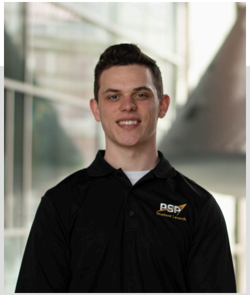
Project Voss
Critical Design Review

PSP-SL 2021

2021 Executive Board

Skyler Harlow
Project Manager

Lauren Smith
Assistant Project Manager



JJ Bagdan
Construction Team Lead

Katelin Zichittella
Avionics Team Lead

Luke Hecht
Payload Team Lead

Andrew Darmody
Safety Team Lead

Natalie Keefer
Business Team Lead

Jason Hickman
Outreach Team Lead

Subscale Flight

Launch Date	11/7/2020
Temperature	65-70 °F
Weather	Clear Day with no precipitation
Launch Wind Speed	6 mph SSW
Launch Location	Purdue Dairy Farm West Lafayette, IN
Predicted Apogee (Simulink)	625 ft
Recorded Apogee	620 ft

PSP

Project Voss R&VP System

- The team has created a new R&VP system to inform vehicle design and verification
- Focused on usability and simplicity
- Broken into Project and Subteam level requirements to provide autonomy to subteam SMEs

Requirement ID	Requirement Summary	Verification		Verification Plan / Prerequisite Requirement Summary	Status
		Type(s)	Plan ID(s)		
N.1.1	All work will be completed by the team specifically for this year's competition. A mentor will assist with handling of potentially explosive or flammable devices.	D	N/A	PSP-SL members shall demonstrate the new work they have completed through milestone documentation and presentations.	Incomplete

PSP

Systems Requirement Status

6.2.6 PLS Battery Drain Testing

Test Objective: To verify that the Planetary Lander System is compliant with S.P.1.11 and S.P.1.12. These requirements dictate that all PLS subsystems must have sufficient battery life to sustain their pre-flight state for 18 hours, and their launch-ready state for an additional 2 hours.

Success Criteria: The Planetary Lander System will contain enough battery to successfully perform it mission after staying in a pre-flight state.

Why it is necessary: If the battery were to drain too much during the pre-flight and launch-ready phases, then the battery may not contain enough charge for the system to carry out its tasks, resulting in a failed mission. To avoid this, the team will test the batteries to identify any faults before the design is finalized.

Excerpt of payload battery drain test procedure

Test Type	Completed	In Progress	Incomplete
NASA Derived	51	41	42
Team Derived	15	18	36

(Avionics has 1 discontinued requirement not counted here)

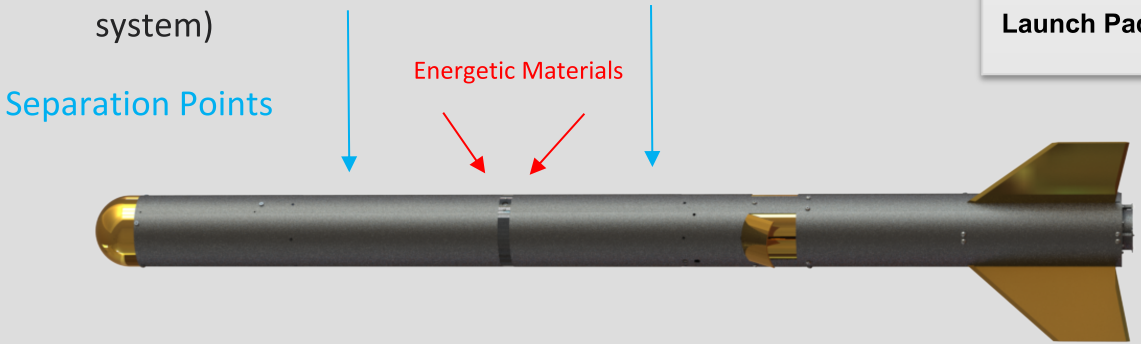
PSP

Vehicle Design

Launch Vehicle Overview

- High power rocket targeting an apogee of 4100’ using an active drag management system
- Designed following industrial standards for manufacturability and verification
- Dual deployment with GPS tracking on all sections
- 30% payload mass fraction (lander and aerobraking system)

Vehicle Name	All Gas, All Brakes
Vehicle Length	87.2"
Expected Lift-off Weight	52.1lbm
Body Tube Inner Diameter	6.00"
Launch Pad Stability	2.94cal
Launch Pad CoM	45.1” aft of tip
Launch Pad CoP	63.3” aft of tip



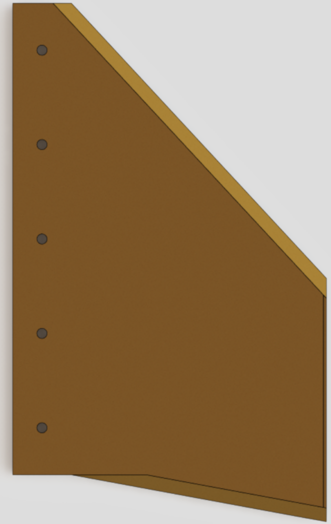
PSP

Booster Section

- 20.5lbm estimated weight
- 43.2” OAL (Over All Length)
- Contains AeroBraking Control System (ABCS), Motor and Fin Support Structure (MFSS), and Booster Tracker
- Transfers thrust and aerodynamic loads to the rest of the vehicle
- All body tubes are constructed from G-12 Fiberglass, chosen for its strength and availability

Fins

- 3 swept trapezoidal Fins
- 6.5” Height, 12” Root Chord
- Holes for mounting on MFSS
- Optimized for minimum drag while maintaining stability of 2.98 cal at rail exit
- Waterjet G-10 fiberglass sheet, allowing for design flexibility

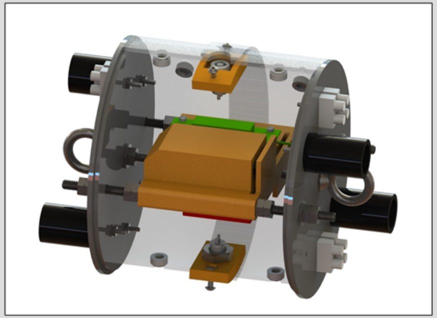


Recovery Section

- 10.3lbm estimated weight
- 32” OAL
- Forward bay for main parachute and aft bay for drogue
- Connects with shear pins to booster and payload couplers
- Joined during flight by bolts to the avionics bay

Avionics Bay

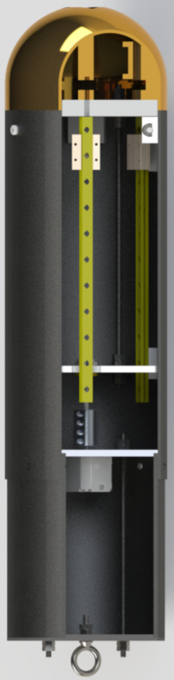
- 5” internal length
- 1” switch band
- Contains redundant recovery hardware including altimeters and ejection charges
- 3D printed altimeter support structure



PSP

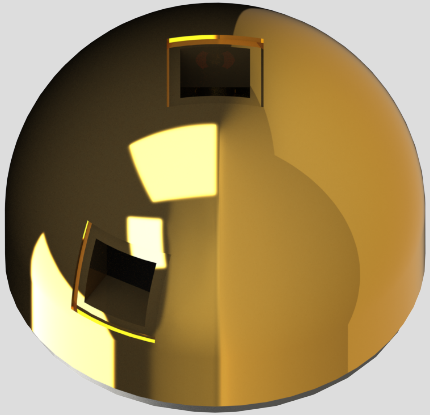
Payload Section

- 14lbm estimated weight
- 18” OAL
- Contains Planetary Lander System (PLS), all PLS support systems, and the Payload Tracker
- Connects with shear pins to the upper recovery section



Nose Cone

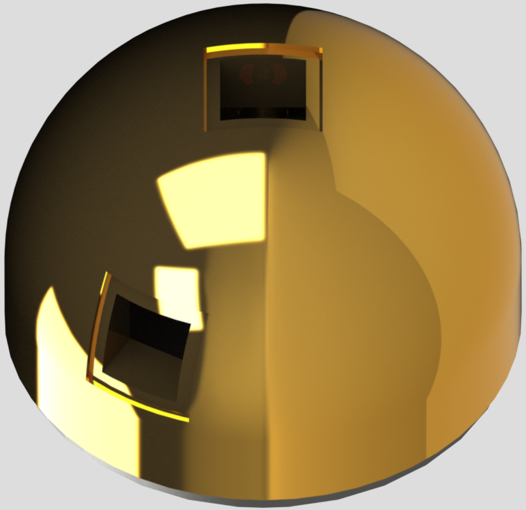
- 2lbm estimated weight
- 4” OAL
- 3” radius hemisphere with 1” shoulder
- 3D printed carbon fiber reinforced nylon
- Contains In Flight Video Recording (IFVR) system, and adjustable ballast.



PSP

Nose Cone

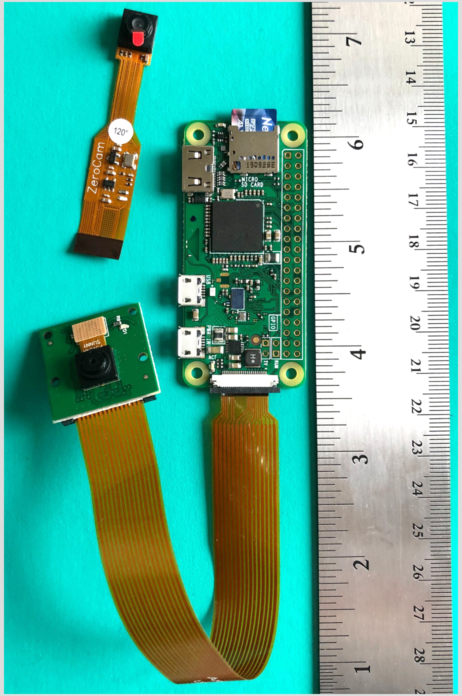
- 3” hemisphere with 1” shoulder. Selected for reduced dead mass and wetted surface area vs long ogive
- Primarily carbon fiber reinforced 3D printed nylon, with acrylic camera windows
- Will contain 3 cameras for recording forward, outward and aft
- Permanently attached via Payload Retention & Deployment



