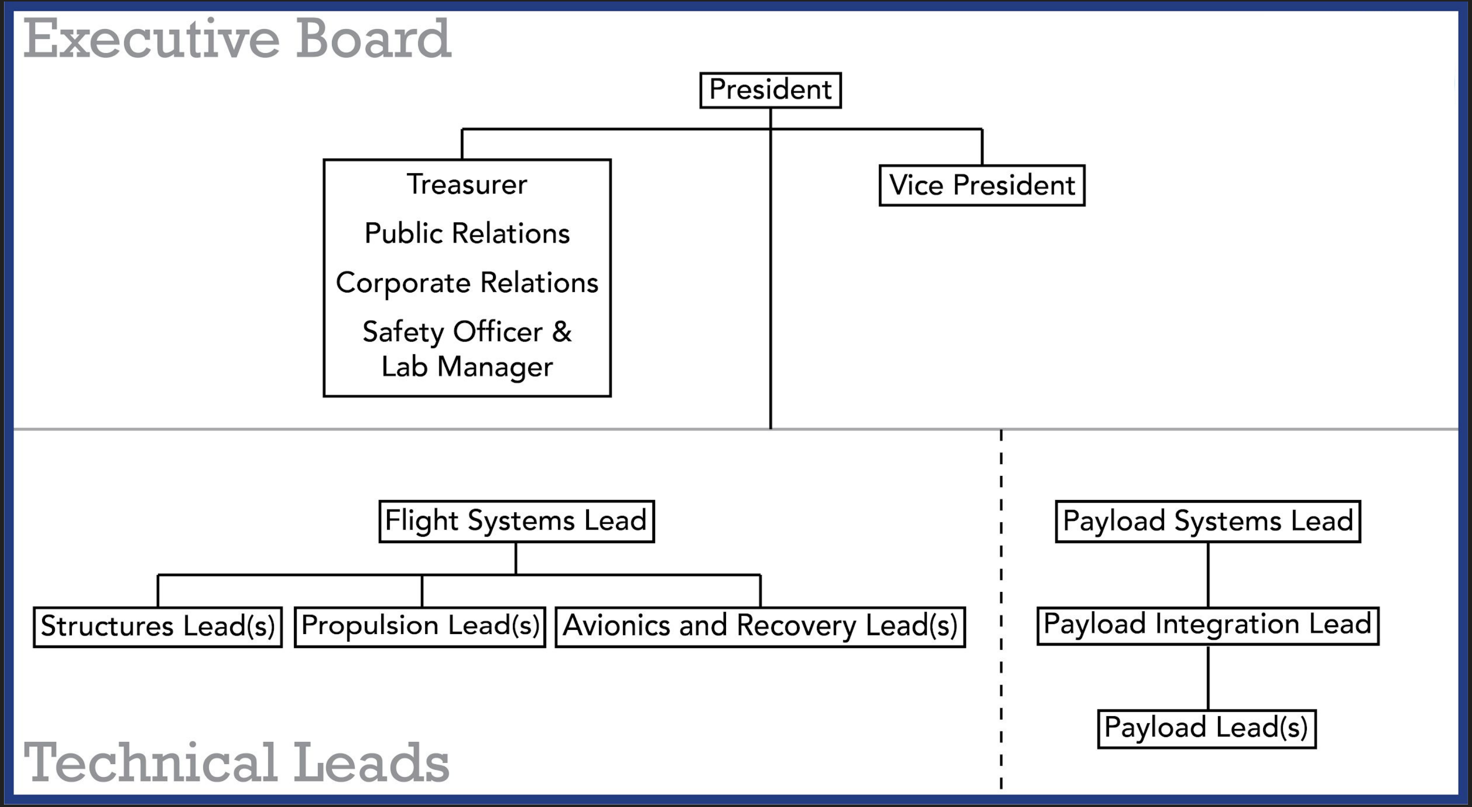
# Stratus I
# Preliminary Design Review

LionTech Rocket Labs, November 2019

# Outline

- Club Overview
- Project Overview
- System Architecture
- Subsystem Designs
- Schedule
- Budget

# Introductions



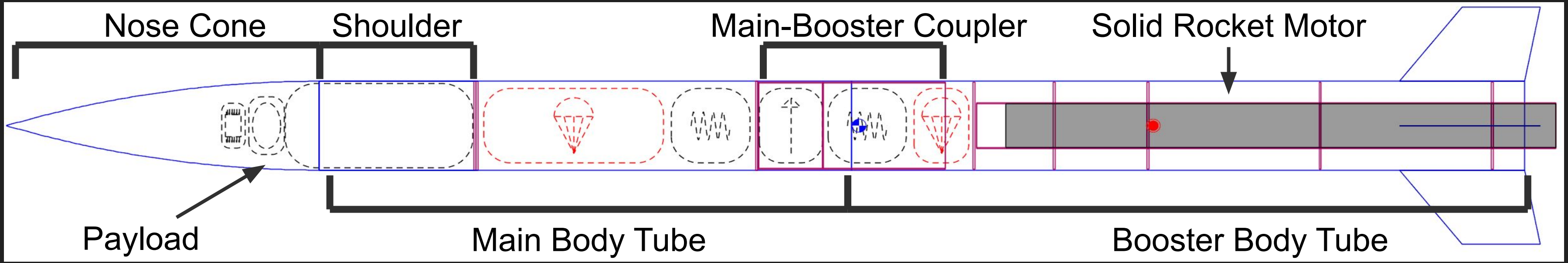
# Club Overview

- Entirely student-run
  - Around 35 active members, 15 of those are in leadership positions
- Subsystems
  - Flight Systems
    - Structures
    - Propulsion
    - Avionics and Recovery
  - Payload Systems
- Lab space in Supplemental Mail Room next to sailplane and Aero Design

