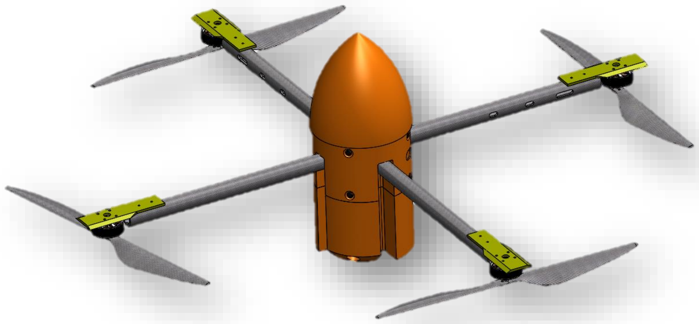
Argonia Cup Senior Capstone Competition
Final Presentation

OSU Rocket Squad
School of Mechanical and Aerospace Engineering
Oklahoma State University

May 2, 2018



ROCKET SQUAD


Nick Foster


Lucas Utley


Andrew Walsh


Ben Kadavy


Logan Kunka


Chad Kenkel


Jake Rosario


Caleb Ritchie


Gerald McCullers


Nicolas George

Argonia Cup Mission

The goal for the 2018 Argonia Cup competition is to launch a rocket powered vehicle containing a golf ball payload to an altitude in excess of 8,000’ AGL and to recover the payload safely at a predetermined location on the rocket range.

Requirements and Objectives

Team Goal

Win the Argonia Cup

Requirements

1. Launch to +8,000ft
2. Carry golf ball payload
3. 5:1 Thrust to weight ratio
4. 1 body caliber CP/CG stability
5. Below 300’ travel less than 30 fps
6. Re-flyable condition
7. Max of L motor
8. Safe (Does not pose risk to life/property)
9. $5k budget

Objectives

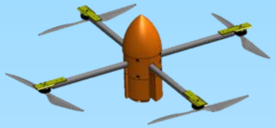
1. Land payload at a predetermined location
2. Fully autonomous recovery system
3. Low cost (fits in budget)
4. Multiple systems
5. Robust recovery system (operates within launching conditions)

ConOps

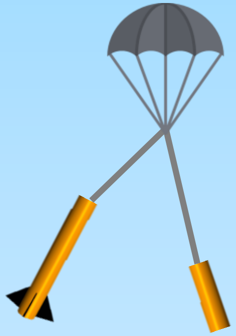
Minimum 8,000’ AGL

2) Apogee (+8,000’)
- Quad deployment
- Drogue chute deployment

3) Descent
- Quadcopter engages at 8,000’
- Rocket descends under drogue



Overall Mission
Launch to 8,000 feet
Return a golf ball as close to the target as possible



4) Rocket
- Main parachute deploys at 1,000’
- Rocket lands safely

1) Launched Pad
- System connected to ground control station
  - *In-situ telemetry data*
- Autopilot active at launch
  - *Pre-programmed on board flight path waiting for appropriate deployment sequence*

5) Quadcopter Executes Mission
- Autonomous flight
  - *Lands on designated target*

Structures Team

- Build SRAD fiberglass parts
  - Tubes: airframes, couplers, motor mount tubes, pistons
  - Sheets: CNC cut to produce fins, centering rings, bulkplates, quad motor mounts
- Build rockets and ejection charge test
- Handle recovery and recovery electronics
- Manage general launch operations

Everything Is Sticky

- Purpose: prototype to verify fiberglass parts will withstand flight stresses:
  - Motor boost, coast, parachute ejection, parachute deployment, touchdown
- Flew on February 17, 2018 on an I357T
- Used for demo flight during Speedfest on an I500T
  - One fin became loose during touchdown

Everything Is Slippery

- Purpose: first iteration of our competition-ready rocket
  - Verified our design would reach above 8000’ of altitude on the identical motor used in competition
  - Confirmed our parts would withstand the stresses from the actual competition flight
- Flew on March 11, 2018 on an L1500T
  - Reached 10,222 ft AGL
  - Unsuccessful ejection at apogee
  - Nominal main deployment at 1200 ft AGL
  - No structural damage – confirmed our fiberglass parts were adequate
- Used for extensive ejection charge testing
  - Difficulties with piston-cylinder ejection, and this rocket was the test article
  - Used in CapEx testing

The Other Things

- Purpose: second and final iteration of our competition rocket
  - Nearly identical dimensions to *Everything Is Slippery*
  - Longer build time ensured it was even stronger
  - New fiberglass cloth used that made it heavier, but even more sturdy
- Flew on April 8, 2018 on an L1500T
  - Reached 8,556 ft AGL
  - Successful ejection at apogee
  - Main deployment far above 1200 ft AGL, not sure why
  - No structural damage

Fiberglass Tube Process

- Purpose: To provide a launch vehicle that is both strong and lightweight
- Process:
  - Use 5” steel casting mandrel from McMaster-Carr
  - Properly lubricate mandrel with two layers of wax paper, petroleum jelly, and non-stick spray.
  - Tightly wrap 6 layers of fiberglass around mandrel, leave for at least 45 minutes to cure
  - Resin is added progressively during the wrapping process
- Results
  - Successfully made 48” airframe sections
  - The airframe sections were proven under static load testing, ejection charge testing and ultimately flight proven with all of our rockets
  - Some tubes were cut away from mandrel due to improper lubrication techniques
  - Saved approximately $500 by making our own tubes and sheets

Fiberglass Sheet Process

- Purpose: Provide material to cut fins and centering rings
- Process:
  - Sheets made in 1 square foot sections
  - Pressed between two commercial fiberglass sheets
  - 12 layers used for fins, 8 layers for centering rings.
  - Resin was poured and spread between each layer
  - 1 square foot required about 12 oz of resin
  - Sheets cut down to size with table saw then shapes cut with CNC machine
- Result:
  - Fins and centering rings very sturdy, survived launch and recovery with no damage on our first prototype *Everything is Sticky*
  - Possibly could have been made lighter however this was not a major concern since tubes were much lighter than expected

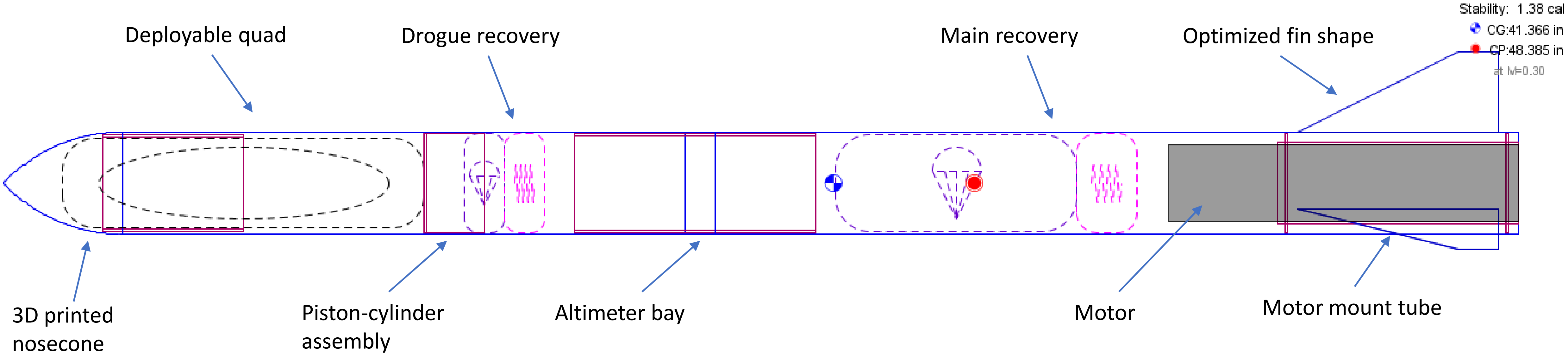
Fiberglass Coupler Fabrication

- Purpose: To provide a way to connect different sections safely
- Process:
  - Use a 3D printed mandrel to cast upon based upon previous tube thicknesses
  - Properly lubricate mandrel with wax paper and petroleum jelly
  - First iteration for electronics bay used 6 wraps of fiberglass
  - Second iteration for piston used 5 wraps of fiberglass
  - Made in 12” long sections that were trimmed for desired purpose
- Results
  - Successful electronics bay and piston were constructed
  - Both were ejection tested and flight proven to work for needed applications
  - Manufacturing process could be by having tighter tolerance but sanding also is a reasonable solution to this

Ejection Charge Testing

- Ground-testing to confirm intended parts of the rocket separate properly
- Especially critical on larger rockets where shear pins are used
  - Also essential for ejecting our quad payload
- Piston-cylinder ejection was used to deploy the quad and drogue parachute
- Tubes withstood internal pressures of 18+ PSI and dozens of firings

Argonia Cup Launch Vehicle



- Max diameter: 5.1 in
- Length: 84 in
- Gross Lift-Off Weight: 32 lb
- Motor: Aerotech L1500T

Integration – Team Requirements

- Integrate the quadcopter capabilities into the nose cone of the rocket.
- Prototype and design the 3D printed body structure of the quadcopter.
- Develop a deployable arm system.
- Design the mounts that interface the connection of the motor and arm.
- Design the arms using an acceptable material that allow for easy ESC attachment.
- Design the structure all of the electronics will be supported by.
- Work with Avionics to integrate all of their work into the capabilities of the quadcopter.
- Work with Structures to make the quad deployable via a black powder piston ejection system.
- Create the backup parachute mechanism.
- Minimize the added weight to the system.

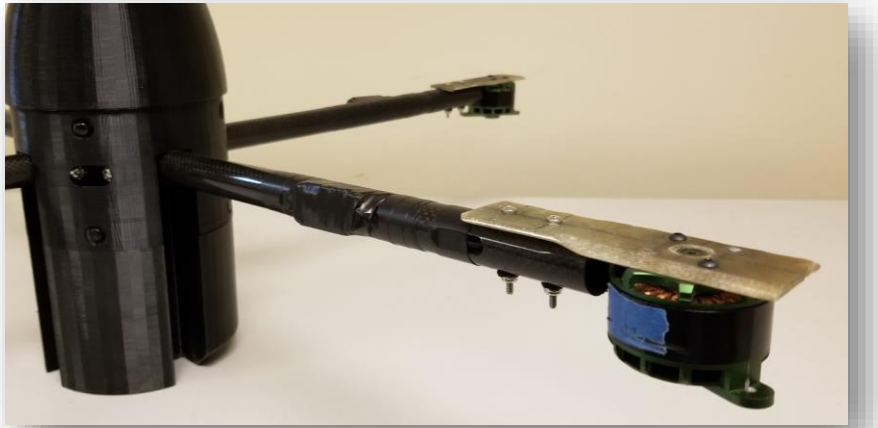
Integration – Design of Quad Body

- Rapid prototyping via 3D printing allowed for quick changes and complex geometry
- Consists of 3 sections, Bottom, Mid, and Nose Cone Section
- The Bottom Section holds battery, FPV, light sensors, wires, and the backup parachute
- The Mid Section contains the connection to the arms and is the base of the electronics structural support
- The Nose Cone is mainly a cover for all of the electronics and acts as the Nose Cone of the rocket during launch

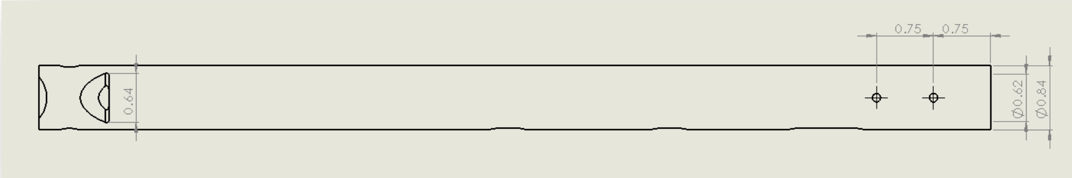
Integration – Design of Quad Arm

Summary of Characteristics:

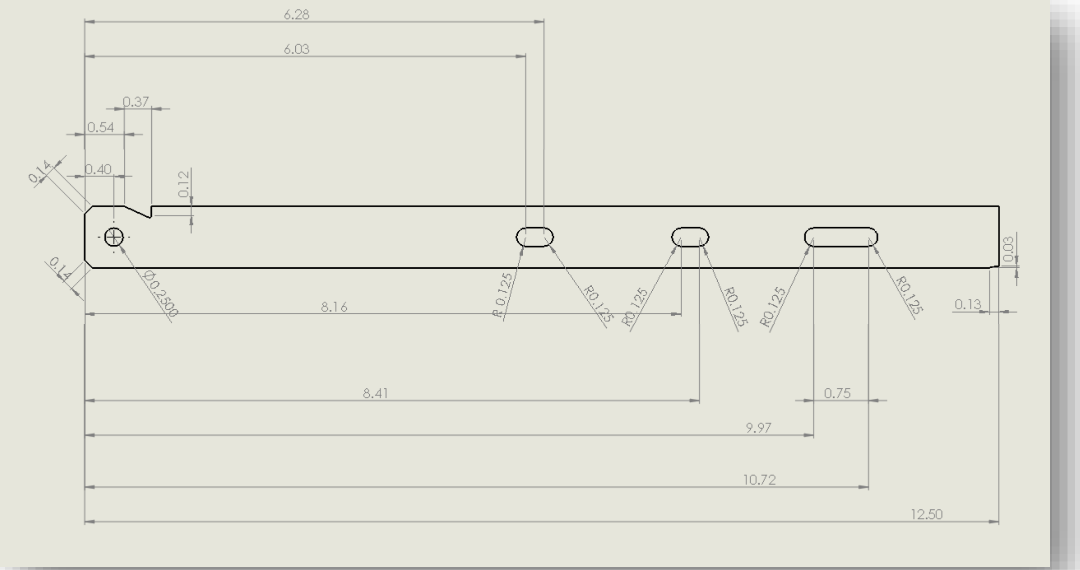
- ½" PVC Tube
- 12.5" long
- ¼" Hole for Pin Joint
- Sanded edges around Pin
- Slot cut for Spring Legs
- Holes Cut for ESC wires
- Notch to Prevent Motor Wire Pinching
- Motor Mount Hole in end.



Top View:



Side View:

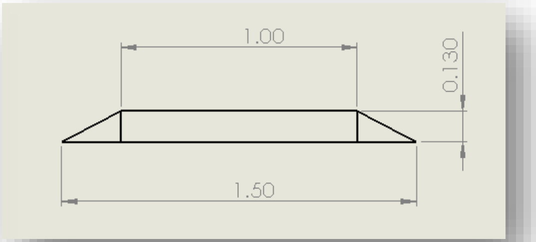


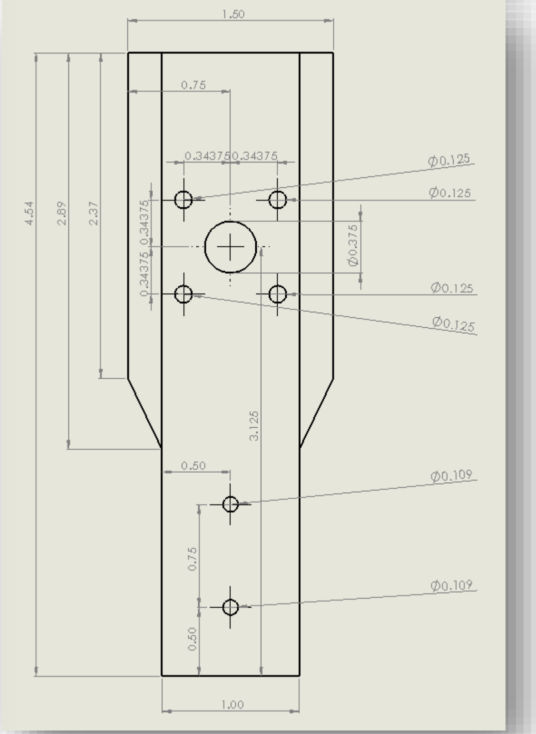
Integration – Design of Arm Deployment

- The deployment mechanism was a two torsional springs and a 1.6” bolt to rotate around
- Each arm had a RHW and a LHW spring with 10.45 lbf-in max torque
- Modifications to the springs were made to allow one leg to be inserted into the arm. The other leg was bent around to avoid getting in the way
- The bolt had a nut with Loctite on the end to prevent it from vibrating out

Integration – Design of Quad Motor Mount

- After failure of 3D Printed Mounts, Fiberglass Sheets were used.
- Roughly 0.13” thick Handmade Fiberglass
- Holes drilled for screws to connect the motor and the quadcopter arm.
- Larger Hole for the Motor Bearing.
- Chamfers to keep the motor mount from scraping the tube on ejection

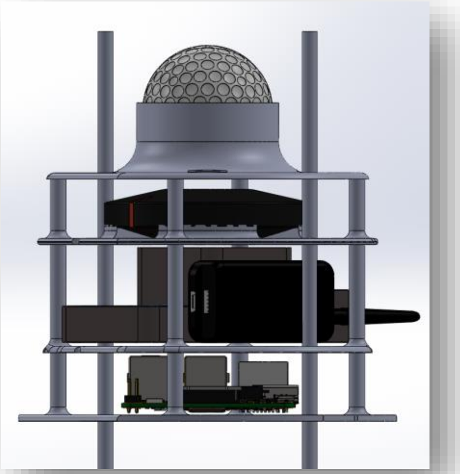


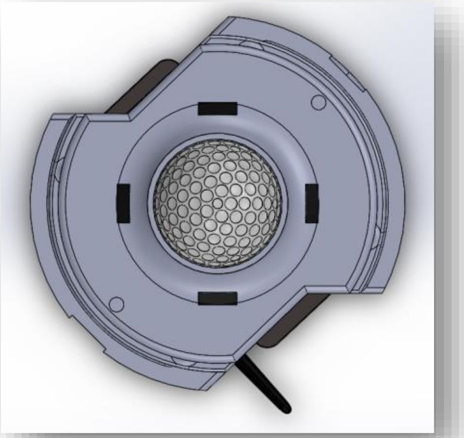


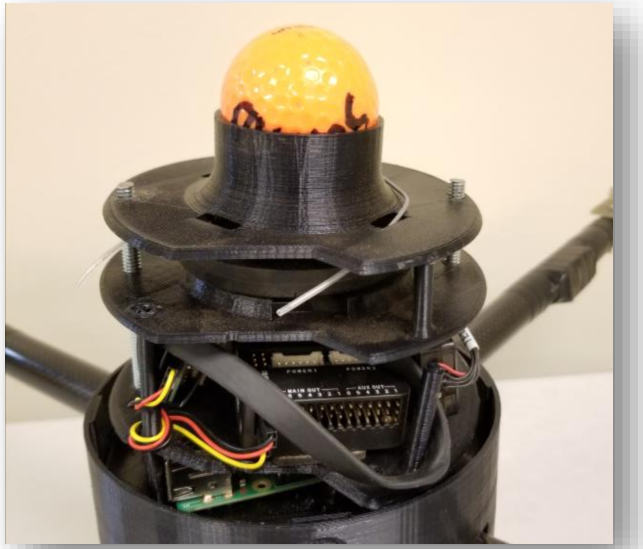
Integration – Design of Avionics Structure

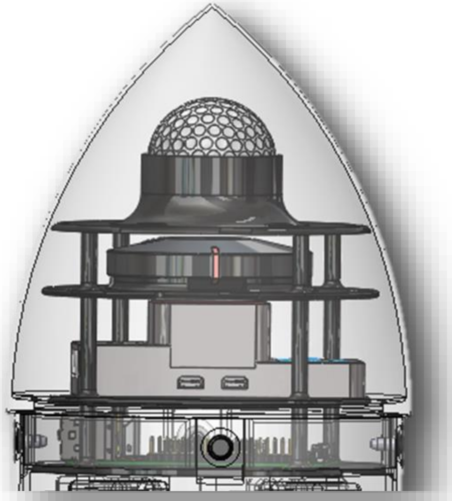
Requirements for Support Structure

- Fit within the nose cone
- Protect the electronics contained
- Effectively deal with the wires running between levels
- Offer suitable attachment points to hold the electronics (zipties)







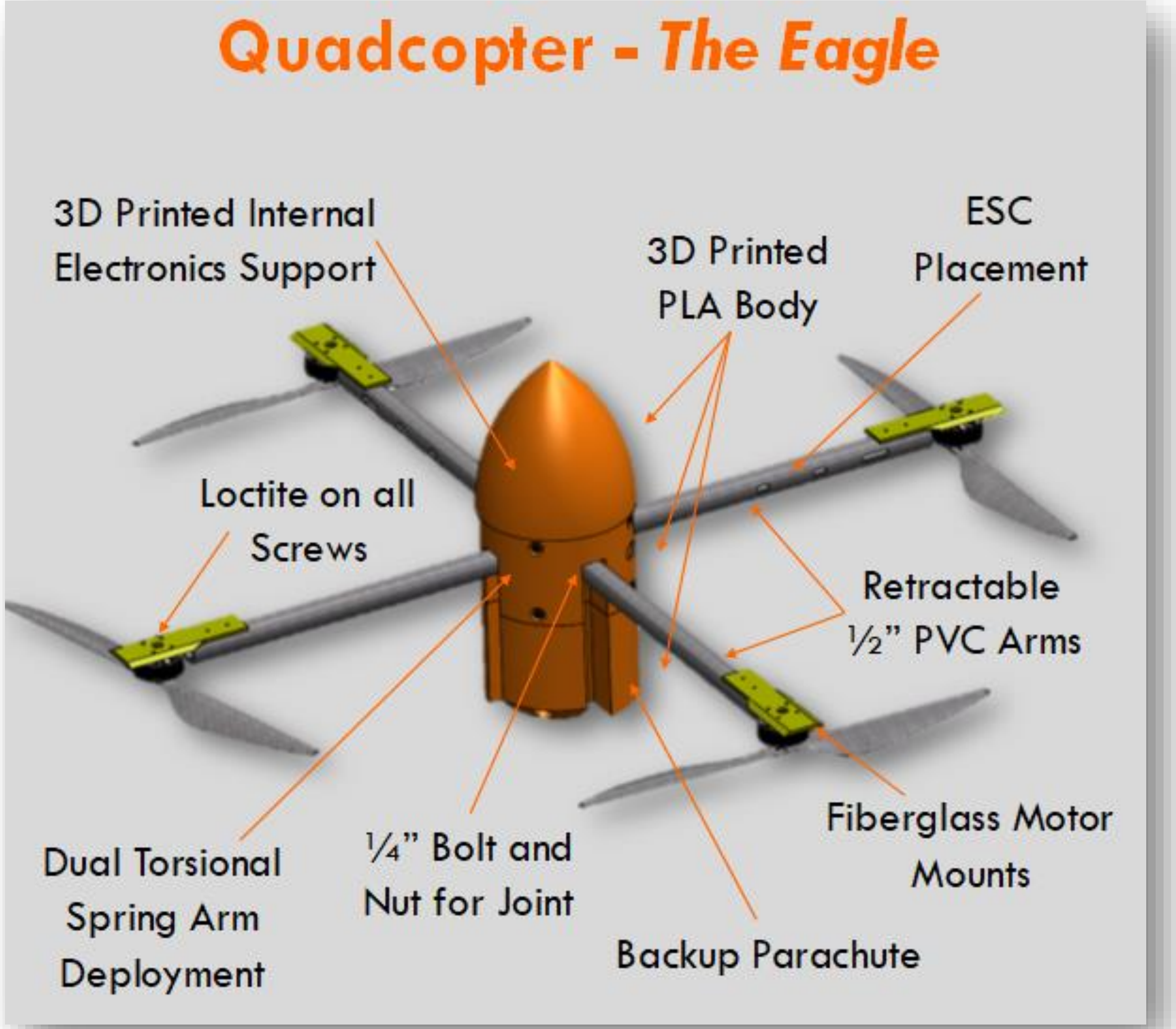


Integration – Design of Backup Parachute

- Final backup system to save the quadcopter from complete failure and loss of components due to crash
- Consists of a 0.4 g black powder charge triggered by a transistor switch controlled by the onboard Pi
- Parachute contained in one of the corners between arm slots and connected to the quadcopter Bottom Section via paracord
- Parachute folded and inserted into fairings and inserted into the Bottom Section.
- Friction fit as to not fall out on launch or quadcopter ejection

