Project Voss
Flight Readiness Review

PSP-SL 2021

2021 Executive Board

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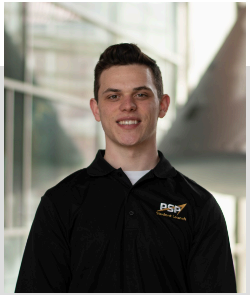

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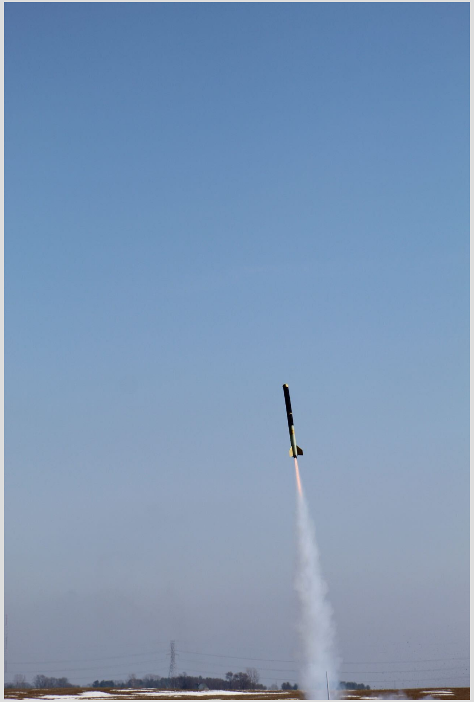
Full Scale Flight

Launch Date	02/27/2021
Temperature	48°F
Weather	Partly Cloudy
Launch Wind Speed	6mph SW
Launch Location	Purdue Dairy Farm West Lafayette, IN
Predicted Apogee (Simulink)	4826’
Recorded Apogee	5196’



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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

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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	80	40	13
Team Derived	32	17	19

(Avionics and Payload each have 1 discontinued requirement not counted here)

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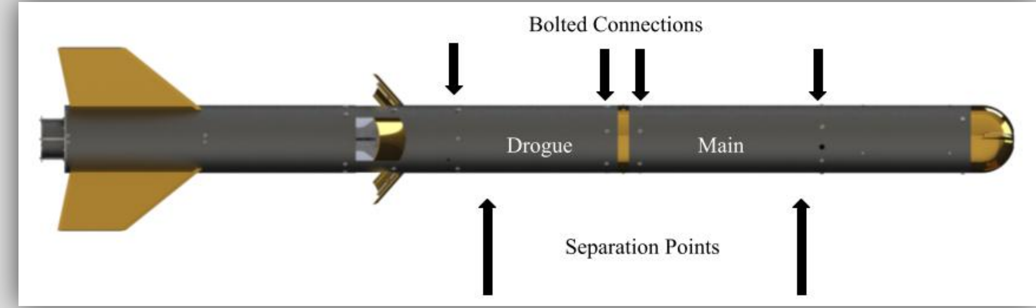
Vehicle Design

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	88.2"
Expected Lift-offWeight	52.1lbm
Body Tube InnerDiameter	6.00"
Launch Pad Stability	3.05cal
Launch Pad CoM	44.5” aft of tip
Launch Pad CoP	63.3” aft of tip

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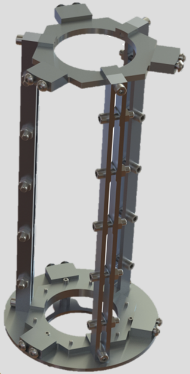
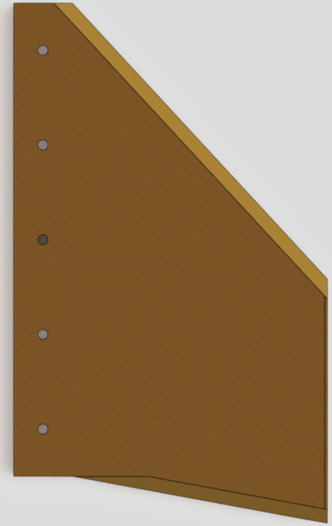
Booster

- 36" in total length and currently 22lbm
- Contains the MFSS and ABCS subsystems
- 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



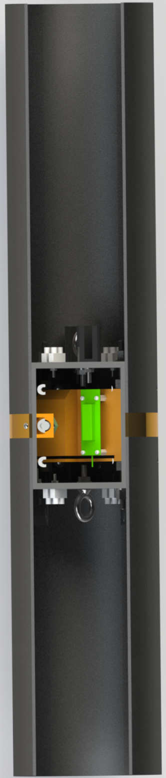
Fins

- 3 swept trapezoidal Fins
- 6.5" Height, 12" Root Chord
- Holes for mounting on MFSS
- Optimized for minimum drag while maintaining stability of 3.04 cal at rail exit
- Waterjet G-10 fiberglass sheet, allowing for design flexibility



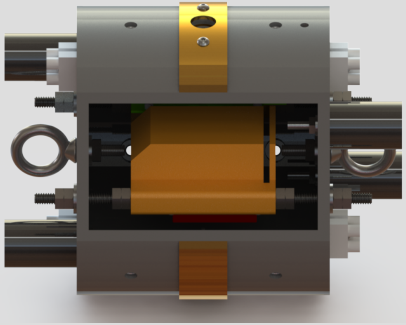
Recovery

- 32" in length and currently 12lbm
- 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

- 5” internal length with a 1” switch band
- Currently 3.8lbm
- Contains redundant recovery hardware including altimeters and ejection charges
- 3D printed altimeter support structure



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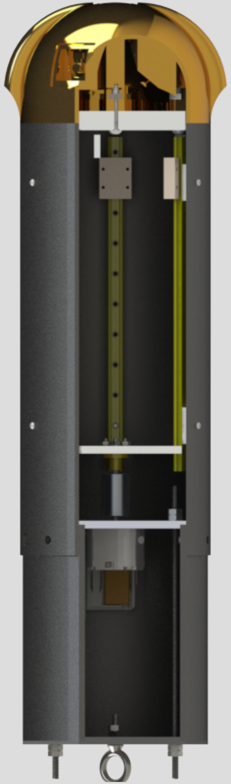
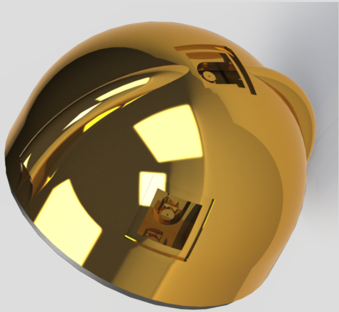
Payload

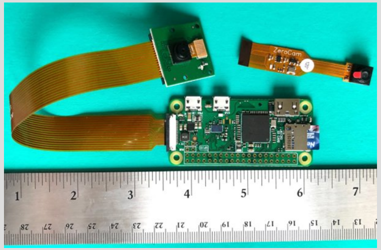
- 18" in length, including the nose cone
- Currently around 9lbm
- Contains Planetary Lander System (PLS), all PLS support systems, and the Payload Tracker
- Connects with shear pins to the upper recovery section



Nose Cone

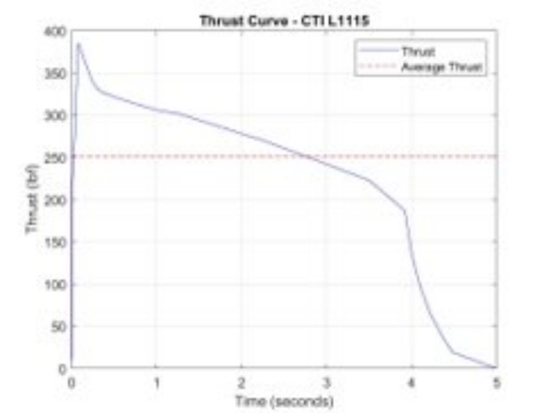
- 4” OAL
- 3” radius hemisphere with 1” shoulder
- Currently 1.2lbm
- 3D printed ONYX carbon fiber reinforced nylon
- Contains In Flight Video Recording (IFVR) system

