Preliminary Design Review

University of Illinois at Urbana-Champaign

NASA Student Launch 2018-2019

Team Composition

Project Manager:
Hamza El-Kebir

Payload Project Manager:
Kenneth Tochihara

Payload Chief Engineer:
Ayberk Yaraneri

Structures and Recovery:
George Petrov

Avionics:
Mois Bourla

Flight Dynamics:
Robert Filipiuk

Ancillary and Safety:
Zana Essmyer

Presentation Contents

- Mission overview
- Launch vehicle design
  - Leading full-scale design
  - Flight simulations
  - Subscale design
- Avionics design
  - Recovery triggering
  - Payload deployment
- Payload design
  - Payload configuration
  - Payload deployment
  - Payload guidance navigation and control
- Project plan

Mission Overview

- Top-level objectives:
  - Apogee of the launch vehicle between 3500 and 5500 ft
  - Retrieve a ground-based ice sample (10 mL)
  - Achieve full reusability of the system
- Team-derived top-level objectives:
  - Aerially deploy an unmanned aerial vehicle (UAV)
  - Receive real-time range safety officer (RSO) permission
  - Autonomously operate the UAV to retrieve an ice sample
  - Achieve pressurized nose cone separation
  - Demonstrate adapted payload bay/fairing design

Launch Vehicle Summary

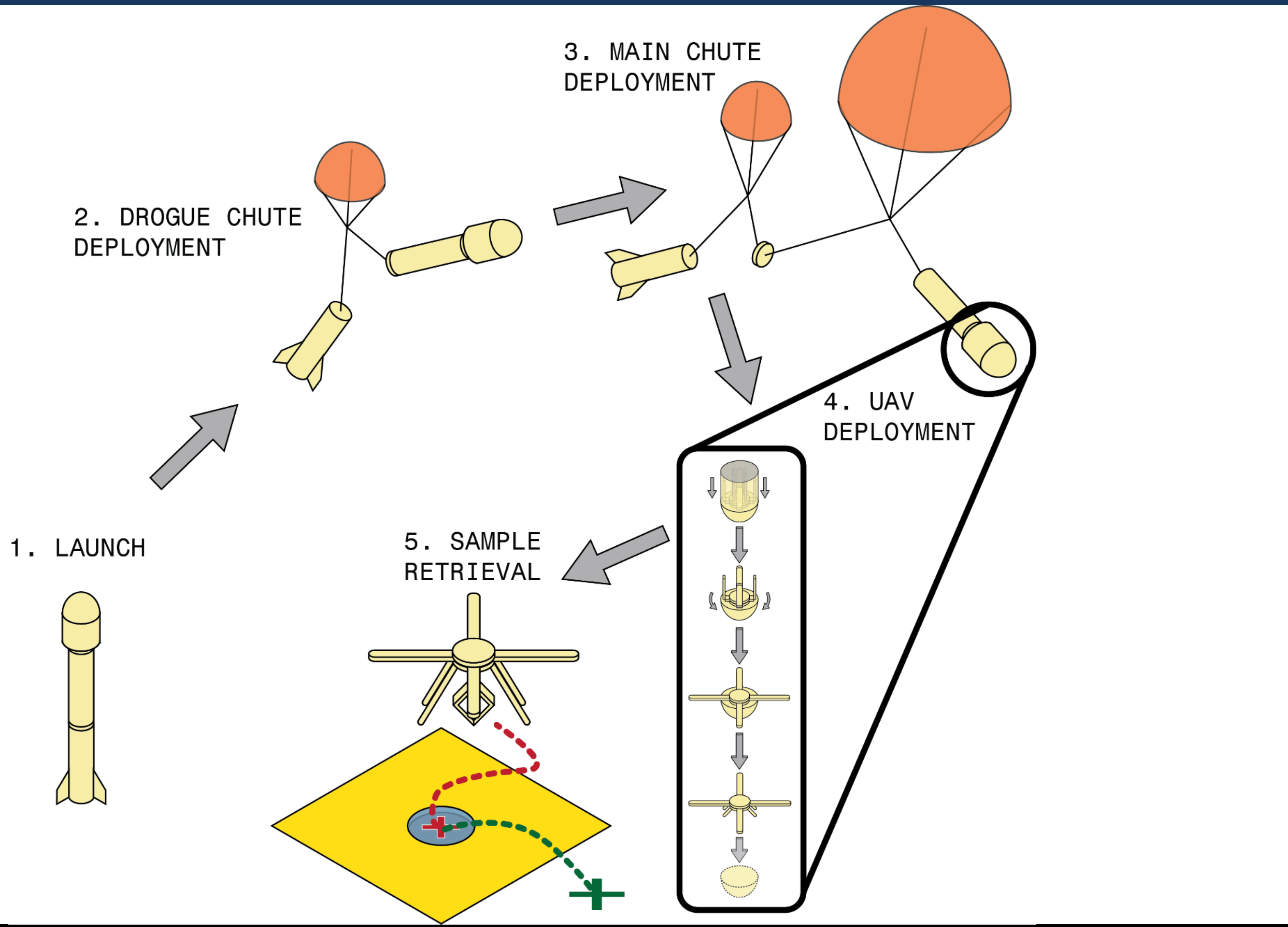
George Petrov, Robert Filipiuk

Launch Vehicle Overview

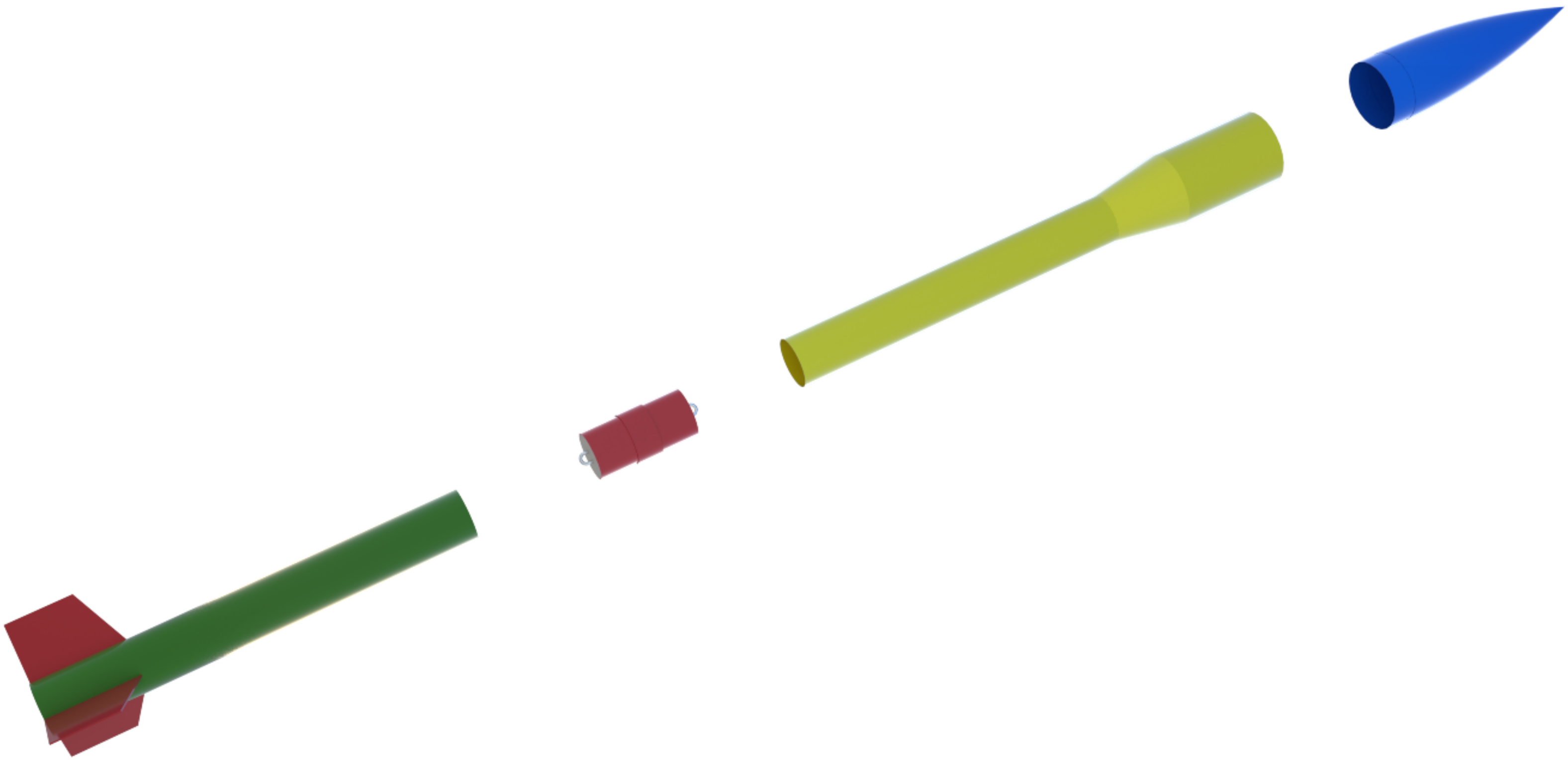
- The launch vehicle will deliver a payload to 4,450 feet by adhering to requirements of being aerodynamically efficient, stable, safe, velocity, and cost efficient
- Will be recoverable by abiding to requirements of parachute deployment, kinetic energy, and redundancies

Specifications	
Length	95 inches
Max Velocity	Mach 0.53 (593 ft/s)
Weight	25.6 lbs.
Diameter	4->6 inches

Flight Profile

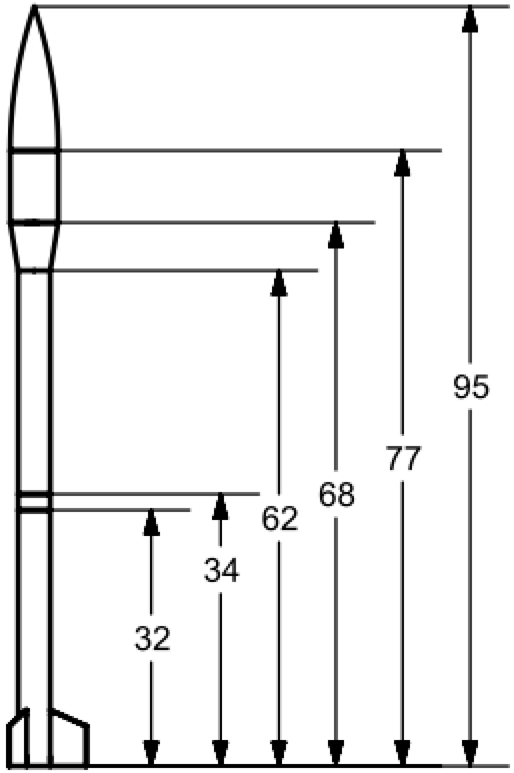


Sections



Vehicle Major Dimensions

- Overall Length: 95″
- Overall Estimated Mass: 25.6 lbs.
- Body Tube: 36″
- Nose Cone Length: 18″
- Interstage: 6″
- Booster System Length: 32″
- Avionics Coupler Length: 10″
- Payload Bay Length: 9″

