PURDUE UNIVERSITY

PROJECT WALKER

2019

500 Allison Road
West Lafayette, IN 47906

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1. Summary of PLAR Report

1.1. Team Summary

1.1.1. Team Name and Mailing Address

Team Name	Purdue Space Program Student Launch (PSP-SL) a SEDS chapter
Mailing Address	500 Allison Road, West Lafayette, Indiana 47907

1.1.2. Team Lead Contact Information

Position	Name	Phone Number
Project Manager	Michael Repella	330-495-1270
Acting / Assistant Project Manager	Luke Perrin	219-798-7066
Safety Team Lead	Jory Lyons	219-252-2816
Avionics Team Lead	Bret Reser	779-400-6241
Payload Team Lead	Josh Binion	614-535-5223
Construction Team Lead	Zach Carroll	765-860-0861
Funding Team Lead	Sean Heapy	206-849-7329
Social Team Lead	Isaac Byely	765-631-5828

1.1.3. Mentor Contact Information and TRA/NAR Certifications

Mentor Name	Victor Barlow
Mentor Email / Cell	vmbarlow@purdue.edu / 765-414-2848
TRA/NAR Certifications	NAR 88988 L3CC, TRA 6839 TAP Level 3 Certified

1.2. Launch Vehicle Specifications

Launch Vehicle Height [in]	120
Launch Vehicle Nominal Diameter [in]	5.15
Gross Lift-Off Weight (Wet Weight) [lbs]	42.5
Dry Weight [lbs]	34.45
Launch Vehicle Airframe / Nose Cone Material	Filament Wound Composite Fiberglass
Launch Vehicle Fin Material	FR-4 / G-10 Fiberglass
Launch Day Motor	**AeroTech Rocketry L1520 Blue Thunder**
Launch Day Motor Diameter [in]	2.95276
Launch Day Motor Grain Count	3
Launch Day Motor Total Impulse [N sec]	3,716
Launch Day Motor Burn Time [sec]	2.4
Launch Day Motor Total Thrust [N]	1,779
Launch Day Motor Propellant Weight [lbs]	4.09
Launch Day Motor Loaded Weight [lbs]	8.05

1.2.1. Recovery System

Launch Vehicle Primary Altimeter	Altus Metrum - Telemetrum
Primary Altimeter Receiver	Altus Metrum - TeleDongle with Yagi 3 Arrow Antenna
Primary Altimeter Power Supply	3.7V LiPo Battery - 900 mAh
Launch Vehicle Secondary Altimeter	Missile Works - RRC3+ Sport
Secondary Altimeter Receiver	N/A
Secondary Altimeter Power Supply	Duracell 9V Battery
Drogue Parachute	SkyAngle Cert-III Drogue
Drogue Parachute Diameter [in]	24
Drogue Parachute Coef. of Drag	1.16

Altitude Deployment	Apogee
Main Parachute	SkyAngle Cert-III X Large
Main Parachute Diameter [in]	100
Main Parachute Coef. of Drag	2.59
Altitude Deployment AGL[ft]	700-900
Shock Cord Length [in]	40
Shock Cord Thickness [in]	1/2
Shock Cord Material	Tubular Kevlar
Shock Cord Weight Rating [lbs]	7,200
Launch Vehicle Rail Size [in]	1.5
Launch Vehicle Rail Length [ft]	12

