Project Voss

Proposal

500 Allison Road
West Lafayette, IN 47906

Purdue Space Program – Student Launch

September 2020

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1 General Team Information

1.1 Team Member Information

1.1.1 Team Structure

Due to the multi-faceted nature of the NASA USLI Competition, Purdue Space Program – Student Launch has multiple subteams, each responsible for the team's various technical and non-technical projects. The subteams are as follows:

Subteam	Responsibility Summary
Project Management	Facilitating communication between subteams and the completion of mission objectives.
Safety	Ensuring all other subteams are following safe design and operation practices.
Social & Outreach	Spreading awareness of the team and rocketry through social media and activities.
Business	Sourcing and managing team finances.
Construction	Vehicle propulsion, cameras, passive aerodynamics, and overall design.
Payload	Design and assembly of the competition-specific payload, and the aerobraking system.
Avionics and Recovery	Design and verification of the 2-stage recovery system and trajectory simulations.

1.1.2 Leadership Team

Position	Name	Email
Project Manager	Julian Petrillo	jpetril@purdue.edu
Assistant Project Manager	Skyler Harlow	sharlow@purdue.edu
Systems Manager	Lauren Smith	smit3204@purdue.edu
Student Mentor	Michael Repella	mrepella@purdue.edu
Safety Team Lead/Safety Officer	Andrew Darmody	adarmody@purdue.edu
Social & Outreach Team Lead	Jason Hickman	hickman4@purdue.edu
Business Team Lead	Natalie Keefer	keefern@purdue.edu
Construction Team Lead	Justin (JJ) Bagdan	jbagdan@purdue.edu
Payload Team Lead	Luke Hecht	lhecht@purdue.edu
Avionics and Recovery Team Lead	Katelin Zichittella	kzichitt@purdue.edu

1.1.3 Team Mentor Information

Mentor Name	Victor Barlow
Mentor Email	vmbarlow@purdue.edu
Mentor Cell Phone	(765)-414-2848
Mentor TRA / NAR Certifications	NAR 88988, TRA 6839, Level 3 Certified
Team TRA / NAR Section	NAR 88988, TRA 6839

1.1.4 Member Division
The following chart illustrates the current breakdown of the team's approximately 50 members across it's various subteams.

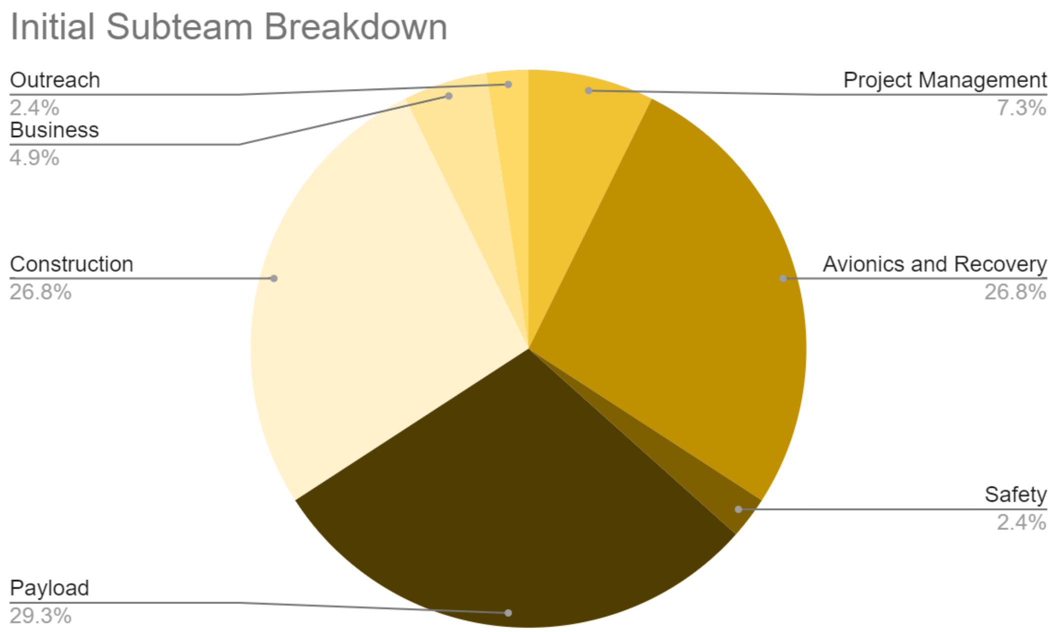

Figure 1.1 Subteam Breakdown

1.1.5 Total Proposal Hours
The team has tracked all hours working on the 2021 PSP Proposal using an online form filled out by each member after all meetings and independent work sessions. The team has spent approximately 210 total hours in creating the proposal and the design described within.

1.2 Facilities
The team has access to several manufacturing and assembly facilities on the Purdue campus. These facilities provide workspaces where the team can work and contain machine tools that the team can use for free. The team will abide by the safety protocols instated by all facilities.

1.2.1 Aerospace Sciences Laboratory (ASL)
The Aerospace Science Laboratory is the primary assembly space for PSP-SL, providing ample square footage and storage for vehicle and payload needs. The team has a set of shelving units reserved for hardware storage and a well-lit, heated workspace with large tables. In past years, the team has had 24/7 card access to the facility, but this access is temporarily suspended due to the COVID-19 pandemic. The building management has indicated that the space will become available in the coming months once the University is more certain of the status of COVID-19 on campus, for now, the team can gain access via appointment. The facility also contains a wind tunnel which may be used for testing of the AeroBraking Control System (ABCS).

Machinery equipment available at the ASL includes drill presses, shop vacuums, and table saws. The team provides additional tools including Dremel rotary tools, abrasives, adhesives, power drills, and electrical prototyping equipment. All team members will be briefed by their Subteam lead or the Safety lead on the proper handling of all tools.

1.2.2 Bechtel Innovation and Design Center (BIDC)
The Bechtel Innovation and Design Center is the primary manufacturing facility for PSP-SL, with an assortment of advanced prototyping tools including FDM 3D printers, 3 and 5 Axis CNC mills, drill presses, CNC lathes, a waterjet, sandblasters, routers, panel saws, welding equipment, painting booths and more. To access BIDC, team members must

complete training specific to each tool and be accompanied by a BIDC Teaching Assistant. Despite the COVID-19 pandemic, BIDC remains open to manufacturing appointments 9-5 M-F.

1.2.3 Zucrow Propulsion Laboratories

The Maurice J. Zucrow Propulsion Laboratories (Zucrow Labs) are the world's largest academic propulsion laboratories and provide a facility for PSP-SL to run high energy vehicle tests. Likely, the area around Zucrow Labs will be used for the avionics ejection charge tests. Access to this area and the facility as a whole is solely by appointment with its director: Professor Scott Meyer. The team will also use Zucrow Labs for long term storage of energetics such as black powder and motors. The safety officer will be present for all operations at Zucrow Labs.

1.3 Equipment and Supplies Summary

PSP-SL has amassed a large supply of ANSI fasteners, components, hardware, and tools over previous competition seasons. This supply is likely satisfactory for all general-purpose assembly needs, and team members will be encouraged to use components already in storage in their designs. Additional equipment and supplies will be purchased for specific payload, avionics, and construction designs. These new purchases may include but are not limited to, electronics components, stock material, assembly hardware, hand tools, and testing equipment. Specific purchase plans will be included in PDR and CDR as the team solidifies its vehicle and payload design.

1.4 STEM Engagement

To engage the community of West Lafayette and beyond through the promotion of space exploration and rocketry, the team will actively participate in several planned virtual events throughout the coming 2020-2021 school year. The team plans to do the following:

- Participate in the virtual Purdue Space Day, a live broadcast designed to reach children both locally and across the country
- Create informative videos detailing the aspects of each subteam as a means of advertising the club and garnering interest from the student body and greater community
- Reach out to local schools to promote interest in STEM

To evaluate our success in these endeavors, the team will gauge the involvement of those we reach and track team member participation.

2 Project Plan

2.1 Requirements and Verification Plans

2.1.1 R&VP System Summary

After careful analysis of past competitions and NASA requirements, the PSP-SL Project Management team has created a new standard for the team's internal Requirements and Verification Plans (R&VP). This system emphasizes the value of R&VP in guiding the team throughout the year, rather than simply satisfying NASA requests. The Project Management team has created a 10-page R&VP handbook which has been digitally distributed to all team members to aid them in R&VP design. The most relevant information for NASA has been included in the following sections, but the entire handbook can be found at the following link https://tinyurl.com/pspr-vp.

2.1.1.1 Requirement Types

An important part of the team's new R&VP system is the internal removal of the distinction between NASA requirements and team requirements. While this distinction is made in this report for the sake of NASA review with superscript "^{TD}", the team has internally replaced this distinction with one based on the subject of the requirements. The team has broken up requirements into two categories: Project Requirements and Subteam Requirements.

2.1.1.2 Project Requirements

Project Requirements include all requirements from NASA as well as high-level requirements created by the PSP-SL Project Management team. All Project requirements are general and describe the overall needs of the mission. Some project requirements are simple enough to be satisfied by a simple verification plan, having a classic verification type: *Demonstration, Inspection, Analysis, Testing* (DIAT). Other requirements are more complicated in which case the requirement is marked as verified by *Prerequisite*. To complete verification by prerequisite, a selected set of subteam requirements must be verified.

2.1.1.3 Subteam Requirements

Subteam requirements are generated independently by the PSP-SL subteams and are generally very specific. By allowing the subteams to create their own requirements, the team ensures that the requirements are as detailed as possible and are strictly relevant to the subteam. These subteam requirements can exist either to directly satisfy a project requirement which is verified by prerequisite or independently, describing a system feature desired by the subteam lead. All subteam requirement verification plans must use DIAT. All subteam requirements satisfy the NASA definition of a team derived requirement.

2.1.1.4 Requirements Numbering

2.1.1.4.1 Subsystem Prefix Table

Within the team, R&VP system subsystem prefixes have been added to all requirements to help members quickly identify the system relevant to the requirement. These prefixes are assigned according to the following table:

Subsystem	**Letter**	**Mnemonic**
Social, Business, Outreach, Documentation	N	Non-technical
Airframe and Propulsion	V	Vehicle
Payload	P	Payload
Avionics and Recovery	A	Avionics
AeroBraking Control System	B	Brakes
Standards, Guidelines	G	Guidelines
Systems, Project Management	M	Management
Safety	H	Health
Subteam Identifier (**Not a subsystem)**	S	Subteam

Table 2.1 Subsystem Prefix Table

2.1.1.4.2 NASA Requirements

NASA requirements are numbered with the ID provided by NASA, and a subsystem identifier prefix.

2.1.1.4.3 Team Derived Project Requirements

Project requirements are numbered to emulate the NASA requirements, and are added at the end of sections, or as sub-requirements to NASA requirements.

2.1.1.4.4 Subteam Requirements

Subteam requirements are prefixed by an S, the prefix letter of the relevant subteam, and numbers assigned by the subteam lead.

2.1.1.4.5 Additional Information

Examples and additional information about the PSP-SL requirements numbering system can be found in the R&VP handbook: https://tinyurl.com/pspr-vp.

2.1.2 Project Requirements Table

2.1.2.1 Table Layout

The following table outlines the structure of the PSP-SL R&VP Master Table:

Requirement ID	Requirement Summary	Verification		Verification Plan Summary	Status
		Type(s)	Plan ID(s)		
Subteam.#.#.#	*An abridged version of the NASA requirement OR a description of the requirement from project management.*	*D,I,A,T,P*	*The verification plan(s) (DIAT) or prerequisite requirement(s) (P) ids needed to ensure requirement completion.*	*The success criteria for the requirement (DIAT), or a description of the prerequisite requirements (P)*	Incomplete/ Complete

Table 2.2

2.1.2.2 Table Guide

Throughout the table, the team uses certain syntax to mark information that will be added in future revisions. The use of "*.x.x.x" refers to at least one requirement from the subteam with the letter "*". All instances of "*.x.x.x" will be replaced with specific requirements from the given subteam by PDR.

2.1.2.3 PSP-SL Proposal Project R&VP Table

The following table represents the team's project requirements, consisting of both NASA and team derived requirements. Along with this requirement table, future reports will contain tables outlining subteam requirements in their corresponding sections.

