Preliminary Design Review

Team 1: PI&ZA
Space Works 1 Workforce Development
Fall 2024

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1. Introduction

For this project, the team was tasked with designing, building, and testing a prototype planetary lander. The lander, named PI&ZA (Payload Interface & Zeroed-Velocity Apparatus), must carry a given payload during descent and deploy the payload upon landing. To do this successfully, systems must be implemented into the lander to both slow its fall to a safe landing speed and reliably deploy the payload from the lander to the ground. In addition to these critical goals, there are also design requirements that must be met. The system implemented for descent purposes must be enclosed within the volume of the lander before it is dropped and must deploy during its descent. This system, nor any other part of the lander, may be attached to the release mechanism after dropping. The payload may only be deployed after landing. It must be deployed in an upright position and the top of the payload must be within view. Finally, the payload must either be in full contact with the ground or have a clear view of the sky. Not only does the lander have to accomplish these goals, its design must also fit within certain limitations. Constraints include a budget of $75, a total lander mass less than 400 grams, and an undeployed lander volume of 25 cm × 25 cm × 25 cm. Deployment of the descent subsystem must also increase the total volume of the lander.

To meet the goals of the mission and fit within the constraints, a planetary lander utilizing a parachute as the descent subsystem and a contact rod as the payload deployment subsystem was designed. The payload deployment system is designed to release the payload by using contact with the ground. For this, a rod that extends from within the lander body, through the bottom of the lander, and a length past the lander's base is implemented. This rod is able to move in the vertical direction. The top of the rod inside the lander has a hook that latches into the payload to keep it in place. Upon landing, the rod will make contact with the ground first, being pushed up as the lander body continues to fall. When pushed up, the rod unhooks from the payload, which will allow it to roll down an integrated ramp and out onto the ground.

1.1 Mission Success Criteria

	Project Requirements					
Req #	Requirement	Rationale	Parent Req	Child Req	Relevant Subsystem	Req met?
Level 1(Project requirements)						
PR-1	Lander shall successfully land and deploy a payload within target area	Provided by Project requirements	Customer	TBD	All	Not Met
PR-2	Lander shall survive a drop from 85 feet	Provided by Project requirements	Customer	DES-1, DES-2	Descent	Not Met
PR-3	Lander shall successfully integrate to the provided release mechanism and payload	Provided by Project requirements	Customer	MECH-1, MECH-2	Payload, Mechanical	Not Met
PR-4	Lander shall deploy at least one descent/landing system following release	Provided by Project requirements	Customer	DES-1, DES-2	Descent	Not Met
PR-5	Lander shall deploy at least one payload deployment system after touchdown	Provided by Project requirements	Customer	MECH-1	Mechanical	Not Met
PR-6	The payload shall be secured to the lander during decent and be deployed after landing	Provided by Project requirements	Customer	MECH-1, MECH-2	Mechanical	Not Met
PR-7	The payload bottom shall be in full contact with the ground	Provided by Project requirements	Customer	PAY-1, PAY-2	Payload	Not Met
PR-8	The payload shall have a clear view of the "sky"	Provided by Project requirements	Customer	PAY-1, PAY-2	Payload	Not Met
PR-9	The overall project costs should lie within $75	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Not Met
PR-10	The lander(undeployed) should lie within 25cmx25cmx25cm	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Not Met
PR-11	The overall project mass should lie within 400grams	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Not Met

Fig. 1 Project Requirements

The mission objective is to successfully land and deploy a scientific payload. The lander shall deploy a parachute to slow descent and the scientific payload must withstand the force of landing. After which, the lander shall implement some method to deploy the payload. This scientific payload shall either be in full contact with the ground or have a clear view of the sky.