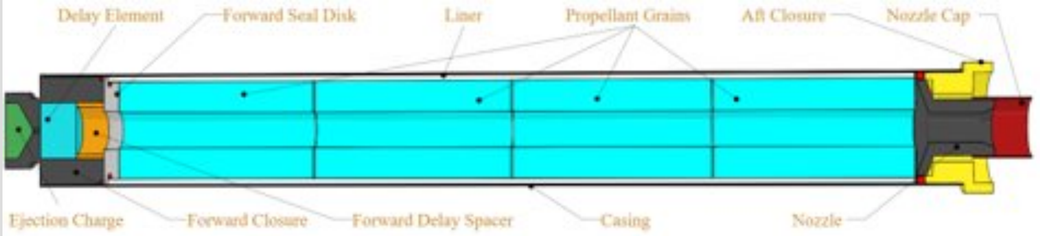




Launch Day Motor

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”





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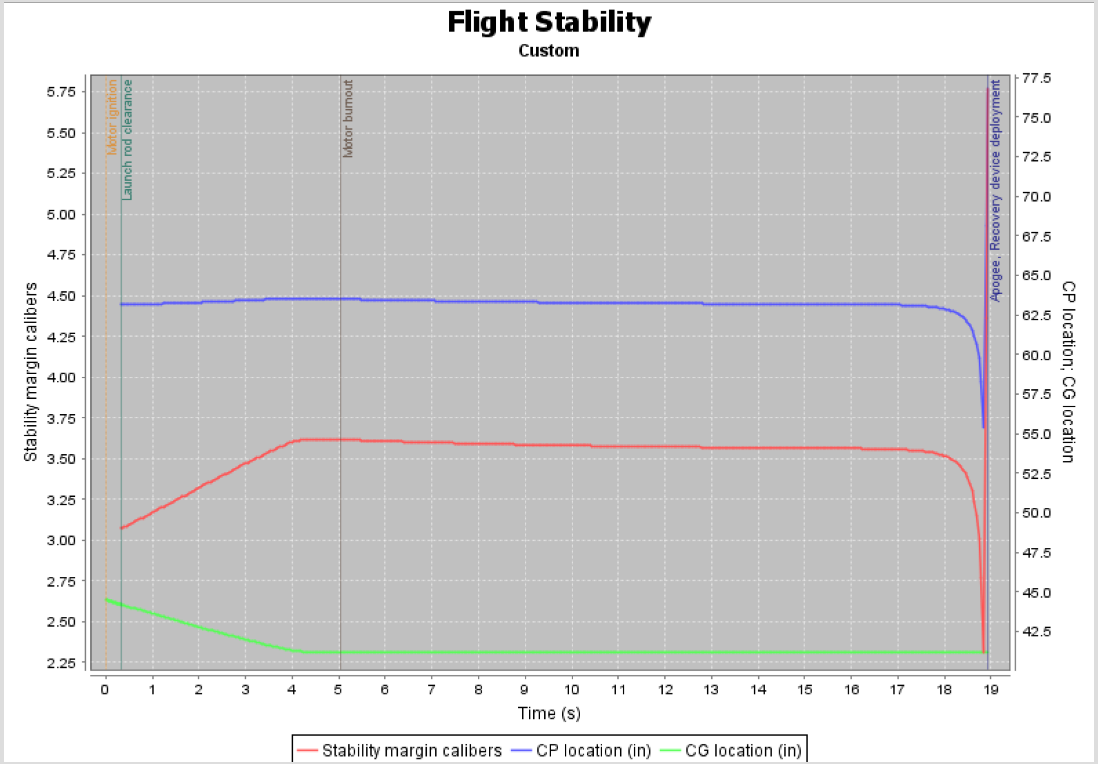
Altitude Predictions

6mph Wind Speed	Apogee (ft)	
Lauch Angle (deg)	No Ballast (49.2lbs)	Ballasted (52.0lbs)
0	5456	5077
5	5264	4869
10	4952	4571
15	4540	4253

Drift Predictions

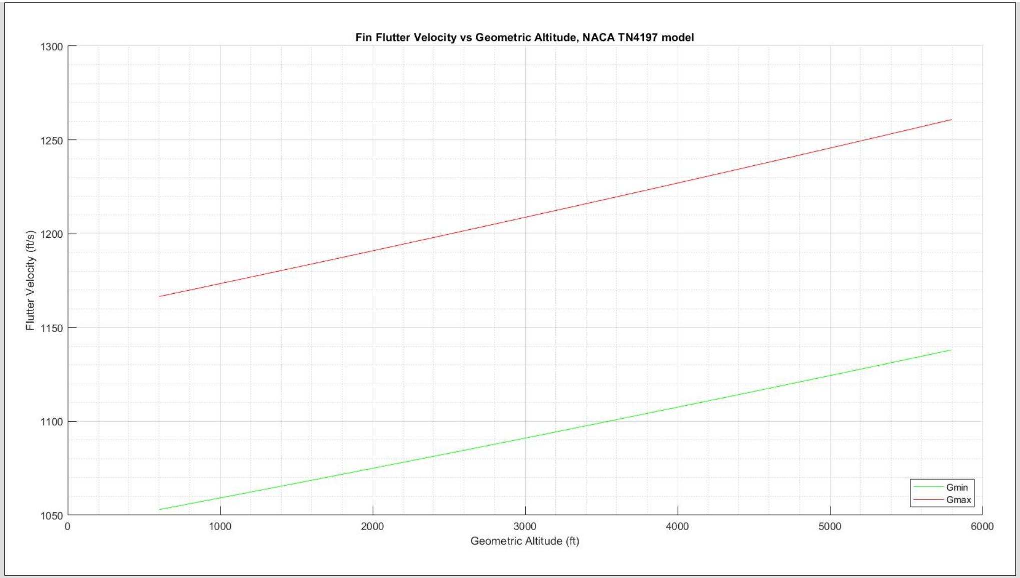
	Drift Distance (ft)	
Wind Speed (mph)	Hand Calculation	OpenRocket
0	0	10
5	290	725
10	580	1310
15	870	1916
20	1160	2256

Stability and Flight Criteria



Metric	Value
Rail Exit Velocity	66.2ft/s
Thrust-to-Weight Ratio	6.1
Maximum Velocity	550ft/s
Maximum Acceleration	205ft/s^2
Maximum Dynamic Pressure	342.71lbf/ft^2

Fin Flutter Analysis

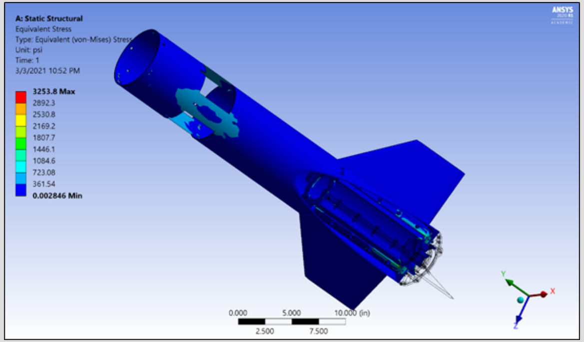


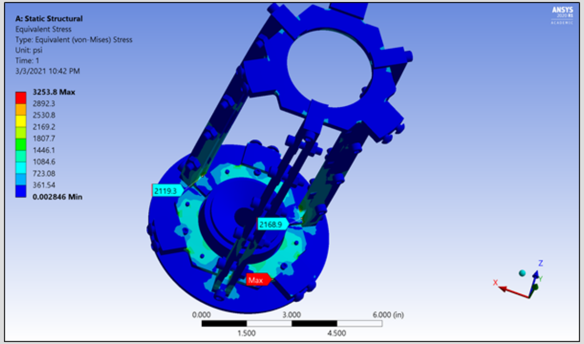
NACA TN 4197 equation results	Flutter Velocity (ft/s)
Minimum	1052.983
Maximum	1260.808