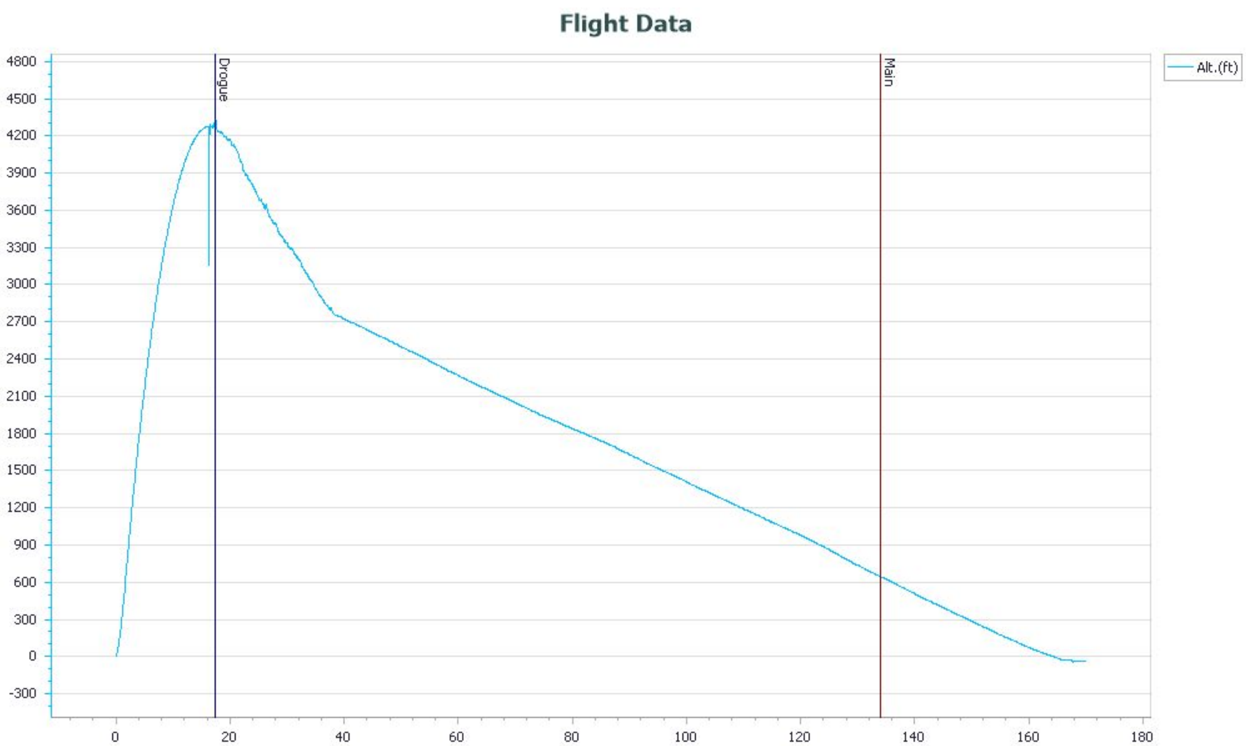
1.2.2. Launch Vehicle Altitude Summary

Launch Vehicle Predicted Altitude [ft]	4,950
Launch Day Achieved Altitude: [ft]	4,403

1.2.3. Launch Vehicle Summary

On launch day, despite some unforeseen circumstances, the rocket finally launched. Lift off the launch pad was as expected and the rocket climbed to apogee. Shortly following arc over, the drogue parachute deployed as expected. Both the primary and secondary charges went off at the proper time visually. However, in between drogue deployment and expected main deployment, the main parachute deployed. The team believes that the shear pins holding the avionics bay to the upper airframe sheared prematurely. While this did not cause the parachute to deploy immediately at apogee, the parachute was more free to open early. As later noticed, the main charges deployed at the proper time, so it was clearly not an avionics issue. Due to the early main deployment, the rocket had a long descent time, much higher than expected. However, the rocket landed softly and is reusable, so overall, the team cannot complain too much about performance, especially since it was many members' first experience with any kind of rocketry.

1.2.3.1. Data Analysis & Results



The two graphs above show the Telemetrum and RRC3+ Sport on-device data. The telemetrum recorded a max height of 4456 ft and the RRC3+ Sport recorded a max height of 4413 ft.

1.2.3.2. Scientific Value Achieved

Over the course of the year, the team learned a lot about the process of designing and building rockets.