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
N.1.2	The team will provide and maintain a project plan describing all aspects of the project.	D	N/A	The team will submit an up-to-date project plan with all milestones.	Incomplete
N.1.3	For security reasons Foreign National team members will be identified by PDR.	D	N/A	The team will submit a list of FN team members with PDR.	Incomplete
N.1.4.1-3	The team will create launch week team member roster by CDR consisting of students engaged throughout the year and a single adult mentor.	D	N/A	The team will submit a list of team members and the project mentor with CDR.	Incomplete
N.1.5	The team will engage more than 200 participants in STEM activities.	D	N/A	The team will submit relevant outreach activity forms within two weeks of a given activity.	Incomplete
N.1.5.1[TD]	The team will host virtual software tutorials for its members and the greater college community	D	N/A	The team will submit relevant outreach activity forms within two weeks of a given activity.	Incomplete
N.1.6	The team will establish a social media presence.	D	N/A	The team will submit a list of active team social media accounts.	Incomplete

N.1.7-10	All deliverables will be properly formatted and emailed to the USLI team by the specified deadlines.	D	N/A	The team will submit properly formatted deliverables on time at all milestones.	Incomplete
N.1.7.1	All subteams will complete milestone editing 3 days prior to the official NASA deadline. After this time only the Project Management team will have access to the documentation to perform final edits.	D	N/A	The team will submit properly formatted deliverables on time at all milestones.	Incomplete
N.1.11	The team will use proper teleconferencing equipment for all calls with the USLI team.	D	N/A	The team leads will perform professional video calls for all milestone meetings.	Incomplete
V.1.12	The launch vehicle will use USLI standard launch rails and pad configurations.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
N.1.13	The team will identify an experienced mentor.	D	N/A	The team will submit information about the team mentor in CDR.	Incomplete
N.1.14	The team will track, and report hours spent working on all milestones.	D	N/A	The team will submit member timesheets with all reports.	Incomplete
N.1.14.1[TD]	The team will set up a software tool to allow members to submit their working hours.	D	N/A	The team will submit member timesheets with all reports.	Incomplete
V.2.1	The vehicle's apogee shall be between 3,500 and 5,500 feet.	P	V.x.x.x, B.x.x.x	The team will conduct analyses and tests to verify this requirement with the ABCS active and deactivated. This verification will also include the vehicle demonstration flight.	Incomplete
B.2.1.2 [TD]	The launch vehicle will actively control its apogee using an AeroBraking Control System (ABCS). Using the ABCS, the vehicle will reach within 15the PDR target apogee.	P	B.x.x.x	The ABCS team will conduct a multifaceted verification of the ABCS system to ensure its ability to function as intended.	Incomplete
N.2.2	The team will declare a target altitude at PDR.	D	N/A	The team will submit its target altitude in PDR.	Incomplete
A.2.3	The launch vehicle shall contain a commercially available barometric altimeter for recording apogee.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
G.2.4	The vehicle shall be designed to be recoverable and reusable.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
G.2.4.1 [TD]	The vehicle shall withstand all expected flight loads with a minimum safety factor of 1.5.	P	V.x.x.x, P.x.x.x, A.x.x.x, B.x.x.x	All subteams will independently verify the strength of their subsystems through analysis and testing.	Incomplete
V.2.5	The launch vehicle shall have a maximum of 4 independent sections.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete

V.2.5.1-2	Couplers at inflight separation points shall be at least 1 cal in length. Nose cone couplers shall be at least ½ cal in length.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
V.2.6	The launch vehicle shall be able to launch within 2 hours of flight authorization.	D	D.M.2.1	VDF will demonstrate the team's ability to prepare the launch vehicle for flight.	Incomplete
V.2.6.1 TD	The launch vehicle will be assembled in a quality conducive assembly area separate from the launch site. A quality conducive assembly area has (but is not limited to) the following attributes: climate control not necessitating thermal protective clothing, bright overhead lighting, and access to tools and components.	D	D.M.2.1	VDF will demonstrate the team's ability to prepare the launch vehicle for flight.	
V.2.7	The launch vehicle and payload shall be able to remain in the flight ready configuration for at least 2 hours.	P	V.x.x.x,	All subteams will perform battery drain testing on their subsystems.	Incomplete
V.2.7.1 TD	The launch vehicle and payload shall be able to remain in the pre-flight state for at least 18 hours.	P	V.x.x.x,	All subteams will perform battery drain testing on their subsystems.	Incomplete
V.2.7.2 TD	The transition between the pre-flight state and flight ready state will not require the disassembly of the launch vehicle.	I	I.M.3.1	The systems manager will inspect all checklists to ensure procedural compliance.	Incomplete
V.2.8-9	The vehicle shall be capable of being launched via a 12v DC firing system as provided by the launch services provider	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
V.2.10	The launch vehicle shall use an APCP motor.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
V.2.10.1-2	The final motor choice shall be declared by CDR. Any changes after CDR must be approved by the RSO.	D	N/A	The team will submit its motor selection in the CDR milestone report.	Incomplete
V.2.11	The launch vehicle will be limited to a single stage.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
V.2.12	The total impulse of the launch vehicle shall not exceed 5120 Ns (L-Class).	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
V.2.13.0-3	Pressure vessels on the vehicle must be approved by the RSO and maintain safe standards.	N/A	N/A	No pressure vessels will be included in the vehicles design.	Incomplete
V.2.14	The vehicle shall have a minimum stability margin of 2.0 cal at rail exit.	P	D.M.2.1, A.x.x.x	The avionics and construction subteams will independently verify the launch stability of the	Incomplete

				vehicle. Compliance will also be demonstrated during VDF.	
B.2.14.1 TD	The ABCS shall not reduce the stability margin below 2.0 cal at any point, under any failure mode.	P	D.M.2.1, A.x.x.x	The team will perform FMEA and other analyses on the ABCS system to ensure compliance. Compliance will also be demonstrated during VDF.	Incomplete
V.2.15	The vehicle shall not have any structural protuberance forward of the burnout CoM. Excepting aerodynamically insignificant camera housings.	I/A	I.M.1.1	The team will inspect the PDR design for forward structural protuberances. If any are present, the team will perform CFD analysis to ensure aerodynamic insignificance.	Incomplete
V.2.16	At rail exit the vehicle shall have a minimum velocity of 52fps.	P	D.M.2.1, V.x.x.x	The team will perform launch analysis to ensure proper rail exit velocity.	Incomplete
V.2.17	A subscale rocket will be successfully flown by CDR.	D	N/A	The team will submit subscale altimeter data with CDR.	Incomplete
V.2.17.1	The subscale rocket shall resemble and perform similarly to the full-scale rocket but will not be the full-scale rocket.	I	I.M.1.2	The team will inspect the subscale vehicle design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
V.2.17.2	The subscale rocket shall contain an altimeter to record apogee.	I	I.M.1.2	The team will inspect the subscale vehicle design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
V.2.17.3	The subscale rocket will be newly constructed for the 2021 competition	I	I.M.1.2	The team will inspect the subscale vehicle design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
N.2.17.4	Proof of the subscale flight shall be included in CDR	D	N/A	The team will submit subscale altimeter data with CDR.	Incomplete
N.2.18	The team shall complete the following demonstration flights.	P	N.2.18.1-2	The team will verify all prerequisite requirements.	Incomplete
N.2.18.1	The team will fly the launch day vehicle in its final configuration in order to validate its flight capabilities. This Vehicle Demonstration Flight (VDF) has the following success criteria.	P	V.2.18.1.1-9	The team will verify all prerequisite requirements.	Incomplete
G.2.18.1.1	The vehicle and recovery system will have functioned as designed.	P	V.x.x.x, P.x.x.x, A.x.x.x, B.x.x.x	All subteams will complete post launch system assessments.	Incomplete
N.2.18.1.2	The full-scale rocket must be newly designed and constructed for the 2021 competition.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
P.2.18.1.3	The payload does not have to be flown during VDF.	N/a	N/a	The team overrides this requirement with N.2.18.2.2.	Incomplete

P.2.18.1.3.1-2	If the payload is not flown, a mass simulator will be used to simulate the payload mass and will be located in approximately the same location as the payload CoM.	P	P.x.x.x	If included, the effect of the payload mass simulator will be quantified by the payload team.	Incomplete
P.2.18.1.4	If the payload effects the external surface of the rocket or manages the total energy of the vehicle, those systems will be active during VDF.	I	I.M.3.1.1	Before VDF, the systems manager will ensure all protrusions and energy management systems are present.	Incomplete
V.2.18.1.5	During VDF, the vehicle shall use the declared launch day motor.	I	I.M.3.1.1	Before VDF, the systems manager will ensure the declared launch day motor is installed in the vehicle.	Incomplete
V.2.18.1.6	The vehicle shall have the launch day ballast configuration for the VDF.	I	I.M.3.1.1	Before VDF, the systems manager will inspect the vehicle for proper ballasting	Incomplete
N.2.18.1.7	The team will not modify the vehicle after VDF without permission from the RSO.	D	N/A	The vehicle present at LRR will be identical to the vehicle discussed in FRR.	Incomplete
N.2.18.1.8	Altimeter data will be provided in the FRR report to prove a successful flight	D	N/A	The team will submit VDF altimeter data in FRR.	Incomplete
N.2.18.1.9	VDF must be completed by the FRR submission deadline. If a re-flight is required, an extension may be granted.	D	N/A	The team will submit VDF altimeter data in FRR	Incomplete
N.2.18.2	The team will fly the launch day payload aboard the launch day rocket in a successful Payload Demonstration Flight. This PDF will be considered successful if the vehicle experiences stable ascent and the following requirements are met.	P	P.2.18.2.1-3	The team will complete all prerequisite requirements for PDF.	Incomplete
P.2.18.2.1	The payload will be fully retained until the intended point of deployment, and all R&D mechanisms will function as intended and suffer no damage	I	P.x.x.x	All subteams will complete post launch system assessments.	Incomplete
N.2.18.2.2 [TD]	VDF will contain the final payload system, unless waiting until the completion of the payload would bar the team from satisfying requirement N.2.19.1	I	I.M.3.1	The systems manager will inspect the vehicle for proper installation of the payload system before flight.	Incomplete
G.2.18.2.3 [TD]	Test launches will only be attempted if all subsystem designs are frozen and thorough assembly protocols have been created.	I	I.M.3.2	The systems manager management team will conduct a survey of subteam leads and confirm their confidence in the vehicles ability to have a safe and successful flight.	Incomplete
N.2.19	An FRR Addendum will be required for teams completing PDF or VDF re-flight after the FRR report deadline.	D	N/A	The team will submit FRR Addendum if required.	Incomplete
N.2.19.1	The FRR Addendum must be submitted for all teams whose circumstances require its submission.	D	N/A	The team will submit FRR Addendum if required.	Incomplete
N.2.19.2	If the PDF fails, the team will not be permitted to fly at the competition launch.	N/A	N/A	N/A	Incomplete

N.2.19.3	If the PDF partially fails, the team may petition the RSO for permission to fly the payload at launch week.	N/A	N/A	N/A	Incomplete
N.2.20	All separable components will have the team's name and Launch Day contact information clearly visible.	I	I.M.3.1	The systems manager will inspect the launch vehicle and payload for proper labeling before all flights.	Incomplete
N.2.22.0-10	The vehicle will not use any of the following prohibited design features or modes: • Forward Firing Motors • Motors that expel titanium sponge • Hybrid Motors • Motor Clusters • Friction Fit Motors • Exceed Mach 1 at any point • Ballast exceeding 10% of the unballasted weight • Transmitters with individual power greater than 250 mW • Transmitters which create excessive interference • Excessive / dense metal. Lightweight metal will be permitted for structural purposes	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
V.3.1[TD]	The vehicle will contain an In-Flight Video Recording (IFVR) system to record flight video for downloading after recovery.	P	V.x.x.x	The IFVR team will verify the functionality of the IFVR system through a variety of DIAT methods.	Incomplete
V.3.1.1[TD]	The IFVR will have at least two sensors, aligned aft and radially, and may have a sensor aligned forward.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
V.3.1.2[TD]	The IFVR will be considered a vehicle element, not a payload experiment.	D	N/A	The construction team will be solely responsible for the IFVR and IFVR documentation will be included in the vehicle construction section of all reports.	Incomplete
A.3.1	Vehicle recovery process will abide by the requirements A.3.1.1 – A.3.1.13	P	A.3.1.1 – A.3.1.13	The team will complete all prerequisite recovery requirements.	Incomplete
A.3.1.1	The main parachute will be deployed no lower than 500 feet.	P	A.x.x.x	The team will ensure the proper deployment of the main parachute through a variety of verification and design methods	Incomplete
A.3.1.2	The apogee event will contain a delay of no more than 2 seconds.	P	A.x.x.x	The team will ensure the proper deployment of the drogue parachute through a variety of verification and design methods	Incomplete
A.3.1.3	The motor will not be ejected at any point.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete

A.3.1.4 TD	The recovery process will be designed to minimize shock to the vehicle.	P	A.x.x.x	The team will ensure the minimization of shock through various subteam requirements.	Incomplete
A.3.2	The team will perform a ground ejection test for all electronically initiated recovery events.	T	N/A	The team will submit ejection test results with FRR.	Incomplete
A.3.3	Each independent section of the launch vehicle will have a maximum kinetic energy of 75ft-lbf (101J)	P	A.x.x.x, V.x.x.x	The team will ensure acceptable landing energy through verification up to and including post launch examination of flight telemetry.	Incomplete
A.3.4	The recovery system will contain redundant, commercially available altimeters.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
A.3.5	Each altimeter will be equipped with a commercially available, dedicated power supply.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
A.3.6	Each altimeter will be armed (placed into the flight-ready state) by a dedicated mechanical arming switch	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
A.3.7	The A&R system shall not be capable of disarmament due to flight sources.	P	A.x.x.x	The team will design and test the avionics bay to ensure that disarmament due to flight sources is impossible.	Incomplete
A.3.8	A&R electrical circuits will be completely independent of payload electrical circuits.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
A.3.9	Removable shear pins will be used for both parachute compartments.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
A.3.10	The recovery area will be limited to a 2,500 ft. radius from the launch pad.	P	A.x.x.x	The team will verify the acceptability of the recovery area through a variety of methods.	Incomplete
A.3.11	The descent time of the launch vehicle (apogee to touch down) must be less than 90 seconds.	P	A.x.x.x	The team will verify the acceptability of the vehicle descent time through a variety of methods.	Incomplete
A.3.12	The launch vehicle will have a tracking device which transmits its position to a ground station.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
A.3.12.1	Any untethered component of the launch vehicle will contain a tracking device.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete

A.3.12.2	All electronic tracking devices will be fully functional during launch day	I	I.M.3.1	Before launch, the systems manager will inspect all tracking devices' downlinks.	Incomplete
A.3.12.3 TD	Any tethered component of the launch vehicle will contain a tracking device.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
A.3.13	The recovery system will not be adversely affected by other electronics devices during flight.	P	A.x.x.x	The team will verify the electronic resilience of the avionics system through a variety of methods.	Incomplete
A.3.13.1	Recovery system altimeters will be located in a compartment separated from other RF/EM emitting devices.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
A.3.13.2-4	Recovery system electronics will be shielded from other RF/EM emitting devices.	P	A.x.x.x	The team will verify the electronic resilience of the avionics system through a variety of methods.	Incomplete
P.4.2	The payload will consist of a planetary lander capable of ejection during descent which will self-right during or after landing. After leveling the system will take a 360-degree panoramic photo of the landing site and transmit the photo to the team.	P	P.4.3, D.M.2.2	The team will complete all prerequisite requirements and demonstrate success in the payload demonstration flight.	Incomplete
P.4.3	The landing system will adhere to requirements P.4.3.1.-P.4.3.4.4	P	P.4.3.1.-P.4.3.4.4	The team will complete all prerequisite requirements.	Incomplete
P.4.3.1	The landing system will be completely jettisoned from the launch vehicle between 500 & 1000 ft AGL. The landing system must land within the external borders of the launch field. The landing system will not be tethered to the launch vehicle.	P	P.x.x.x.	Once specific subteam requirements defined by the payload team have been verified, this requirement will be verified.	Incomplete
P.4.3.2	The vehicle will land in an upright orientation or will be capable of self-orienting autonomously.	P	P.x.x.x.	Once specific subteam requirements defined by the payload team have been verified, this requirement will be verified.	Incomplete
P.4.3.3	The landing system will self-level within 5 degrees of vertical.	P	P.x.x.x.	Once specific subteam requirements defined by the payload team have been verified, this requirement will be verified.	Incomplete
P.4.3.3.1	The lander must autonomously self-level.	P	P.x.x.x.	Once specific subteam requirements defined by the payload team have been verified, this requirement will be verified.	Incomplete
P.4.3.3.2	The landing system must record pre- and post-leveling orientation data. This data will be provided in PLAR	P	P.x.x.x.	Once specific subteam requirements defined by the payload team have been verified, this requirement will be verified.	Incomplete
P.4.3.3.2.1	PDF orientation data will be provided in FRR	D	N/A	The team will submit PDF orientation data in FRR.	Incomplete
P.4.3.4	After self-leveling the lander will produce a 360-degree panoramic image of the landing site and transmit it to the team.	P	P.x.x.x.	Once specific subteam requirements defined by the payload team have been verified, this requirement will be verified.	Incomplete