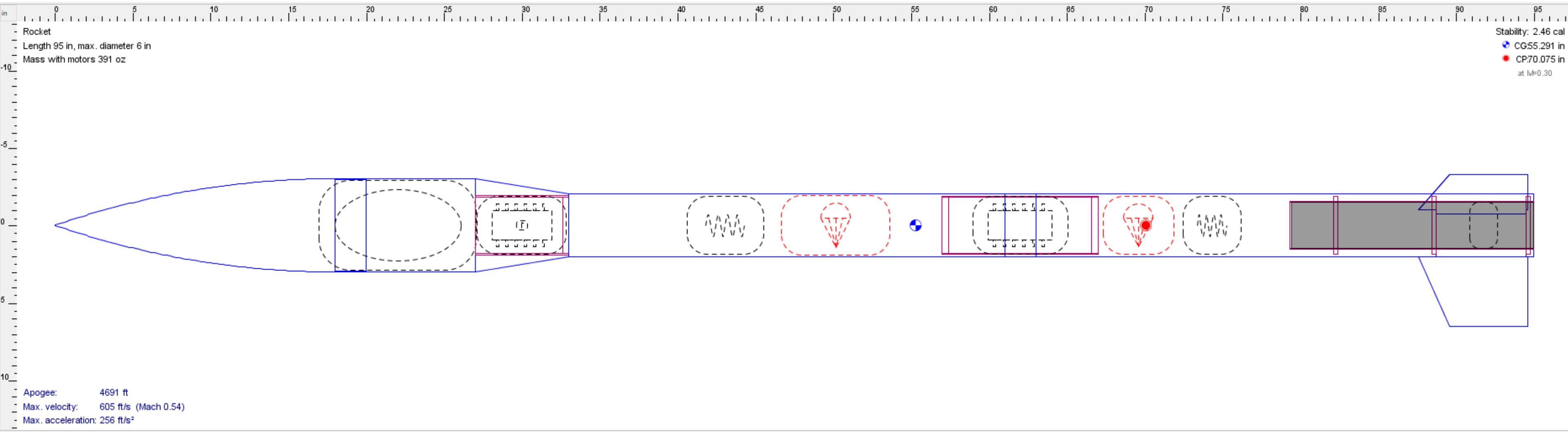


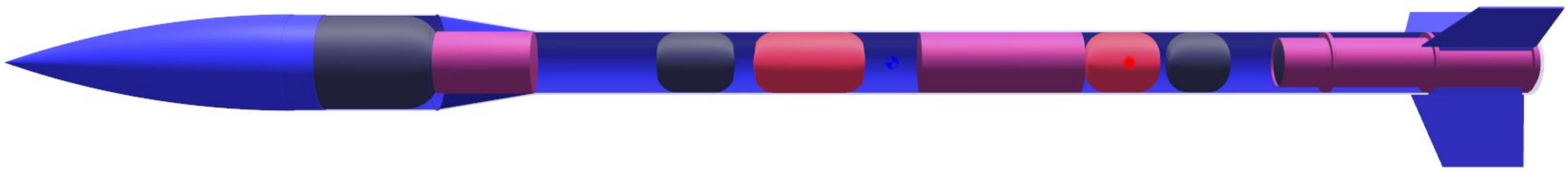
Launch Vehicle Materials

- Booster and Body Tube: Blue Tube
  - Lighter weight
  - Cost effective
- Fairing and Nose Cone: Fiberglass
  - Stronger material
  - Will protect the payload under stresses
- Fins: Fiberglass
  - High strength
  - Team experiences with custom fiberglass fins
- Centering Rings: Fiberglass
  - Added strength, desired over plywood due to large motor
- Bulkheads: Fiberglass
  - Two layers for a total height of ¼″

Static Stability Margin

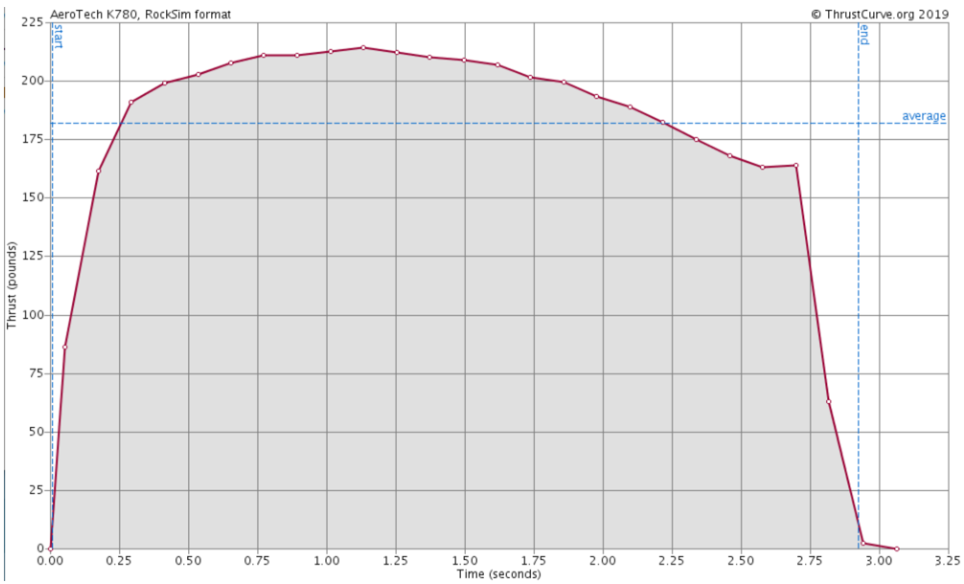
- Current CP Location: 70.08 in
- Current CG Location: 55.29 in
- Stability Margin (at liftoff): 2.46 calibers





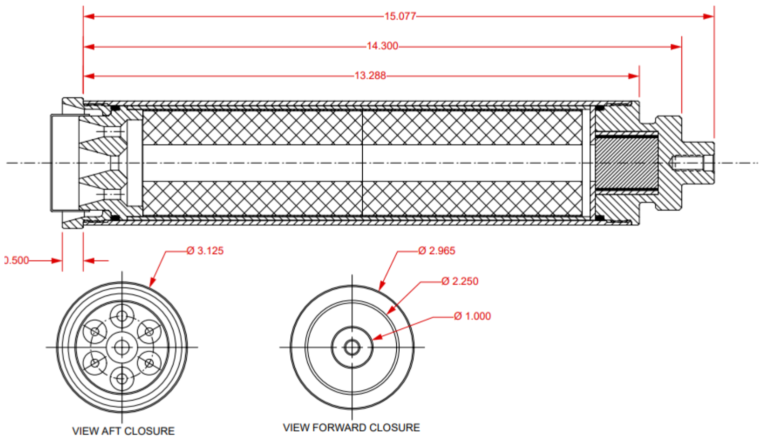
Motor Selection

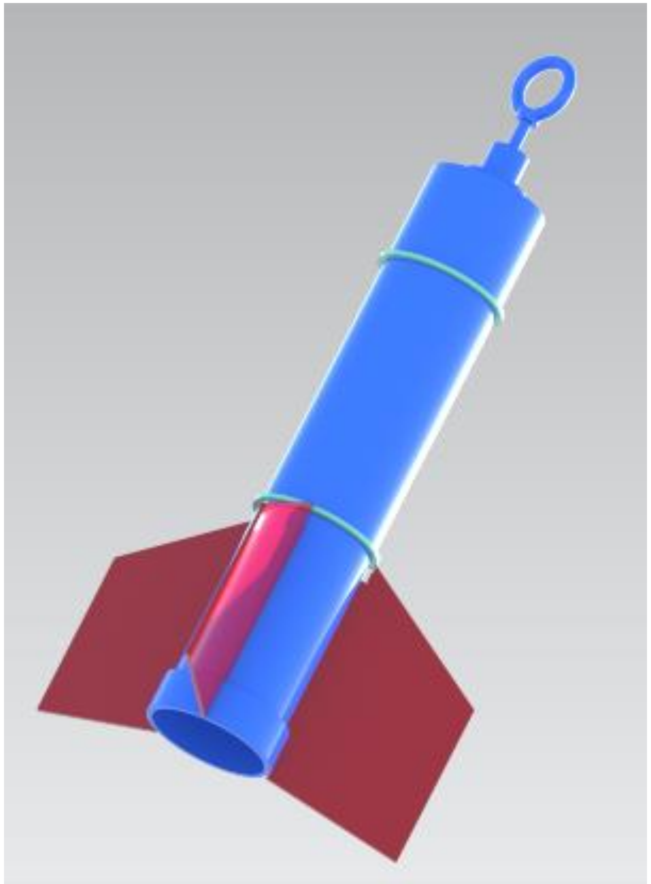
- Motor: AeroTech K780R-P
  - Motor Diameter: 75 mm
  - Maximum Thrust: 965 N
  - Total Impulse: 2371 Ns
  - Burn time: 3 sec
  - Liftoff T/W: 8.5
  - Off Rail Speed: 59 ft/s



Motor Subsystem

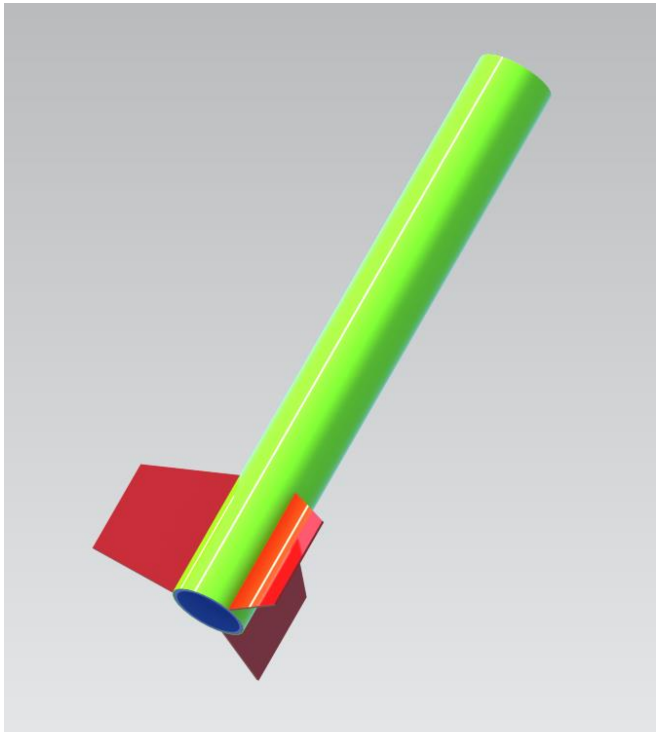
- RMS 75/2560 Motor Casing
  - Constructed from high strength aluminum
- Blue Tube Mount 28"
  - Permanently attached to centering rings
- Fiberglass Centering Rings
  - 3 Centering Rings for Reliability
- 2.95-in Aero Pack Retainer