1.2 ConOps

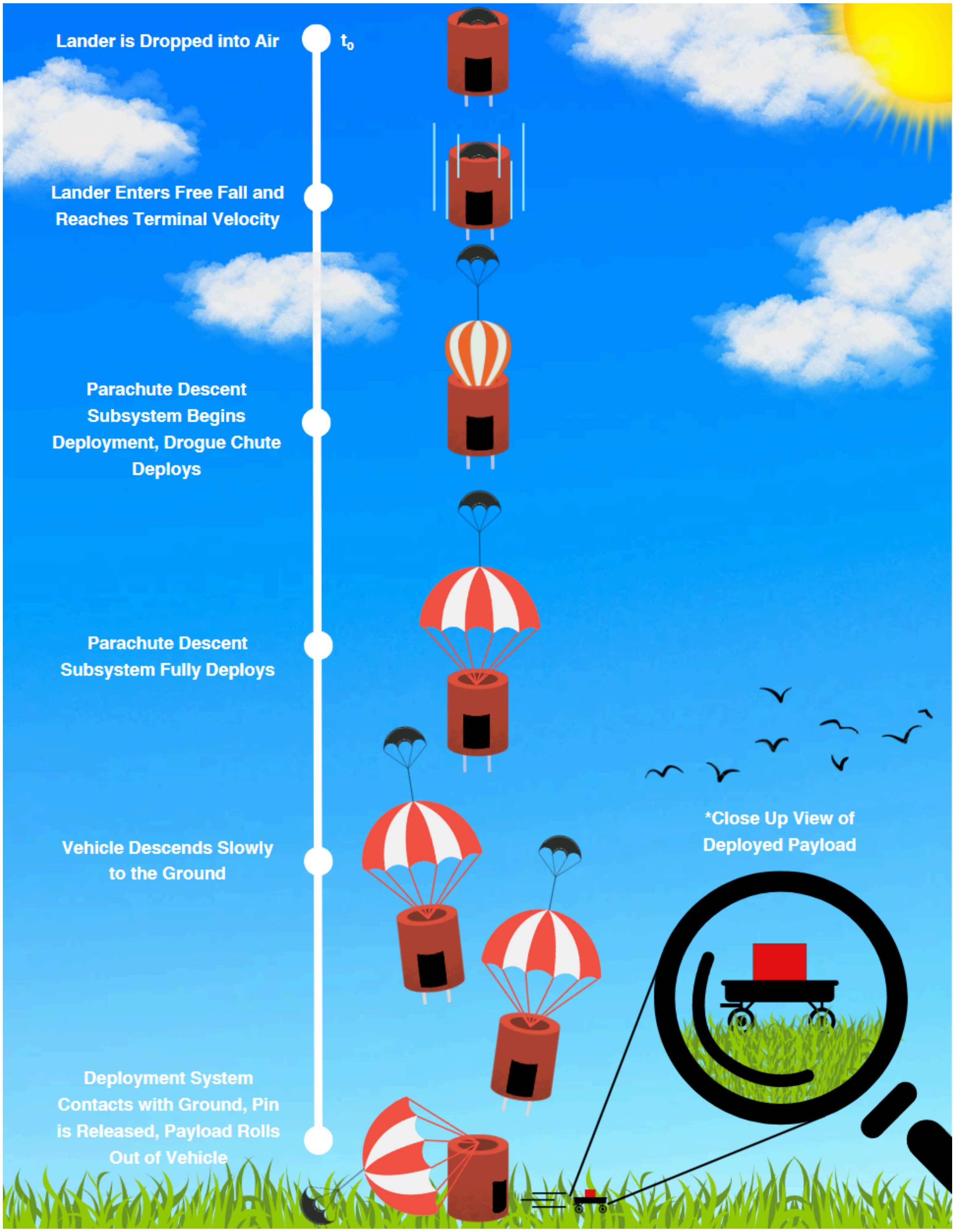

Fig 2. Concept of Operations

2. Overall Lander Design

The lander is nearly cubic in shape, and fits within 25 cm cubed. The top of the lander is reserved for the descent subsystem (the parachute) to be packed, while the bottom is reserved for the payload and deployment subsystem (contact rods). During freefall, the parachute will inflate with a drogue parachute and the help of air pathways cut into the lander body. The primary parachute shall slow the lander down to a gentle descent of around 3.5 m/s. Once the lander touches ground, the contact rods that stick slightly out the bottom will be pushed upwards, releasing a pin holding the payload cart in place. Once the pin is removed, the payload cart will be allowed to freely roll down the integrated ramp. The payload will then be deployed safely onto the ground, exposed to the sky.

