Project A.P.E.S.
Critical Design Review

Presented by:

Georgia Institute of Technology
Mile High Yellow Jackets

Agenda

1. Mission Overview (3 Min)
2. Educational Outreach Update (2 Min)
3. Project Budget (3 Min)
4. Launch Vehicle (7 min)
5. Flight Systems (5 Min)
6. Flight Avionics (7 min)
7. Questions (15 Min)

Project A.P.E.S. CDR

MISSION OVERVIEW

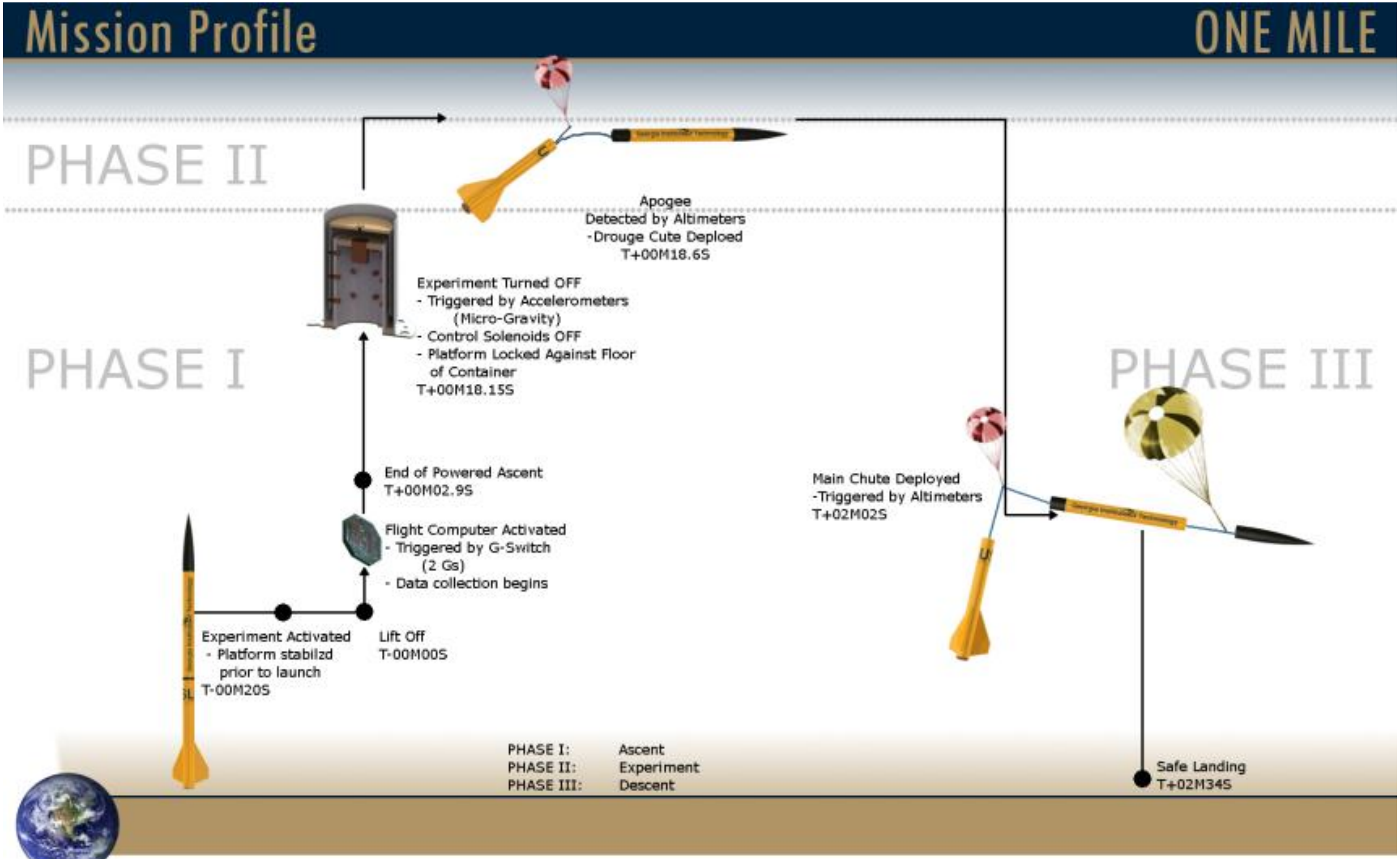
Mission Overview

TO MAINTAIN A SUSTAINABLE TEAM DEDICATED TO THE GAINING OF KNOWLEDGE THROUGH THE DESIGNING, BUILDING, AND LAUNCHING OF REUSABLE LAUNCH VEHICLES WITH INNOVATIVE PAYLOADS IN ACCORDANCE WITH THE NASA UNIVERSITY STUDENT LAUNCH INITIATIVE GUIDELINES.

Mission Success Criteria

Requirement	Design feature to satisfy that requirement	Requirement Verification	Success Criteria
Provide a suitable environment for the payload	The payload requires a steady, but randomly vibrating platform to test the APES system. Unsteadiness in the motor's thrust and launch vehicle aerodynamics cause vibrations.	By measuring the acceleration with the payload's accelerometers	The APES system dampens out a recordable amount of vibration.
To fly as close to a mile in altitude as possible without exceeding 5,600 ft.	A motor will be chosen to propel the vehicle to a mile in altitude	Through the use of barometric altimeters	The altimeters record an altitude less than 5,600 ft
The vehicle must be reusable	The structure will be robust enough to handle any loading encountered during the flight	Through finite element analyses and structural ground testing of components	The vehicle survives the flight with no damage

Mission Timeline



Georgia Tech USLI UNIVERSITY STUDENT LAUNCH INITIATIVE

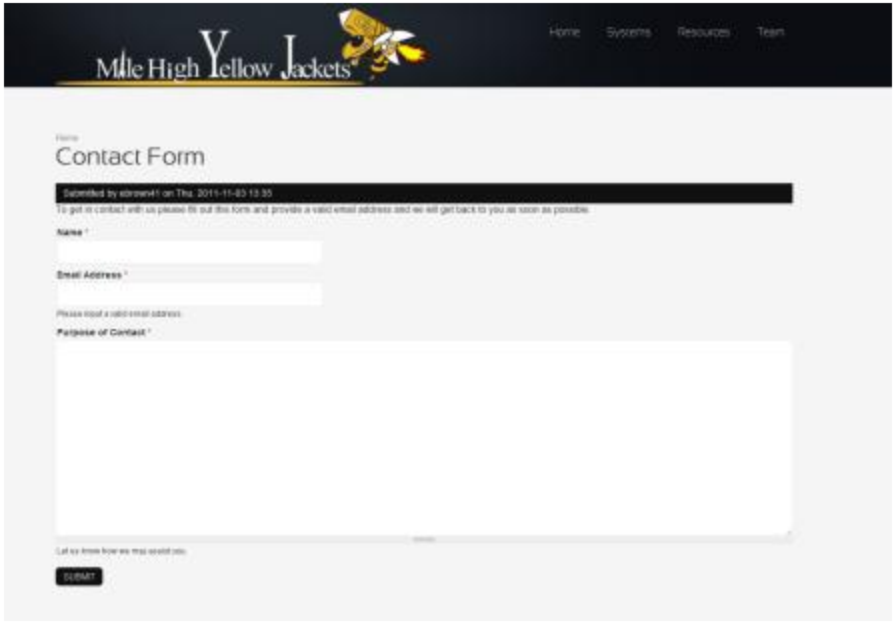
Project A.P.E.S. CDR

EDUCATIONAL OUTREACH

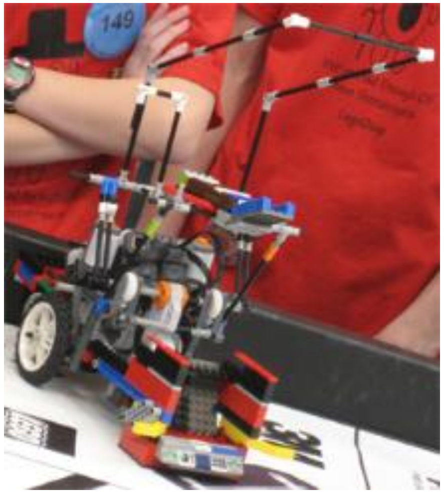
Educational Outreach

- Goal: Promote interest in STEM fields

- Educators can request presentations or hands-on activities for their classroom



Education Outreach Activities



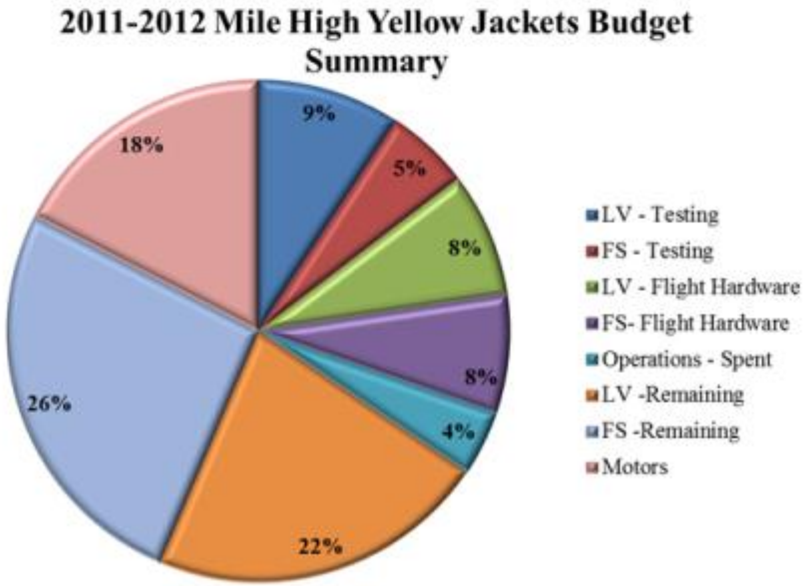
Activity	Date
FIRST LEGO League	Jan. 28th
Civil Air Patrol Model Rocketry Program	TBD
National Air and Space Museum Discovery Station	Discovery Station Proposal submitted – in the approval process
Young Astronauts Prograram	TBD

Project A.P.E.S. CDR

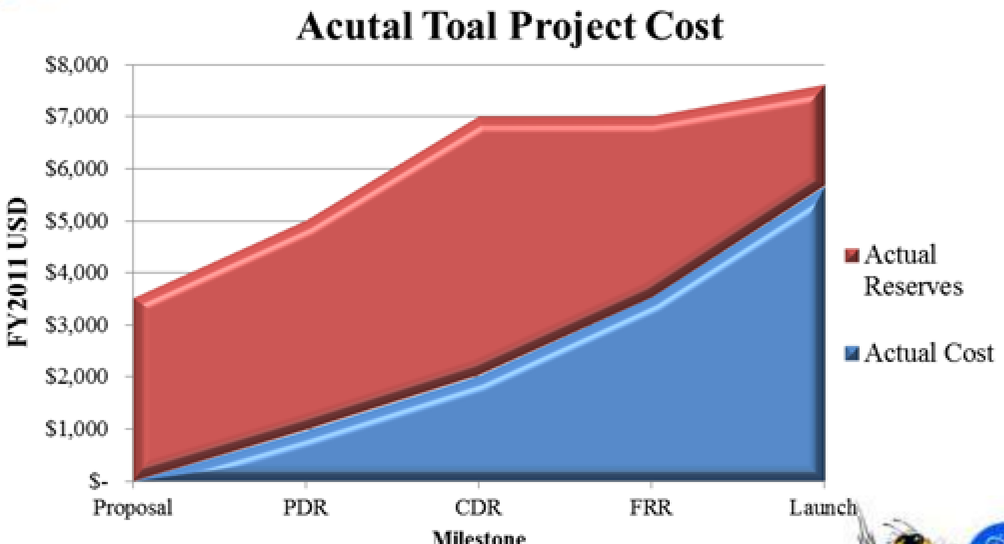
PROJECT BUDGET

Budget Summary

2011-2012 Budget Breakdown	
LV - Testing	$ 530.17
FS - Testing	$ 310.93
LV - Flight Hardware	$ 458.90
FS- Flight Hardware	$ 438.20
Operations - Spent	$ 239.41
LV -Remaining	$ 1,260.93
FS -Remaining	$ 1,500.87
Motors	$ 1,000.00
Operations - Remaining	$ 1,260.59
Total	$ 7,000.00

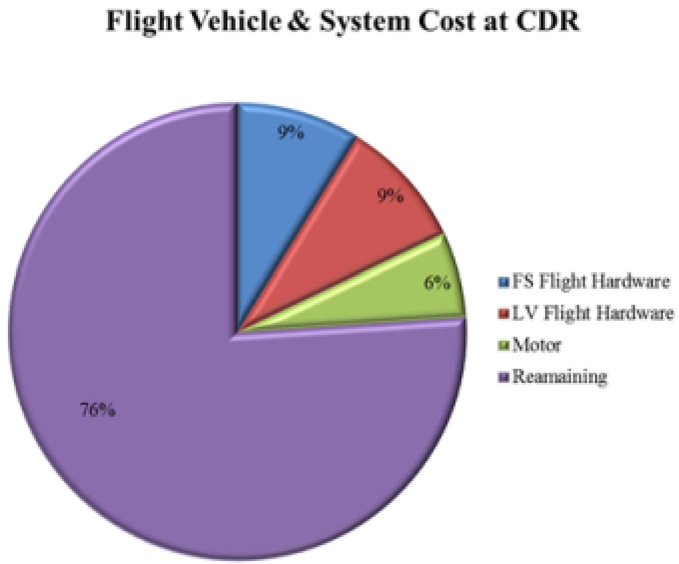


	Actual Cost	*Project Reserves*
PDR	$ 981.44	35.52%
CDR	$2,032.62	62.43%
FRR	$3,532.62	78.21%
Launch	$5,657.62	42.14%

