tests will be needed to ensure proper lander parachute deployment
  - The integrated test for the parachutes will be conducted at the same time as the high altitude drop tests for the mechanical system

Integration & Testing

- **Power/Electrical**
  - Last subsystem to test
  - Once all electrical subsystems are tested and working properly, an extended test will be conducted to ensure ample battery life

- **Communications**
  - This subsystem is a primary concern
  - Ensuring proper protocol and antenna selection are vital for the carrier and GCS to communicate throughout the entire mission, this subsystem is a primary concern
    - Testing: Long distance tests will be conducted to ensure that all data is passed to the GCS correctly

Integration & Testing

- **Sensors (in order of importance)**
  - **Barometer**: Needed for both carrier and lander, vital for knowing altitude, and thus vital for mission success
    - Testing: Will test altitude readings alongside GPS to ensure that the values are close
  - **Accelerometer**: This sensor must have its data to read at the highest data rate and has never been used so it has the highest risk for problems
  - **GPS**: Necessary for reading and predicting the landing location, reading data from module is not difficult, but predicting landing location will require extensive tests
  - **Memory Module**: Needed to store data on the lander, standard and well documented process for the Arduino, so should not be a problem
  - **Battery Monitor**: Simple voltage divider going into ADC, won't be a problem to get voltage level, but will require some testing to get the percentage of battery remaining

Integration & Testing

- **Ground Control**
  - Already worked extensively with test data from the Arduino, will need further testing once all subsystems are integrated
    - Current version: Reads serial data and formats it for display. Also graphs the data it receives in real time
    - To do: Read data stored on a memory module, conduct testing with transceiver, create a mapping and landing prediction algorithm
- **Flight Software**
  - Work in progress because it is connected to all of the other subsystems

Subsystem Integration & Testing

Communication
- Vital for mission success as well as testing
- Other systems are connected to this subsystem

Sensors
- Selection of sensors needed before FSW programming can begin

FSW
- Programming needed to monitor subsystems, first individual then as a whole

Mechanical
- Completing the mechanical system next allows the team to begin structural assembly

Descent Control
- Completion of this subsystem is dependent on the separation mechanism

Electrical/Battery
- Cannot begin testing until all sensors are working and responding correctly

Ground Control
- Basic software already complete, testing and extra features must wait until FSW is workable

Mission Operations & Analysis

Younes Taleb

Overview of Mission Sequence of Events

- **Pre-launch Sequence of Events**

Arrival at Launch Site

- Set up ground station
- Connect communication devices
- Make any last minute assemblies to the CanSat
- Measure wind speeds for landing estimates

Pre-Launch Checks

- Go through pre-flight checklist
  - Check subsystems
  - Ensure ground station is operational
  - Antenna positioned correctly
- Estimate of landing zone

Integration into Rocket

- Slide components into CanSat
- Insert egg in lander
- Power CanSat on
- Integrate CanSat into rocket payload

Overview of Mission Sequence of Events

- **Launch Sequence of Events**

Rocket Launch
- Begin ground communications with CanSat
- Receive telemetry

Deployment
- Carrier parachute deploys
- Pressure and temperature data acquired and plotted

Separation
- An approximate altitude of 500 m initiates separation
- Lander parachute deploys

Landing
- Audible beacons activates on carrier and lander upon landing
- Impact force recorded by the lander

Overview of Mission Sequence of Events

- **After-Launch Sequence of Events**

Recovery	• Carrier and lander retrieved • Egg checked for damage
Analysis	• Data retrieved from the lander via USB connection and analyzed • Telemetered data from the carrier analyzed
Post Flight Analysis	• Presentation created from results of the flight • Presentation given the next day

Lander Landing Coordinate Prediction

- **MATLAB code used to calculate landing coordinates**
- **Variables for code:**
  - Wind speed taken at the ground station
  - Accelerometer data retrieved after CanSat deployment
  - Temperature and pressure data measured with onboard sensors throughout descent to evaluate air density

Cansat Location and Recover

- **The carrier and lander will be equipped with a 100 dB buzzer**
  - Operates for 60 minutes
  - Allows for CanSat retrieval in case of remote locations
- **MATLAB code used to estimate landing location**
- **After recovery, the telemetry data is retrieved from the lander via a USB connection**

Management

Stephanie Butron

Budget - Hardware

Components	Model Name	Quantity	Unit Price	S/H	Price Definition
Accelerometer	Triple Axis Accelerometer Breakout - ADXL345	1	$27.95	$5.00	Estimate
GPS	32 Channel LS20031 GPS 5Hz Receiver	2	$59.95	$7.24	Estimate
RF Module	Laird AC4790-200A	2	$63.85	$7.24	Actual
	Laird AV4790-200M	1	$62.50	$7.24	Actual
Antenna (ground station)	ANTENNA OUTDR OMNIDIR 915MHZ STR	1	$52.00	$11.47	Actual
Microcontroller	Arduino Pro Mini 328 - 3.3V/8MHz	2	$37.90	$7.34	Actual
Actuator	56:1 Micro Geared Motor	1	$18.99	$5.60	Actual
Battery	Li-Ion 14500 Battery	1	$19.90	$17.51	Actual
Switch	360-2131-ND	2	$5.46	$9.33	Actual
Battery Charger	Smart Charger (0.5A) Battery Pack	1	$12.95	$9.33	Actual
Buzzer	668-1028-ND	2	$9.02	$8.83	Actual

