End-Item Data Package

Team 1: PI&ZA
Space Works 1 Workforce Development
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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

Requirements								
Req #	**Requirement**	**Rationale**	**Parent Req**	**Child Req**	**Relevant Subsystem**	**Req met?**	**Notes**	**Modifications after PDR**
Level 1 (Project requirements)								
PR-1	Lander shall successfully land and deploy a payload within target area	Provided by Project requirements	Customer	TBD	All	Met	The lander successfully landed and deployed a payload within the target area and to achieve this an apex vent was introduced by the end to ensure that the lander do not drift in case of heavy winds	
PR-2	Lander shall survive a drop from 85 feet	Provided by Project requirements	Customer	DES-1, DES-2, PAY-3, PAY-4	Descent	Met	The lander successfully have withstood a drop of at least 85 feet, as nothing was damaged or out of position after the landing.	
PR-3	Lander shall successfully integrate to the provided release mechanism and payload	Provided by Project requirements	Customer	MECH-1, MECH-2	Payload, Mechanical	Met	The lander has succesfully integrated into the release mechanism and the payload forming one single system.	
PR-4	Lander shall deploy at least one descent/landing system following release	Provided by Project requirements	Customer	DES-1, DES-2	Descent	Met	Atleast one of the descent subsystems(parachute) was deployed after the release	
PR-5	Lander shall deploy at least one payload deployment system after touchdown	Provided by Project requirements	Customer	MECH-1, MECH-3	Mechanical	Met	Atleast one of the payload deployment subsystems was deployed after the release	
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	Met	The payload was secure and intact to the lander during the course of the descent and only deployed after touchdown	
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	Met	The bottom(wheels) of the payload was successfully in full contact with the ground	
PR-8	The payload shall have a clear view of the "sky"	Provided by Project requirements	Customer	PAY-1, PAY-2, PAY-5	Payload	Met	The payload rolled down the ramp and had clear view of the sky after the touchdown	
PR-9	The overall project costs should lie within $75	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Met	The project expenses lied within $75 dollar range	
PR-10	The lander(undeployed) should lie within 25cmx25cmx25cm	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Met	The volume constraints of the lander was met	
PR-11	The overall project mass(without the payload) should lie within 400grams	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Met	The mass of the system(lander, payload amd parachute) together weighed under 400 grams.	

Figure 1: Project requirements table

The mission objective is to successfully land a planetary lander and deploy a scientific payload within the target area. It is required for the lander to successfully integrate to the decided release mechanism and the payload. After the release before the lander touches the ground, it is necessary for the payload to be secured to the lander during descent and be only deployed after it lands. Moving further, the lander should deploy at least one descent/landing system after the release and should deploy at least one payload system after touching down on the ground. Once it lands the payload shall be in direct and full contact with the ground for landing legs to rise and release the payload cart for it to roll on the ground and have a clear view of the sky. But prior to meeting all these requirements it is necessary for the lander to survive the drop from a height of at least 85 feet in a way that it does not damage any lander parts, payload cart or the scientific payload itself. The physical dimensions of the project constraints the lander(along with the payload and descent subsystem) to lie within the volume of 25 cm x 25 cm x 25 cm and weigh less than 400 grams(without the payload). The overall budget of the project should not exceed $75 in total.

1.2. Concept of Operations

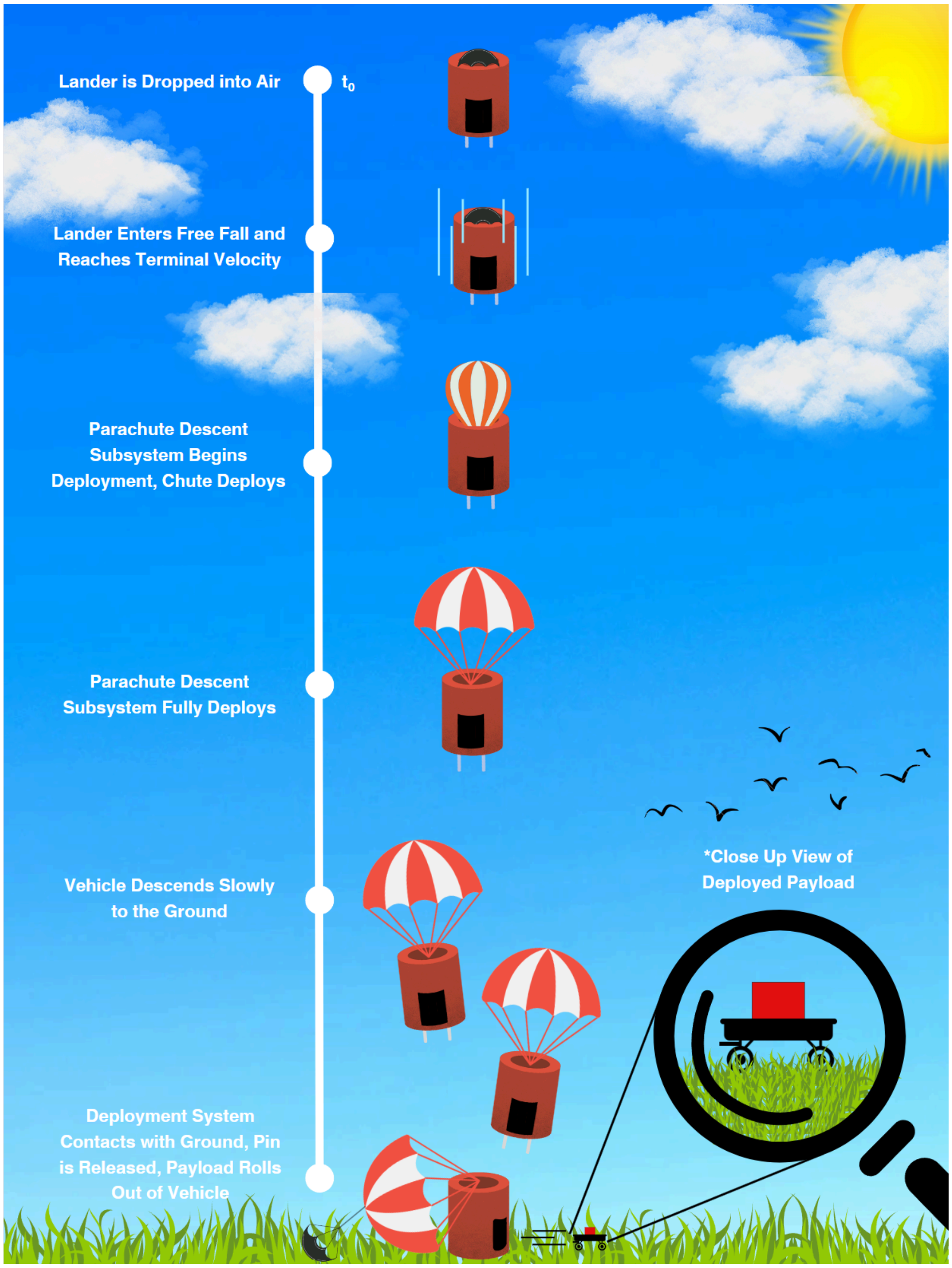


Fig 2. Concept of Operations

2. Overall Lander Design

The final lander design was intended to keep each subsystem as simple as possible. The idea behind this design being that with less moving parts, there will be a lower chance of any failures of the subsystems. This led to creating a lander with only 1 moving part needed to deploy the payload, shown below.