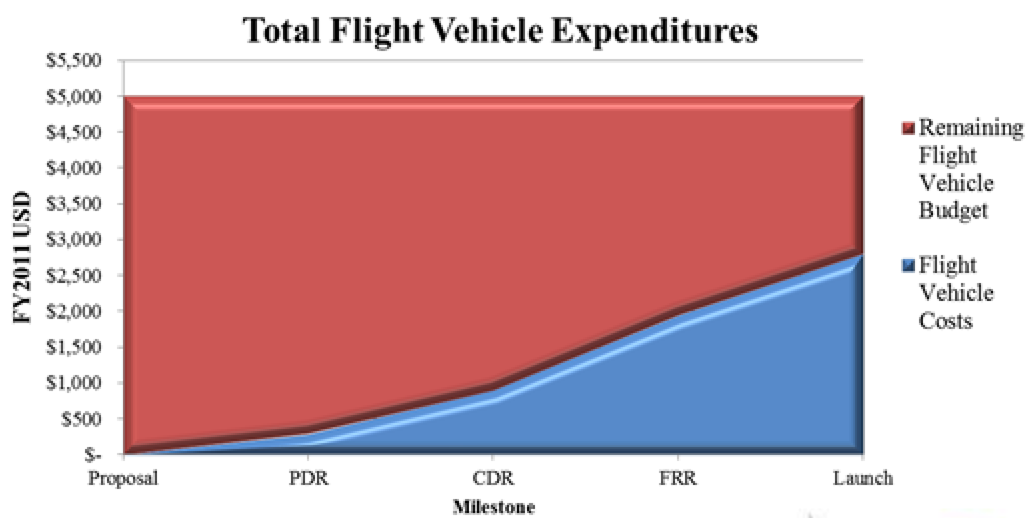


Flight Vehicle Expenditure Summary

2011-2012 Overall Flight Vehicle Costs ($5,000 Limit)	
FS Flight Hardware	$ 438.20
LV Flight Hardware	$ 458.90
Motor	$ 300.00
Remaining	$ 3,802.90
Total	$ 5,000.00



	Remaining	*Cumulative Costs*	*% Remaining*
PDR	$ 4,713.10	$ 286.90	94.26%
CDR	$ 4,102.90	$ 897.10	82.06%
FRR	$ 3,067.90	$ 1,932.10	61.36%
Launch	$ 2,205.40	$ 2,794.60	44.11%



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Project A.P.E.S. CDR

LAUNCH VEHICLE

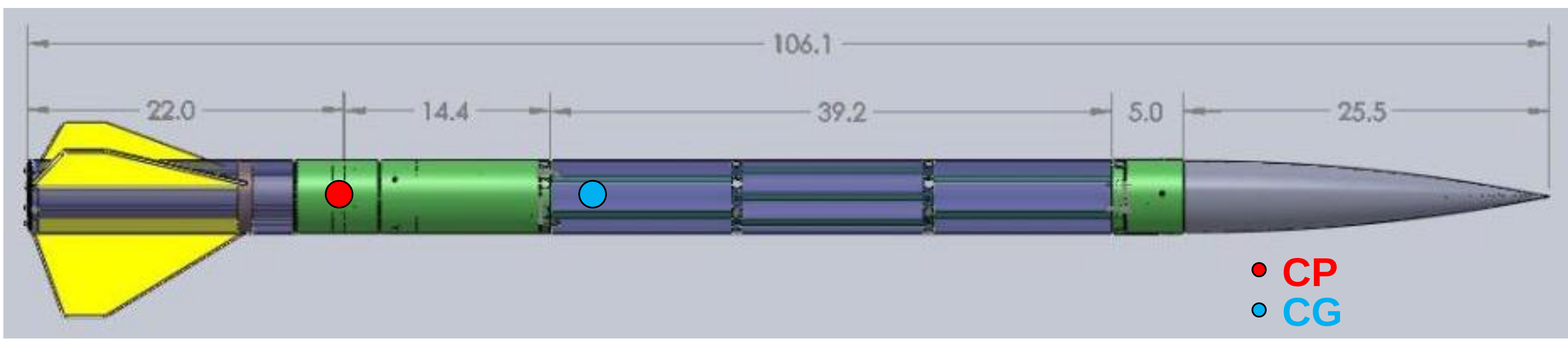
Changes Since PDR

Rocket:

- Drogue is now 4 ft in diameter and slows down the vehicle to 50 ft/s
- Main chute diameter is now 12 ft and slows down the vehicle to 15 ft/s
- Ejection charge masses increased to account for parachute packing.
- Cardboard motor tube added for increased fin epoxy surface area
- Thrust plate to be cut from a wood block using a waterjet
- Thrust retention ring to be cut from an aluminum plate on a waterjet
- L-brackets added at epoxy joints for added strength

Vehicle Summary

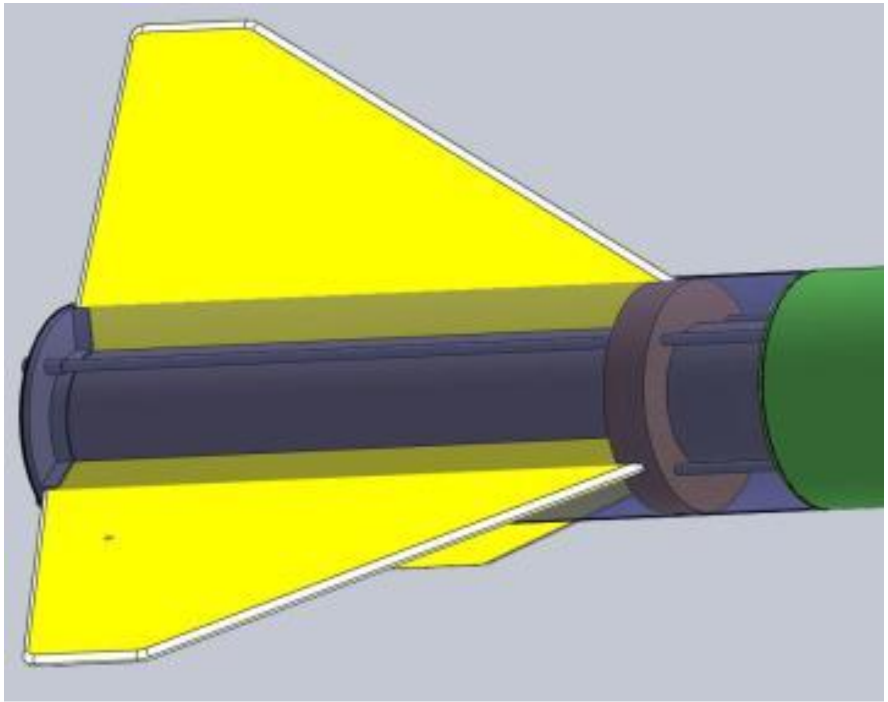
- Predicted apogee: 5315 ft
- Stability margin: 3.6 calibers
- Motor: AeroTech L1390
- 47 ft/s at 60 inches up the rail
- Max Mach 0.55
- Total weight: ~41 lbs
- Dual deployment



Rocket Fins

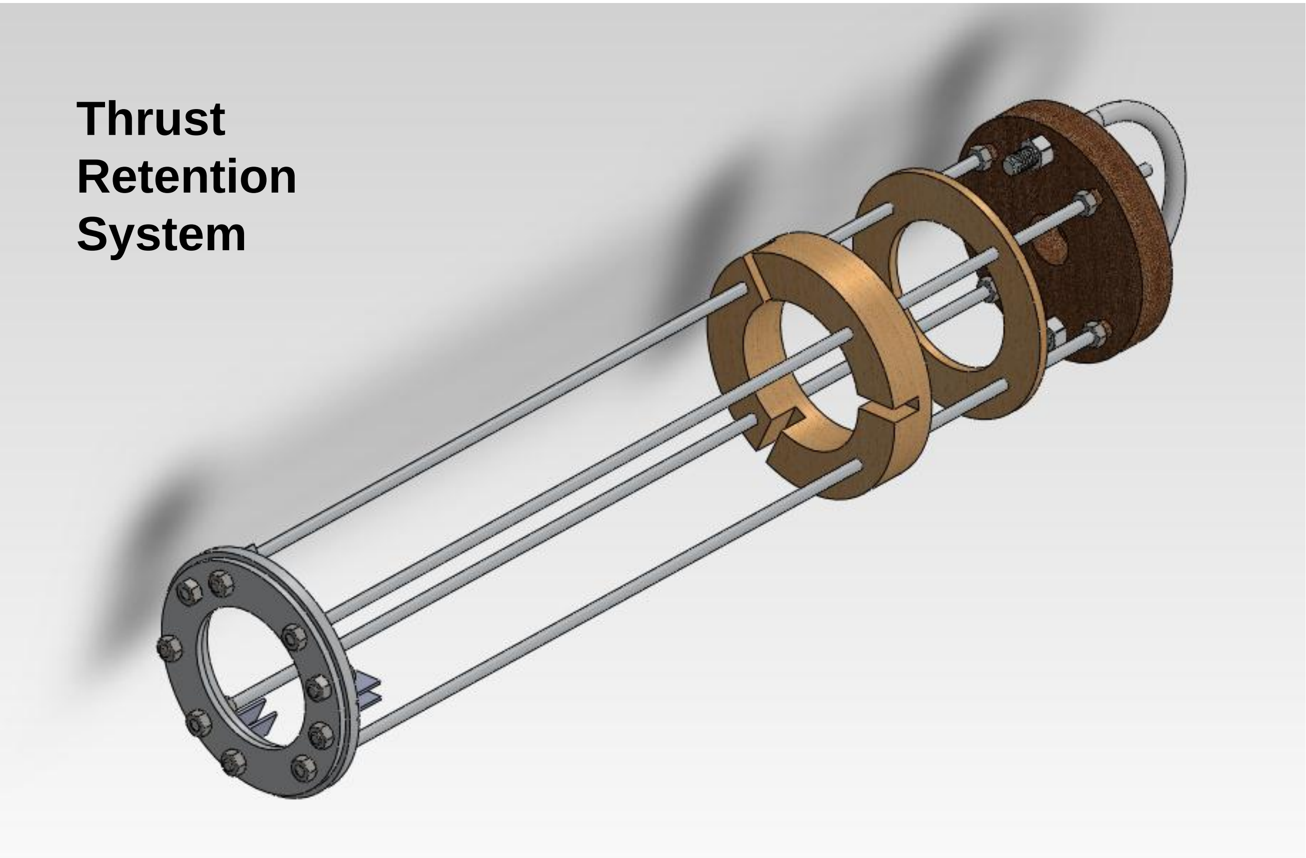
- Material: Carbon fiber honeycomb
- Attachment: Epoxy

Variable	Value
Number of fins	3
Root chord	15 in
Tip chord	3 in
Height	6 in
Sweep Angle	59.6°
Sweep Length	9.8 in

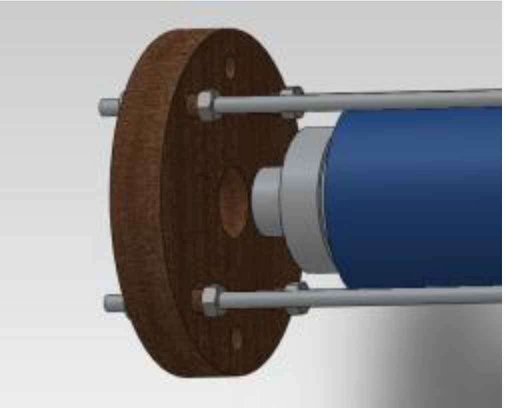


Booster Section

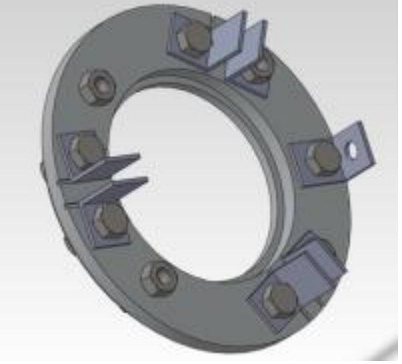
- Material: Aluminum and wood
- Attachment: Nuts, bolts, and epoxy