PSP

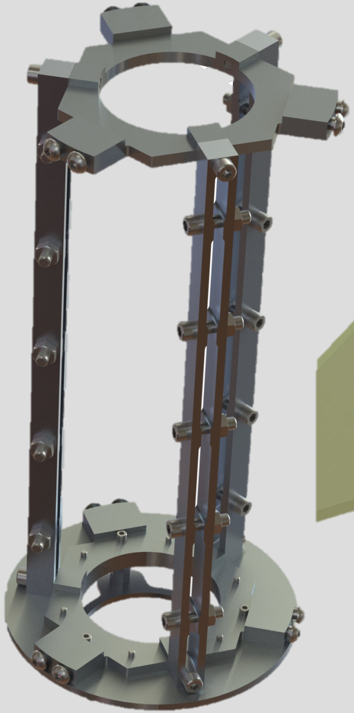
In-Flight Video Recording System

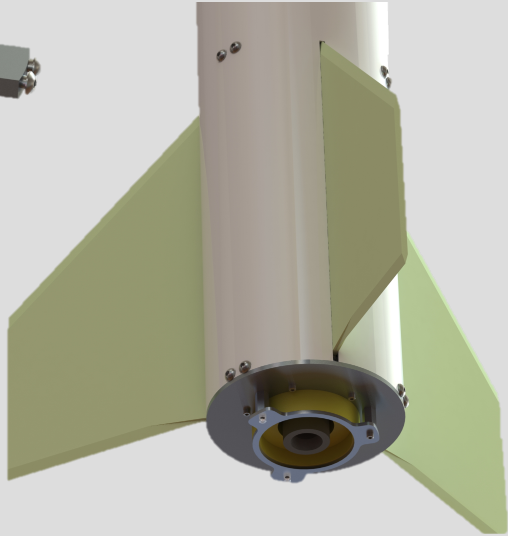
- The launch vehicle will contain 3 cameras, recording to SD cards via Raspberry Pi Zero single board computers
- 3 cameras will be installed in the nose cone, looking through acrylic windows upward and outward



Motor and Fin Support Structure

- CNC machined aluminum structure for fin mounting and transmitting motor thrust loads
- Assembled without motor, then inserted into the rocket for motor loading and launch
- Modular and easy to assemble vs. epoxy and centering rings



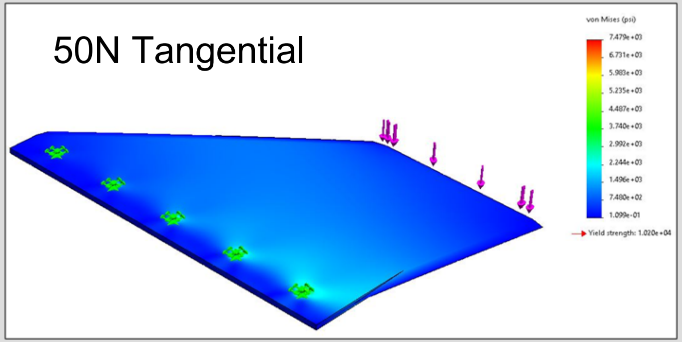


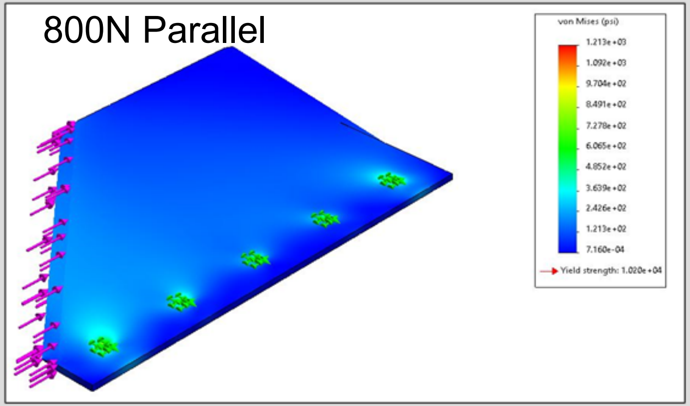
Fin Analysis

- Fins were fixed at the at the 5 spar holes
- Yield Strength is 1.02e+4 psi

Test	Max Von Mises Stress (psi)
Tangential	2.244e+03
Parallel	3.639e+02

- Fins proved to remain very sturdy during flow simulations.
- Yield strength was less than an order of magnitude.





PSP

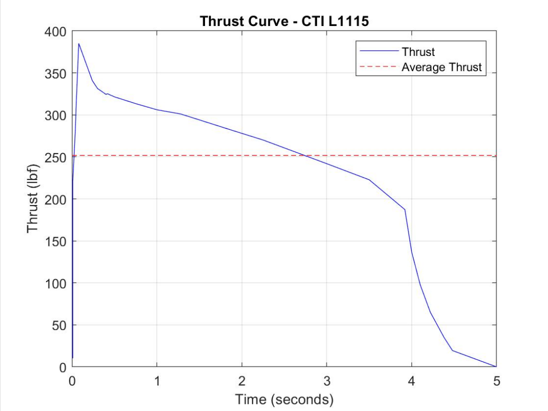
Important Launch Vehicle Criteria

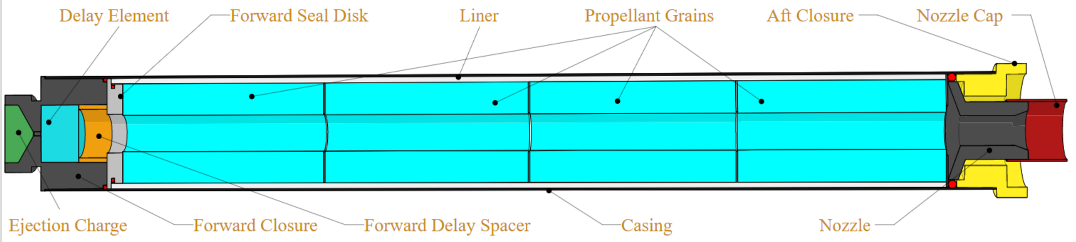
Rail Exit Velocity	66.2ft/s
Thrust-to-Weight Ratio	6.1
Maximum Velocity	537ft/s
Maximum Acceleration	199ft/s^2
Maximum Dynamic Pressure	342.71lbf/ft^2

PSP

Motor Choice – CTI L1115

Loaded Weight	9.63lbf
Propellant Weight	5.24lbf
Total Impulse	1128.38lb-s
ISP	213.60s
Maximum Thrust	385.48lbf
Average Thrust	251.78lbf
Liftoff Thrust	327lbf
Burn Time	4.48s
Dimensions	2.95” x 24.45”





Mass Margin

Component	Expected Mass (lb)	Current Mass (lb)
Payload	9	9.17
ABCS	8	5.5
MFSS	4	2.78
Upper and Nose Cone	3.64	4.14
Motor	9.63	9.63
Avionics Bay	5.00	5.00
Recovery	5.6	5.6
Booster Section	7.24	7.24
Total	52.1 (No Ballast)	49.1

- Expected Mass is based off the initial design.
- Current masses are based on OpenRocket and SolidWorks data.
- Weight will be larger due to weights currently not available (epoxy, nuts, washers, paint), and ballast will be added, as necessary.

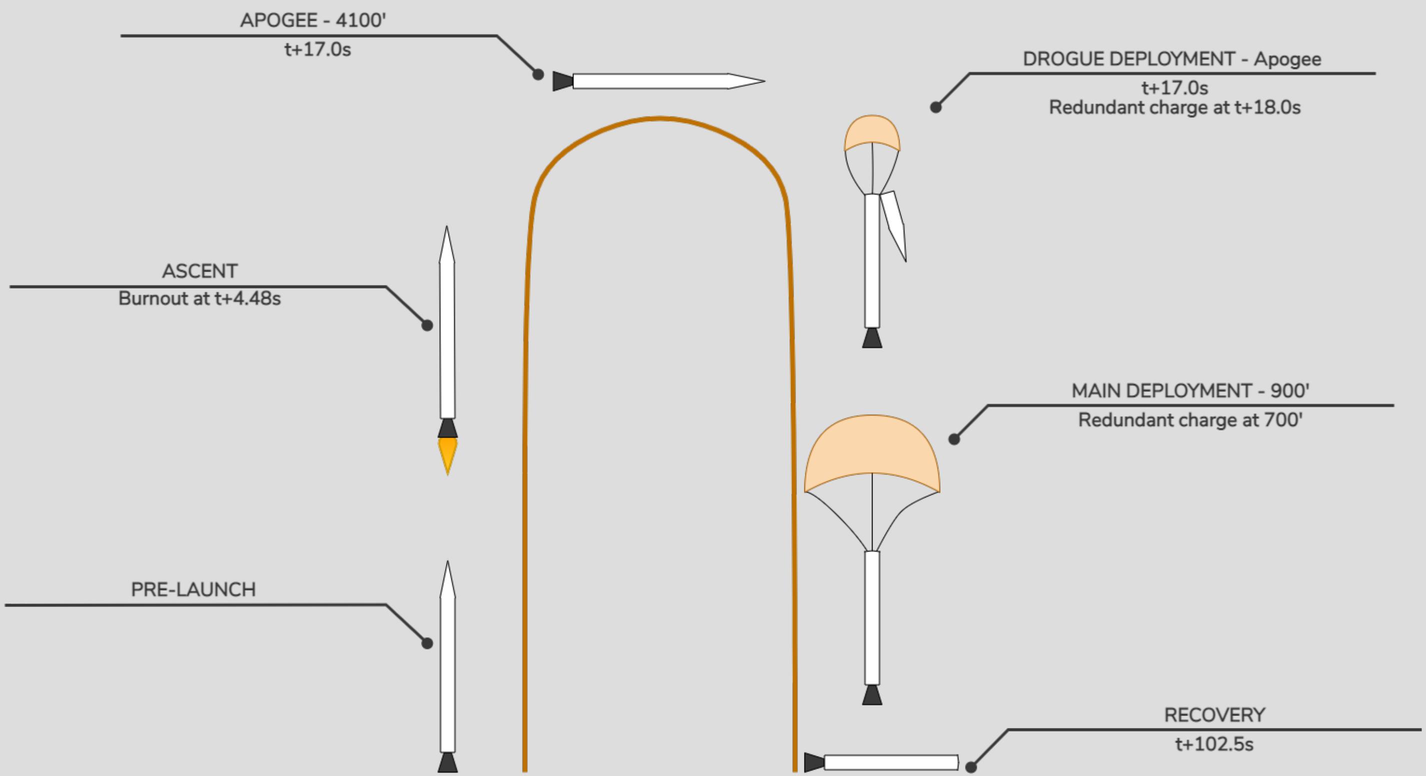
Drift Calculations

	Drift Distance (ft)	
Wind Speed (mph)	Hand Calculation	OpenRocket
0	0	10
5	622	653
10	1245	1295
15	1868	1736
20	2490	2155