# Project Overview

- Past four years we've competed in NASA Student Launch
  - We wanted freedom to explore our own interests as a club
- **Spaceport America Cup 2020**
  - Experimental Sounding Rocket Association
    - Intercollegiate Rocket Engineering Competition
  - Space Dynamics Laboratory at Utah State University
    - SDL Payload Challenge
  - Takes place in Las Cruces, New Mexico in mid-June
  - 150 teams from universities and schools all around the world
- Our entry in this competition is **Stratus I**

# System Architecture

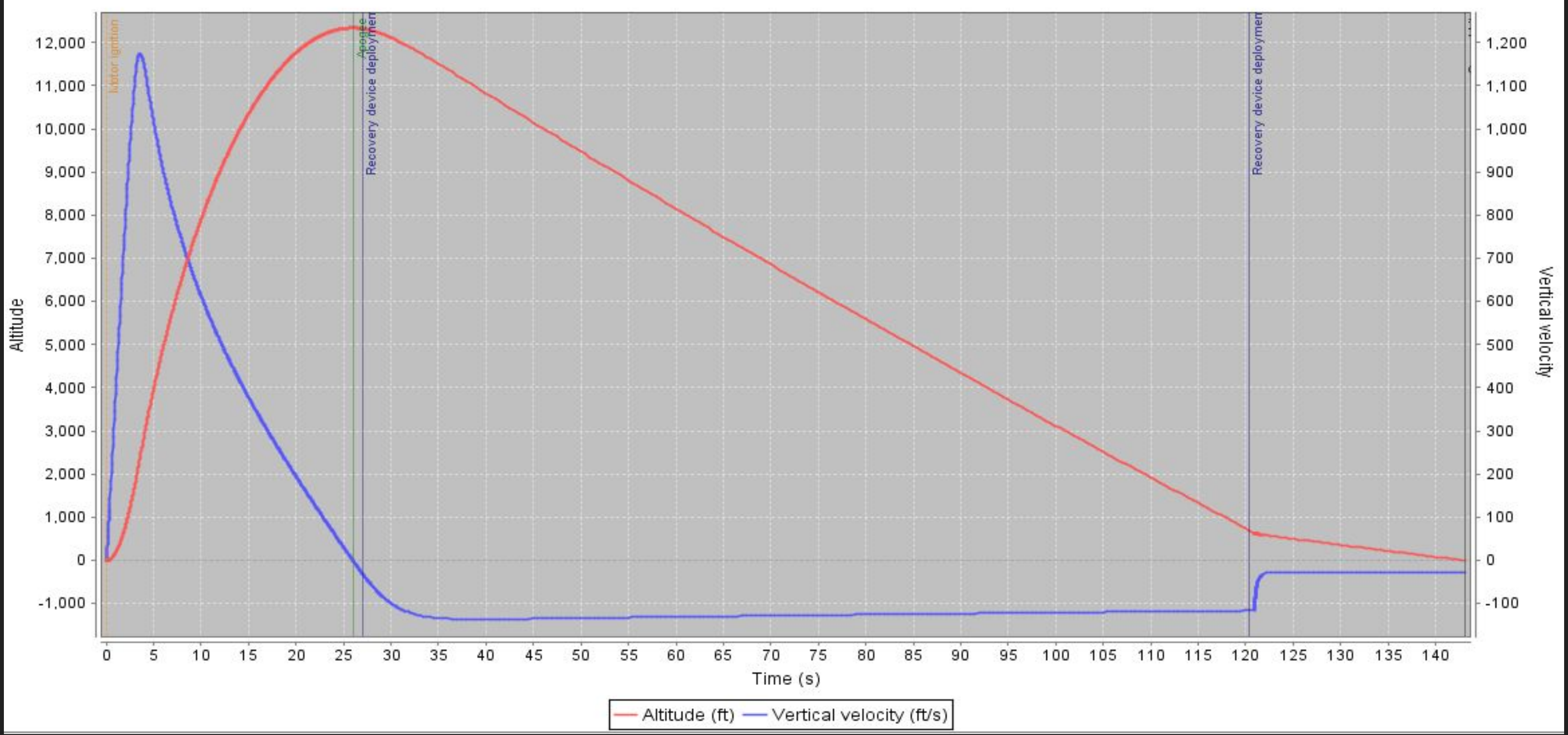



# Phases of Flight

| | | | | | | |
|---|---|---|---|---|---|---|
| Motor Ignition | Motor Burnout | Apogee | Drogue Parachute Deployment | Main Parachute Deployment | Landing | Recovery |