P.4.3.4.1	Image receiving hardware will be located within the team's assigned preparation or viewing area.	D	I.M.3.1	The team will display image receiving hardware to the NASA RSO before launch.	Incomplete
P.4.3.4.2	Only transmitters on board the vehicle during launch will be permitted to operate outside of the preparation or viewing areas.	D	I.M.3.1	The team will display image receiving hardware to the NASA RSO before launch.	Incomplete
P.4.3.4.3	After landing, the payload may use transmitters with a power greater than 250 mW.	N/A	N/A	N/A	Incomplete
P.4.3.4.4	The team will provide the 360-degree panoramic image in PLAR.	D	N/A	The team will submit the final panoramic image in PLAR.	Incomplete
P.4.4	The payload will adhere to requirements P.4.4.1-6	P	P.4.4.1-6	The team will complete all prerequisite requirements.	Incomplete
P.4.4.1	Black Powder and/or similar energetics will only be used for in-flight recovery systems.	I	I.M.1.1	The team will inspect the vehicle and payload design at PDR to ensure compliance with NASA requirements. Relevant design aspects will be frozen after the submission of PDR.	Incomplete
P.4.4.2	Teams will abide by all FAA and NAR rules and regulations.	I	I.M.3.1	The systems manager will inspect the vehicle and payload before launch to confirm FAA and NAR compliance.	Incomplete
P.4.4.4	UAS payloads will be tethered to the vehicle and will not be released until RSO permission has been granted.	D	N/A	The team will inform the RSO of the relative location of the payload throughout flight.	Incomplete
P.4.4.5	UAS payloads will abide with all FAA regulations.	I	I.M.3.1	The systems manager will inspect the vehicle and payload before launch to confirm FAA and NAR compliance.	Incomplete
P.4.4.6	Any UAS weighing more than .55lbs will be registered with the FAA and be marked with its registration number.	I	I.M.3.1	The systems manager will inspect the vehicle and payload before launch to confirm FAA and NAR compliance.	Incomplete
P.4.5 TD	The payload team will be responsible for the design, manufacture, and operation of the ABCS	D	N/A	Project management will monitor the proper division of labor across the team.	
H.5.1	The team will use a launch and safety checklist which will be included in FRR and used in LRR and for all launch day operations	D	N/A	The team will submit all checklists with FRR.	Incomplete
M.5.1.1 TD	The team will utilize checklists for all pre-flight operations including but not limited to: A&R assembly, Payload assembly, Motor installation, and Vehicle integration.	D	N/A	The systems manager will create and review all checklists before use.	Incomplete
M.5.1.2TD	The team will not launch a vehicle until the Systems Manager is satisfied with the status of all pre-flight checklists.	D	I.M.3.1	The systems manager will receive confirmation of checklist completion from all subteam leads.	Incomplete
H.5.2	The team will identify a student safety officer who is responsible for all sub requirements of requirement M.5.3.	D	N/A	The team will submit information regarding its selected safety officer in the Proposal	Incomplete

H.5.3	Safety officer responsibilities are defined in H.5.3.1 - H.5.5	P	H.5.3.1-H.5.5	The team will complete all prerequisite requirements	Incomplete
H.5.3.1	The safety officer will monitor team activities will an emphasis on safety during operations H.5.3.1.1-9 and H.5.3.2-4.	D	S.1.1	The safety officer will affirm their responsibility for the safety of the team.	Incomplete
H.5.3.1.1-9	Safety officer will oversee all of the following operations: • Vehicle and Payload design • Vehicle and Payload construction • Vehicle and Payload Assembly • Vehicle and Payload ground testing • Subscale launch tests • Full-scale launch tests • Launch Day • Recovery Activities • STEM Engagement Activities	D	S.1.1	The safety officer will affirm their responsibility for the safety of the team.	Incomplete
H.5.3.2	Ensuring the implementation of safety procedures for construction, assembly, launch and recovery.	D	S.1.1	The safety officer will affirm their responsibility for the safety of the team.	Incomplete
H.5.3.3-4	Maintain and lead the development of team hazard analyses, failure mode analyses, and MSDS/chemical inventory data.	D	N/A	The team will submit hazard analyses and FMEAs in all relevant milestone reports.	Incomplete
H.5.4	The team will follow all guidance from the local rocketry clubs RSO and will be in constant communication to ensure safety.	D	S.2.1	All team members will sign pledges affirming their intention to follow all local, state and federal regulations regarding the project.	Incomplete
H.5.5	The team will abide by all rules set by the FAA	D	I.M.3.1	The systems manager will inspect the vehicle and payload before launch to confirm FAA and NAR compliance.	Incomplete
N.6.1	At the NASA Launch Complex, the team must satisfy requirements N.6.1.1-4	P	N.6.1.1-4	The team will complete all prerequisite requirements.	Incomplete
N.6.1.1	Teams must pass LRR during launch week.	D	N/A	The team will pass LRR during launch week.	Incomplete
N.6.1.2	The team mentor must be present for vehicle preparation and launch.	D	S.3.1	The team will not proceed with launch procedures without the team Mentor.	Incomplete
N.6.1.3	The scoring altimeter must be presented to the NASA scoring official upon recovery.	D	N/A	The NASA RSO will receive the scoring altimeter after flight.	Incomplete
N.6.1.4	Teams may only launch once.	D	N/A	The team will only attempt a single flight.	Incomplete
N.6.2.1	At Commercial Spaceport Launch Sites (local launch fields), the team must satisfy requirements N.6.2.1-8.	P	N.6.2.1-8	The team will complete all prerequisite requirements.	Incomplete
N.6.2.1	The launch must occur at a NAR or TRA insured launch.	D	I.M.3.1	The systems manager will inspect the vehicle and payload before launch to confirm FAA and NAR compliance.	Incomplete
N.6.2.2	The launch site RSO will inspect the rocket and payload and determine its flight-readiness.	D	I.M.3.1	The team will not launch until receiving RSO approval.	Incomplete

N.6.2.3	The team mentor must be present for vehicle preparation and launch.	D	S.3.1	The team will not proceed with launch procedures without the team Mentor.	Incomplete
N.6.2.4	The team mentor and Launch Control Officer (LCO) will report any anomalies during ascent or recovery on the Launch Certification and Observations Report (LCOR).	D	N/A	The team will submit LCOR after flight	Incomplete
N.6.2.5	The scoring altimeter will be presented to the team's mentor and the RSO.	D	I.M.3.1	The RSO will receive the altimeter after flight.	Incomplete
N.6.2.6	The mentor, RSO, and LCO will complete all applicable sections in the LCOR.	D	N/A	The team will submit LCOR after flight.	Incomplete
N.6.2.7	The RSO and LCO shall not be affiliated with the team, team members, or academic institution.	D	N/A	The RSO and LCO will affirm their status on the LCOR.	Incomplete
N.6.2.8	Teams may only launch once.	D	N/A	The team will only attempt a single flight.	Incomplete

2.2 Project Work Breakdown Structure

The following chart represents the major technical challenges the team must complete to satisfy all of its project requirements. This challenges are separated according to the relevant subteams and subsystems.

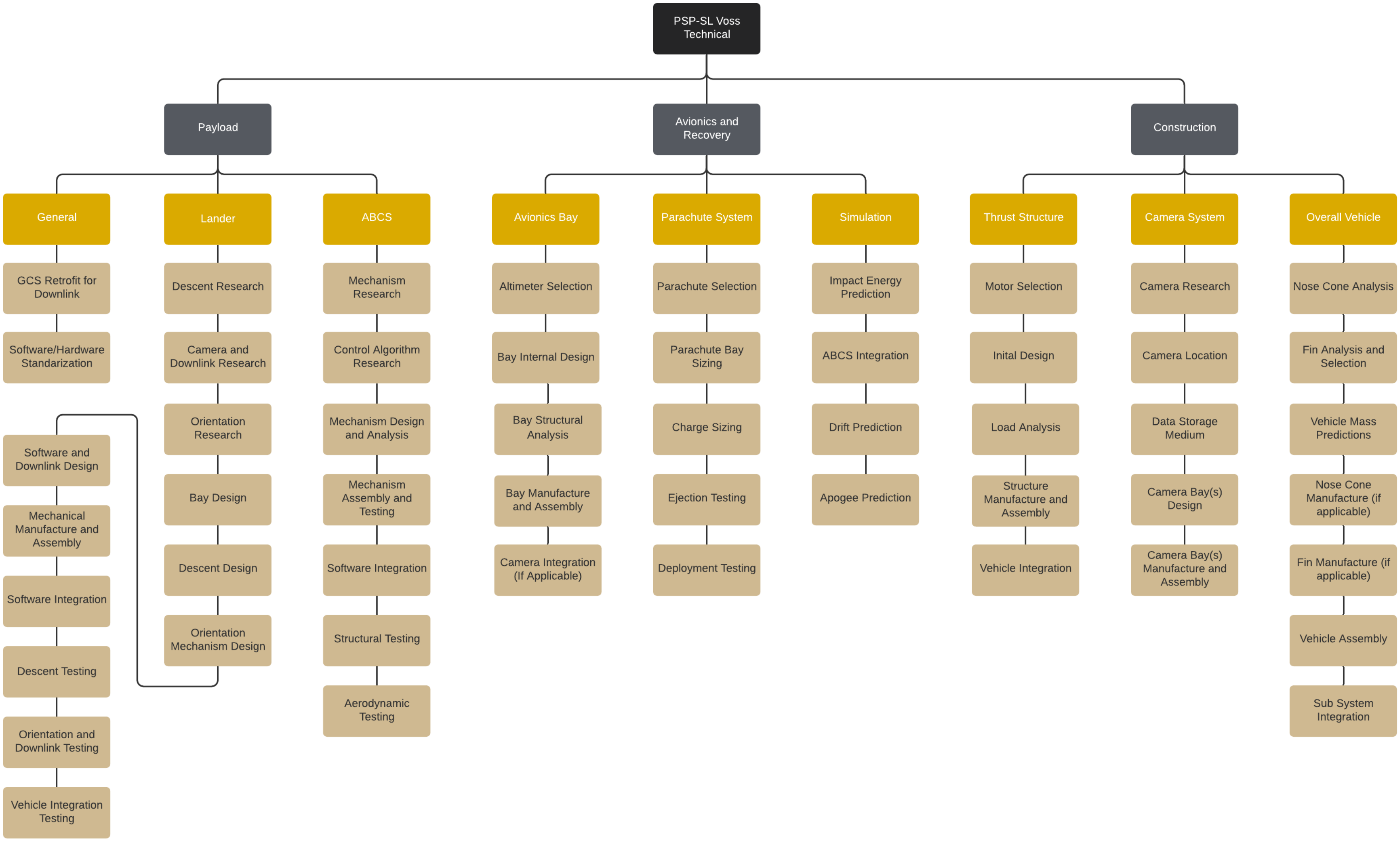

Figure 2.1 PSP-SL Voss Technical WBS

2.3 Project Timeline

The PSP-SL team will follow the timeline below - however, items are subject to change. The timeline outlines events such as general team meetings, meetings or teleconferences with NASA officials, launch opportunities, deadlines, and miscellaneous events.