PSP

Recovery Design

Vehicle Trajectory Overview

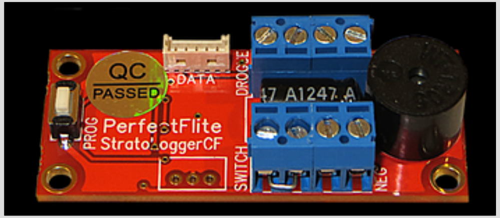


Primary Altimeter

- **Atlus Metrum TeleMetrum**
  - 3.7V LiPo Battery
  - Reliable in past launches
  - Has GPS/live telemetetry capabilities
  - Also used as primary rocket locator

Redundant Altimeter

- **PerfectFlite StratoLoggerCF**
  - 9V Battery
  - Fits in shorter avionics bay
  - Advertised capabilities satisfy mission needs



Drogue Parachute

- **24" Fruity Chutes Classic Elliptical**
  - **CD:** 1.5
  - **Materials:** 1.1oz rip-stop, 220lb nylon shroud lines, 1000lb swivel
  - Reliable in past launches
  - Compact and lightweight
  - High drag coefficient

Main Parachute

- **144" Rocketman High-Performance CD 2.2**
  - **CD:** 2.2
  - **Materials:** 1.1oz rip-stop, 250lb nylon shroud lines, 3000lb swivel
  - Supports a vehicle with a maximum weight of around 54lbm
  - Compact and lightweight
  - High drag coefficient

PSP

Heat Shielding

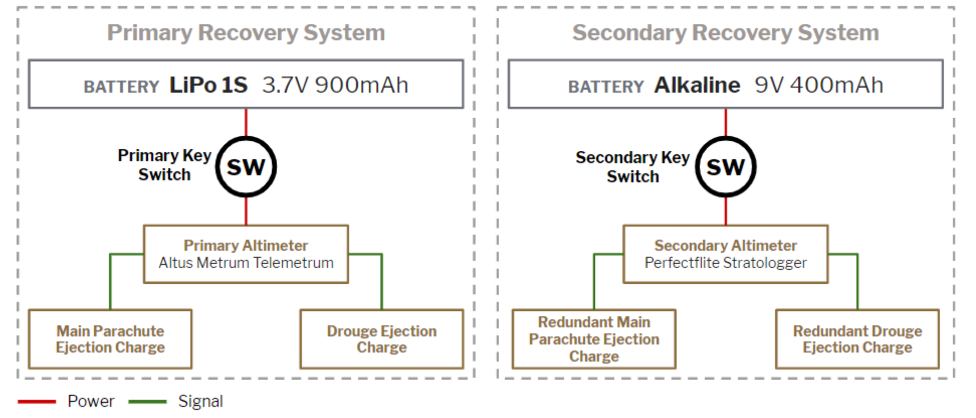
- **Nomex blankets**
  - Square, 18” side
  - One wraps around the drogue parachute and one wraps around the main parachute while packed
  - Serve to protect the parachutes from hot ejection charge gases

Attachment Hardware

- **Drogue Shock Cord**
  - ⅜" tubular Kevlar
  - 30' long
- **Main Shock Cord**
  - ⅜" tubular Kevlar
  - 60' long
- **Harness/Airframe Interfaces**
  - ¼" stainless steel quick links through looped tether ends
  - ¼" stainless steel eyebolts through bulkheads

PSP

Wiring Diagram



Ejection Charges

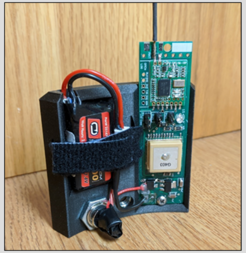
Ejection Charge Type	FFFFg Black Powder
Ejection Charge Locations	Forward and Aft Avionics Bay Bulkheads
Primary Drogue	2g
Redundant Drogue	3g
Primary Main	3g
Redundant Main	4g

Tracking Devices

Primary – TeleMetrum Altimeter

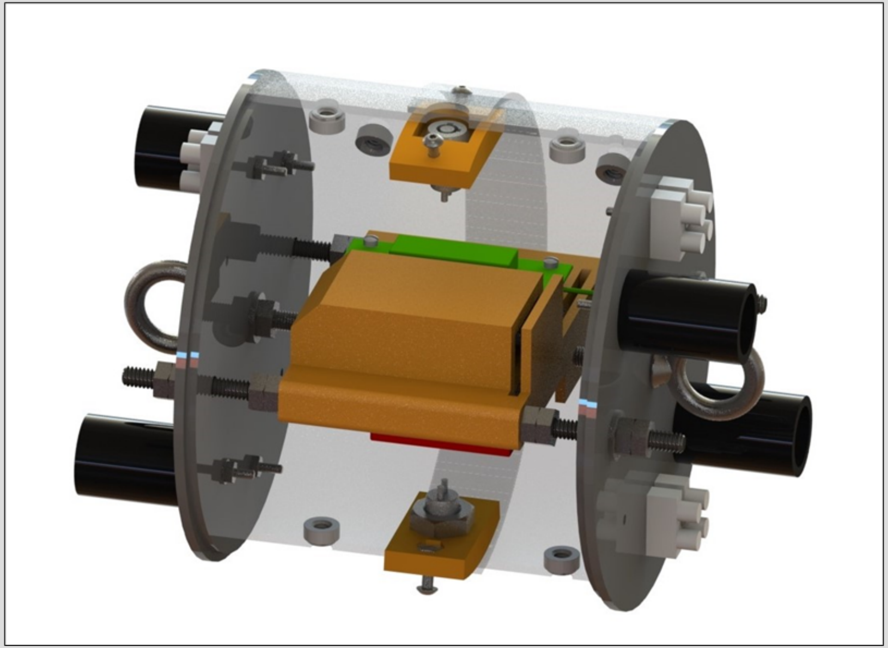
- Specific frequency used by the team: **434.55 MHz**
- Reliable in establishing and maintaining connection to ground station
- Connection made using a TeleDongle and Yagi Arrow 3 Element antenna to a laptop

Secondary – EggTimer Rocketry EggFinder TX



- Long range tracking, low weight, and low power consumption
- Housed in 3D printed housing containing GPS module, battery, and key switch
- Two modules in final vehicle, located in each breakpoint coupler

Overall Avionics Bay Design



Key Details	
Coupler Length	5”
Overall Weight	5lbm
Switch Type	Keylock
Altimeter/Battery Retention	Altimeter Sled/Battery Guard
Ejection Charge Retention	Black Powder Canisters

PSP

Simulink Vehicle Trajectory Simulation and Mission Performance Predictions

Parameter	Value	Pass/Fail
Apogee	4482’	N/A
Ascent Time	17.0s	N/A
Drogue Descent Velocity	87.7ft/s	N/A
Landing Velocity	14.3ft/s	N/A
Descent Time	85.5s	Pass
Drift Distance	521’	Pass
Rail Exit Velocity	62.2ft/s	Pass
Landing Kinetic Energy of the Heaviest Section	74.8ft-lbf	Pass

Vehicle Section	Kinetic Energy Under Drogue (ft-lbf)	Landing Kinetic Energy (ft-lbf)
Upper Section	1648.0	43.8
Middle Section	1223.5	32.5
Lower Section (Dry)	2813.5	**74.8**
Total Launch Vehicle (Dry)	5685.0	151.1

Notes: This simulation was run with a launch rail angle of 10° from vertical, the horizontal wind speed set to 10mph, and no additional mass. The vehicle was launched into the wind.

Avionics and Recovery Testing

Req. ID	Test ID	Test	System Under Test	Status
S.A.5.1, S.A.5.2, S.A.6.1, S.A.6.3	VT.A.5.1, VT.A.5.2, VT.A.6.1, VT.A.6.3	Altimeter Continuity and Battery Drain Test	StratoLoggerCF altimeter, 9V battery, TeleMetrum altimeter, 3.7V LiPo battery	Complete
S.A.2	VT.A.2	Parachute Drop Test	Drogue parachute, main parachute	Complete
S.A.5.3	VT.A.5.3	Altimeter Ejection Vacuum Test	StratoLoggerCF altimeter, TeleMetrum altimeter	Incomplete
S.A.2.1, S.A.3	VT.A.2.1, VT.A.3	Black Powder Ejection Test	Drogue and main black powder ejection systems	Incomplete

PSP

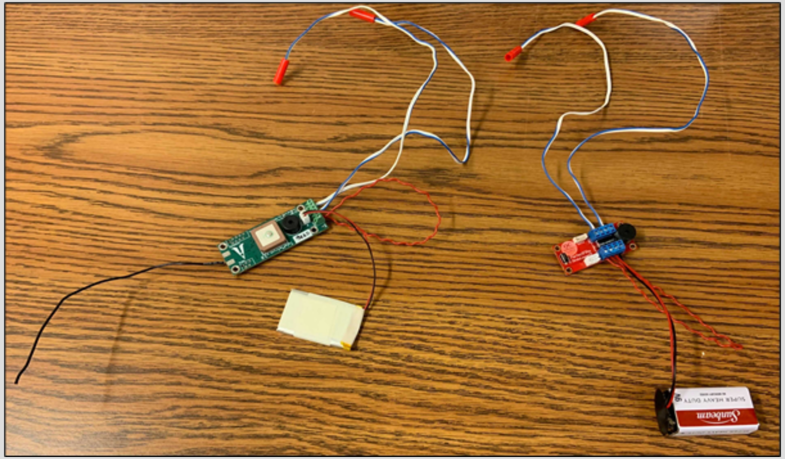
Altimeter Continuity and Battery Drain Test

- **Objective:** Altimeter systems fulfill the requirements that they function continuously across all likely flight temperatures and durations.
- **Success Criteria:** Both altimeters must maintain continuity and receive adequate power from their respective batteries for 3 hours powered on, and the voltages of both batteries must remain the same after 18 hours powered off.
- **Methodology:** Connect altimeters to batteries and lighters and periodically check continuity and voltage in two temperature extremes.
- **Results**: Both altimeter systems passed the continuity test for warm and cold weather, and also the battery drain test.

Parachute Drop Test

- **Objective:** Parachutes fulfill the requirements that they open consistently within an appropriate distance range or time frame to allow for full deployment after ejection.
- **Success Criteria:** Both parachutes must fully deploy within their respective maximum parameter.
- **Methodology:** Drop and video record weighted drogue and main parachutes from the top of a parking garage to simulate ejection during flight.
- **Results:** Both the drogue and main parachutes passed this test.

Altimeter Continuity and Battery Drain Test



Parachute Drop Test

PSP

Altimeter Ejection Vacuum Test

- **Objective:** Altimeters fulfill the requirements that they consistently ignite both ejection charges at the appropriate times.
- **Success Criteria:** Both altimeters must ignite the drogue parachute lighters at apogee (or 1s after apogee) and the main parachute lighters at the correct altitude during descent.
- **Methodology:** Simulate a flight with both altimeter systems in a homemade vacuum chamber, recording event data.
- **Results:** This test will be conducted in late January 2021. A pass indicates the success criteria have been met, and a fail requires retesting and reevaluation.