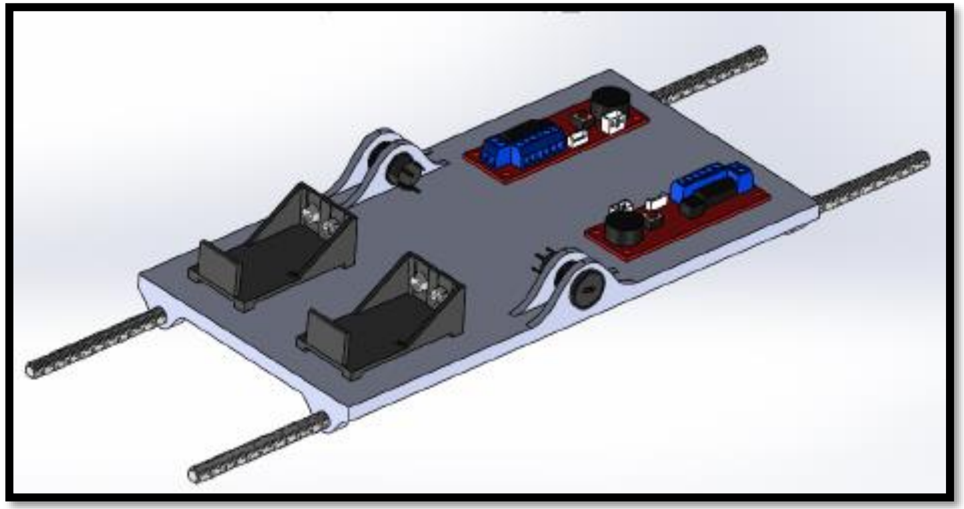
Integration – Overall Final Design

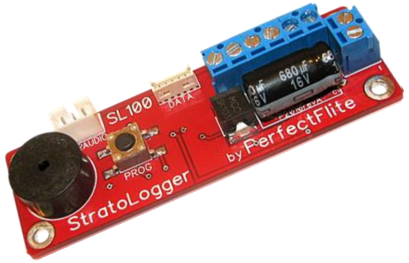
- ½” PVC Quadcopter Arm with ESC Placement
- Fiberglass Motor Mount
- 1.6” long, ¼” Pin
- Finalized Electronics Structure
- Parachute Backup System
- Dual Spring Arm Deployment
- Loctite on all screws/bolts to protect against vibration



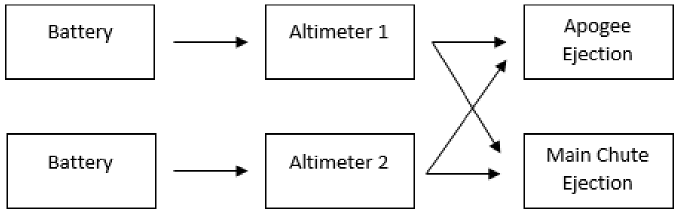
Avionics Hardware

- 3DR Pixhawk 2.1 used for autopilot
- Python script running on Raspberry Pi 3
  - Mid-air system arming sequence
  - In-flight tracking
  - Coordinated deployment
- COTS multi-rotor hardware

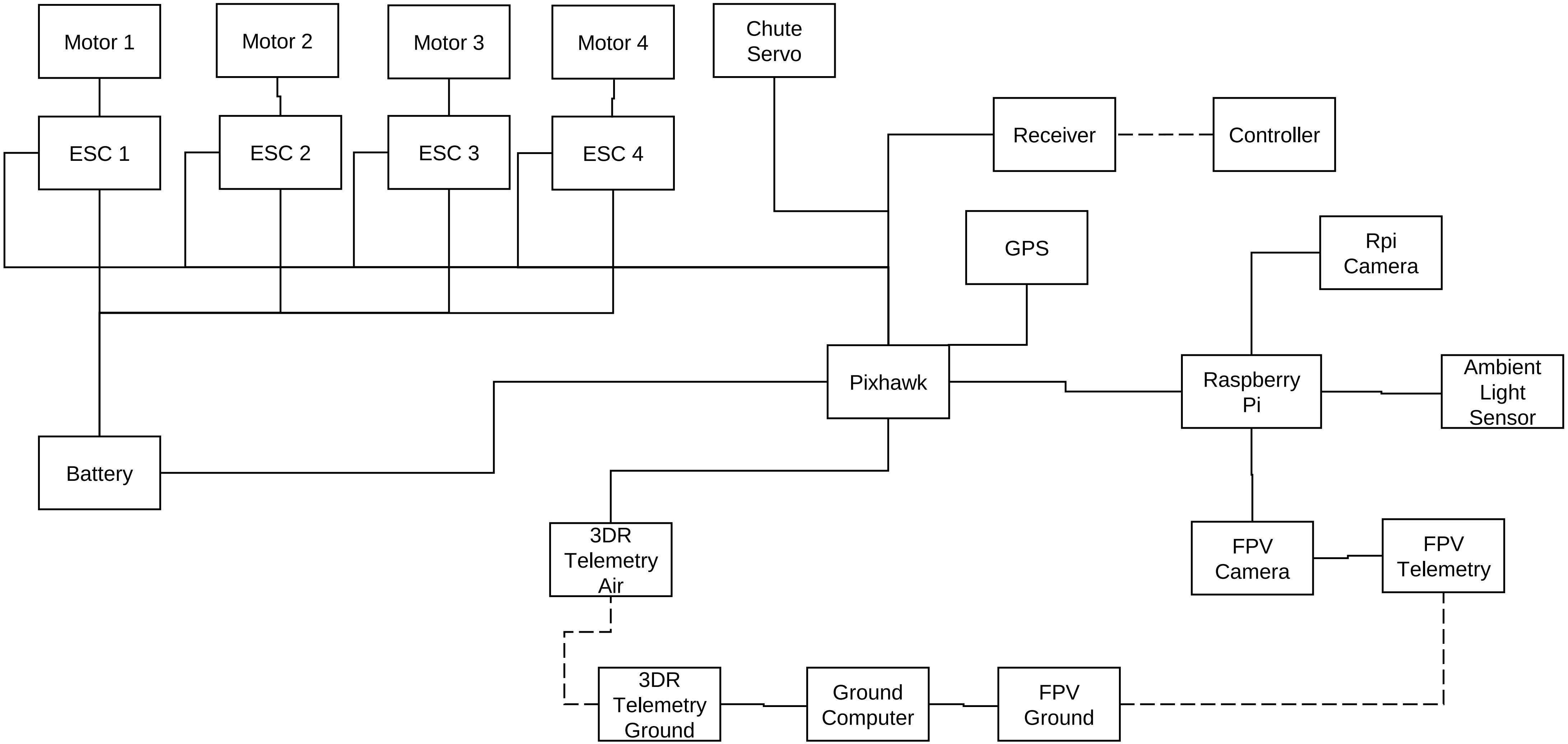




Rocket Layout

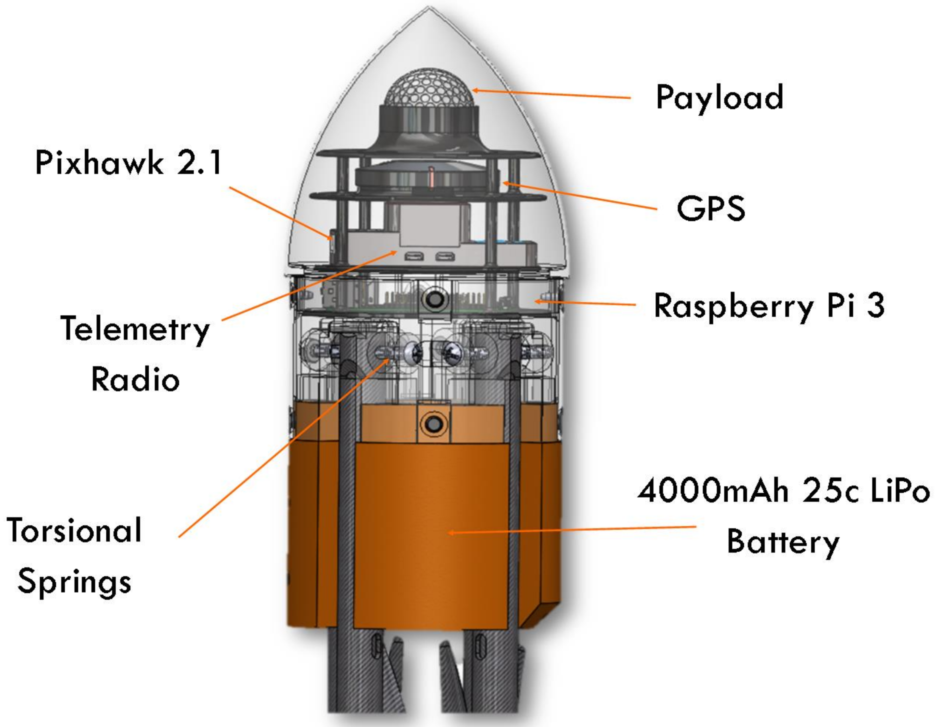


Avionics Hardware



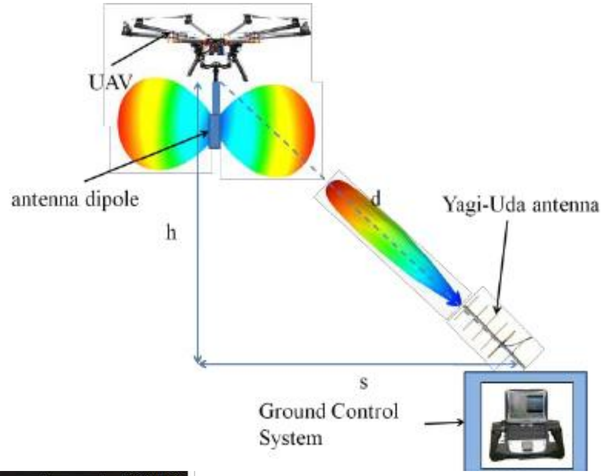
Flight Systems and Characteristics

- Multistar Elite 4114 330KV
- Multistar 30A Opto ESC
- Zippy 4000mAh 6s 25C battery
- Foldable 15.5” props
- Approximate Hover Time: *14 minutes*
- Estimated Max Horizontal Range: *2 miles*
- Thrust to Weight Ratio: *2.2*



Ground Control Station

- Using MissionPlanner over MAVlink protocol.
- Used to relay telemetry and flight data through high gain antenna.
- Send manual flight commands in needed.
- Make quick in-flight decisions.
- Monitor progress during flight.



Software

Quadcopter

Flight Summary

1. Separate from rocket at apogee
2. Free fall to 7,000’
3. Stabilize
4. Descend to 500’
5. Fly to latitude and longitude
6. Land

Initial and Backup Plans

Plan A: Full Autonomy

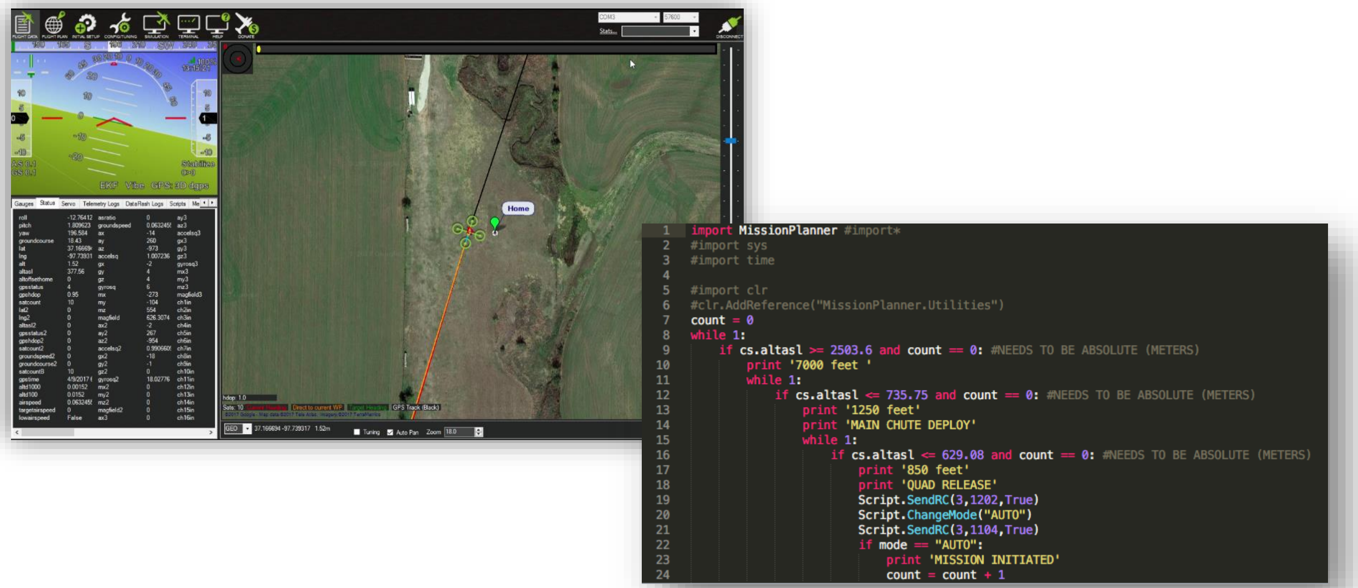
Plan B: Manual override at 4,000’

Plan C: Blow parachute below 2,000’

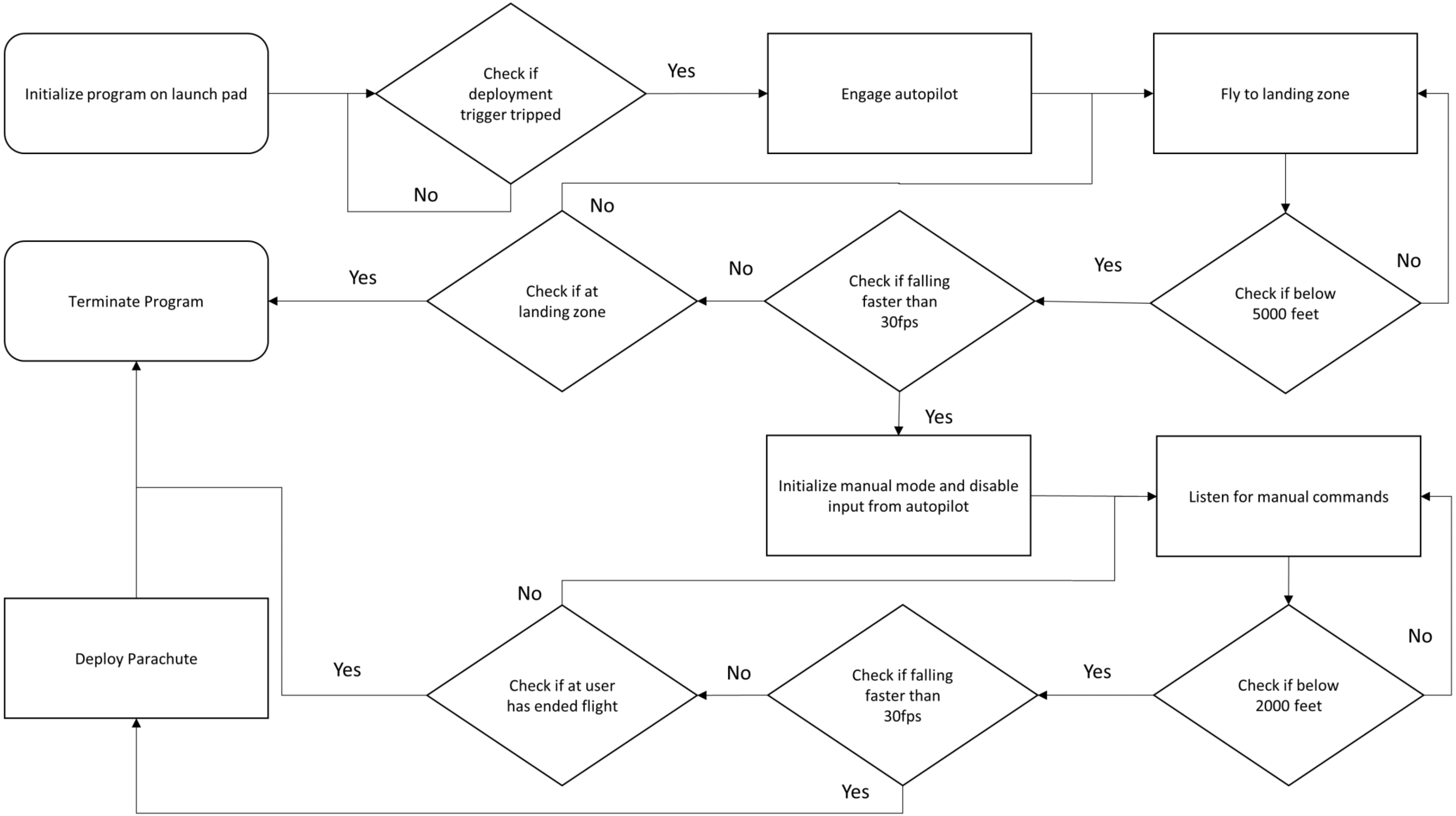
Rocket

Flight Summary

1. Deploy quad and drogue parachute at apogee
2. Deploy main parachute at 1,000’

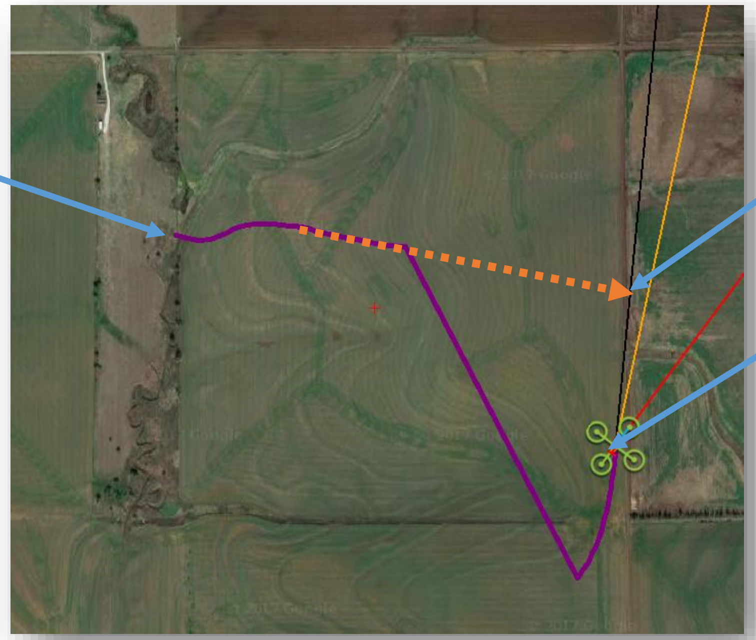


Decision Flow Chart



Hardware Failure Analysis

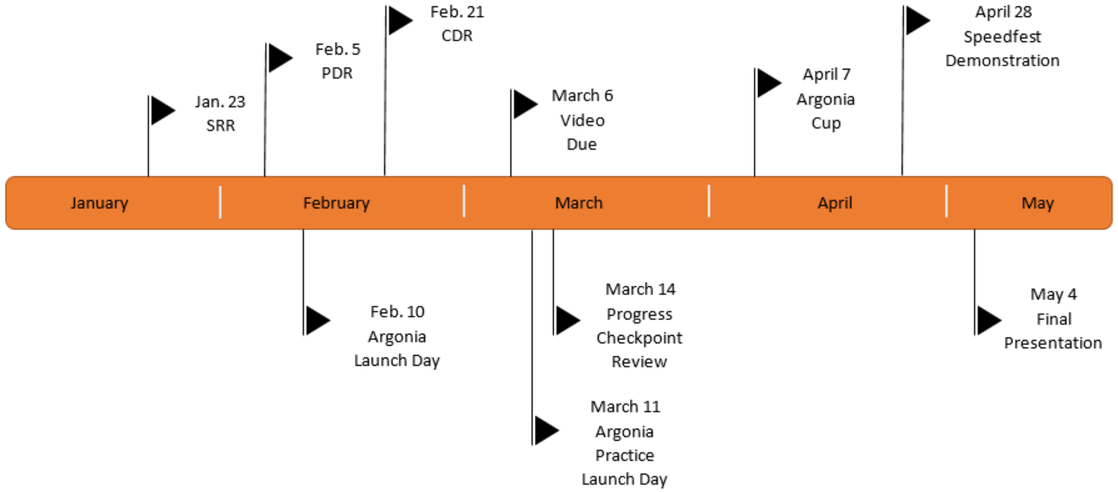
- Perfect flight operation until approximately 3 seconds after apogee
- All data coming from the Pixhawk 2.1 froze
  - Both telemetry and on-board data
- Ballistic trajectory should have crashed after T+50



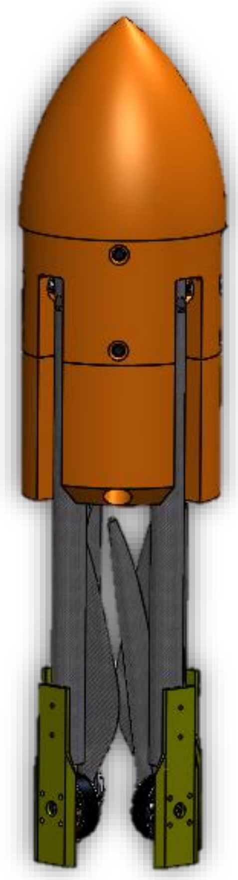
Time	Event
T+0	Launch
T+22	Quad Eject
T+24	Quad Flight Engaged
T+29	Fire Parachute
T+33	Stabilize Mode
T+69	Acro Mode
T+88	Loiter Mode/Power Loss

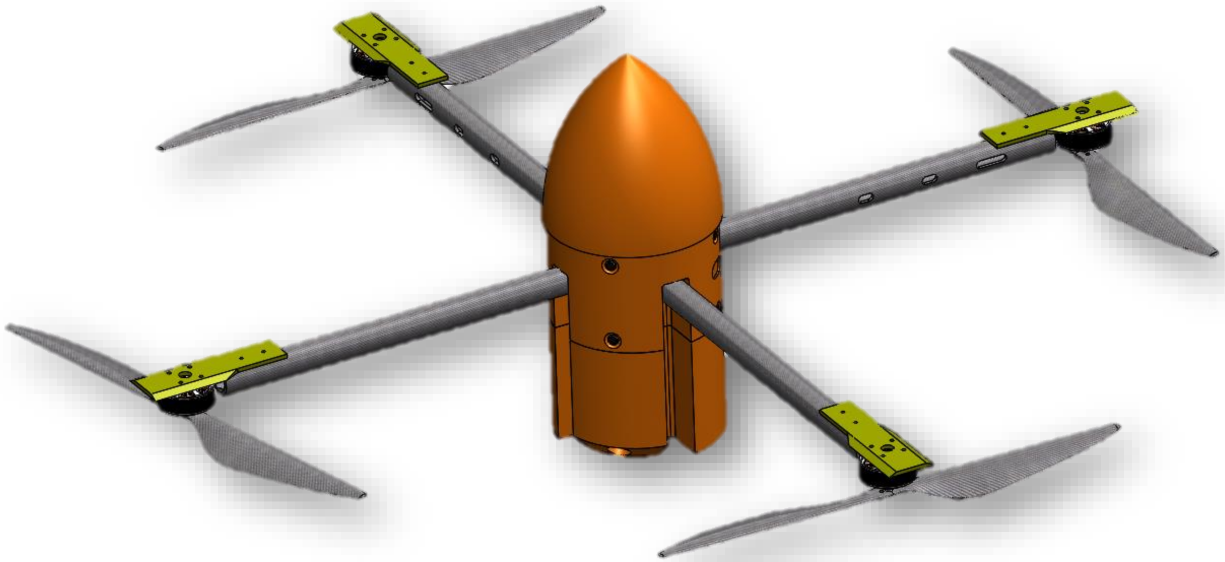
Conclusions

- Completed with a total spent just over $4,000.
- Partial success, but a lot of progress!
- Accelerate the schedule!
- Keep it simple, rockets are hard!
- Have at least two full systems with one simple backup.
- Keep a team of ten with two EE/EET students.