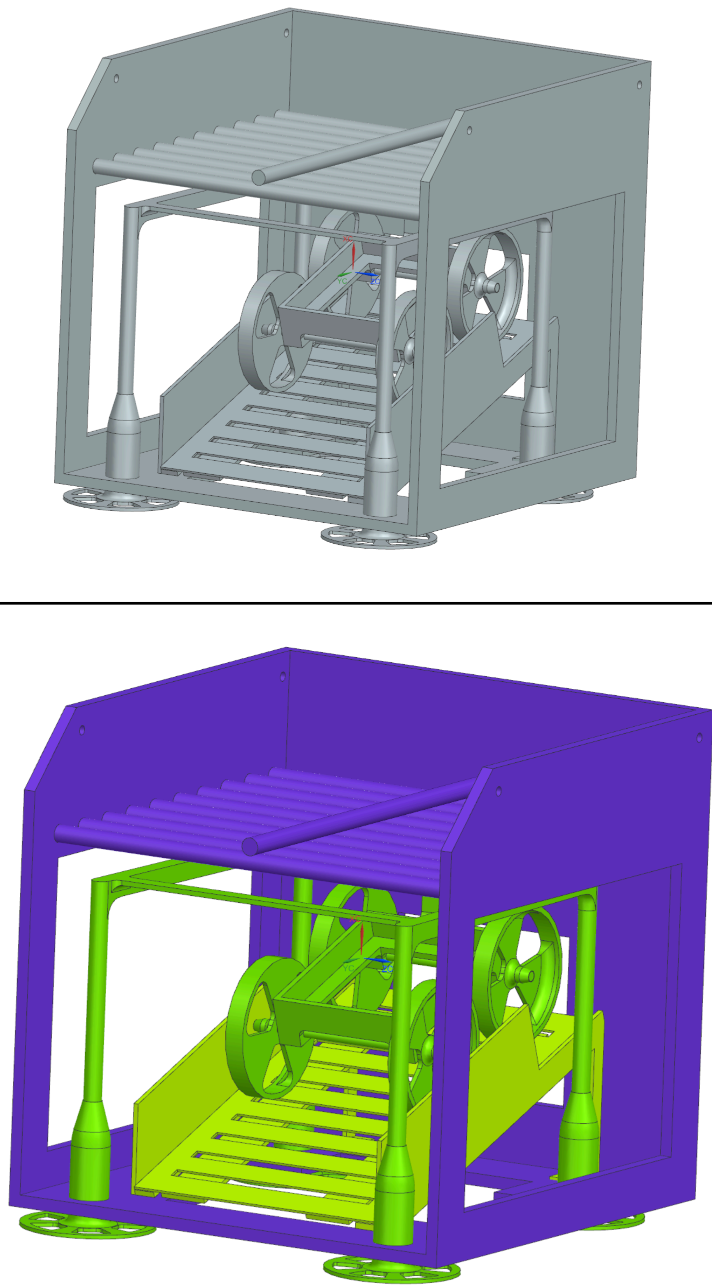


Fig. 3 Final Lander Design

The main chassis of the lander was made of cardboard for its lightweight and low cost, shown in purple. The rods above are where the parachute will be stored before the drop. The rest of the lander includes the contact rods, landing feet, ramp frames, ramp supports, ramp, the cart, as well as the wheels. All of which together make up the payload deployment subsystem, shown in green. The entirety of the payload deployment subsystem was 3d printed for accuracy, rapid prototyping, and reliable testing.

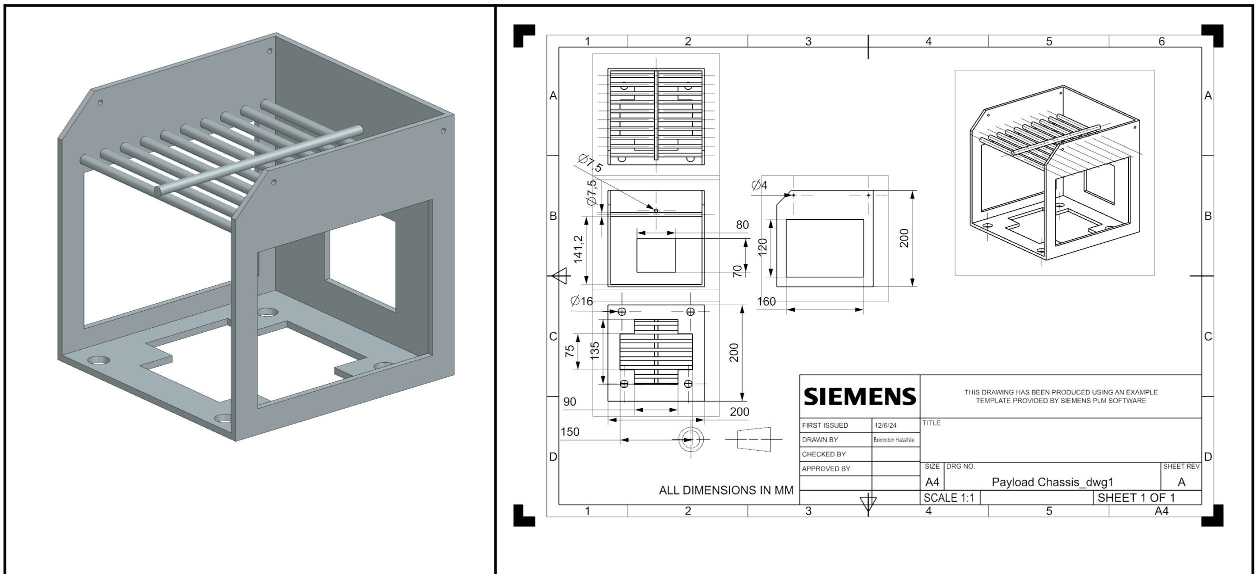


Fig 4 Chassis Model and Drawing

To keep minimal moving parts and create a reliable parachute deployment, the chassis itself was designed to have as much air flowing through the body as possible. With that idea in mind, the left and right walls of the lander were cut out large enough to let air flow through while still having enough to support the structure of the lander without deforming. Due to the ramp being installed, the back wall could not cut the same as the left and right due to the ramp frame limiting the width of cardboard that could be removed. The front of the lander has no wall at all which allows, not only an easier install of the contact rods, but also a larger footprint of contact rod which can be installed. Holes for the contact rods and feet to pass through were made at the corners of the lander. Finally, the rods above were made from chopsticks and served as a compartment for the parachute to be stored in, the rods allowed for good airflow and a large area for the parachute which reduced the risk of the parachute not being deployed due to friction keeping it in, or getting caught on the lander and tangling which would cause a lack of deployment or incomplete deployment.