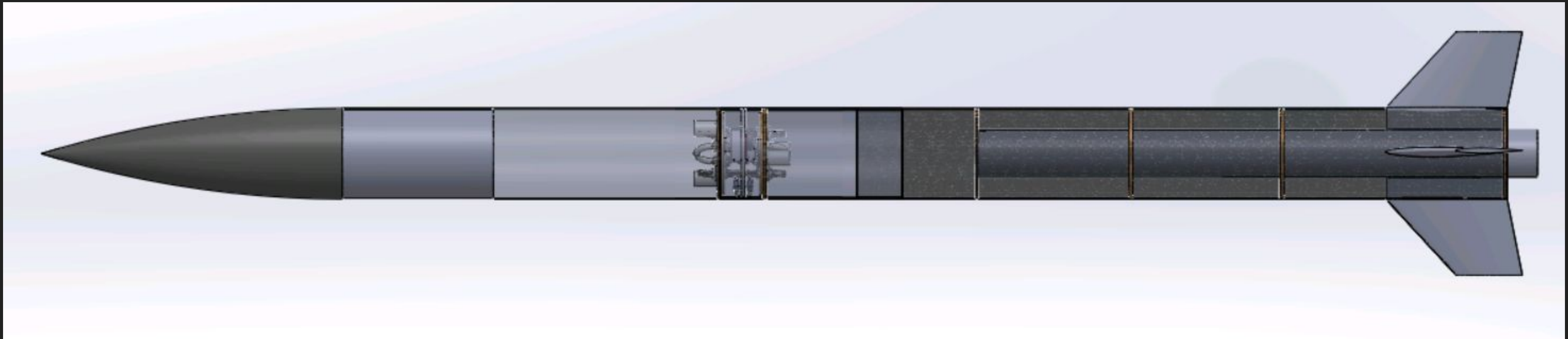
T-0 → T+145

# Launch Vehicle Flight Simulation



# Structures Subsystem

# Structures Subsystem Overview



- Filament wound G10 Fiberglass nose cone
- Carbon Fiber body tubes
- Carbon Fiber reinforced fins

# Body Tube Trade Study

- Body tube material: Pre-preg Carbon Fiber
  - Mainly due to strength and educational value

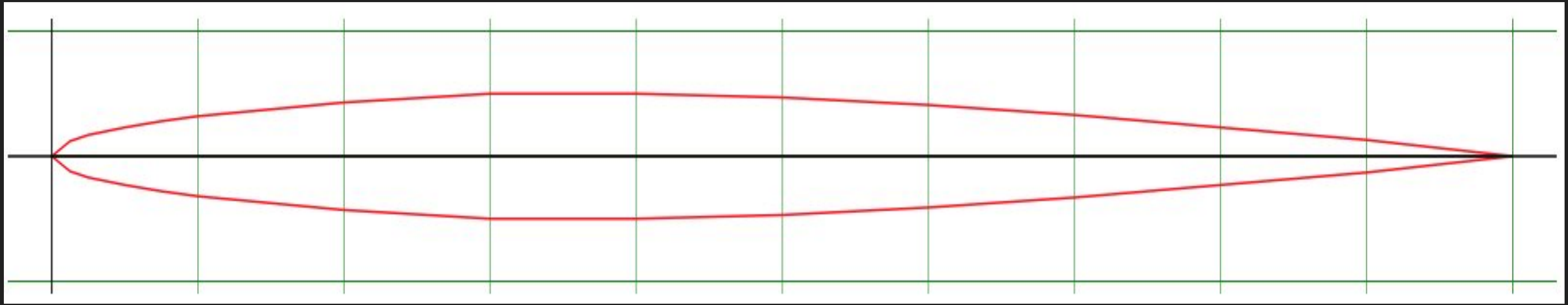
| | | Pre-Preg Carbon Fiber with Shrink Tape | | Wet Layup with Shrink Tape | | Wet Layup with Vacuum Bagging | |
|---|---|---|---|---|---|---|---|
| **Attribute** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Strength** | 0.409 | 4.0 | 1.636 | 3.0 | 1.227 | 3.5 | 1.432 |
| **Cost** | 0.197 | 5.0 | 0.985 | 3.0 | 0.591 | 2.5 | 0.492 |
| **Manufacturable** | 0.129 | 3.0 | 0.386 | 4.0 | 0.515 | 4.0 | 0.515 |
| **Educational Value** | 0.265 | 5.0 | 1.326 | 4.0 | 1.061 | 4.0 | 1.061 |
| **Total** | 1.000 | | **4.333** | | **3.394** | | **3.500** |
| **Ranking** | | | **1** | | **3** | | **2** |

# Carbon Fiber Body Tubes

- Utilizing Out-of-Autoclave (OoA) pre-impregnated carbon fiber
  - CYCOM 5320-1 Epoxy with T800 Unidirectional Tape
- Manufactured completely in house
  - Wrapped on aluminum mandrel
  - Cured at 350 ℉ in an oven
- Currently calculating layers of pre-preg needed
  - MATLAB code for structural analysis
  - Load testing to verify structural integrity

# Fin Design

- Using an airfoil to reduce total drag on rocket
  - Currently researching various airfoils
  - Looking for a symmetric airfoil with a max thickness of about 5%
    - Ex: Gottingen 443, Max thickness 5% at 30% chord
- Using XFOIL to help determine Cd of airfoil at various altitudes

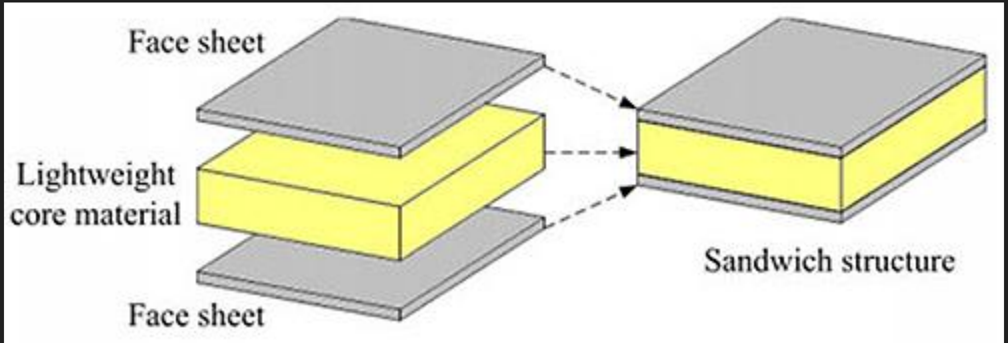


# Fin Core Material

- Testing two construction methods
  - 3D printed fins (PLA fo PETG)
    - Pros:
      - Ease of manufacturing, cost, rapid prototyping
    - Cons:
      - Bond strength with epoxy
  - Divinycell Foam
    - Pros:
      - Strength, designed for use with composites
    - Cons:
      - Manufacturability