Questions?





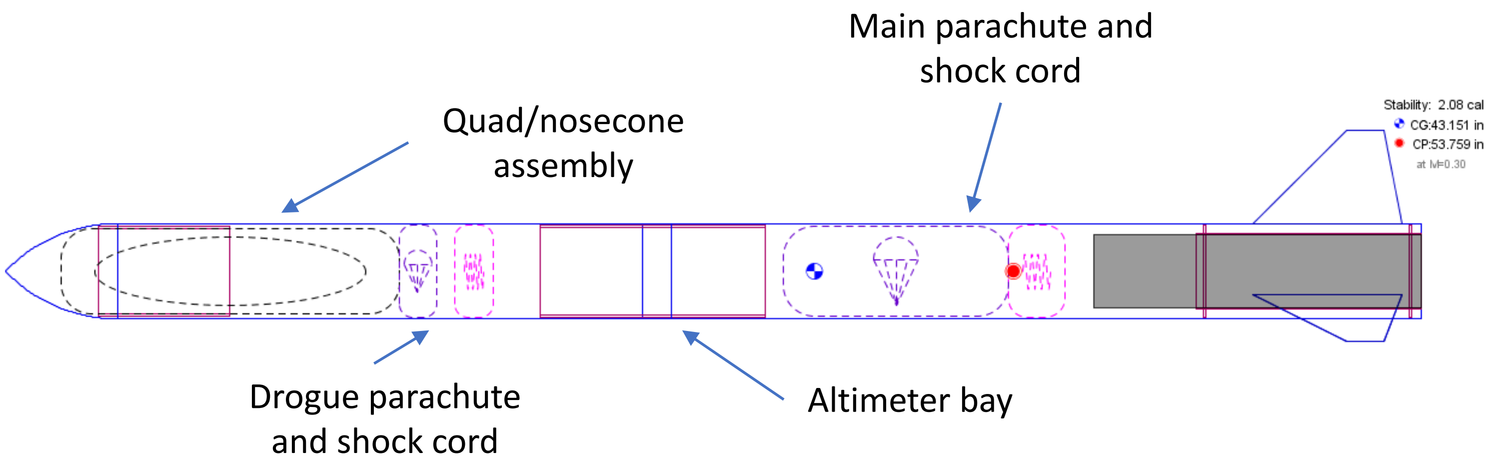
BACKUP SLIDES

Mission Planner Flight

Rocket System

- Scratch-built, custom rocket
- Primary materials: fiberglass airframe and couplers, fiberglass sheet
- Commercial 5” fiberglass rocket body: $560
- Custom 5” fiberglass rocket body: $150

Sample structural parts, Madcow Rocketry



- Length: 6.3 ft
- Max diameter: 5.1 in
- Gross Lift-off Weight: 34.8 lb
- Apogee: 9125 ft
- Max velocity: 638 mph
- Max acceleration: 10.4 G

Fiberglass Vs Carbon Fiber Commercial Cost

Commercial Fiberglass 5 in	Commercial Carbon fiber 4 in	Commercial Carbon fiber 6 in
2 X 60 in body tube, 170$ each	2X 60 in body tube, 300$ each	2X 60 in body tube, 550$ each
1 X 12 in coupler, 45$ each	1 X 12 in coupler 75$	1X 12 in couple, 120$
4X plates, 15$ each	4X plates (carbon fiber not available) 15$ each	4X plates (carbon fiber not available) 15$ each
1 X E-Bay ring, 15$ each	1 X E-Bay ring (carbon fiber not available) 15$ each	1 X E-Bay ring (carbon fiber not available) 15$ each
3 X fins 15$ each	3 X fins 15$ each (cut out of sheet, not available in carbon fiber)	3 X fins 15$ each (cut out of sheet, not available in carbon fiber)
2 X Centering Rings, 15$ each	2 X Centering Rings, 15$ each	2 X Centering Rings, 15$ each
Motor coupler, 25$ each	Motor coupler, 25$ each	Motor coupler, 25$ each
Total: 560 $	Total: 850$	Total: 1380$

Fiberglass Vs Carbon Fiber References

Fiberglass	Carbon Fiber
Resin 50 $	Resin 100$
Fiber 50$	Fiber: Free (Donated)
Motor coupler 25$	Motor coupler 25$
Molds etc. 50$	Molds etc. 50$
150$	150$

- Mad Cow Rocketry (commercial parts pricing)
- Rocket west (carbon fiber vs fiberglass properties)

https://www.rockwestcomposites.com/blog/carbon-fiber-vs-fiberglass-tubing-which-is-better/
https://www.linkedin.com/pulse/difference-between-carbon-fiber-glass-shao-liya

Updated Budget

Rocket Budget: $5,200

Avionics Budget: $3,700

Overall Preliminary Estimated Budget: $8,900

	cost	quantity	Real Price	Estimated Price
DJI E1200 Pro 2 arm kit	315	4	1260	1500
Pixhawk 2.1 edison and here GNSS kit	309.39	2	618.78	650
Pixhawk wire kit	21.5	3	64.5	100
Pixhawk Telemetry Radios	300	2	600	600
DJI Smart ESC Updater	15	1	15	20
Raspberry Pi 3 Model B	39.99	3	119.97	150
32 GB Sandisk MicroSD	11.69	2	23.38	40
Radio Controller	189.99	2	379.98	400
Misc.	200	1	200	200
		Total Items	Total Real	Total Estimated
		20	3281.61	3660

Item	Quantity	Price each	Price rounded	Price total	Price rounded
98mm forward seal disk stainless steel	1	$ 49.50	$ 50.00	$ 49.50	$ 50.00
98/5120 PACKAGE	1	$ 522.00	$ 550.00	$ 522.00	$ 550.00
1/4"-20 Black Oxide threaded rod stainless - 3 ft	1	$ 9.77	$ 10.00	$ 9.77	$ 10.00
U bolts for ebay	4	$ 0.93	$ 1.00	$ 3.72	$ 4.00
7/16" eyebolt (for forward closure)	1	$ 4.79	$ 5.00	$ 4.79	$ 5.00
Nuts 1/4"-20 pack of 100	1	$ 3.36	$ 5.00	$ 3.36	$ 5.00
Washers 1/4" pack of 100	1	$ 3.37	$ 5.00	$ 3.37	$ 5.00
98mm retainer	2	$ 62.00	$ 65.00	$ 124.00	$ 130.00
Rocketpoxy 2 pint	1	$ 33.25	$ 50.00	$ 33.25	$ 50.00
Nosecone 5:1 Von Karman with metal tip	1	$ 122.55	$ 150.00	$ 122.55	$ 150.00
Rail buttons 1.5"	2	$ 4.65	$ 5.00	$ 9.30	$ 10.00
Battery holder	2	$ 2.86	$ 5.00	$ 5.72	$ 10.00
9V Batteries alkaline pack of 12	1	$ 28.71	$ 30.00	$ 28.71	$ 30.00
Ematches pack of 10	2	$ 15.79	$ 20.00	$ 31.58	$ 40.00
Igniter	1	$ 7.50	$ 10.00	$ 7.50	$ 10.00
Perfectflite Altimeter	1	$ 58.80	$ 75.00	$ 58.80	$ 75.00
Shear pins pack of 20	4	$ 3.10	$ 5.00	$ 12.40	$ 20.00
1" shock cord (per yard, 3yd tall x 4yd=12yd*2 sections)	24	$ 1.13	$ 1.20	$ 27.12	$ 28.80
Cert-3 XL Parachute	1	$170.10	$200.00	$ 170.10	$ 200.00
Nomex 24x24	2	$ 13.46	$ 15.00	$ 26.92	$ 30.00
6in tube				$ -	$ -
6in coupler				$ -	$ -
3/16" Garolite sheet				$ -	$ -
98mm 75mm adapter	1	$ 44.00	$ 50.00	$ 44.00	$ 50.00
Aluminum tube fasteners 6-32	2	$ 17.27	$ 20.00	$ 34.54	$ 40.00
Terminal blocks 4 circuits CHECK THESE	4	$ 1.20	$ 1.25	$ 4.80	$ 5.00
Wire - EasyID Low-Voltage 24 AWG, 50ft	1	$ 7.50	$ 10.00	$ 7.50	$ 10.00
Nylon standoffs	4	$ 3.68	$ 4.00	$ 14.72	$ 16.00
Rotary switches	2	$ 9.93	$ 10.00	$ 19.86	$ 20.00
				$ -	$ -
Aerotech L1500T	4	$ 279.99	$ 325.00	$ 1,119.96	$ 1,300.00
Aerotech K1000T	2	$ 159.99	$ 200.00	$ 319.98	$ 400.00
Estimated needs for a launch rail, ignition equipment	1	$ 300.00	$ 300.00	$ 300.00	$ 300.00
Office supplies/tools	1	$ 300.00	$ 300.00	$ 300.00	$ 300.00
GPS+tracking	1	$ 300.00	$ 300.00	$ 300.00	$ 300.00
Composites	1	$ 300.00	$ 300.00	$ 300.00	$ 300.00
Travel and/Or lodging costs w/ snacks	11	$ 45.00	$ 65.00	$ 495.00	$ 715.00
				$ 4,592.82	$ 5,168.80

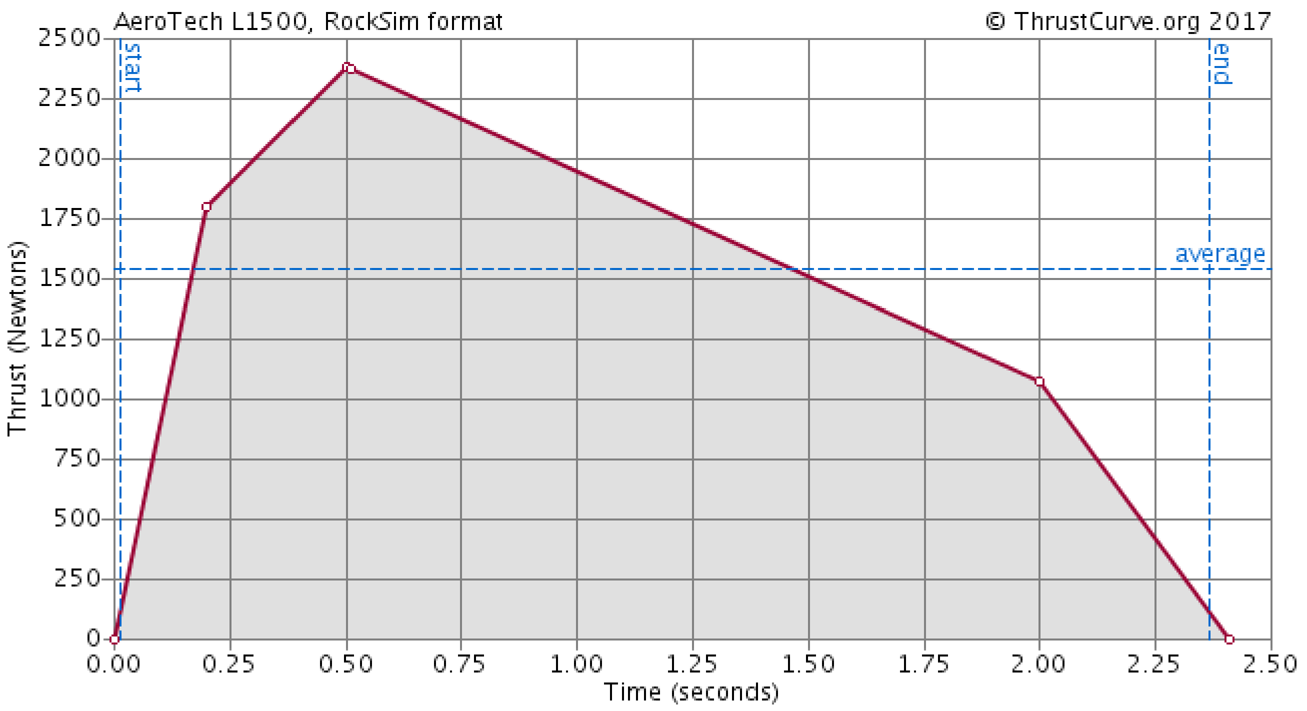
Requirements Traceability Matrix

Req ID	Requirement Description	Source	Responsibility	Justification	Strategy	Objective/Threshold	Status	Active/Inactive	Comments
1	Launch to +8,000’	Argonia Cup Rules	Full Team	Disqualified if not met	Design rocket to achieve this apogee	Once simulations show launch will achieve 8,000'	In Progress	Active	N/A
1.1	Land payload at target	Argonia Cup Scoring	Full Team	Closest to target wins	Design accurate recovery system	Recovery system lands on target	In Progress	Active	N/A
1.1.1	Fully autonomous recovery system	Argonia Cup Scoring	Integration/Avionics	More accurate than manual controlled	Program hardware for autonomy	Once recovery system can autonomously fly payload back	In Progress	Active	N/A
2	Carry golf ball payload	Argonia Cup Rules	Integration	Designated payload	Incorporate payload into design	Once design is finalized to carry ball	In Progress	Active	N/A
3	5:1 Thrust to weight ratio	Argonia Cup Rules	Structures	Must be met to be flightworthy	Design rocket with maximum weight to meet requirement	Weight meets max for L motor and 8,000' apogee	In Progress	Active	N/A
4	1 body caliber CP/CG stability	Argonia Cup Rules	Structures	Must be met to be flightworthy	Design fins to allow a 1 body caliber	Once weight and fin size are determined	In Progress	Active	N/A
5	Below 300’ travel less than 30 fps	Argonia Cup Rules	Integration/Avionics	Must be a controlled descent	Design to control descent	Once recovery system can descend slower than 30fps	In Progress	Active	N/A
6	Re-flyable condition	Argonia Cup Rules	Full Team	The launch must be completely successful	Design rocket recovery system and payload system to slow descent	Once rocket and payload have landed without damage	In Progress	Active	N/A
6.1	Robust Recovery System	Self Inflicted	Integration/Avionics	Must be capable of launching in any launch conditions	Design system to be flyable in any launch conditions	Once system is capable of flying in 20mph	In Progress	Active	N/A
7	Max of L motor	Argonia Cup Rules	Structures	Rule requirement	Purchase max L motor size to allow for highest apogee possible	Purchased	Complete	Active	N/A
8	Safe (Does not pose risk to life/property)	Argonia Cup Rules	Full Team	Must meet Tripoli research standards	Design backup systems to ensure safe recovery	Once rocket and payload are capable of safe backup systems	In Progress	Active	N/A
9	$5k budget	“Customer”	Full Team	Available funding for project	Fabricate own tubes to reduce cost	Once final purchase order totals less than $5k	In Progress	Active	N/A
9.1	Multiple Systems	Self Inflicted	Full Team	If system failure, will have backup system	Keep system cost low in order to allow for second system	Once single system allows for secondary system construction	In Progress	Active	N/A

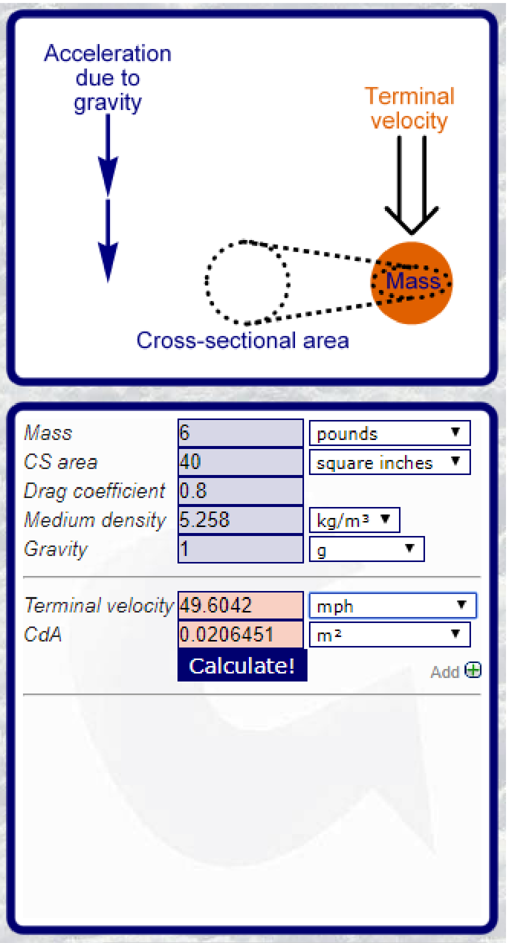
L1500 Motor

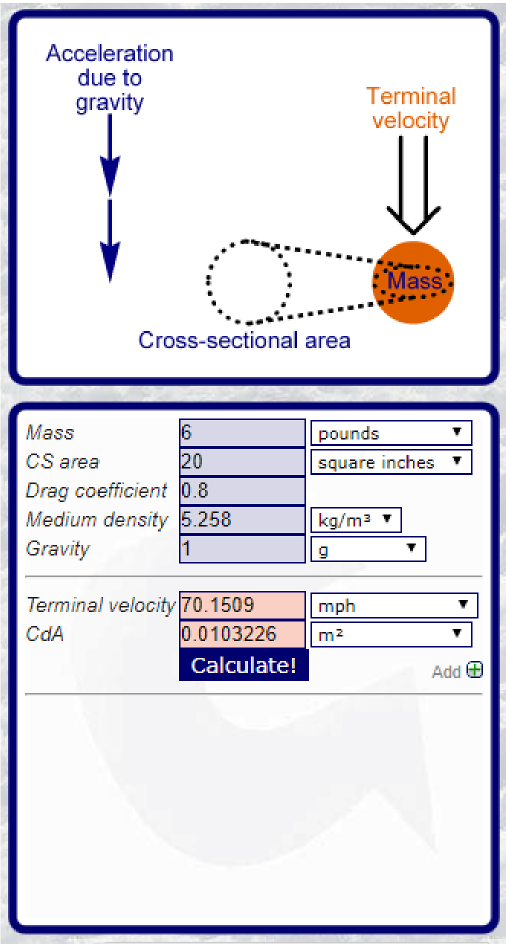
Motor:	AeroTech L1500		
Contributor:	John Coker		
Submitted:	Mar 1, 2008		
Last Updated:	Jun 30, 2008		
Data Format:	RockSim		
Data Source:	User-Created		
License:	Unknown		
Statistics	*Declared*	*Calculated*	*Official*
Diameter (mm):	98.0	n/a	98.0
Length (cm):	66.5	n/a	66.5
Prop. Weight (g):	1,644.0	n/a	2,490.9
Total Weight (g):	2,300.0	n/a	4,659.2
Avg. Thrust (N):	1,500.6	1,538.1	1,500.0
Max. Thrust (N):	2,381.0	2,381.0	1,752.0
Tot. Impulse (Ns):	3,616.4	3,616.5	5,089.3
Burn Time (s):	2.4	2.4	3.5
Download:	Download Now	Add to Outbox	