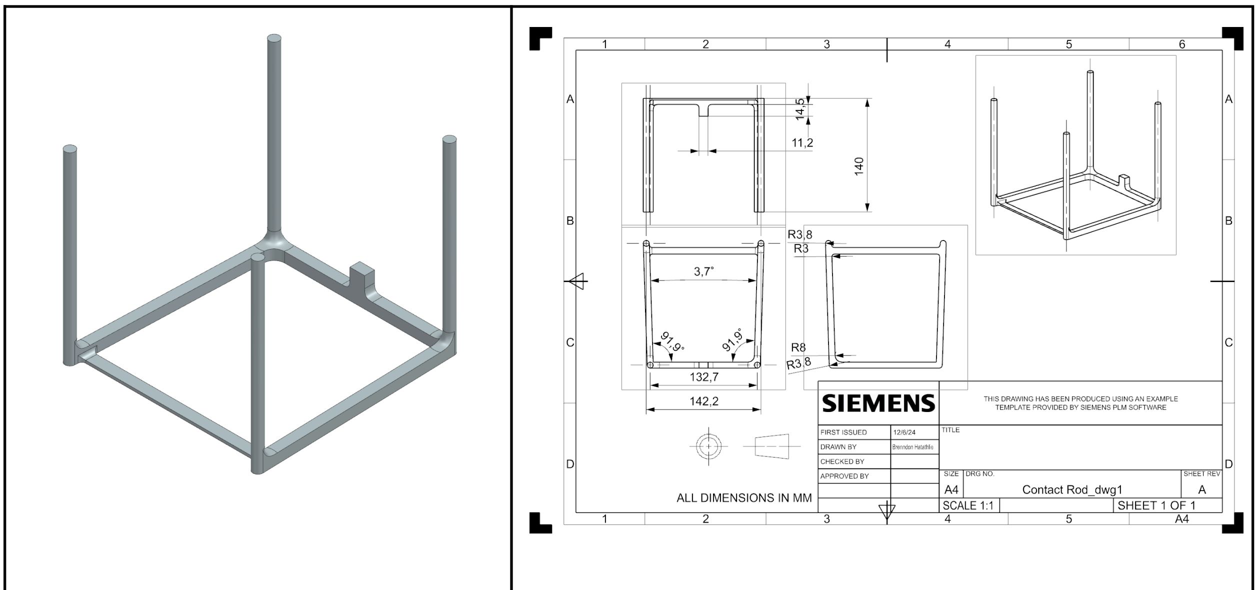


Fig. 5 Contact Rod Model and Drawing

The contact rod was designed to be the only part that is needed to move in order to deploy the payload. The height of the rods was modeled to have .5 centimeters of clearance between the the top of rods and the rods holding the parachute once fully deployed. The taper between the front and back legs was made to fit the holes created in the chassis. The small bar near the front was created to add stability to the rods and prevent undesired flexing. All the corners have been filleted as this better distributes the force rather than a stress point at which the legs would break. However the most important part to keeping the overall design minimal was the rectangular pin which holds the cart. The rectangular design keeps the payload cart oriented facing the front of the lander during descent which a circular pin would not be able to guarantee. The contact rods hold onto the cart via gravity and only release once the pin is raised, when the feet make contact with the ground.

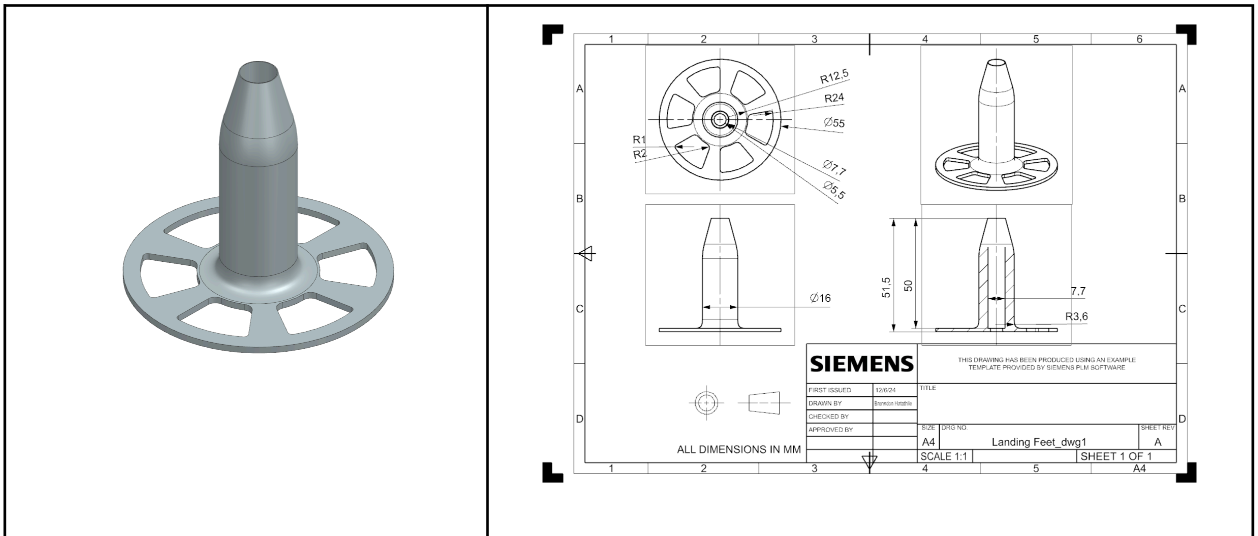


Fig. 6 Landing Feet Model and Drawing

The feet of the lander were created to reliably deploy on grass. Although the risk of the legs touching down with enough force to get stuck in the ground rather than raising the pin was low, the feet made sure this would not be a problem as the wider surface area ensures the legs cannot get stuck in the soil. They fit onto the legs of the contact rods after the rods have been installed. Towards the top of the landing feet, there is a chamfer as well as a fillet, this is to ensure that if the feet were to fall below the holes in the chassis body, they can still smoothly guide themselves back through without failing to deploy the payload. The holes in the feet were added to reduce the risk of air resistance raising the contact rods during deployment, as well as to reduce the overall weight of the lander.