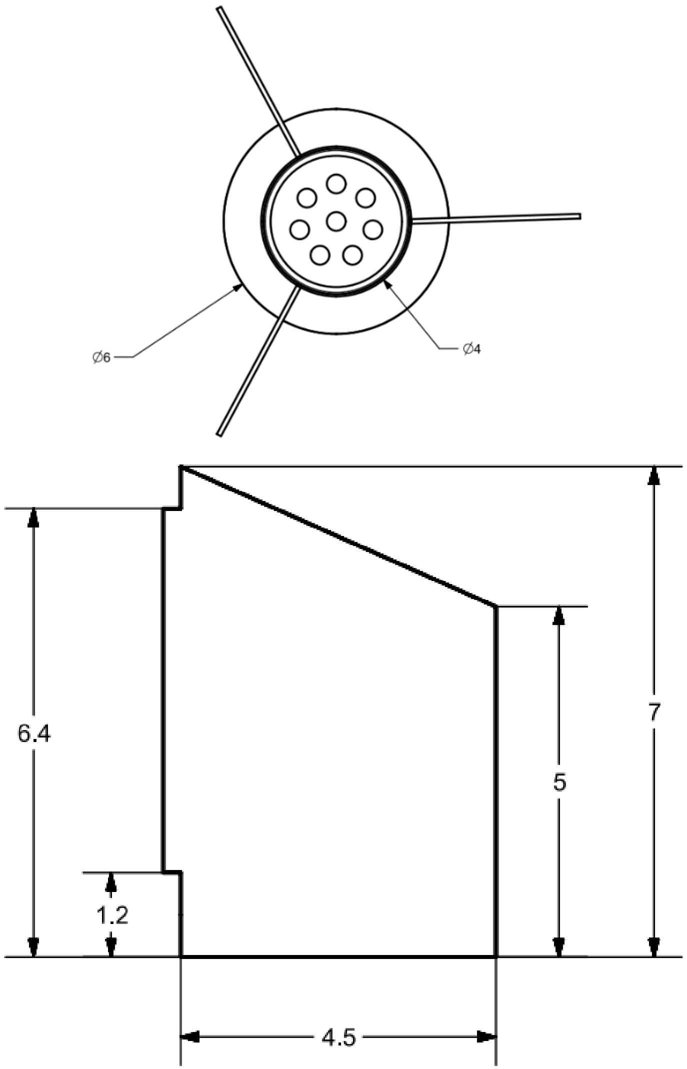




Booster Subsystem

- Houses motor subsystem
- Fiberglass fins
  - Slotted between centering rings
- Houses drogue parachute

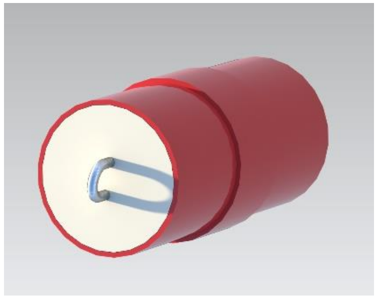


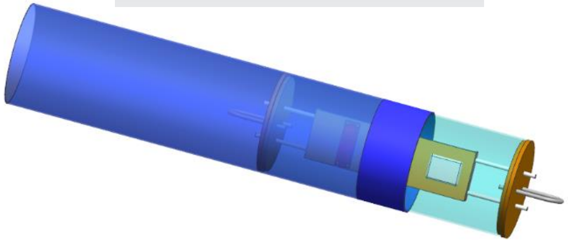


Body Tube & Coupler Section

Coupler

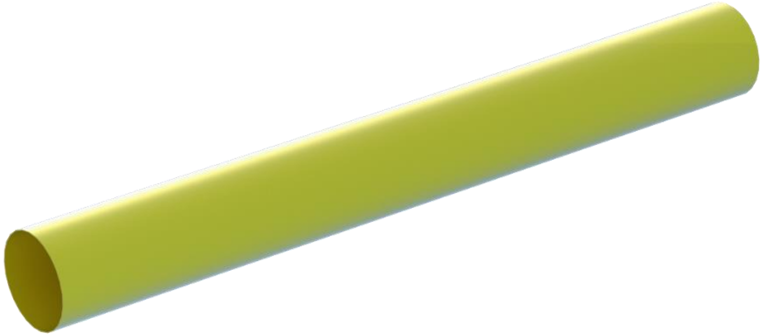
- U-Bolt parachute connections for strength
- ¼" Threaded rods to hold payload sleds
- Holds recovery electronics and ejection charges





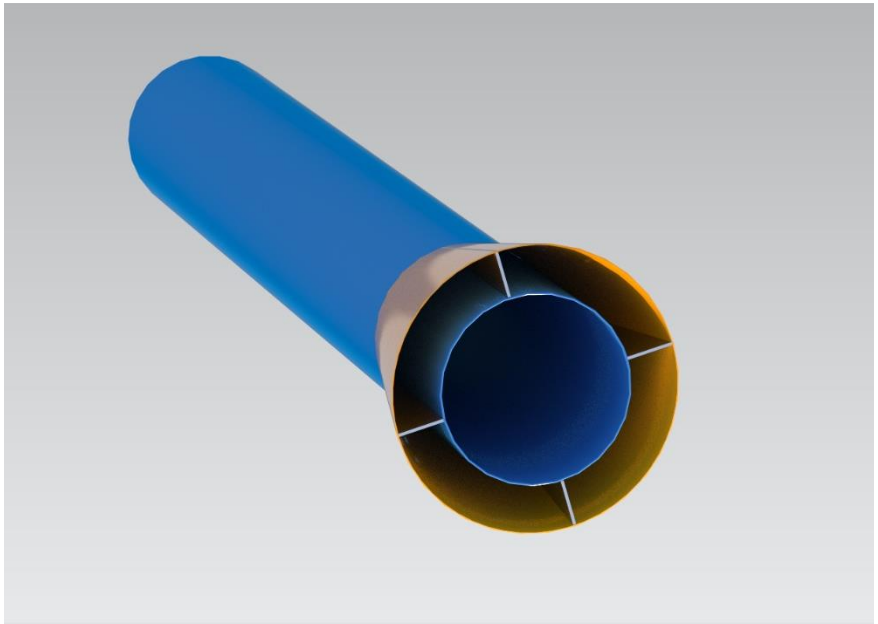
Body Tube

- Material: Blue Tube
- Contains Main Parachute + Shock Cord
- One Section with Interstage
- Length: 36''



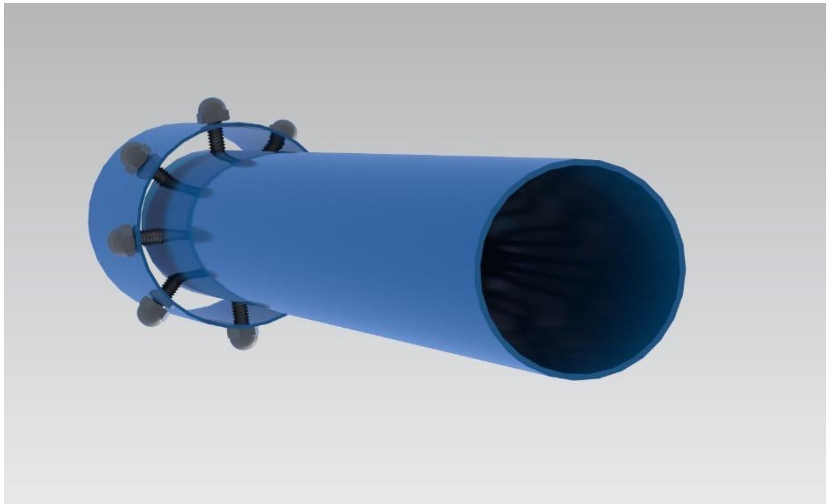
Interstage

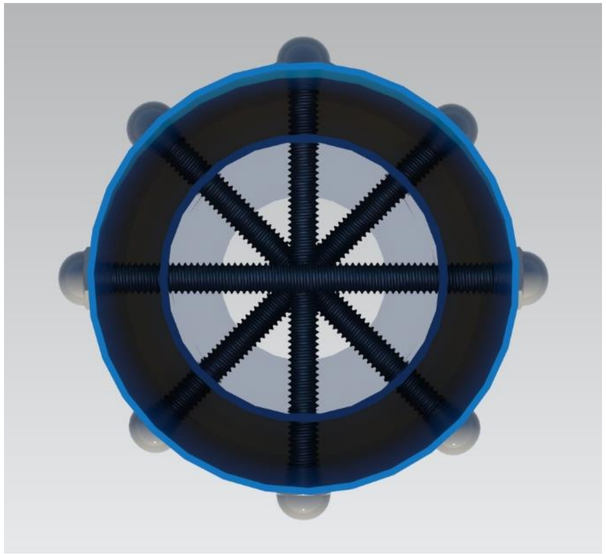
- Transition
  - 4 to 6 inches
- Metal Plate Supports
  - Give structural support to aerodynamic load experienced
- Outer Transition
  - Filled with 3D prints



Body Tube & Interstage Interface

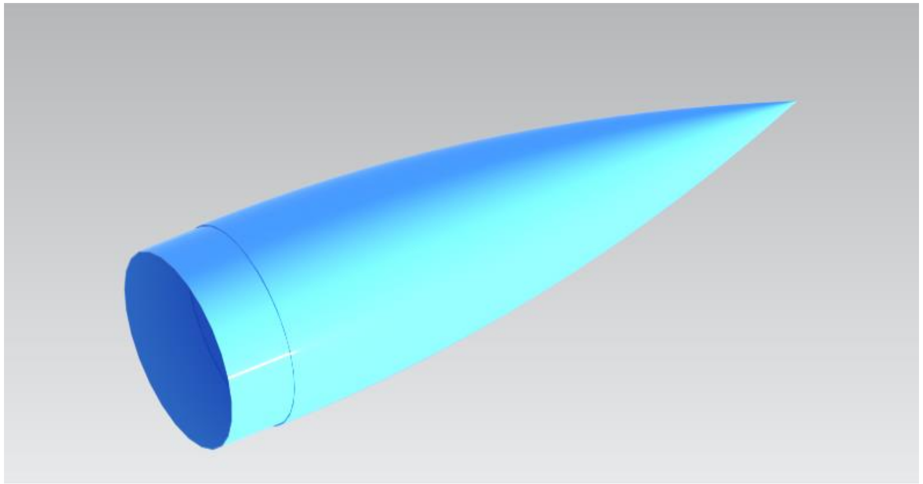
- Design threaded rod system to connect body tube to interstage
  - Structurally Stable
  - Manufacturable
- Body tube will extend 2 inches into Payload Bay
  - 4 rods off set by 45 degrees each





Nose Cone

- Contains nose cone parachute
- Fiberglass nosecone
  - Structurally strong
  - Aerodynamic tangent ogive shape
  - Team experience with material
  - 6-inch diameter by 18-inch length



Main Parachute

- Make: Iris Ultra
- Diameter: 72″
- Material: Ripstop Nylon
- Shape: Toroidal

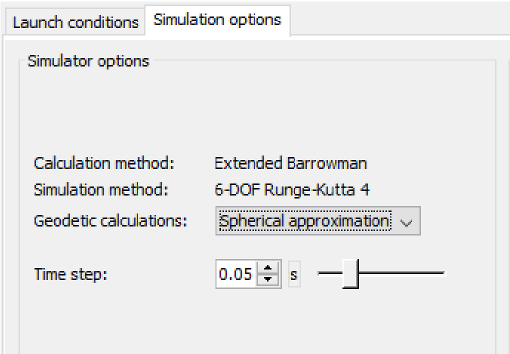
Drogue Parachute

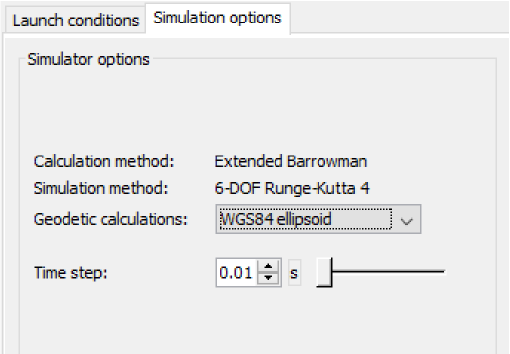
- Make: Fruity Chutes
- Diameter: 18″
- Material Ripstop Nylon
- Shape: Elliptical