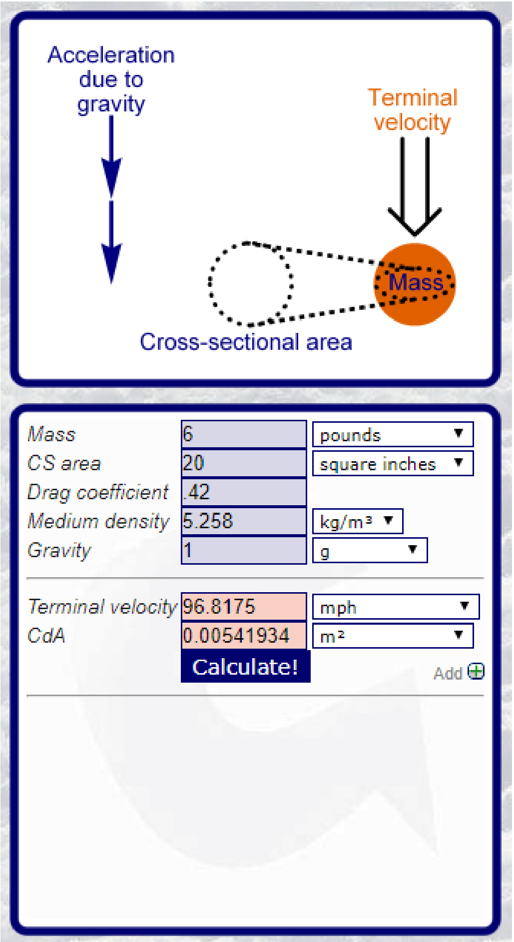
Data Graph

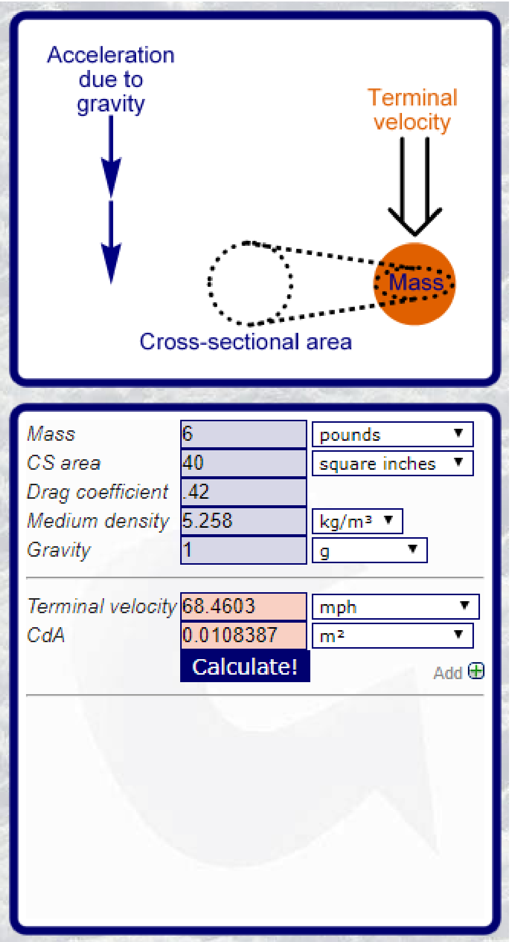


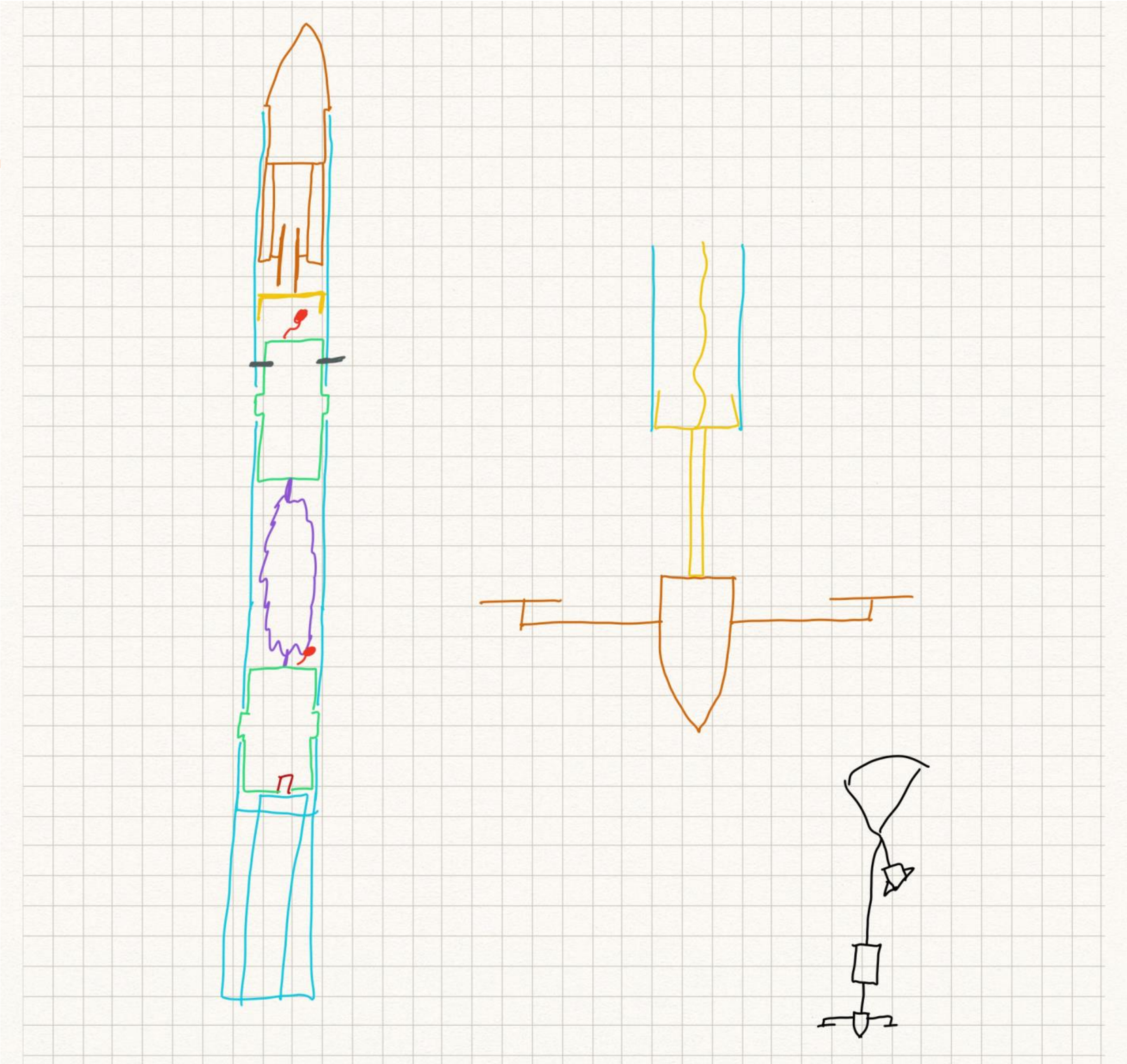
Terminal Velocity Calculations

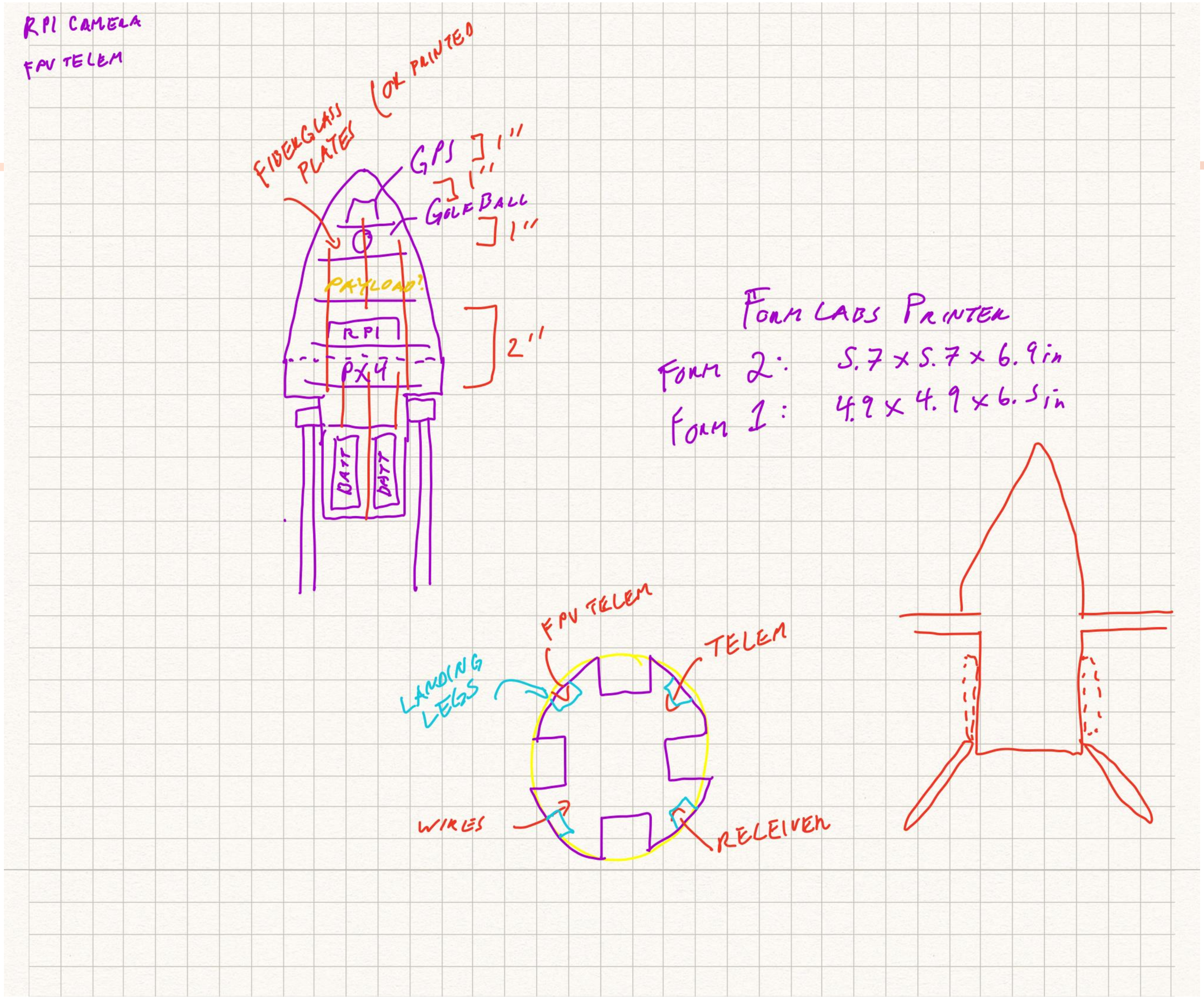


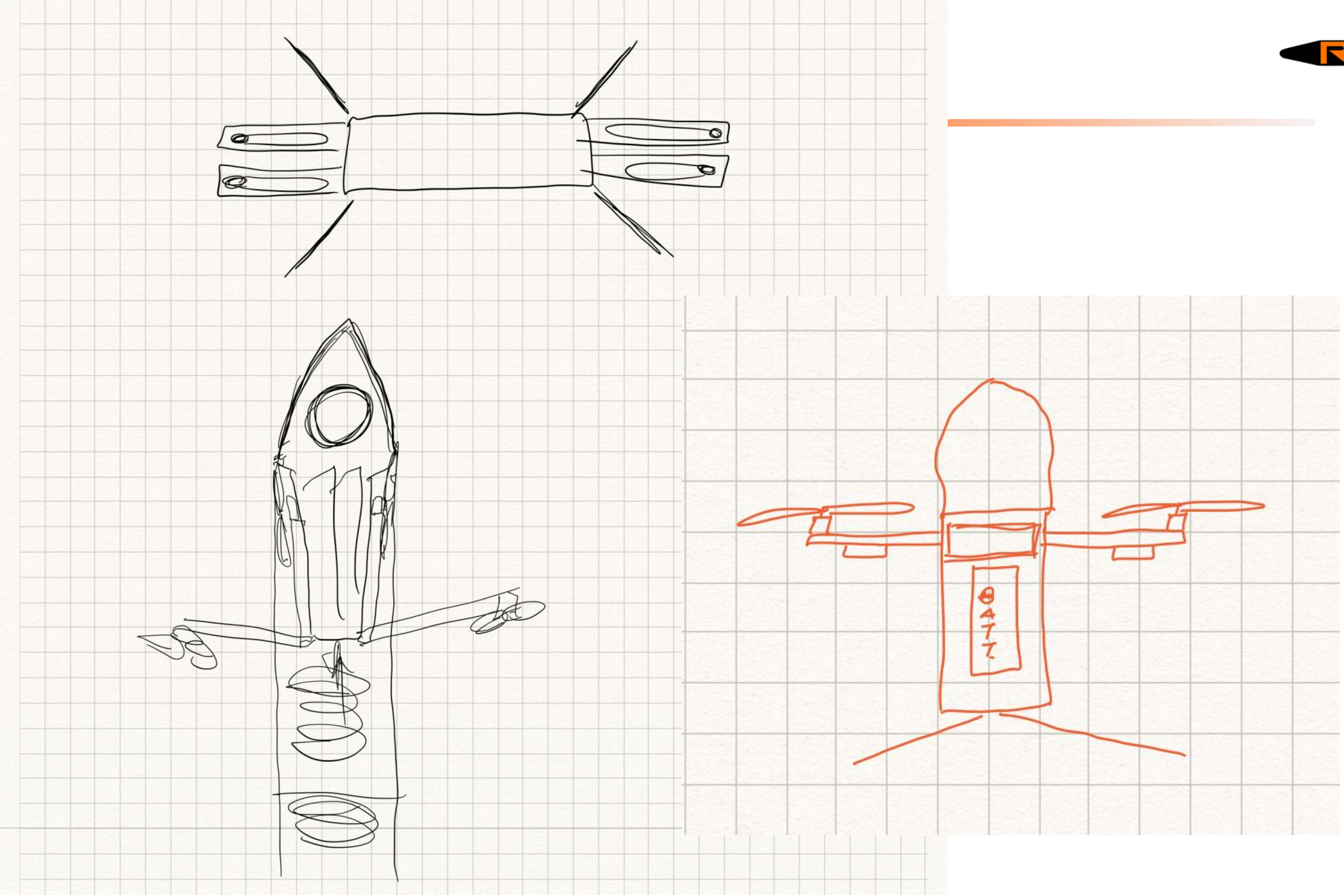









RPI CAMERA
FPV TELEM
FIBERGLASS PLATES
(OR PRINTED
GPS
1"
1"
GOLF BALL
1"
PAYLOAD?
RPI
PX4
BATT
BATT
2"
FORM LABS PRINTER
FORM 2: 5.7 x 5.7 x 6.9 in
FORM 1: 4.9 x 4.9 x 6.5 in
FPV TELEM
TELEM
LANDING LEGS
WIRES
RECEIVER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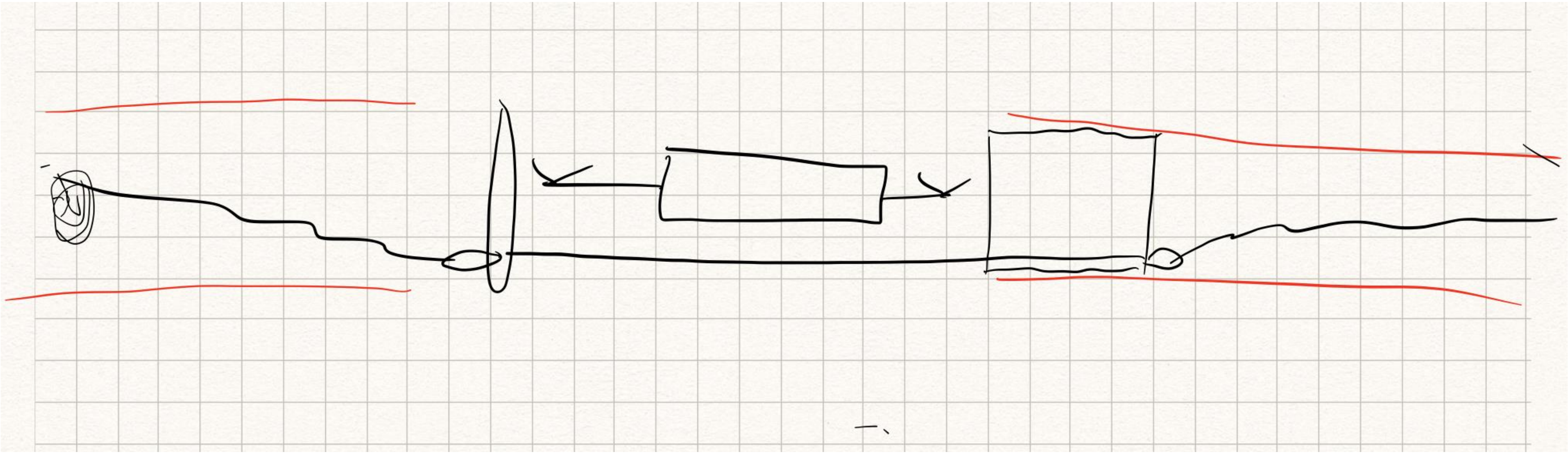
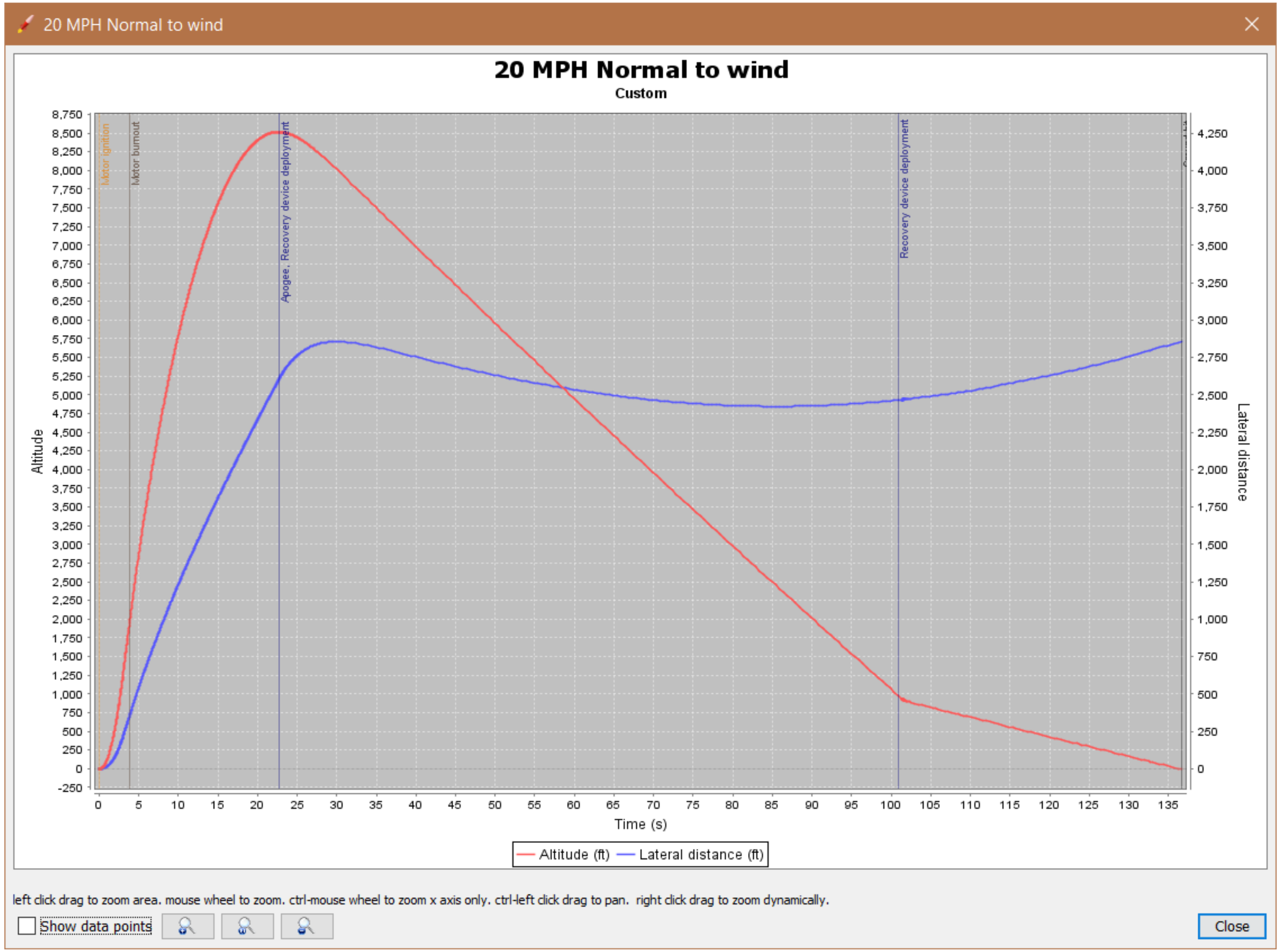
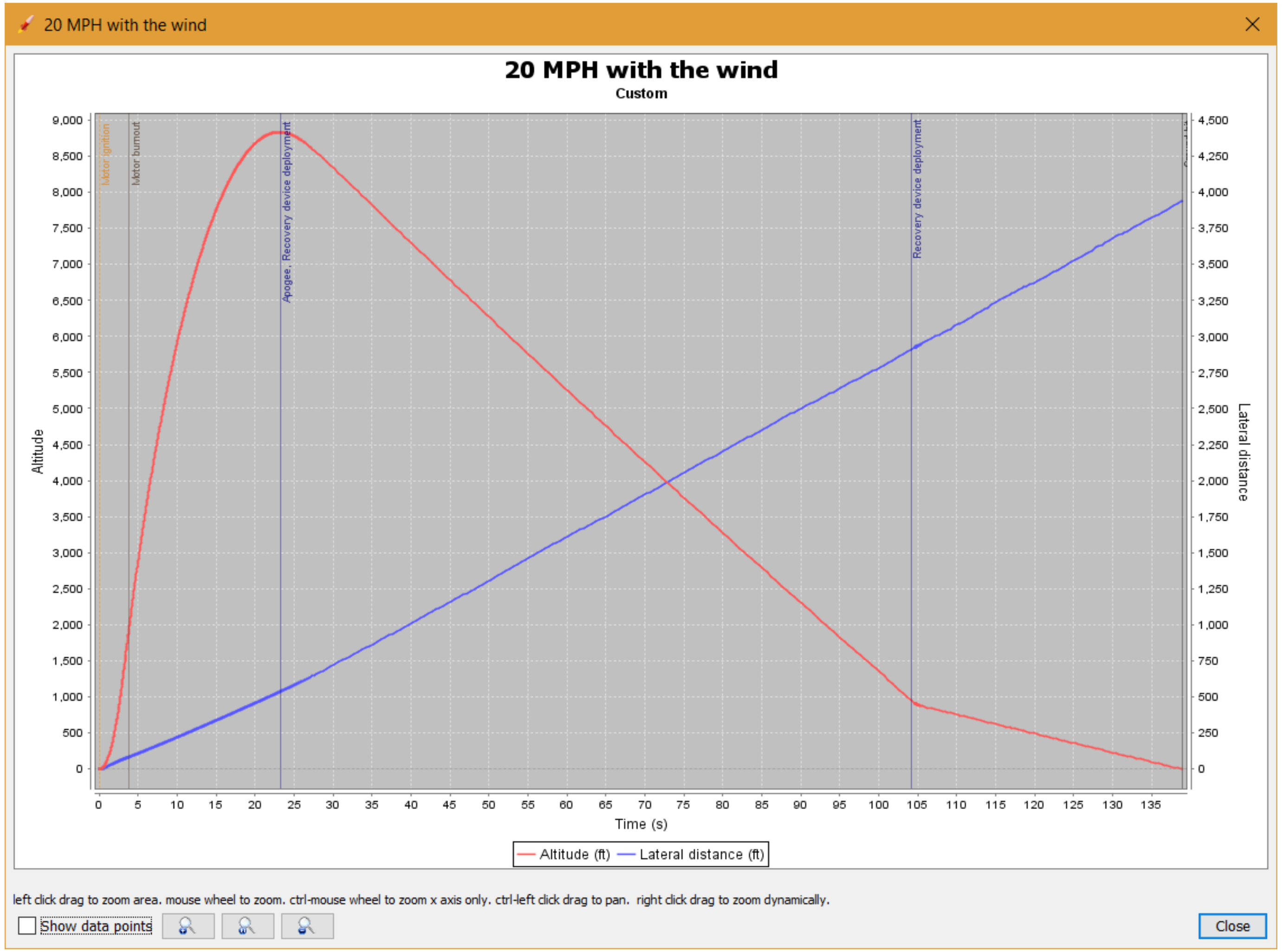
Sketches