# Fin Construction

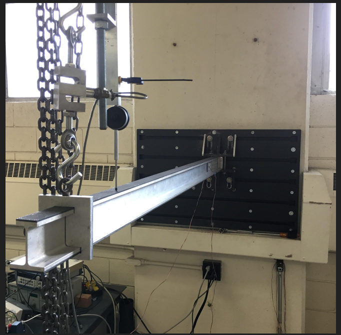
- Carbon Fiber overwrap on fins
  - Creating a sandwich structure
- Wet layup of carbon fiber with vacuum bag
- Testing various designs after construction to determine stiffness



# Future Testing

- Body Tube Tensile Test (1)
  - Dog Bone sample for testing
- Cantilever Load Test (2)
  - Determine strength of 90° plies
- Body Tube Torsion Test
  - Finsim for torsional load produced by fins
- Bulkhead Retention Test
  - 12 inch test sections
  - Aersp 47 Lab





# Propulsion Subsystem

# Propulsion Subsystem Risk Assessment

- COTS rocket motor significantly safer than team-manufactured motor
- Club will be using Level 3 M-class motor
  - Smaller Level 2 L-class motors that reach 10,000 feet had far too high average thrust values
  - Higher thrust motors add more risk than higher impulse motors
- Handling of motor will be strictly overseen by National Association of Rocketry (NAR) Level 3 certified club advisor, Joseph Coverston

# Propulsion Risk Assessment

| Propulsion Risk Assessment | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Hazard** | **Cause** | **Effect** | **Pre-Mitigation Risk** | **Likelihood** | **Severity** | **Risk** | **Mitigation** |
| Motor CATOs | Motor components fracture | Catastrophic damage to the rocket<br>Potential harm to civilians on ground | 3-High | 5 | 1 | 6-Low | Inspect motor grains and components prior to installation.<br>Assemble the motor according to the assembly instructions.<br>Check for fracture on any motor components after the launch.<br>Develop an internal checklist and complete checklist with others observing. |
| Motor does not stay retained | Motor thrust causes failure of motor block. | Catastrophic damage to rocket | 4-Moderate | 5 | 1 | 6-Low | Verify through rigorous calculations and physical tests that the motor retention system can handle the motor impulse. |
| Motor does not stay retained | Ejection charges dislodge motor from casing. | Motor potentially becomes ballistic at apogee<br>Rocket becomes unstable on descent<br>Damage to rocket on landing | 4-Moderate | 5 | 2 | 7-Low | Use of active motor rentention.<br>Carefully calculate appropriate amount of black powder charge. |
| Motor does not ignite | Igniter fails to make contact with propellant.<br>Igniter fuse burns out before reaching propellant.<br>Batteries in remote starter fail. | Rocket remains static | 4-Moderate | 3 | 4 | 7-Low | Use of recommended igniters by rocket motor vendor.<br>Properly store of the motor to prevent oxidation.<br>Verify the initiator is inserted fully to the top of the motor grains on the launch pad and batteries in starter are new. |

# Motor Design Considerations

- Single-stage COTS solid rocket motor
- Cesaroni or AeroTech brands
- 75mm or 98mm diameter
- Price and availability from vendors
- Apogee must be at least 10,000 feet (additional height ideal for flexibility in future design work)
- Max velocity far greater than Mach 1 pose threats to structural integrity
- Stability of 2.5 to 3.5 calibers is standard for high-powered rockets
- Thrust to weight ratio and velocity off the launch rail must meet or exceed rule of thumb values

# Preliminary Motor Selection

- Began with extensive list of OpenRocket M class motors
- Narrow down to seventeen available motors capable of reaching 10,000 feet
- Gathered data on every design consideration for each of these motors

| Company | Type | Price | Apogee | Speed | Stability | Thrust to Weight | Landing Speed |
|---|---|---|---|---|---|---|---|
| | | USD | Feet | Mach | Calibers | | MPH |
| Cesaroni | M2020 | 495 | 12008 | 1.11 | 2.76 | 10.992 | 17.045 |
| AeroTech | M1315 | 335 | 10248 | 0.89 | 3.14 | 7.696 | 16.773 |
| Cesaroni | M840 | 374 | 11571 | 0.8 | 3.05 | 4.538 | 17.045 |
| Cesaroni | M2045 | 374 | 10637 | 1.05 | 3.3 | 11.547 | 16.977 |
| AeroTech | M1850 | 400 | 10774 | 0.9 | 3.23 | 9.970 | 17.386 |
| Cesaroni | M2150 | 374 | 10661 | 1.06 | 3.24 | 11.989 | 16.977 |
| Cesaroni | M1590 | 374 | 11199 | 0.99 | 3.3 | 8.978 | 17.045 |
| AeroTech | M685 | 450 | 11707 | 0.73 | 3.21 | 3.665 | 17.250 |
| Cesaroni | M1545 | 418 | 11457 | 0.99 | 3.27 | 7.820 | 17.591 |
| Cesaroni | M2245 | 572 | 13320 | 1.24 | 3.21 | 11.187 | 17.455 |
| | | | | | | | |
| Cesaroni | M1060 | 473 | 11610 | 0.89 | 2.22 | 5.955 | 17.114 |
| Cesaroni | M520 | 545 | 12110 | 0.71 | 2.22 | 2.922 | 17.045 |
| Cesaroni | M2505 | 473 | 10954 | 1.11 | 2.32 | 14.435 | 16.977 |
| AeroTech | M2400 | 480 | 11193 | 1.11 | 2.43 | 13.620 | 16.977 |
| AeroTech | M1845 | 480 | 11932 | 1.08 | 2.37 | 10.340 | 17.045 |
| Cesaroni | M1450 | 675 | 14061 | 1.07 | 2.28 | 7.274 | 17.659 |
| AeroTech | M2500 | 625 | 13186 | 1.24 | 2.51 | 12.769 | 17.591 |