Black Powder Ejection Test

- **Objective:** The black powder ejection systems fulfill the requirements that they create appropriate separation between the airframe sections.
- **Success Criteria:** Both black powder canisters must separate the correct airframe sections the appropriate amount on the ground, not damage any vehicle components, and fully eject the parachutes.
- **Methodology:** Ignite both black powder ejection systems with the full vehicle on the ground and record airframe separation.
- **Results:** This test will be conducted in early February 2021. A pass indicates the success criteria have been met, and a fail requires retesting with greater amounts of black powder and reevaluation.

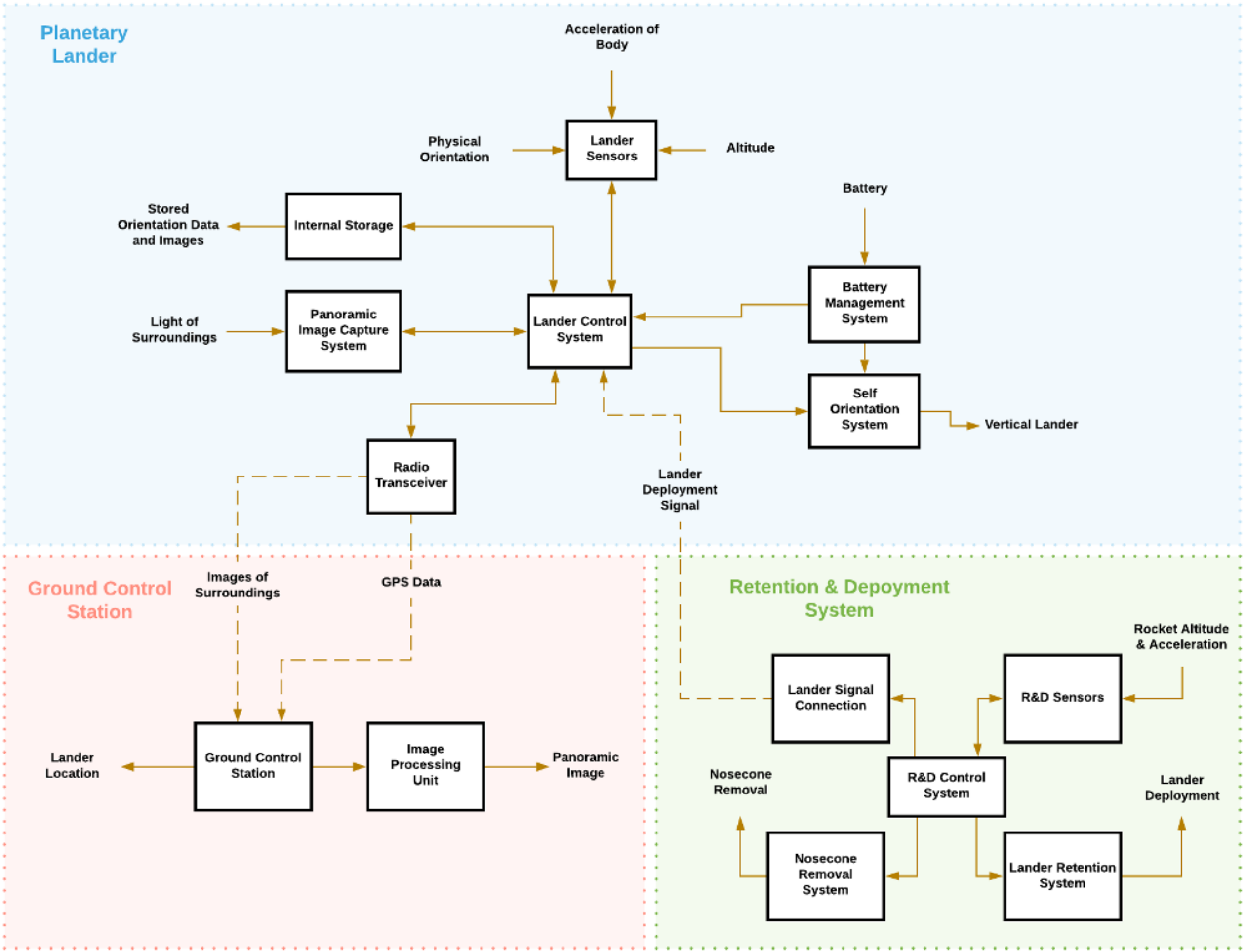
PSP

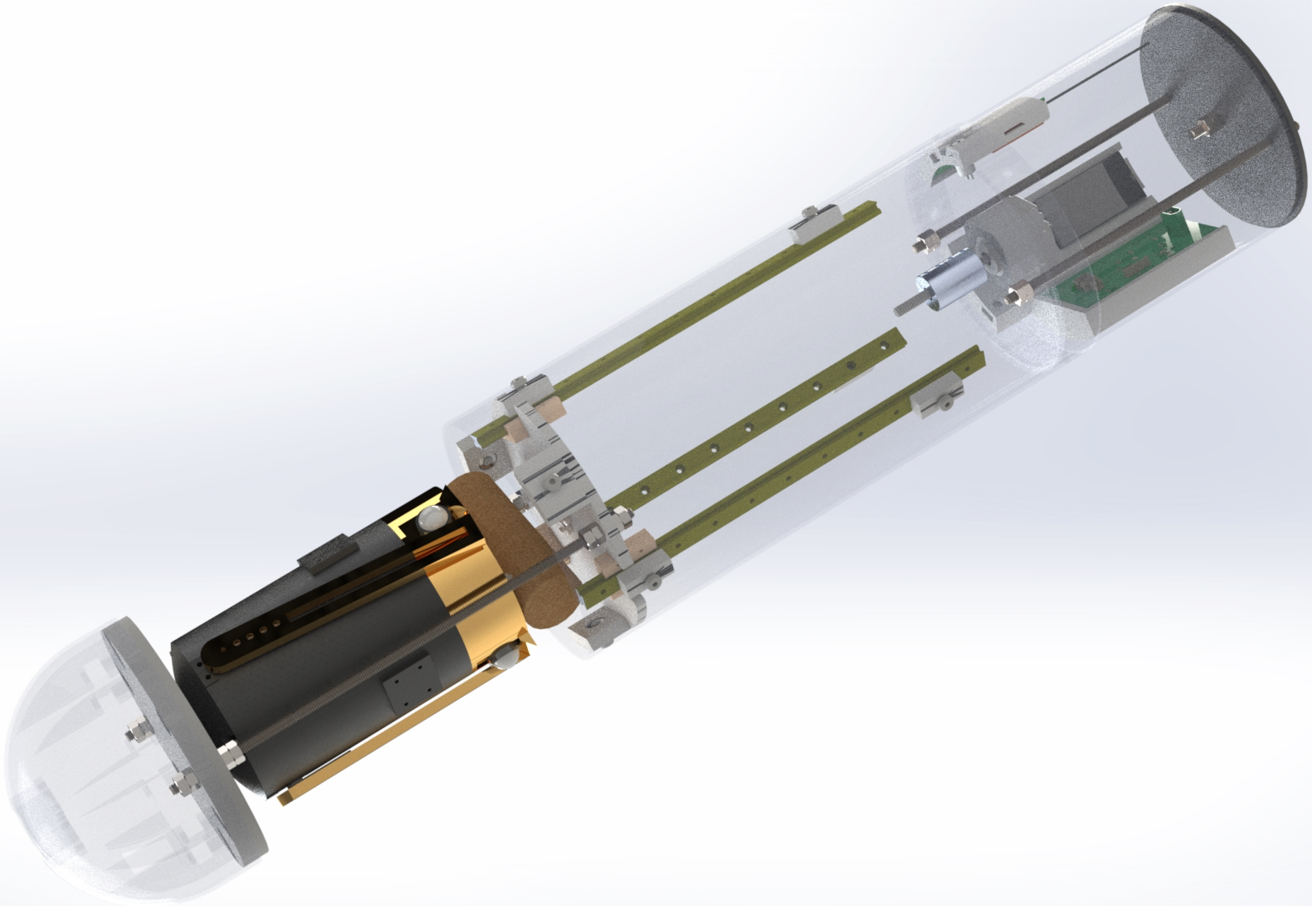
Payload Design

Planetary Landing System Overview

- PLS Central Mission:
  - Capture a level, 360° panoramic photograph of the landing site of the launch vehicle after being safely deployed from the vehicle during main parachute descent
- Subsystem Breakdown:
  - Retention and Deployment (R&D)
  - Lander:
    - Descent and Landing (D&L), Self Orientation Subsystem (SOS), Panoramic Image Capture Subsystem (PICS), Lander Control Subsystem (LCS)
  - Ground Control Station (GCS)