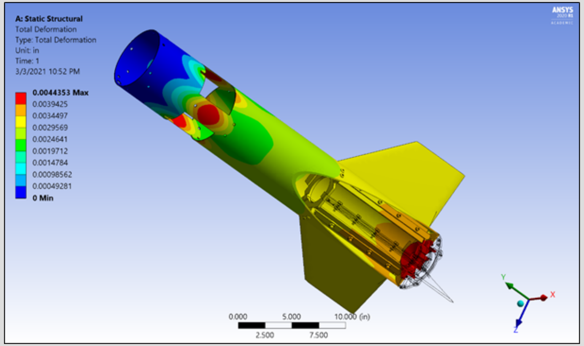
Apogee Components Newsletter #291 equation results	Flutter Velocity (ft/s)
Minimum	1489.089
Maximum	1782.987

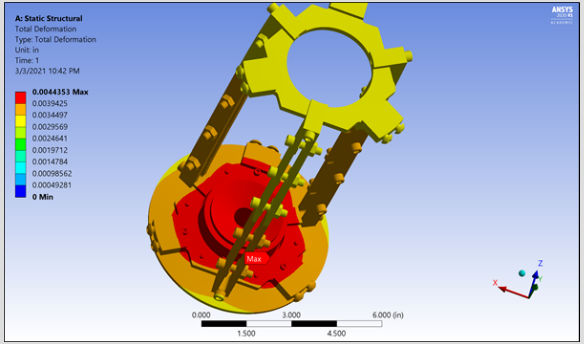
- NACA Technical Note 4197 model used primarily:
  - $v_{flutter} = \alpha * \sqrt{\frac{G}{2.67*p*\frac{AR^3*(\lambda+1)}{\left(\frac{t}{c}\right)^3*(AR+2)*2}}}$
- Complementary model from Apogee components newsletter issue 291:
  - $v_{flutter} = \alpha * \sqrt{\frac{G}{1.337*p*\frac{AR^3*(\lambda+1)}{\left(\frac{t}{c}\right)^3*(AR+2)*2}}}$
- v_{max} = 540ft/s << $v_{flutter,min}$
- No fin flutter observed in aft nosecone camera video during the VDF. Agreement with results.

FEA









- FEA was conducted to verify the deformation and load transfer
- No simulation resulted in permanent deformation or a failure of any sort

Mass Margins

Section	Expected Mass (lb)	Current Mass (lb)
Booster	21.5	22
Recovery	10.5	12
Payload	13	9
Nose Cone	2	1.2
Motor (no prop)	5	5
Total	52.0	49.2

- Expected mass is based off CDR design
- Current masses were measured prelaunch
- The team is allocating around 3lbs of ballast to the payload section

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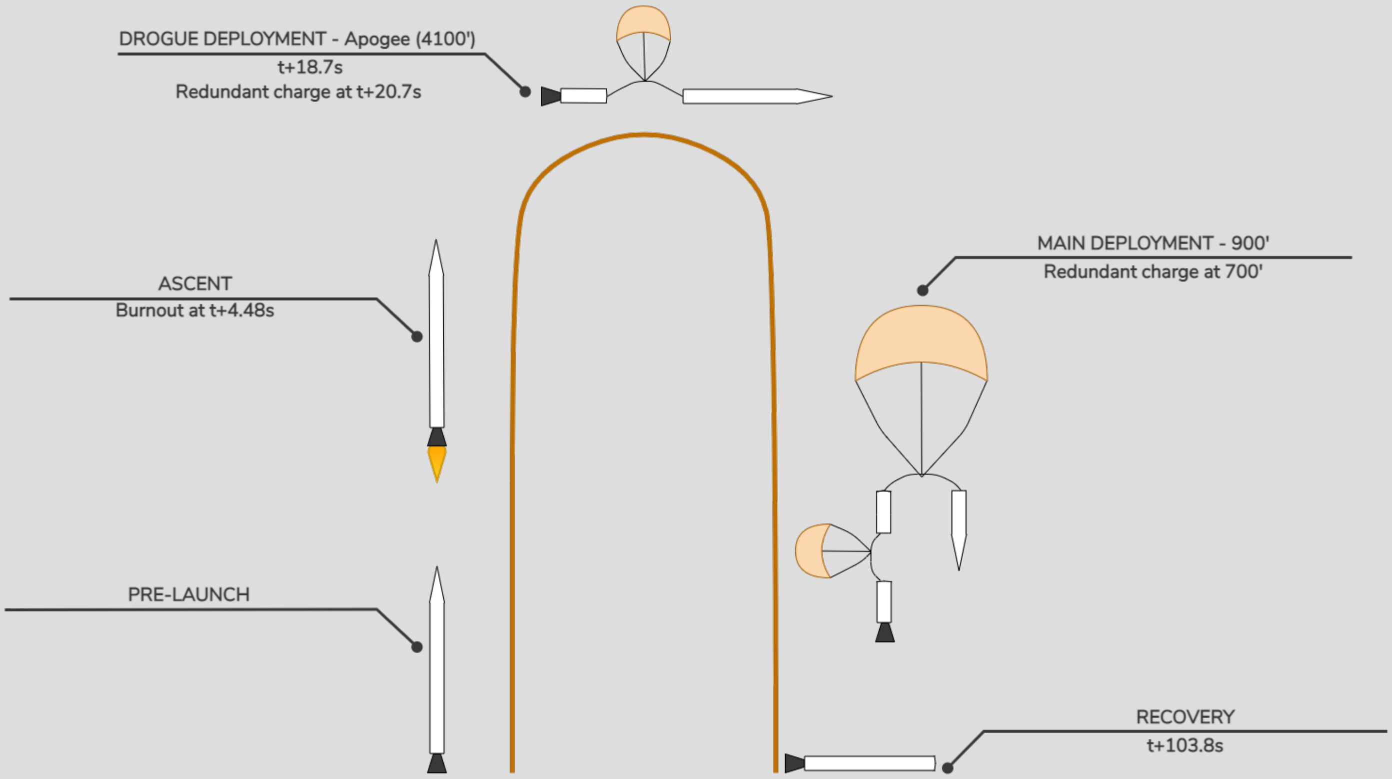
Recovery Design

Vehicle Trajectory Overview

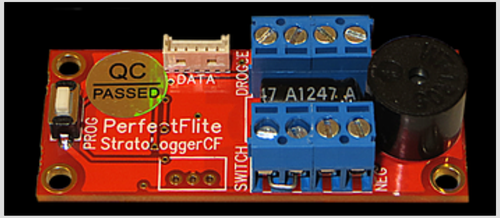


Primary Altimeter

- **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:** 1.55
  - **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

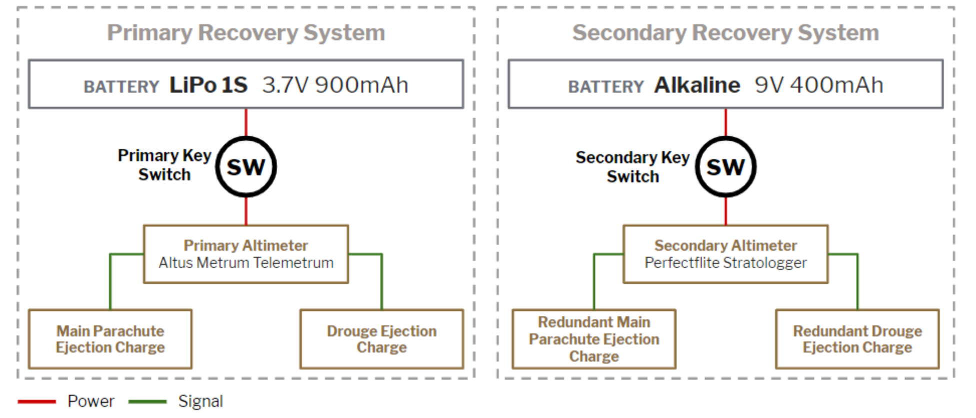
Heat Shielding

- **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

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

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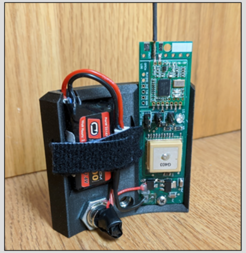
Tracking Devices