➢ ½″ Tubular Kevlar shock cord

Flight Simulations

- OpenRocket
- Two different simulation conditions
  - Spherical Earth Approximation, Δt = 0.05s
  - WGS84 (World Geodetic System 84), Δt = 0.01s
- Varied launch parameters
  - Wind: 0-, 5-, 10-, 15-, 20-mph
  - Launch angle: 5, 7.5, 10 degrees
- Simulated altitude, drift vs. time under both simulation conditions





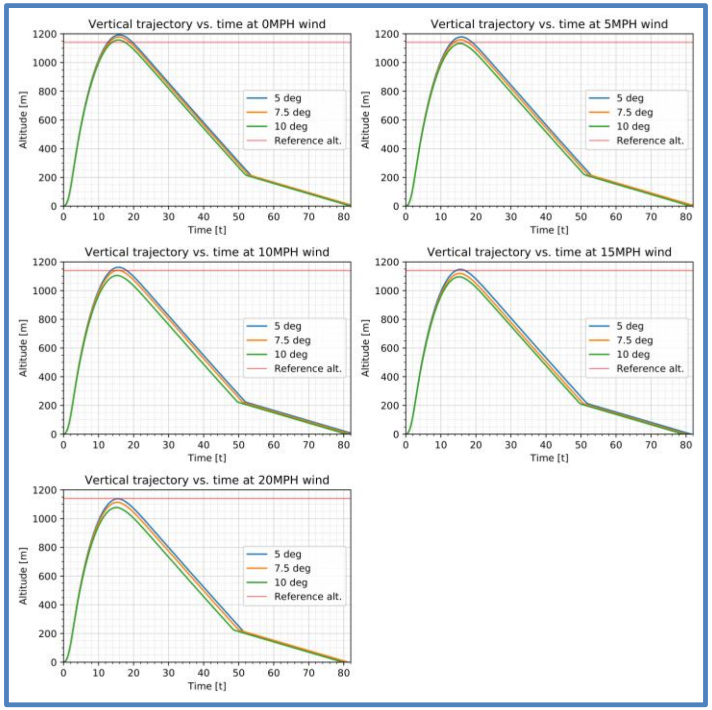
Simulation Results

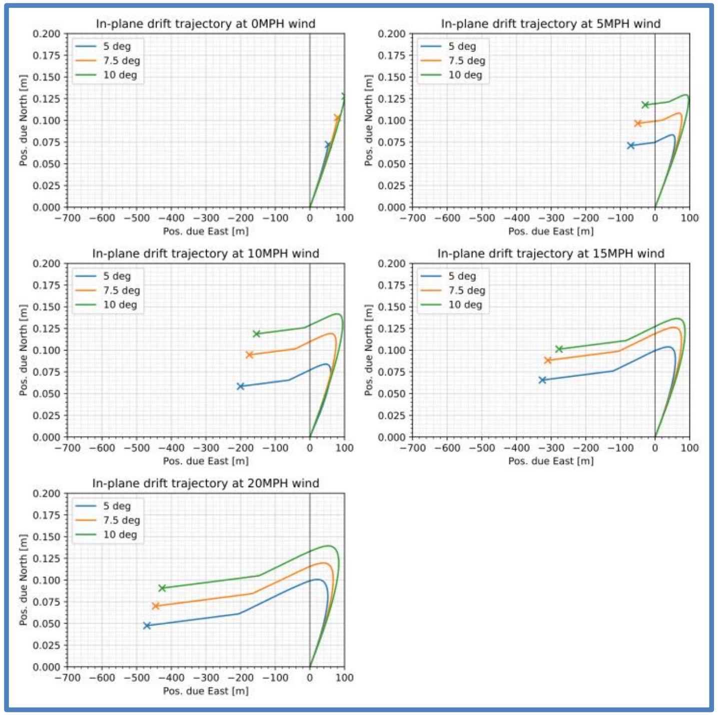
- Static margin stability = 2.4
- Target altitude = 4,450 ft
- Calculated RMS error between two simulation conditions
  - Significant discrepancy in apogee predictions
  - Relatively low RMS for all scenarios—Reliable models

Angle (deg)	Wind (mph)	RMS (ft)
5	0	1.830
5	10	2.975
5	20	1.870
7.5	5	0.152635
7.5	15	0.501
10	0	5.401
10	10	4.801

Drift and Altitude Predictions

- All values calculated in Open Rocket
- All calculated drift distances meet the competition requirement of 2,500 ft
- Chose target altitude closer to WGS84 prediction due to greater expected accuracy





Kinetic Energy

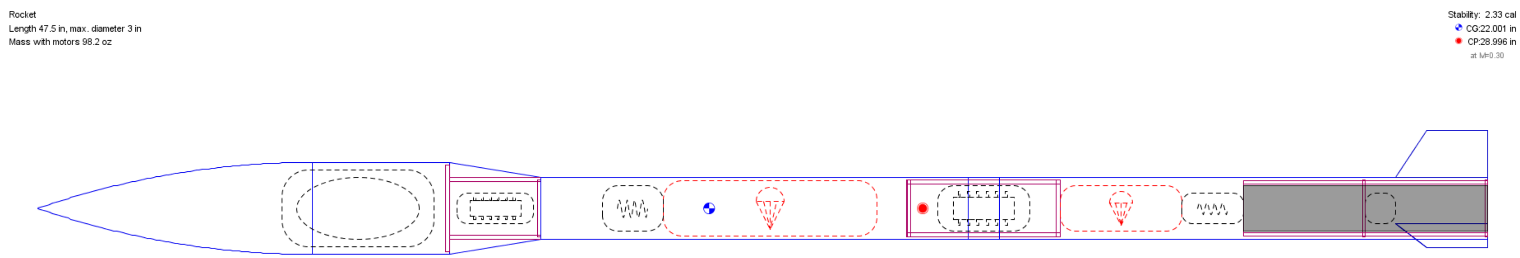
- Terminal Velocities
  - Assumption: all vehicle components land with same terminal velocity
  - Terminal velocity: 24.4 ft/s
- Kinetic Energies

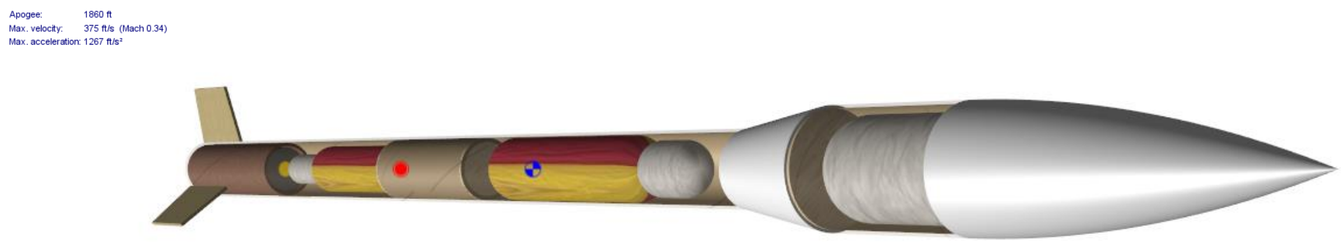
Part	Terminal Kinetic Energy (ft · lbf)
Nose cone	17.8
Fairing	22.8
Upper Body	24.9
Switch Band	15.8
Lower Body	72.9

- All terminal kinetic energies are lower than the competition requirement of 75 ft · lbf

Subscale Vehicle

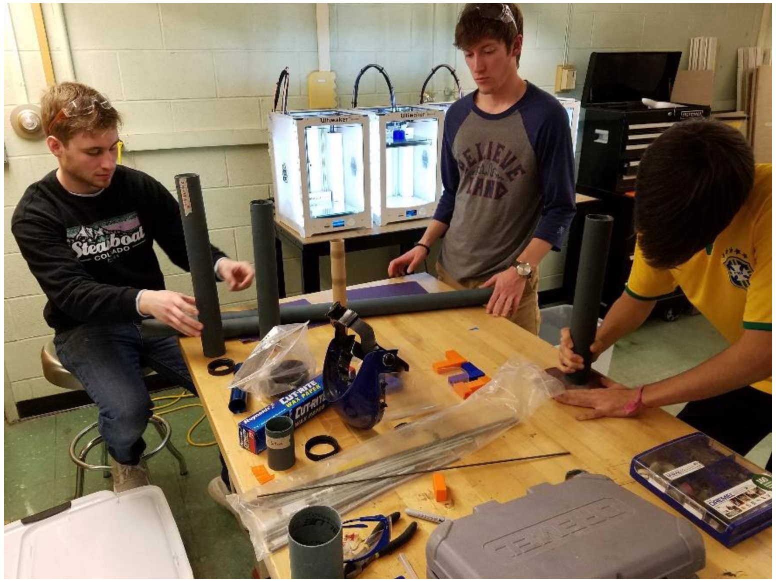
- ~Half sized scale model of full-scale vehicle
  - Same materials and similar stability margin
  - Similar motor characteristics
- Test flight data will be used to refine simulated models
- Parts ordered

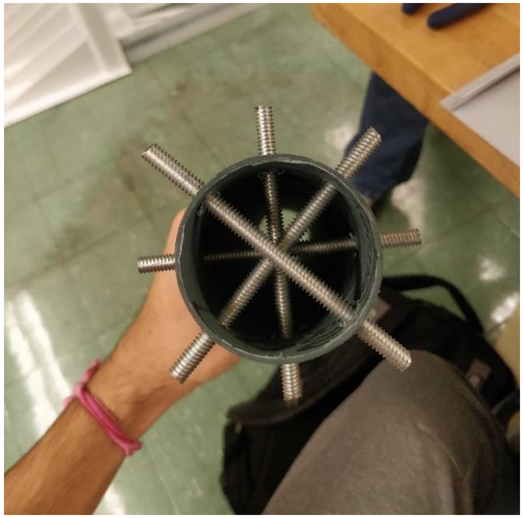




Manufacturing Progress

- Safely Manufacturing Subscale
  - Booster Tube, Body Tube, and Fairing Tube have been cut
  - Threaded Rods design
  - CAD of 3D printed interstage transition
  - AeroTech H999N-P Motor
- Launch Date : Mid-December
- Ejection Charge Testing: Early December