Planetary Landing System Overview

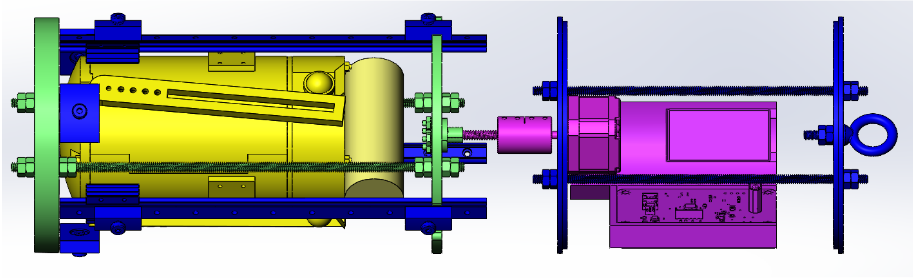


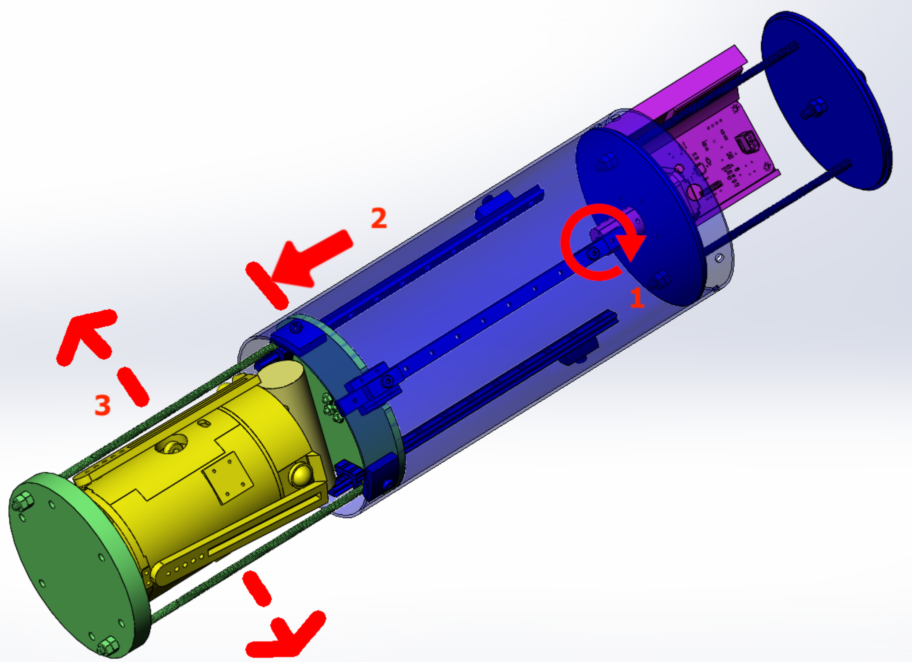


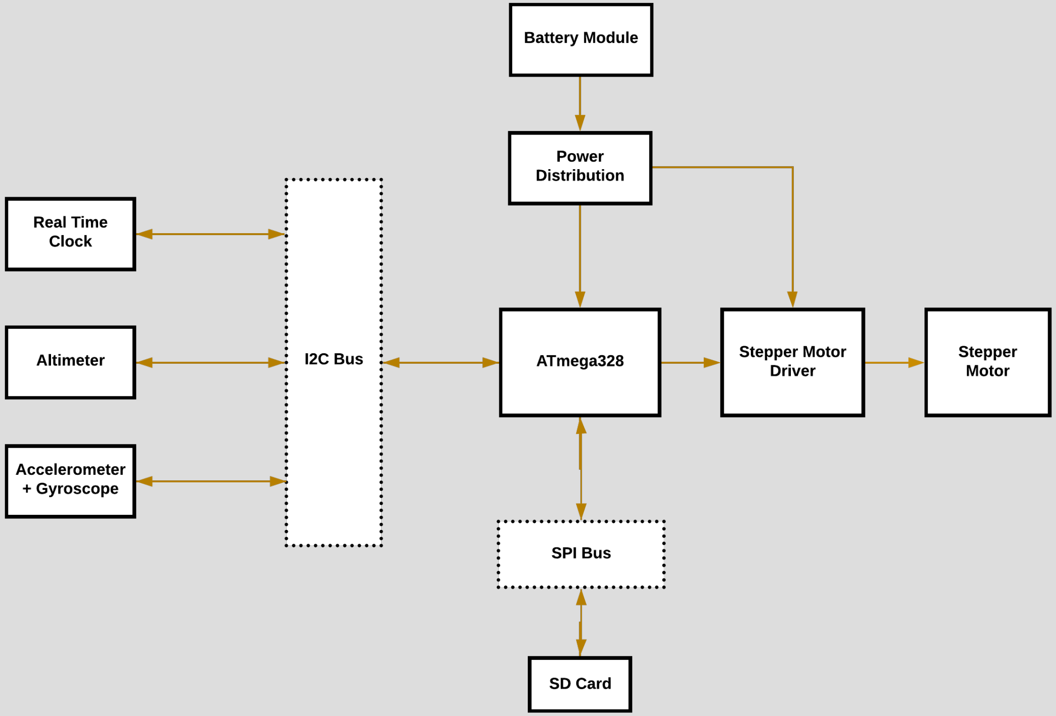
PSP

R&D Design

- The "Pizza Table"
  - Retains nosecone mechanically after deployment
  - Three linear sliding rails constrain Lander in flight
  - Uses an altimeter and IMU to detect vehicle state for activation
    - Main Parachute Deployment
  - NEMA 17 motor activated to unscrew 9.46" long Lander Bay via ~1", 2mm pitch, T8 Lead Screw
    - This is a permanent change in state
  - Acts as sled during deployment to guide the Lander
  - Lander falls sideways out of Lander Bay to begin descent







R&D Electrical System

Payload Descent and Landing Design

- Parachute: Fruity Chutes 24 inch
  - Chosen for its low packing volume and target descent rate
  - 24” diameter for a 3lbm payload, resulting in a descent rate of just over 20 fps
  - To avoid parachute tangling, team will use a parachute deployment bag
  - Parachute will be attached to lander via an expendable cable which the Lander will sever upon reaching the ground with nichrome wire

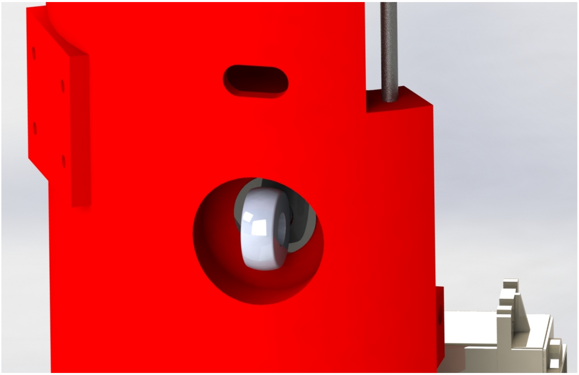
Rocketman Parachute Bag

Fruity Chutes 24 Inch Parachute

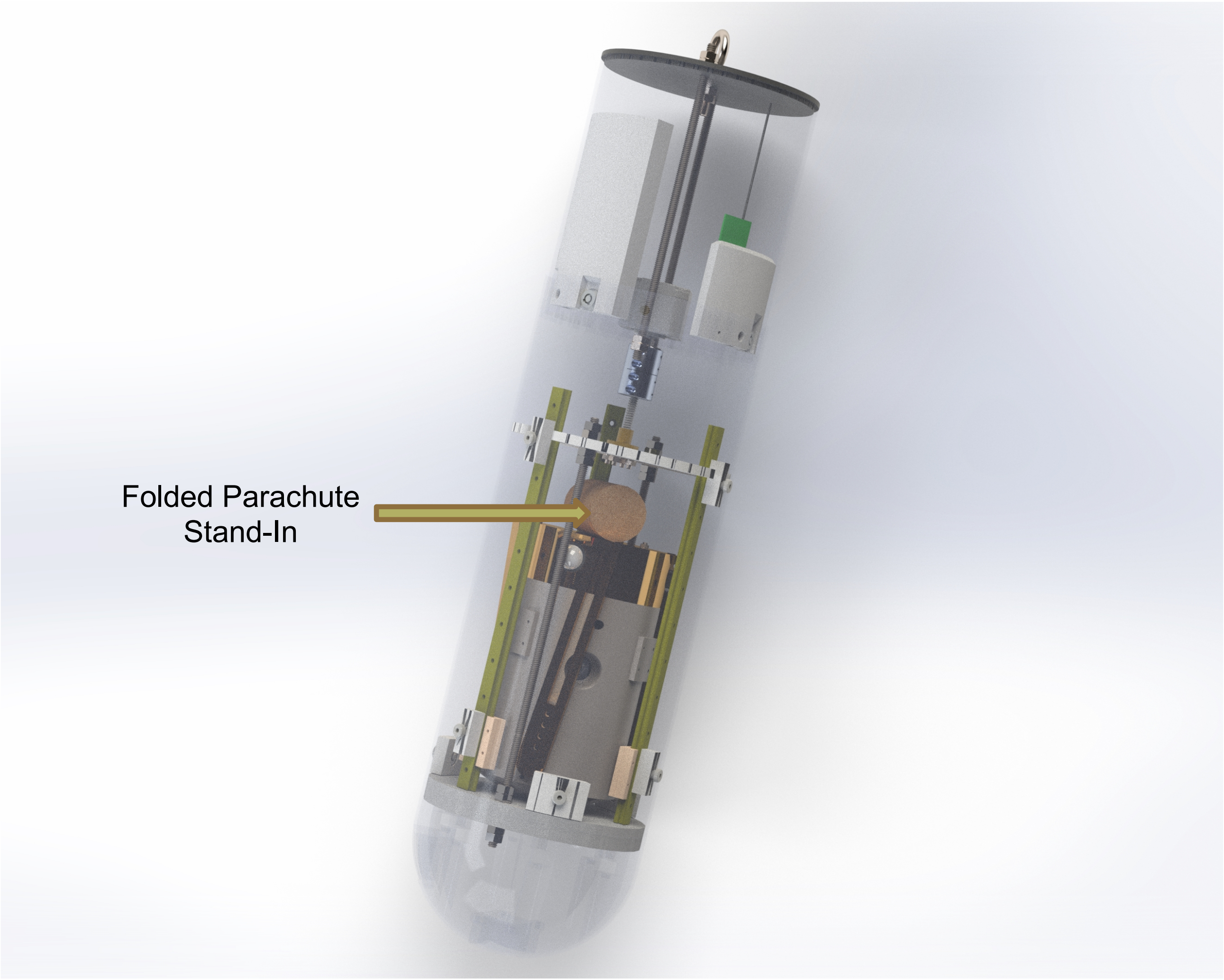
PSP

Payload Descent and Landing Design

- 50lbf test nylon rope attaches to the parachute
- D&L severs the nylon once grounded
    - Uses ~8" of nichrome wire, powered by LCS
    - Only activates after descent timer, altimeter grounded, and IMU grounded
    - Cutting process may take between 1 and 5 minutes, testing soon
- Severed parachute will not interrupt SOS