Date	Event	Date	Event
08/19/2020	NASA 2020 Student Launch Handbook Released	01/19/2021	Purdue Spring Semester Begins
08/24/2020	Purdue Fall Semester Begins	01/24/2021	Purdue SL general meeting
08/30/2020	Purdue SL general meeting	01/26/2021	CDR video teleconferences end
09/6/2020	Purdue SL general meeting	01/27/2021	FRR Q&A
09/13/2020	Purdue SL general meeting	01/31/2021	Purdue SL general meeting
09/20/2020	Purdue SL general meeting	02/07/2021	Purdue SL general meeting
09/21/2020	Proposal due to project office by 3PM CDT	02/14/2021	Purdue SL general meeting
09/27/2020	Purdue SL general meeting	02/21/2021	Purdue SL general meeting
10/01/2020	Awarded proposals announced	02/28/2021	Purdue SL general meeting
10/04/2020	Purdue SL general meeting	03/07/2021	Purdue SL general meeting
10/07/2020	Kickoff, PDR Q&A	03/08/2021	Final day for full-scale launch/Vehicle Demonstration Flight
10/11/2020	Purdue SL general meeting	03/08/2021	Vehicle Demonstration Flight data reported to NASA
10/18/2020	Purdue SL general meeting	03/08/2021	FRR reports, slides, and flysheet posted online by 8AM CDT
10/21/2020	Social Media presence established, handles sent to project office by 8AM CDT	03/11/2021	FRR video teleconferences start
10/24/2020	Purdue Space Day	03/14/2021	Purdue SL general meeting
10/25/2020	Purdue SL general meeting	03/21/2021	Purdue SL general meeting
11/01/2020	Purdue SL general meeting	03/28/2021	Purdue SL general meeting
11/02/2020	PDR reports, slides, and flysheet posted online by 8AM CDT	03/29/2021	FRR video teleconferences end
11/03/2020	PDR video teleconferences start	03/29/2021	Payload Demo Flight/Vehicle Demonstration Re-flight deadlines
11/08/2020	Purdue SL general meeting	03/29/2021	FRR Addendum submitted to NASA by 8:00 AM CDT (if needed)
11/15/2020	Purdue SL general meeting	03/30/2021	Launch window opens for teams not traveling to launch week (PLAR is due within 14 days of the launch)
11/22/2020	Purdue SL general meeting	03/31/2021	Launch Week Q&A

11/22/2020	PDR video teleconferences end	04/04/2021	Purdue SL general meeting
11/23/2020	CDR Q&A	04/07/2021	Travel to Huntsville, Alabama
11/24/2020	In-person instruction ends for Fall semester	04/07/2021	OPTIONAL – LRR for teams arriving early
11/25/2020-11/28/2020	THANKSGIVING BREAK	04/04/2021	Official Launch Week Kickoff and activities
12/06/2020	Purdue SL general meeting	04/08/2021	Official LRRs if not done on 04/07
12/12/2020-01/19/2021	WINTER BREAK	04/09/2021	Launch week activities
12/13/2020	Purdue SL general meeting	04/10/2021	Launch day
12/20/2020	Purdue SL general meeting	04/10/2021	Awards Ceremony
01/04/2021	Final day for subscale launch	04/11/2021	Backup launch day
01/04/2021	Final motor choice made for launch	04/18/2021	Purdue SL general meeting
01/04/2021	CDR reports, slides and flysheet posted online by 8AM CDT	04/25/2021	Purdue SL general meeting
01/07/2021	CDR video teleconferences start	04/27/2021	PLAR posted online by 8AM CDT for Teams Traveling to Launch Week
01/10/2021	Purdue SL general meeting	05/02/2021	Launch window closes for teams not traveling to launch week (PLAR is due within 14 days of the launch)
01/17/2021	Purdue SL general meeting		

Table 2.3 PSP-SL Timeline

2.4 Project Business Plan

2.4.1 Project Budget

This year's planned total budget is $12,300. This is broken down into Full-Scale Rocket: $3000, Subscale Rocket: $250, Avionics: $900, Payload: $2500, Branding: $550, Travel: $4000, AeroBraking Control System: $1000, and Outreach: $100. The team currently is starting the season with $5666.07 which has carried over from the previous season. The team has implemented an emergency fund, should something go wrong, which will allow the team to purchase new materials without great economic issues. This emergency fund will consist of 15% of the original budget, making this competition season's emergency fund to be $1845. This should allow the team to have a buffer if anything unexpected comes up. With the addition of this emergency fund, the total amount needed for the year is $14,145.

2.4.2 Project Funding Plan

This year, the team has started the season with 40% of the total budget, and the remaining funding will likely come from Purdue Department Heads. These asks will occur before October, so the team hopes to have at least 75% of the budget acquired before November. The remaining 25% shall be evaluated and be acquired through a crowdfunding campaign if not entirely covered by the department heads.

2.5 Team Sustainability Plan

2.5.1 Talent Sustainability

The team understands that to be successful in both the competition and in its goal of giving Purdue students hands-on experience in aerospace, it must constantly educate and support new members. Due to COVID-19 restrictions, this education and support will be done virtually, through recorded or live-streamed tutorials.

2.5.2 Financial Sustainability

The team plans to always have additional funds available should something go wrong during the project. With experience from previous competition seasons, the team has a great appreciation for the value that goes into the rocket and understands the importance of fundraising at least an additional 15% of the original budget for unplanned incidents. This additional funding will carry over year to year, and help the team start with a decent amount of fundraising. This also allows the team to continue with the competition should there be an unplanned incident requiring the purchase of new materials.

2.5.3 Ongoing Partnerships

Along with the team's financial sponsors, the team continues to partner with NAR 88988, TRA 6839 to support rocketry in the local area.

3 Safety Information

3.1 Safety Officer Identification and Responsibilities

The Safety Officer for the 2020 - 2021 PSP-SL team will be Andrew Darmody. As Safety Officer, this team member is responsible for the safety and well-being of all personnel throughout the competition. This involves ensuring that all members are constantly aware of the safety plans, emergency procedures, necessary precautions, and personal protective equipment (PPE) required to perform project activities. Once procedures and plans are set by the team, any amendments to them must be authorized by the Safety Officer. The Safety Officer will review operation plans for all manufacturing and assembly meetings. It will also be required of the Safety Officer to have a working knowledge of all facility, equipment, and organizational rules set outside the realm of the team and personnel. This includes adherence to the NAR and TRA high power rocketry safety codes, NFPA 1127, and Federal Aviation Regulations 14 CFR. The Safety Officer will be responsible for the following:

- Creating and maintaining risk analysis matrices to be used throughout the competition
- Creating preflight, flight, and postflight checklists to be carried out
- Creating and enforcing the team's safety plans and procedures
- Ensuring that all team members are properly trained and supervised to be carrying out their current task
- Ensuring that all team members are wearing appropriate PPE for the task they are conducting
- Ensuring that all team members are following proper operating procedures for using facilities and equipment
- Enforcing all laws and regulations set for the team by authorities and governing bodies
- Attending all build sessions and launches
- Attending all educational opportunities or events where legal minors are expected to be present

3.2 Safety Plan

3.2.1 Safety Plan Summary

Integral to any successful mission is safety. To ensure a safe working environment, both when manufacturing and launching a rocket, carefully considered guidelines should be laid out ahead of time, governing operations such as construction, material handling, and transportation, and launch procedures. The following pages will outline the team's safety plan and lay the groundwork for creating a safe working environment for all team members.

3.2.2 Material Safety

Hazardous materials that will be used on this project may include black powder, ammonium perchlorate composite propellant, pre-made motor igniters, and irritants such as fiberglass and carbon fiber. Hazardous materials will be stored off-site, within the Zucrow Labs research facilities adjacent to the Purdue University Airport. The team's faculty mentor will be solely responsible for handling the acquisition, transportation, and storage of the hazardous materials involved in this project. All team members will be given a briefing on the plan to properly purchase, store, transport, and use hazardous materials by the safety officer before any such operation. This safety brief will provide knowledge of and access to Material Safety Data Sheets (MSDS) for all potentially hazardous substances which will be used on the project and will ensure the use of proper PPE when handling hazardous materials. The MSDS must be read before working with the respective substances.

3.2.3 Manufacturing Safety

Safety documents will outline requirements for power tool and machine usage, hazardous material handling, and personal protective equipment use. Safety documents will also outline safety procedures when dealing with high voltage or explosive components and will be written in compliance with any relevant state, local, and federal laws, as well as applicable workplace safety standards. All team members will be briefed before using any tool or piece of equipment located at any facility open to the team for the machining and testing of the launch vehicle.

3.2.4 Operational Safety

Before any operations which may present a risk to the safety or wellbeing of any team member, facility, or the environment, a comprehensive list of safety instructions, procedures, and requirements will be written. These requirements will be understood and followed by all students wishing to participate in the aforementioned operations, including but not limited to testing, construction, and launching.

3.2.5 Biological Safety

All team members, as students of Purdue University, must follow the COVID-19 protocols defined by the Protect Purdue Pledge and the extended safety measures taken by the team. All club meetings will be held online, and all construction and testing operations that require in-person participation will require extra safety precautions. A rotation of no more than five people will be used in construction and testing operations in all of the facilities the team has access to.

3.2.6 Energetics Handling Protocols

All motor and energetic device purchasing, assembly, handling, and transport will be performed by the project mentor including but not limited to, motors and ignition devices. In addition to the regulations set forth by the NAR/TRA, all state, local, and federal laws will be followed. The team's mentor, Victor Barlow, will maintain possession and provide transportation for any such regulated devices to launch activities/demonstrations. Installation of the motor will only be conducted by the team mentor due to NAR/TRA regulations. The Avionics and Recovery sub-team will pack parachute ejection charges under the supervision of the Safety Officer.

3.3 Regulating Agency Compliance

3.3.1 NAR/TRA

All team members are expected to abide by the operational procedures outlined by the NAR/TRA. These rules include governing procedures regarding but not limited to material usage, ignition operations, launch procedures, and rocket size. A complete list of NAR/TRA safety regulations can be found at the following locations:

NAR Safety Code:
https://www.nar.org/safety-information/high-power-rocket-safety-code/
Tripoli Safety Code: http://www.tripoli.org/Portals/1/Documents/Safety%20Code/HighPowerSafetyCode%20-%202017.pdf

During all briefings, the safety team will emphasize these codes and ensure compliance throughout the team.

3.3.2 FAA

The team will abide by the rules and guidelines set by the FAA for high powered rocketry. This includes the FAA Form 7711-2 (8-08), which will be submitted at least 45 days before the launch.

3.4 Safety and Compliance Briefing Plans

Before the first construction meeting, the team will hold a short briefing on basic launch vehicle construction safety in which all team members will be instructed on fundamental safety procedures (e.g. wearing protective eyewear during construction), as well as how to use lab equipment and recognize any potential hazards associated with it. In addition, the team will compose a checklist before all launches detailing the exact procedures that must be performed to ensure success and maximize launch safety. All team members will receive a briefing about basic launch safety and potential hazards.

Briefings will be carried out before major events and launches. A dedicated seminar during a team meeting will initially be provided to students on hazard recognition and accident avoidance to promote safety and keep students aware of the potential threats that exist. Historical and fictional examples will be generated to exemplify potential hazards and avoidance. Students will be required to sign a form acknowledging the potential threats as described at the seminar. Students must sign the form to ensure that safety standards are met and understood. The briefings and seminars will be recorded and shared throughout the team so that all members have permanent access. Dedicated pre-launch briefings will be presented and must be acknowledged to attend a launch. Additional briefings and seminars will similarly be posted and required to ensure problems or concerns are addressed.

Examples of briefing topics include:

- Lawful launch procedures which comply with FAA regulations, federal laws, and Purdue University policies
- What to do if the launch vehicle poses a threat at the time of launch
- What to do if the launch vehicle poses a threat during the flight
- What to do if the launch vehicle causes injury to students or personnel
- What to do if the launch vehicle veers off the calculated course
- What to do in the case of unpredicted weather on the day of the launch

3.5 Team Safety Statement

3.5.1 Description

The team safety statement is crucial to aligning the interests of the team in a manner that promotes safety in every operation. The following statement acts as a structure to the tenets of safety that the Purdue Space Program upholds.

3.5.2 Statement

The following statement will be printed out for all team members to sign:

As a member of the Purdue Space Program Student Launch (PSP-SL) team, I agree to:

1. Adhere to any and all relevant local, state, and federal laws and regulations.
2. Adhere to the NAR High Power Rocket Safety Code.
3. Comply with all instructions given to me by the team mentor, the Safety Officer, and by any Range Safety Officers.
4. Wear appropriate personal protective equipment whenever constructing or operating the launch vehicle.
5. Understand the hazards of each material or machine I plan to use or operate.
6. Never misuse the materials or equipment I will work with in this project for any reason.
7. Acknowledge that the team will not be permitted to fly a rocket until the team mentor has reviewed the design.
8. Recognize that the team is expected to comply with established amateur rocketry design and safety guidelines as determined by the team's mentor.
9. Acknowledge that the team mentor, the Safety Officer, and any Range Safety Officers reserve the right to approve or deny the flight of the launch vehicle for any relevant reason.
10. Acknowledge that failure to comply with any of the aforementioned safety regulations is cause for removal from the team.

My signature confirms that I have read and understood the aforementioned agreements. I recognize that any violation of these agreements may result in being unable to participate in Project Voss or the PSP-SL program.

Name____

Signature____ Date_______________

3.6 Risk Assessment Table

The seriousness of a risk will be evaluated by two criteria: the likelihood of an event to occur and the severity of the event should it happen or fail to be prevented. Categories of likelihoods and impacts are discussed below:

3.6.1 Likelihood Of Event

Category	Value	Gauge
Remote	1	Extremely unlikely to occur
Unlikely	2	Unlikely to occur
Possible	3	Average odds to occur
Likely	4	Above-average likelihood to occur
Very Likely	5	Very likely to occur/has occurred previously

Table 3.1

3.6.2 Severity Of Event

Category	Value	Health and Personal Safety	Equipment	Environment	Flight Readiness
Negligible	A	Negligible injury. No first aid required. No recovery time needed.	Minimal and negligible damage to equipment or facility. No required correction.	Negligible damage. No repair or recovery needed.	No flight readiness disruption.
Minor	B	Minor injury. Requires band-aid or less to treat. 5-10 minutes of recovery time required.	Minor damage. Consumable equipment element requires repair.	Minor environmental impact. Damage is focused on a small area. Little to no repair or recovery needed. Outside assistance not required.	Flight proceeds with caution.
Moderate	C	Moderate injury. Gauze or wrapping required. Recovery time up to one day.	Reversible equipment failure. Non-consumable element requires repair. Outside assistance not required.	Reversible environmental damage. Personal injuries unlikely. Outside assistance recommended. Able to be contained within team.	Flight delayed until effects are reversed.
Major	D	Serious injury. Hospital visit required. No permanent loss of function to any body part.	Total machine failure. Outside assistance required to repair.	Serious but reversible environmental damage. Outside assistance required. Personal injuries possible.	Flight on hold until system is removed.

Disastrous	F	Life-threatening or debilitating injury. Immediate hospital visit required. Permanent deformation or loss of bodily function.	Irreversible failure. Total machine loss. New equipment required.	Serious irreversible environmental damage. Personal injuries likely. Immediate outside assistance required. Area must be vacated. Needs to be reported to a relevant environmental agency.	Flight scrubbed or completely destroyed.