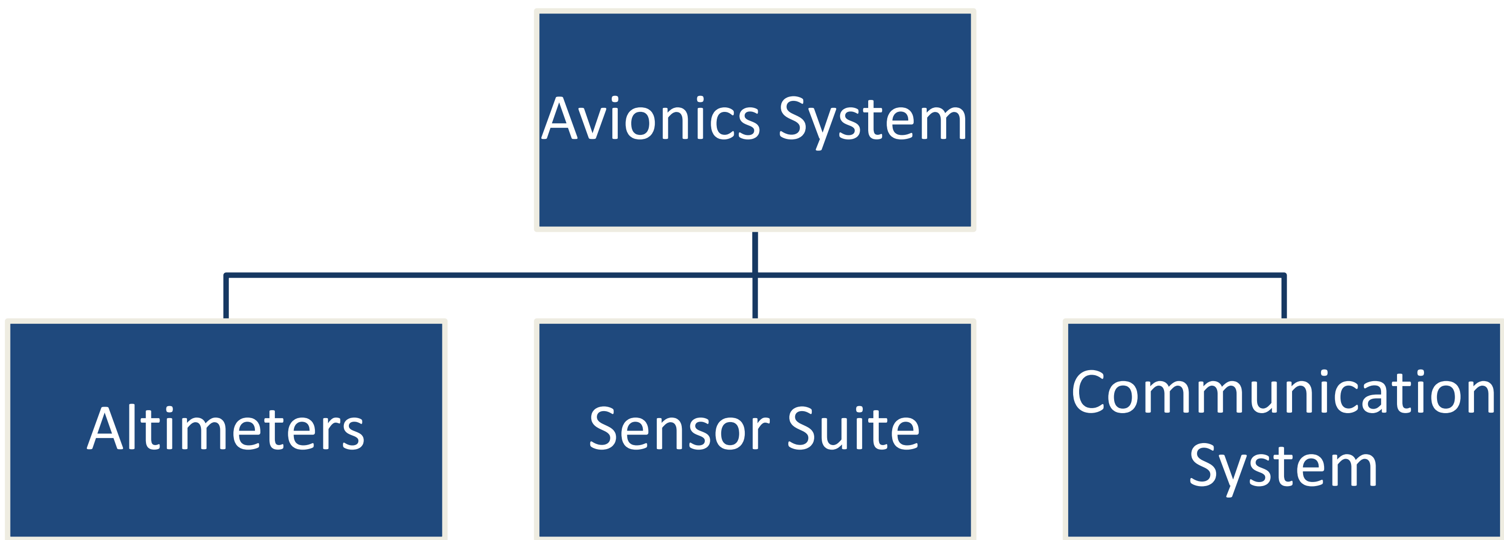


Avionics

Mois Bourla

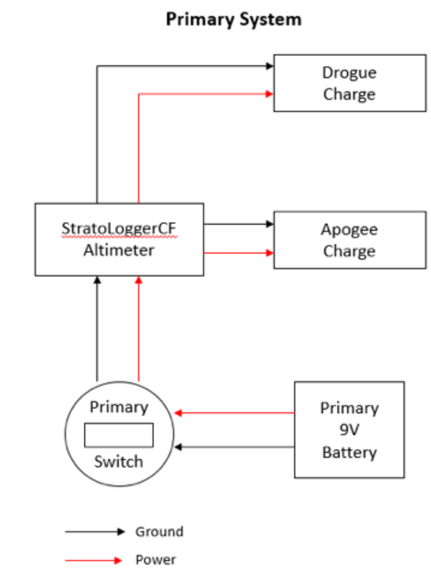
Avionics – Overview

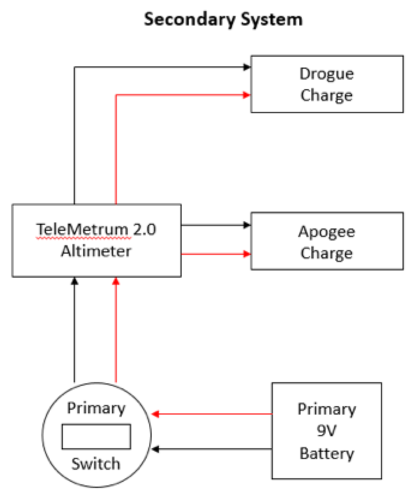
- Our mission:
  - Ensure the successful deployment of altimeter triggered black-powder charges
  - Manage the sensor suite to gather data about the flight
  - Design a communication system to clear the payload for deployment

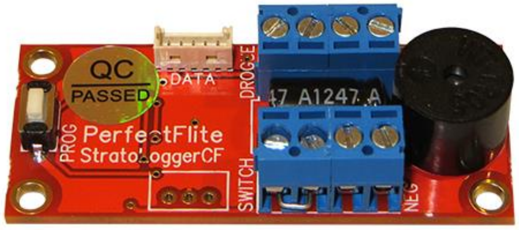


Avionics - Altimeters

- Four Redundant Altimeters
  - 2 Stratologger CF altimeters for altitude
    - Will be official competition altimeter
  - 2 TeleMetrum altimeters for altitude and tracking

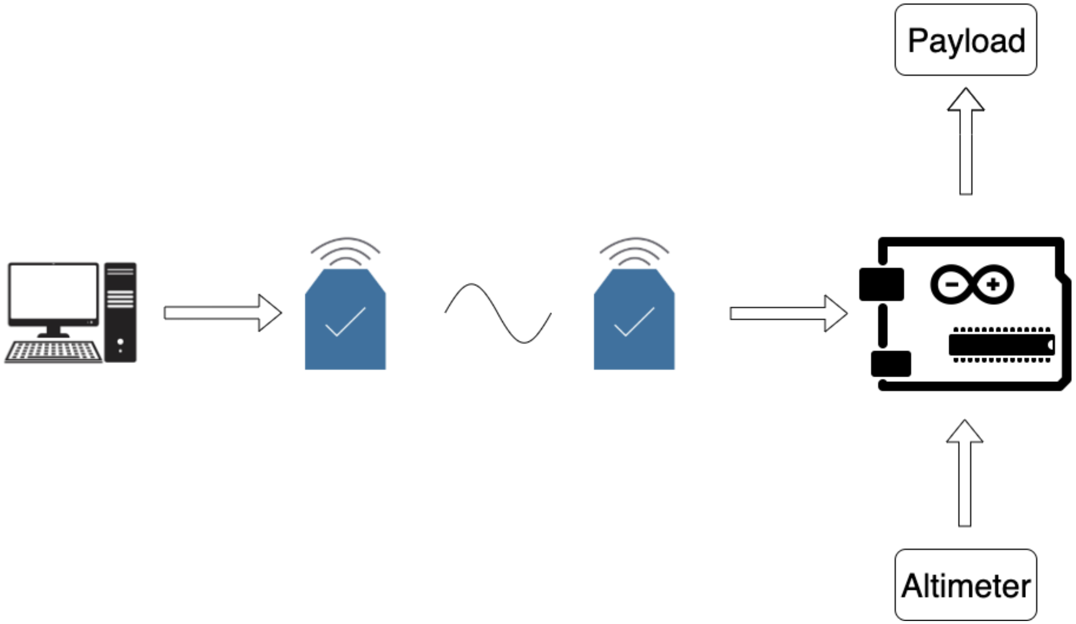






Avionics – UAV Deployment System

- Utilizes the Xbee XSC S3B RF module as the systems transceiver
  - 250 mW transmission power
  - According to the manufacturer, it features a 28 mile range with 2.1 dB dipole antennas.
- Accompanied by the MPL3115A2, a barometric altimeter that seamlessly integrates with the Arduino system



Air Deployed UAV Payload

Ayberk Yaraneri, Kenneth Tochihara, Hamza El-Kebir

Payload Mission Statement

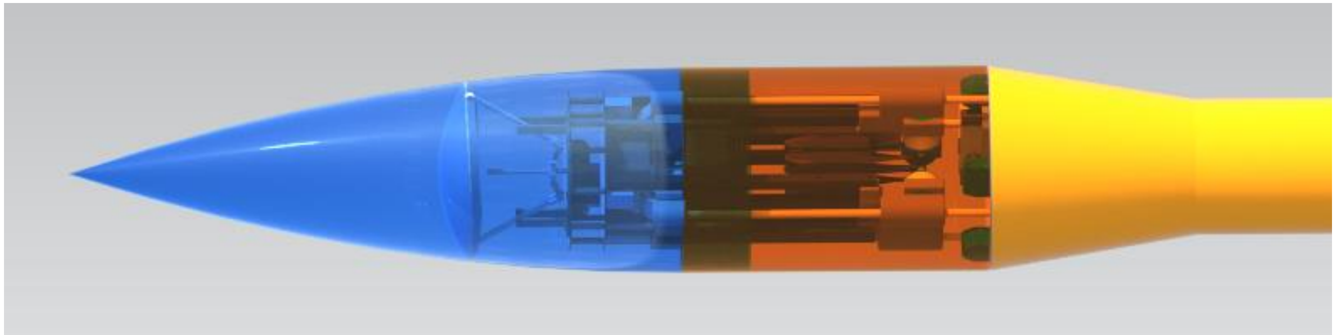
***GOAL:** Autonomously collect and transport 10 milliliters of sample materials 3 meters (10ft)*

FAA Compliance

- Compliance with Small Unmanned Aircraft Rule (Part 107)
- Register aircraft with the FAA
- Pilot Licensing
  - A pilot will be designated and registered in case of manual control takeover
- Regulated operation of the UAV
  - Must be below 122 meters (400 ft) above the ground

Payload Requirements

- Internal requirements
  - UAV must fit within 6″ tube in the fairing of the nose cone
  - UAV must be secured during rocket transport
  - UAV must have a redundant set of inertial measurement units (IMUs)
- Deployment of UAV during descent
  - Must be deployed in 30 seconds due to low altitude
  - Jettison nose cone to allow UAV deployment
  - Lower UAV from payload bay on a tether
  - Cut tether and begin powered flight

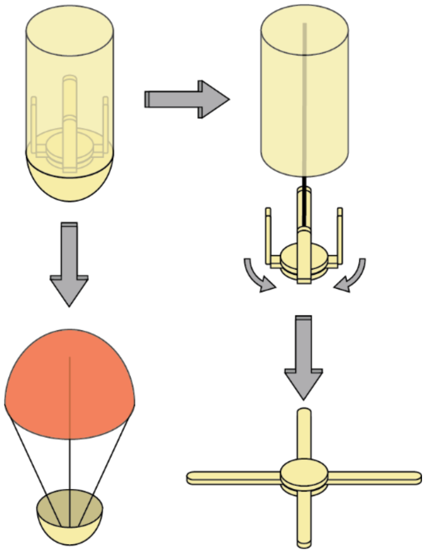


Payload Requirements

- Power distribution of UAV
  - Support for two hours of extended operations (E-OPS)
    - Stand-by on launch pad to mission termination
  - Support for 12 minutes of core operations (C-OPS)
    - Payload deployment to mission termination
  - Support for 5 minutes of close-quarter operations (CQ-OPS)
    - Landing, capture, retrieval to mission termination
- Independent Operations
  - Autonomous under pilot supervision, with the possibility of direct remote control
  - Capable of determining its own inertial position
  - Capable of waypoint navigation
  - Connected wirelessly with a ground control station

Payload Mission Timeline

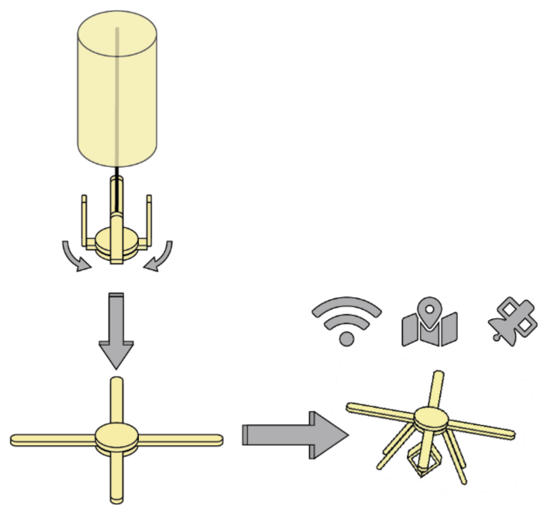
- Deployment
  - Nose cone jettison
  - Lower payload via winch system
  - Arms deploy and winch is severed