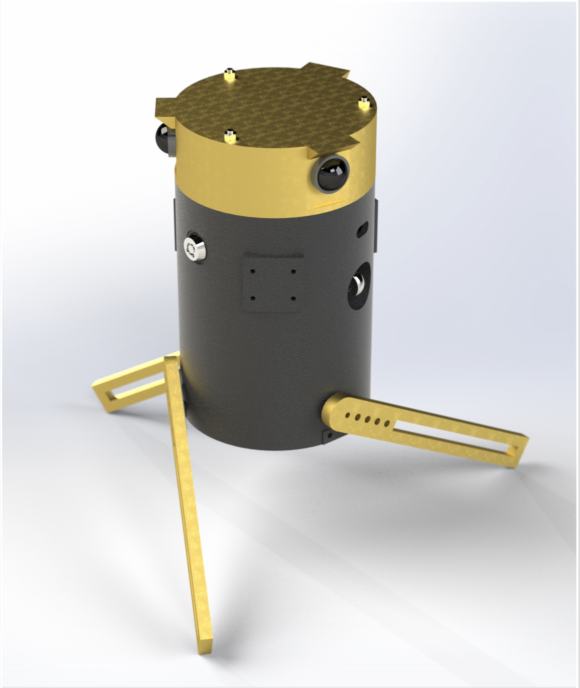


PSP

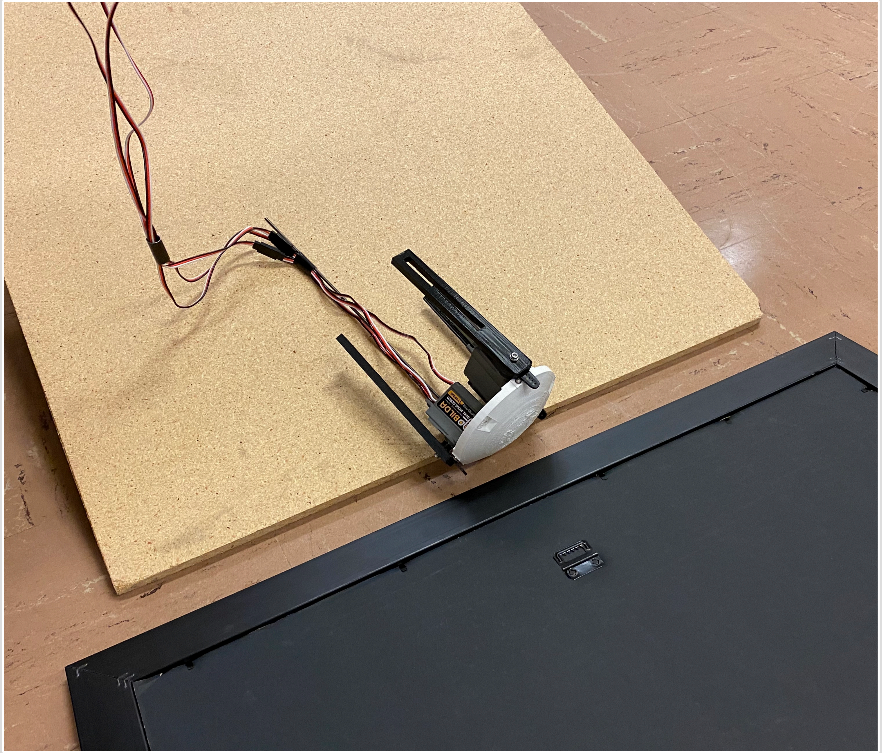

Folded Parachute
Stand-In

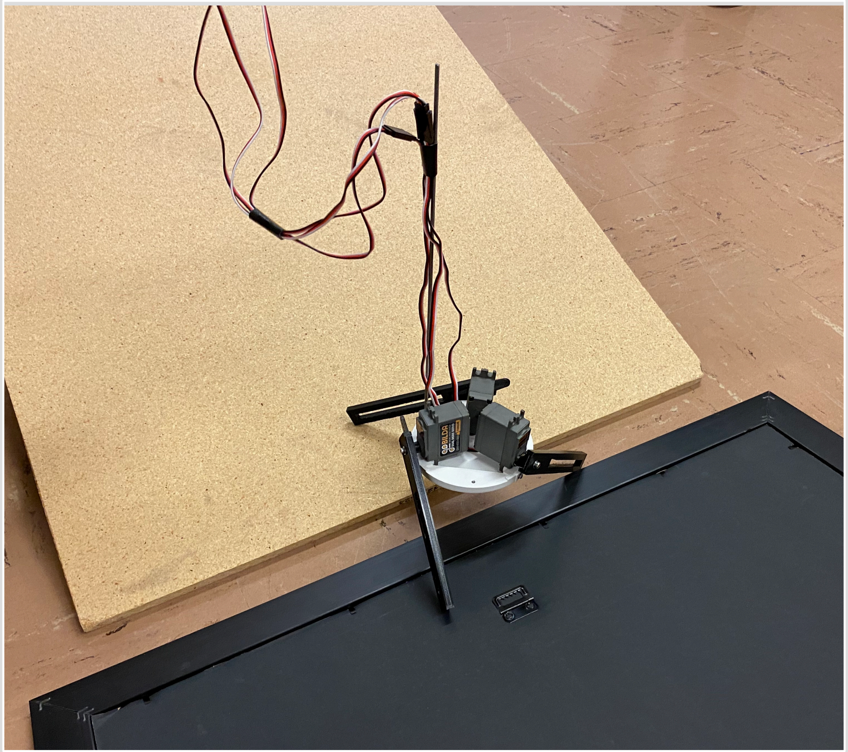
Self Orientation Subsystem Design

- 3-Legged "Pinwheel"
  - Axial pattern of 3 goBilda servo motors actuate three Lander-length legs. Overall Lander length: 7.24"
  - Main body: Markforge Onyx Carbon Fiber
  - Utilizes a low center of mass to remain stable
    - CoM ~3.5" from Lander bottom
  - Lander Control System will continuously adjust legs to bring axis within 5° of local gravitational vector
    - Algorithm formulated to first adjust, stand, and then level one leg at a time



PSP

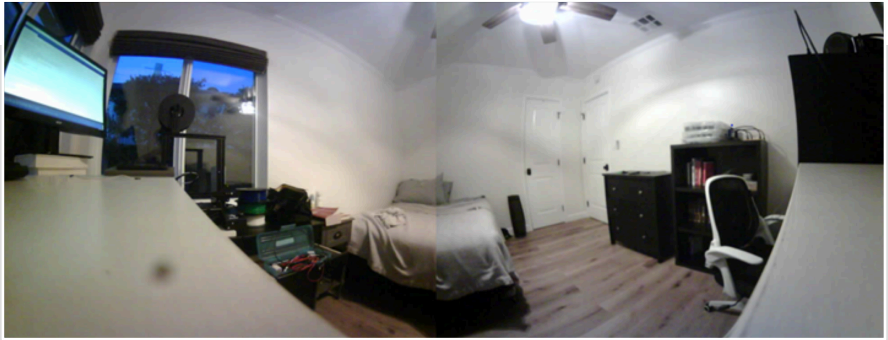




Self Orientation System Prototype Testing

PSP

Panoramic Image Capture Subsystem Design

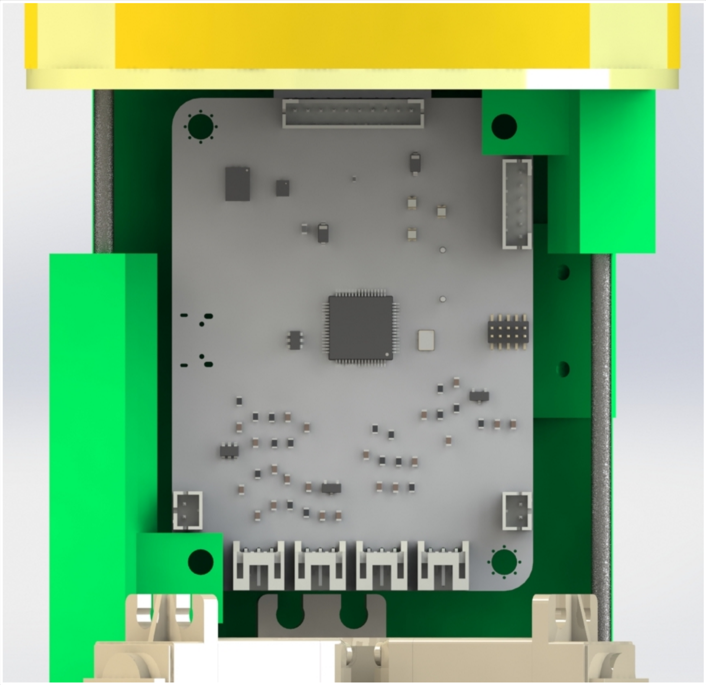


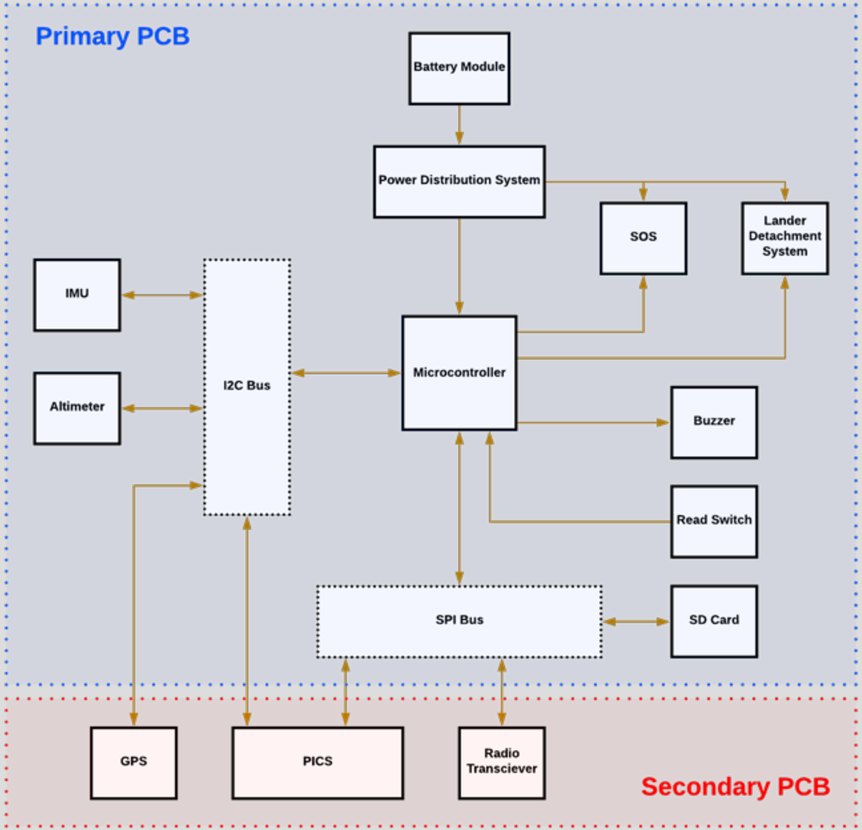
- 3 Static Cameras
  - Triple 120° Fisheye
  - Three images are stored locally
  - PICS waits to connect with the team's custom Ground Control Station (GCS) computer
    - 250mW transmitter connection for 1mi transmission capability
    - The GCS is built with a Raspberry Pi 4
  - Images are sent to the GCS for processing and display
    - The GCS will combine the transmitted images and display on-screen

PSP

Lander Control Subsystem Design

- Coordinates all software and hardware on the Lander
- Handles Lander activation decision processes
  - Standby during flight-ready
  - Activated by deployment, senses grounding for SOS & PICS
  - Intakes & transmits panoramic image