Table 3.2

3.6.3 Risk Analysis Methods

By cross examining the likelihood of an event with the impact it would have if it occurred, a total risk can be determined and is which is detailed in the table below. The color code displayed is as follows:

- Green: Minimal risk
- Yellow: Low risk
- Orange: Medium risk
- Light red: High risk
- Dark red: Very high risk

		Severity				
		Negligible (A)	Minor (B)	Moderate (C)	Major (D)	Disastrous (F)
Likelihood	Remote (1)	A1	B1	C1	D1	F1
	Unlikely (2)	A2	B2	C2	D2	F2
	Possible (3)	A3	B3	C3	D3	F3
	Likely (4)	A4	B4	C4	D4	F4
	Very Likely (5)	A5	B5	C5	D5	F5

Table 3.3

3.6.3.1 Personnel Hazards

The following are personnel hazards identified in the development stage of designing and manufacturing prototypes for the systems of the launch vehicle and payload. Additional hazards will be added as the team and the competition moves into later design stages.

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**	**Verification**	**Post Mitigation Risk**
Contact with Airborne Chemical Debris	3 (Airborne particulate debris)	B (Minor burns, abrasions)	B3, Low	Wear appropriate PPE such as gloves, lab coats and breath masks, wash immediately with water if contact is made.	Safety Team will verify with each participating member that appropriate PPE is worn.	B1, Minimal
Direct Contact with Hazardous Chemicals	3 (Chemical spills, improper use of chemicals)	C (Moderate burns, abrasions)	C3, Medium	Wear appropriate PPE such as gloves or lab coats, wash with water.	Safety Team will verify with each participating member that appropriate PPE is worn.	C1, Low
Dust or Chemical Inhalation	3 (Airborne particulate debris)	C (Short to long-term respiratory damage)	C3, Medium	Wear appropriate PPE or respirator, work in a well-ventilated area.	Safety Team will verify with each participating member that appropriate PPE is worn.	C1, Low
Dehydration	3 (Failure to drink adequate amounts of water)	C (Exhaustion and possible hospitalization in worst case scenario)	C3, Medium	Ensure all members have access to water.	Mandatory water breaks will be held every hour where no work may be done during that period.	C1, Low
Electrocution	2 (Improper use of equipment, static build-up)	D (Possible explosion, destruction of electrical tools or components, possible severe harm to personnel)	D2, Medium	Give labels to all high voltage equipment warning of their danger; ground oneself when working with high-voltage equipment.	Pre-operation inspection will be done by safety officer to ensure no open electrical components prior to high-voltage event. Allow only one member to work on electrical components at a time with proper PPE and student supervising.	D1, Medium
Entanglement with Construction Machines	3 (Loose hair, clothing, or jewelry)	F (Severe injury, death)	F3, High	Secure loose hair, clothing, and jewelry; wear appropriate PPE.	No physical contact allowed without call out before use to make sure PPE is worn. Make sure rules followed as set forth by machining rules.	F1, Medium

Epoxy Contact	3 (Resin Spill, Carelessness)	C (Exposure to Irritant)	C3, Medium	Wear appropriate PPE such as gloves or lab coats, wash with water.	Safety officer or approved safety team member will verify proper PPE is used before and during epoxy handling.	C1, Low
Eye Irritation	3 (Airborne particulate debris)	B (Temporary eye irritation)	B3, Low	Wear appropriate PPE or protective eyewear, wash with water if contact is made.	Guaranty PPE worn at all times during manufacturing. Call out before use to make sure PPE is worn by surrounding team members.	B1, Low
Hearing Damage	4 (Close proximity to loud noises)	C (Long term hearing loss)	C4, Medium	Wear appropriate PPE such as earmuffs when using power tools.	PPE equipment check must be done by a safety team member before conducting construction.	C1, Low
Physical Contact with Heat Sources	3 (Contact with launch vehicle parts which were recently worked with, improper use of soldering iron or other construction tools)	C (Moderate to severe burns)	C3, Medium	Wear appropriate PPE, turn off all construction tools when not in use, be aware of the safety hazard that parts which were recently worked with present.	Confirm that appropriate PPE is being used. Make sure that all team members are informed of the hazard.	C1, Low
Physical Contact with Falling Construction Tools or Materials	3 (Materials which were not returned to a safe location after use)	F (Bruising, cuts, lacerations, possible severe physical injury)	F3, High	Brief personnel on proper clean-up procedures, wear shoes that cover the toes.	Clean workspace every time after use. Create a checklist of where to put items after use.	F1, Medium
Power Tool Cuts, Lacerations, and Injuries	3 (Carelessness)	F (Possible Hospitalization)	F3, Medium	Secure loose hair, clothing, and jewelry; wear appropriate PPE; brief personnel on proper construction procedures.	No contact allowed without call out before use to make sure PPE worn. Make sure rules followed as set forth by machining rules.	F1, Medium
Tripping Hazards	3 (Materials which were not returned to a safe location after use, loose cords on or above the ground during construction processes)	C (Bruising, abrasions, possible severe harm if tripping into construction equipment)	C3, Medium	Brief personnel on proper clean-up procedures, tape loose cords or wires to the ground if they must cross a path which is used by personnel.	Have a clean-up sheet for workspace occupants to confirm everything is placed where it should be.	C1, Low
Workplace Fire	2 (Unplanned ignition of flammable substance,	F (Severe burns, loss of workspace,	F2, High	Have fire suppression systems nearby,	Make sure all members are updated on the workplace fire	F1, High

	overheated workplace, improper use or supervision of heating elements, or improper wiring)	irreversible damage to project)		prohibit open flames, and store energetic devices in Type 4 magazines as stated in CFR 27 part 55.	safety protocols. Have lists of all required fire suppression system accounted for and found near the area of work.	

3.6.3.2 Failure Modes and Effects Analysis

The following is Failure Modes and Effects Analysis identified in the development stage of designing and manufacturing prototypes for the systems of the launch vehicle and payload. Additional entries will be added as the team and the competition moves into later design stages. Some severity entries in this analysis effects only launch operations but can be mitigated in the design and prototyping stages of launch vehicle and payload development

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation	Verification	Post Mitigation Risk
Broken Fastener	2 (Excessive force)	F (Ballistic trajectory)	F2, Medium	Use fasteners with a breaking strength safety factor of 2.	Conduct stress tests on fasteners before launch day to confirm that they meet force requirements.	F1, Medium
Thrust Structure Failure	2 (Excessive force from motor, poor construction)	F (Partial or total destruction of vehicle, ballistic trajectory)	F2, Medium	Use appropriate centering rings according to mathematical and physical flight analyses, make use of reliable building techniques, confirm analyses with test launches.	Centering ring will be inspected prior to launch as part of launch operations	F1, Low
Battery Overcharge	3 (Unsupervised/undocumented charge)	C (Destruction of battery)	C3, Medium	Ensure batteries are documented and supervised if charging.	Ensure alarms set and other individuals are aware of batteries charging.	C1, Low
Destruction of Bulkheads	2 (Poor construction or improper bulkheads chosen which cannot withstand launch forces, faulty stress modeling)	F (Partial or total destruction of vehicle, ballistic trajectory)	F2, High	Use appropriate materials according to extensive high-stress mathematical and physical analyses, make use of reliable building techniques, run stability tests, confirm analyses with test launches.	Bulkheads will be visually inspected for damage prior to launch.	F1, Medium

Damaged Nose Cone	2 (Poor construction, damage from previous flights, poor storage, or transportation)	C (Lower launch vehicle stability, possible deviations from flight path)	C3, Medium	Check the nose cone for damage before and after each launch, choose a nose cone which is strong enough to withstand launch forces according to mathematical and physical flight simulations, confirm choice of nose cone with subscale launches.	Nose cones will be inspected and repaired before and after each launch in order to make sure they are up to launch standards.	C1, Low
Motor Tube Angled Incorrectly	2 (Poor construction, damage from previous flights, poor storage, or transportation)	D (Lower launch vehicle stability, launch vehicle does not follow desired flight path well)	D2, Medium	Ensure proper measurements and alignments are made during construction, ensure there is no rush to attach the motor tube, double-check the alignment of the motor before each flight, test that the desired motor alignment is correct with subscale flights.	Measurements will be made at 4 rotational points around the motor tube to ensure equal distance from edge to launch vehicle edge coupling.	D1, Medium
Forgotten or Lost Components	3 (Carelessness with launch vehicle components, failure to take note of inventory before attempting to launch)	D (Launch vehicle does not launch at the desired launch time)	D3, Medium	Have spares for components which are small and easy to lose, have an inventory of all launch vehicle parts to be checked before moving the launch vehicle to a launch site.	Ensure at least two team members double check that everything in the launch vehicle inventory will be taken to the launch site and is accounted for upon arrival.	D1, Medium
Propellant Explosion	1 (Faulty motor preparation, poor quality of propellant, damage to motor)	5 (Catastrophic destruction of vehicle, possible harm to bystanders)	F1, Medium	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member.	A team member will be designated to observe the motor preparation procedure, only approved propellant sources will be used.	F1, Medium
Power Loss to Avionics Bay	3 (Faulty wiring, battery failure, poor setup of wiring causes a	F (Objectives not met, failure to	F3, High	Test the reliability of the wiring and batteries through	Continuity checks will be used, visible wires	F1, Medium

and/or Payload	connection to come undone, forgotten connection)	correctly trigger ejection charges)		subscale flights, check batteries and connections before flight.	will be inspected for nicks or damage prior to launch.	
Avionics Bay Fire	2 (Faulty wiring, battery failure, poor setup of wiring, adverse weather)	F (May be disqualified if objectives are not met, possible failure to trigger ejection charges, damage to internal launch vehicle components)	F2, High	Thermal protection of avionics bay, do not overload avionics bay with wiring, only purchase avionics and payload equipment from reliable sources, check avionics bay and payload performance with test launches.	Make sure no wires are exposed and that the avionics bay is sufficiently protected from heat.	F1, Medium
Battery Leakage/ Combustion	2 (Battery compartment becomes punctured)	C (Loss of battery, damage to personnel or materials)	C2, Low	Check battery integrity before each launch.	Include checking battery condition in pre-launch checklist.	C1, Low
Improper Separation of Vehicle Sections	5 (Quick Links meant to attach parachute to vehicle unfastened)	F (Complete or unrepairable damage to vehicle, payload, and avionics equipment)	F5, Very High	Ensure quality witness procedures are completed on all parts of vehicle assembly for testing and launches.	Include quality witness procedures in testing and launch checklists.	F1, Medium

3.6.3.3 Environmental Hazards

The following are environmental hazards identified in the development stage of designing and manufacturing prototypes for the systems of the launch vehicle and payload. Additional hazards will be added as the team and the competition moves into later design stages.

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation	Verification	Post Mitigation Risk
Landscape	3 (Trees, brush, water, power lines, wildlife)	F (Inability to recover launch vehicle, payload crash)	F3, High	Angle launch vehicle into wind as necessary to reduce drift and avoid hazards.	Inspect launch site before launch to verify that it is a suitable area to launch.	F1, Low
Humidity	3 (Climate, poor forecast)	A (Rust on metallic components)	A3, Low	Use as little metal as possible. Store indoors.	Check weather beforehand for ideal launch time.	A3, Low
Winds	3 (Poor forecast)	D (Inability to launch, excessive drift, payload drift/control issues)	D3, Medium	Angle into wind as necessary and abort if wind exceeds 20 mph.	Check weather beforehand for ideal launch time.	A3, Low

Rain/Storms	3 (Poor forecast)	C (Damage to electrical components)	C3, Medium	Keep launch vehicle away from moisture/elements prior to launch. Cover any exposed electrical components.	Visual inspection of electrical components to ensure dry surface.	A3, Low
Low Visibility	2 (Fog)	D (Inability to maintain visual contact with the launch vehicle)	D2, Medium	Postpone launch if horizontal visibility is less than 5 miles, or if there is a cloud ceiling below the expected apogee with a 20% safety factor.	Check weather forecast for visibility conditions.	D1, Low
High Temperatures	3 (Poor forecast)	C (Heat stroke or damage to electrical components)	C3, Medium	Keep launch vehicle in shaded area until before launch. Provide shaded area to team members as needed.	Check weather beforehand for ideal launch time. Contact will be made with launch site ahead of time to ensure presence of shaded structure, or some structure will be brought by the team.	A3, Low
Low Temperatures	3 (Poor forecast)	C (Frostbite, frost on ground, ice on vehicle, clogging of vehicle ventilation, change in launch vehicle rigidity and mass, higher drag force on launch vehicle)	C3, Medium	Ensure team is wearing appropriate clothing for extended periods of time in cold environments, keep the launch vehicle at room temperature or bundled in materials which hold in heat, if ice appears anywhere on the launch vehicle do not launch and return it to a warm location. Provide team members with warm environment above 60°F.	Ensure team is notified through email or instant message of all weather on day of launch or manufacturing to wear proper clothing. Do not launch if weather is below designed intent of launch vehicle. Team members exhibiting signs of frostbite will be escorted to designated warm space (heated interior space or vehicle)	A3, Low
Pollution from Exhaust	5 (Combustion of APCP motors)	A (Small amounts of greenhouse gasses emitted)	A5, Medium	Use only launch vehicle motors approved for use by the National Association of launch vehicle, Canadian Association of launch vehicle, or Tripoli Rocketry Association.	Launch vehicle motors in consideration will be checked by a safety team member to ensure compliance.	A5, Medium
Pollution from Vehicle	2 (Loss of components from vehicle)	C (Materials degrade extremely slowly, possible harm to	C2, Low	Properly fasten all components. Scavenge for fallen parts after launch is completed.	Inspect the securements of components before launch. Have designated clean up team for each launch.	C1, Low

		wildlife or water contamination)				
Pollution from Team Members	2 (Failed disposal of litter, improper cleanup procedures, members walk through important plant life, farming fields, sod, etc.)	D (Litter may degrade extremely slowly; wildlife may consume harmful litter)	D2, Medium	Brief team members on proper cleanup procedures. Foster a mindset of leaving no trace at launch sites. Only the minimum number of required team members should retrieve the launch vehicle.	Follow societal standards and leave site cleaner than was found. Make sure disposable equipment is kept track of and guaranteed to remain at designated locations, designated waste disposal will be provided.	D1, Medium
Collisions with Man-made Structures	2 (Failure to properly predict trajectory, failure to choose an appropriate launch area)	F (Damage to public property or private property not owned by the team, damage to team equipment)	F2, High	Do not launch under adverse conditions which may affect the course of the launch vehicle (See Wind). Run a large number of tests which analyze the launch vehicle's trajectory mathematically and physically. Choose a launch area which is not close to civilization. Follow launch procedures closely.	Run tests to analyze and estimate the launch vehicle's trajectory so that the launch vehicle's path is known to the team. Do not launch under adverse weather conditions (See Wind) and choose a launch location which allows for open space to avoid accidents.	F1, Medium
Wildlife Contact with Launch Vehicle	1 (Failure to accurately predict trajectory, unexpected appearance of wildlife, poor choice of launch area)	D (Damage to vehicle components, damage to wildlife)	D1, Medium	Launch in an open area with high visibility. Be aware of the surroundings when choosing a launch area and launching.	Perform visual sweep of launch field to ensure no wildlife is present. Gently encourage wildlife displacement if any is present: if cannot be displaced, relocate launch location.	D1, Medium
Wildlife Contact with Launch Pad	1 (Failure to monitor the launch pad, poor choice of launch area)	D (Possible inability to launch the launch vehicle, unpredictable launch behavior or trajectory)	D1, Medium	Have at least one team member monitoring the launch pad at all times. Launch in an open area with high visibility. Be aware of the surroundings when choosing a launch area and launching. If animals tamper with the launchpad do not launch.	Perform visual sweep of launch field to ensure no wildlife is present. Gently encourage wildlife displacement if any is present: if cannot be displaced, relocate launch location.	D1, Medium