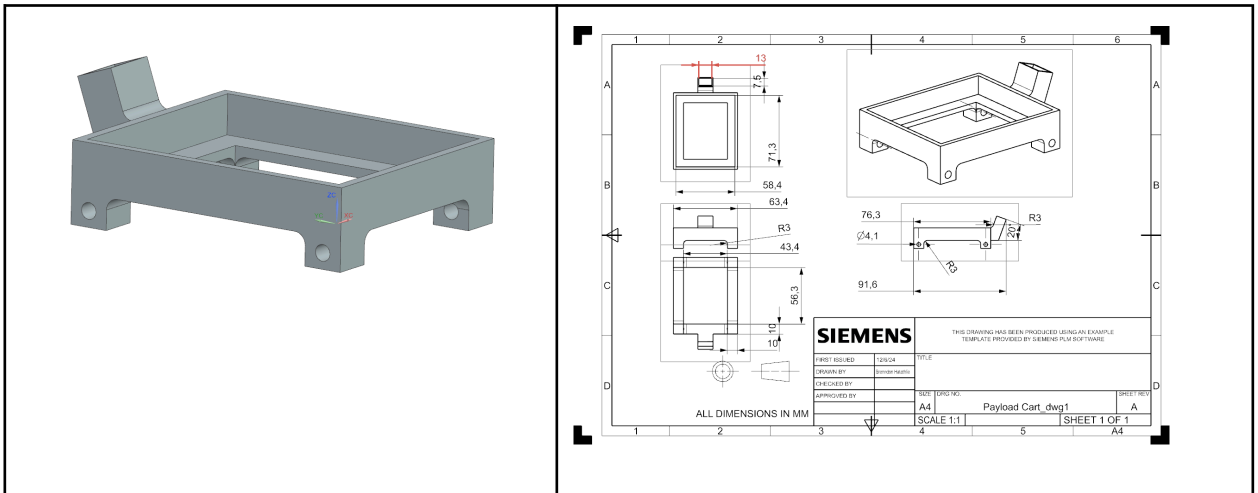
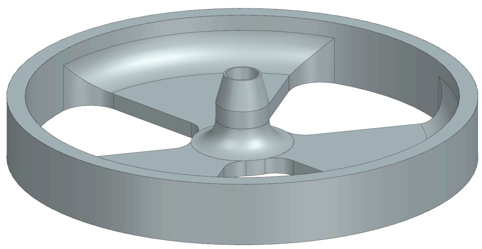


Fig. 7 Payload Cart Model and Drawing

For our method of payload deployment, a cart along with wheels was decided to be the best option as it would allow the payload to travel a longer distance away from the lander which reduces the risk of being blocked by the falling parachute. The Large opening in the center of the cart was made to reduce the weight of the cart while still allowing enough room for the payload to fit snugly. The models show a hole on the four pegs where the axle would fit, when printed, these four pegs were solid. Once an axel was chosen for the cart, holes were drilled which matched the diameter of the axel. The slot where the pin will be stored is angled at 20 degrees which matches the slope of the ramp. As with the other models, fillets were added at any sharp corner which may be taking lots of stress.



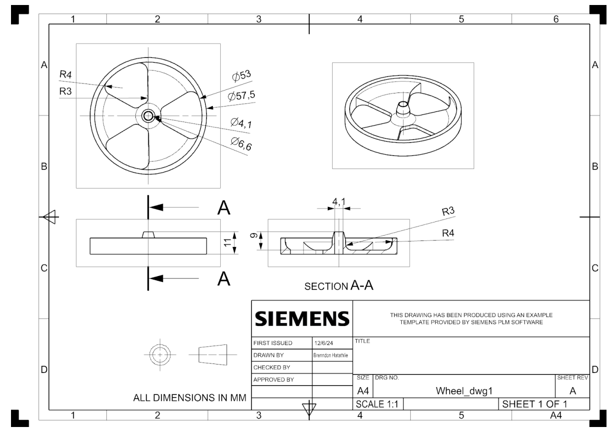


Fig. 8 Wheel Model and Drawing

Similar to the landing feet, the wheel design was created with the idea of landing on grass. The wheels were created large enough so ensure a smooth transition between the ramp and the grass. The large wheels would have a lower likelihood of getting stuck in the grass or in any small holes which may be present in the grass. The cutouts from the wheels not only made the wheels lighter, but also stronger as a result of how it was printed. This allowed for more wall loops along the inner portion of the wheel. The cylindrical portion where the axle fits was designed to protrude slightly, acting as a spacer, which prevents the wheels from rubbing against the cart itself and impeding the ability to rotate evenly. Although printed as shown in the drawing, 2 of each were glued together to create a thicker wheel which is better for clearing any small obstacles which may be present on the grass. Once glued together, the overall length for the axle to fit is almost 2 centimeters long. Although this was not considered when designing the wheels, this extra length helped prevent the wheels from wobbling on the axle and creating unpredictable movements.

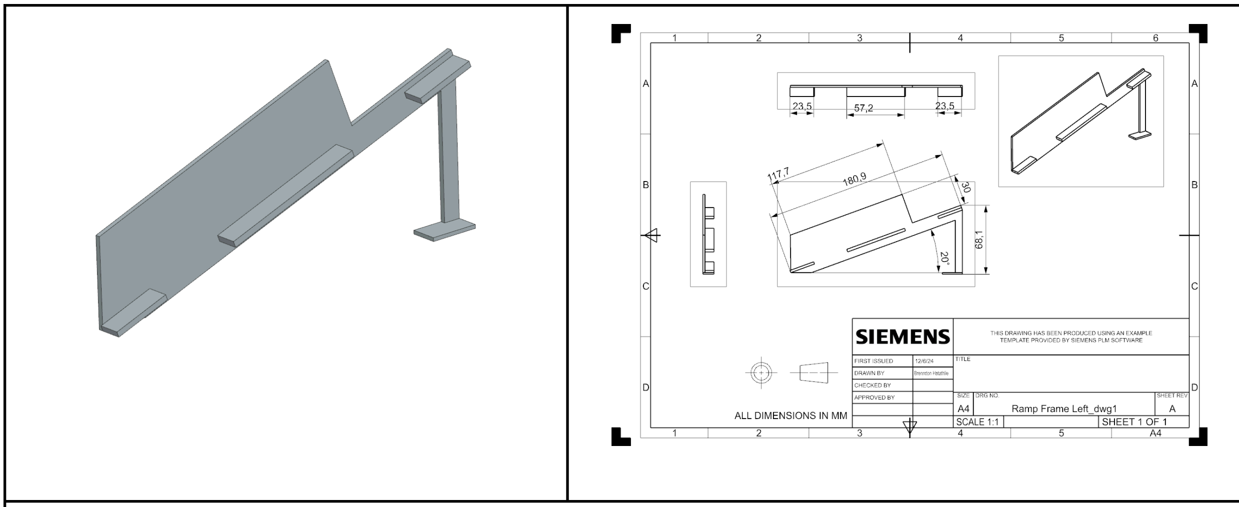
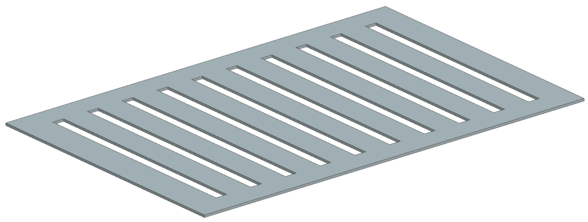