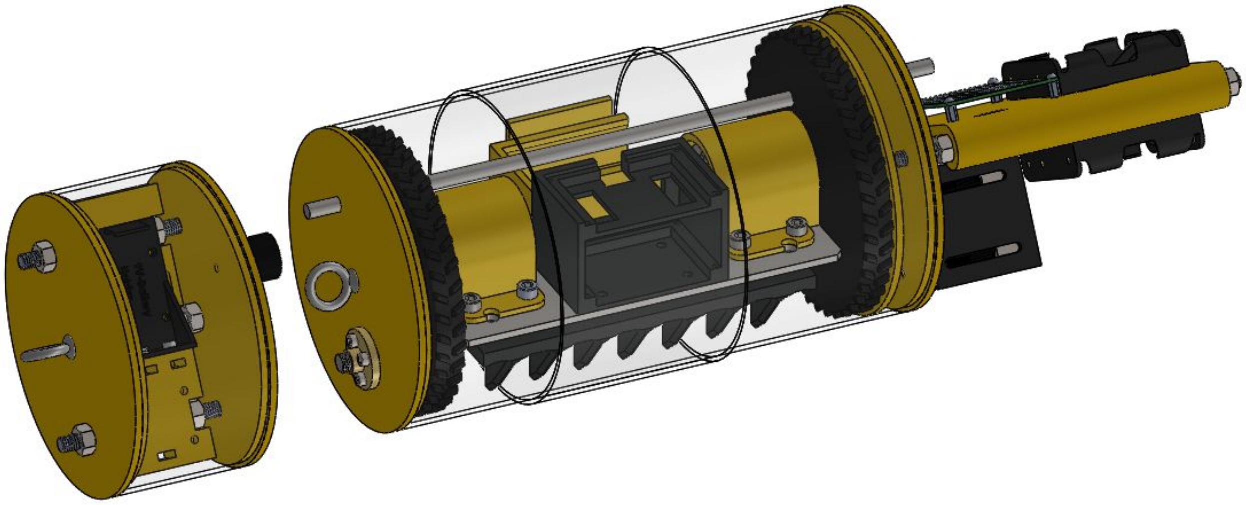
1.2.3.3. Visual Data Gathered

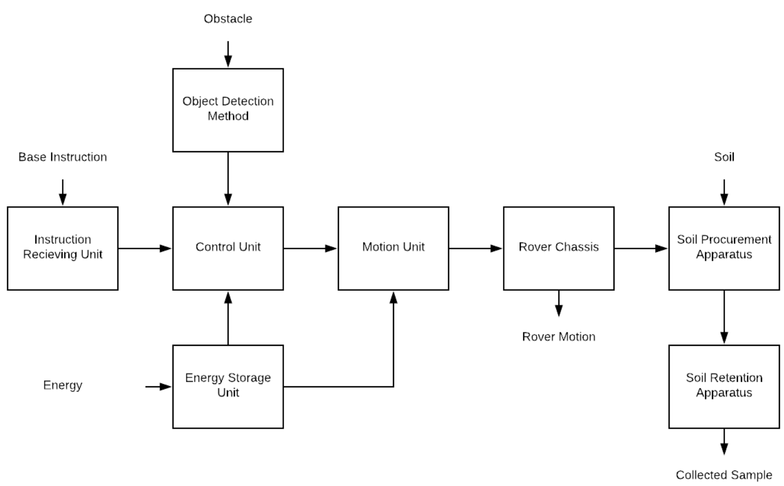
From start to finish there was a lot of data gathered through our final test in Huntsville. The team’s rocket launched with a little delay but took off nevertheless. As the rocket ascended, the sound of the rocket fuel burning could be heard for about 3 seconds. Once the rocket reached apogee, the ejection charges could be seen going off for the drogue parachute. Unfortunately, the main parachute deployed much earlier than anticipated. The reason for the premature deployment of the main parachute was unknown while the rocket was descending. It was determined that the cause was not because of early ejection charges, as the charges went off at the correct altitude. As the rocket landed, the drift distance was extremely minimal compared to what it could have been with such a high main deployment. As the pieces of the rocket landed, the nosecone stuck in the ground which would have been disastrous for the payload deployment. Fortunately, the nosecone and payload bay fell over so that the payload could be deployed. During payload deployment, a signal was being sent to the payload but no ejection charge was going off. This was determined to be because of faulty wiring once the payload bay was disarmed on site. The payload was then signaled to deploy and the rover slowly slid out of the containment bay. Once the rover was on the ground, it could not traverse on the loose dirt. It appeared as though the rover didn't have enough torque to move around on such loose farm soil. Unfortunately, the payload didn’t work out as hoped, but the lessons were learned and will be remembered for next year.

2. Payload Summary

2.1. Payload Description and CAD

2.1.1. Overall Design





2.1.2. Component Operation

After a successful ejection, the autonomous completion of the rover's task was deemed a failure. By analyzing each of the individual systems, it was concluded that, though many components seemed to not operate as properly as planned, there were fairly clear reasons why each system struggled as they did. The team will take this failure to heart and will strive to make clear improvements in the future.