Deployment	UAV Independence	Retrieval Site Maneuver

Payload Mission Timeline

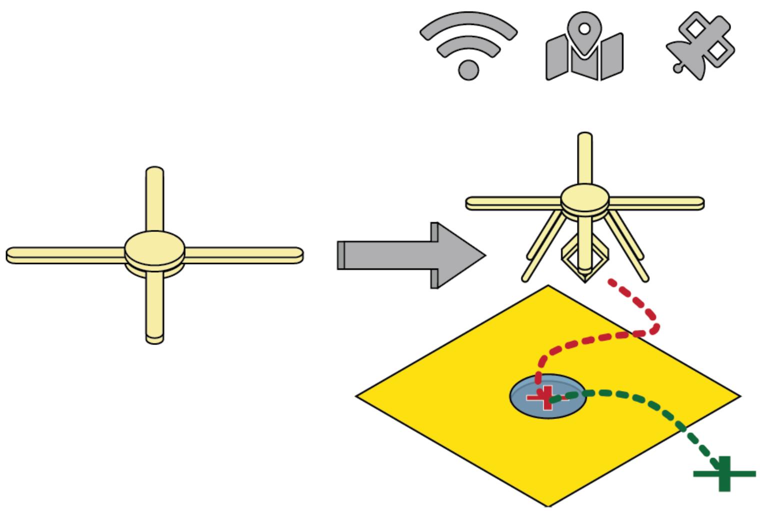
- UAV Independence
  - Critical systems check
  - Fly away maneuver from upper body tube
  - Begin waypoint navigation towards sample site



Deployment	UAV Independence	Retrieval Site Maneuver

Payload Mission Timeline

- Retrieval Site Maneuver
  - Begin descent towards sample site
  - Land on top of sample site using computer vision
  - Collect sample and fly away 3 meters to land on ground



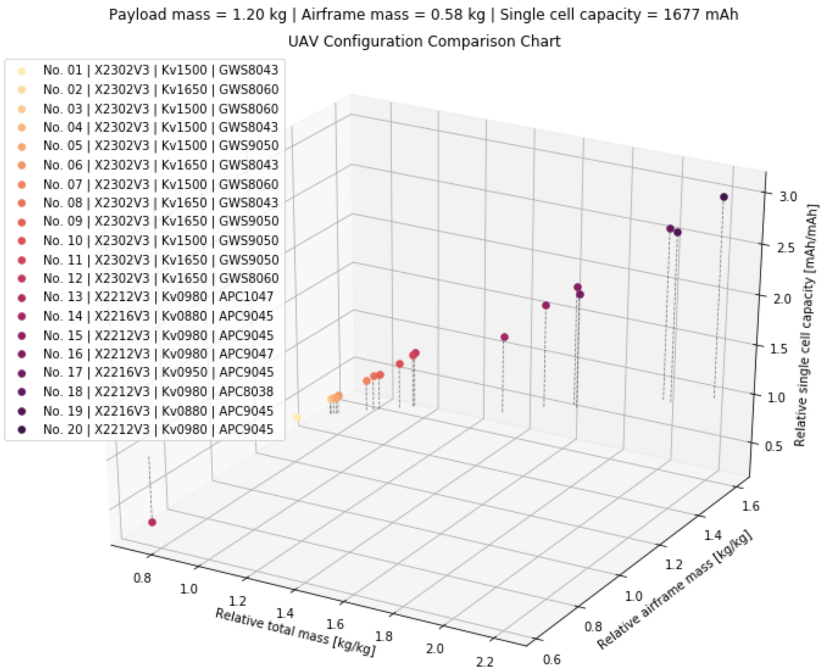
Deployment	UAV Independence	Retrieval Site Maneuver

Division of Task Groups

1. *Structures and Deployment*
2. *Flight Controller*
3. *Ice Retrieval and Mobility Agent*
4. *Computer Vision*

Structure System Sizing

- Iterative trade-off study based on the methodology of Winslow et al. (2018)
- Engine/propeller database consisting of 11 motors and 5 propellers
- X4 design powered by:
  - Four SunnySky X2212 V3 980Kv motors
  - Four 10″x4.7″ propellers
  - Two 3000 mAh Li-Po batteries (11.1 V)



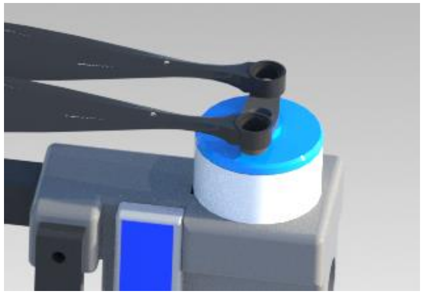
Structure System Sizing (cont'd)

- Leading mass estimate is both feasible and < 24.95 kg (55 lbs) (FAA)
- Take off mass budget of 1.45 kg
  - Airframe: 0.6 kg
  - Battery 0.5 kg
  - Motors, rotors, engine speed controllers: 0.35 kg
- Thrust-to-weight ratio of 2
- Hover time: 12 minutes

Propulsion System Components

Motor: SunnySky X2212 V3 980Kv

- Reputable brand with large model selection
- Previous experience with manufacturer
- Cost effective



Propellers: 10x4.7 foldable propellers

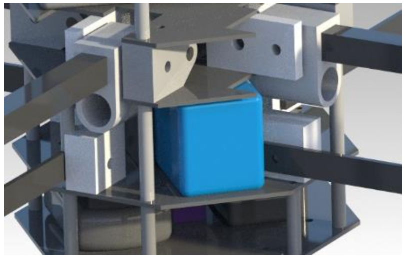
Maximum Thrust: **1650** gram-force, **3.64** pounds

Maximum Power: **405.52** watts

Power Consumption @ Hover: **27.565** watts

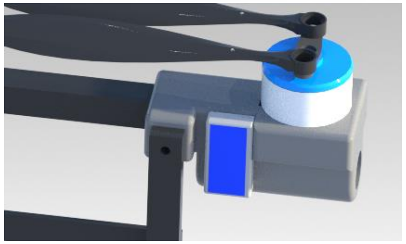
Propulsion System Components

Batteries: 2x Turnigy Graphene 3000 mAh 3s in Parallel



Voltage: **11.1** V (nominal)
Continuous Current Rating: **45** A
Total Capacity: **6000** mAh
Total Usable Capacity: 0.85 * 6000 **= 5100** mAh
Total Usable Power Capacity: 11.1 * 5.1 = **56.61** Wh

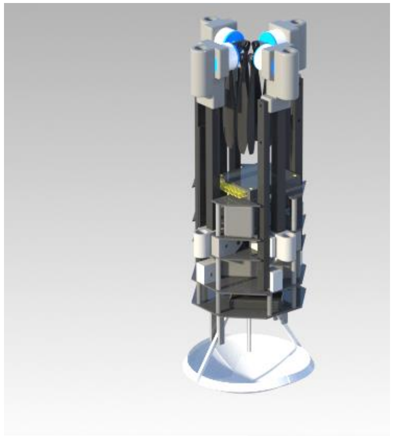
ESC: Lumenier 30A BLHeli ESC

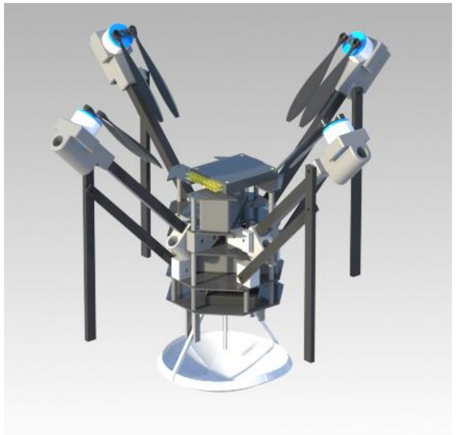


Maximum Continuous Load: 30A
Burst Current: 40A / 5 seconds

Structures Subsystem

- Arm Configuration
  - X4 Configuration
  - Arms fold upwards parallel to the rocket body
  - Parallel four-bar linkage utilized to extend landing legs

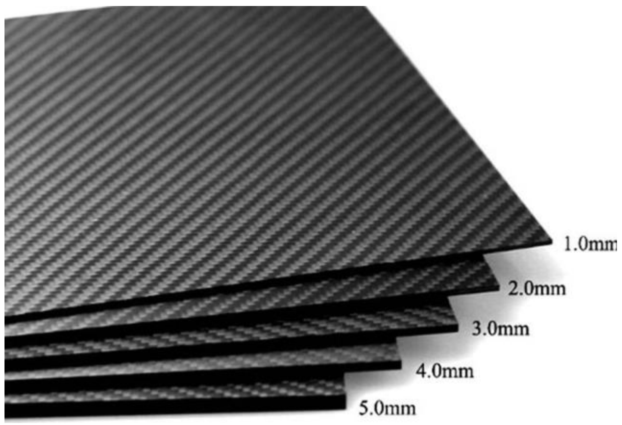




Structures Subsystem

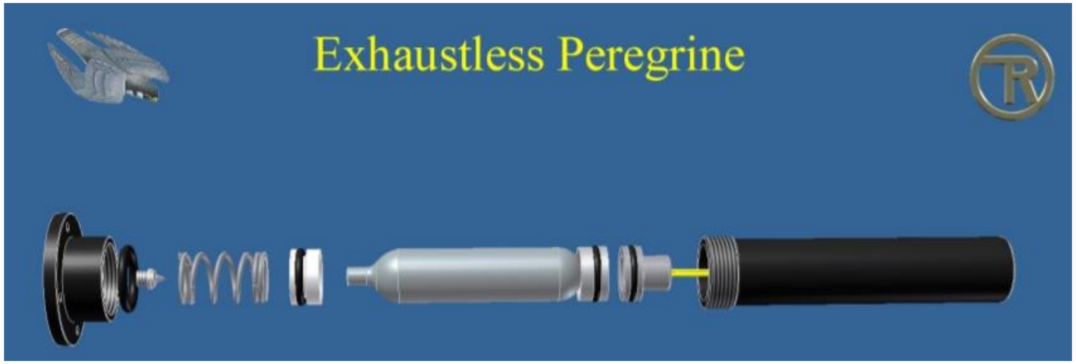
- Airframe material selection
  - 10mm x 10mm square aluminum extrusions for arms
    - Cost effective
    - Easy to machine
  - 3D printed components
    - Complex geometries
    - Stiffness can be modulated (locking mechanism)

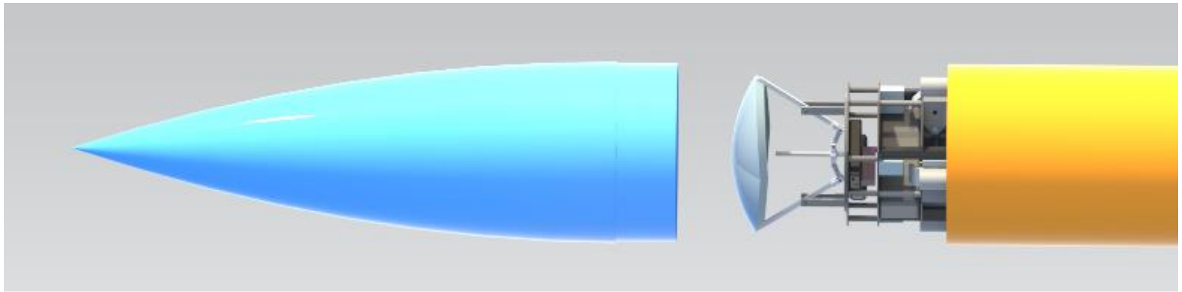
- Plating material selection
  - 2×2 weaved carbon fiber composite plates
  - Will be machined through a 3rd part machining service