Thrust Plate

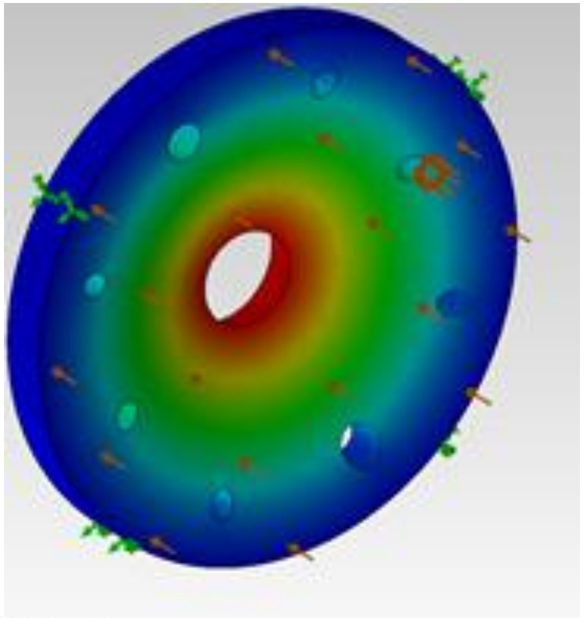


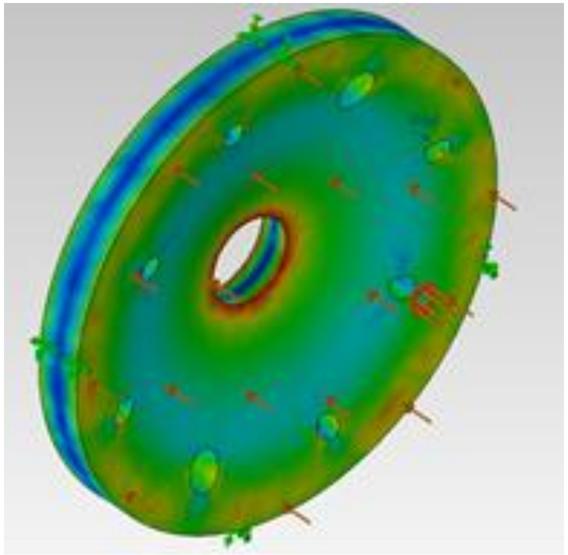
Retention Plate



FEA Analysis & Results

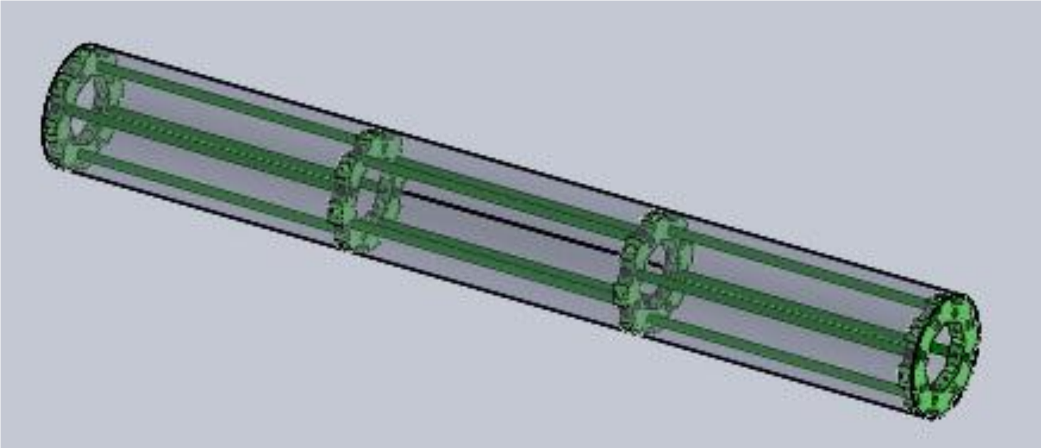
Part	Material	Force applied (lb_f)	Max displacement (inches)	Max stress (psi)	Safety factor
Thrust Plate	BS1088 Plywood	408	.00838	404.6	3.3
Stringers	AL 6061	408	.00526	483.3	2.9



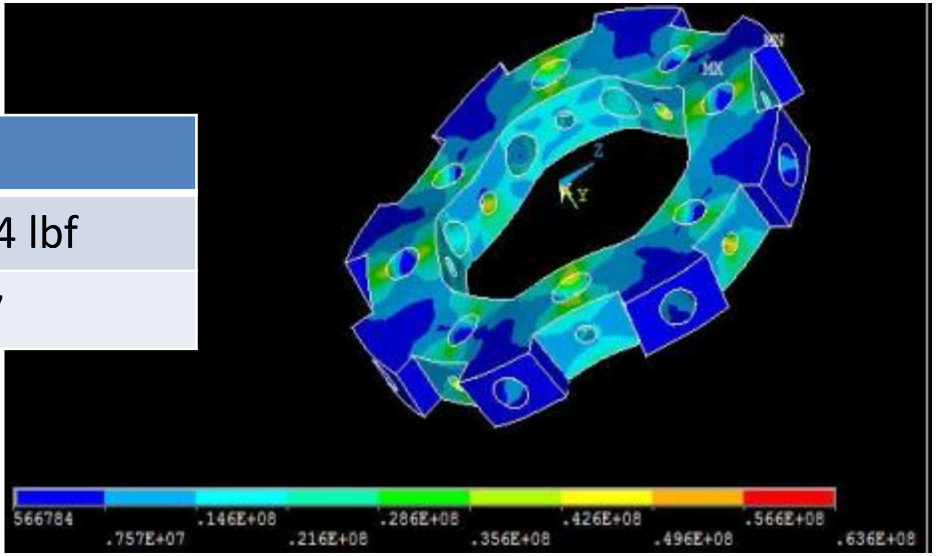


Integrated Modular Payload System (iMPS)

- Material: G10 Fiberglass, bolts

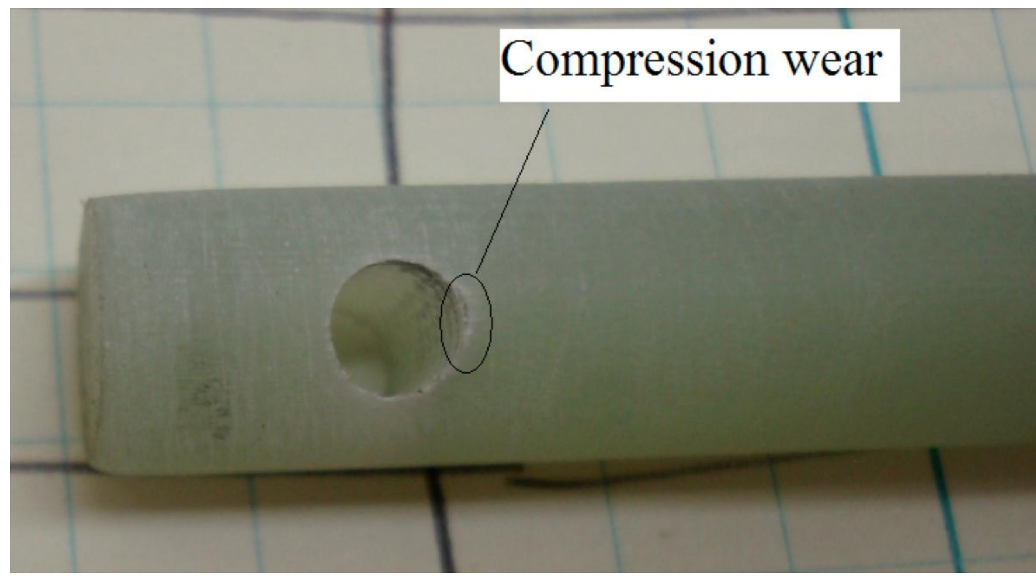


Rib FEA	
Load	684 lbf
FS	4.7

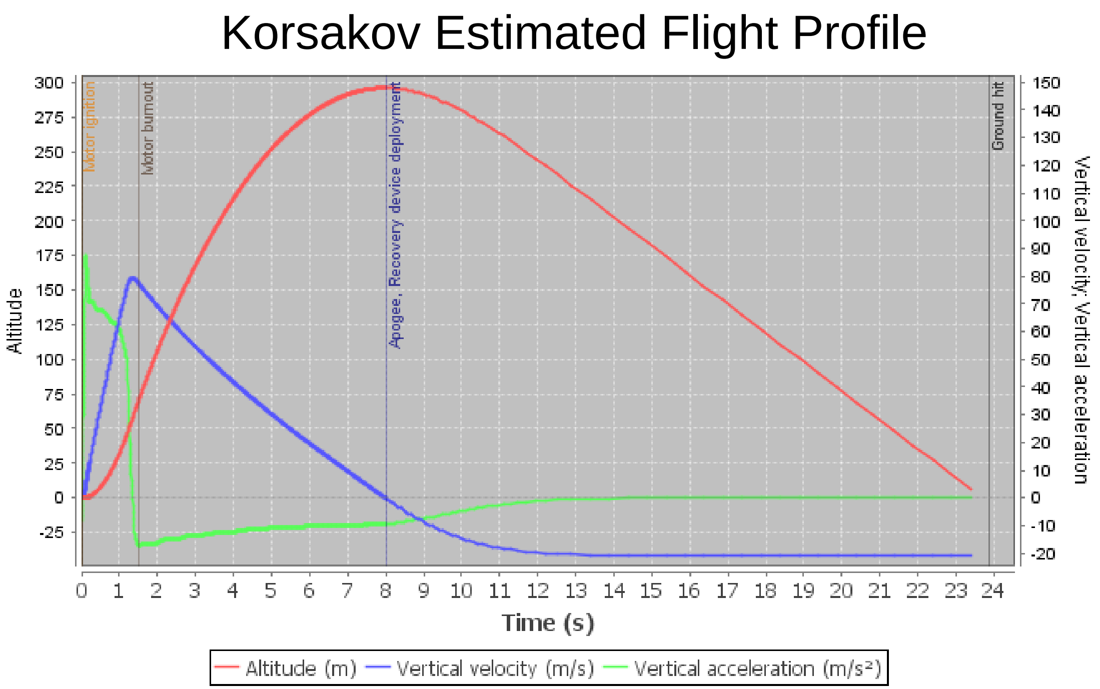


Payload Structure Impact Test

Impactor mass (kg)	Factor of Safety	Impact Energy (J)	Impactor Height (in)	Stringer length (in)	Notes
3.98	1	5.23	11.08	14	Pass
3.98	2	10.47	22.16	14	Pass
3.98	3	15.70	33.24	14	Pass



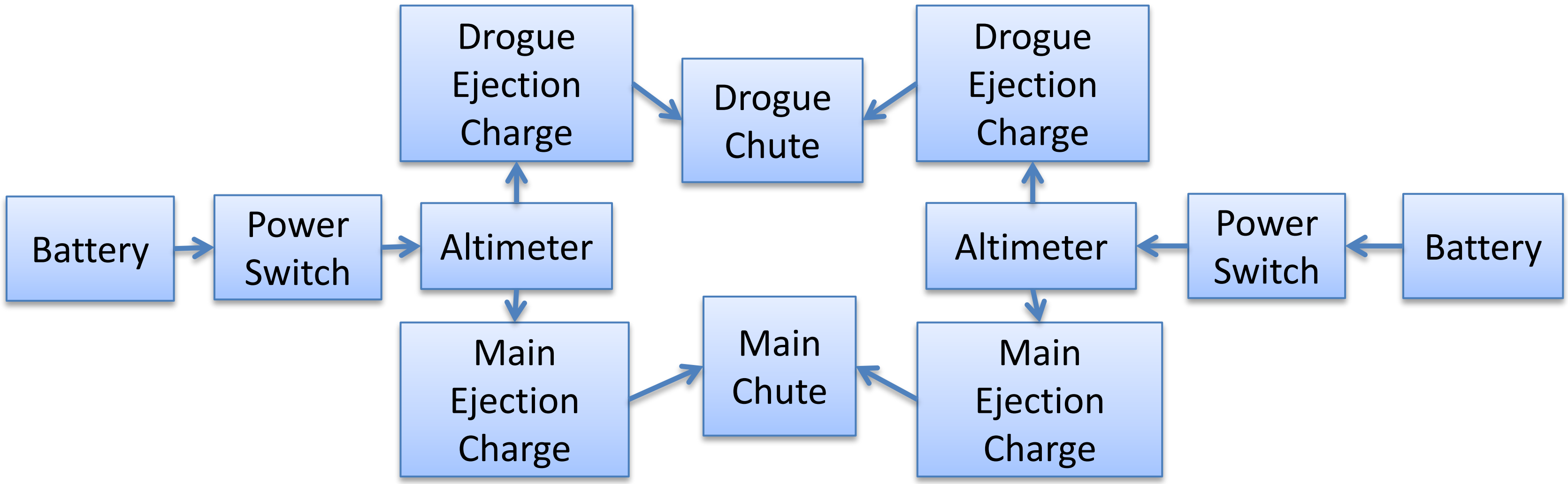
Skin – Test Vehicle, Korsakov



Recovery

- Dual deployment system
- Altimeter: 2 StratoLoggers for redundancy

	Mass (lbs)	Velocity (ft/sec)	KE (ft-lb)	KE Margin (ft-lb)	KE (joules)
Nose Cone	1.610	15	8.12	66.9	10.99
Booster Section	10.62	15	37.13	37.87	50.35
Payload Section	20.42	15	71.4	3.6	96.8