Fig. 9 Ramp Frame Model and Drawing

The ramp frame was made to keep the ramp at a predetermined angle, as well as provide surface area to sufficiently bond the ramp in place. During initial testing of the cart, 20 degrees was the best angle we found to ensure the cart gains enough velocity to roll while ensuring a smooth transition from the ramp to the ground. The cut out sides of the ramp were initially created to reduce the risk of blocking the landing feet from fully deploying and failing to deploy the payload. This also had reduced the weight by a large amount. Finally, the raised lip towards the bottom was created to make sure the cart does not get caught on the contact rods if it were to turn slightly while rolling down the ramp. Another mirror image of this ramp was created as well to support the other side of the ramp, all dimensions are the same.



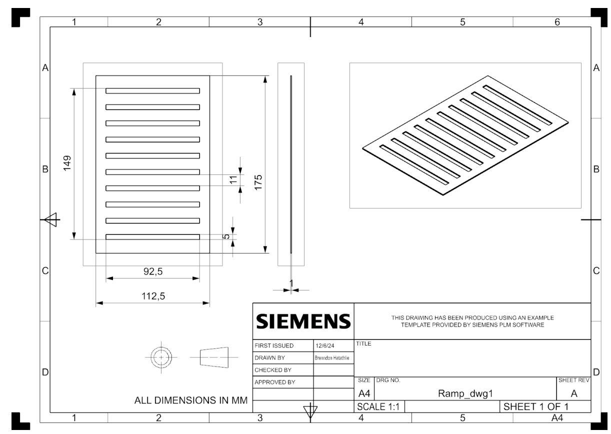
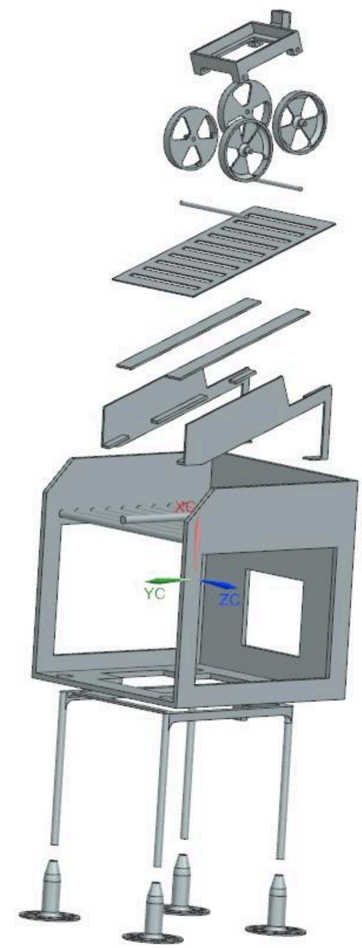


Fig. 10 Ramp Model and Drawing

The ramp was modeled with a width which provides sufficient room for the payload cart to roll down while allowing as much room as possible for the landing feet to raise properly. Horizontal slats were created to further reduce weight while allowing extra airflow without impeding the wheel's ability to roll properly.


XC
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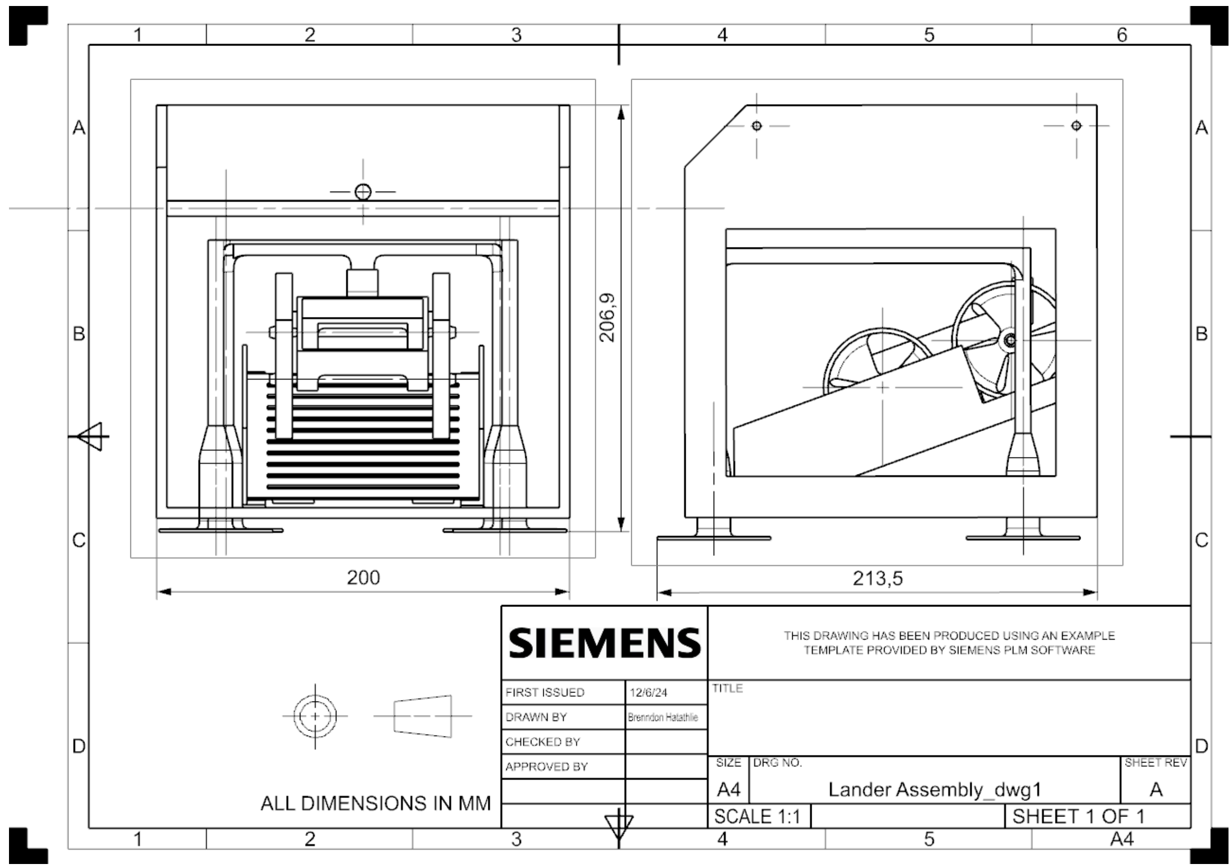


Fig. 11 Exploded View of Final Assembly and Drawing

The drawing shows the intended packing and assembly of the lander and its components. The overall height of the lander, including the undeployed contact rods, is less than 25 centimeters in height.