Before contemplating the lack of functionality of certain subsystems, it should be noted that the control subsystem appeared to have worked exactly as intended. The activation switch as well as redundant code loop ensured that the rover did not activate prematurely before ejection. This is evidenced by the fact that the rover's motors and servos did in fact activate after the designated time delay. Additionally, this also means that our communication units were functioning properly; these were designed to work at about a range of a half mile and activated successfully.

Within the chassis subsystem, though all parts remained in place after touchdown, the rover motion system failed to provide adequate torque to provide the wheels sufficient force to drive the rover forwards. Though the motors used in the final iteration of the rover contain gearboxes to increase torque while sacrificing top speed, it was speculated and concluded that the torque provided by the drive motors was still insufficient to negotiate the incredibly jagged and inconsistent field. It would seem that the testing surfaces the team used to simulate the farm terrain far underestimated the sheer difficulty of propelling a rover through course terrain without issue.

Energy Storage

- Arduino voltage glitch
- Motor torque low voltage
- Needs greater voltage battery

Soil

- Unable to collect
- Rover was unable to move
- Servo actuation functional, though insufficient torque for pushing through dirt

2.2. Payload Ejection Description

The payload ejection subsystem retains the payload inside the launch vehicle during flight until a signal is received after vehicle touchdown to begin payload ejection. The payload ejection involves primarily a black powder component separation followed up by a stepper motor that pushes the rover outside of its encapsulation. The black powder charges are stored below rover containment bay and are ignited by a separate coupler that houses radio electronics and isolates the payload from the recovery system. Once the charges are ignited, the rover containment bay is separate from the launch vehicle and a radio controlled stepper motor pushes the rover outside the rocket in its starting configuration.

2.3. Data Analysis & Results

The payload team looked at a variety of data to evaluate the performance of the overall payload system. Visual inspection and analysis of the payload's post-flight operation was the largest source of data the team used. After analyzing and discussing video footage and still photography, the payload team has concluded the following:

- Upon being armed on the launch pad, the rover and payload bay systems stayed in their launch states throughout their time on the pad, during the entirety of the flight, and during the post-flight phase leading up to ejection. Therefore the payload team concluded that the launch phase of the payload's mission was completed nominally.

- The next phase of the mission was the payload remote deployment. Upon receiving instructions from NAR launch personnel, the payload team took the remote deployment tower out to the rocket's landing site. When the ejection signal was sent to separate the rover containment bay from the payload ejection bay, no separation occurred. Upon inspecting LED indicators on the remote deployment tower, it became evident that a connection had not been established between the XBee radio on the tower and the XBee radio in the payload ejection bay.
- After receiving permission from a NAR safety official, a member of the payload team manually separated the rover containment bay from the payload ejection bay. Upon doing so, it was determined that an electrical connection providing power for the payload ejection bay had not been made pre-flight.
- After manually separating the rover containment bay and the payload ejection bay, as well as ensuring that conditions were safe, the team sent the deployment signal to the rover containment bay to deploy the rover. This action took place nominally. The stepper motor inside the rover containment bay pushed the rover out of the payload bay.
- Upon exit from the payload bay, the rover began attempting to drive forward. It was quickly determined, however, that the rover's two DC motors were not providing enough torque to propel the rover forward over the thick dirt at the landing site.
- After applying a torque to the motors for the designed amount of time, the servo motors on the rover's soil sampling system attempted to actuate the rover's scoop to collect a soil sample. However, due to the orientation of the rover, the servos could not provide enough torque to open the scoop.

2.4. Scientific Value Achieved

Over the course of this project, the payload team developed a wide array of engineering skills. The team went through numerous design-construct-test cycles over the 8 months of the project, picking up technical expertise in every facet of the payload design. One specific achievement that best encapsulates the scientific value achieved by the payload team this year was the team's remote deployment tower design.