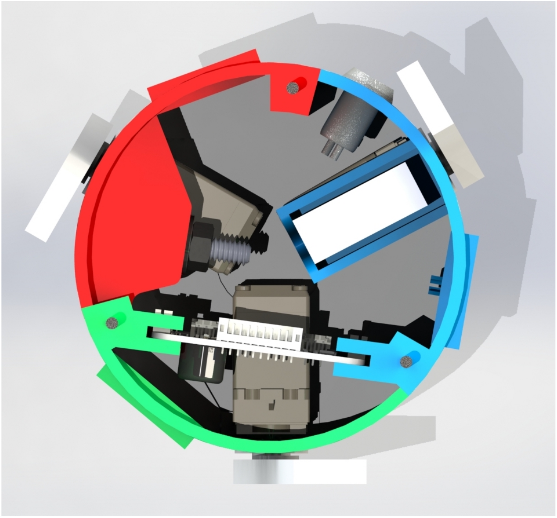


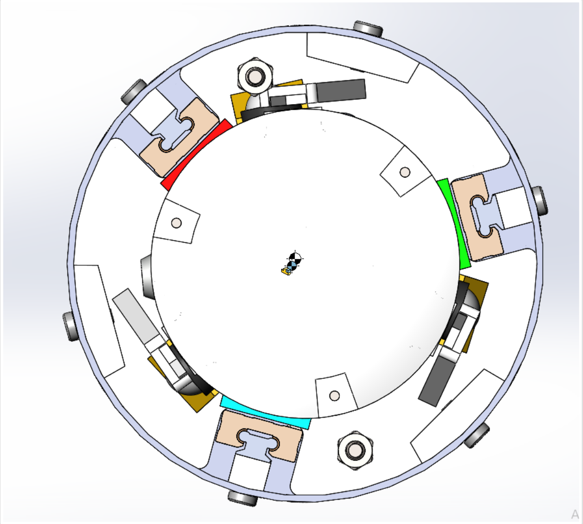
Consolidated Lander Control System

PSP

PLS Integration

- Four systems come together in one 4" ⌀ Lander design
  - Three central intermeshed plates w/ threaded rod support
  - Each plate locks-in with the next, allowing for a rigid but modular structure.
- The Lander fits within the Pizza Table in one orientation to allow for system activation
- The R&D connects to the launch vehicle's nosecone by a mutual attachment plate





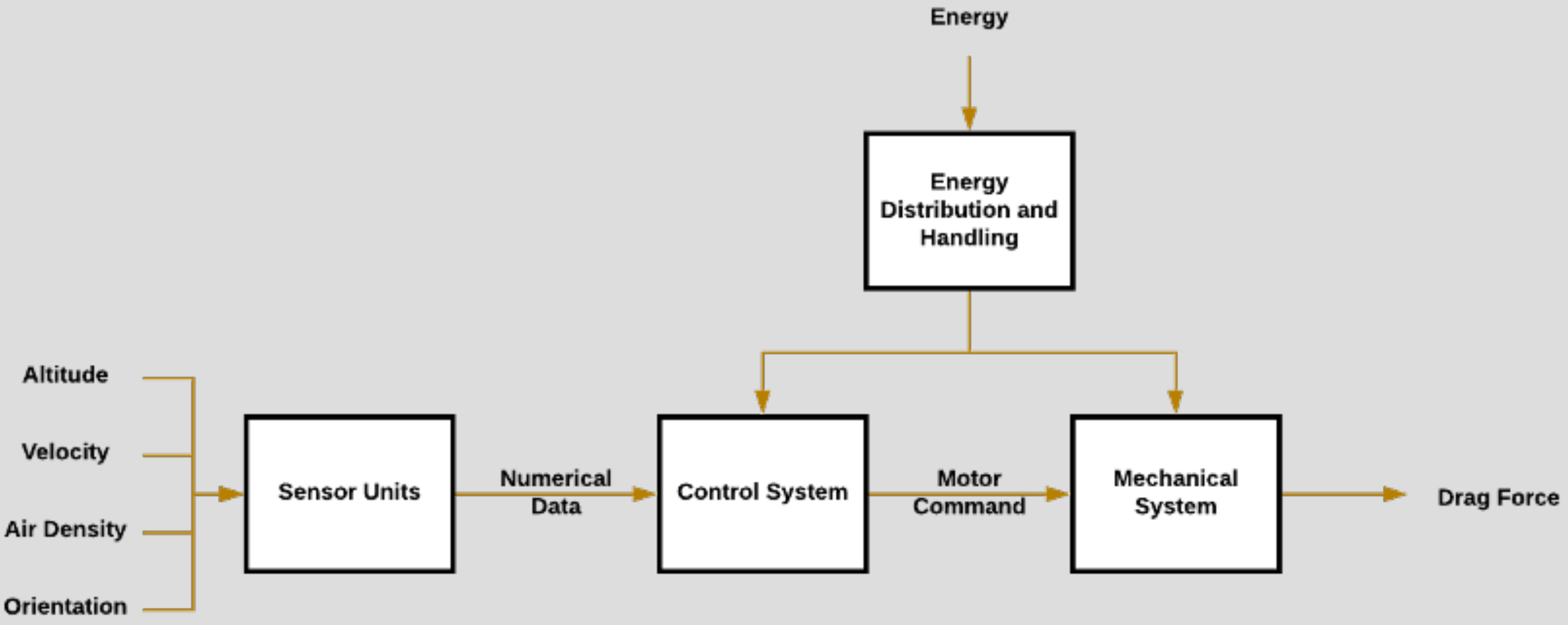
Notable PLS Testing Plans

- R&D Deployment Time Testing
- R&D Retention Testing
    - Ensure the R&D can hold through drogue to main.
- SOS Orientation Testing
    - Ensure SOS algorithm can achieve 5° orientation
- D&L Wind-Release Testing
    - Ensure that nichrome method operates without issue.
- D&L Structural Integrity Testing

PSP

AeroBraking System Overview

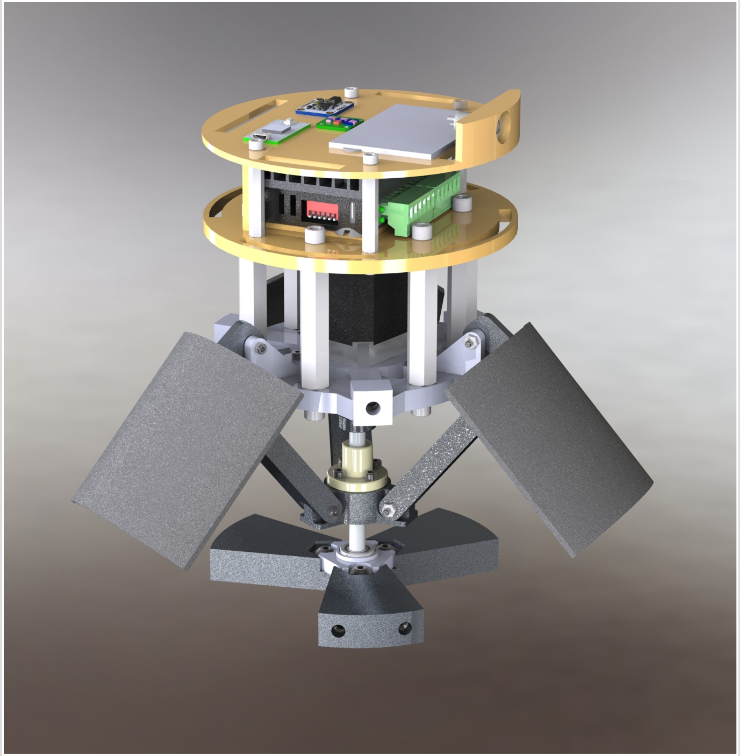
- ABCS Central Mission:
    - Provide the launch vehicle with active control over its final apogee through the modulation of vehicle drag
- Designed to provide the minimum possible deviation from the target apogee of 4100’ using airbrakes continuously modulated by a closed loop control system
- The system must not interfere with the structural integrity of the launch vehicle or significantly impact its stability


Energy
Energy Distribution and Handling
Altitude
Velocity
Air Density
Orientation
Sensor Units
Numerical Data
Control System
Motor Command
Mechanical System
Drag Force

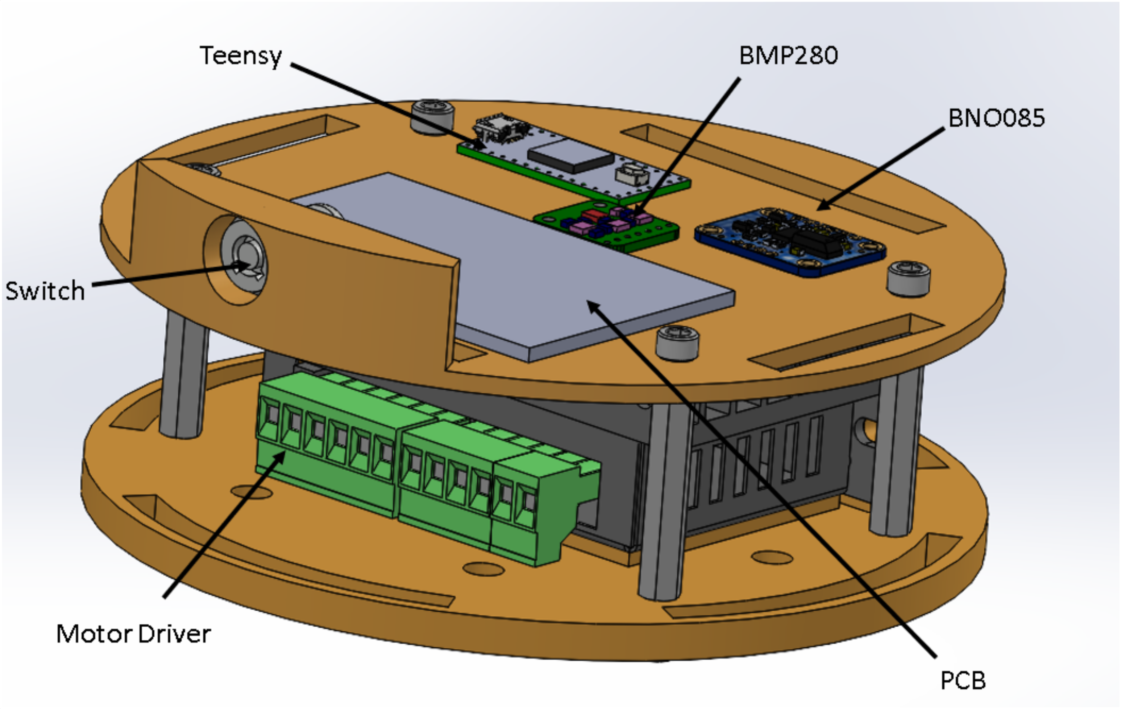
PSP

Mechanical Design

- Three radially symmetric curved aeroplates, which lay flush with the airframe during the boost phase
- Actuation provided by central lead screw and NEMA stepper motor
  - Bottom plate transmits load from airbrakes to the airframe
  - Stepper allows for precision actuation at acceptable torque
- System has been redesigned to account for all components being 3D printed
- 3D printed Markforge 17-4 PH stainless steel on all load bearing components
- MATLAB Simulation provides position and torque relationships