Primary – TeleMetrum Altimeter

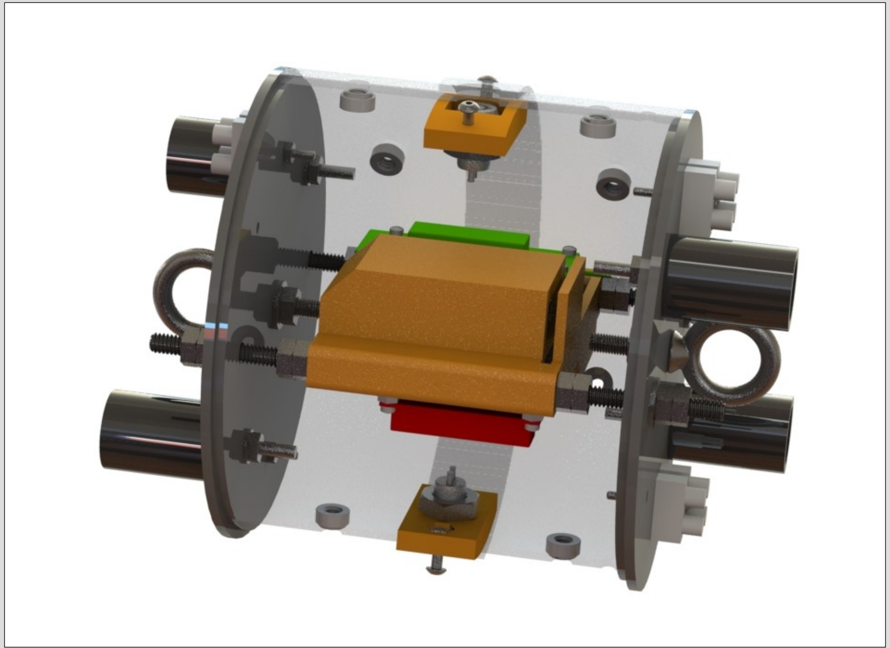
- Specific frequency used by the team: **434.55 MHz**
- Reliable in establishing and maintaining connection to ground station
- Connection made using a TeleDongle and Yagi Arrow 3 Element antenna to a laptop

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	3.8lbm
Switch Type	Keylock
Altimeter/Battery Retention	Altimeter Sled/Battery Guard
Ejection Charge Retention	Black Powder Canisters

Simulink Vehicle Trajectory Simulation and Mission Performance Predictions

Parameter	Value	Pass/Fail
Apogee	4826’	N/A
Ascent Time	18.7s	N/A
Drogue Descent Velocity	89.9ft/s	N/A
Landing Velocity	15.0ft/s	N/A
Lander Landing Velocity	21.6ft/s	N/A
Descent Time	85.1s	Pass
Drift Distance	1361’	Pass
Rail Exit Velocity	59.8ft/s	Pass
Landing Kinetic Energy of the Heaviest Section	74.3ft-lbf	Pass

Vehicle Section	Kinetic Energy Under Drogue (ft-lbf)	Landing Kinetic Energy (ft-lbf)
Upper Section	1890.5	52.6
Middle Section	1175.5	32.7
Lower Section (Dry)	2653.9	**74.3**
Total Launch Vehicle (Dry)	5719.9	159.6
Lander	N/A	13.7

Notes: This simulation was run with a launch rail angle of 8° from vertical, the horizontal wind speed set to 6mph, and no additional mass. The vehicle was launched with the wind.

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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	Complete
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	Complete

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.

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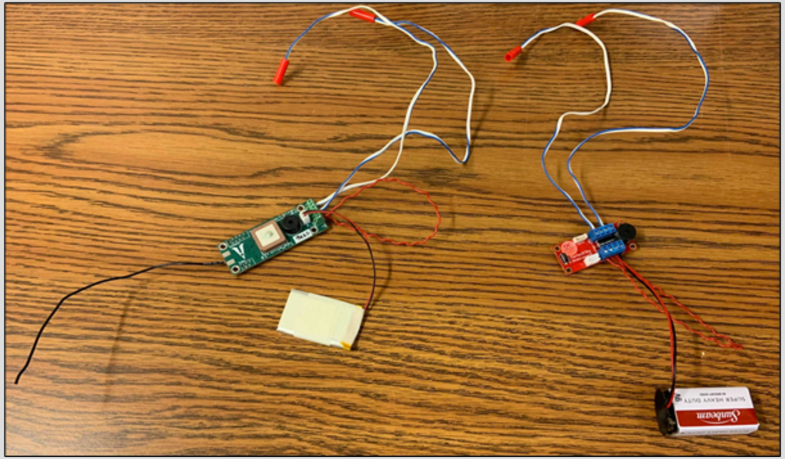
Altimeter Continuity and Battery Drain Test



Parachute Drop Test

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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:** Initial tests prompted the team to change the drogue delay setting to 2 seconds. Both altimeters passed once this change was made.

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:** Both black powder ejection systems passed this test.

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Altimeter Ejection Vacuum Test

Black Powder Ejection Test

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)

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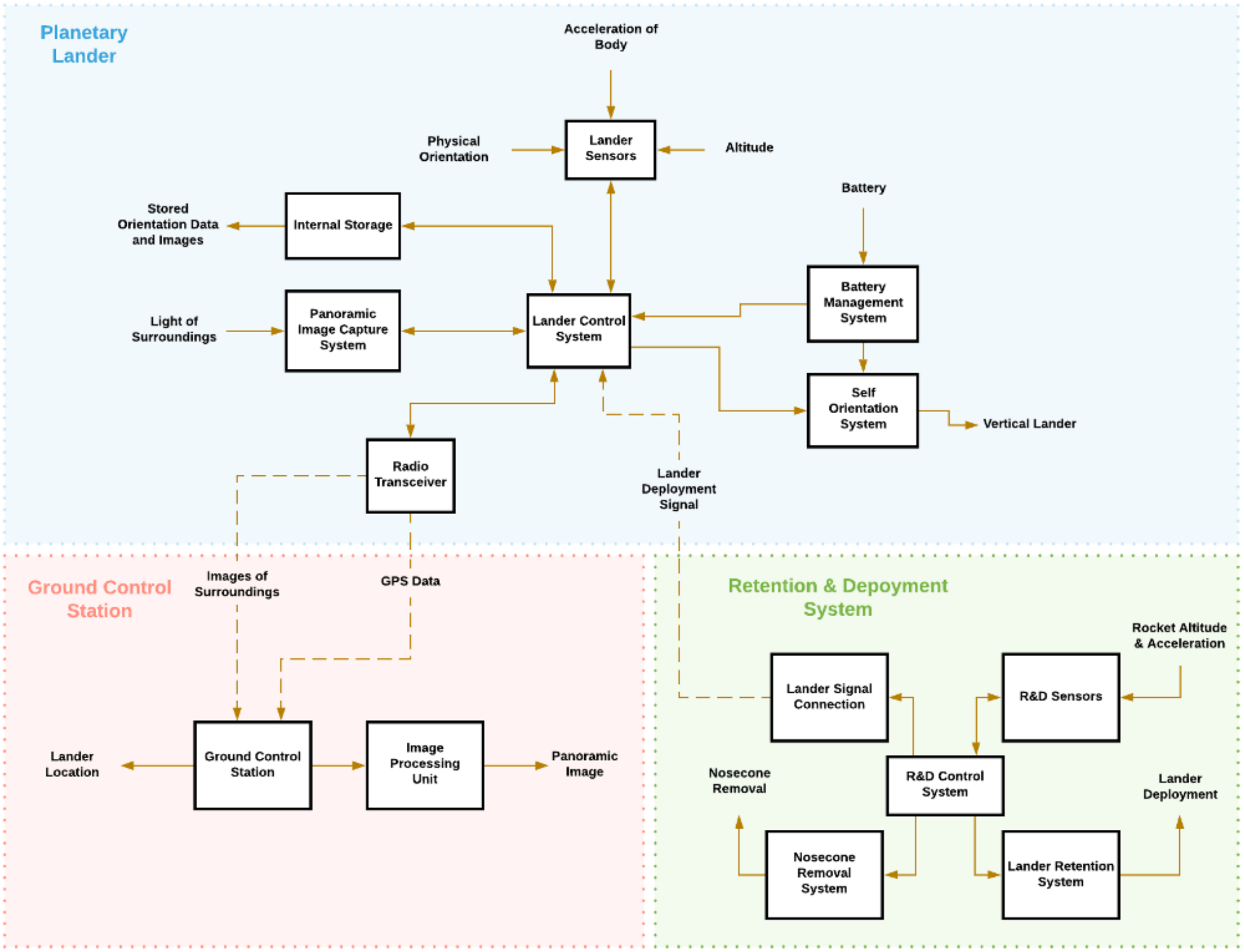
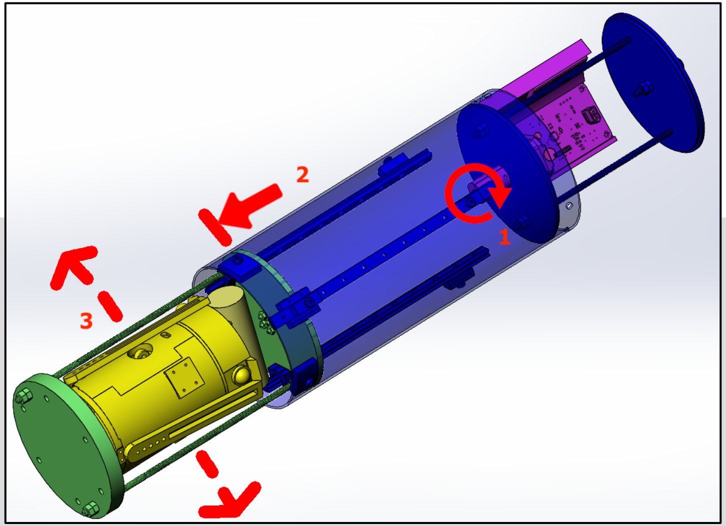
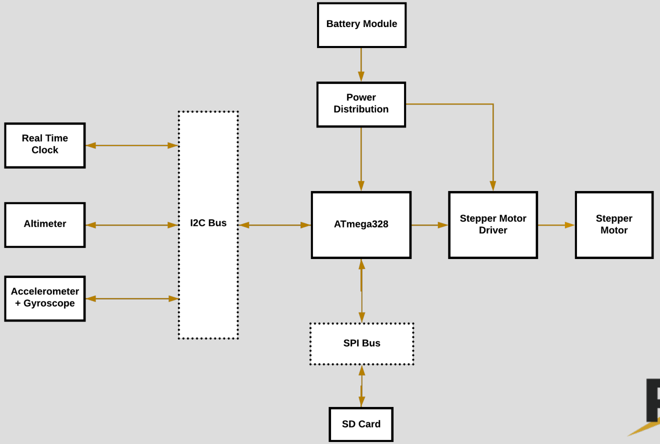
Planetary Landing System Overview