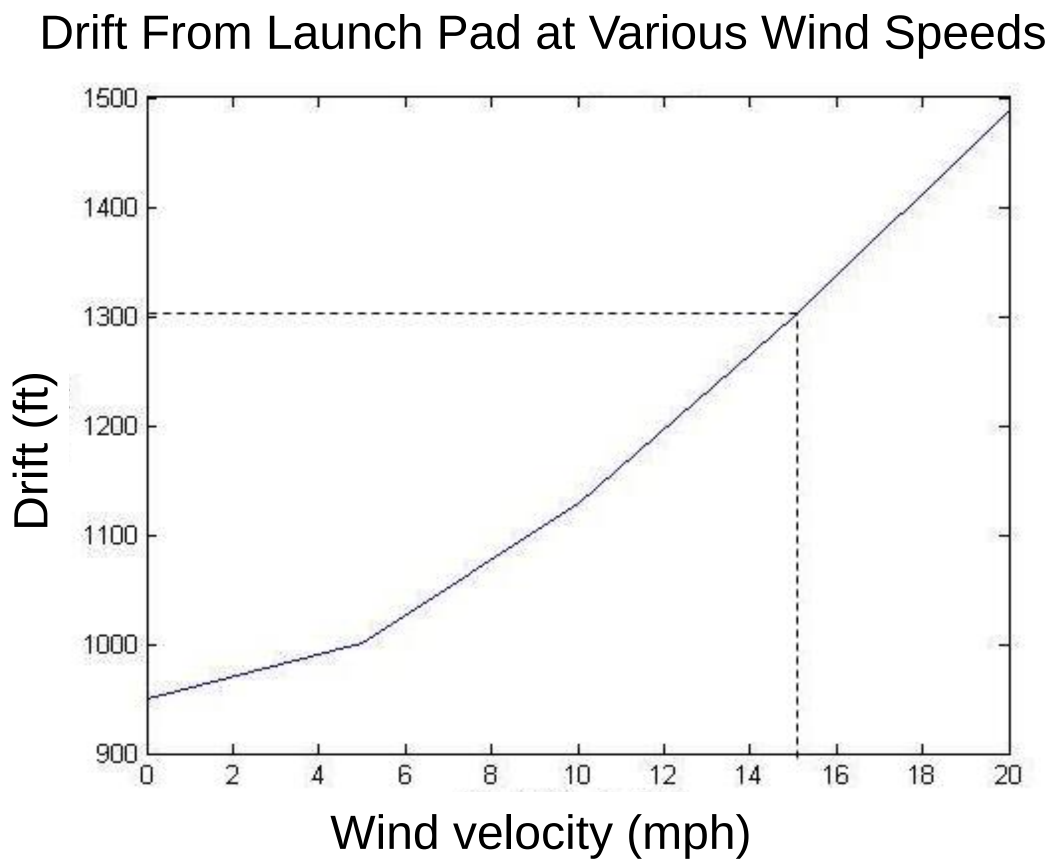


Ejection Charges

- Black powder ejection charges
- Ground testing will be performed prior to test flight

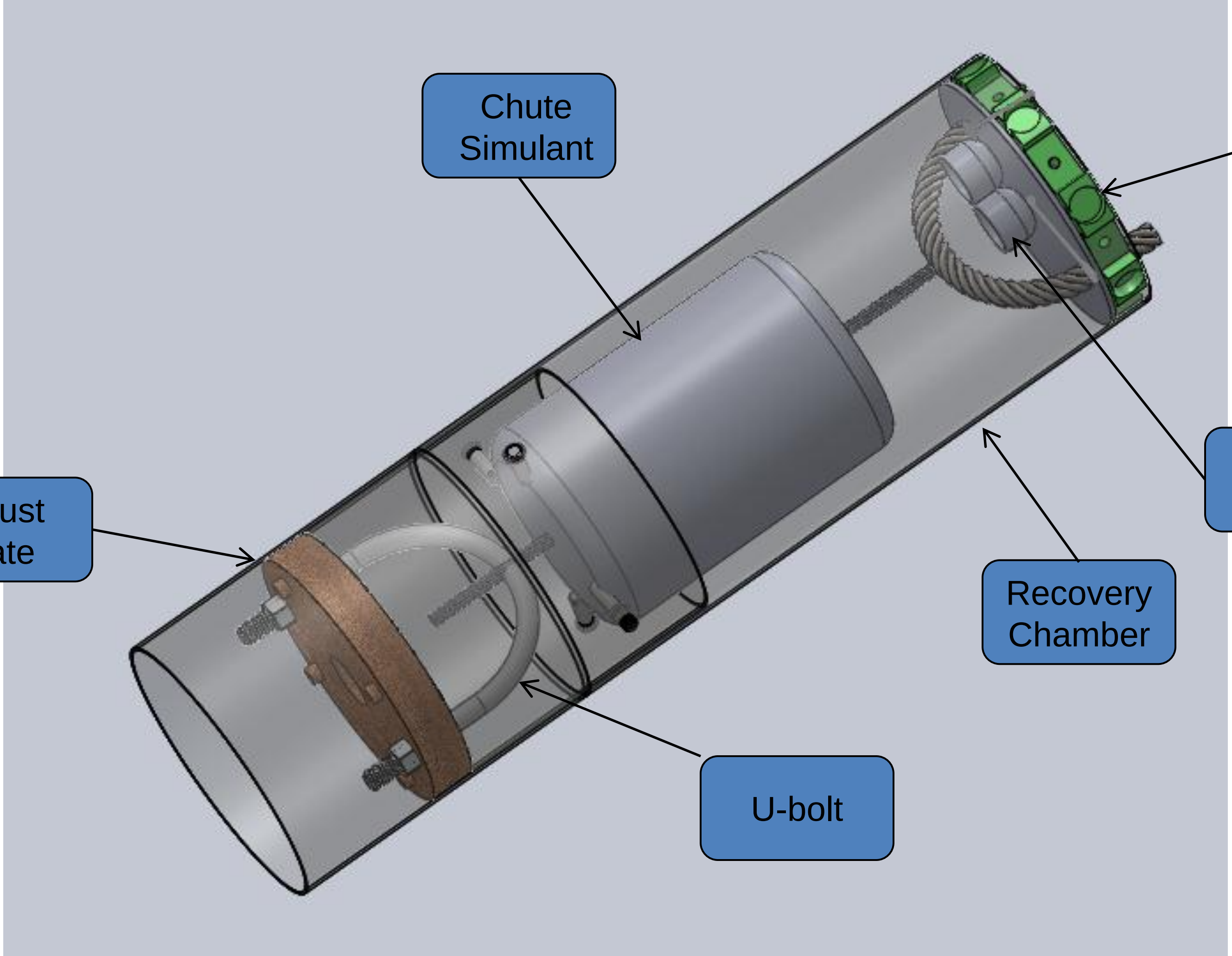
	Main Parachute	Drogue Parachute
Total Pressurization	24.7 psia	23.7 psia
Pressure at Deployment Altitude	14.4 psia	12.1 psia
Differential Pressurization	10.3 psi	11.6 psi
Ejection Force	202.2 lbf	227.8 lbf
Amount of black powder	4.5 grams	3.6 grams
Factor of Safety	1.26	1.42

Drift Profile

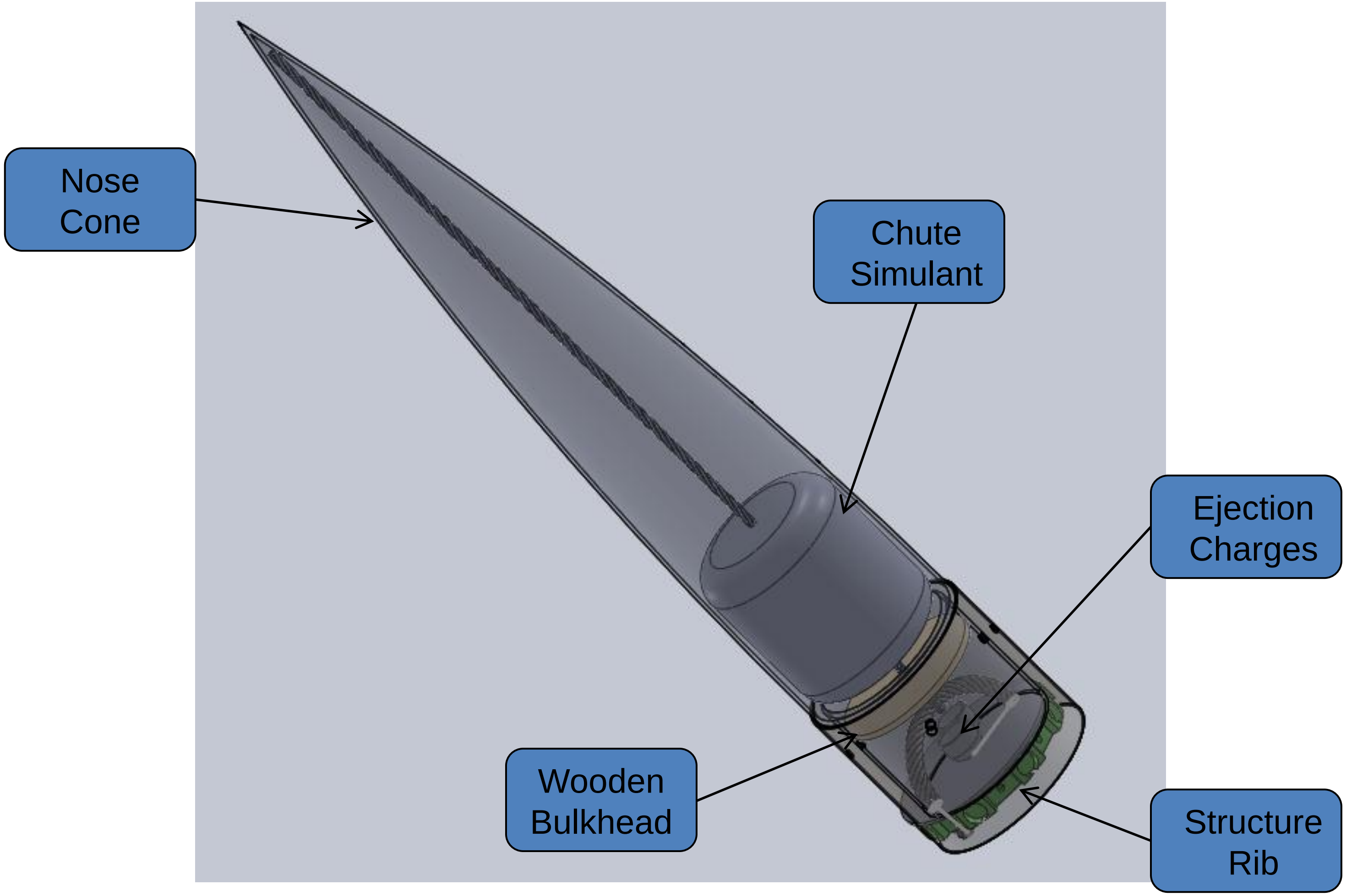


Test data point supporting accuracy of Recovery Calculations located in the back-up slides

Recovery – Main

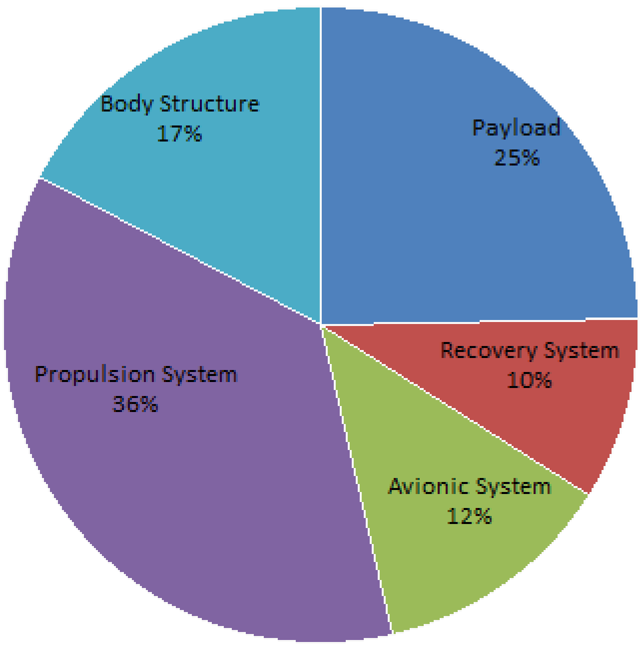


Recovery – Drogue



Mass Breakdown

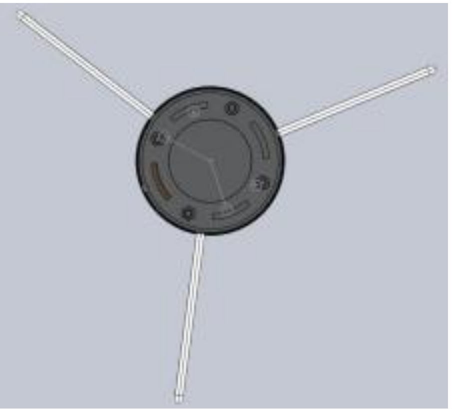
Component	Weight (lbs)
Nose Cone	1.6
Avionics System	5.0
Allotted Payload	10
Payload Structure	3.5
Recovery System	5.8
Booster Structure	6.2
AeroTech L1390 Motor	8.6
Total	**40.7**

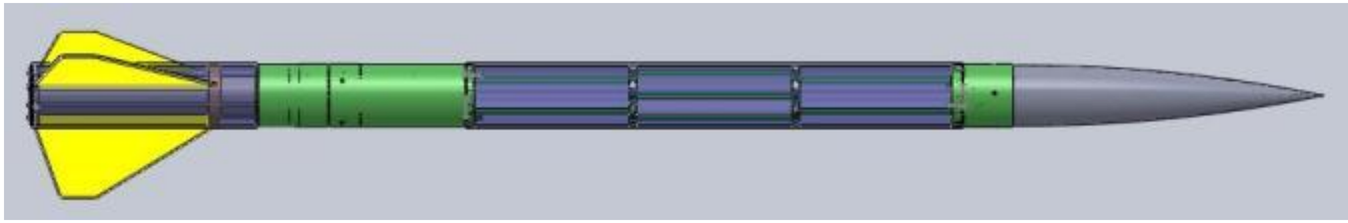


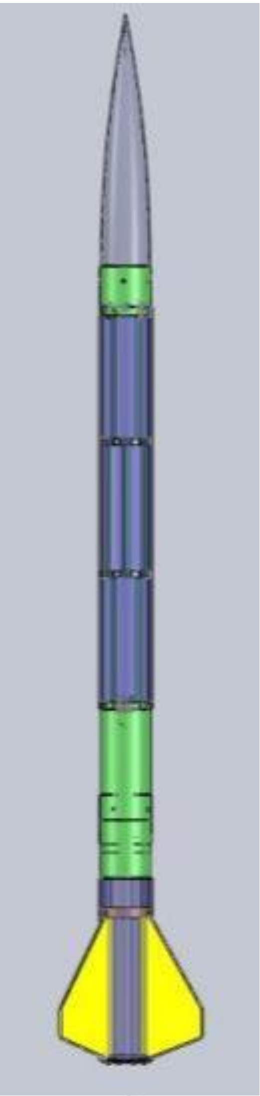
Motor Selection

Total Weight without Motor (lbs)	Total Weight with Motor (lbs)	Motor Required	Apogee (ft)
28	36.0	AeroTech L1150R-P	5242
30	38.0	AeroTech L850W-P	5253
32	40.0	AeroTech L1520T-PS	5170
32	40.5	AeroTech L1390G-P	5315
33	41.5	AeroTech L1390G-P	5259