Battery Leakage	3 (Absence of or damage to battery casing causing puncture or cracking)	D (Possible toxic acid leak, heavy metal contamination)	D3, Medium	Batteries will be individually enclosed in plastic casing. Parachutes will be selected to reduce landing kinetic energy below levels that will damage the casing.	Inspect battery casing prior to launch to ensure the battery is properly protected and unlikely to become punctured.	D1, Medium
Fire	3 (Exhaust caused by launch vehicle engine)	F (Possible spread of wildfire, burns to personnel)	F3, High	Ground will be cleared per NAR standard. Fire extinguishers will be on hand. Flame retardant tarp will be deployed to prevent catching fire. Launch will not be performed on dry brush.	Inspection by safety officer will be performed to ensure compliance with NAR safety standard on minimum clear area. Launch site will be sprayed with water as necessary.	F1, Medium
Unstable Ground	2 (Poor choice of launch site, inclement weather creating mud or softening the ground)	C (Personnel may slip or fall and damage equipment or themselves, launch pad may sink into the ground and cause an unexpected trajectory)	C2, Low	A rigid system which can be used to support the launch pad, such as wooden planks (if needed to reduce their flammability, they may be wetted directly underneath the rocket), choice of a launch site which has rigid ground, observation of launch pad condition shortly before launch.	Use designated launch areas as designated to which must strictly follow this rule to be approved.	A1, Minimal

3.6.3.4 Project Hazards

The following are project hazards identified in the development stage of designing and manufacturing prototypes for the systems of the launch vehicle and payload. Additional hazards may be added as the team and the competition moves into later design stages.

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**	**Verification**	**Post Mitigation Risk**
Improper Funding	3 (Lack of revenue)	F (Inability to purchase parts)	F3, High	Create and execute a detailed funding plan properly, minimize excessive spending by having multiple members check the necessity of purchases	The Business Team Lead will coordinate funding acquisition and management with the team's financial account with Purdue University.	F1, Medium
Failure to Receive Parts	2 (Shipping delays, out of stock orders)	F (Cannot construct and fly vehicle)	F2, High	Order parts while in stock well in	Project Management will ensure parts are ordered	F1, Medium

				advance of needed date	ahead of construction and testing operations.	
Damage to or Loss of Parts	2 (Failure during testing, improper part care during construction, transportation, or launch)	F (Cannot construct or fly vehicle without spare parts)	F2, High	Have extra parts on hand in case parts need to be replaced, follow all safety procedures for transportation, launch, and construction	Extra parts will be ordered for all needed systems of the launch vehicle and payload.	F1, Medium
Rushed Work	2 (Rapidly approaching deadlines, unreasonable schedule expectations)	D (Threats of failure during testing or the final launch due to a lower quality of construction and less attention paid to test data)	D2, Medium	Set deadlines which both keep the project moving at a reasonable pace and leave room for unforeseen circumstances	Project Management will coordinate with the Sub team Leads to ensure work is completed on time.	D1, Medium
Major Testing Failure	2 (Improper construction of the rocket, insufficient data used before creating the rocket's design)	F (Damage to vehicle parts, possible disqualification from the project due to a lack of subscale flight data, an increase in budget for buying new materials, delay in project completion)	F2, High	Only include reliable elements in the design which have been confirmed to work through prior designs or extensive mathematical and physical analysis	The Safety Team Lead will ensure the other sub teams design systems with a proper safety factor and safety considerations.	F1, Medium
Unavailable Test Launch Area	2 (Failure to locate a proper area to launch subscale rockets for testing, failure to receive an FAA waiver for the test launch)	F (Disqualification from the project due to a lack of subscale flight data)	F2, High	Secure a reliable test launch area and FAA waiver well in advance of the dates on which test launch data is required	The Safety Team Lead will submit the waiver to the FAA as soon as a launch day is decided.	F1, Medium
Loss or Unavailability of Work Area	1 (Construction, building hazards,	D (Temporary inability to construct vehicle)	D1, Medium	Follow work area regulations and	Project Management and the Sub team Leads will ensure the proper	D1, Medium

	loss of lab privileges)			have secondary spaces available	use of the facilities the team has access to.	
Failure in Construction Equipment	1 (Improper long-term maintenance of construction equipment, improper use or storage of equipment)	C (Possible long-term delay in construction)	C1, Low	Ensure proper maintenance and use of construction equipment and have backup equipment which can be used in case of an equipment breakdown	Each team member shall be responsible for maintaining the longevity of the machines used in construction and testing operations by following part 6 of the Safety Statement found in Section 3.5.2 of this proposal.	C1, Low
Insufficient Transportation	1 (Insufficient funding or space available to bring all project members to launch sites or workplace)	C (Loss of labor force, team members lose knowledge of what is happening with the project, low attendance to the final launch)	C1, Low	Organize and budget for transportation early and keep track of dates on which large amount of transportation are needed	Project Management and the Sub team Leads will be responsible for communicating which team members need transportation to team events and what transportation is available to the team.	C1, Low

4 Technical Design

4.1 Vehicle Design

4.1.1 Airframe Design

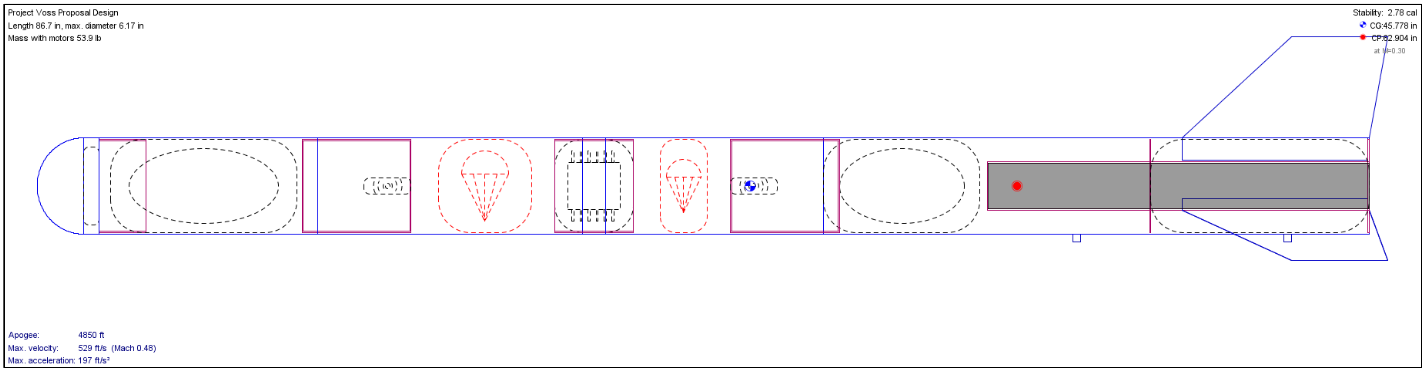

Figure 4.1.1: Launch Vehicle Design

Launch Vehicle Length [in]	86.7
Launch Vehicle Outer Diameter [in]	6.17
GLOW [lbm]	53.9
Dry Weight [lbm]	48.6
Average Stability [Cal]	3.78
Launch Stability [Cal]	2.1
Maximum Velocity [Mach]	.48
Apogee (ft)	4850

Table 4.1.1: Launch Vehicle Design Parameters

The overall design characteristics of the launch vehicle are displayed in Figure 4.1.1. The vehicle consists of three independent sections and 4 total fiberglass tubes. The 3 independent sections are as follows:

4.1.1.1 Payload Section

This section consists of the Nose Cone, a fiberglass tube, and a coupler connecting to the avionics section. All couplers in the vehicle will have the NASA required 1cal (6in) of overlap at separation points. To save weight and enable assembly/disassembly, the fixed side of all vehicle couplers will be attached using a radial bolt circle. This section is tethered to the recovery section via the main parachute shock cord.

4.1.1.2 Recovery Section

The avionics section consists of two fiberglass tubes and the avionics bay and also contains the two recovery parachutes. The two fiberglass tubes are joined to the avionics bay for the duration of the flight by radial bolt circles on the avionics coupler.

4.1.1.3 Booster Section

The motor section consists of a fiberglass tube, the ABCS, the motor, the thrust structure, and the fins. This section is tethered to the recovery section via the drogue parachute shock cord.

4.1.2 Notable Design Modifications

For the competition this year, PSP-SL has discussed and composed some notable design features to implement into the launch vehicle.

4.1.2.1.1 Nose Cone Selection

The nose cone this year has been selected to have a much lower fineness ratio, resulting in a blunter shape. Initial calculations and simulations suggest that this change is acceptable due to the low Mach number of the vehicle, and provides an efficiency gain due to the reduced vehicle mass and skin drag. This change is possible this year as the payload is unlikely to require a large nose cone volume. Since the majority of off the shelf nose cones are for amateur rocketry where appearance is valued over performance, it is difficult to purchase a nosecone with a <4:1 aspect ratio. This means the team will have to custom manufacture the nose cone. The custom manufacture of the nose cone will also allow custom hardware to be installed in the nose cone, such as inflight cameras. Currently, the team plans to 3d print the nosecone and is considering multiple manufacturing options including FDM PETG and continuous carbon fiber reinforcement. The team will conduct numerous tests and analyses to ensure the integrity of the nose cone through launch, recovery, and landing.

4.1.2.1.2 Thrust Structure

Another main design update is a custom Thrust Structure. This structure will provide a lightweight, modular alternative to the epoxy and centering rings used on the team's previous lower airframes. The structure will be machined out of aluminum with supports for the 3 fins, a motor retention system, and attachment points to the booster section. The inclusion of the structure will alleviate previous error which occurred when attaching fins with epoxy. The epoxy drying process was slow and imprecise, leading to asymmetric fillets and overbuilt joints. This design is also completely removable from the lower airframe, allowing a variety of modifications to the vehicle after assembly, including fin swaps.

4.1.2.1.3 Avionics Bay

One last major design update it is shortening the avionics and parachute bays. The avionics team has opted to incorporate a much smaller altimeter to transmit in-flight data. This allowed the avionics team to greatly reduce the length needed for the bay, which the construction team then incorporated into the design. Both parachute bays have been permentantly attached to the avionics bay to ensure proper in-flight deployment.

4.1.3 **Projected Altitude**

The projected apogee of the launch vehicle was calculated through simulation in OpenRocket, an open source launch vehicle design program. The simulation utilizes the extended Barrowman equations with six degrees of freedom and a fourth-order Runge-Kutta differential equation approximation. The current vehicle model predicts an apogee of 4850' above ground level, utilizing a Cesaroni Technology Inc. L1115 motor. This is a buffer of 1350' over the minimum scoring altitude of 3500'. This current simulation uses upper limit mass estimations for all internal systems, including but not limited to the payload system, avionics bay, ABCS, and thrust structure. In the event the vehicle is underweighted, the ABCS will ensure the vehicle does not surpass the maximum competition altitude. Following the completion of full-scale construction, system masses will be measured, and the OpenRocket masses will be updated to match.

4.1.3.1 OpenRocket Simulation

Figure 4.1 simulates the projected flight of the launch vehicle in OpenRocket. On the graph, the Altitude, Vertical Acceleration, and Vertical Velocity are all plotted versus the time of flight. Based on the simulation, the projected apogee occurs at about T+ 20 seconds, at an altitude of just over 5000' where the drogue parachute will be deployed. This simulation was conducted under Huntsville, Alabama geographical conditions, which is at 34.7° N, 86.6° W longitude, and latitude respectively.