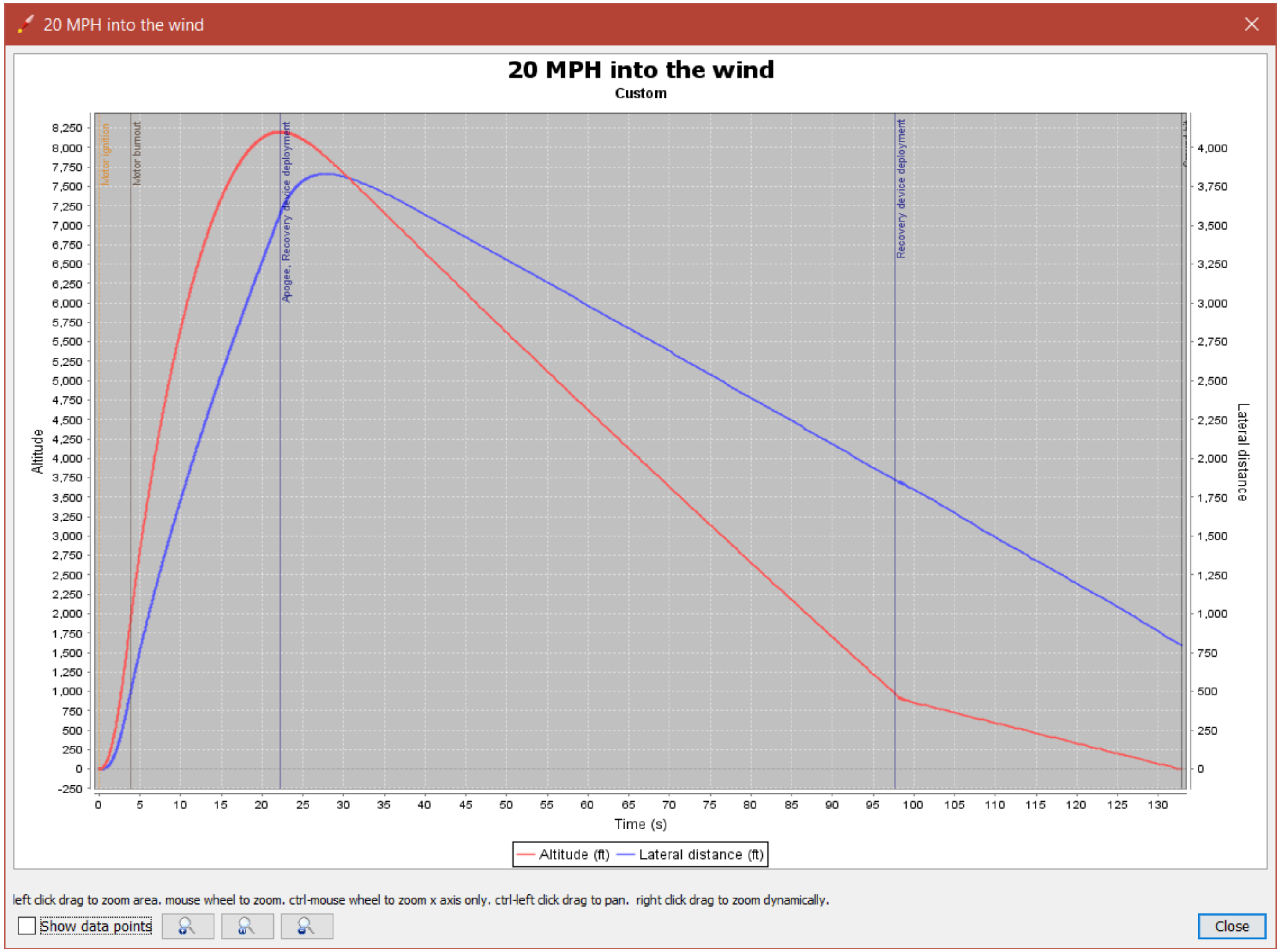
Worst Case Scenarios



Worst Case Scenarios



Worst Case Scenarios



Rules

1. There must be at least one (1) TRA certified Level 2 member per team. This team member must be present at the competition and will be considered the flyer of record of the rocket. All team members must currently be enrolled at the competing university or college. Multiple teams from the same university or college are permitted.

2. The maximum installed impulse for this competition will be one commercially available 5,120 Newton Second motor (L Motor). Motor clusters, air starts, and multi- stage motor configurations are prohibited. Spark emitting motors (Skidmark type motors) are prohibited.

3. Any deployable payload shall limit the descent velocity to less than 30 FPS below 300' AGL.

4. Any propulsion/steering system designed to recover the payload cannot be used to boost the payload to the target apogee.

5. A commercially available, altitude recording altimeter with onboard data storage shall be used for altitude determination and may be used for payload deployment and/or rocket recovery. If two or more altimeters are used, the averaged apogee height of each altimeter will be used for determination of rocket apogee.

Rules Cont'd.

6. The Launch vehicles shall be launched at an elevation angle between 83 and 85 degrees (5 to 7 degrees off vertical). All flights will be angled away from the flight line regardless of wind direction.
7. All flights must have a minimum of a 5:1 thrust to weight ratio at liftoff.
8. Launch configuration light stability shall be achieved by maintaining a minimum CP/CG static margin of no less than 1 body caliber during flight.
9. Apogee must occur at or above 8000' AGL (field elevation is approximately 1249' MSL). Any flight not reaching this altitude will be disqualified. Each team may make up to three flight attempts with the closest qualified landing score being their official flight.
10. All launch vehicle components must be recovered in a "re-flyable condition" after flight.

Launch Operations

1. TRA Research Safety Code will be followed for all launch activities.

2. The launch organizers will provide all launch pads, launch rails, and the launch control system. Both 1.5” x 1.5” (commonly known as 1515) and 1” x 1” (commonly known as 1010) rails will be available in 8’ or 12’ lengths. A minimum of two (2) rail guides must be used.

3. All rockets will be subjected to a rocket safety inspection before the teams will be cleared to fly their projects. Any safety of flight issues noted in this inspection will be resolved before flight. These safety inspectors have the final say regarding any projects suitability for flight.

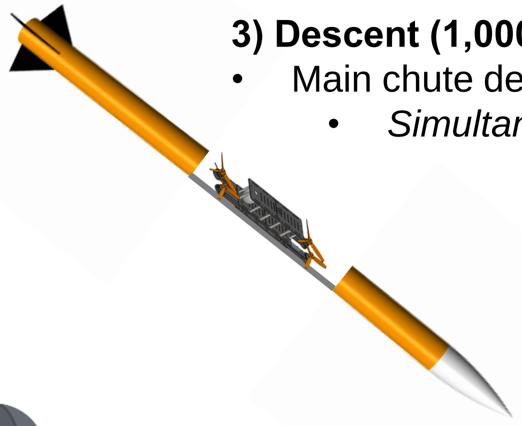
Scoring

Prior to the start of any launch activities, the location of the landing target will be clearly marked and will be available for inspection by the competing teams. The landing target will be established by the launch organizers and will be within line-of-site and not more than 300’ from any launch pad location. At the completion of each flight, the distance from the center of the payload to the center of the target will be measured by the launch organizers before the teams are allowed to remove their payloads. The point of initial touchdown will be used if it can be determined in the event of the payload skipping across the surface. Closest distance to the target landing spot will determine the winner. In the event of a tie based upon distance, the team with the highest recorded apogee will be the winner.

2017 ConOps

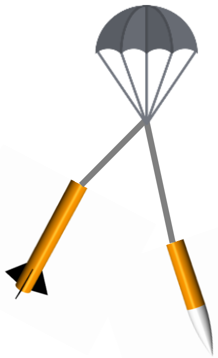
Minimum 8,000’ AGL

2) Apogee (+8,000’)
- Separation of aft and forward end
    - *No chute*



3) Descent (1,000’)
- Main chute deploys
    - *Simultaneously deploys quad*

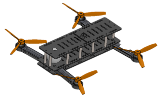
Overall Mission
Launch to 8,000 feet
Return a golf ball as close to the target as possible



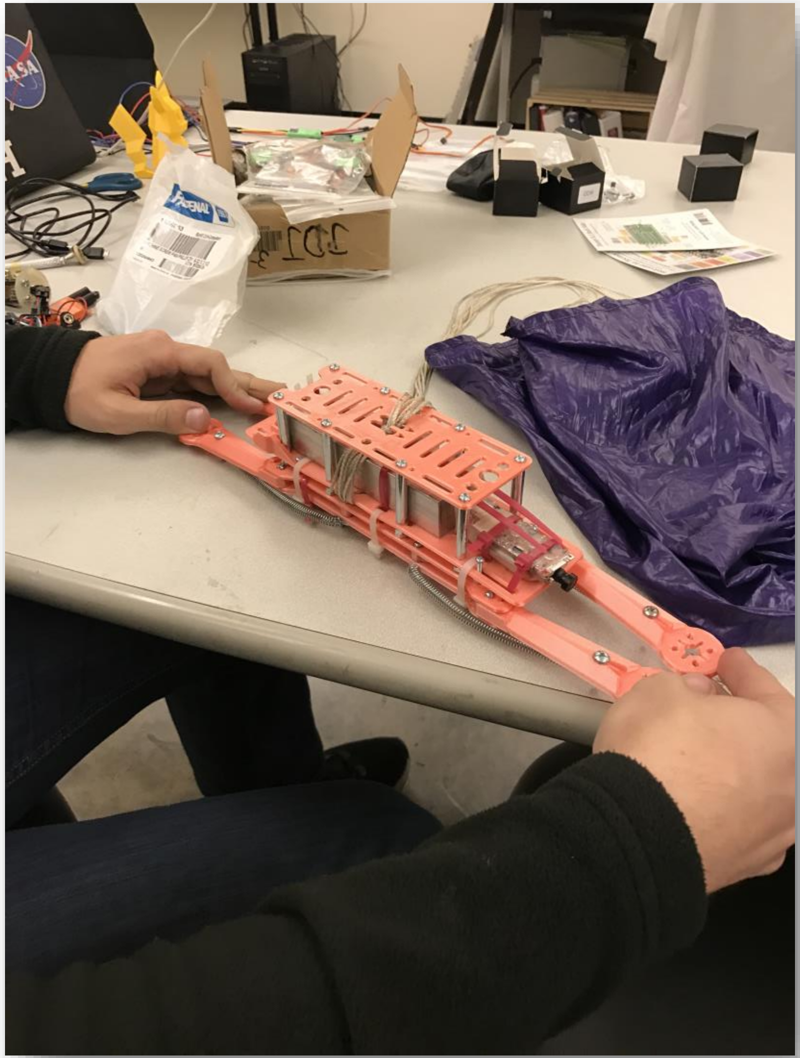
4) Rocket Safely Lands
- Main chute recovery system
    - *Re-flyable condition*

1) Launched Pad
- Quad connected to ground control station
    - *In-situ telemetry data*
- Autopilot active at launch
    - *Pre-programmed flight path waiting for appropriate deployment sequence*

5) Quad Executes Mission
- Autonomous flight
    - *Lands on designated target*



2017 Design




OKLAHOMA
STATE

Risk Assessment and Mitigation

- Risks identified by OSU team and labeled as technical, program, cost or schedule (T, P, C, and S) risks along with probability and impact
- Individual teams will identify additional risks for their design(s)
- Mitigation plans will be constructed for each identified risk

Probability of Occurrence

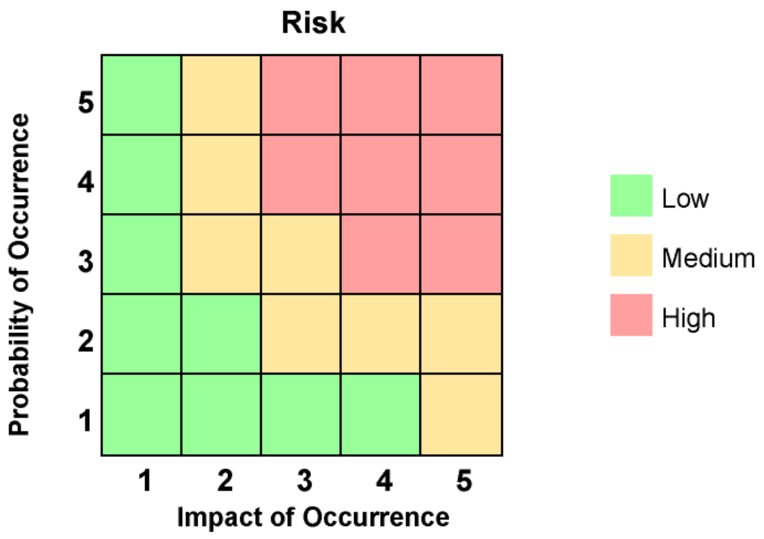
Scale	Measure
5	Near certain to occur (80-100%).
4	Highly likely to occur (60-80%).
3	Likely to occur (40-60%).
2	Unlikely to occur (20-40%).
1	Not likely; Improbable (0-20%).

Impact of Consequences

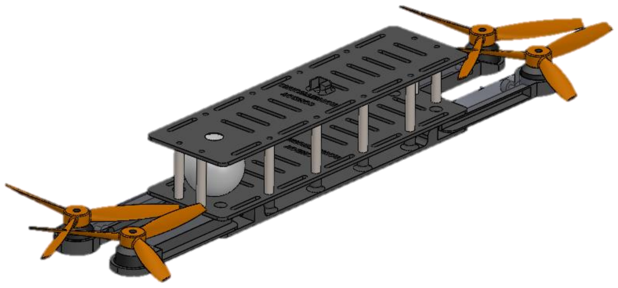
Class	Technical	Schedule	Cost
Class I Catastrophic (Scale 5)	A condition that may cause death or permanently disabling injury, facility destruction on the ground, or loss of major systems, or vehicle	launch window to be missed	cost overrun > 50 % of planned cost
Class II Critical (Scale 4)	A condition that may cause severe injury, or major property damage to facilities, systems, equipment, or flight hardware	schedule slippage causing launch date to be missed	cost overrun 15 % to 50 % of planned cost
Class III Moderate (Scale 3)	A condition that may cause minor injury, or minor property damage to facilities, systems, equipment, or flight hardware	internal schedule slip that does not impact launch date	cost overrun 2 % to 15 % of planned cost
Class IV Negligible (Scale 2)	A condition that could cause the need for minor first aid treatment but would not adversely affect personal safety or health; damage to facilities, equipment, or flight hardware more than normal	internal schedule slip that does not impact internal development milestones	cost overrun < 2 % of planned cost

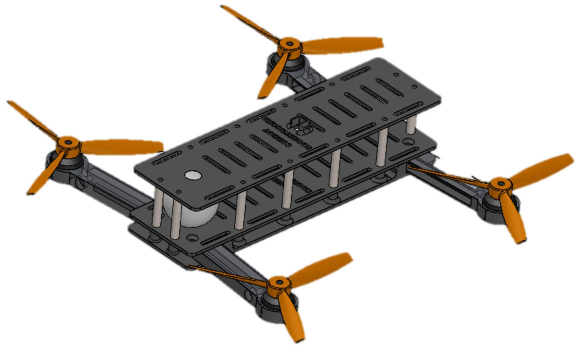
Risk Matrix

- High risks – mission success jeopardized - immediate action required
- Medium risk – review regularly – contingent action if does not improve
- Low risk – watch and review periodically

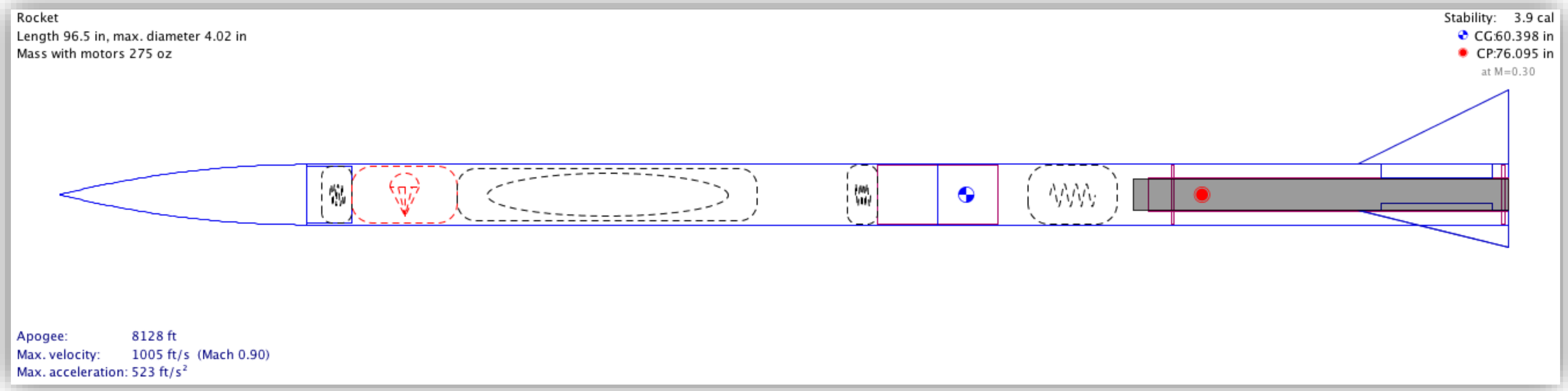


OSU 2017 Design

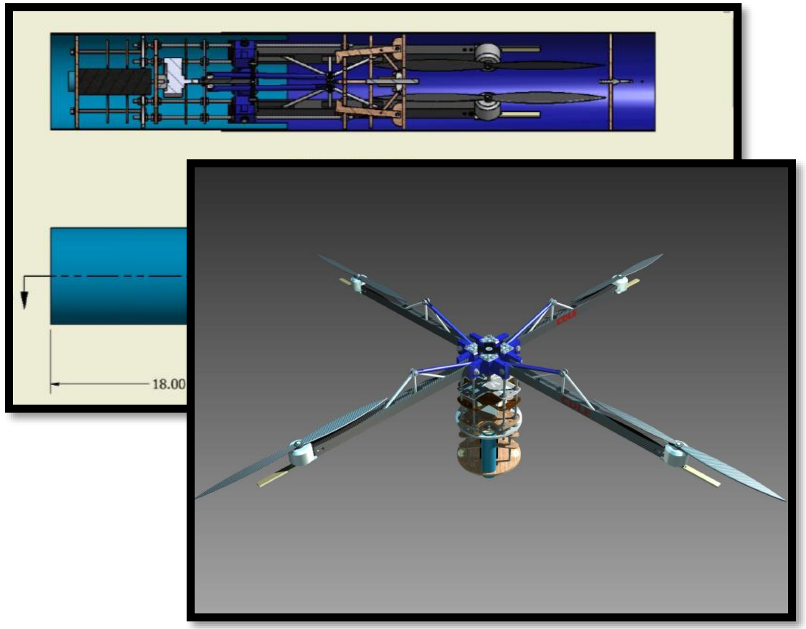




- All major components additively manufactured
- Approximately 3lbs
- Folding propellers
- Spring loaded arm deployment
- “Quad-Sled” designed to hold quad inside rocket until deployment

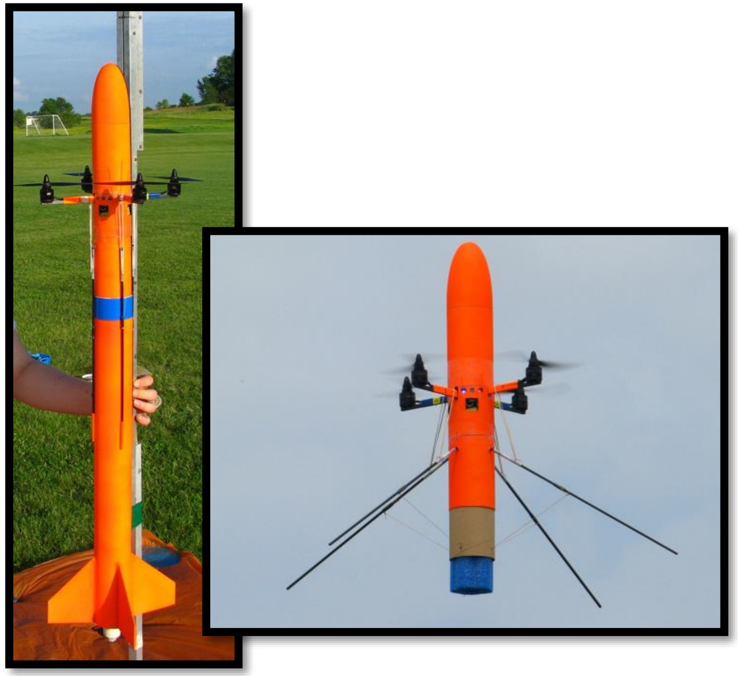


Previous Work – Quads



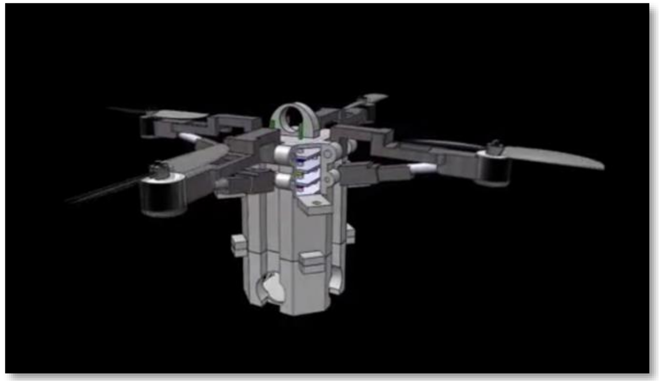
Northeastern University

- Goal: Deploy quad from rocket and collect weather data.
- Rocket destroyed upon ascent.
- Quad never deployed.



"Rocket Girl"

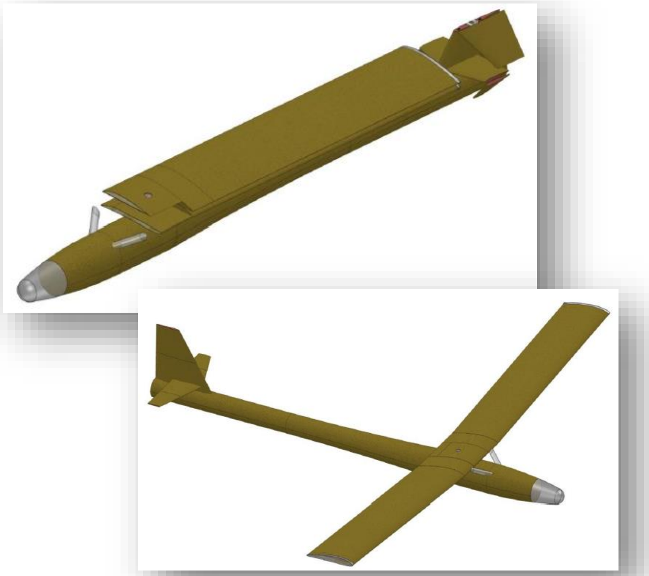
- Goal: Deploy rocket/quad payload and return safely to ground.
- Successful rocket launch.
- Quad never engaged.