The electronic design of the tower centered around two XBee wireless transmitters. The team elected to use a high-frequency (2.4 GHz) model of this transmitter to save on costs, but quickly realized that range would be a problem. Instead of giving up on the idea altogether, the team researched means of extending the range of such a signal. This led to the discovery of the "Fresnel zone," referring to the shape of the radio pattern transmitted by the XBee's. If the team could create a vertical displacement between the two XBee's, the range could be extended. With this information in hand, the team developed a 16 foot extendable tower for the ground transmitter. After much testing, the team was able to achieve communication ranges exceeding the mission requirements. The tower worked successfully on the day of the launch, validating the team's design.

2.5. Visual Data Gathered

(Above) The landing site of the nose cone upon arrival of the team.

(Above) The payload during the process of controlled ejection from the payload bay. Ejection is clean and unhindered.

(Above) Final unassisted location of the payload rover. High surrounding tilled piles of dirt prevent any and all further motion.

3. Lessons Learned & Overall Experience

3.1. Lessons Learned

General:

- Bring sunscreen and/or a tent to Huntsville.

Avionics and Recovery:

- Put tape over shear pins to ensure they do not fall out during flight.
- Consider using the RRC3+ Sport as the altimeter to get the auditory indication of altitude from after launch. This will allow the team to recover the data if we accidentally turn the altimeter off prematurely. Also, the altitude is given in feet, rather than meters as with the Telemetrum, so no conversion would be necessary.
- For the vacuum chamber altimeter ejection test, use Plumbers' Putty or bag seal tape instead of caulk to make the seal. The team originally had considered using Plumbers' Putty, and upon conversing with another team who had also used this during Launch Week, we discovered that we were originally on the right track. This or bag seal tape would allow the seal to be more reusable and less messy.

Payload:

- Prototypes need to be built early and often.
- Standardize mechanical components - nuts, bolts, screws, etc.
- For Arduino programming, come up with one toolchain and stick with it. As bad as the Arduino IDE is, this is probably easier than getting everyone working on a 3rd party platform (e.g. PlatformIO)
- Simulate Huntsville conditions as best as possible. Just because a rover can drive on a concrete floor doesn't mean it can drive over Alabama red clay.
- Protoboards are incredibly difficult to put together and are even harder to do so nicely. Learning custom PCB design would've taken more time upfront, but would've saved hours and hours of time overall.
- Separate power supplies when dealing with high current/voltage devices.
- High frequency radios have less range. If using XBee's for long range communication, buy the 900 Mhz version, not the 2.4 GHz version.
- Wireless communication range can be increased by raising the radio antenna off the ground.

Safety:

- Safety is large margin of score and barely changes year to year, therefore recycle but update/change payload sections.

Construction:

- Construction should begin with the lower airframe and payload sections.
- Overestimate the final weight of the rocket at the beginning of the year, it is always easier to add weight.

3.2. Overall Launch Week Experience

3.2.1. Positive Feedback

Overall, launch week went relatively well, most of the events were spread out well and allowed time for teams to work on small modifications to the rocket and rover. Launch Readiness Review (LRR) went very smoothly and the NAR inspectors completed thorough inspections of each team. Our team thought that it was very beneficial to be able to have a second round of LRRs. For the high majority of our team, missing Wednesday of class was not an option, so being able to leave Wednesday night worked out. The hotel location and location of the event was very good.

3.2.2. Negative Feedback

One of the main suggestions that our team had was to have required events for Wednesday. About 90% of our team pulled stayed up all night, driving from West Lafayette, IN to Huntsville, AL. This caused our team to be extremely exhausted when the team arrived. With this, this caused issues when going to the Team Welcome and Brief. Another issue the team faced was that there was not as much interest in the speaking event. We think if would be more beneficial to have a wider span of speakers.

3.3. Overall Competition Experience

3.3.1. Positive Feedback

Overall, the competition was a great experience for everyone. Team leads were able to teach newer team members, our team got to learn from a lot of mistakes and we got to launch four rockets the entire year. The team felt that all of the timelines were very reasonable and having the extra week for CDR was extremely beneficial. The high majority of our team was on break and was not around to work on any documentation or testing and having the extra week allowed us to do just that.