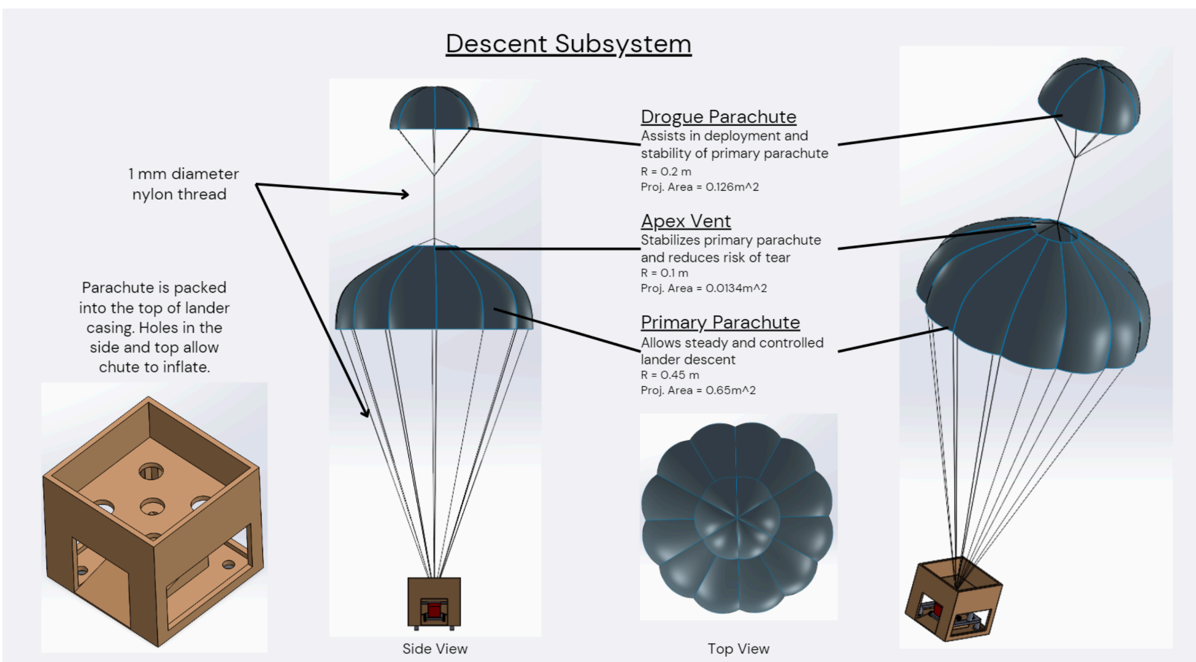

Fig 3. Descent Subsystem

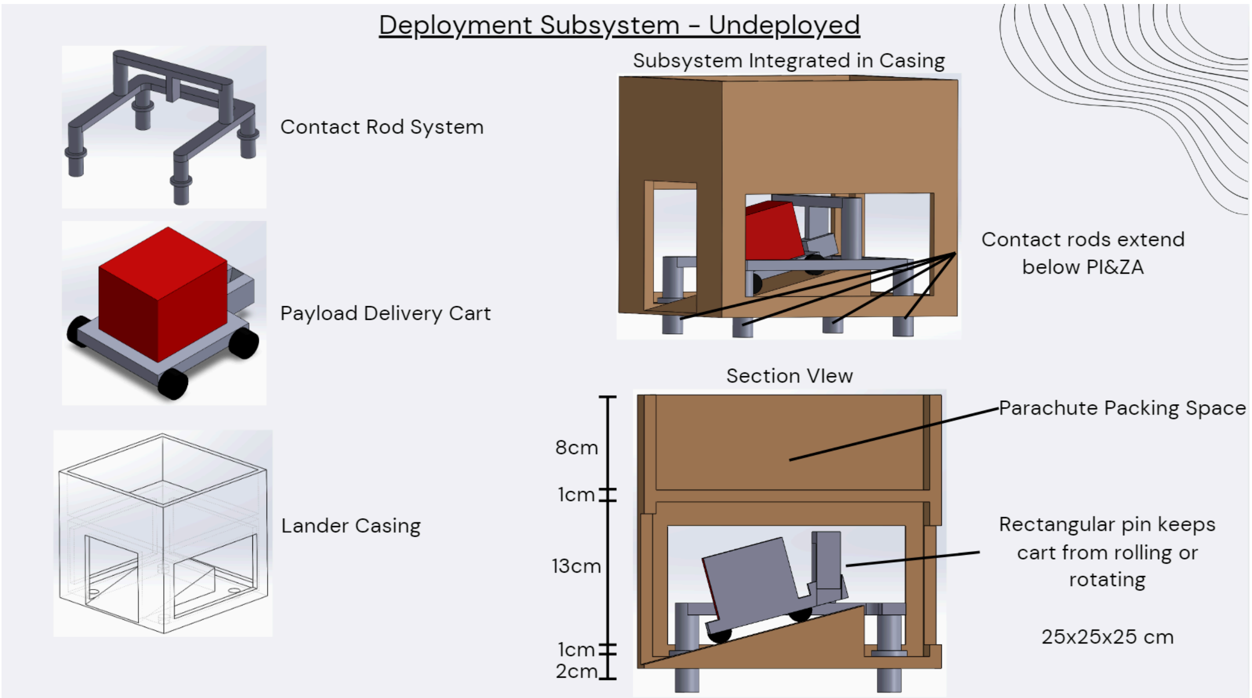

Fig 4. Deployment System (Undeployed)