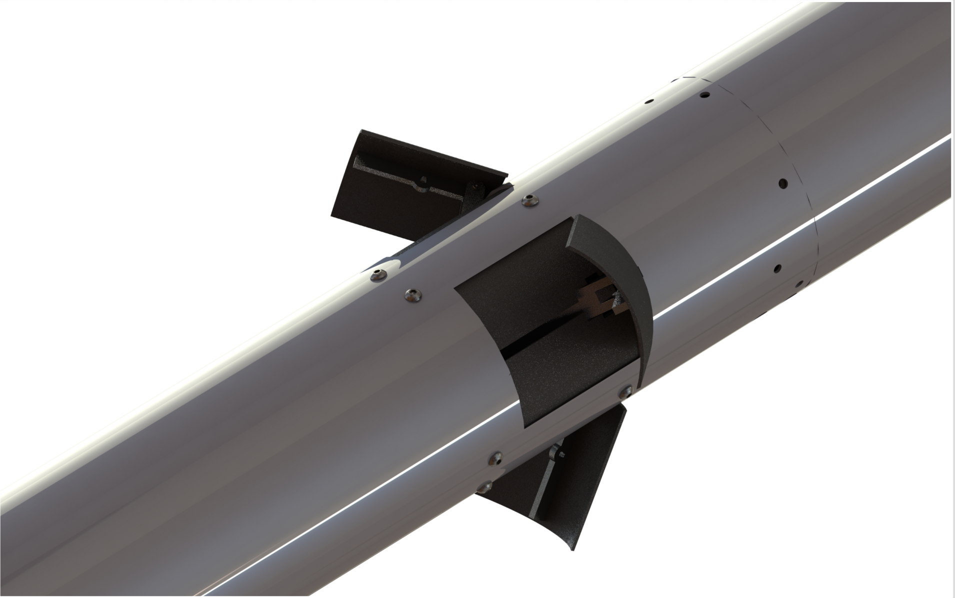


Electronics Bay



- 3D printed like main mechanism
- Attached via stand-offs to motor plate
- Takes in altitude data directly from three static portholes

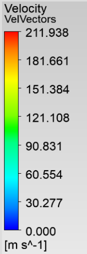
Vehicle Integration

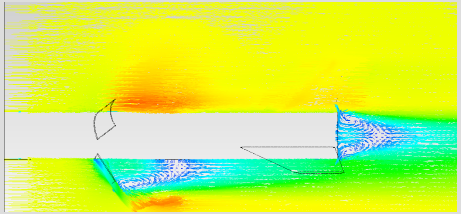


- Within the airframe, a coupler provides structural integrity to counteract the slots and pockets cut for ABCS actuation
- The coupler and airbrakes are attached through multiple ¼”-20 screws
- Located as aft as possible to decrease negative effect on stability
- Switch placement will be a part of the ABCS on the Electronics Bay
- The battery will be placed in the coupler above the ABCS.

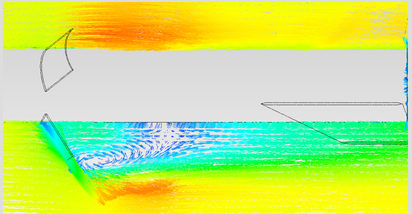
Aerodynamics Design

- CFD was executed to confirm loading per Aeroplate: 120 N at Burnout
- CFD also confirmed plate sizing - Length: 100 mm, Width: 100 mm
- Assumptions made during the Aerodynamic Analysis
    - ABCS Aeroplate actuation will only take place during the coast phase of flight
        - The IMU will remain on to sense burnout
    - Drag analysis completed in compressible regime: Max speed = 154.4 m/s (@ Burnout)

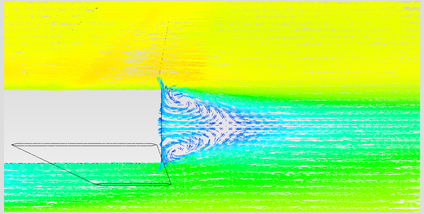




Booster Section

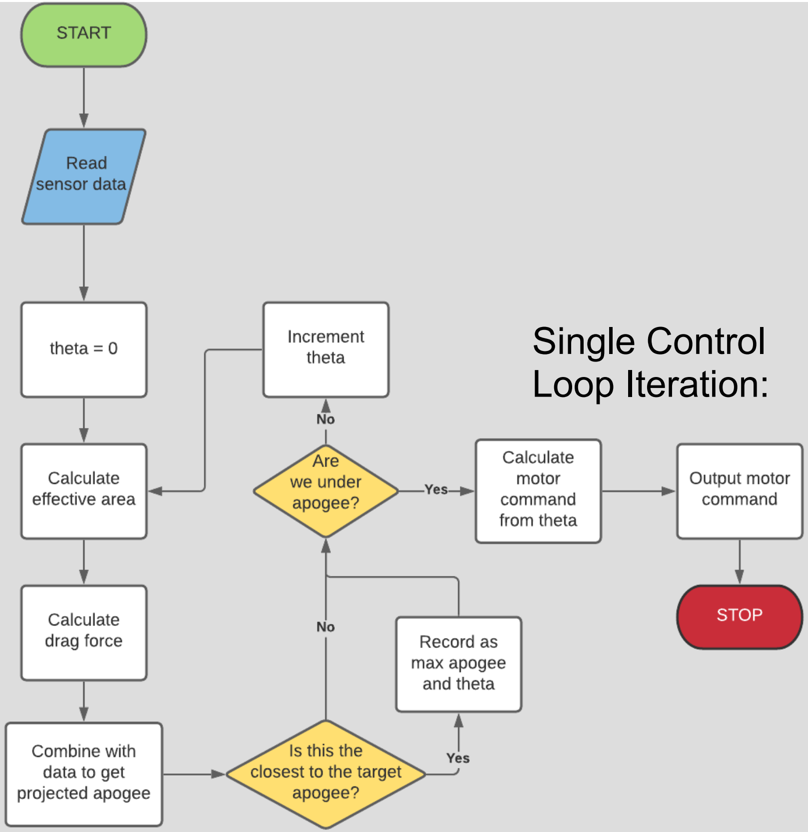


Flow around Aeroplates



Rocket Wake

Control System Design



Single Control Loop Iteration:

Selected design is a continuous closed-loop control system

- Inputs – altitude, velocity, acceleration, air pressure
- Output – motor command to stepper motor
- Chosen for accuracy and speed

If the ABCS fails to activate

- the ABCS will activate after a specific time if the IMU did not detect burnout
- the ABCS will remain or become inactive if other failures are detected

Flowchart code currently being tested for speed and responsiveness

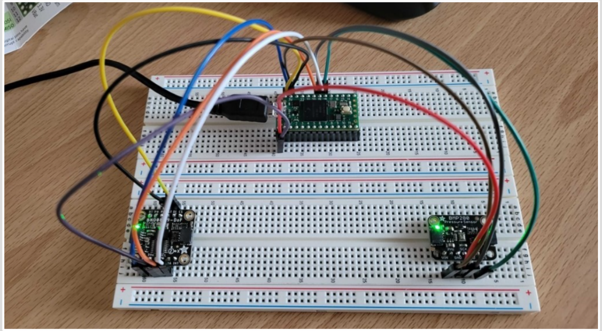
Control System Hardware Design

Devices:

- Microcontroller: Teensy 4.0
  - Operating CPU speed: 600 MHz
    - Overclock capabilities (if required):
      - 816 MHz without cooling
      - 1.008 GHz with cooling
- Altimeter: BMP 280
  - Pressure sensor capable of outputting altitude
- IMU: BNO085
  - Advanced sensor with onboard signal processing algorithms
  - Expected usage:
    - For Burnout and Speed: Linear Acceleration
    - **Safety Measures: Angular Velocity, and Angular Orientation about primary axes to prevent "Super Stall"**

Driver Motor:

- Stepper Online NEMA 17 motor
  - Lower torque, precision control
  - Highly compatible with microcontroller control loops



PSP

Next Steps - ABCS

- Finalize electronics functionality of the prototype with respect to schematics.
- Design PCB for mounting flight hardware

- Write flight software and test using electronics prototype
- Confirm deviation thresholds from nominal flight state. Implement safety measures in the flight software

- Test mechanical system of the ABCS to ensure structural integrity under worst-case load

Notable ABCS Testing Plans

- Mechanical Physical Load Testing
  - Calculations ranged from 120N (CFD) to 150N (Hand)
  - 55 kg tension testing to ensure 1.5 FoS
- IMU Testing
- Activation Time Testing
  - Ensure that the ABCS can adjust fast enough during flight
  - Ensure the ABCS can close quickly in the case of adverse flight conditions

Safety

Adjustments to Hazard Analysis Methods

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation	Verification	Post Mitigation Risk
Burns from Motor	2 (Improper proximity to launch pad, touching engine too soon after landing)	C (Mild to moderate burns)	C2, Low	Maintain minimum safe launch distance from vehicle according to NAR standards. Wait an appropriate amount of time after launch to retrieve vehicle.	The Safety Team lead will ensure the minimum safe distance region is marked and communicated to team members at the launch.[1]	C1, Low

For verification of certain mitigation plans, see the following footnotes:

1. *5.1.1.4 On Launch Site, "Selecting a Launch Area"*
2. *3.1.6.2.2.1 MFSS FEA Static Studies Summary*
3. *5.1.1.4 On Launch Site, "Briefing to team members by Safety or Systems Team Lead"*
4. *5.1.1.4 On Launch Site, "Installing Ignitor"*

PSP

Checklists / Procedures

What They Are

- Guide to constructing and assembling the vehicle
- Clear checkpoints on how to prepare and execute launch

What They Aren't

- Itinerary of launch day events
- Rigid procedures for vehicle assembly

Business

Budget and Funding Plan

Budget	
Full Scale Parts	$3,000
Subscale Parts	$250
Avionics	$900
Payload	$2,500
ABCS	$1,000
Safety	$100
Travel	$4,000
Branding	$450
Outreach	$100
Total	**$12,300**
Technical Total	**$7,750**

Funding Source	
Rollover from last Competition	$5,166.07
Department Heads	$500
Grants	$600
Total remaining needed for Technical	**$1,483.93**
Total remaining needed total	**$6,033.93**

PSP

Outreach

Future Plans

- Virtual Seminars
- Interactive Livestreams
- K-12 Demonstrations
- On-Campus Events/Activities

Questions & Answers

purdueseds.space/student-launch/   @psp.studentlaunch