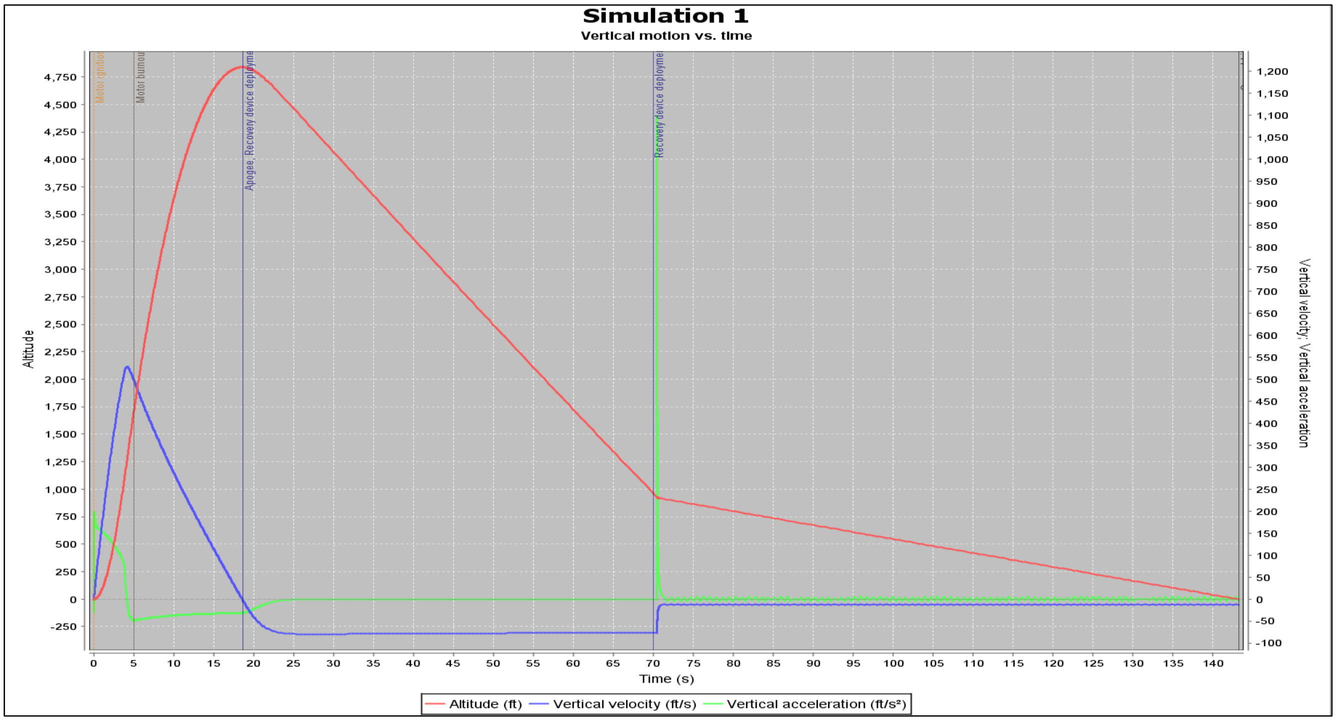

Figure 4.1.2: OpenRocket Flight Simulation

4.1.3.2 Simulink Simulation

Over the summer months, the team developed a custom vehicle trajectory simulation in Simulink format to get a feel for how different possible vehicle configurations affect flight and to also affirm the selection of the new main parachute. Developing a custom simulation parallel to OpenRocket offers a greater range of control of different parameters to achieve as much accuracy as possible, acts as verification of the OpenRocket simulation, and increases the team's knowledge of and experience with flight dynamics.

The simulation includes a multitude of useful features. Various vehicle and vehicle component characteristics such as mass, size, drag coefficient, and motor thrust, as well as environmental characteristics such as launch rail angle and wind speed, can be input and modified via a MATLAB script. The Simulink model itself utilizes these parameters and established motion equations to simulate the powered ascent, coast, descent under the drogue parachute, and descent under the main parachute phases of flight. Altitude, drift distance, vertical velocity, and horizontal velocity over the flight time are then returned to MATLAB to be plotted and analyzed.

The four critical requirements that this simulation is tasked with are to verify descent time, drift distance, rail exit velocity, and landing kinetic energy of the heaviest section of the vehicle. These values are calculated from the simulation results and compared to the numerical requirements. Pass/fail results are returned to the user to provide a very quick and simple verification.

4.1.4 **Motor Selection**

Our team is still considering a handful of motors for the full-scale launch. The top choice currently is the Cesaroni Technology Inc. L1115 motor. The L1115 is a 75mm motor, with a length of roughly 2'. Capable of providing 5015 N*s of impulse, it is one of the most powerful L-class motors within the requirements of the competition. The motor has a gross takeoff weight of 9.75lbm, expelling mass for 4.48s during the burn time, and landing with a weight of about 4.25lbm.

Long discussions have been held within the team to determine which motor would be favorable for the competition. The main reason this motor was selected is its relatively high impulse when compared to the other L-class motors. A high impulse will allow the team to obtain the predicted apogee much more easily, in cohesion with the new ABCS. Since the ABCS can only remove energy from the vehicle after burnout, the more energy the vehicle has at burnout, the larger the

ABCS' range of control. Another reason the team selected this motor is heritage. The PSP-SL team used this motor in the competition last year and had great success with it.

4.1.5 Motor and Fin Support Structure (Thrust Structure)

The Thrust Structure is a tubeless assembly designed to support the motor and the fins inside the lower airframe while maximizing flexibility with the design of the fins, and the assembly process for the lower airframe. It is designed to be made from aluminum 6061-T6 supporting G10 fiberglass Fins. The aluminum 6061-T6 material has a high yield and tensile strength making it a good choice for this application. The thrust structure assembly consists of:

- The thrust plate, which is 8mm thick, has the shape of two concentric circles, with an inner diameter of 75mm and a 95mm outer diameter. The shape includes six equally spaced spokes, three of which are in contact with the lower body tube. The thrust plate takes the load of the motor thrust and has the motor retainer and the six spars attached to it. It is fastened to the external lower body tube with three radial screws. The thrust plate transmits force from the motor thrust to the body tube.
- The motor retainer is thinner than the thrust plate and locks the motor in place. It is attached to three standoffs, normal to the retainer and the thrust plate, with three screws.
- The upper centering plate is nearly identical to the thrust plate but has screw holes on all six spokes.
- Six spars that are placed vertically in sets of two, forming three equally spaced pairs between the upper centering plate and the thrust plate. These spars also have three linearly spaced holes across their length to have the fins attached with bolts and nuts.
- Three equally spaced fins are attached by three sets of horizontal bolts and nuts to the spars.

The thrust structure has been designed so that it is assembled before it is inserted into the lower airframe tube. This means it is much easier to secure all parts in place, ensure structural symmetry, and allows for redesign or replacement of parts.

After the thrust structure is assembled, it is then inserted into the lower airframe tube from the bottom of the tube, and then secured onto the tube by the three screws onto the thrust plate and the six screws onto the upper centering plate.

Detailed Finite Element Analysis with loads more than 2x than the expected has been conducted in SolidWorks Simulation, utilizing the Static study tool. Loads on the thrust structure, included fin leading-edge aerodynamic drag loads, loads from fin tip aerodynamic lift moment, loads from the rocket motor, as well as landing impact on one fin. In none of these cases was the yield strength of aluminum 6061-T6 exceeded, and in most cases, the maximum stress was an order of magnitude below the yield strength of aluminum 6061-T6 (3.8e+04 psi). These tests verify the structural integrity of the geometry of the design and the choice of material, aluminum 6061-T6, for the thrust structure.

4.1.6 In-Flight Video Recording System

The launch vehicle will contain three cameras, facing radially, aft, and forward. The goal of such cameras is to provide information on the general flight and performance of the launch vehicle and identify any errors that are not easily visible on the ground. Many locations and configurations are being considered for location and capturing. The cameras currently being considered are the ESP32 Cam with its respective computer and the SainSmart 5MP Mini with a Raspberry Pi Zero. Both cameras are lightweight with sufficient memory capacity through microSD cards. The ESP32 has been acquired and testing for functionality, quality, and durability is being conducted. If unsuccessful the SainSmart and Raspberry Pi Zero will be acquired for further testing. The forward-facing camera is being considered for placement within the nosecone, via integration into the 3D printed nosecone itself. The integration of the forward camera in the nose cone would minimize the aerodynamic effect of the camera housing. The outward-facing camera is also being considered for nosecone placement and would likely be placed on the aft shoulder of the nosecone. Again, if in the nosecone, this camera would be integrated smoothly into the 3D printed nosecone to avoid protrusion. The possible integration of cameras in the nosecone would not only provide adequate video coverage of the flight but would also provide functional ballast in the nosecone which would increase the overall stability of the launch vehicle. The outward camera is also being considered for placement within the avionics bay of the launch vehicle. The avionics bay is also under heavy consideration for the aft-facing camera. A separate power source will have to be included in the avionics bay to support this camera. Any protrusions on the launch vehicle will be encased in a covering (likely 3D printed) to decrease the aerodynamic effect of the cameras on the vehicles flight, and the necessary calculations will be made for any protrusions forward of the burnout center of mass to prove aerodynamic insignificance.

4.2 Avionics and Recovery Design

4.2.1 Recovery Process Overview

The flight of the vehicle has four phases: powered ascent, coast, descent under the drogue parachute, and descent under the main parachute. On the pad before launch, the two altimeters will be switched on, and continuity will be verified. It will also be verified that the Avionics Ground Control Station (AGCS) can receive the GPS/live telemetry transmissions of the TeleMetrum altimeter. Then, the vehicle will be launched. At apogee, the drogue parachute will be released using a black powder ejection system (with a redundant charge set to fire one second later). Once the vehicle has descended to 900' AGL, the main parachute will be released also using a black powder ejection system (with a redundant charge set to fire at 700' AGL).

4.2.2 Avionics Bay Design

The avionics bay will be located within the recovery section of the vehicle, with a switch band included to separate the two fiberglass sections and provide access to the altimeter switches. The bay will be sealed on both ends with fiberglass bulkheads held shut with bolted threaded rods. A custom-designed 3D-printed altimeter sled will slide onto the threaded rods to hold the primary and redundant altimeters and their respective batteries in place inside the bay. Located on the exterior of the bulkheads will be black powder canisters to hold the ejection charges, terminal blocks to facilitate the wiring of the lighters, and eye bolts to secure the parachutes to the avionics bay. Key switches will be secured to the inside of the bay underneath the switch band with custom-designed 3D-printed holders to be accessible from the exterior of the vehicle.

The primary altimeter will be the Altus Metrum TeleMetrum. This altimeter was chosen because of its high reliability in many past launches as well as its GPS/live telemetry capabilities. The redundant altimeter will be the PerfectFlite StratoLoggerCF, which differs from the Missile Works RRC3+ Sport used in past years. This change was due to configuration changes in the vehicle that necessitated a relatively short avionics bay (5" in length), so the RRC3+ Sport would be a tight fit. The StratoLoggerCF is much shorter (only 2") and has all of the capabilities of the RRC3+ Sport, so it was chosen instead to serve as the redundant altimeter.

All avionics systems will be activated via key switch. Rocker switches have been used in past years, but concerns have been raised that they may be disarmed due to flight forces. In contrast, key switches cannot be disarmed by anything other than the key itself, so they are much safer to use for this application.

As per the competition requirements, the avionics bay will contain two completely redundant and separated altimeter/ejection systems. Each system will contain a switch, altimeter, battery, drogue terminal block and black powder canister, and main terminal block and black powder canister. The events the redundant system controls (drogue and main parachute release) will be set to occur slightly after the events the primary system controls. This reinforces the likelihood both events will occur close to the desired times in flight. The fact the two systems are fully separated also ensures that a failure in one system is unlikely to affect the other system.

4.2.3 Parachute Selection

The drogue parachute that will be used is a 24" diameter Fruity Chutes Classic Elliptical parachute. This parachute was chosen because it is especially compact and lightweight, and it has a relatively high drag coefficient for its size (1.55). It was also used last year with great success. The main parachute that will be used is a 144" diameter Rocketman High-Performance parachute, which differs from the 120" SkyAngle CERT-3 XXL parachute used last year. The reason this change was made was that it was retroactively determined that the SkyAngle parachute was undersized for the vehicle last year, and the team is planning to size the vehicle similarly this year. Therefore, a search was made for a larger main parachute that was not excessively expensive. Considering factors such as cost, diameter, and maximum vehicle weight, the search was narrowed down to the aforementioned Rocketman parachute. This parachute can support a vehicle with a maximum weight of around 54lbm, is also quite compact and lightweight, and has a fairly solid drag coefficient (2.2). Both parachutes are made of 1.1oz ripstop nylon.

4.2.4 Ejection Configuration

The ejection charge type that will be used is FFFFg black powder stored in black powder canisters on the bulkheads of the avionics bay. Each bulkhead will control the ejection of either the drogue or the main parachute and will have both a primary and a redundant charge in separate canisters. These charges will be sized based on the open volume of the airframe on either side of the avionics bay. The redundant charges will contain 1g more of black powder to ensure ejection occurs at the expected times in flight. Black powder was chosen as the ejection charge because it is relatively lightweight, quite reliable, and has been used successfully in many past launches.

The ejection charges and parachutes have been located such that the detonation of the ejection charges forces the parachutes onto a coupler bulkhead, breaking the shear pins and releasing the parachute. This is in contrast to last year where the ejection charges forced the parachute deep into a section of the vehicle, increasing deployment time and risk of deployment failure.

4.2.5 Independent Section Trackers

During the 2019-2020 competition, PSP-SL suffered a recovery failure that resulted in the lower airframe being separated from the rest of the launch vehicle during descent. Following this failure, the team was unable to locate the lower airframe for over a month. To avoid this failure mode, all major vehicle sections (tethered or otherwise) will be equipped with active GPS tracker/transmitters. This will provide constant position information for the entire vehicle during flight, easing recovery after any accidents.

4.3 Payload Design

4.3.1 Mission Overview

PSP-SL's Payload Sub-team will focus on two missions for the 2020-2021 competition, a Planetary Lander System (PLS), and an AeroBraking Control System (ABCS). The Planetary Lander System will satisfy all NASA defined payload requirements, as well as team defined requirements. These requirements include multiple new technical hurdles, primarily including mid-air deployment of the lander system, kinetic energy dissipation during descent, landing and up-righting capabilities, as well as transmission of photo data to the payload Ground Control Station (GCS). The planetary lander must be capable of being jettisoned from the vehicle's upper airframe during main parachute operation below 1000' AGL, but no lower than 500' AGL, calling for a quick but safe active method of retention. Afterward, likely using a drag increasing device like a parachute, the lander will slow down and maintain a safe terminal velocity for landing. Once touched down in expectedly unlevel farmland terrain, the lander will act to ensure its proper orientation within 5° to the vertical. Finally, using a camera system, the lander will take a 360° panoramic photo of its surroundings, then process, and transmit the image data back to the team's Ground Control Station for display.

The needs of the overall system will likely lead to an electronic subsystem within both the planetary lander itself and its associated retention bay, meaning careful consideration of electronic safety and weight limitations will be of high priority. The success of this system's mechanical design will depend on the expediency and reliability of activation during dynamic operation regimes. The avoidance of accidental deployment of either the lander or its associated parts is essential to mission safety and success.