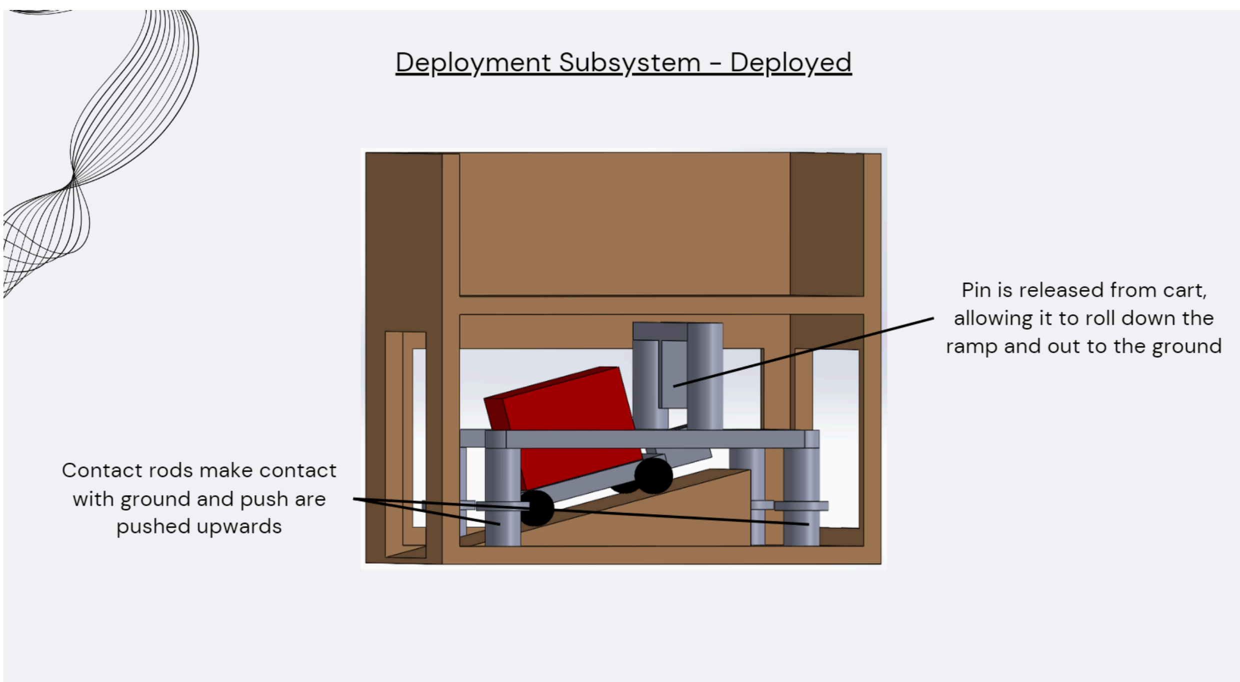

Fig. 5 Deployment subsystem (Deployed)

2.1. Landing/Descent Subsystem

The landing/descent subsystem is designed such that not only should the landing be smooth and controlled but also attain the required terminal velocity for the lander. This system along with a primary chute uses a drag chute for higher stability and drogue during descent.

a. Primary parachute:

   The primary parachute is almost dome shaped canopy of octagonal circumference, cut out of a mylar blanket, with a diameter of ~90cm. It also has an apex vent of diameter ~90cm which ensures stability during the descent by facilitating the escape of the excess air. The canopy is connected to the payload using a set of 24 suspension lines of length ~135cm. The suspension lines are made out of fishing line which is light in weight and ensures higher strength. Along with holding the payload, suspension lines can withstand the forces during the deployment and descent.

b. Drogue Parachute:

   A drogue parachute, also called a drag chute, is deployed prior to the primary parachute. A drag chute helps in deployment of the primary chute, while maintaining its velocity efficiency. This not only manages initial high velocity but also provides a better control over the whole system. This is smaller, with a diameter of 18cm and is then connected to the main parachute using another set of suspension lines.

c. Packing:

   The bigger parachute is folded into half and then along the y-axis until all the suspension lines lie along one line. The suspension lines are then placed over the canopy and then the canopy is folded along the x-axis. This is then stuffed into the payload. The drogue parachute is packed in a similar manner and placed over the bigger parachute.

d. Deploy mechanism:

    Upon initial stages of descent, the drogue is deployed automatically and slides out due to a smaller size of the canopy. It then pulls the primary chute along with it, deploying the whole system.

After the deployment , the canopy opens up, slowing the overall velocity of the system. This combination of parachutes helps in higher stability and increased efficiency, a more reliable parachute deployment, and maintaining a sequential deployment and controlled descent meeting the mission success criteria of soft landing of the lander.