Finished Product





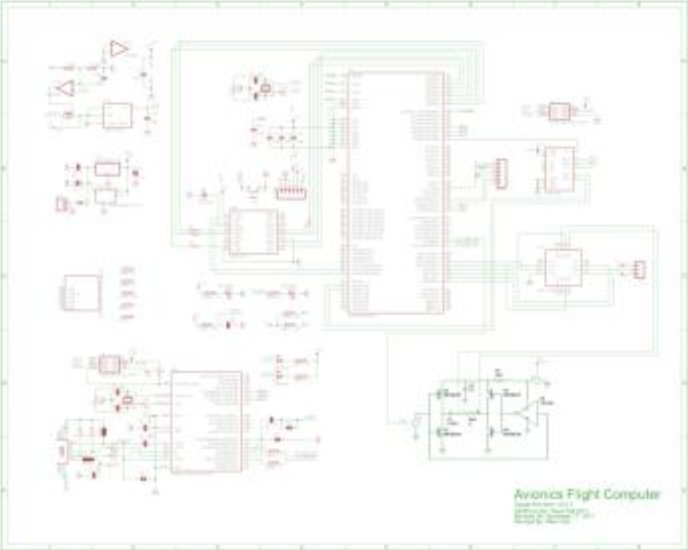


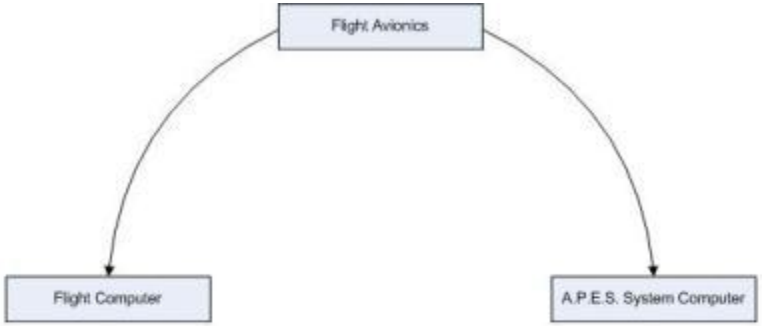
Project A.P.E.S. CDR

FLIGHT SYSTEMS

Flight Systems Responsibilities

- Payload
- Avionics
- Communications
- A.P.E.S. Ground Testing

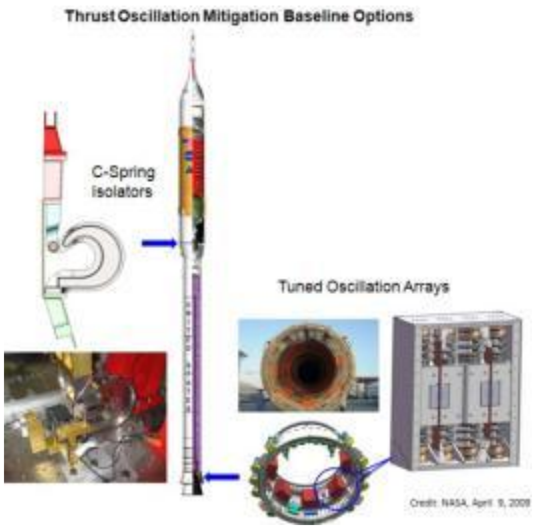




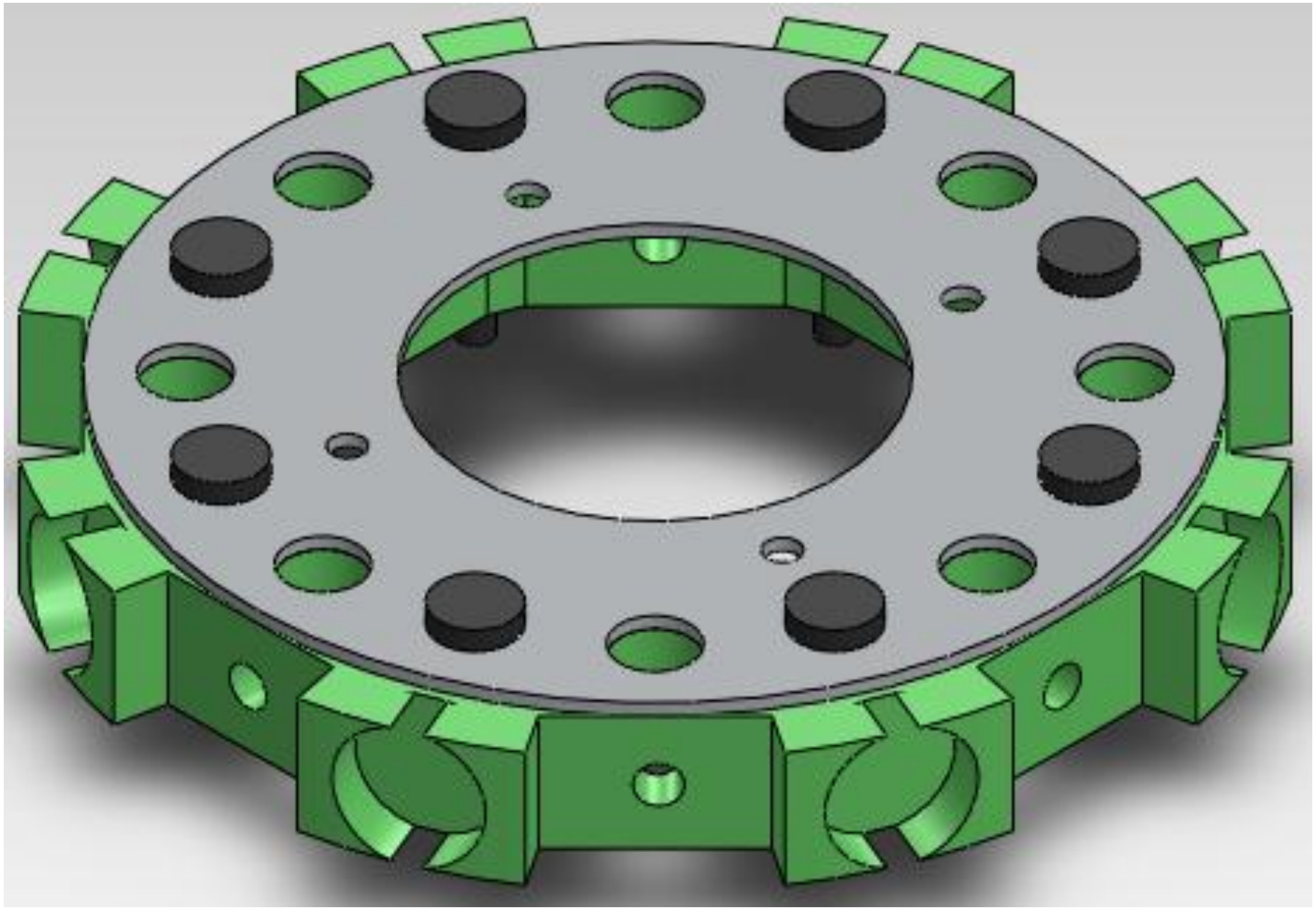
Flight Systems: Payload

- Current solutions to the problem of eliminating natural frequency oscillations
  - Mechanical C-Spring Isolators
  - Tuned Oscillation Arrays

- Use of advanced isolation components adds mass and design constraints

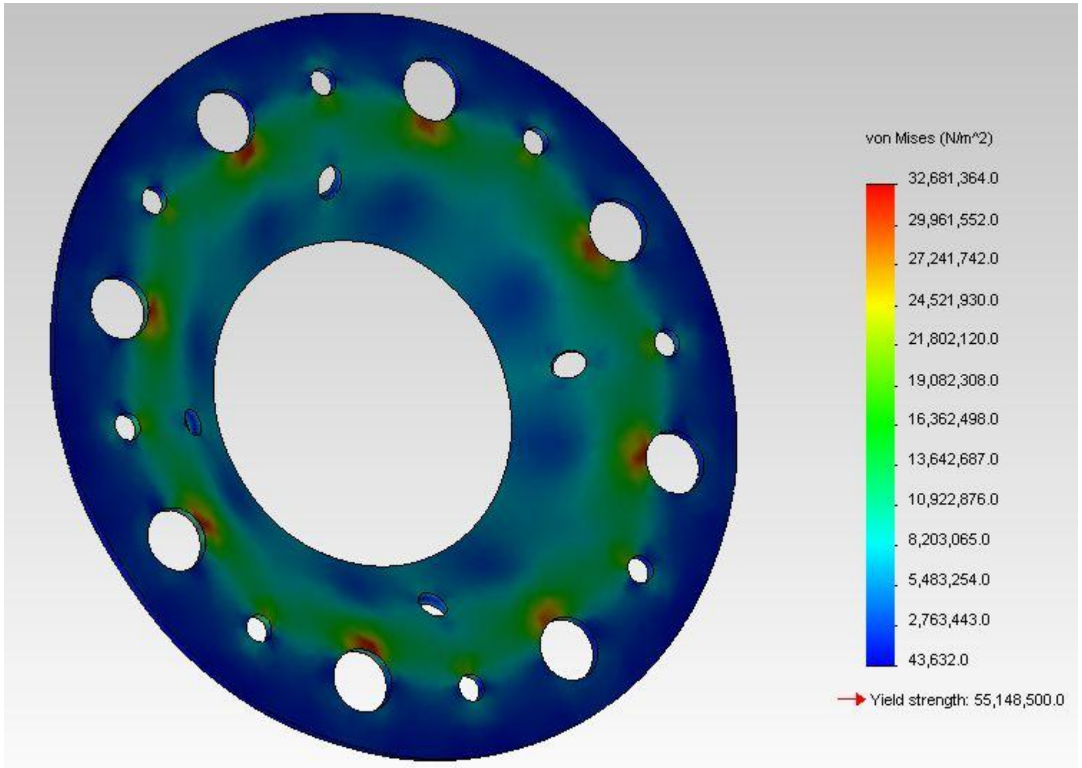


Flight Systems: Universal Mounting Bracket



Flight Systems: Universal Mounting Bracket

- Repeatable manufacturing
- Few constraints on Payloads
- Ease of mounting hardware
- High durability



**Deformation Exaggerated

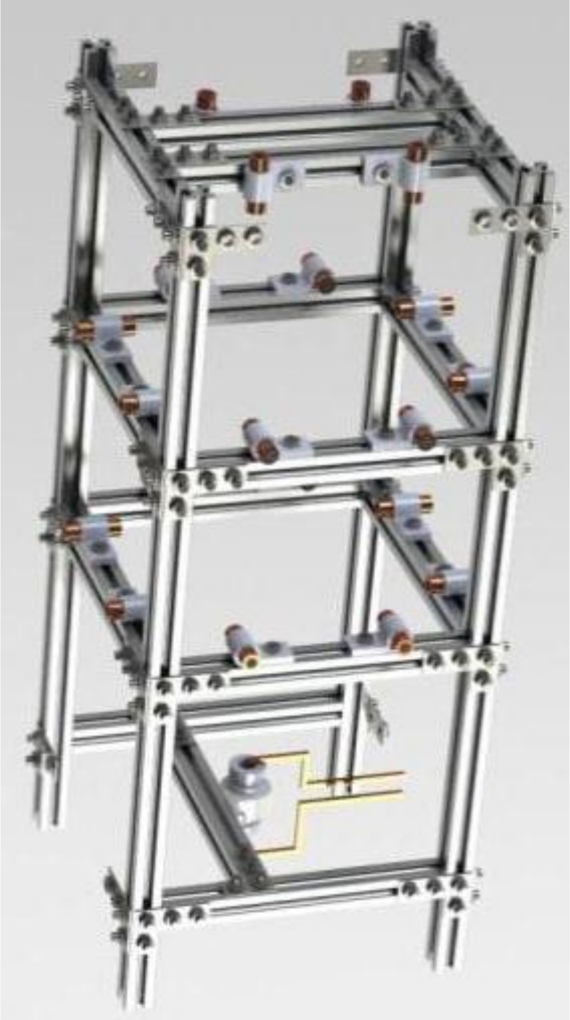
Flight Systems: Ground Test Plan

Goals:

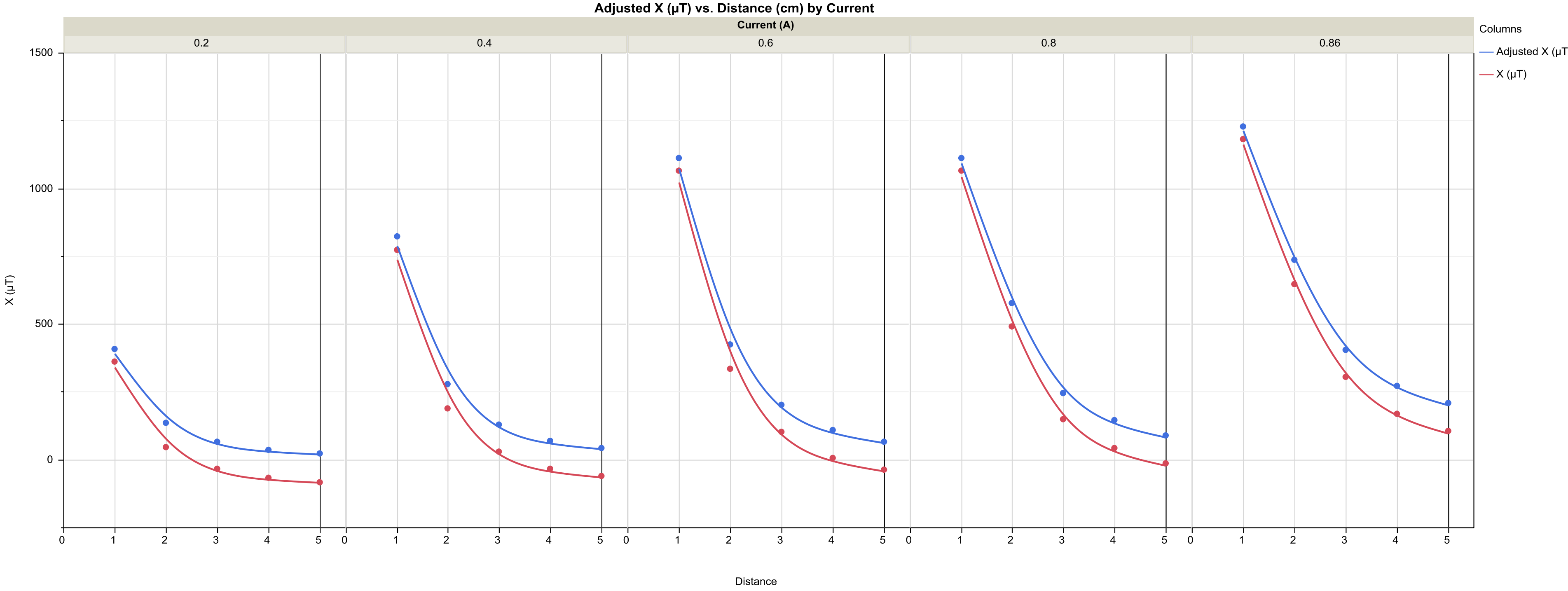
1. Develop Control Theories
2. Confirm Force Equations
3. Produce Flight Experiment

Ground Test Sequence

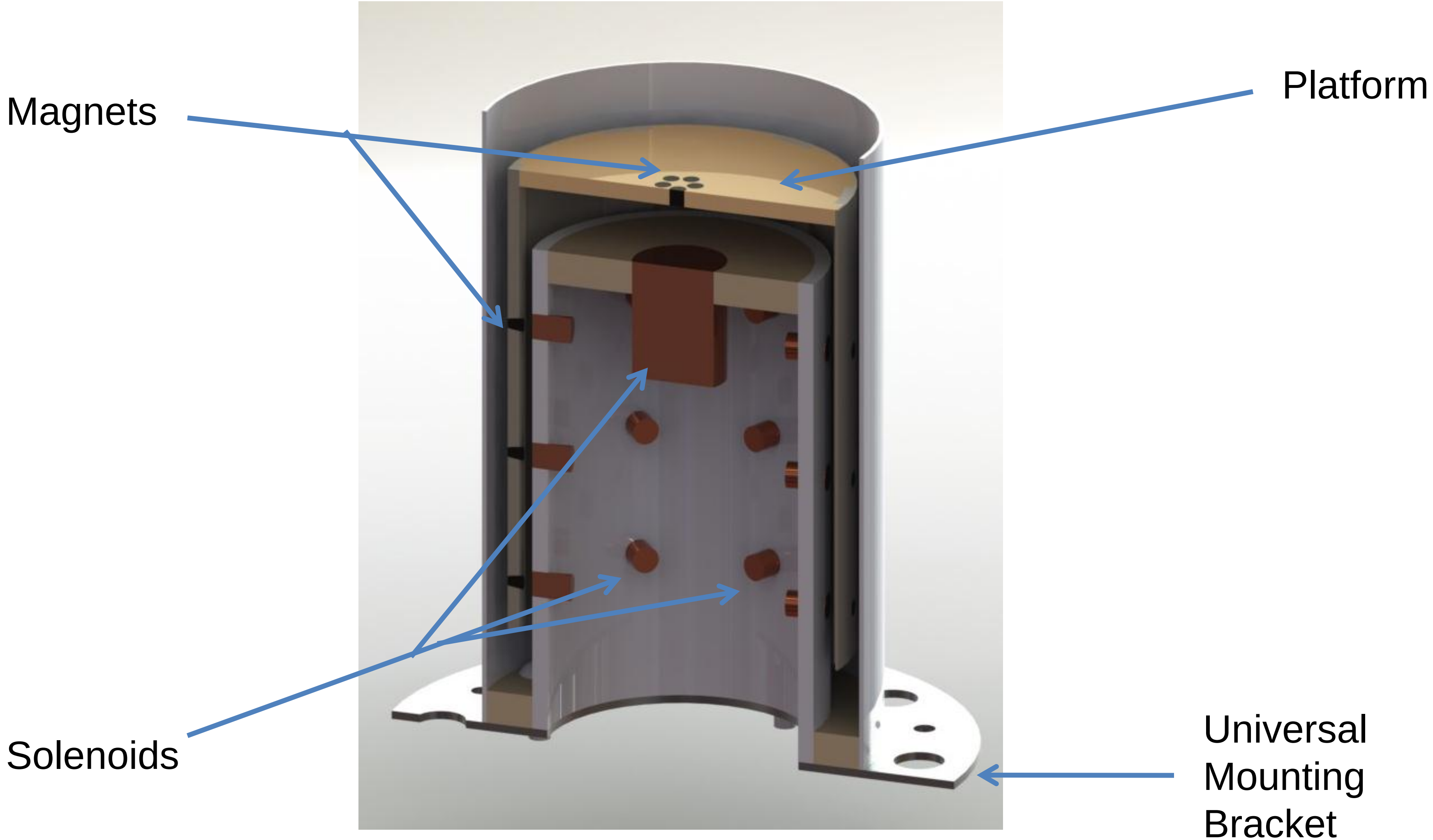
1. Sensor Calibration
2. 1-D Testing
3. 2-D Testing
4. 3-D Testing
5. Flight Model Test



Preliminary Solenoid Ground Testing



Flight Systems: A.P.E.S.

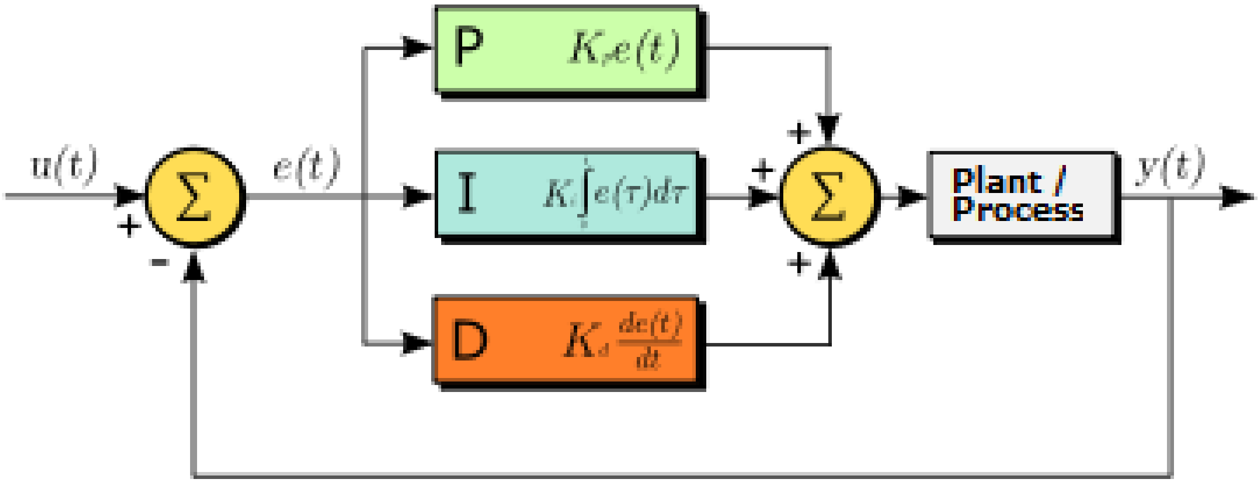


Project A.P.E.S. CDR

FLIGHT AVIONICS

A.P.E.S. Controller

PID Control System to be Implemented



Proportional-Integral-Derivative feedback loop

Set point: Platform in center of module

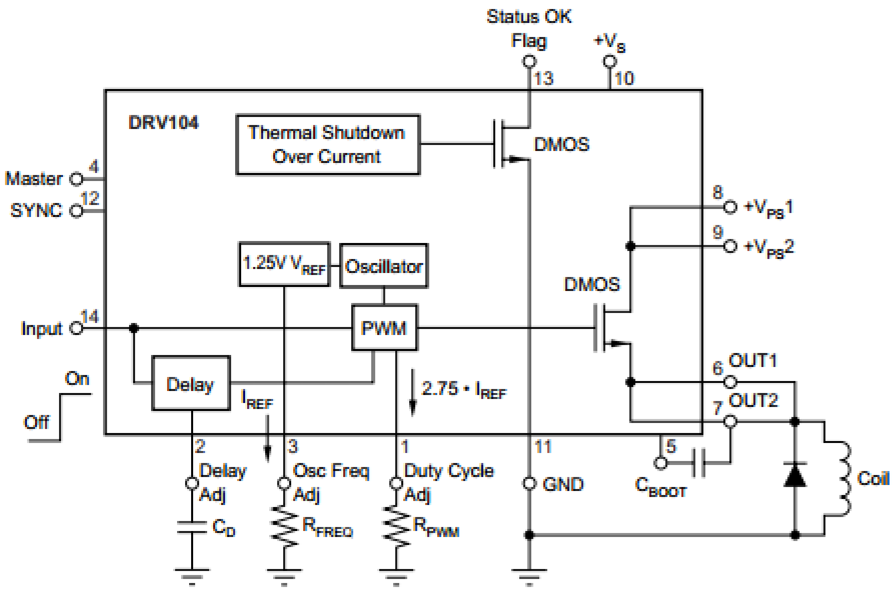
Error: Distance from Set point

Distance Detection

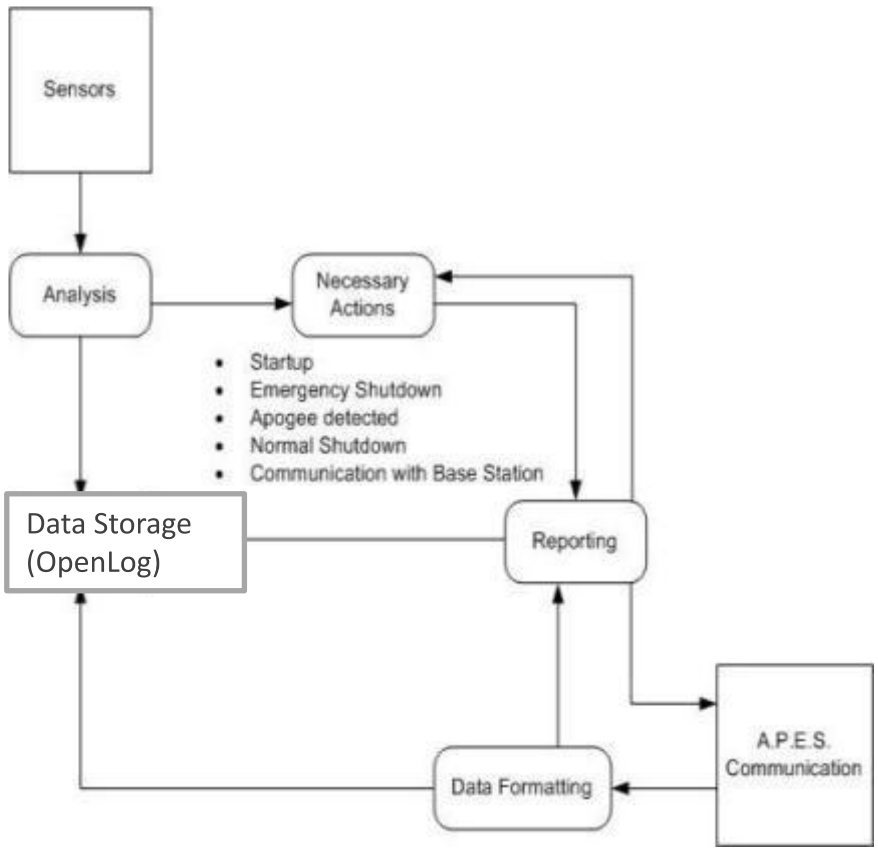
- Commercial Board
  - ARM Cortex M3 Processor
- Sensors:
  - 2x OVM7690 Camera Cubes
- Software:
  - OpenCV object tracking and distance estimation

Control

- 6x TI DRV104 Solenoid driver ICs
- 6x solenoids with ~300 turns of 30 gauge magnet wire