In addition to the main mission, the Payload Sub-team will be designing an additional system, known as the Aero-Braking Control System (ABCS), as the team's secondary experiment. In years past, achieving the decided upon vehicle apogee relied solely on known approximation formulae, flight simulation software, and general rocketry experience. If there was a possible way to better control the maximum altitude other than by iterative mass changes and aerodynamic modifications, then the potential final apogee scoring could be optimized substantially. To that end, PSP-SL has decided to move forward on a device that can respond to the vehicle's state in-flight and adjust its drag characteristics to achieve a desired apogee. This device's active stage occurs during the vehicle's coast towards apogee. This system will likely need to intake information about the vehicle's current state and make decisions about when and how to act to best produce the desired altitude. The mechanism of action will likely be through protruding drag plates which will actuate into position when directed by the electronics subsystem, producing the desired change in vehicle drag.

Due to the inherent danger of modifying the aerodynamic pressure state of the vehicle, much care must be taken to produce a system which will under no circumstances cause the rocket to lose attitude control during ascent. To that end, the Payload Subteam will be working closely with the Construction and Avionics Subteams to ensure that proper safety measures are taken during design and construction. In the unlikely scenario that the ABCS system is unable to meet these safety criteria, the subsystem would likely be omitted altogether.

4.3.2 Planetary Lander System (PLS)

The Planetary Lander System (PLS) will be a system designed with the end goal of capturing and transmitting a panoramic photo of the vehicle landing site. However, to do so, the PLS must first be ejected from the upper section of the vehicle during descent below 1000' and above 500' AGL, very likely after or during main parachute deployment. The ejection method will need to comply with safety regulations while in the air and once deployed should likely not interfere with the decent of the main vehicle; this will ensure that both systems can safely reach the ground. Once deployed, the PLS will need to activate a means of reducing its landing kinetic energy. Once the lander has reached the ground in a configuration where all components are still operational, the process of orienting the lander body and capturing a panoramic photo may begin. Due to the chaotic descent and natural terrain features, the orientation system will have to compensate for uneven terrain and be able to reliably right itself. To ensure good picture quality and signal connectivity with the Ground Control Station, the team is looking into possible elevated camera designs. Once the image is taken and processed on-site, the image will be transmitted back to the Ground Control Station. Once this action is complete, the mission will be considered a success.

For the payload to land safely, level itself, and take a panoramic photo of the landscape, the team decided to split the functions of the Planetary Landing System into subsystems. The primary functions of the lander as mentioned above are covered by the subsystems named as follows: Retention and Deployment (R&D), Orientation, and Panoramic Camera.

4.3.2.1 Retention and Deployment Subsystem (R&D)

The Retention and Deployment Subsystem (R&D) must eject the payload at an altitude of 1000"-500" AGL and in such a manner that allows the lander to land within the designated launch field. During the ascent phase of flight, this means constraining and protecting the payload from movement or vibrational damage. Upon activation, the deployment mechanism should act to release the lander and allow it to enter a temporary freefall state; this process must all happen within the time taken for the vehicle to descend between 1000'–500' AGL. After deployment, the payload will not be tethered to the rocket and ideally should not interfere with the rocket's descent. Additionally, the team has decided that the deployment system must not require damaging/cutting the rocket's nosecone and should avoid the use of explosives to deploy if possible to protect electronic components. The R&D subsystem extends and integrates with the orientation system through the usage of a drag-producing device. Without additional drag, it is highly likely that the lander will fall at an unsafe terminal velocity, posing a threat to onlookers below as well as the lander itself.

The team has come up with various initial ideas with some driving principles: The solution should be as simple as possible and should interfere as little as possible with other subsystems. Under these principles, several ideas have emerged, including using the main parachute's shock cord to drag out and deploy the lander and/or its parachute. Alternatives include constructing a fairing around the payload section of the rocket to allow the payload to simply fall out and deploy its parachute just like the main vehicle. Lastly, a design concept that has come to recent prominence involves pushing off the vehicle's downward-pointing nosecone and allowing the payload to slide or fall out of the vehicle, afterward deploying its parachute. In this last case, the nosecone and lander could be potentially constrained during flight with the same active mechanism. Once the lander has cleared the vehicle, the nosecone would have to remain tethered to the upper airframe for regulatory reasons as well as to protect potential electronic devices present inside.

Currently, the idea to have the nose cone detach and allow the lander to fall out appears most optimal, due to positioning and safety. It does not require modifying the structure of the rocket as in the fairing idea—reducing weight and improving structural integrity, and it does not put additional strain on the main parachute's shock cord. Additionally, we can utilize the force of gravity to our advantage rather than attempt to work against it. However, other ideas might become more appealing depending on how much they would impact the other subsystems.

A top challenge involved with this approach is the possibility for the lander to deploy and strike the nosecone, causing damage to both components. Also, the active mechanism which deploys these components must operate with enough speed to finish in time—as well as with enough constraining force to prevent accidental deployment. All of these components must operate within the allotted space provided to the payload team and must not exceed weight limits that would disrupt the stability of the vehicle in flight. Constructing a mechanism capable of retaining and separating parts of the rocket has been done before on PSP-SL, but never while in the air; the team may stumble upon dynamics issues that would not be ordinarily present in a ground-based system.

4.3.2.2 Orientation Subsystem

The Lander's Orientation Subsystem must be capable of landing close to vertically or self-righting to a vertical position after landing within a 5° tolerance of the local vertical gravitational acceleration vector. The mechanism must be able to withstand all predicted impact loads. From prior experience, the team is aware of the often uneven landing surface of the vehicle and its components, so the team has decided to design with a surface irregularity tolerance in mind; should the lander land on uneven terrain, the orientation subsystem should still be able to operate properly.

One of the more prominent ideas is to design folded legs which would extend after the device had presumably landed on its side, tilting the device up to a vertical position as determined by internal orientation sensors. This would involve the use of some sort of motorized actuation method or spring-loaded system. The team also discussed the exact definition of orientation; for example, would a ball not be considered vertically orientated regardless of which way it "faces"? The team will continue to inquire as to the exact nature of this requirement, as other possibilities include a spherical or symmetrical lander.

The leading idea is to use self-righting legs to correct the lander's orientation upon landing. This approach would allow the lander to correctly orientate itself regardless of the orientation that it lands. This may change depending on whether a spherical shaped device would fit the requirements.

The issue of torque was the main concern of the leading design, as self-righting legs would need a significant amount of torque (and therefore also a potentially heavier motor) to correct the orientation of the lander from a compact pivot point. The team foresees a trade-off between low weight and functionality on this front. The lander must be able to orientate itself on uneven surfaces, given that the landing area is unpredictable. Therefore, care must be taken to properly test components in environments that match the predicted terrain. The lander software must be capable of making the appropriate decisions to self-orientate; this subsystem will likely have to be integrated with the lander's panoramic camera system electronics. Finally, the orientation system must be able to survive landing impact, something which will require much impact testing, something that could become expensive to the team if proper methodology and precautions are not taken.

4.3.2.3 Panoramic Camera Subsystem

The Panoramic Camera Subsystem will be located on the lander. It will be able to take a full 360° picture of the surrounding landscape after the lander has completed self-orientation. The image produced must be high enough quality to allow for the inspection and observation of the landing area and horizon. Additionally, this image will be processed and transmitted to the team's Ground Control Station for viewing by the team and NASA personnel.

The team has produced two general design approaches: One approach is to have a single camera that is rotated to take pictures at multiple angles after which all photos would be combined to produce the single panoramic photo. The other approach is to have multiple static cameras that have a combined field of view of 360°. All the cameras would take a photo simultaneously and the photos would be combined to produce a single panoramic image.

Both approaches would be able to produce the required panoramic photo. However, the team favors the multiple static camera approach. The static camera approach is less mechanically complex and more robust. The rotating camera would have more mechanical parts that weigh more and could be damaged on impact. The team believes that the simplicity of the static camera system will allow for more reliable outcomes.

This is the team's first time developing a custom camera system and will require research into new hardware and new software techniques. The team expects the greatest software challenge to be the capturing and combining of multiple images from different cameras. The team will also have to ensure that the camera system has a high enough vantage point to ensure that the images are not obstructed by the terrain.

4.3.3 Aero-Braking Control System (ABCS)

The Aero-Braking Control System (ABCS) will be a system able to actively control the altitude and velocity of the vehicle by adjusting the amount of drag the vehicle experiences. It will be located aft of the center of mass of the vehicle to avoid stability issues. This device aims to allow the vehicle to reach the team's chosen apogee with substantial accuracy and precision far exceeding that of past years' vehicles.

Per the project requirements, the ABCS will not reduce the stability margin of the vehicle to less than 2cal at any point and under any failure mode. Furthermore, as this is a new system, it is paramount throughout the design and prototyping phases to not get carried away with the procurement of overly expensive flight hardware associated with the ABCS. It will be important for the ABCS to retain a high degree of accuracy, with minimal noise, for its measurements while remaining within the specified budget.

4.3.3.1 Mechanical Subsystem

The mechanical subsystem must reliably and accurately alter the drag experienced by the vehicle based on calculations from the control subsystem. To this end, the subsystem will consist of a motor assembly actuating multiple airbrakes, modifying the external surface of the vehicle to increase or decrease the cross-sectional area. The airbrakes will be able to smoothly alter the total area up to a given limit, effectively allowing the vehicle to have the desired drag coefficient and cross-sectional area among a range of possible values.

The basic design of the mechanical subsystem will use one or more motors to either extend the airbrakes out past the surface of the vehicle or push the surface itself outwards to increase cross-sectional area and drag. In either case, the team decided that one or multiple DC motors would be more suitable than servos or stepper motors, as it would allow for continuous actuation of the airbrakes and would provide more torque that could better handle the load on the airbrakes. From there, the subsystem could convert the rotational motion of the motor into linear actuation through a rack and pinion system, worm gears, or any such solution. If the subsystem ultimately uses only one motor, an "umbrella design" may be most effective in ensuring that all airbrakes actuate simultaneously, similar to the spokes of an umbrella. On the other hand, a design with multiple motors allows us to control more precisely the cross-sectional area of the vehicle and its orientation as well. A design risk with the multiple motor design is asymmetrical actuation, which would cause asymmetric loading of the vehicle potentially resulting in a loss of stability and vehicle destruction, something that must be avoided at all costs.

For such a dynamic system, the issue of stability is present, which the team will account for through the control system primarily, but also by taking great care when manufacturing the mechanical subsystem to ensure that all parts are properly machined and that slight imperfections will not decrease the stability margin during the flight. Said parts will also be made so that they will be able to withstand the loads and stresses that actuation during the flight may place on them. In the event of mechanical failure, the control system will dictate how to proceed to guarantee flight safety and completion of the mission without deploying the ABCS.

4.3.3.2 Aerodynamics and Control Subsystem

The aerodynamics and control portion of the ABCS will perform the needed calculations to determine how much extra drag the mechanical subsystem needs to add to the vehicle to achieve the desired apogee. It must be able to react quickly based on real-time data to alter the vehicle's drag coefficient as necessary; sensor data will be relayed to a microcontroller that will then send the necessary signals to the ABCS motors to increase or decrease the cross-sectional area of the vehicle. All operations of the ABCS will be autonomously performed by the control subsystem during flight.

The current design approaches vary in complexity and effectiveness. The two considered approaches to control are implementing a fully active control system—which would regularly use sensor data to adjust the vehicle's drag forces—or pre-programming the microcontroller to actuate the airbrakes at specific altitudes based on a projected vehicle trajectory. For active control, solutions include a closed-loop control algorithm, such as PID, that uses altimeter data to find the necessary motor commands for the ABCS; a fixed equation that takes sensor data as inputs and outputs the needed drag coefficient to reach the target apogee; and slew rate control, to limit the acceleration of any moving parts in the mechanical subsystem. A comprehensive software solution may include one or several of these implementations.

Since the ABCS is a new system, the team must account for technical challenges beforehand and attempt to solve or compensate for them during the development process. With regards to software, ensuring that the code is robust and follows strict quality standards is key to making the ABCS reliable and guaranteeing flight safety during ascent. Due to the real-time nature of the airbrakes, all sensors, microcontrollers, and programming must be fast enough to allow for rapid calculations and low latency in the actuation of the airbrakes during the flight. To add to this, all hardware and electronics used for the control subsystem must be able to withstand the forces of the vehicle's flight and of the airbrakes' actuation; redundancy may also be used to ensure that the risk of failure remains low. As we are modifying the aerodynamics of the vehicle, we must ensure that control algorithms are written to carefully actuate the airbrakes to minimize stress and instability. If necessary, it may be possible that the team tests scale models or individual components of the ABCS in a Purdue's wind tunnel; while this would require much setup and precautions, it could potentially be a boon for the effectiveness of the subsystem if undesirable characteristics are uncovered.

4.3.4 Payload Ground Control Station

The Ground Control Station (GCS) will be a comprehensive base station that will be able to communicate to the payload via RF Transmitters and in-house software. The GCS will be capable of sending and receiving commands, as well as receiving images from the payload to satisfy the competition requirement.

The hardware of the GCS will be like that of a laptop, but with some additional features. It will contain a 720p laptop screen, two speakers for sound output, a keyboard/touchpad for computer operations, and a raspberry pi. The Raspberry Pi 4 4GB will be responsible for running the software for the GCS. The GCS will run draw power from two 12V Lithium-Ion batteries which will power both the screen and the Raspberry Pi. These batteries are rechargeable and can be replaced/swapped easily.

The software for the GCS will be written in house and has two separate options. Either a similar software to the previous year's GCS will be utilized, using Python and a module named Kivy. Another option is with the use of C++ and a framework called Qt; both are viable options. This software will be able to send/receive commands and requests to and from the payload while also being able to receive a 360° image over RF transmission. The software will provide a full range of commands and operations dealing with payload operation and statistics.

5 Closing Remarks

3 years after Purdue's return to the USLI Competition, PSP-SL is looking forward to another successful year, with new developments across the project. Thanks to the team's success in the 2020 competition, the team has seen its largest new membership ever, with more than 30 new members joining the team. These new members bring in a variety of skills and experiences that will shape the face of PSP-SL for years to come. This new generation also brings an ambition to tackle challenges above and beyond the requests of NASA and to truly understand the engineering required to make their goals a reality. Team members are now spread across 5 years of progression in their university studies but stand united in a goal to learn together and excel in the 2020-2021 NASA University Student Launch Initiative.