2.2. Payload Deployment Subsystem

The payload deployment subsystem aims to satisfy both success criteria: The payload will be in contact with the ground and the payload will have an unobstructed view of the sky. The payload deployment subsystem relies on the impact force of the lander to the ground to initiate deployment of the payload. To do this, a hooked rod is utilized to secure the cart and payload onto a ramp during descent, and during ground contact this rod is to disengage and allow the payload to roll down and away from the cart.

a. Cart - Initially, the payload rests on a cart, constructed with legos, within the lander body. Wheels are attached to the cart for ease of deployment upon landing. Once released, the cart carrying the payload will naturally roll down the ramp and out of the lander. This cart is sufficiently low to the ground that the payload is considered in ground contact for mission requirements. By moving the payload away from the lander during ground contact, the potential for the parachute to land on the payload and obstruct its view of the sky is mitigated.

b. Ramp - To initiate movement of the payload once released, the payload is situated on a ramp. The ramp is designed steeper than the critical angle to allow the payload to passively roll out of the lander once released. For the prototype ramp and cart, this critical angle was empirically determined to be 10 degrees. Similar testing will be conducted to determine the critical angle of the final ramp. To fit the size of the payload, the ramp is constructed to be 12.7 x 12.7 cm. For a reliable form and smooth surface of the ramp, it will be made by 3D printing.

c. Contact Rod - To keep the payload stable as the lander falls, the payload is hooked in place by a thin, metal rod. This rod extends out from where it latches the end of the cart, down through the ramp, and out from the base of the lander such that the rod is the first component to make contact with the ground. Once the rod hits the ground, it will be pushed up as the lander body continues to fall, until the hook disengages from the payload and cart, releasing it. The base of the rod is widened to prevent it from sliding fully into the lander and potentially obstructing the motion of the cart.

3. Design Evolution

The first subsystem that was proposed was a payload deployment subsystem that used contact rods to complete a ramp. The payload was to be deployed upon impact via 4 landing legs that would rise up into the lander, and complete a ramp for the payload to roll down. This subsystem was abandoned, as since the payload rested on the contact rods, it had the potential to launch the payload upon ground contact. Additionally, there was the worry that the lander legs would break upon impact and not unlock the payload from the ramp. This led to the current design of having a rod inserted through the lander and hooked over the cart, securing it in place.

Upon ground contact the rod shall move upward and unlock the payload, allowing it to deploy by rolling down the ramp. Upon testing this prototype, it was identified that the cart would need to be more resilient and the contact rod would need to account for situations where the lander does not fall flatly onto the ground. The single contact rod was identified as a single point of failure, so the design was revised so that multiple ground contact points would unlock the payload. This testing also revealed that a ramp may not enable the payload to sufficiently distance itself from the rest of the lander to avoid the parachute falling onto it, so alternate designs of moving the payload away are being considered.

Another subsystem that was ultimately ruled out was the first iteration of the descent subsystem, a simple round parachute. The parachute needed to be large to accommodate the weight of the entire system. Based on experience gained from the parachute mini project, larger parachutes have a difficult time deploying quickly and easily. Knowing this, the air flow from falling was likely not going to be enough to ensure that the parachute inflated and deployed consistently. Also, keeping a large parachute in a small enclosure would compress the parachute into the sides of the packing area, thus creating a large friction force that the parachute would have to overcome before deployment. This would mean that the air coming from below the parachute would have to supply significant force to deploy the large parachute - force significant enough that the group could not count on airflow alone to deploy the large chute. Due to this, the group decided to add a drogue chute to the top of the parachute. The drogue chute will be placed on top of the primary parachute, and will easily be able to catch air and inflate, since it is much smaller and will not be as tightly packed. Once the drogue chute catches air, it will be able to pull on the primary chute, contributing more force than just air alone. The drogue chute will also improve stability, as its position at the very top of the lander will serve to oppose any swinging motion the lander might generate.

4. Requirements

	Requirements					
Req #	Requirement	Rationale	Parent Req	Child Req	Relevant Subsystem	Req met?
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PR-3	Lander shall successfully integrate to the provided release mechanism and payload	Provided by Project requirements	Customer	MECH-1, MECH-2	Payload, Mechanical	Not Met
PR-4	Lander shall deploy at least one descent/landing system following release	Provided by Project requirements	Customer	DES-1, DES-2	Descent	Not Met
PR-5	Lander shall deploy at least one payload deployment system after touchdown	Provided by Project requirements	Customer	MECH-1, MECH-3	Mechanical	Not Met
PR-6	The payload shall be secured to the lander during decent and be deployed after landing	Provided by Project requirements	Customer	MECH-1, MECH-2	Mechanical	Not Met
PR-7	The payload bottom shall be in full contact with the ground	Provided by Project requirements	Customer	PAY-1, PAY-2, PAY-5	Payload	Not Met
PR-8	The payload shall have a clear view of the "sky"	Provided by Project requirements	Customer	PAY-1, PAY-2, PAY-5	Payload	Not Met
PR-9	The overall project costs should lie within $75	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Not Met
PR-10	The lander(undeployed) should lie within 25cmx25cmx25cm	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Not Met
PR-11	The overall project mass should lie within 400grams	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Not Met
Level 2 (System requirements)						
Mechanical Reqs						
MECH-1	The contact rod will hold the payload stable during descent	The contact rod must hold the payload in place to prevent premature deployment	PR-3, PR-5, PR-6	TBD	Mechanical	Not Met
MECH-2	The contact rod will raise upon ground contact and successfully release the pin to deploy payload	The contact rod must make sufficient ground contact in order to release the payload	PR-3, PR-6	TBD	Mechanical	Not Met