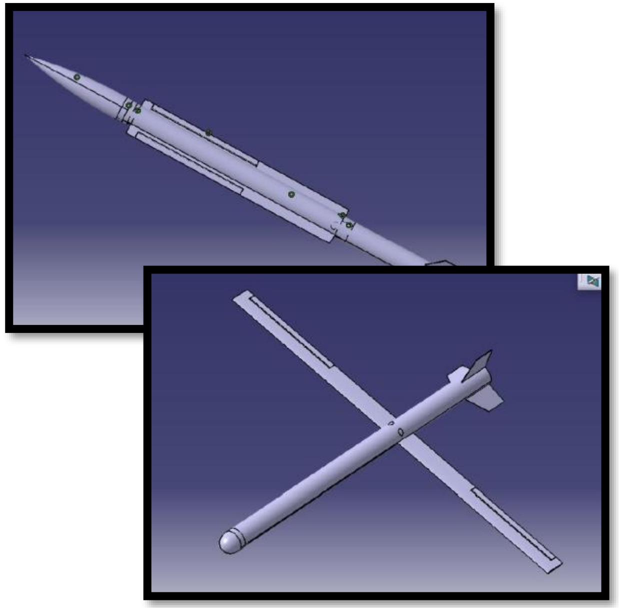


McGill Rocket Team

- Goal: Deploy quad from rocket.
- Launched at Spaceport America Cup 2017.
- Unknown results.

Previous Work – Gliders





MIT

- Goal: Deploy glider to complete search and rescue missions.
- Expected apogee of 5280 feet.
- State of testing unknown.

UPES – India

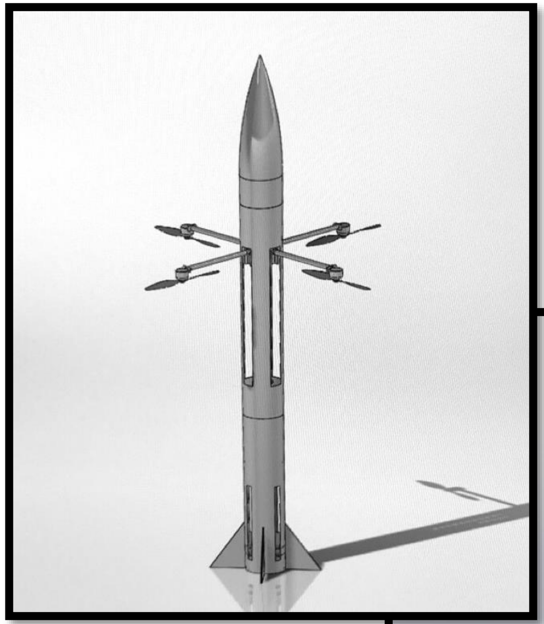
- Goal: Create reusable sounding rockets with.
- Research determined this was a viable solution.
- No proof of concept.

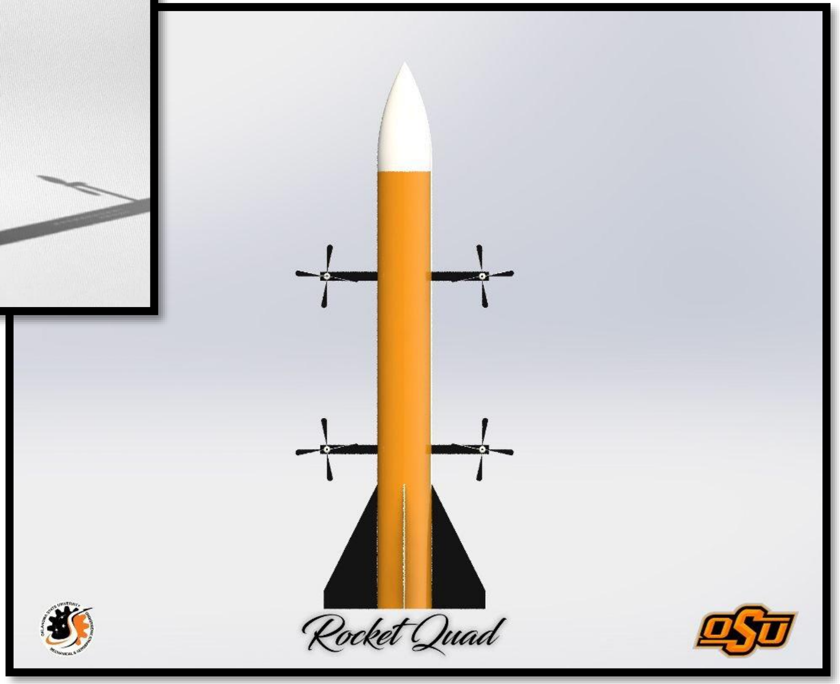
OSU

- Goal: Deploy glider from rocket and return to ground target.
- Apogee: 2080 feet and landed 660 feet from target.
- Glider damaged upon landing.

Initial Brainstorming Options

- Full Top or bottom quad
- Full side quad
- Deployable quad
- Full Quad with Deployable Quad
- Half quad
- Full glider
- Half glider





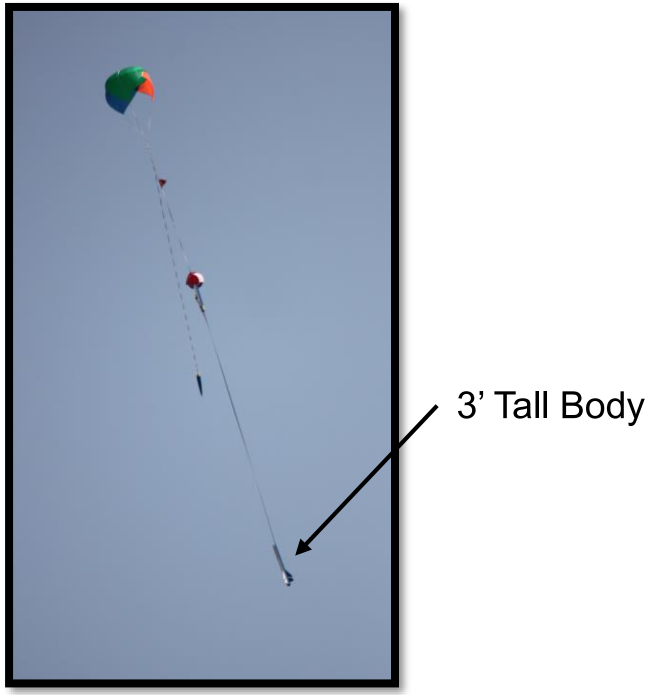
Decision Matrix

Generic Design Weighted Decision Matrix											
		Options									
Criteria	Weight	Deployable Quad		Deployable Glider		Integrated Quad		Integrated Glider		Parachute Only	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Accuracy of landing	10	5	50	4	40	4	40	3	30	1	10
Impact of recovery failure	7	4	28	4	28	2	14	2	14	5	35
Predicted apogee +8,000'	6	3	18	4	24	1	6	2	12	5	30
Cost	6	2	12	3	18	1	6	3	18	5	30
Weight of recovery system	5	3	15	4	20	1	5	2	10	5	25
Testing simplicity	5	4	20	3	15	2	10	1	5	3	15
Simplicity of operation	4	4	16	4	16	2	8	2	8	5	20
Ease of manufacturing	3	4	12	4	12	2	6	2	6	5	15
	TOTAL		171		173		95		103		180

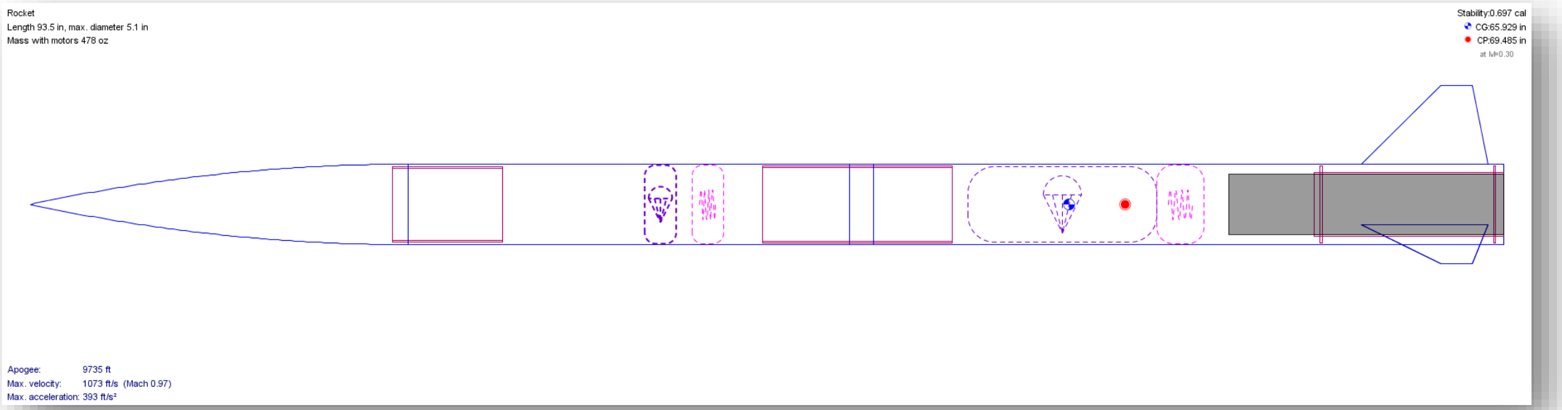
Parachute

Major Pros
- Simple
- Reliable
- High apogee

Major Cons
- Not accurate
- Weather dependent
- Entanglement



Argument Against:
This solution can easily be implemented as a backup system in one of the other design options and therefore should not be pursued as a primary solution.

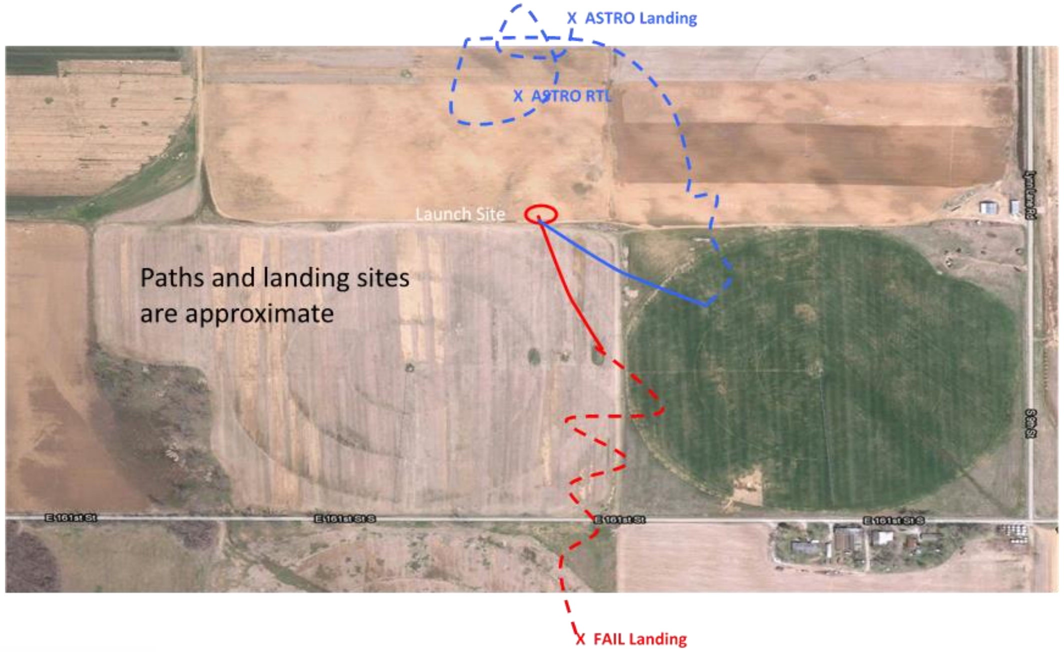


- Length: 7.8 ft
- Max Diameter: 5.1 in
- Gross Lift-off Weight: 29.9 lb
- Apogee: 9735 ft
- Max Velocity: 731 mph
- Max acceleration: 12.2 g

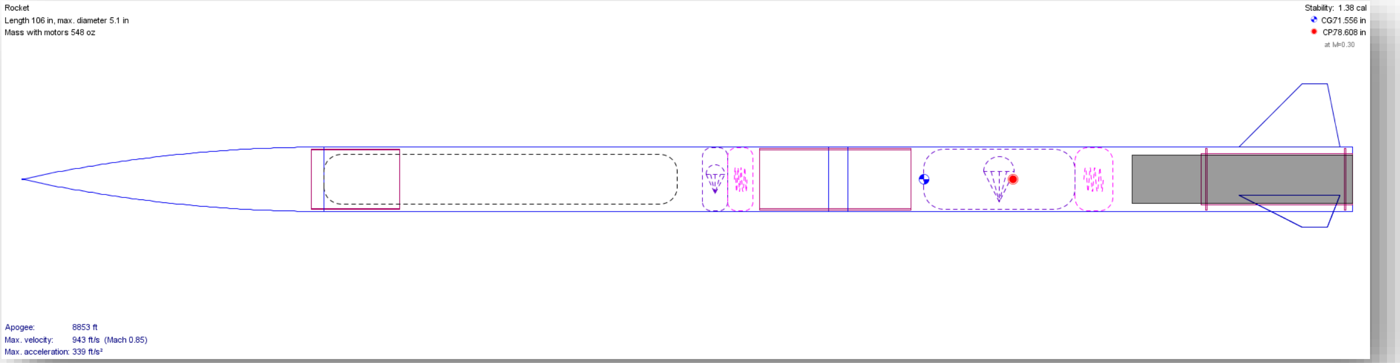
Deployable Glider

Major Pros
- Dynamically stable
- Power efficient
- Book knowledge

Major Cons
- Less accurate
- GPS dependent
- Non-recoverable altitude
- Weather dependent



Argument Against:
This solution has previous success, but is not as accurate and frequently suffers damage upon landing, therefore disqualifying the flight.



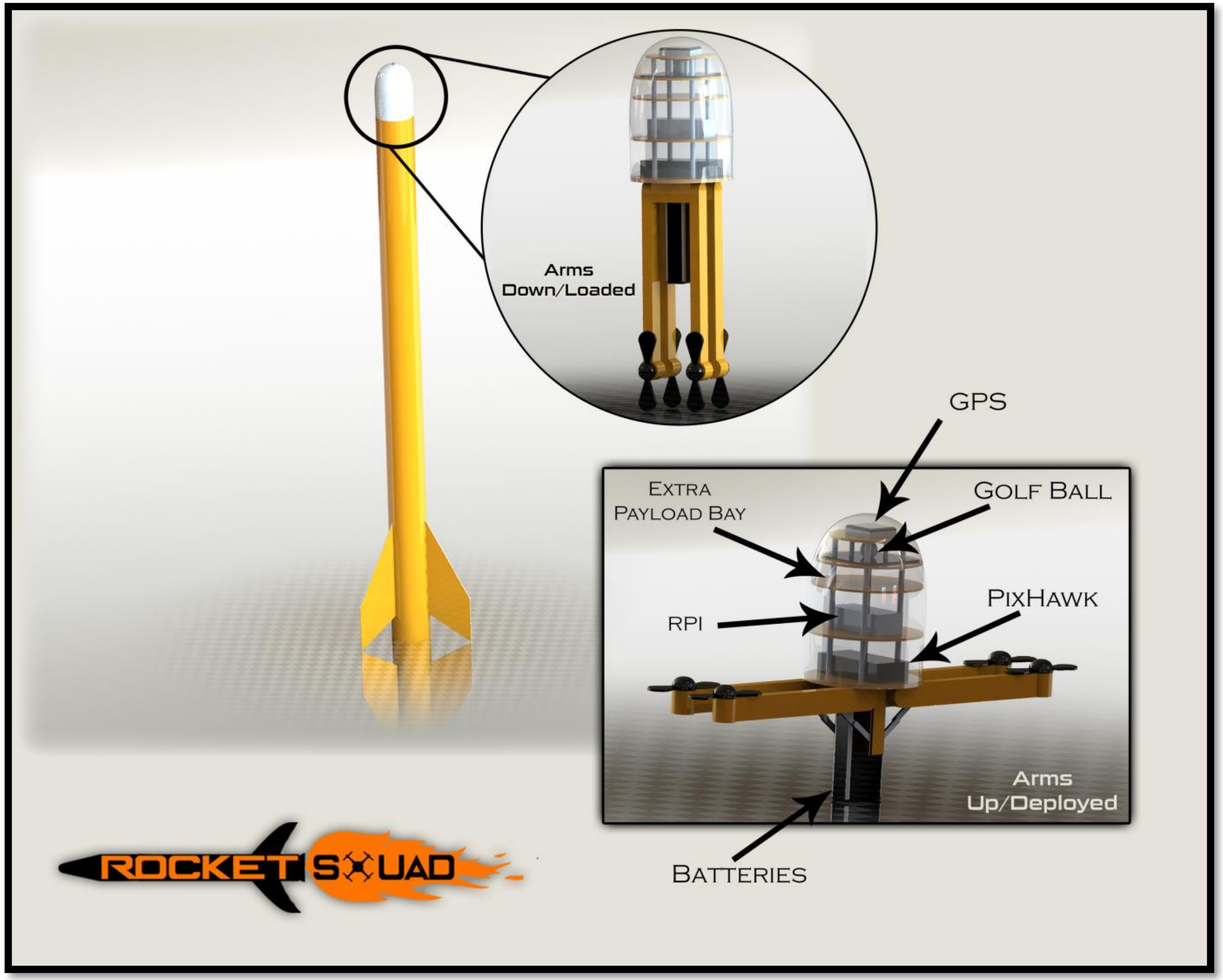
- Length: 8.8 ft
- Max Diameter: 5.1 in
- Gross Lift-off Weight: 34.25 lb
- Apogee: 8853 ft
- Max Velocity: 643 mph
- Max acceleration: 10.5 g

Deployable Quad

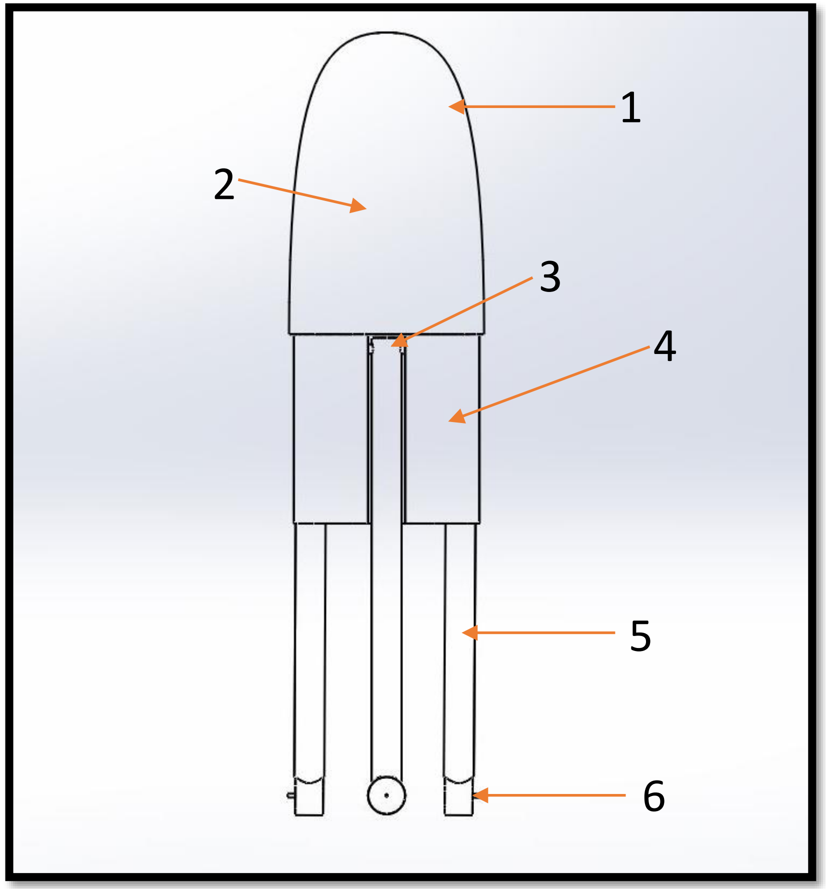
Major Pros
- Very precise
- Fairly weather resistant
- Simple manual override
- Recoverable altitude

Major Cons
- Battery limited
- GPS dependent
- Heavier

Argument For:
This solution gives an extremely precise landing in more extreme conditions, therefore giving the greatest chance for mission success.