# Final Motor Selection

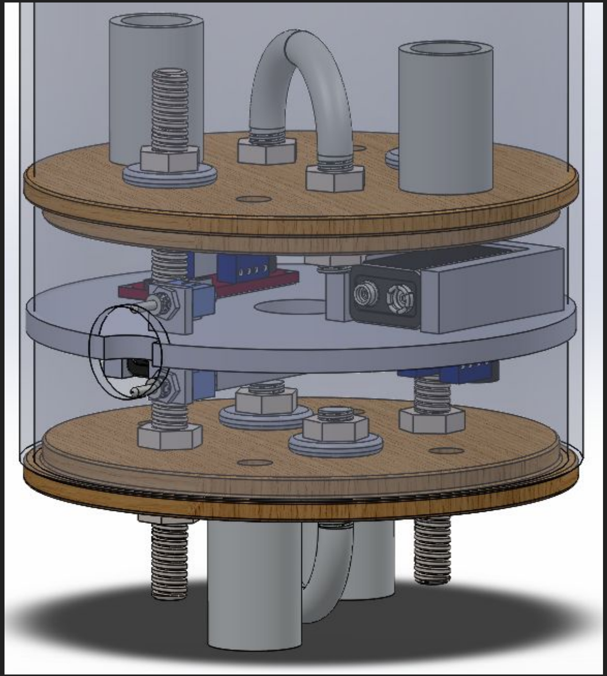
- Each motor was given a raw score from 1 to 5 for all seven design criteria
- Each raw score was multiplied by the 'factor of importance' metric to get a weighted score, then the weighted scores were summed to get a final score
- Motor Selection: **Cesaroni Pro75-6G 7388M2045-P**

| | | M2020 | | M1315 | | M840 | | M2045 | |
|---|---|---|---|---|---|---|---|---|---|
| | **WEIGHTS** | *Raw Score* | *Weighting* | *Raw Score* | *Weighting* | *Raw Score* | *Weighting* | *Raw Score* | *Weighting* |
| Price | 0.1204 | 3 | 0.3613 | 5 | 0.6022 | 4.5 | 0.5420 | 4.5 | 0.5420 |
| 10k Accuracy | 0.2468 | 1.5 | 0.3702 | 3 | 0.7403 | 2.5 | 0.6169 | 3.5 | 0.8637 |
| Availability | 0.0602 | 3 | 0.1807 | 3 | 0.1807 | 3 | 0.1807 | 3 | 0.1807 |
| Max velocity | 0.0952 | 2 | 0.1904 | 3 | 0.2855 | 3 | 0.2855 | 2 | 0.1904 |
| Stability | 0.2203 | 3 | 0.6610 | 3.5 | 0.7712 | 3.5 | 0.7712 | 4 | 0.8813 |
| Thrust to weight | 0.0632 | 5 | 0.3158 | 3 | 0.1895 | 2 | 0.1263 | 5 | 0.3158 |
| Safe recovery | 0.1939 | 3 | 0.5817 | 3 | 0.5817 | 3 | 0.5817 | 3 | 0.5817 |
| | **TOTALS** | | **2.6610** | | **3.3511** | | **3.1043** | | **3.5555** |

# Avionics and Recovery Subsystem

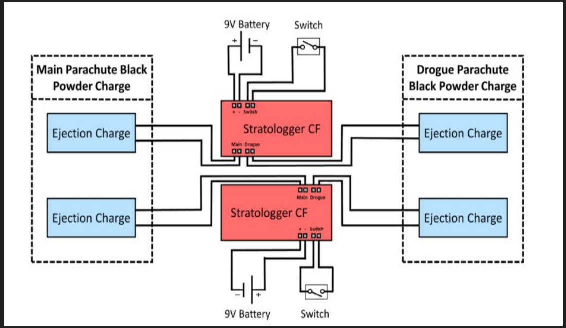
# Avionics Bay

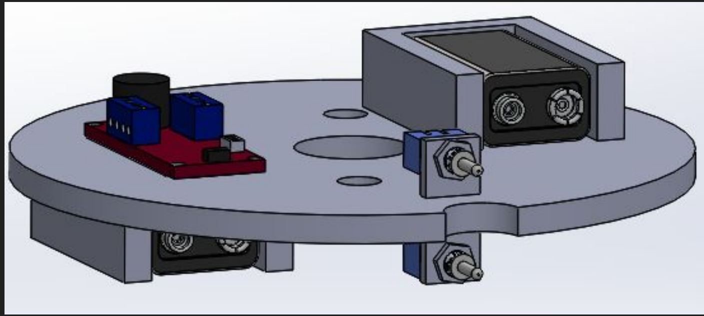
- Housed within the main-booster coupler
- Sandwiched between two sealed bulkheads
  - Heritage design that has been tested over many years
  - Pressure equalization hole through coupler and airframe for barometric altimeters
- U-bolts on each side connect to parachute shock cords
- Threaded-rods keep bulkheads together