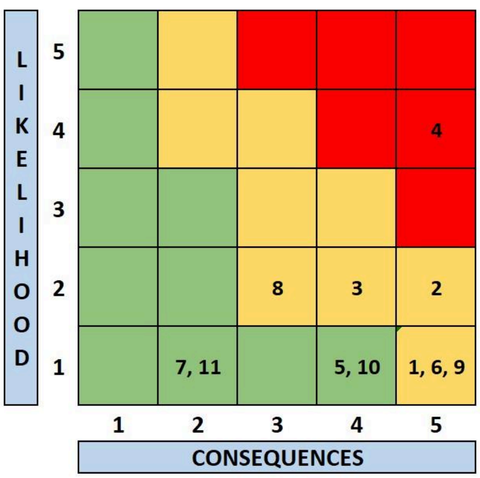
MECH-3	The contact rod should deploy the payload at angles other than 90 degrees	The lander is most likely not going to land perfectly vertical, in which case the contact rod must stil be able to deploy the payload	PR-5	TBD	Mechanical, Payload	Not Met
MECH-4	The ramp shall keep the payload cart from falling off the rear or edges	The payload deployment ramp must keep the cart from accidentally rolling off the sides once the deployment begins	PR-6	MECH-5, PAY-1, PAY-5	Mechanical, Payload	Not Met
MECH-5	The contact rod should not interfere with the landers structure	The contact rod should not damage the lander which may put the deployment of the payload at risk	MECH-4	TBD	Mechanical, Payload	Not Met
MECH-6	The pin of the contact not shall not damage the payload cart	Damage to the payload cart may prevemt it from deploying	PR-5, PR-6	PAY-1, PAY-2, PAY-5	Mechanical, Payload	Not Met
Level 3 (Subsystem/Component requirements)						
Descent Reqs						
DES-1	Descent subsystem will reduce the payload to a managable terminal velocity	If the paylaod does not slow to an expected terminal velocity, the state of the payload after touchdown may cause mission failure	PR-2, PR-4, DES-9, DES-10	DES-6, PAY-3, PAY-4	Descent	Not Met
DES-2	The parachute will fully deploy and reach the terminal velocity before touchdown	Parachute must deploy with enough time to show the lander to the expected terminal velocity	PR-2, PR-4, DES-7, DES-8	DES-1, PAY-3, PAY-4	Descent	Not Met
DES-3	Descent and landing system shall be completely enclosed within the volume of the lander at time of release	Provided by Project requirements	Customer	TBD	Descent, Mechanical	Not Met
DES-4	The descent/landing system shall increase the total lander volume to greater than the intial volume	Provided by Project requirements	Customer	TBD	Descent, Mechanical	Not Met
DES-5	Nothing shall remain attatched to the release mechanism once the lander is released	Provided by Project requirements	Customer	TBD	Mechanical	Not Met
DES - 6	The descent subsystem shall ensure the lander touches down in the upright position	Landing at an angle increases the likelihood of the contact rod not deploying the payload	DES-1, DES-8	DES-7, DES-8	Descent	Not Met
DES-7	The parachute lines shall deploy without tangling	Adding a drogue chute to help the main canopy deploy increases the risk of tangled lines, these lines should not tangle during or after deployment	DES-2, DES-6	TBD	Descent	Not Met
DES-8	The parachute lines shall deploy without snapping or dislodging	The increased mass of the lander will increase the force once the parachute deploys, the lines must be able to withstand the force of this deployment	DES-2, DES-6	TBD	Descent	Not Met
DES-9	The drogue chute shall successfully deploy the main parachute from the lander	The drogue chute will be able to pull the main paradchute out once the drogue chute is fully deployed	DES-1	TBD	Descent	Not Met
DES-10	The drogue chute shall deploy quickly	The main parachute relies on the deployment of the drogue chute, the sooner it deploys, it gives the main parachute more time to lower the velocity to the terminal velocity	DES-1	TBD	Descent, Mechanical	Not Met
Payload Reqs						
PAY-1	The payload will roll out onto ground with full view of the sky	Mission success criteria states that the payload shall have full view of sky or be in contact with ground	PR-7, PR-8, MECH-4	TBD	Mechanical, Payload	Not Met
PAY-2	The payload should cover the distance of shroud lines before the canopy touches down	The distance of the shroud lines in additon to the height of the parachute must be covered in order to ensure the payload will not be covered	PR-7, PR-8	TBD	Mechanical, Payload	Not Met
PAY-3	The Scientific Payload shall withstand the force of landing	The PICD states that the scientific payload can only withstand a force of .6J	PR-2, DES-1, DES-2	TBD	Payload	Not Met
PAY-4	The payload cart shall withstand the force of landing	Upon testing, the first design of the cart was not able to survive the force of landing and failed to deploy the cart.	PR-2, DES-1, DES-2	TBD	Payload	Not Met
PAY-5	The payload cart shall be able to roll on the provided landing mat	The wheels of the cart must be able to roll on the mat in order to deploy properly	PR-7, PR-8, MECH-4, MECH-6	TBD	Payload, Mechanical	Not Met