3.3.2. Negative Feedback

One issue was that for the Review Presentations, different applications were used (Skype and Vidyo). Our team thinks that it would be beneficial for a little bit more consistency. With this we know that the government was shutdown for longer than expected, but if there is ever a chance of a government shutdown, just make it consistent to use a application like skype. The payload team felt that the launch-day events related to the deployment of the rover was quite different than described in the NASA Student Launch Handbook. The payload team spent a considerable amount of time and effort designing a system that would be able to deploy the rover remotely from over 0.5 miles away. The payload team thoroughly tested this system to ensure it was ready for launch day, but was told by NAR safety personnel after the launch to take the system out to the landing site, therefore deploying the rover from a distance of roughly 20 feet. In the future, the payload team recommends better communication between NASA Student Launch officials and NAR safety personnel so that the required payload mission profile can be achieved.

4. STEM Engagement Summary

4.1. Summary

In order to reach out to a majority of K-12 students as well as others, team members participated in the annual Purdue Space Day on Saturday, October 27, where they were randomly placed in teams in charge of various groups consisting of 10-90 students. The students created model rockets, astronaut arms, solar sails, and many other space-related projects with the help and supervision of team members. Team members showed the students the physics and reality of propulsion using systems such as dry ice rockets, and also showed the students the different organizations around Purdue that were involved in STEM related projects. This allowed for the students to have an understanding of space exploration as well as the impact Purdue University has on the space industry. At this event, the children were broken up into groups of 30 - 50 and participated in a variety of STEM related activities which varied by age range which were coordinated and led in part by PSP-SL members.

4.2. Documentation of Outreach

The STEM Engagement Activity Reports which were filled out by the team members who attended Purdue Space Day can be found in the following location:
https://drive.google.com/drive/folders/1Eu2VYxXYnDArzS3gj4UYcuKABaqxSReR?usp=sharing

4.3. Outcome of Outreach

Team members who participated in Purdue Space Day were unable to see the evaluation reports the children gave to Space Day officials at the end of the day, but through word of mouth the team heard that feedback was very positive in terms of both enjoyment and concepts learned. Team members also report that, in person, the kids made design choices with good judgement after being taught background information on their projects and were very excited to complete the activities which were set up for them and see their work in action, such as when their dry ice rockets launched. The students used their initial experience from the dry ice rockets to make changes and learned that creating a higher internal pressure would allow the cap to pop off at a higher required force and therefore provide more thrust. The students overall were extremely excited by creating these rockets and shared their joy after learning from team members by pondering how they would similarly launch from home and if they were able to learn more on rocket science. By the end of the academic year, PSP-SL reached out to a total of about 1000 student directly and about 300 indirectly.

5. Final Budget Summary

Budget Section	Total Cost	Discount	Final Total
Full Scale	$2340.69	$2071.34	$269.35
Subscale	$197.93	$0	$197.93
Avionics	$823.48	$470	$353.48
Payload	$560.37	$0	$560.37
Branding	$550	$550	$0
Travel	$2544	$0	$2544
	$7016.47	$3091.34	**$3925.13**

5.1. Summary

Ultimately sufficient funding was found across various sources to pay for all project associated costs. A fair portion of the total project costs were paid for through donations and previously used components (discounts). The total costs paid for by the team through various funding activities this year was $3091.34. This total was paid for by a restaurant fundraiser, money obtained through our crowdfunding campaign, a grant given to us by the AAE department at Purdue, the stipend given to us graciously by Northrop Grumman, and some money from our parent organization, SEDS. There was some difficulty paying for redundant parts necessary due to the various incidents that occurred throughout the project period. With the pitching in of students on the team for these additional parts, we were able to sufficiently fund the entire project.

5.2 Lessons Learned

Purdue University does not offer many opportunities to fund student projects, unlike many other schools. As a result, the students on future PSP-SL teams should be conscientious of the necessity to be crafty with their fundraising efforts. Next year's team will have the opportunity to obtain company sponsorships, as well as have the opportunity to take part in a fundraising arrangement between Levy Restaurants and PSP-SL. Overall, the most important lesson learned is the focus on getting funding much earlier than it is needed, as often organizations will require ample time to process payments and disburse funds. Restaurant fundraisers and departmental grants are both reliable sources of funding, although they will not be sufficient enough to fund the entire project, as we learned this year. Money given to us by Purdue SEDS, although helpful, should also not be relied upon, as SEDS has its own budget requirements to meet as well.