# Avionics Board

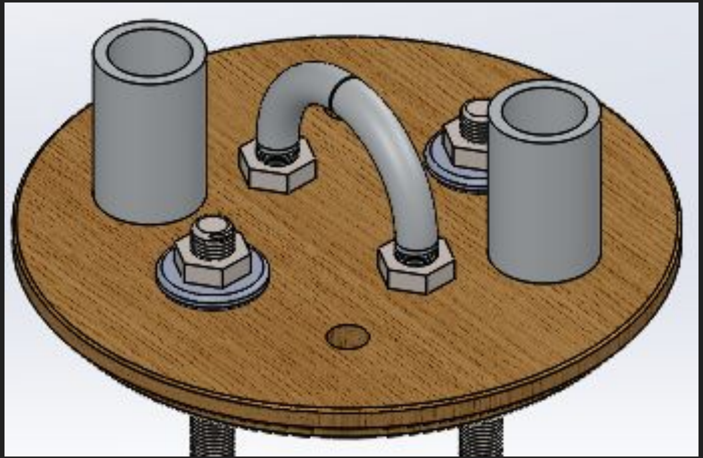
- 3D printed structure
- Stratologger CF altimeters
  - Commercial Off-the-Shelf
  - Redundant with two identical altimeters
  - Ours have been flight tested numerous times each
- Mechanical arming switches
  - Keeps circuit open until launch vehicle is upright on the launch pad



# Parachute Deployment System

- Primary and redundant charge for each deployment sequence
  - Redundant charge ~1.5x size of primary charge
- PVC blast caps contain:
  - Black powder
  - Electronic initiators
  - Wadding
- Black powder ignition pressurizes airframe
  - Airframe separates when nylon shear pins fail



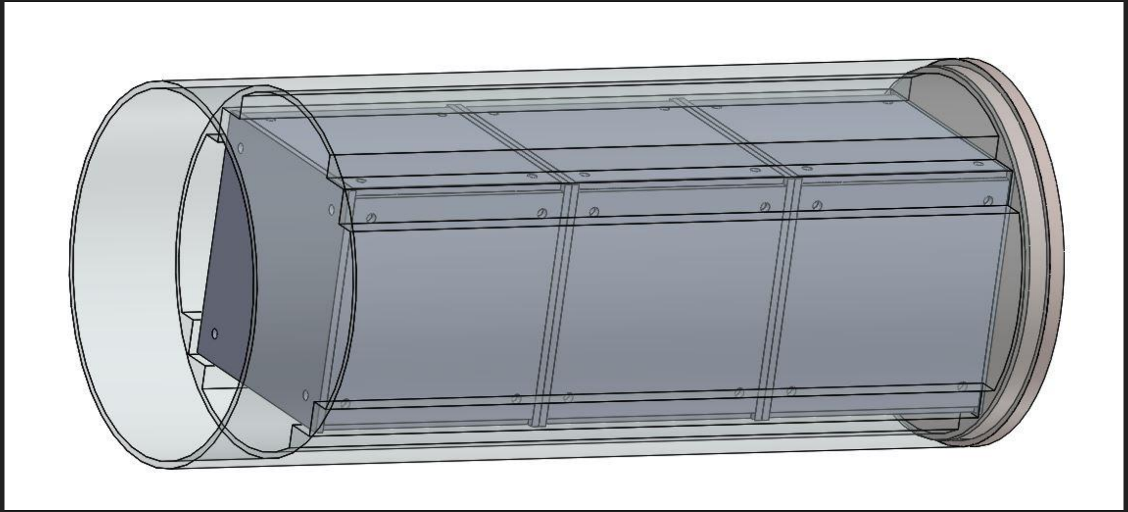
# Future Testing

- Altimeter calibration
  - Using club’s negative pressure chamber
  - Simulates flight conditions
- Faraday cage interference test
  - Gathering test data on different designs
  - Will be completed on the ground
- Parachute deployment test
  - “Ground test”
  - Validates major deployment system components

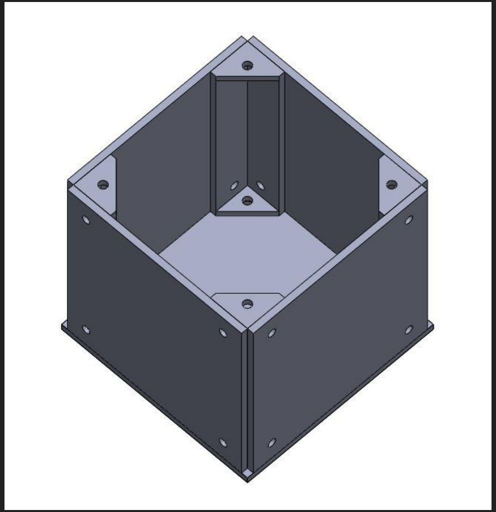
# Payload Subsystem

# Payload Section Overview

3 CubeSat Constellation



Open CubeSat



# Payload Subsystem Architecture

- Objectives
  - Create a data acquisition system capable of storing and transmitting acceleration, altitude, temperature, pressure, gyroscopic, and GPS data
  - Create a computational and hardware foundation for building a variable drag system for active altitude compensation
- Top Level Requirements (IREC)
  - Create a payload with mass no less than 8.8 pounds
  - Create a payload that fits the cubesat form factor (3U)

# Payload Subsystem Architecture

- Internal Requirements
  - Collect flight data that is useful for high powered rocketry (accelerometer, gyroscope, temperature, GPS, etc)
  - Store up to 256 GB of data onboard the rocket
  - Transmit data ~2 miles line of sight to a ground station at 915 MHz
  - Determine the position of the rocket within 15 feet of accuracy
  - Enable all electronics remotely once rocket has been prepared for launch