Fig. 6 Mission Requirements

Since the last submission of the requirements table, the payload deployment subsystem team had conducted tests to better understand the forces of which the cart and payload could withstand. In addition to this, the descent/landing subsystem team had added a drogue chute to the design. Using these tests and prototypes, more requirements have been added to further break down the overall project and understand the steps that need to be taken in order for mission success.

5. Risks

5.1 Risk Chart



Criticallity
HIGH
MED
LOW

Prototype Lander Risk Summary

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Contact rod fails to touchdown	1	5	→	R	The contact rod must be designed to successfully deploy the payload upon landing. If the rod is not a succient length or lands in a hole, it may not have the ability to make contact with the landing zone.	Active
2	Payload pin fails to deploy payload	2	5	→	R	The pin of the conatct rod holding the payload needs to be able to reliably release the payload without fail.	Active
3	Payload dislodges during descent	2	4	→	R	As the payload descends, the air resistance or initial forces of the parachute deployment may cause an accidental release of the payload. This requires the weight of the conatct rod or the design of the pin to be tested before a final drop.	Active
4	Payload is inverted upon landing	4	5	→	W	Upon touchdown, if the final velocity is too high, the payload as a whole is at risk of being inverted or deviating from vertical in some direction. This requires the descent and landing subsystems to keep the payload vertical at touchdown.	Active
5	Premature deployment of payload	1	4	→	R	The current design involves a door/ramp that lowers once landed, the slope of this ramp will provide the payload with the velocity to deploy properly. If released before the ramp is completely lowered, we risk the payload not deploying as intended.	Active
6	Parachute gets stuck in payload	1	5	→	W	The parachute must be able to reliably deploy. The current design is one already proven to be reliable, simply scaled up, testing is required for the new size.	Active
7	Suspension lines snap	1	2	→	R	Upon deployment of the parachute, the increased mass of the new payload in combination with the time it takes to deploy the parachute may have enough force to snap or dislodge the suspension lines of the parachute. This needs to be tested with different masses.	Active
8	Suspension lines tangle	2	3	→	R	The packing of the parachute may cause a tangle of the suspension lines. As a result, the different packing methods must be tested for consistency.	Active
9	Payload is blocked from deployment	1	5	↓	R	Depending on the landing zone, the payload door may be obsutructed and prevent a deployment of the scientific payload. This may require a resign based on a confirmation of the final drop site.	Active
10	Insufficient meeting time to work	1	4	↓	A	Sufficient communicatrion is a must between the different subsystems and therefore more outside of the class meeting times will be needed to work together and set group goals for the work needed.	Active
11	Project goes over budget	1	2	↓	W	The allotted budget for the project is $75. The final lander, excluding the costs of prototyping, must be within this range.	Active

LxC Trend
↓ - Decreasing (improving)
↑ - increasing (worsening)
→ - unchanged
NEW - added this week

L = Likelyhood (1-5)
1 = not likely
5 = extremly likely
C = Consequence (1-5)
1 = low consequence
5 = high consequence

Approach
A - accept
M- mitigate
W - watch
R - research

Fig. 7 Risks

5.2 Risk Mitigation

For the risks associated with the contact rod, this includes risks 1, 2, 3, and 5. This may be split into 3 categories, the contact rod during descent and the contact rod during landing. Risks 1 and 2 are very similar, both deal with the contact rod upon touchdown. When the lander reaches the landing zone, due to the uncertainty of dropping indoors or outside, there is a slight risk that the contact rod lands above a hole and fails to deploy the payload. As stated in risk 1, this has a low likelihood of happening as the outdoor location is the SDFC, which has fairly even grounds. Some brief scouting of the outdoor landing site to determine the minimum height of the contact rod to ensure it can deploy over any uneven terrain will suffice as research for this. Once landed, the 2nd risk states that although the contact rod will touchdown properly, the pin itself might not release the payload as it was designed to. The initial likelihood of this happening is set at 2, once prototyping begins, this will go down as we settle on a design to best release the payload reliably.