Flight Systems: Avionics



Custom flight computer board

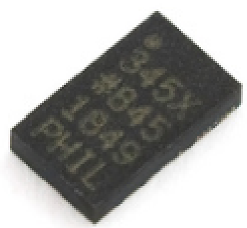
- ATmega 2560

- OpenLog

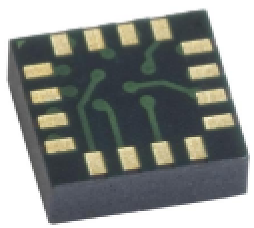
- Xbee Pro

- Sensors

Sensors Used



- ADXL345 Triple Axis Accelerometer
  - Logs orientation and acceleration
  - Data sent to A.P.E.S. controller and logged

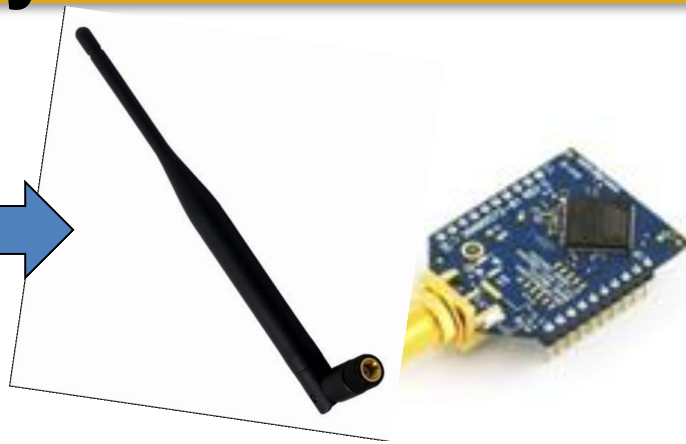


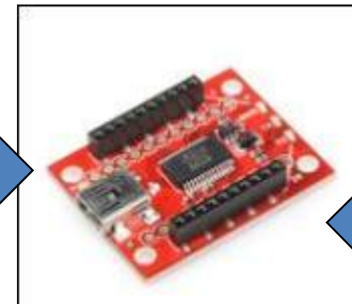
- HMC1043 3-Axis Magnetic Sensor
  - Magnetic field strength logging

- Fastrax UP501 GPS Module
  - Tracking data for logging and recovery

Flight Systems: Ground Station Comm

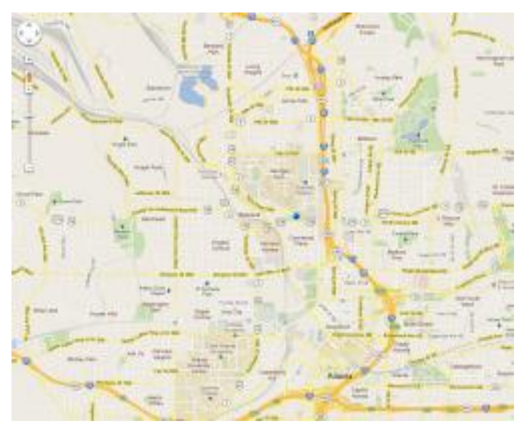
GPS Data





Xbee Explorer

- GPS Data will be received via Xbee pro
- Xbee Explorer will convert data packets
- Data sent to computer and displayed on map



BACK-UP

Team Summary

Team Summary	
School Name	Georgia Institute of Technology
Team Name	Mile High Yellow Jackets
Project Title	Active Platform Electromagnetic Stabilization (A.P.E.S.)
Launch vehicle Name	Vespula
Project Lead	Richard Z.
Safety Officer	Matt S.
Team Advisors	Dr. Eric Feron, Dr. Marilyn Wolf
NAR Section	Primary: Southern Area Launch vehicle (SoAR) #571 Secondary: GA Tech Ramblin' Launch vehicle Club #701
NAR Contact	Primary: Matthew Vildzius Secondary: Jorge Blanco

Georgia Tech Team Overview

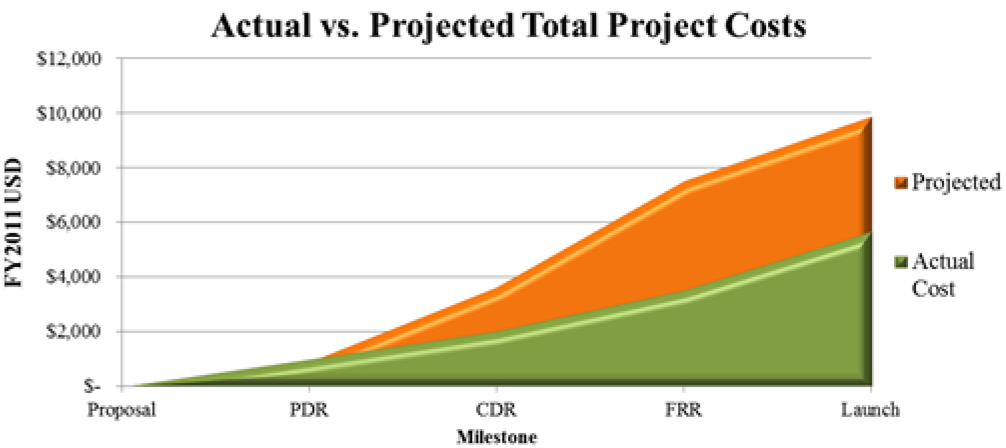
- 7 person team composed of both undergraduate and graduate students
  - Grad Students: 2
  - Undergraduates: 15

- Highly Integrated team across several disciplines

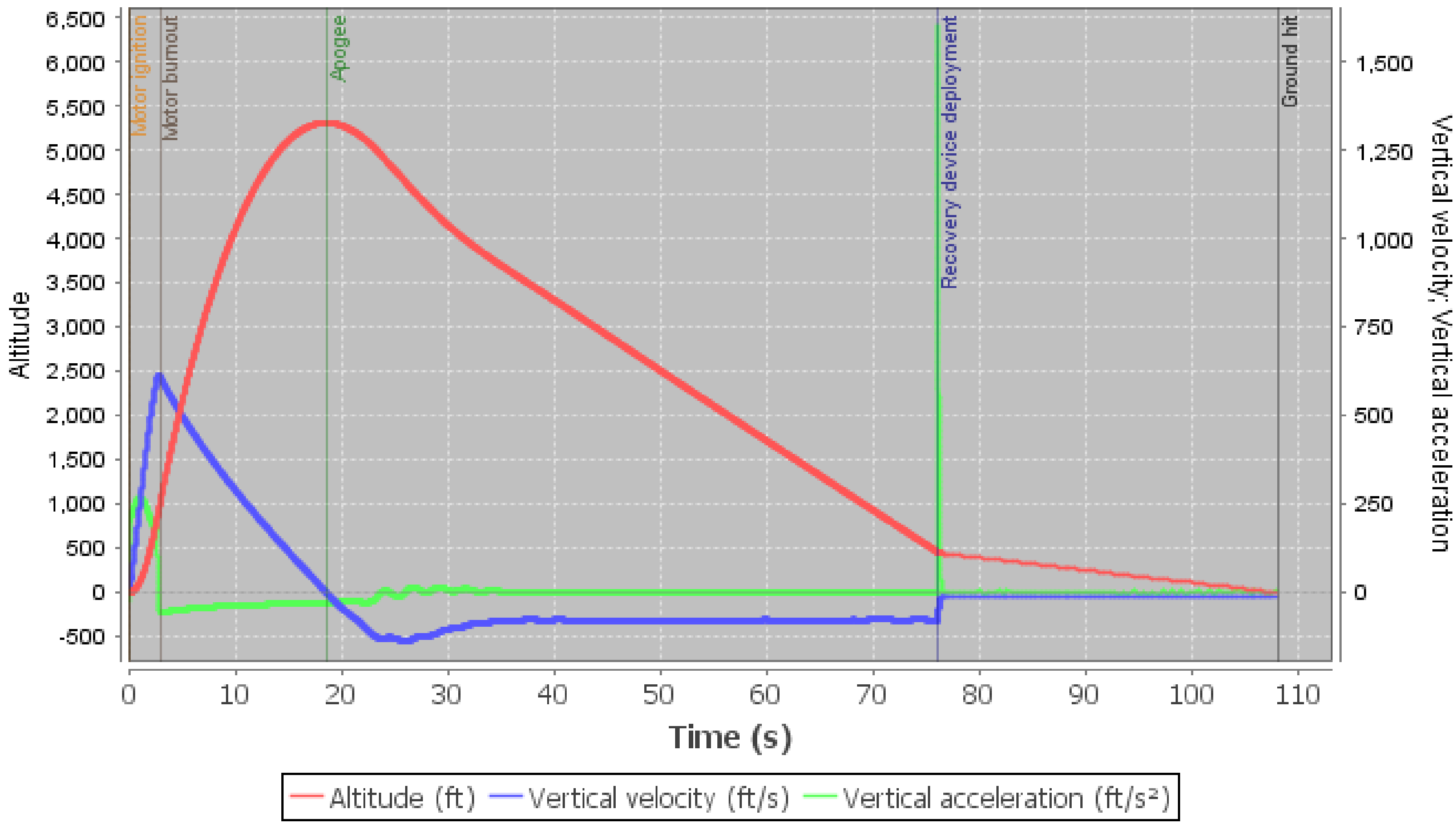
Field	No. of Students
Aerospace Engineering	9
Computer Science/ Computer Engineering	3
Electrical Engineering	6
Mathematics	1

Actual vs. Predicted Budget

	Predicted	*Actual*	*% Difference*
PDR	$ 924.53	$ 981.44	5.80%
CDR	$ 3,636.80	$ 2,032.62	-44.11%
FRR	$ 7,513.39	$ 3,532.62	-52.98%
Launch	$ 9,854.58	$ 5,657.62	-42.59%



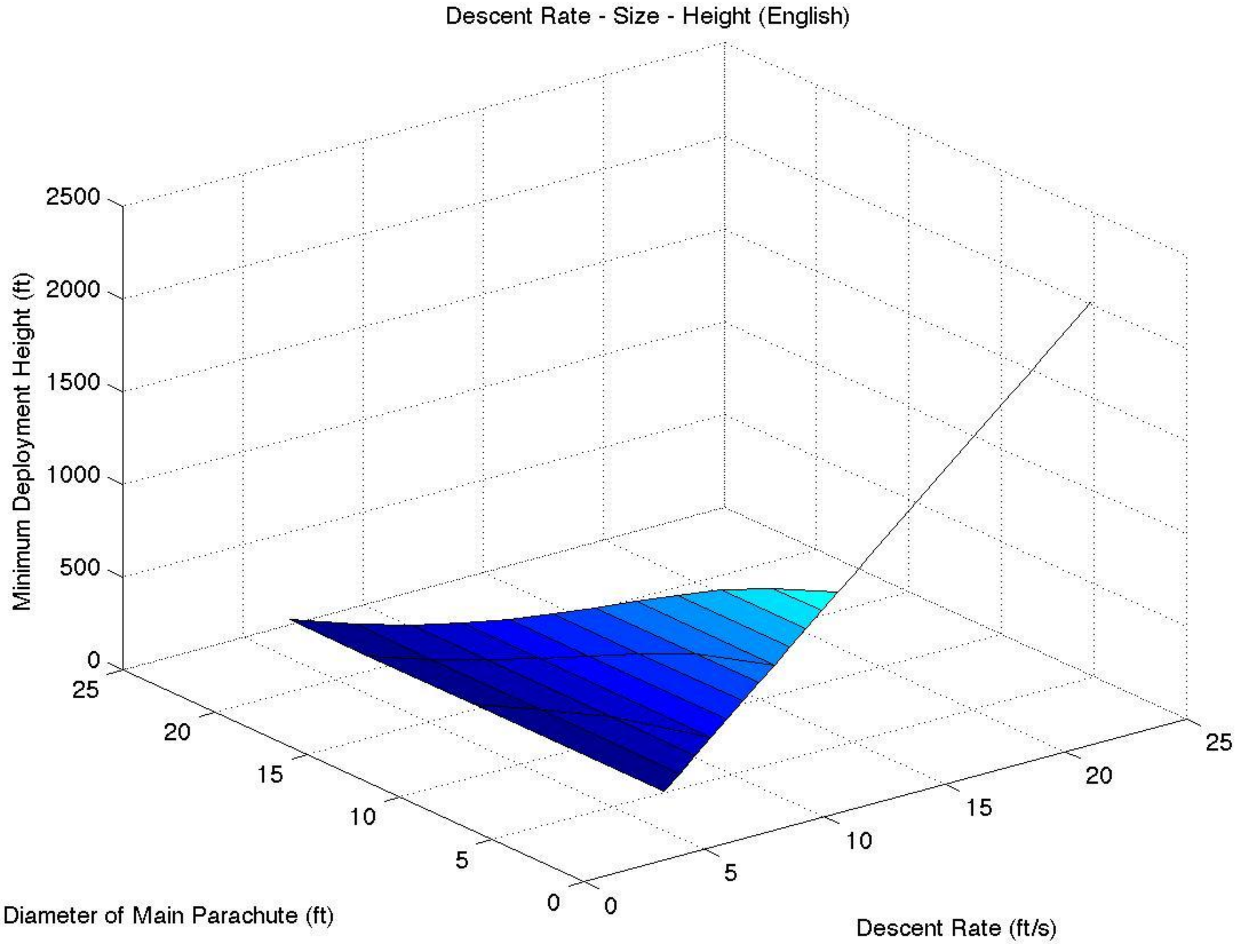
Backup Slide - Flight Profile



Backup - Payload Structure – Test Result

Fastener location	F.S. = 1	F.S. = 1.5	F.S. = 2	F.S. = 2.5	F.S. = 3
1	p	P	p	p	P
2	P	P	P	P	P
3	P	P	P	P	P
4	P	P	P	P	P
1A	P	P	P	P	X
2A	P	P	P	X	X
3A	P	P	P	X	X
4A	P	P	P	P	P
5	P	P	P	P	P
6	P	P	P	P	P
7	P	P	P	P	P
8	P	p	P	P	P