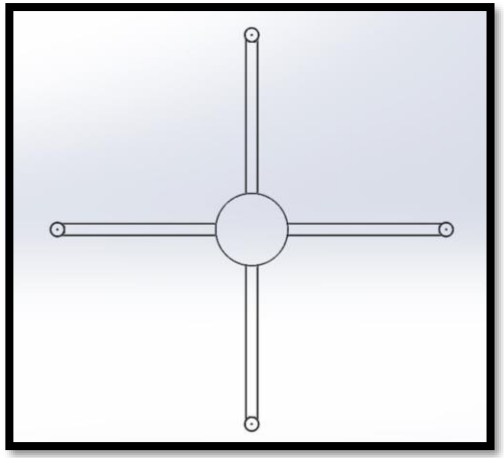


Quad System

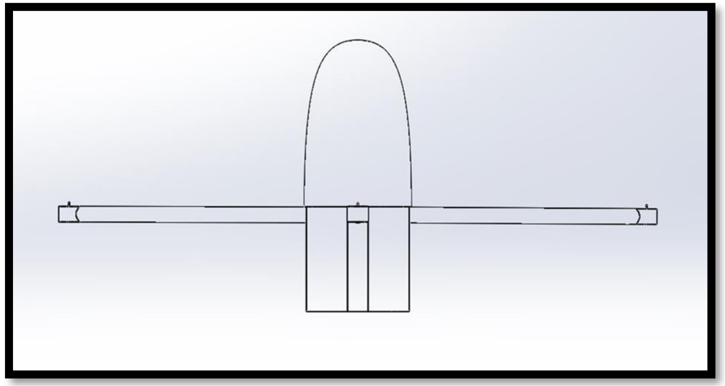


Side View: Arms Retracted

1. 3D Printed Nose Cone
2. Internal Avionics
3. Quad Arms Torsional Spring Joint
4. Portion of Quad Covered by Rocket Tube
5. Quad Arms
6. Quad Motors

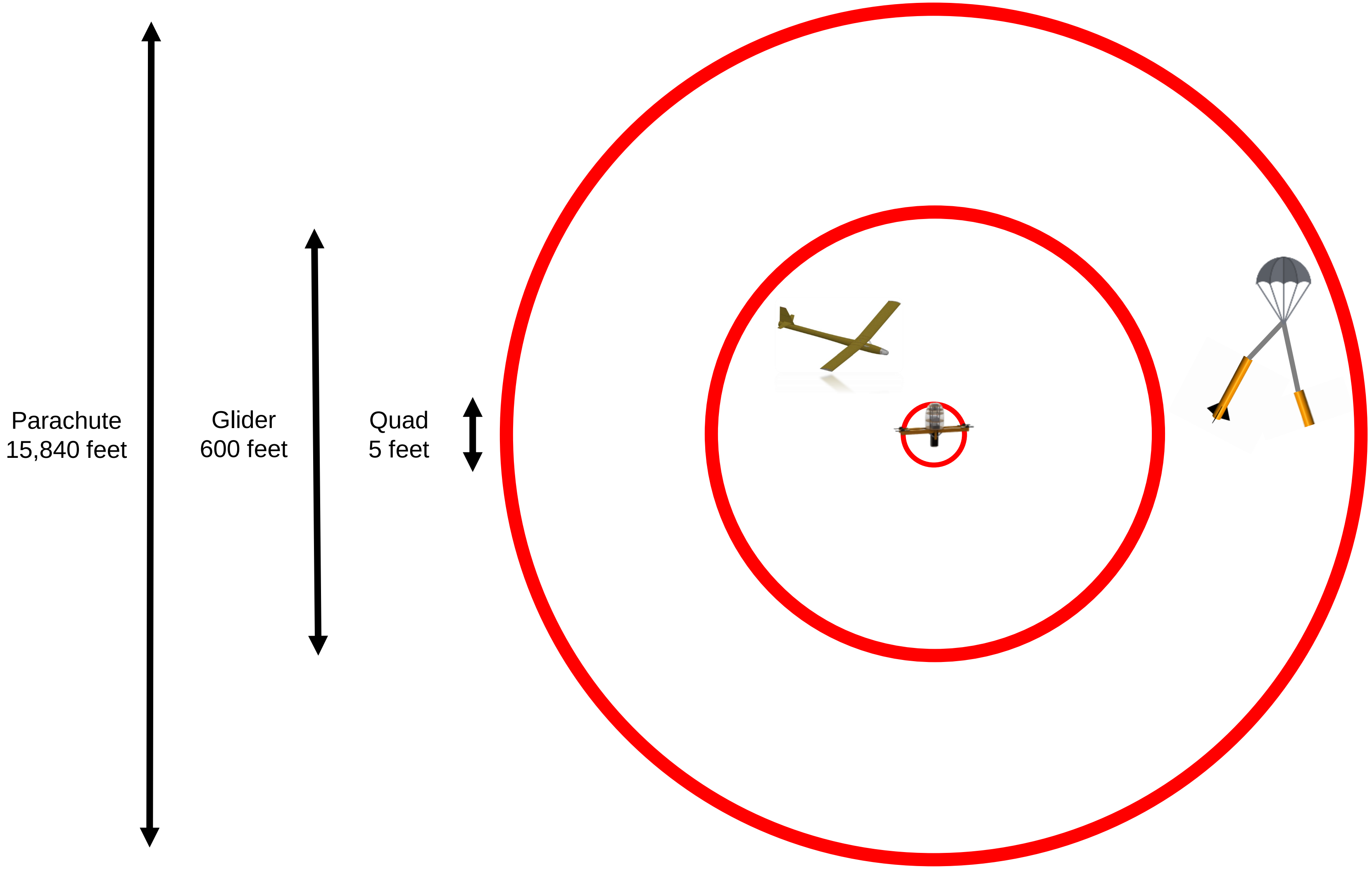


Top View: Arms Extended



Side View: Arms Extended

Accuracy Comparison



Final Design Plan

Structures
Task 1: Manufacture and analysis of rocket tubes
Task 2: Iterate manufacturing process of couplers
Task 3: Use finalized quad structure to design fin shape

Integration
Task 1: Iterate designs for quad assembly
Task 2: Prototype arm deployment
Task 3: Weight comparison for main structure

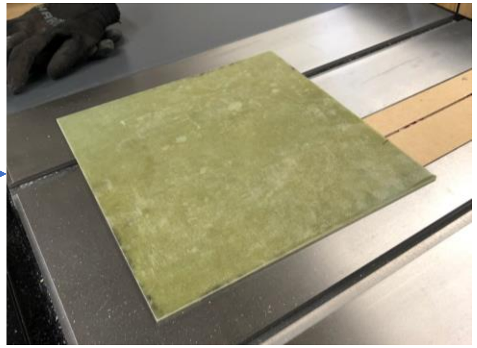
Avionics
Task 1: Initial software testing
Task 2: Finalize quad avionics layout
Task 3: Select motors, ESCs, and batteries

Structures – Completed Work

- First iterations of fiberglass parts
  - Tubes – used 4” PVC pipe as casting mandrel to make three tubes of varying thicknesses and materials
  - Sheets (plates) – used to cut centering rings, fins, and bulkplates
    - CNC parts for assembly
- Assembly and flight of *Everything is Sticky*
  - Allowed for practice in making all composite components of a basic high-power rocket
  - 3D printed nosecone
  - Build of this rocket aided in identifying improvements for a future rocket
  - Withstood flight stresses, including 17G
  - Undamaged recovery, flawless flight

Structures – Construction Process

- Fiberglass tubes
  - Cast onto 4.5” OD PVC pipe
  - Lubricated with cooking spray, Vaseline on later iterations and wax paper
  - Pre-cut length of fiberglass cloth for given number of wraps
  - “Pour and Pet” method with three team members to wrap tube and let cure
  - 6 wraps used on *Everything is Sticky,* finished with sanding
- Fiberglass sheets
  - Pre-cut square sheets of fiberglass cloth to cover 12”x12” square
  - “Slather and Scrape” method to apply resin between layers
  - Compressed with weights and then edges trimmed on table saw
  - Parts cut as necessary with CNC
  - 3x 1ft^2 sheets made: 1 is 1/8” thick, 2 and 3 are 0.17” and 0.165” thick both weigh 21.9 oz

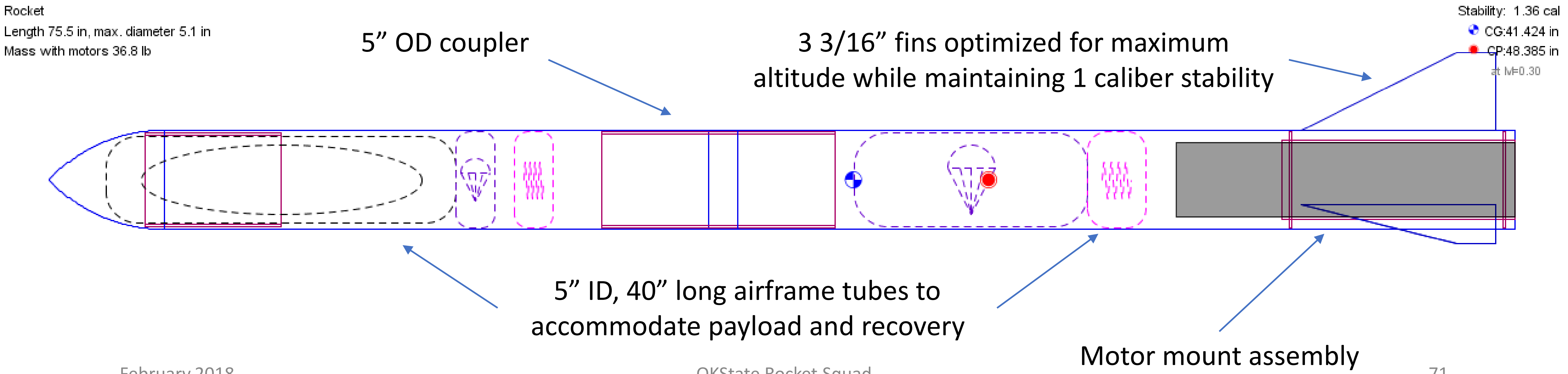


Structures – Tubes

- Emphasis on fiberglass tubes
  - 5” tubes purchased commercially run $34/foot
  - Frequently out of stock
  - Cut in per-foot segments meaning some parts of cut off and unusable
- We made a 4.5” ID fiberglass tube from 4” PVC pipe
  - 40” section is longest expected section to be flown in final flight configuration
  - Commercial 4.5” fiberglass tube, 40” length: 3.5 lb
  - Our 4.5” fiberglass tube, 40” length: 2.6 lb (6 wraps)

Structures – Upcoming Tasks

- Acquire 5” casting mandrel
- Refine techniques for achieving smooth inside and outside surfaces
- Be able to make secure, consistent coupler sections (so far unaccomplished)
- Compression testing of airframe sections
  - To determine whether fiberglass tubes will buckle under rockets weight and expected accelerational loading (40lb rocket x 10G loading)
  - If buckling does occur, construct tubes that will withstand expected flight stresses
- Build next iteration of rocket for March 11th test launch (last known opportunity before April 7th)



Structures – Final Deliverables

- Parts Structures Team will be required to build to complete two rockets:
  - Airframe sections (x4)
  - Airframe couplers for altimeter bay (x2)
  - Motor mount tube (x2)
  - Custom CNC-cut fins (x6)
  - Custom CNC-cut centering rings (x4)
  - Custom CNC-cut bulkplates (x8)
  - Motor retention (x2)
- Assembly and tests:
  - Structural build of motor mount tube, fin can, and altimeter bay
  - Ejection charge testing to verify adequate separation of payload and recovery

Slip band	NEW FIBERGLASS (1.2 oz/in²)	Dia_{in} 4.9 in Dia_{out} 5.1 in	Len: 1.5 in	Mass: 0.177 lb
Altimeter bay	NEW FIBERGLASS (1.2 oz/in²)	Dia_{in} 4.7 in Dia_{out} 4.9 in	Len: 12 in	Mass: 2.5 lb
Body tube	NEW FIBERGLASS (1.2 oz/in²)	Dia_{in} 4.9 in Dia_{out} 5.1 in	Len: 40 in	Mass: 4.71 lb
Inner Tube	NEW FIBERGLASS (1.2 oz/in²)	Dia_{in} 3.855 in Dia_{out} 4.055 in	Len: 12 in	Mass: 1.12 lb
Centering ring	Cardboard (0.698 oz/in²)	Dia_{in} 4.055 in Dia_{out} 4.9 in	Len: 0.125 in	Mass: 0.157 lb
Centering ring	Cardboard (0.698 oz/in²)	Dia_{in} 4.055 in Dia_{out} 4.9 in	Len: 0.125 in	Mass: 0.157 lb
Trapezoidal fin set (3)	Fiberglass (1.07 oz/in²)	Thick: 0.187 in		Mass: 0.893 lb

BOM & Manufacturing Plan

	Part ID	Part Name	Revision	Quantity
QUAD	1	Top Quad	A	1
	2	Bottom Quad	A	1
	3	Metal Rod	-	2
	4	Rotor Arm	-	4
	5	Motor Mount	A	4
	6	ESC	-	4
	7	Motor	-	4
	8	Propeller	-	4
	9	Propeller Mount	-	4
	10	Torsion Spring	-	8
	11	Nuts	-	16
	12	Plates	A	4
	13	Pixhawk	-	1
	14	GPS	-	1
	15	Golf Ball	-	1
	16	Raspberry Pi	-	1
	17	Receiver	-	1
	18	FPV Radio	-	1
	19	OSD	-	1
	20	Pixhawk Radio	-	1
	21	Camera	-	2
	22	Parachute	-	1
	23	Battery	-	1
	24	Dampeners	-	4

	Part ID	Part Name	Revision	Quantity
ROCKET	25	Aft Mainframe	A	1
	26	Forward Mainframe	A	1
	27	Large E-Bay Plate	A	2
	28	Small E-Bay Plate	A	2
	29	E-Bay Coupler	A	1
	30	E-Bay Ring	A	1
	31	Motor Coupler	A	1
	32	Centering Ring	A	2
	33	Fin	A	3
	34	Drogue Parachute	-	1
	35	Main Parachute	-	1
	36	Aft Shock Cord	-	1
	37	Forward Shock Cord	-	1
	38	Wadding	-	2
	39	Quick Links	-	6
	40	98mm Motor Casing	-	1
	41	Metal Rod	-	2
	42	Nut	-	12
	43	Washer	-	12
	44	Eye Hooks	-	3
	45	Black Powder Charges	-	4
	46	E-Matches	-	4
	47	Ignitor	-	1
	48	L1500T Motor	-	1

	Part ID	Part Name	Revision	Quantity
Ground Control Station	49	Pixhawk Radio	-	1
	50	FPV Receiver	-	1
	51	Computer	-	1

Manufacturing Plan

- Rocket Tubes
  - Fine tune manufacturing process of rocket tubes.
- Quad Body
  - Find optimal infill density for quad structure.

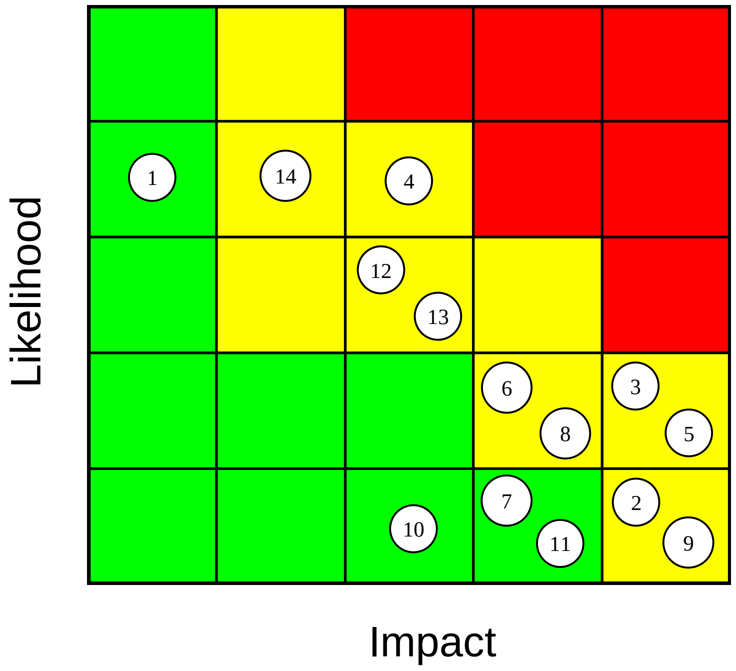
Major Dates

- 2/13/18 - Last day to purchase motor(s) for March 11 launch
- 2/26/18 - last day to purchase parts from rocket vendors for March 11 launch
- 3/13/18 - last day to purchase motor(s) for Argonia Cup

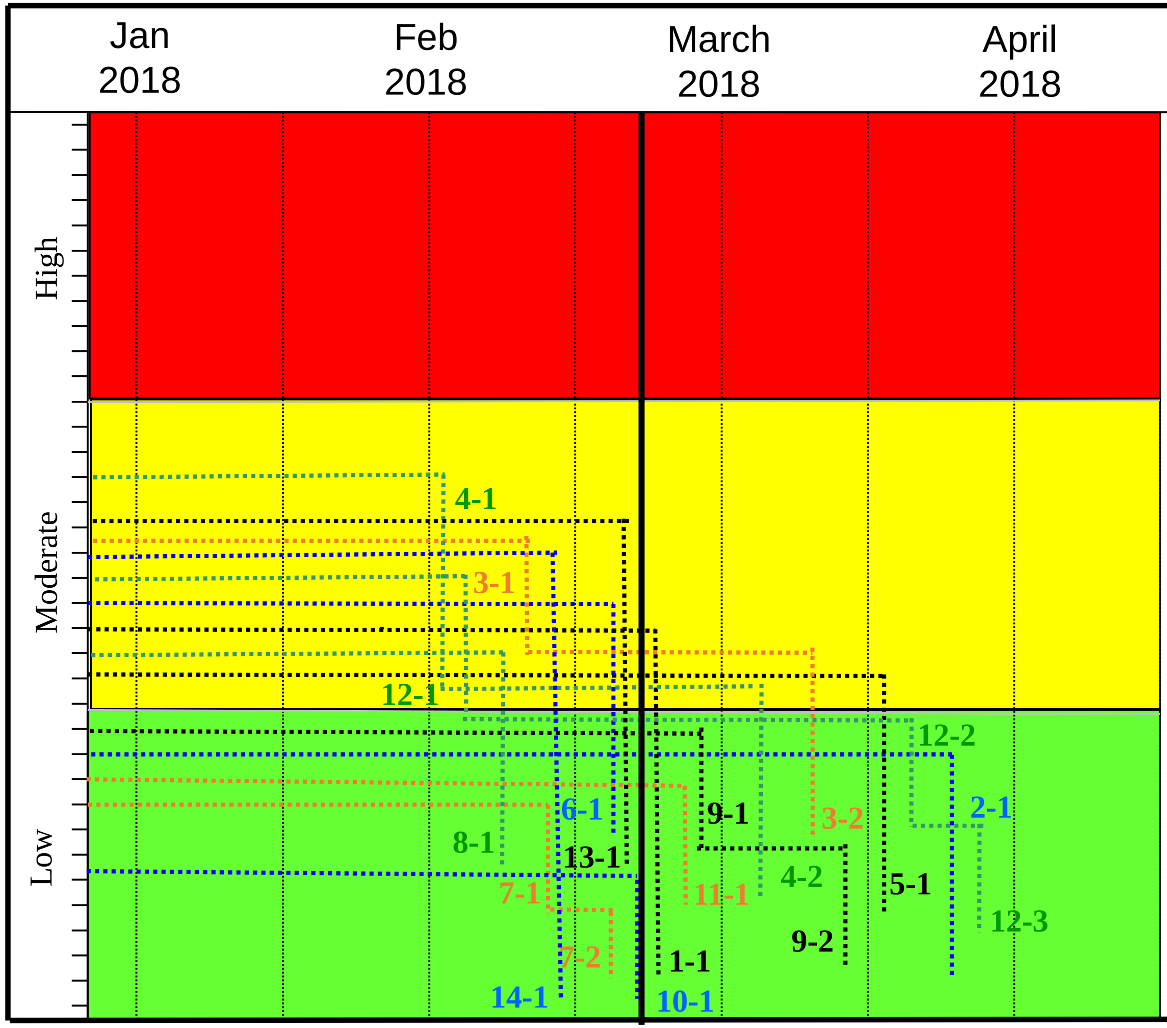
Quad/Rocket Design Risk Assessment

ID	Event	Likelihood	Impact	Responsibility
1	Ignitor Burnout	4	1	Full Team
2	Motor CATO	1	5	Structures
3	Structural Failure	2	5	Structures
4	Avionics Vibration	4	3	Avionics
5	Altimeter Failure	2	5	Avionics
6	Quad Deployment Failure	2	4	Integration
7	Quad/Chute Entanglement	1	4	Integration
8	Quad Arm Deployment Failure	2	4	Integration
9	Quad Electronics Failure	1	5	Avionics
10	Quad Autopilot Failure	1	3	Avionics
11	Quad Stabilization	1	4	Avionics
12	Telemetry Loss	3	3	Avionics
13	Recovery Distance	3	3	Full Team
14	Weather	4	2	Full Team

*CAPEX Lab *Mitigating *Mostly Mitigated



Risk Mitigation Plan



Mitigation Events

1-1 = Purchase reliable ignitor
2-1 = Assemble motor with secondary checker
3-1 = Compression testing
3-2 = Pressure testing
4-1 = Install dampeners
4-2 = Run shaker table tests
5-1 = Install redundant systems
6-1 = Test deployment sequence
7-1 = Design for clean separation
7-2 = Test deployment sequence
8-1 = Test arm deployment mechanism
9-1 = Design redundant system
9-2 = Inspect connections to ensure strength
10-1 = Design manual override system
11-1 = Test stability after deployment sequence
12-1 = Choose appropriate materials
12-2 = Choose appropriate ground control hardware
12-3 = Design on-board backup
13-1 = Analyze and design to worst case scenario
14-1 = Design for worst case scenario

Verification Plan

Test ID	Test	Description	Acceptance Criteria	Verification Technique	Responsibility	Date
1	Telemetry Range	Test telemetry range to 8,000’ for ensured communication during flight.	Connection is not lost during test.	Test	Avionics	2/26/18
2	Stability	Violently shake and spin quad before throwing into the air to ensure ability to gain stability during deployment.	Quad gains stability.	Test	Integration, Avionics	2/26/18
3	Quad Deployment	Deployment test of drogue & quad (separation from rocket ground test), main ejection charge test.	Quad and drogue deploy from rocket body.	Test	Structures	3/6/18
4	Quad Arm Deployment	Test to determine that quad arms will properly deploy and lock into place.	Arms deploy and lock into place.	Test	Integration	2/30/18
5	Avionics Vibration	Test avionics on shaker table to ensure connections and functionality.	Avionics remain connected and operating properly throughout and after test	Test	Avionics	2/30/18
6	Rocket Drift	Calculate worst case scenario for rocket drift to determine ability of quad to travel that distance.	Test flights exceed worst case scenario conditions.	Analysis/Test	Integration	2/8/18
7	Structural Compression	Compression loading test of custom fiberglass airframes and couplers.	Structure remains intact without any damage during testing.	Test	Structures	2/17/18
8	Structural Pressure	Ejection charge test for internal pressure verification of custom fiberglass airframes.	Structure remains intact without any damage during testing.	Test	Structures	2/16/18
9	Software	Test that software plan will operate properly in real flight conditions.	Quad autonomously completes mission.	Test	Avionics	2/23/18

Integration – Preliminary Quad System

Design of the Quad Nosecone

- 3D printed base and cone
- ¾” Deployable quad arms with 15” dia. props at the end
- Torsional spring to extend arms and lock in place
- Ejected from rocket via piston charge
- Internal Structure using platforms to support electronics
- Contain back-up parachute in base

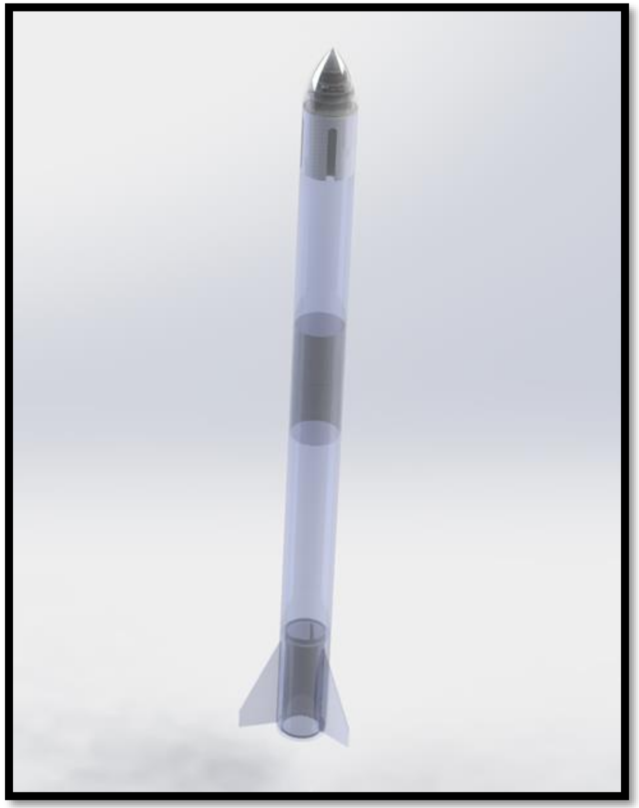
Time (sec)	Process of Quad Transition
0.00	Launch
23.50	Altimeter recognizes apogee – Activates black powder piston
24.50	Piston pushes quad and drogue chute out
25.00	Quad arms fold out locking in place
25.50	Sensor recognizes quad deployment – activates autopilot

Integration – Completed Work

- Tested two methods of deploying arms using simulated weights for loads
  - Linear spring
  - Torsional Spring – Implemented option
- Created quad design iterations that led to the preliminary design
- 3D printed nosecone to test launch
- Verifying locking mechanism for deployed arms

Integration – Upcoming Tasks

- Verify locking mechanism for deployed arms.
- Finalize weights of all components for rocket design criteria.
- Test strength of printed material for base with computer simulations and ground tests.
- Purchase necessary parts.
- Verify arm deployment from body tube.