Deployment Subsystem

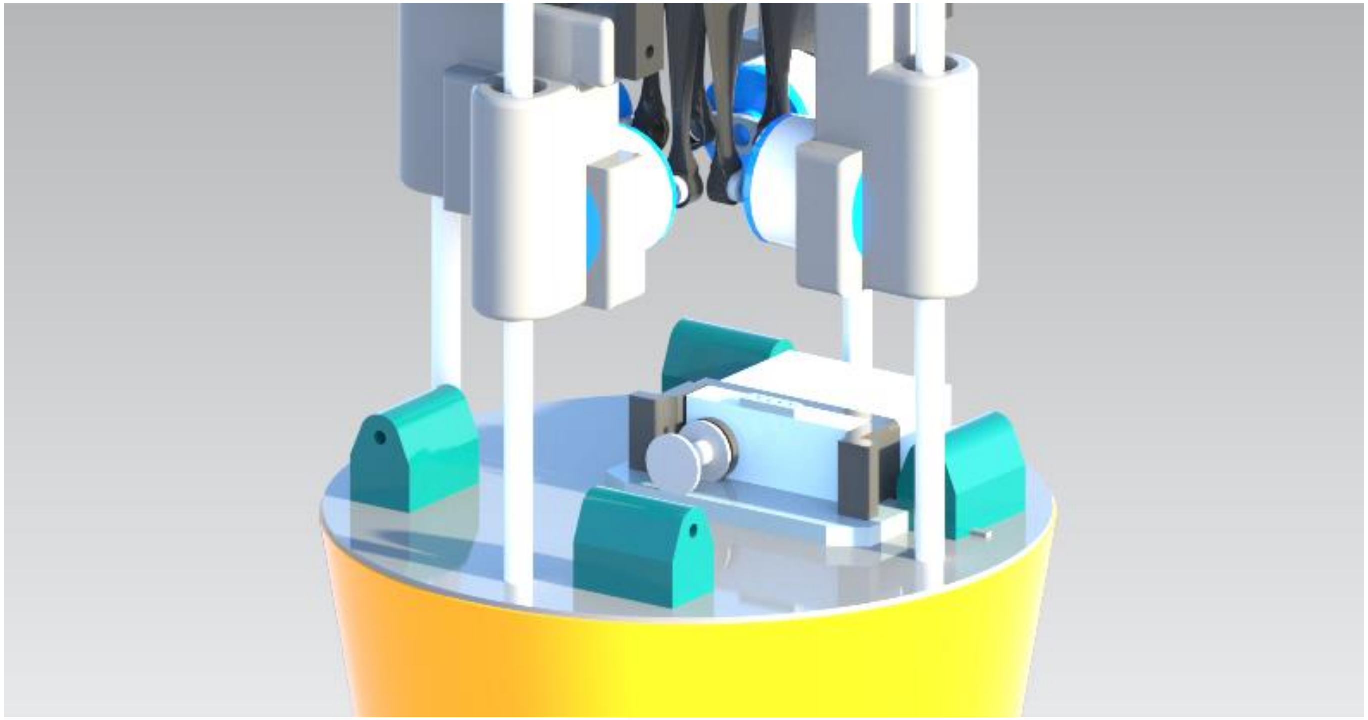
- Nosecone will be jettisoned with a Tinder Rocketry exhaustless CO2 ejection system.
- A 16 gram CO2 cartridge will be used.
- Testing will be done alongside black powder ejection charge testing in preparation for the subscale launch.





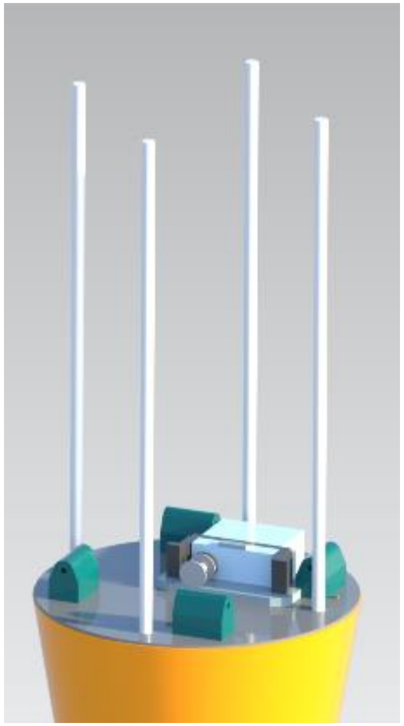
Deployment Subsystem

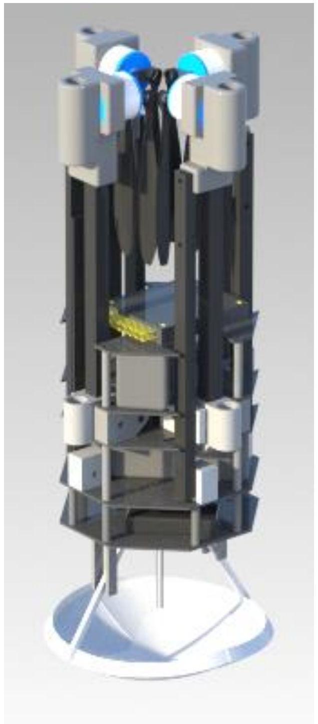
- Winch System to lower the payload from the upperbody tube
- Heat-based approach to sever the winch

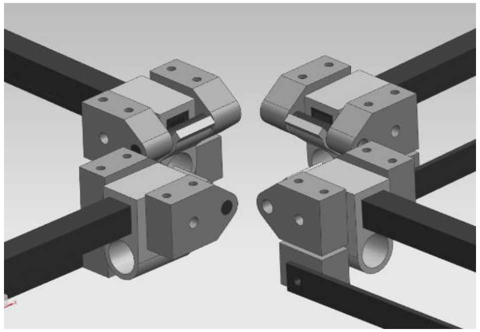


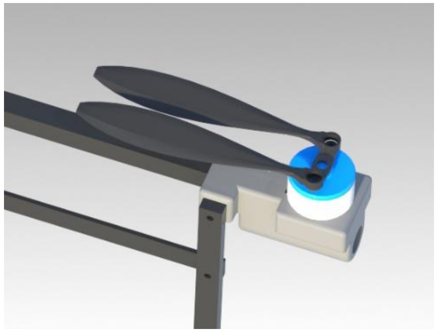
Deployment Subsystem

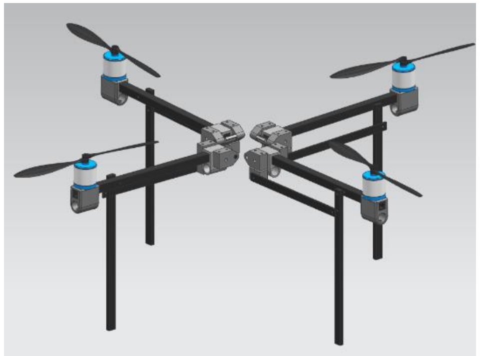
- Spring-loaded deployable arms
- Folds upward in payload bay, deploys automatically upon ejection

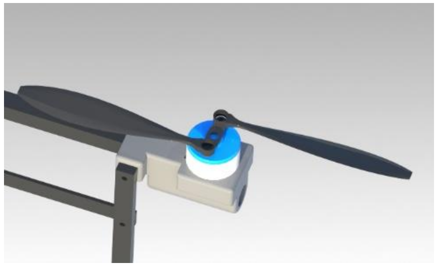






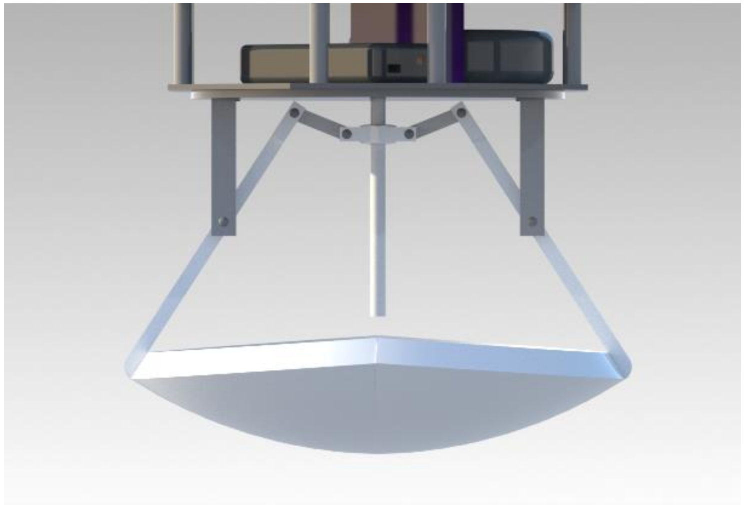


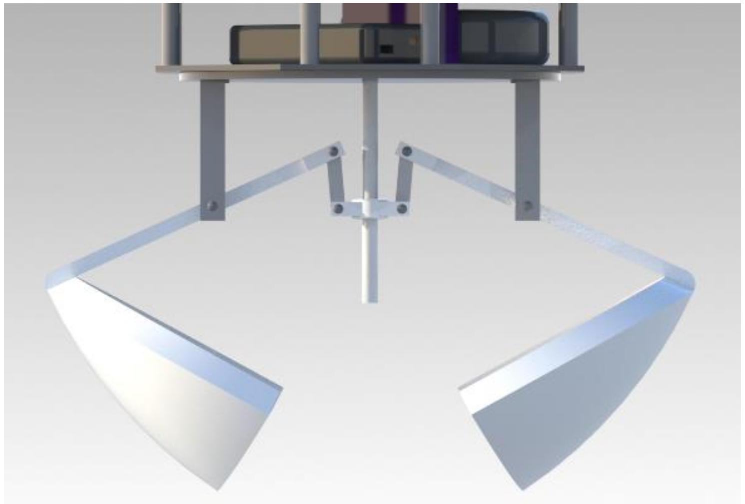




Ice Retrieval and Mobility Agent

- Continuous servo rotates threaded rod to actuate two scoops
- Structural analysis to optimize retrieval agent of the scoops
- Prototyping to be finished for subscale launch





Flight Controller

- Navio2 flight controller chosen over Pixhawk and APM
- Built in co-processor to handle real time control
- Interfaces with Raspberry Pi 3, for guidance and computer vision
- Supports peripherals such as telemetry, power sensor, and GPS