Budget - Hardware

Components	Model Name	Quantity	Unit Price	S/H	Price Definition
EEPROM	Microchip 24LC256	1	$1.00	$7.72	Actual
Parachute	SkyAngle Classic II 20"	2	$31.95	$5.31	Actual
CanSat Casing	Wilson Tennis Ball Can	2	$2.49	N/A	Actual
Plexiglass Sheet	OPTIX 18 in. x 24 in. x 0.093 Acrylic Sheet	1	$9.77	N/A	Actual
Dowel Rods	Wilton plastic Dowel Rods (4 per pack) 16" X 48"	2	$2.16	N/A	Actual
Bubble Wrap	9' x 16" Roll	1	$5.49	N/A	Actual
Wall Tube Insulator	1 X 6 X 1/2	1	$6.06	N/A	Actual
Tools	Poplar Scant/Propolus Grouting	2	5.18	N/A	Actual
Cost of Components			$640.53		
S/H			$104.26		
Total Cost of Components			**$744.79**		

Budget – Other Costs

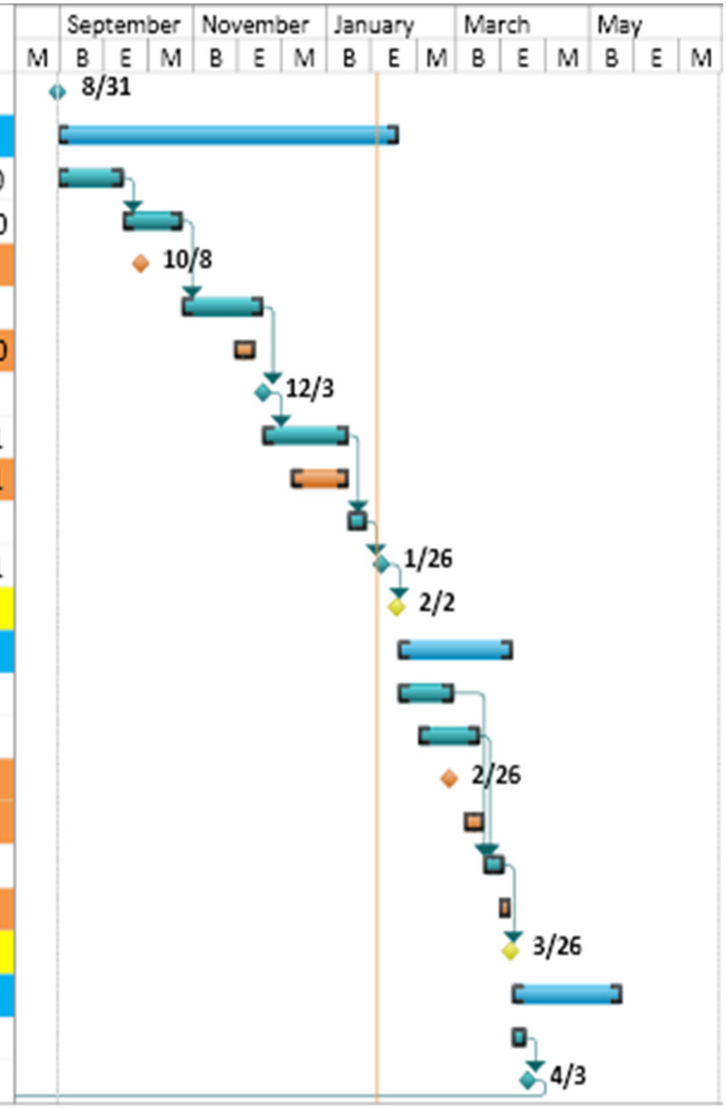
Description	Price	Price Definition
Fleet Services: Large Van (12 Passenger)	$1,065.00	Estimate
Hotel	$800	Estimate
Food	$400	Estimate
Total Cost of Travel and Expenses	$2,265.00	

Total Costs

Description	Price
Components	$744.79
Travel and Expenses	$2,265.00
Total Cost Overall	**$3,009.79**