Backup Slide – Recovery Calculations



Backup Slide – Recovery Calculations

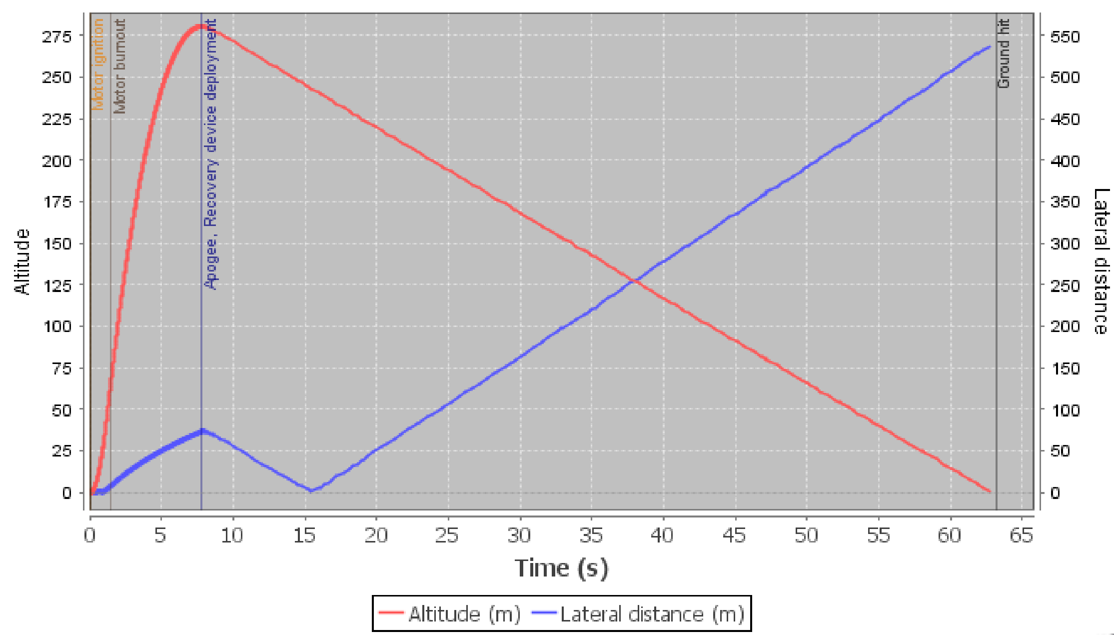
Black Powder Equation: $$W = \frac{V\Delta P}{RT} \quad (1)$$

Variable	*Description*	*Units*
W	Weight of the black powder in pound mass	$454 \cdot W_{gram}$
V	Volume of the container to be pressurized	in^3
ΔP	Pressure Differential	psia
R	Gas Combustion Constant for black powder	$\frac{22.16 f \, t lb_f}{lb_m \cdot R}$
T	Gas Combustion Temperature	3307 °R

$$F_{pin} = \frac{\sigma \pi d^2}{4}$$

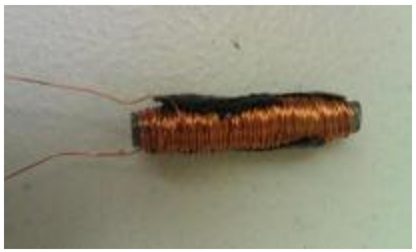
- Volume to be pressurized accounts for the parachute packaging
- Pressure calculated at deployment height for each parachute

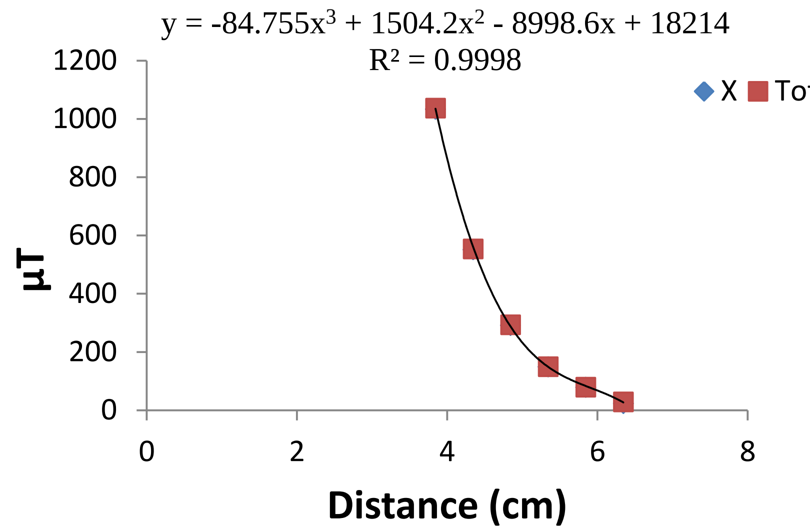
Backup Slide - Korsakov Drift



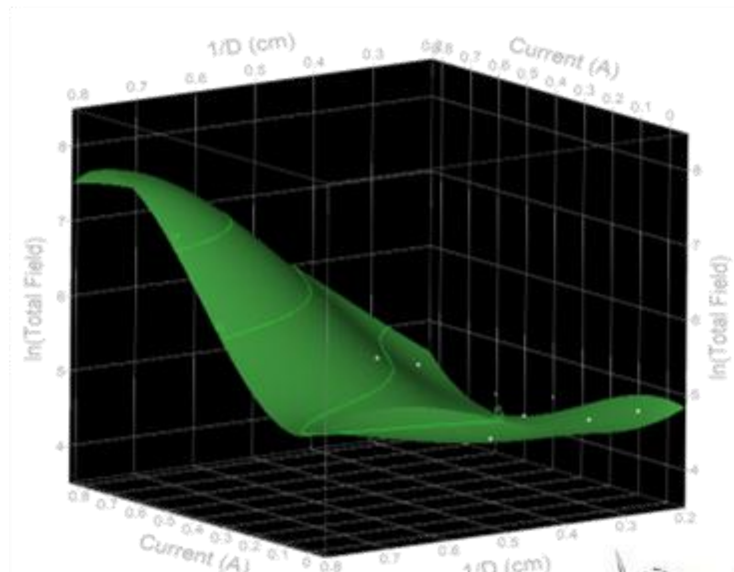
Detailed Ground Testing Results

Initial Steady-State DC Ground Testing of Solenoid

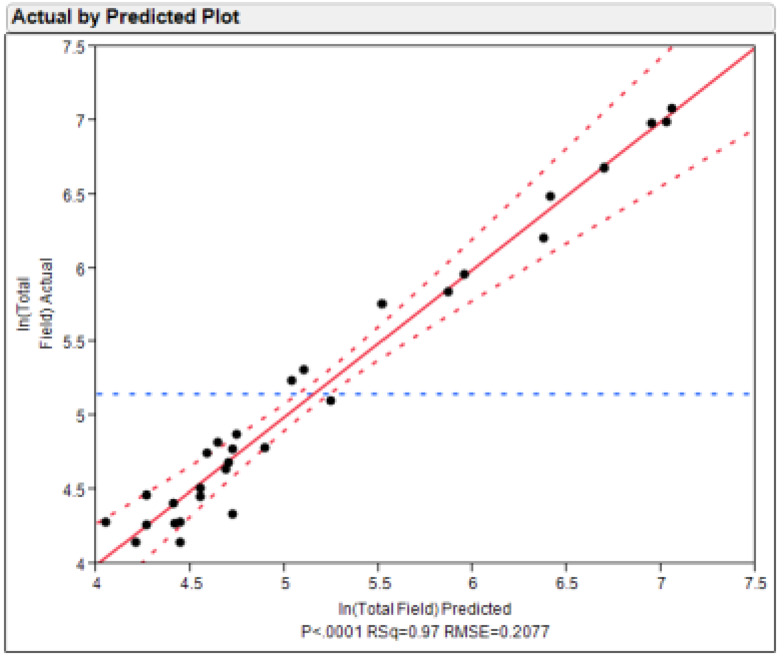


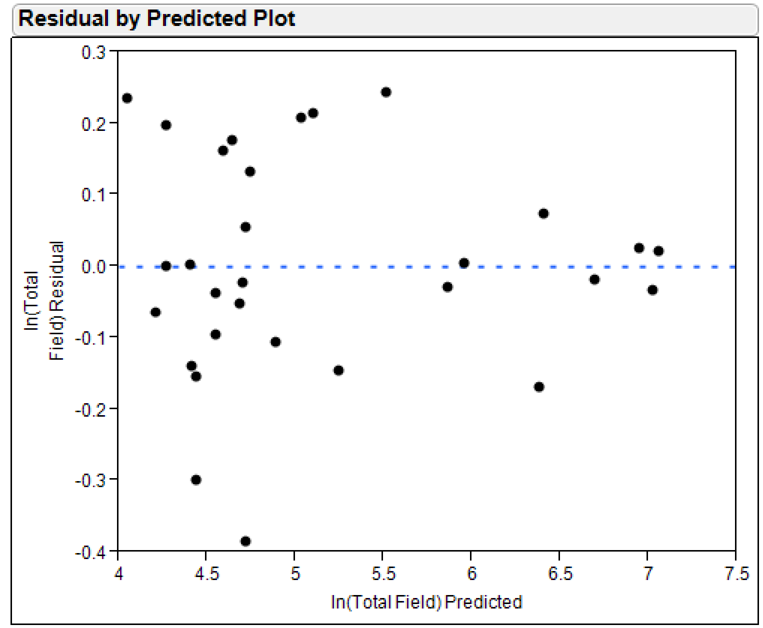


Characteristic	Value
Turns	300
Resistance	2.6 Ω
Wire Gauge	30
Field Strength @ 0.86A	1100 µT

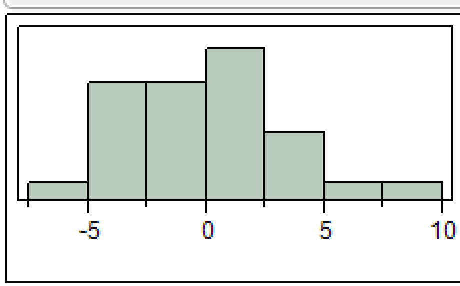


Response Surface: Goodness of Fit





LN Transform Error



Moments

Mean	0.1041408
Std Dev	3.319957
Std Err Mean	0.6061385
Upper 95% Mean	1.3438332
Lower 95% Mean	-1.135551
N	30

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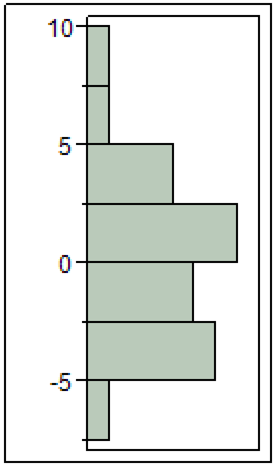
Alternative Response Surface Fits

Distributions

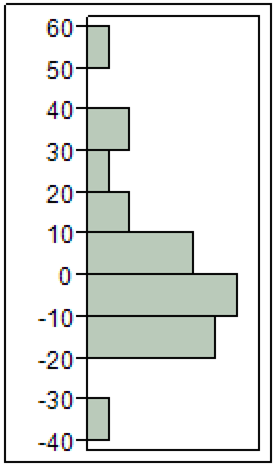
LN Transform Error



Moments

Mean	0.1998487
Std Dev	3.5400164
Std Err Mean	0.7080033
Upper 95% Mean	1.6610957
Lower 95% Mean	-1.261398
N	25

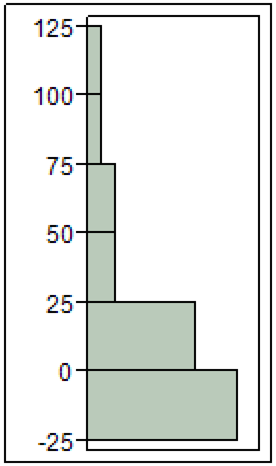
Response Surface Error



Moments

Mean	3.1188285
Std Dev	19.702498
Std Err Mean	3.9404996
Upper 95% Mean	11.25162
Lower 95% Mean	-5.013963
N	25

Neural Error



Moments

Mean	13.72578
Std Dev	32.454862
Std Err Mean	6.4909725
Upper 95% Mean	27.122489
Lower 95% Mean	0.3290711
N	25

Flight Systems: Science

- Interaction of magnetics fields and permanently magnetic or ferromagnetic substances
- For ferromagnetic substance:

$$\mathbf{F}(\mathbf{r},\mathbf{m}_s,\mathbf{m}) = \frac{3VN^2I^2S^2\mu\chi_m}{16\pi^2r^7}[(\hat{\mathbf{n}}\cdot\hat{\mathbf{r}})\hat{\mathbf{n}} - \hat{\mathbf{r}} - 4(\hat{\mathbf{n}}\cdot\hat{\mathbf{r}})^2\hat{\mathbf{r}}]$$

- For permanently magnetic substance:

$$\mathbf{F}(\mathbf{r},\mathbf{m}_s,\mathbf{m}) = \frac{3VNIS\mu_0}{4\pi r^4}[(\hat{\mathbf{n}}\cdot\hat{\mathbf{r}})\mathbf{M} + (\mathbf{M}\cdot\hat{\mathbf{r}})\hat{\mathbf{n}} + (\hat{\mathbf{n}}\cdot\mathbf{M})\hat{\mathbf{r}} - 5(\hat{\mathbf{n}}\cdot\hat{\mathbf{r}})(\mathbf{M}\cdot\hat{\mathbf{r}})\hat{\mathbf{r}}]$$

Flight Avionics Schematic