Guidance, Navigation and Control

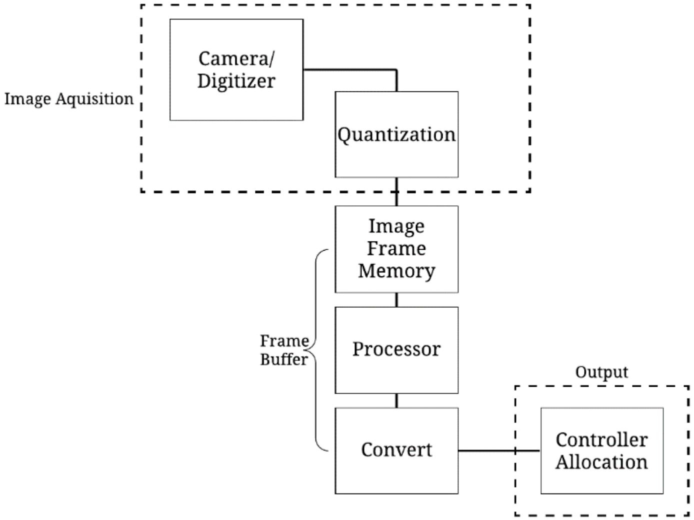
- Sensors: inertial and absolute sensing
  - Inertial measurement units (accelerometer, gyroscope)
  - Time of flight sensors
  - Visual camera with computer vision
  - Global Positioning System
- Prior knowledge of retrieval locations stored as GPS coordinates
  - Online waypoint guidance and motion planning
- Custom GNC protocols for system check, manual control override
- Distinction between GNC and control allocation (CA)
  - Custom guidance, navigation and control code (Raspberry Pi)
  - Off-the-shelf control allocation (Navio2)
- Discrete time control using Linear Quadratic Gaussian (LQG) scheme

GNC (cont'd)

- On-board decisions and parameters broadcast through telemetry
- Computer-aided control system design (CACSD) through Matlab Simulink
- Parameter estimation using Computer-aided design (CAD) software
- Software-in-the-loop (SITL) testing in Gazebo

Computer Vision

- Will attempt to detect and track sample retrieval sites
- Two methods will be investigated
  - Algorithmic approach
  - Machine learning approach



Development and Testing Milestones

- 11/22/2019
  - Have carbon fiber plates sent out for machining by a 3rd party service before fall break.
  - Order miscellaneous structural components for airframe.
  - Conduct maiden flight of test-bed UAV
  - Construct a prototype of I.R.M.A.
- 12/02/2019
  - Mount prototype of I.R.M.A. and begin field testing on test-bed UAV
  - Begin construction of competition airframe
- 12/20/2019
  - Maiden flight of competition airframe

Safety Considerations

- Manufacturing of carbon-fiber pieces out-sourced
- Compliance with FAA regulations
- Thorough testing of UAV deployment and flight
- Proper precautions with Li-Po battery usage
- Proper security of components on UAV

Project Plan

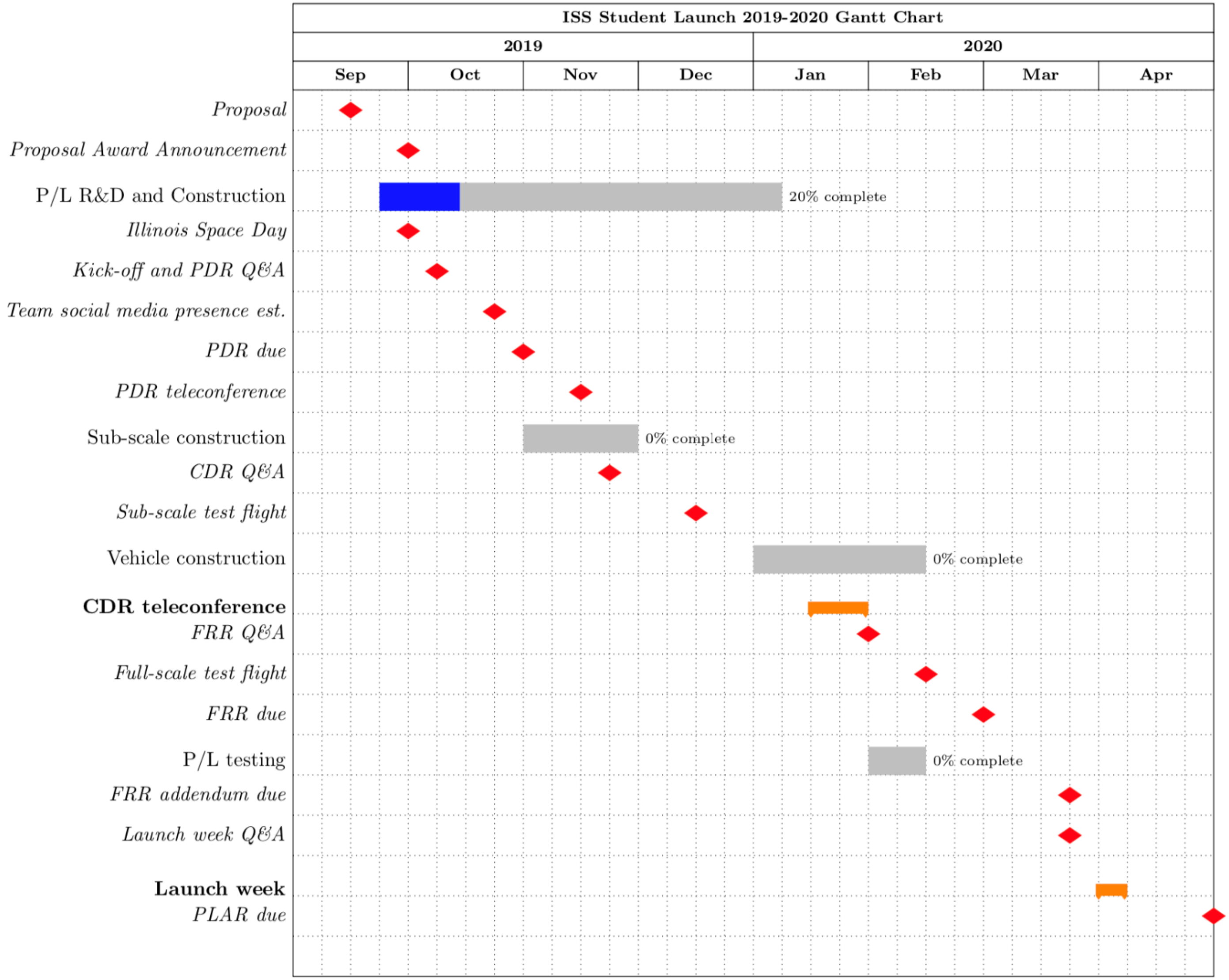
Hamza El-Kebir

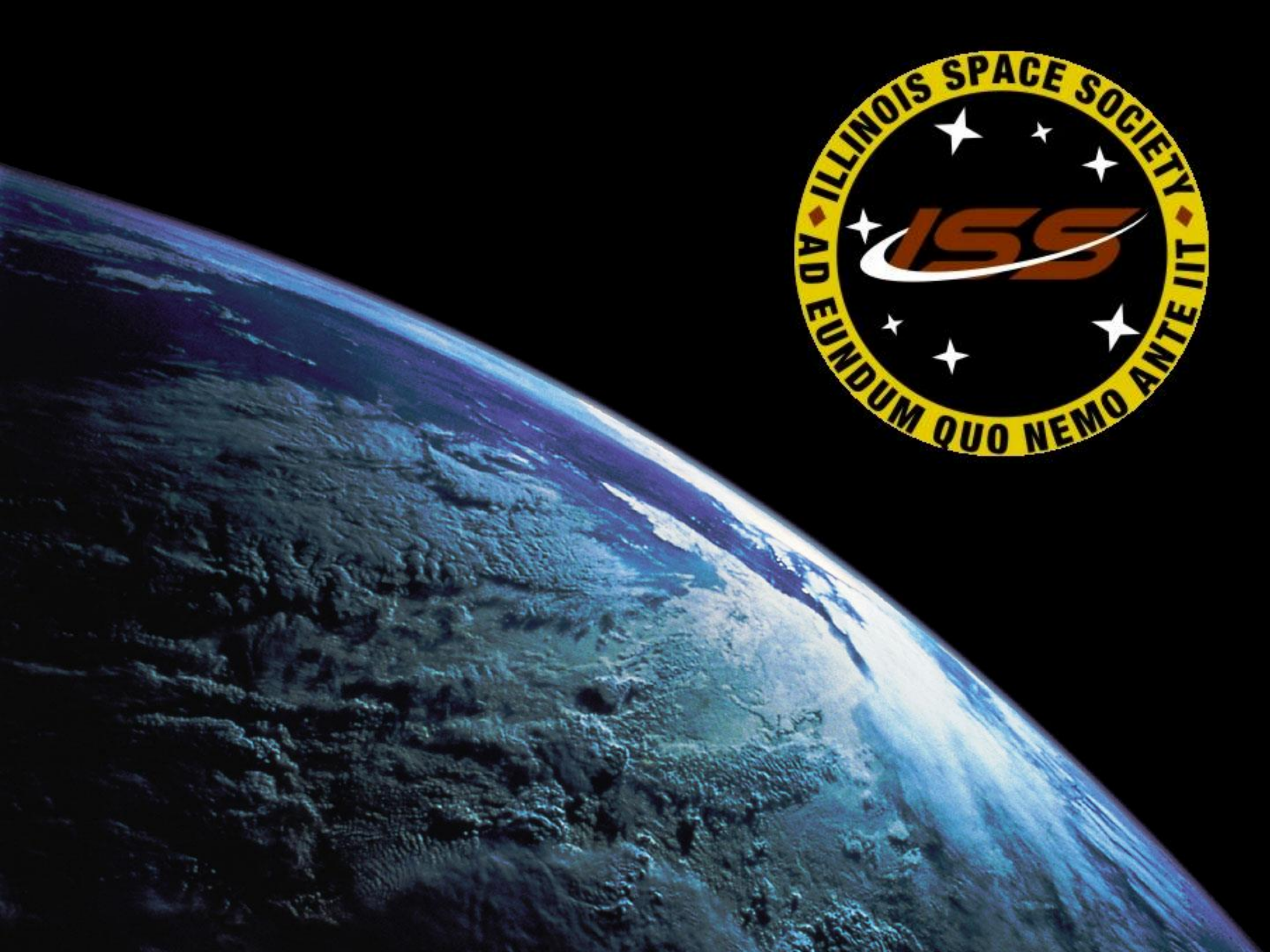
Near-term Milestones

- Preliminary LQR controller design (End Nov. 2019)
- Computer vision field test (Dec. 2019)
- UAV maiden flight (Dec. 2019)
- Subscale flight (Dec. 2019)
- Avionics design (Dec. 2019)
- Upper stage assembly (Dec. 2019)

- Black powder charge testing (Dec. 2019)
- Pressurized ejection system testing (Dec. 2019)
- Payload deployment assembly testing (Dec. 2019)

Gantt Chart


ISS Student Launch 2019-2020 Gantt Chart
2019
2020
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Proposal
Proposal Award Announcement
P/L R&D and Construction
20% complete
Illinois Space Day
Kick-off and PDR Q&A
Team social media presence est.
PDR due
PDR teleconference
Sub-scale construction
0% complete
CDR Q&A
Sub-scale test flight
Vehicle construction
0% complete
CDR teleconference
FRR Q&A
Full-scale test flight
FRR due
P/L testing
0% complete
FRR addendum due
Launch week Q&A
Launch week
PLAR due


ILLINOIS SPACE SOCIETY
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Educational Outreach

Robert Filipiuk

Outreach Events

- Illinois Space Day (ISD)
- Urbana Free Library Read-Along
- Mahomet Seymour Science Club
- Arthur Grade School Visit
- Next Generation Preschool visit