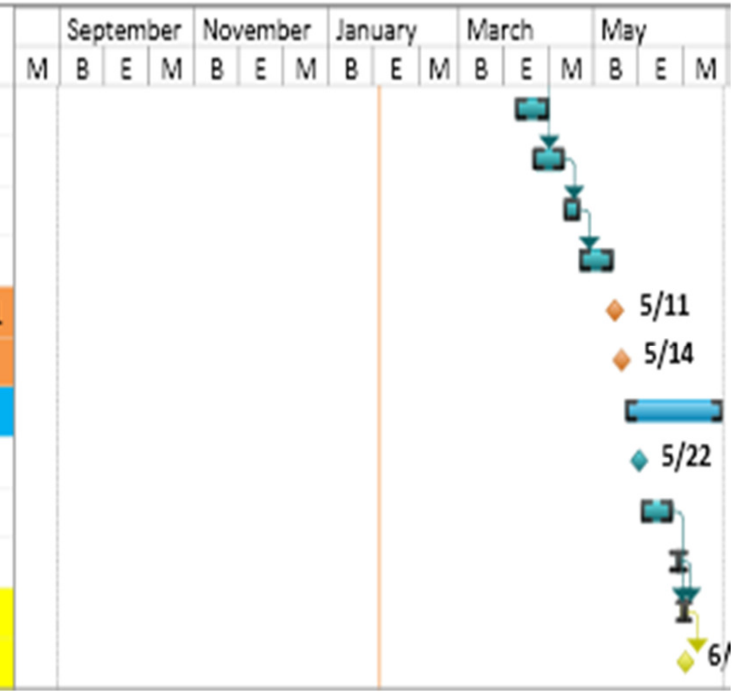
Program Schedule

ID	Task Name	Duration	Start	Finish
1	Start Project	0 days	Tue 8/31/10	Tue 8/31/10
2	Preliminary Design Phase	112 days	Tue 8/31/10	Wed 2/2/11
3	Project Definition	22 days	Tue 8/31/10	Wed 9/29/10
4	Conceptual Study	19 days	Thu 9/30/10	Tue 10/26/10
5	VT Fall Break	0 days	Fri 10/8/10	Fri 10/8/10
6	Preliminary Design Analysis	27 days	Wed 10/27/10	Thu 12/2/10
7	VT Thanksgiving Break	7 days	Sat 11/20/10	Sun 11/28/10
8	AOE Initial Design Results Presentation	0 days	Fri 12/3/10	Fri 12/3/10
9	Design Improvement	27 days	Fri 12/3/10	Mon 1/10/11
10	VT Winter Break	18 days	Thu 12/16/10	Mon 1/10/11
11	Assemble PDR	6 days	Tue 1/11/11	Tue 1/18/11
12	AOE PDR Presentation	0 days	Wed 1/26/11	Wed 1/26/11
13	PDR Presentation	0 days	Wed 2/2/11	Wed 2/2/11
14	Critical Design Phase	38 days	Thu 2/3/11	Sat 3/26/11
15	Final Conceptual Design Improvement	18 days	Thu 2/3/11	Sun 2/27/11
16	Procurement	21 days	Sat 2/12/11	Fri 3/11/11
17	VT Academic Outreach	0 days	Sat 2/26/11	Sat 2/26/11
18	VT Spring Break	7 days	Sat 3/5/11	Sun 3/13/11
19	Assemble CDR	7 days	Mon 3/14/11	Tue 3/22/11
20	VT E-week	5 days	Mon 3/21/11	Fri 3/25/11
21	CDR Presentation	0 days	Sat 3/26/11	Sat 3/26/11
22	Testing and Integration Phase	37 days	Sun 3/27/11	Sun 5/15/11
23	Finalize Test Schedules	6 days	Sun 3/27/11	Fri 4/1/11
24	TRR	0 days	Sun 4/3/11	Sun 4/3/11



Program Schedule

ID	Task Name	Duration	Start	Finish
25	Build	12 days	Sun 3/27/11	Sun 4/10/11
26	Subsystem Level Testing	11 days	Mon 4/4/11	Sun 4/17/11
27	Integration	6 days	Mon 4/18/11	Sun 4/24/11
28	System Level Testing	11 days	Mon 4/25/11	Mon 5/9/11
29	VT Spring Semester Ends	0 days	Wed 5/11/11	Wed 5/11/11
30	VT Academic Outreach	0 days	Sat 5/14/11	Sat 5/14/11
31	Operations Phase	32 days	Mon 5/16/11	Tue 6/28/11
32	OAR	0 days	Sun 5/22/11	Sun 5/22/11
33	Mission Planning	11 days	Mon 5/23/11	Sun 6/5/11
34	Travel to Texas	2 days	Wed 6/8/11	Thu 6/9/11
35	Competition	2 days	Fri 6/10/11	Sun 6/12/11
36	PFR	0 days	Sun 6/12/11	Sun 6/12/11



Color	Meaning
Blue	Phases of Design
Orange	VT Events
Yellow	CanSat Events

Conclusions

- **Major Accomplishments**
  - The subsystem designs have been evaluated in depth and are ready to proceed to building/testing phase
  - We have selected all of our major components
  - Most Components will be procured in the next 2 weeks
- **Unfinished Work**
  - Some programming for the GCS is complete, but code for in-flight sensors has not been started
  - Configuration dimensions are rough estimates and are subject to change once parts are delivered