The contact rod during descent, one issue that may arise is the payload dislodging during the descent. Either the air resistance against the contact rod is enough to lift the pin sufficiently to release the payload, or the force of the initial parachute deployment is enough to cause the payload to break free. As of right now, the likelihood of this is uncertain, however this would require lots of testing in a manner which will ensure the prototype remains intact. This risk cannot currently be mitigated, and must go through a long and extensive testing process to more accurately determine the likelihood of a false deployment. Similarly, risk 5 is a premature deployment of the payload upon landing. The forces of landing may cause the pin to release the payload prior to the ramp/door opening completely. Based on the ideas for an initial design, this was a large topic of discussion in which it was decided that a proper design should allow the payload to game velocity down the ramp at a very slow rate and allow the ramp to fully deploy.

Landing specifically includes risks 4, deviation from vertical at touchdown, and risk 9, the ramp being obstructed from deployment which would cause mission failure as the payload would not be able to be deployed. After observing the drops of the parachute mini project, it became clear that a large majority of the payloads were not slowed down to a low enough velocity to prevent it from bouncing off the ground before becoming completely inverted. The current idea to prevent this, is to design a much larger parachute using a scaled up design of a parachute that was proven to work well during the parachute mini project as well as deploy very quickly. Landing legs added protruding outwards may also reduce the chance of inversion as the wider base will prevent tipping to any one side more than another. Although risk 9 was initially set at a 2 in likelihood, upon the stated preference of the outdoor drop zone, this was reduced to a 1 as there would be fewer possible obstructions to prevent a deployment of the ramp.

For the descent subsystem alone, risk 6 discusses the possibility of the parachute failing to deploy by getting stuck in the payload, whereas 7 and 8 discuss the lines snapping or tangling respectively. Although a failure of parachute deployment would result in a destroyed landerand failed mission, the current parachute design had deployed quickly and reliably during both drops on the final day of the parachute mini project. 7 and 8 both require testing of the new design to better understand how many lines can be tangled/snapped while still lowering to a low enough terminal velocity. Both risks 7 and 8 must be tested before their consequences and likelihoods can be better understood.

Aside from risks related to the different subsystems, there are also risks that affect workflow and productivity. Risk 10 arose when the team had noticed there was an insufficient amount of time to get all the work done needed for the lander project. This was quickly mitigated by adding an additional meeting time on Sundays to discuss ideas of the lander as well as the work that must be completed for the given week. This has been moved to accepted as the extra meeting time has been enough to communicate the weekly work expectations. As for risk 11, this is related to the budget. Seeing as the budget for the final lander is $75, it is important to remain under this as going over budget would negatively impact the overall mission. Despite needing to stay under budget, calculations of the parachute mini project showed that materials cost for the parachute to be very low. This budget does not need any mitigation as of right now considering the extremely low risk of going over budget.

6. Schedule

6.1 Milestones

No	Milestone	Dates
1	Final Project Concept designs	9/24/24
2	Preliminary Design Review	10/9/24
3	Functional Models of Subsystem	11/4/24
4	Lander Submission	11/30/24

Fig. 8 Mission Milestones

The project began on September 2, 2024. The team conducted multiple meetings to discuss their individual CDR to finalize the best functional project concept for this mission. The team finalized a design in the last week of September. Following this, the team started working on PDR. For PDR, team members created schedules, mission success criteria, risks and requirements, CAD drawings for each individual subsystem, and even built a physical prototype. This PDR document will be submitted by October 9. Upon approval of PDR, the team will focus on the next milestone to create a Bill of Materials, procure materials, and actually build individual subsystems by early November. The team will then integrate, test, and iterate the final design until late November.

6.2 Gantt Chart

Fig. 7 Gantt chart

7. Conclusion

Team-1 has designed and created the concept and preliminary design of the Pi&ZA Lander, with the goal of safely descending a 95-gram payload from a height of approximately 80 feet and deploying it with direct contact to the ground, and if possible, a clear view of the sky. Following the Preliminary Design Review, the team will begin actively testing the prototype, making design and functional changes, and commencing the construction of subsystems for the final Lander. Upon successful testing of individual subsystems, the Lander will be integrated and tested as a whole. Thanks to the dedication of some team members, the project is currently on track to achieve the upcoming milestones: submitting final functional models of individual components by the first week of November and delivering the final Lander by late November. The team will need to make efficient use of lab timings for constructing the subsystems, and if necessary, arrange meetings outside official lab timings. All team members will be kept motivated to ensure an efficient and smooth workflow.