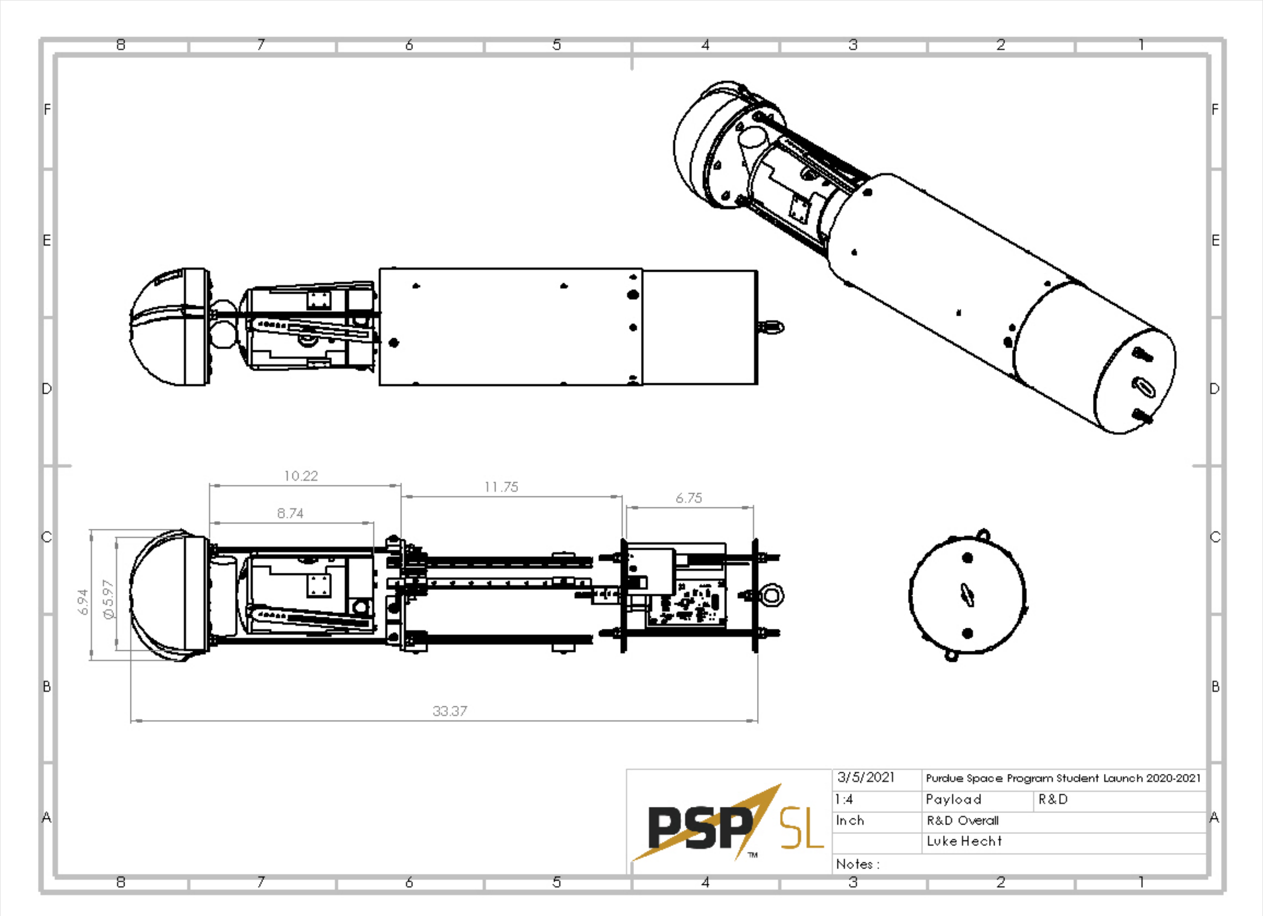


R&D As-Built Design

- The "Pizza Table"
  - Lander and nosecone slide downwards after deployment
  - Lander falls sideways out of Lander Bay to begin descent
  - Retains nosecone mechanically after deployment
- The R&D Electronics Bay
  - The Pizza Table/Nosecone section is locked by a NEMA 17 motor until deployment time.
  - Contains: IMU & Altimeter
  - The R&D code detects: Launch, Apogee, Descent altitude at 700' AGL







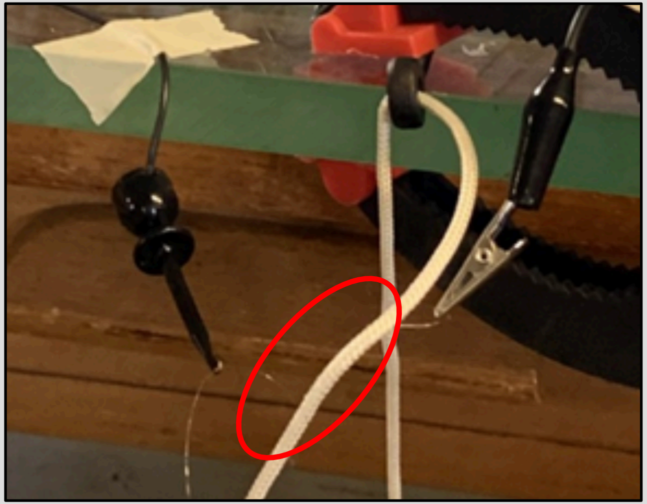
Overall Payload Bay Drawing (Open)