# Trade Studies

- Cubesat structural material: steel
  - Due mainly to high density, high durability, and high educational value

| | | Aluminum | | Steel | | 3D Printed Plastic | | Fiberglass | |
|---|---|---|---|---|---|---|---|---|---|
| Attribute | Weight | score | weighted score | score | weighted score | score | weighted score | score | weighted score |
| Weight | 0.451 | 2.0 | 0.903 | 5.0 | 2.257 | 1.0 | 0.451 | 2.0 | 0.903 |
| Cost | 0.261 | 3.0 | 0.783 | 3.0 | 0.783 | 1.0 | 0.261 | 4.0 | 1.044 |
| Manufacturable | 0.157 | 3.0 | 0.472 | 2.0 | 0.315 | 5.0 | 0.787 | 4.0 | 0.630 |
| Durability | 0.036 | 4.0 | 0.145 | 4.0 | 0.145 | 1.0 | 0.036 | 2.0 | 0.072 |
| Educational Value | 0.094 | 5.0 | 0.470 | 4.0 | 0.376 | 1.0 | 0.094 | 1.0 | 0.094 |
| Total | 1.000 | | 2.773 | | 3.875 | | 1.630 | | 2.743 |
| Ranking | | | 2 | | 1 | | 4 | | 3 |

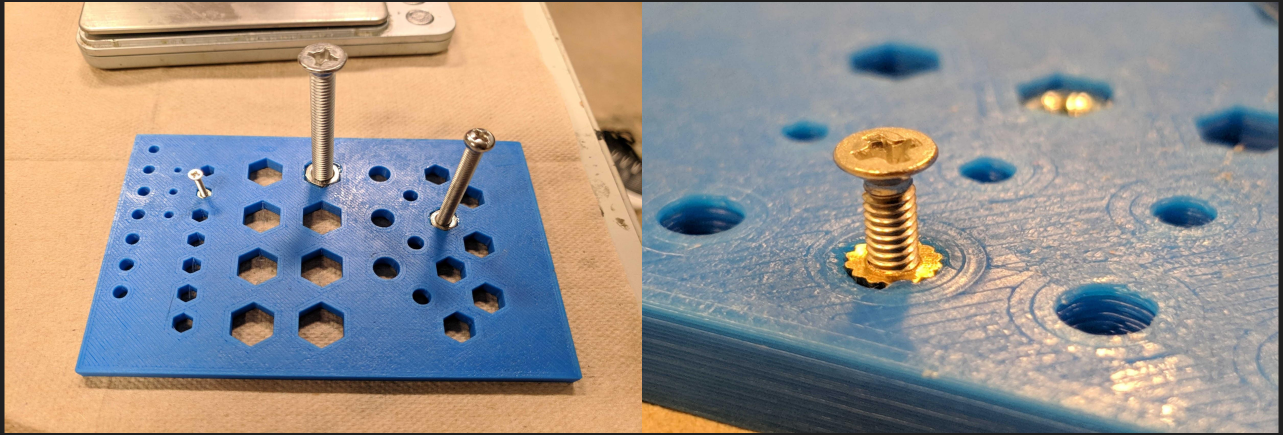
# Trade Studies

- Microcontroller: Arduino Nano or Arduino Uno
  - Size constraints on cubesat dimensions, requirements for digital pins

| | | Arduino Nano | | Arduino Mega | | Arduino Uno | | Rasberry Pi | |
|---|---|---|---|---|---|---|---|---|---|
| **Attribute** | **Weight** | score | weighted score | score | weighted score | score | weighted score | score | weighted score |
| Size | 0.300 | 5.0 | 1.500 | 2.0 | 0.600 | 3.0 | 0.900 | 2.0 | 0.600 |
| Ease of use | 0.250 | 4.0 | 1.000 | 4.0 | 1.000 | 4.0 | 1.000 | 1.0 | 0.250 |
| Number of pins | 0.200 | 2.0 | 0.400 | 4.0 | 0.800 | 3.0 | 0.600 | 2.0 | 0.400 |
| Educational value | 0.100 | 3.0 | 0.300 | 3.0 | 0.300 | 3.0 | 0.300 | 5.0 | 0.500 |
| Weight | 0.150 | 2.0 | 0.300 | 3.0 | 0.450 | 3.0 | 0.450 | 3.0 | 0.450 |
| Total | 1.000 | | 3.500 | | 3.150 | | 3.250 | | 2.200 |
| Ranking | | | **1** | | **3** | | **2** | | **4** |

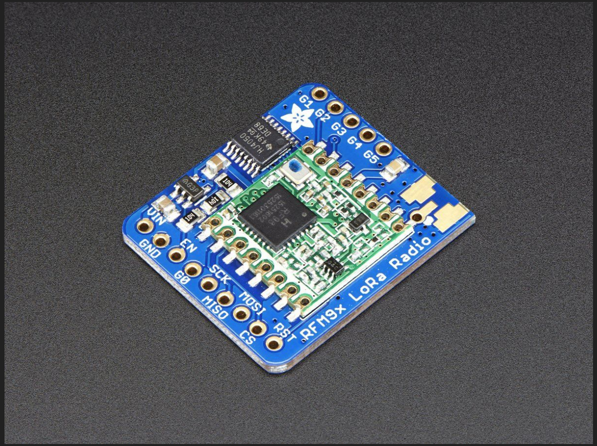
# Ongoing Testing

- Threaded inserts in 3D printed plastic parts
    - Epoxied nuts and heat-set threaded brass inserts
    - Tolerance testing