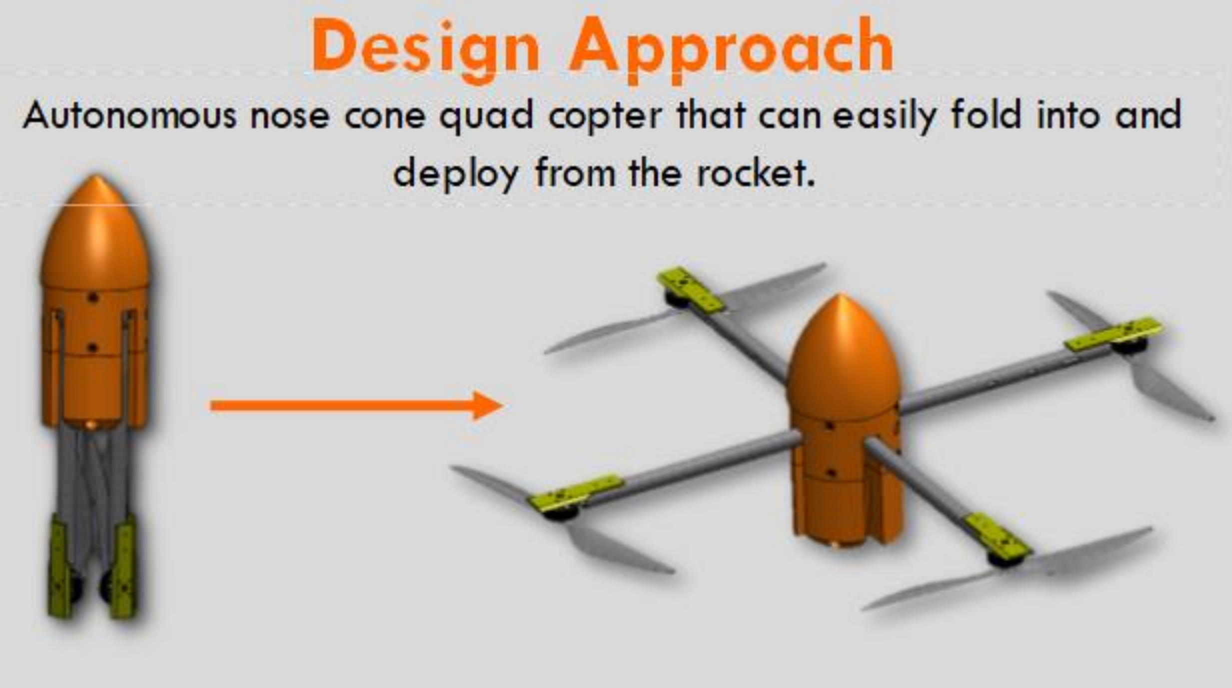


Integration - Risks and Mitigation

- Risk: Failure of deployment of arms
  - Testing for arm deployment and locking mechanism
- Risk: 3D Printed Material Failure
  - Running simulations and test ejection of quad for strength of 3D printed material
- Risk: Quad system is overweight
  - Calculating weight with each iteration and removing unnecessary materials
- Risk: Quad/Chute entanglement
  - Ground test back-up chute

Integration – Next Steps if Continued

- Retest the design under observed circumstances.
- Refine the design to minimize the weight.
- Find a way to eliminate the issue of the propellers hitting the arms.
- Stop the bending of the propeller screws/shearing of the motor propeller threads.
- Deal with the shearing of the rivet holes between the bottom and mid section

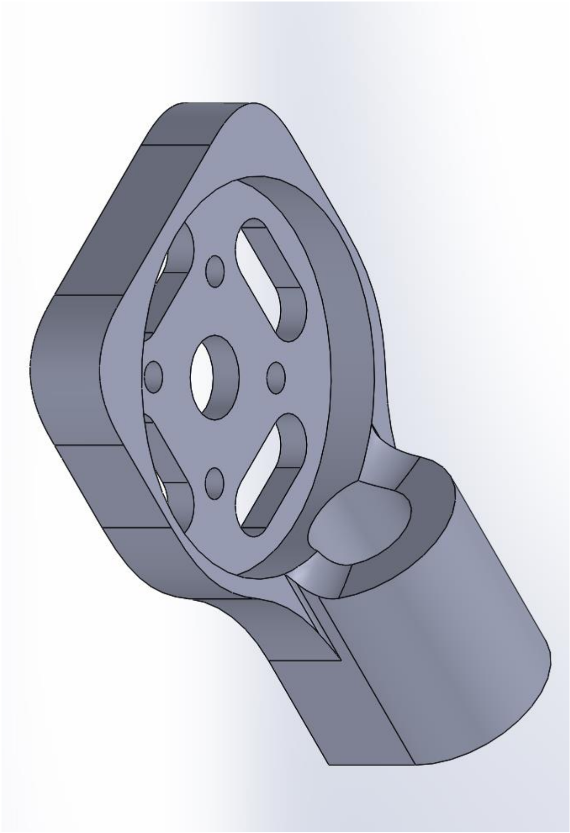


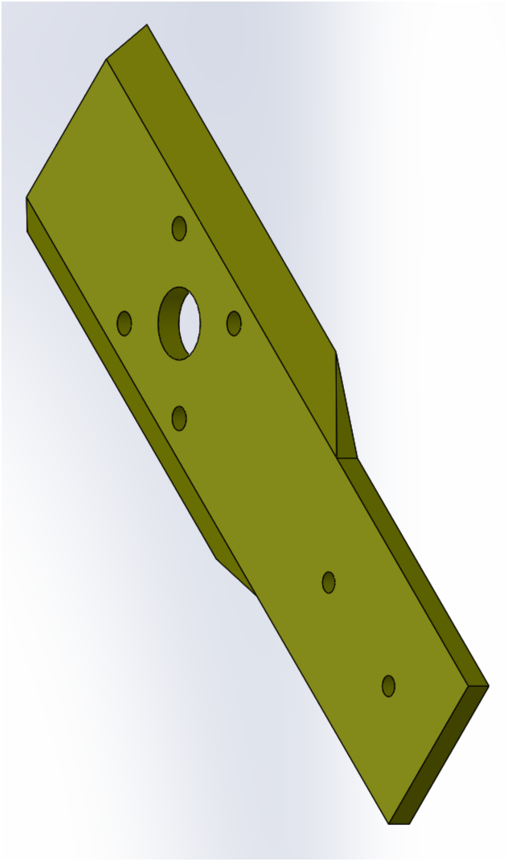
Integration – Verification

- Quad Stability
  - Ground testing to verify all components could handle full thrust.
- Quad Arm Deployment
  - Ground testing by pulling quad out of Rocket and test ejecting
- Rocket Drift
  - Using OpenRocket and other Simulations to estimate the distance and flight time needed

Integration – Motor Mount Design Iterations

- Display of all of the iterations of the motor mount to the final version



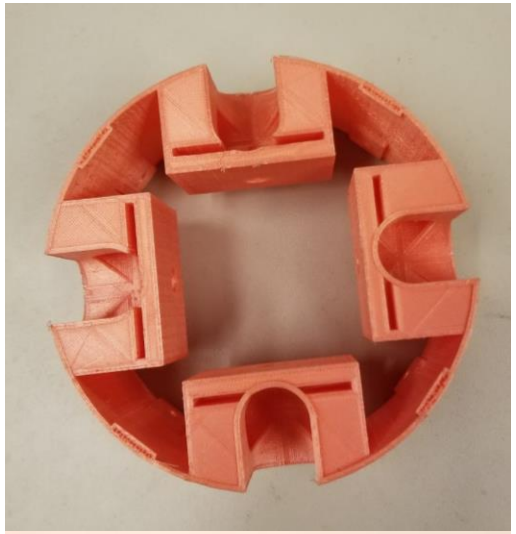



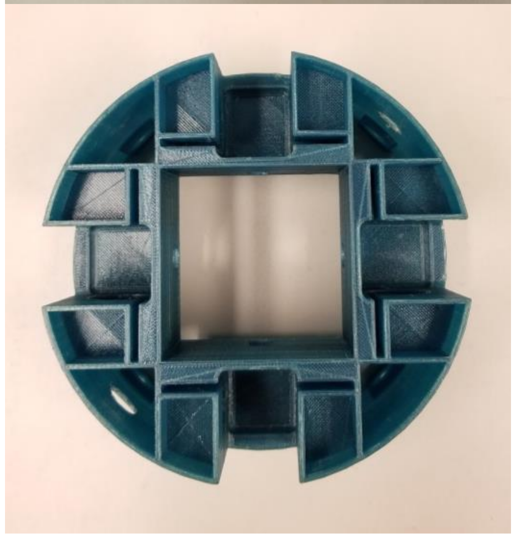
Integration – Quad Arm Iterations

- Initial design used carbon fiber as the material. 20 mm x 18 mm OD x ID
- Test with ½” PVC as it was cheaper, easy to manufacture arms, and close dimensions (0.84” OD)
- Holes drilled in side to allow for ESC wires to be on the inside.
- Sanded edges around the pin connection to keep from scraping 3D structure.
- Notch cut into side where motor wires are attached to keep from pinching them.
- Cracking carbon fiber due to spring force led to PVC replacing it in the final design

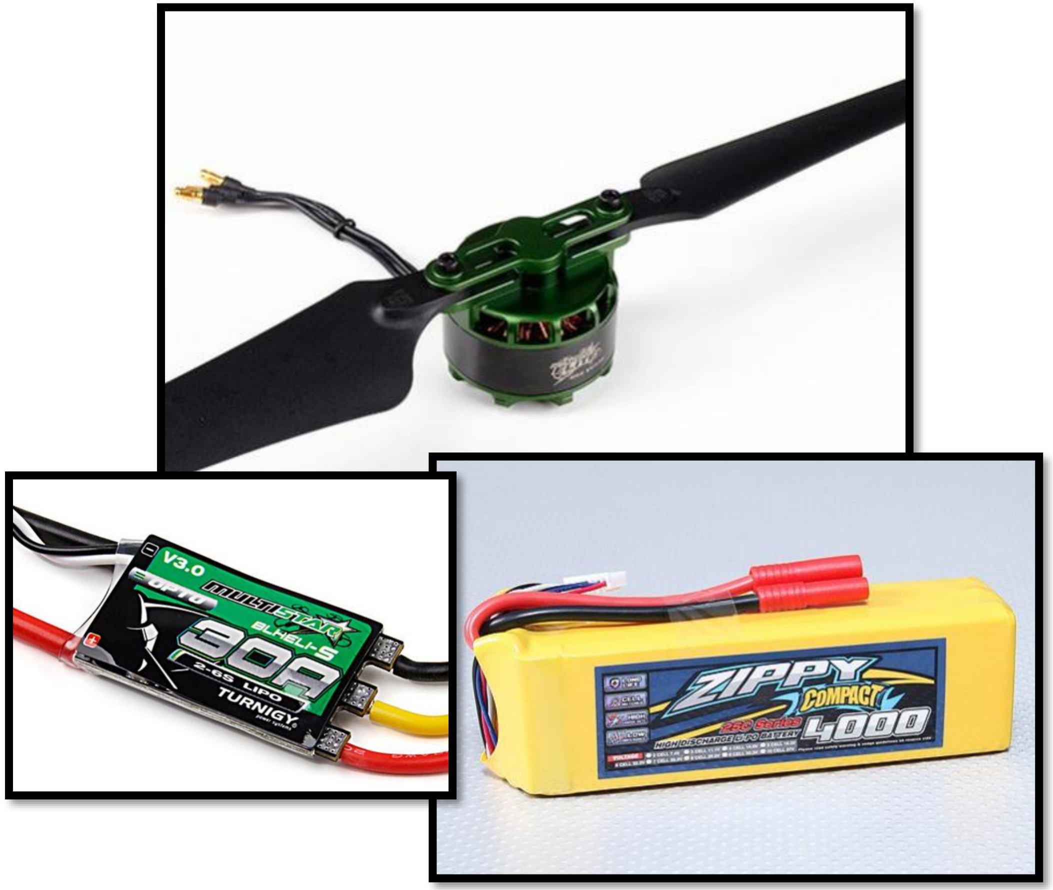
Integration – Quad Body Iterations

- Originally 2 sections, Body and Nose Cone
- Body was split into two for easier access to things around the battery.
- Infill Percent was taken up to 100% for some of the crucial portions
- Wall thickness was increased on some portions to prevent cracking
- Holes for the bolts that attach the arms were added
- Held together by nylon rivets
- Strengthening around the arm portion was required

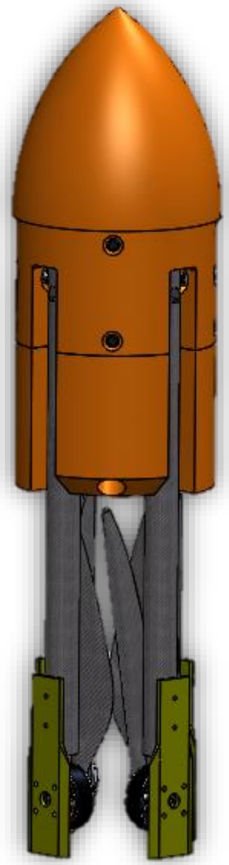


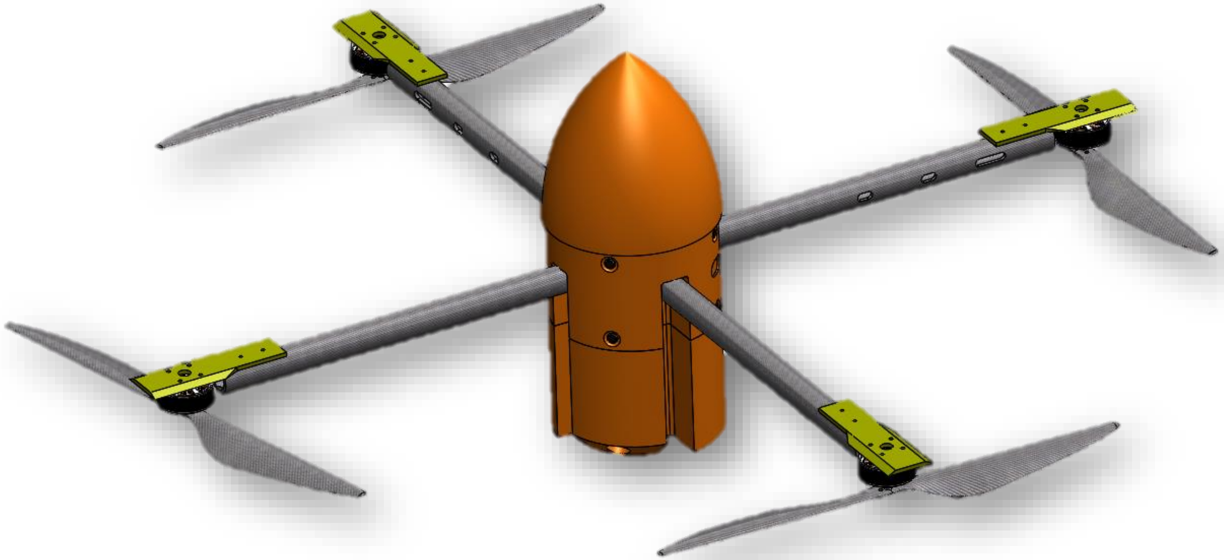


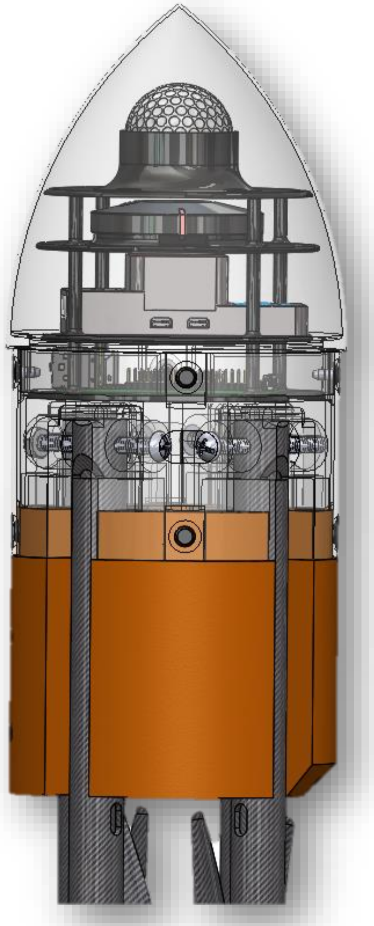
Avionics Materials



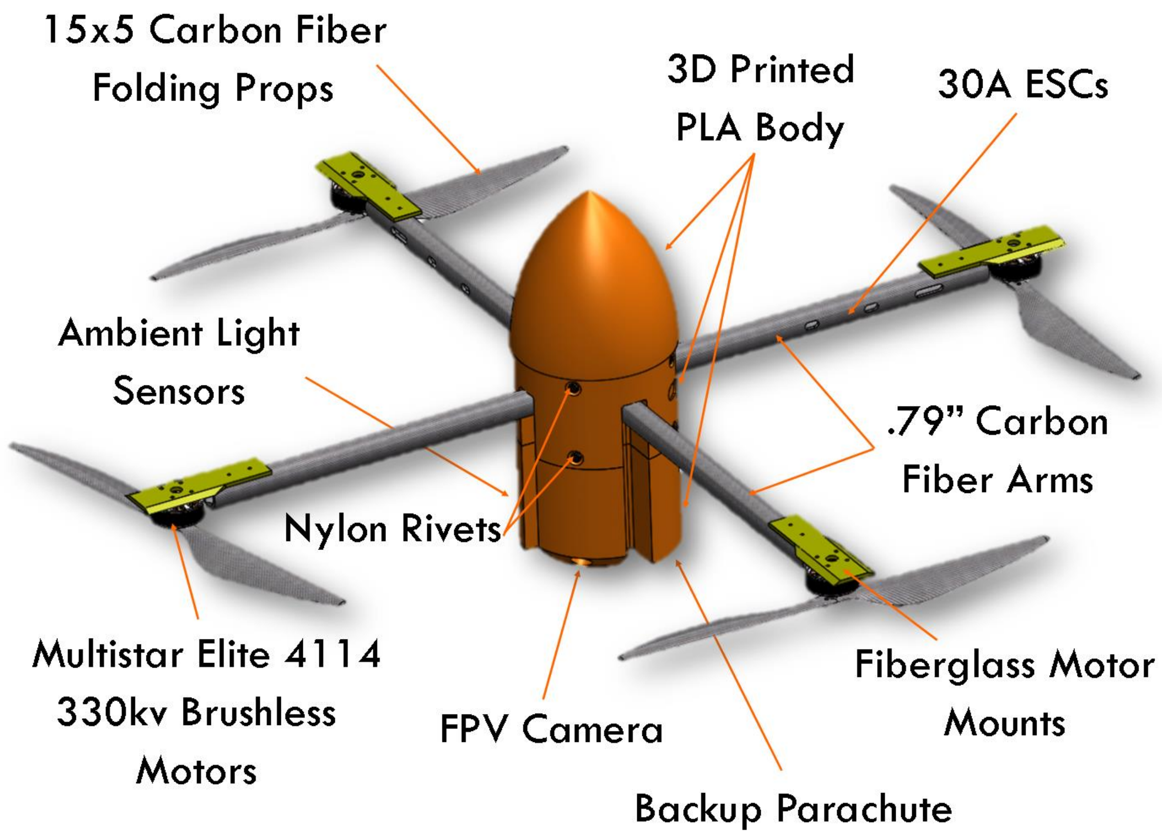
CAD Images

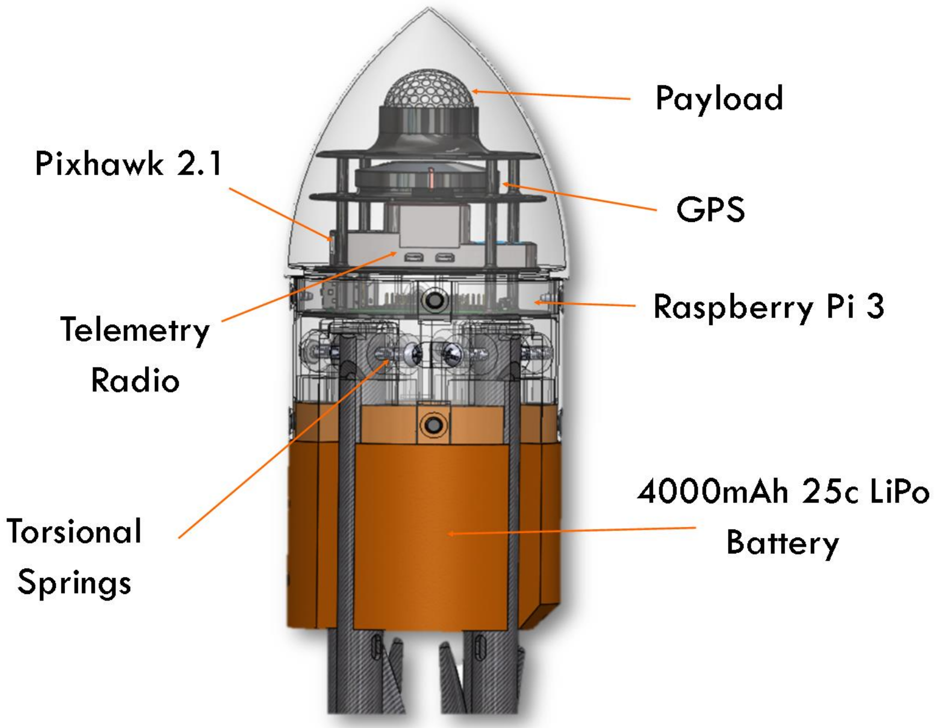






Integration – Quad Design Layout





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