2.1. Landing/Descent Subsystem (4-5 pages)

In order to slow the lander down to a speed deemed safe for payload deployment, the group decided to use a parachute that would deploy as the lander was falling. Once a parachute was picked to be the descent system for the lander, the parachute size was calculated by balancing the estimated coefficient of drag with gravity to determine the size that would produce a specified terminal velocity. The group balanced the forces on the assumptions that the approximate coefficient of drag of the parachute would be 1.5, and the target terminal velocity would be 3m/s. The coefficient of drag was estimated by using previous empirical studies on domed parachutes. A terminal velocity of 3m/s was chosen because it was slow enough to ensure that the lander would impact the ground at a safe speed, ensuring that nothing broke and the payload would easily be able to deploy. The coefficient of drag assumes projected area (a circle). The calculations went as follows:

$$F_d = F_g$$

$$\frac{1}{2} A\rho C V_{ter}^2 = mg$$

$$A = \frac{2mg}{\rho C v_{ter}^2}$$

$$A = \frac{2(0.5kg)(9.8m/s)}{(1.225kg/m^3)(1.5)(9m^2/s^2)}$$

$$A = 0.59m^2$$

*F_d = Force of Drag, F_g = Force of Gravity, A = Projected Area, ρ = Air Density, C=Coefficient of Drag, V_{ter} = Terminal Velocity, m = Mass, g = Acceleration due to Gravity.

Knowing that A = πr^2, the radius of the parachute was estimated to be 0.43m. Which equates to about 16.9 inches, or 33.8 inches for diameter.

The parachute used in the final lander configuration was a model rocket parachute made of nylon ripstop cloth that was 36 inches in diameter when laid flat. As calculated above, this was nearly the perfect size to slow the lander to the targeted terminal velocity. The parachute was actually slightly bigger than the calculated diameter, which was an added bonus because area and velocity are inversely related. This meant that the parachute would actually cause the lander to fall even slower than intended. Though, it is important to note that this effect can only be used to the extent of parachute size and weight becoming a limiting factor for lander performance. This parachute was made by Apogee, a well known model rocket company, and was purchased off of Amazon for $18.69. The group opted to use a professionally produced parachute for the following reasons:

1. The parachute was the most important part of the lander to ensure its safety when dropped from significant heights. Reliability was extremely important, and the purchased parachute had been tested and reviewed by others, so it was proven to work as intended time and time again.
2. It was lightweight and durable. The only other material anyone in the group had used for a parachute prior to making the lander was mylar, which is lightweight, but is also easily subject to wear and tear. For this project, it made sense to have a parachute that could be tested numerous times, in any environment, and have virtually zero risk of anything breaking or tearing.
3. It saved time. Making the parachute by hand would have been a labor intensive process. Precision is important with parachutes, as they must be perfectly symmetrical or they may not provide a smooth descent. Buying a parachute completely removed the labor that

would have been needed to perfect a parachute, and allowed the team more time to work on other tasks.

4. The group had more than enough money to do so. Everything used in the construction of this project was relatively cheap, and with so much budget to spare it was not an issue at all to buy a nicer parachute.

Below are images of what the parachute looked like on the Amazon listing:

Fig. 12 Parachute Amazon Listing

As expected, the parachute looked exactly as pictured in the listing. Though, when the parachute arrived, it was surprising to see that instead of eight individual shroud lines, the parachute lines were actually loops that attached to two opposite points on the parachute. This turned out to be convenient because by attaching the midpoint of the loop to the lander, the loop essentially became two individual shroud lines of equal length with no tying necessary, and no risk of the lines coming apart. So, the four loops were essentially eight very strong shroud lines tied at their midpoint to the lander. Additionally, since the lines began and ended at a point attached to the parachute, they almost never got tangled.

Before deployment, the parachute was placed atop a sort of scaffolding made out of chopsticks at the top of the lander. The chopsticks allowed for a lightweight, sturdy structure that allowed as much airflow as possible to pass through. This structure can be seen in the image below:

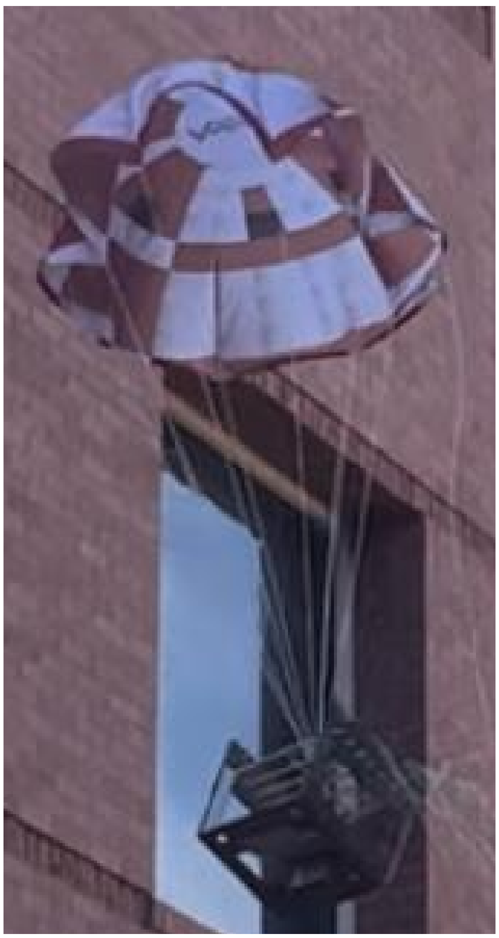
Fig 13 Stowed Assembly

On top of this scaffolding, the parachute was packed in the orientation the group empirically determined to be the most optimal for parachute deployment, called the “flower” method by the project manager, Hitul. This "flower" method both allowed the parachute to deploy as fast as possible, and as frequent as possible. To create this packing orientation, the shroud lines were wrapped in a neat coil, and the parachute was then folded into quarters and placed on top. After the parachute was neatly resting on top of the shroud lines, which were on top of the scaffolding, the center of the folded parachute was held, and the entire chute was twisted 180 degrees. This reduced the area of the packed parachute without introducing more folding, allowing it to fit inside the area of the lander while giving it its characteristic spiral pattern, resembling a rose. Packing the parachute this way every time ensured the best chance of success on drop day. The "flower" packing method can be seen below:

Fig. 14 Flower Packing

Lastly, the 10 ft long shroud lines that connected to the drone were attached to the corners of the lander via binder clips.