Descent and Landing As-Built Design

- Parachute: Fruity Chutes 24 inch
  - 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
- 50lbf test nylon rope attaches to the parachute, tied with 4 Bowline knots

- *For PDF*, 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 uses about 0.8A and make take up to a minute*

Rocketman Parachute Bag



Nicrome Wrapping Method with 7 Turns

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Post-VDF Lander with Fruity Chutes 24 Inch Parachute

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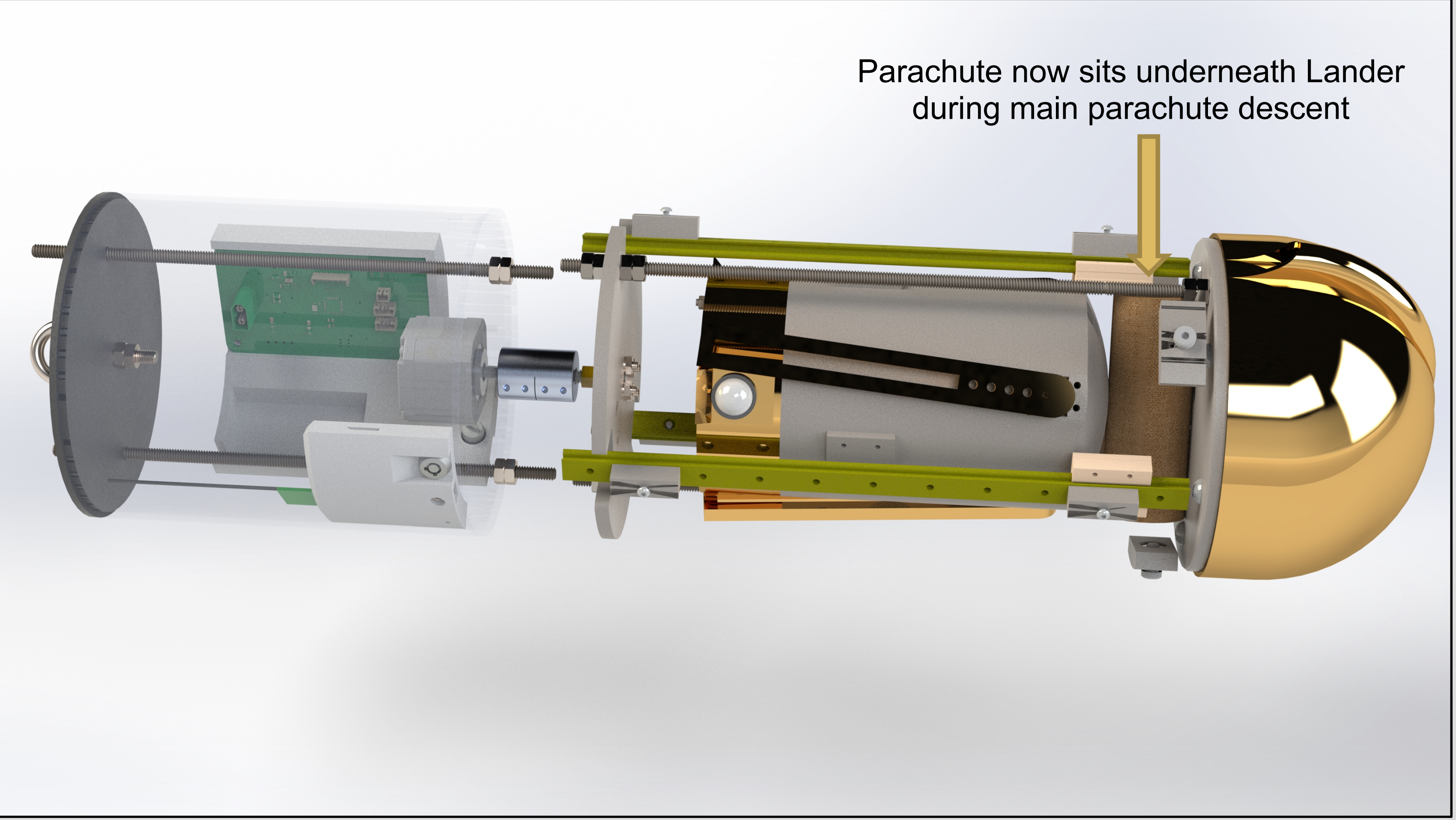
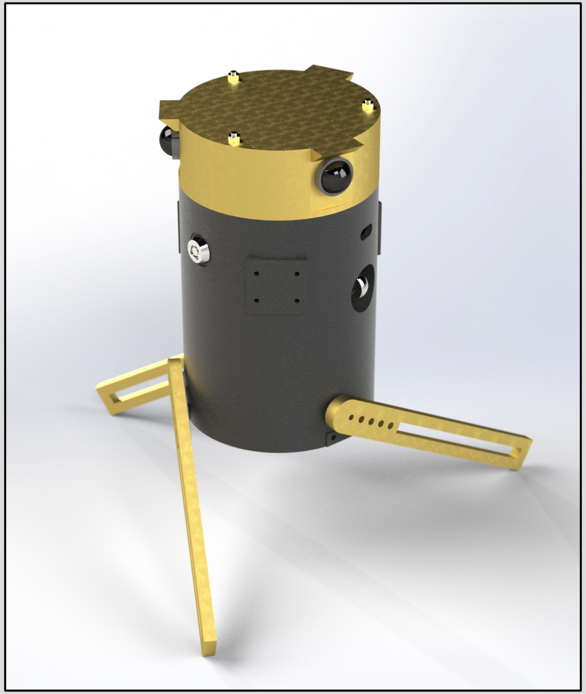


Overall Payload Bay Render (Closed, Transparent Airframe)

Self Orientation Subsystem As-Built Design

- 3-Legged "Pinwheel"
  - Overall Lander length: 7.24"
  - Axial pattern of 3 goBilda servo motors actuate three Lander-length legs.
  - Main body & legs: Markforge Onyx Carbon Fiber
    - *For VDF*, non-essential components are PETG
- *For PDF*, algorithm will be formulated to first adjust, stand, and then level one leg at a time
  - In the future, the SOS will continuously adjust legs to bring axis within 5° of local gravitational vector, meeting its requirement.



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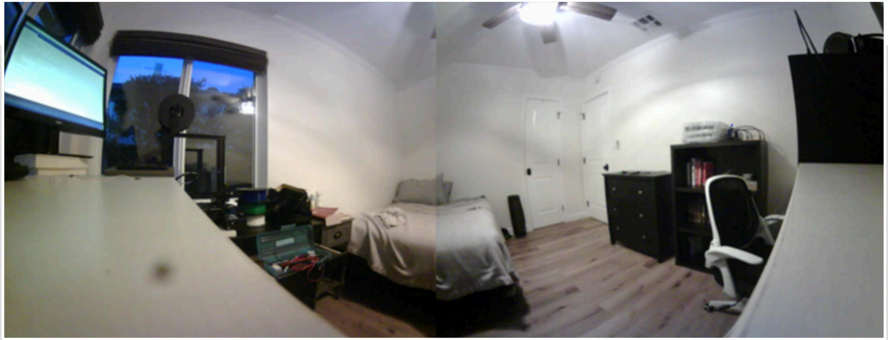
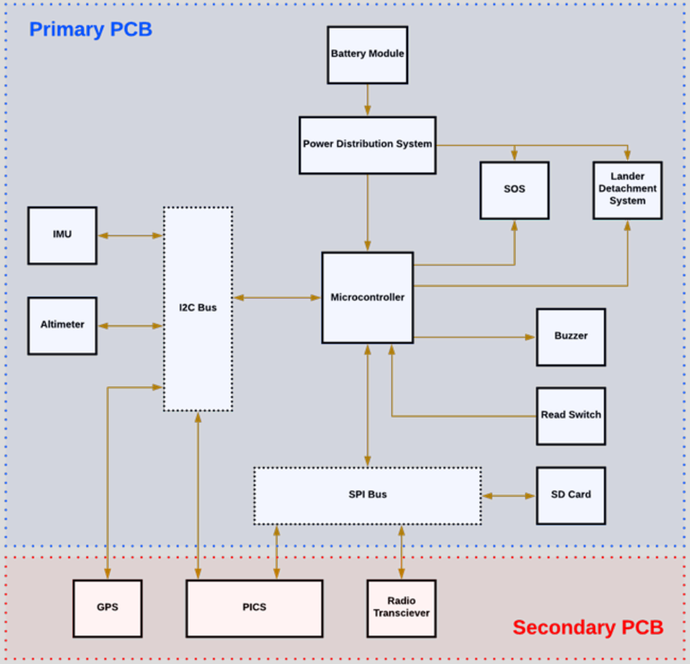
Panoramic Image Capture Subsystem Planned Design