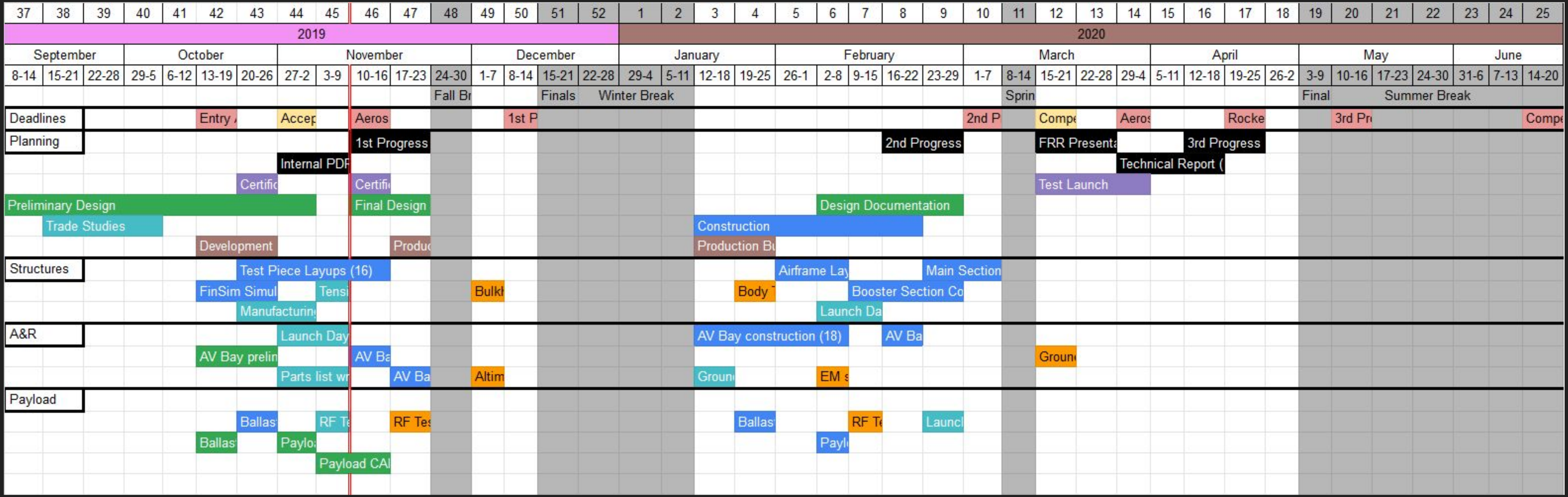
# Future Testing

- Antenna range
  - Line of sight ground testing
  - Subscale test flight on NAR Level 1 certification rocket
- Onboard data storage
  - Large volume data storage lab testing
  - Subscale test flight if hardware is ready
- Cubesat structure prototyping
  - Develop 3D printed prototypes for lab testing and electronics mounting



# Schedule and Budget

# Schedule


37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
2019
2020
September
October
November
December
January
February
March
April
May
June
8-14 15-21 22-28 29-5 6-12 13-19 20-26 27-2 3-9 10-16 17-23 24-30 1-7 8-14 15-21 22-28 29-4 5-11 12-18 19-25 26-1 2-8 9-15 16-22 23-29 1-7 8-14 15-21 22-28 29-4 5-11 12-18 19-25 26-2 3-9 10-16 17-23 24-30 31-6 7-13 14-20
Fall Br
Finals
Winter Break
Sprin
Final
Summer Break
Deadlines
Entry
Accep
Aeros
1st P
2nd P
Compe
Aeros
Rocke
3rd Pr
Comp
Planning
1st Progress
2nd Progress
FRR Presenta
3rd Progress
Internal PDF
Technical Report (
Certific
Certific
Test Launch
Preliminary Design
Final Design
Design Documentation
Trade Studies
Construction
Development
Produc
Production Bu
Structures
Test Piece Layups (16)
Airframe Lay
Main Section
FinSim Simul
Tensi
Bulkh
Body
Booster Section Co
Manufacturin
Launch Da
A&R
Launch Day
AV Bay construction (18)
AV Ba
AV Bay prelim
AV Ba
Groun
Parts list wr
AV Ba
Altim
Groun
EM
Payload
Ballas
RF Te
RF Tes
Ballas
RF Te
Launc
Ballas
Paylo
Payl
Payload CAI

# Budget

- Estimated Inflow: **$16,344**
    - Major funding sources are Pennsylvania Space Grant Consortium and University Park Allocations Committee
- Estimated Outflow: **$11,228**
    - Largest expenses are launch vehicle components and travel
    - Toughest hurdle is getting funding early enough to start testing and manufacturing in the fall semester

# Expected Inflow

| Source | Amount |
|---|---|
| Aerospace Engineering Department | $2,000 |
| Mechanical Engineering Department | $1,500 |
| PA Space Grant | $4,000 |
| Engineering Undergraduate Council | $1,000 |
| Club Fundraising | $500 |
| UPAC Supplies | $3,066 |
| UPAC Travel | $4,278 |
| Total: | **$16,344** |

- UPAC will provide up to $5,000 for both Supplies and Travel during one academic year
- We have put out a request with Mechanical Engineering Department for this year
- We're always looking for corporate sponsors, but they're very hard to come by

# Expected Outflow

| Expense | Amount |
|---|---|
| Lab Supplies and Common Purchases | $1,000 |
| Payload Subsystem | $750 |
| Structures/Propulsion Subsystem | $2,500 |
| Recovery Subsystem | $1,000 |
| Competition Entry Deposit | $200 |
| Competition Rocket Fee | $500 |
| Competition Rocketeer Fee | $1,000 |
| Travel | $4,278 |
| Total: | **$11,228** |

| Expense | Amount |
|---|---|
| Hotels | $1,824 |
| Rental Vans | $1,654 |
| Gas | $800 |
| Total: | **$4,278** |

- Hotel rooms in Las Cruces, NM for the competition and Springfield, MO for the road trip down and back
- Rental vans estimated with PIT Enterprise rates

# Questions?