Once the lander was dropped, the parachute would catch air through the scaffolding and the drag would carry it out from the top of the lander. Once out of the lander, the parachute continued to “catch” more air until it was fully deployed. Full parachute deployment looked like this:



The loose lines in the image are the 10 ft lines that would have connected to the drone. It is difficult to see, but the parachute was connected to the center of the chopstick scaffolding using a binder clip. At the last minute, three days before the official drop date, the group decided to cut a 4 cm diameter apex vent, because the wind was causing the lander to drift during its descent, and the apex vent was an attempt to minimize this effect. Unfortunately, since this change was made late into the project lifetime, it is unclear whether or not it helped with decent stability. The apex vent is not pictured in this image.

Fig. 15 Successful Parachute deployment test

The deployed parachute attached to the lander was modeled in NX CAD and is featured below:

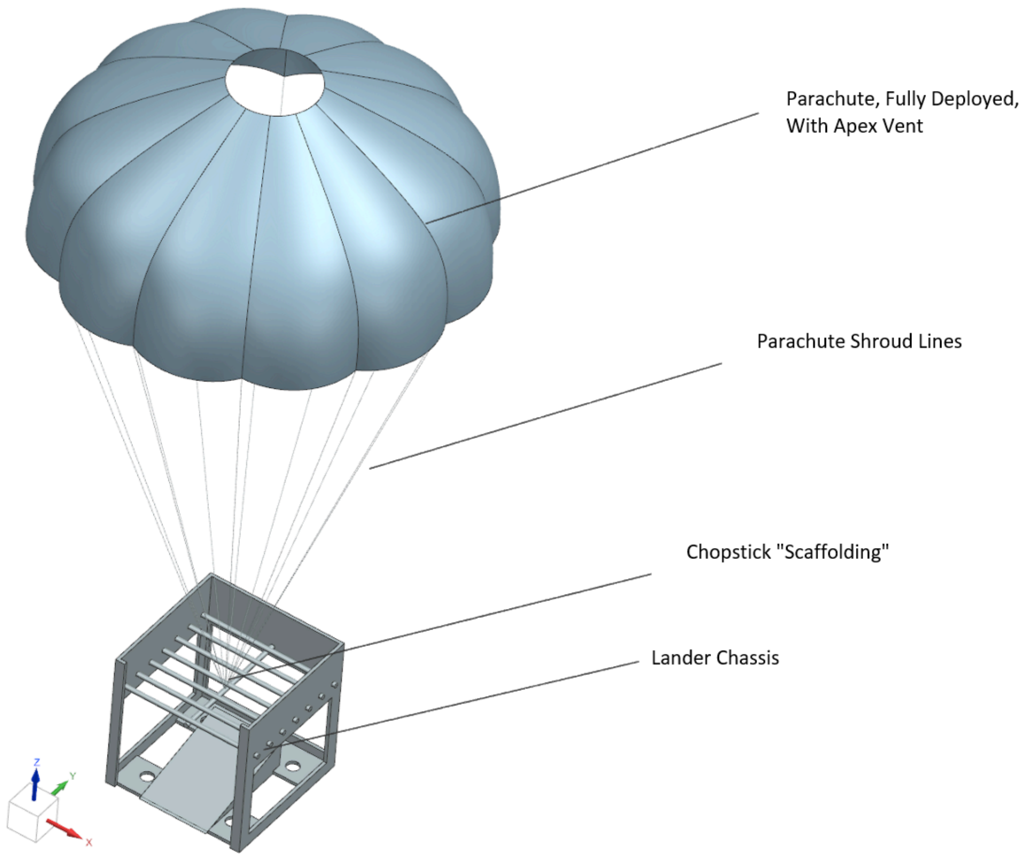


Fig 16 Deployed Assembly CAD Model

On drop day, the parachute successfully deployed as it had in previous testing, and the lander slowly descended to the ground. There was much more wind than the group had prepared for, so when the lander hit the ground, even though it was not travelling that quickly vertically, it had a decent amount of horizontal velocity that was not calculated for. This caused the lander to roll over. Despite the rolls upon landing, the payload still deployed from the lander and it remained completely intact, deeming the project a success.

2.2. Payload Deployment Subsystem

To ensure the best possible chance for payload deployment, the payload deployment subsystem was designed with a few main components: connector rod, ramp, and cart.

The connector rod is the most important part of the payload deployment subsystem. The connector rod was designed with four legs connected to each other in a square shape, with one side left open as depicted below:

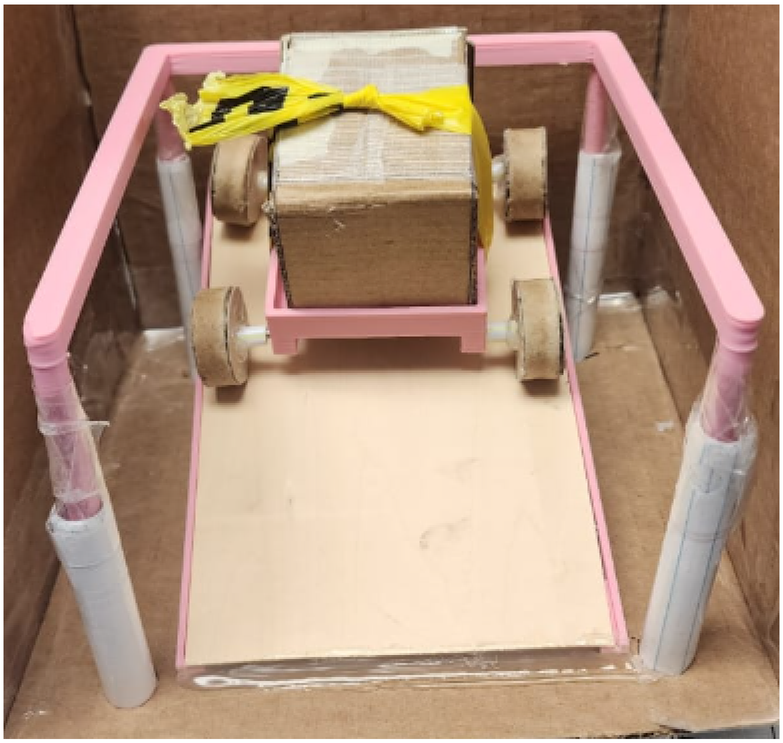


Fig. 17 Prototype Model

The side that was left open is key, because it allows the deployment of the payload without the risk of hitting the top of the connector rod. The connector rod was designed with a peg that protrudes in the back to connect to the cart. When the lander is held in the air, the connector rod, due to gravity, will fall through pre-cut holes in the lander bottom. The force of gravity alone will hold the connector rod into the cart, preventing it from falling down the ramp.