- 3 Static Cameras
  - Triple 120° Fisheye
  - Three images are stored locally
  - PICS waits to connect with the team's Ground Control Station (GCS) computer
    - 250mW transmitter connection for 1mi transmission capability
  - *Going forward*, GCS will be realized with a laptop
    - Images are sent to the GCS for processing and display
    - The GCS will combine the transmitted images and display on-screen
  - *For PDF*, image combination code will be written in Python

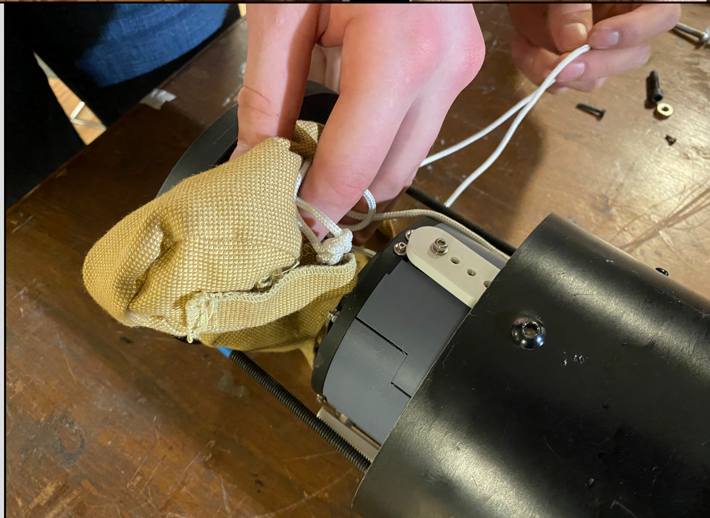
Lander Control Subsystem Design

- Handles Lander activation decision processes
  - Standby during flight-ready
  - Activated by deployment, senses grounding for SOS & PICS with IMU and Altimeter
  - Intakes & transmits panoramic image
- *For VDF*, PCB's had not arrived, so the Lander was inactive. This includes D&L, SOS, & PICS.
- *For PDF*, the LCS will coordinate all software and hardware on the Lander



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 R&D connects to the launch vehicle's nosecone by a mutual attachment plate
- *For VDF onward,* the parachute is loaded beneath the Lander
- *For PDF,* the Lander fits within the Pizza Table in one orientation to allow for LCS system activation



Planetary Lander System VDF Testing

Req. ID	Test ID	Test	System Under Test	Status
S.P.18 G.2.4.1TD	VT.P.1.2	PLS R&D Retention Testing	R&D	Mission Critical, Complete
S.P.1.11 S.P.1.12	VT.P.1.4	PLS R&D Battery Drain Testing	R&D	Mission Critical, Complete
G.2.4.1TD	VT.P.1.10	PLS D&L Structural Testing	D&L	Mission Critical, Complete

PSP

R&D Retention

- **Success Criteria:** The R&D is able to retain the Lander under a Payload Section deceleration force equivalent of at least 2g (FoS = 2.0).
- **Methodology:** Apply weight to the R&D attachment plate with R&D hold activated.
- **Impact of Results:** The results of this test will inform whether the R&D retention design has enough strength and resistance to complete its descent task under the worst possible situations.
- **Results and Conclusions:** The test was successful. The R&D system retained the Lander under the required deceleration of 2g.

D&L Structural

- **Success Criteria:** All elements of the D&L will be able to withstand loading of at least 19lbf without discernable damage for at least 3 cycles.
- **Methodology:** Apply weight to the D&L Body Plate's eyebolt repeatedly.
- **Impact of Results:** The results of this test will inform whether the D&L structural design has enough strength and resilience to complete its descent task under the worst possible situations.
- **Results and Conclusions:** This test has been partially completed for the purposes of VDF. Concluded that these components could be used for launch.

Planetary Lander System Additional VDF Testing

Req. ID	Test ID	Test	System Under Test	Status
S.P.1.9	VT.P.1.9	D&L Wind-Release Testing	D&L	In Progress
S.P.1.6	VT.P.1.11	R&D Altimeter Test	R&D	Complete
S.P.1.6 S.P.1.18	VT.P.1.12	R&D IMU Test	R&D	Complete
S.P.1.1	VT.P.1.13	Lander Drop Testing	D&L	Complete

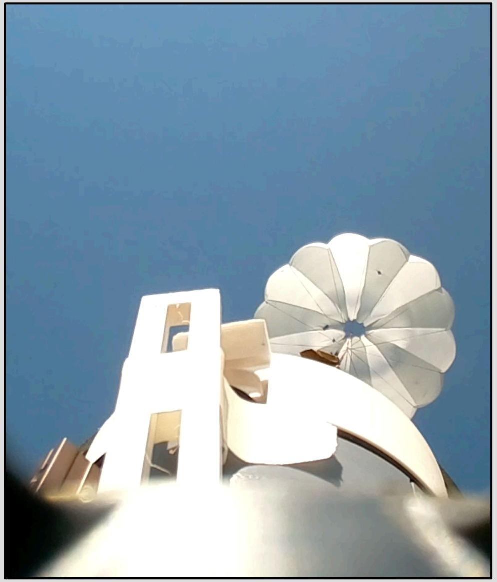
PSP

Planetary Lander System PDF Testing

Req. ID	Test ID	Test	System Under Test	Status
S.P.1.4 S.P.1.18 S.P.1.19 S.P.1.21	VT.P.1.1	R&D Deployment Testing	R&D	Incomplete
S.P.1.15	VT.P.1.3	PLS RF Transceiver Testing	LCS/GCS	Incomplete
S.P.1.11 S.P.1.12	VT.P.1.5	PLS Battery Testing	LCS	Incomplete
S.P.1.11 S.P.1.12	VT.P.1.6	PLS Battery Testing	GCS	Incomplete
S.P.1.10 S.P.1.13 S.P.1.14	VT.P.1.7	PICS Image Testing	PICS	Incomplete
P.4.3.3	VT.P.1.8	SOS Orientation Testing	SOS	Incomplete

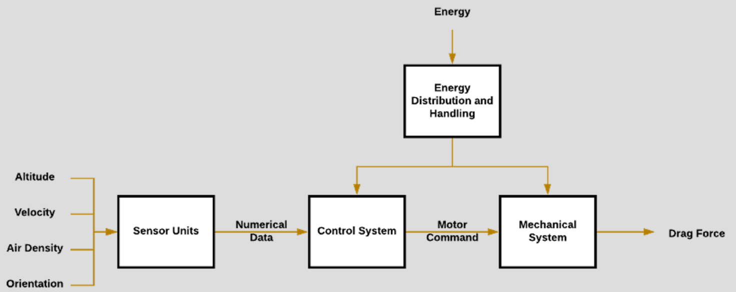
PLS VDF Performance

- The PLS was activated on the pad.
- The R&D subsystem correctly deployed at the target altitude of 700' AGL.
- The Lander was unable to exit the R&D Bay.
- The R&D Bay will be modified to better mediate deployment.
- **The PLS will continue to prepare for PDF.**



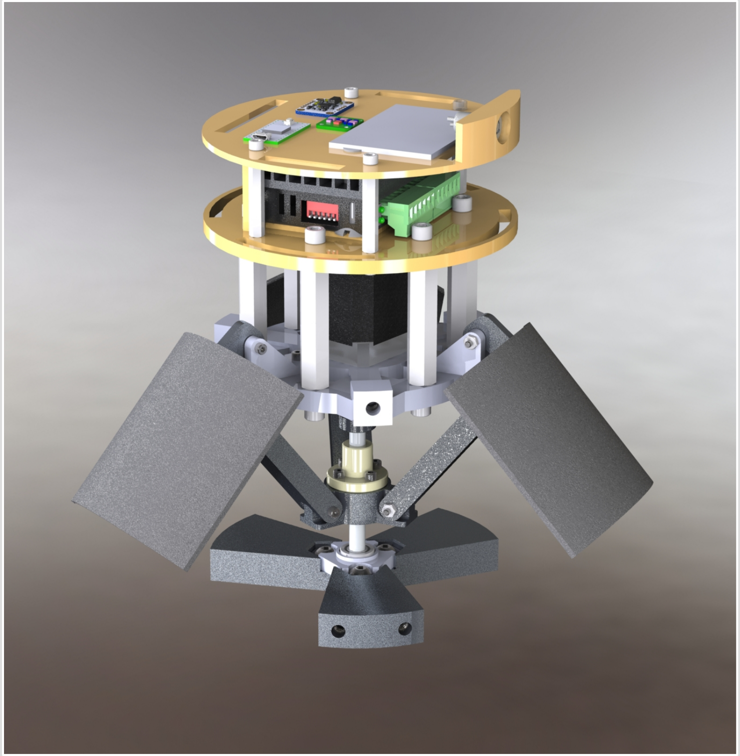
AeroBraking System Overview

- 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



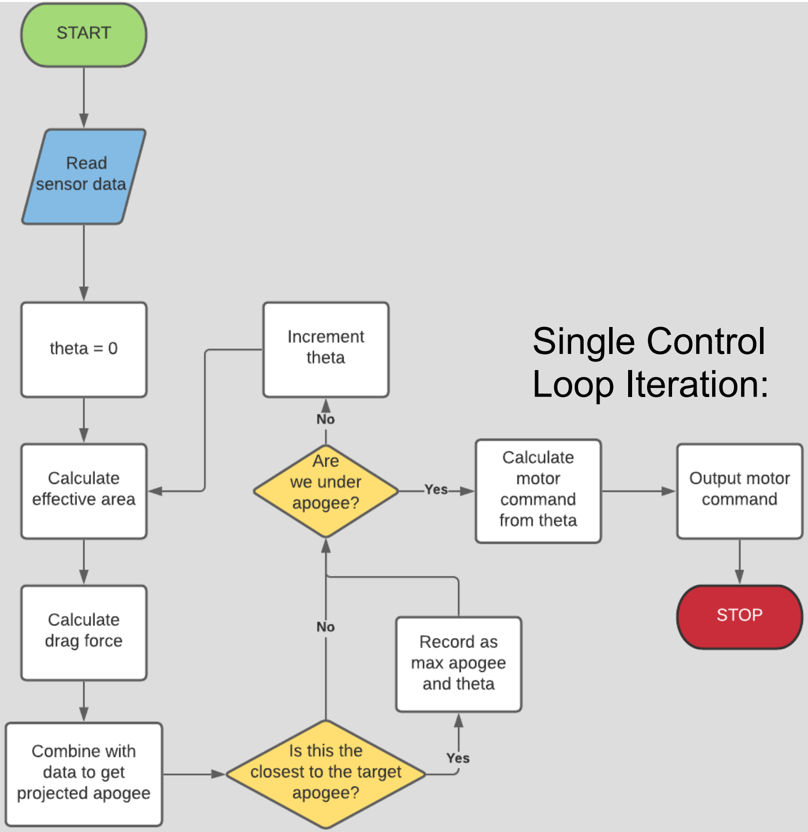
As-Built Mechanical Design

- 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
- 3D printed Markforge 17-4 PH stainless steel on all load bearing components
- Electronics bay attached by standoffs.
    - MATLAB Simulation provides position and torque relationships



PSP

As-Built Control System Design



Selected design is a continuous closed-loop control system

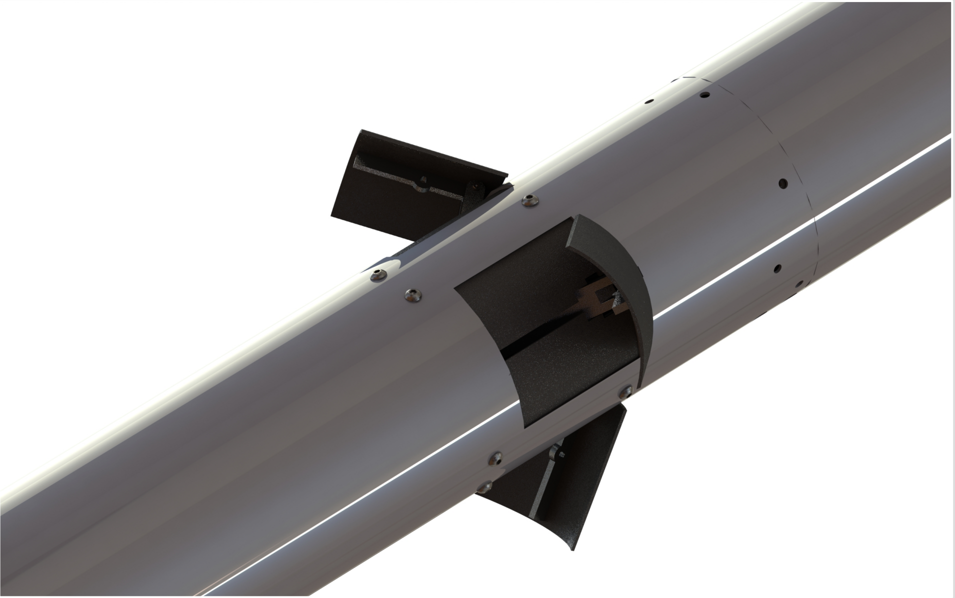
- Inputs – altitude, velocity, acceleration, air pressure
- Output – motor command to stepper motor
- Chosen for accuracy and speed

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

ABCS 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
- Key switch placement within the Electronics Bay
- The battery is placed in the coupler above the ABCS

PSP

AeroBraking Control System VDF Testing

Req. ID	Test ID	Test	System Under Test	Status
G.2.4.1 TD	VT.P.2.1	ABCS Physical Testing	Mechanical	Mission Critical, Complete

ABCS Physical

- **Success Criteria:** The ABCS can withstand the maximum simulated drag load of 120N applied on each Aeroplate with a factor of safety at or above 1.5, meaning 180N each.
- **Methodology:** Apply 55kg tension to ABCS suspended by a vertical beam.
- **Impact of Results:** If the system performs as expected when the maximum anticipated force is applied, then no further action needs to be taken and the ABCS can be fully integrated into the rocket.
- **Results and Conclusions:** The ABCS can reliably perform its operations without the structure losing its integrity during flight.

PSP

AeroBraking Control System PDF Testing

Req. ID	Test ID	Test	System Under Test	Status
S.P.2.7	VT.P.2.2	ABCS Battery Testing	Control System	Incomplete
S.P.2.8	VT.P.2.3	ABCS IMU Testing	Control System	Incomplete
S.P.2.6	VT.P.2.4	ABCS Activation Testing	Control System	Incomplete

ABCS VDF Performance

- The ABCS was activated on the pad.
- The system was likely disconnected from power by high vehicle acceleration.
- The ABCS did not deploy, but proved that the aeroplates can sustain M0.5 flight without induced tumble.
- The Airbrakes team will use flight data to simulate flight more accurately than before.
- **The ABCS will continue to prepare for PDF.**

PSP

Questions & Answers

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