The connector rod was also designed with thicker sleeves and stoppers to go over the bottom half of the legs. This allows for greater friction between the lander body and prevents the connector rod from detaching from the lander body. In the picture above, the connector rod sleeves were first made out of paper to test if they helped with friction and in the deployment of the payload. In the final product, the sleeves were 3D printed to fit exactly with the legs and the holes in the lander body. The next major component is the ramp. The ramp was designed for a critical angle of 20^{o}. This allows the cart to freely fall down the ramp when there isn't a force acting against it. In this case, the force would be the peg from the connector rod. The ramp is then hot glued to the lander body to form a stable connection preventing the ramp from any translational movement during free fall or impact. The ramp was initially designed from two 3D printed supports hot glued to the bottom of the plywood ramp surface. The final design was a full 3D printed structure ramp. Finally, the cart that delivers the payload was meticulously measured and crafted to ensure the payload didn't detach. The cart was 3D printed to create a pressure fit between the payload and the cart. The payload was secondarily secured via caution taped tied around the cart body and the payload as a form of redundancy. The cart initially had cardboard wheels as shown in the picture above. The cardboard wheels allowed for testing that didn't jeopardize the more important 3D printed wheels. Once it was shown that the cart was able to successfully deploy out of the lander, 3D printed wheels were attached. Another key component of the cart is the peg attachment in the back. This attachment is what connected the cart to the connector rod in order to prevent the free rolling of the cart down the ramp. With all of these items in place, the lander should look like the picture below:

After the lander is dropped, the post-deployment picture is similar to the test shown below:

Fig 18. Test Drop Pre Vs Post Landing Images

Finally, calculating the impact energy is an important part due to the restrictions of the design. This was achieved by solving for a parachute size that allowed a max impact force of 0.6J while having max mass. Solving it this way allowed for the maximum values to be accepted, and by therefore having less mass than the max in the final design, would passively allow for a lesser impact force of 0.6J. The greatest energy into the payload will be due to acceleration during impact. Assuming there is no buffering of the impact– the payload accelerates instantaneously from its falling velocity to 0 m/s–the max impact energy will equal the kinetic energy. Since is the kinetic energy of the payload, the mass of the payload is used rather than the mass of the entire lander. The mass used below is 0.1 kg, the maximum mass of the payload. The actual payload mass is 0.095 kg, which if substituted below would increase the maximum allowable velocity.

Kinetic energy of the payload immediately before impact:

$$KE = (1/2)mv^2 < 0.6\,J$$

Solving for velocity yields:

$$v < \sqrt{\frac{1.2}{0.1}}m/s$$

$$v_{max} = 3.46\,m/s$$

3. Data Analysis

The pipeline for processing the data is shown below. The scripting for the full analysis (including raw data) can be found in this github repository: https://github.com/Haloshs123/ses307-analysis

Analysis Pipeline:

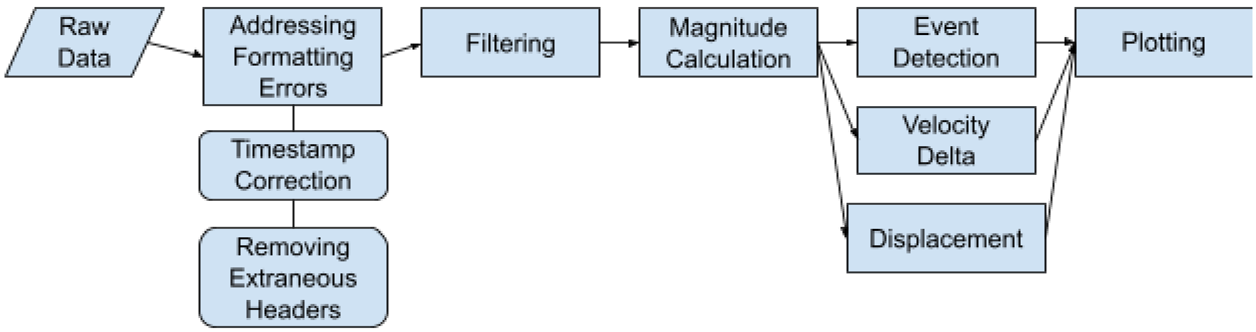


Fig 19, data analysis pipeline.

Raw Data:

The raw data includes 3-axis accelerometer data from each of two drops. Each drop includes an estimated 300 seconds of data with an entry recorded every 0.15 seconds. This data includes information on both the ascent and drop, though the drop only comprised the final ~15 seconds of data. Additionally, the "OCT12F1" example dataset was analyzed through the same pipeline to act as a comparison for the actual drops.

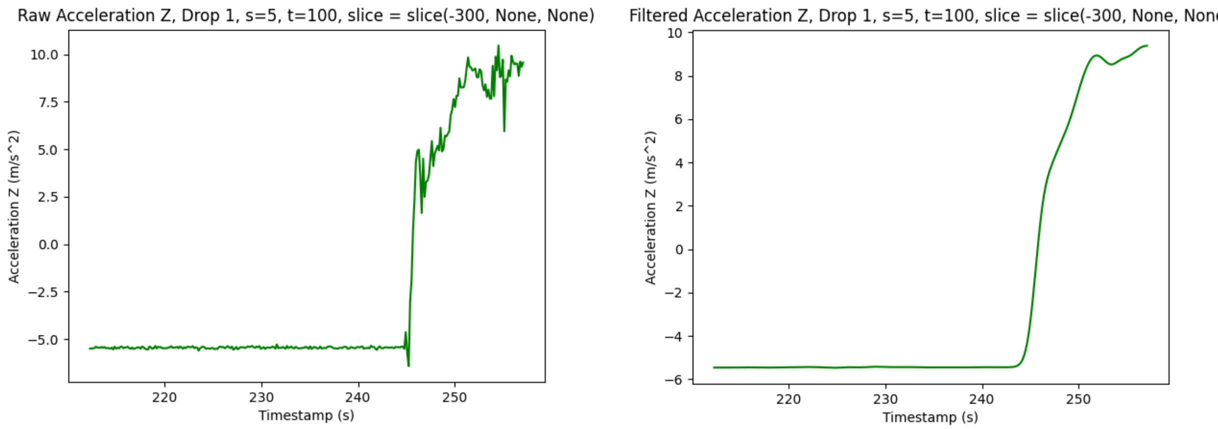
Data Cleaning

There were two major formatting differences between the comparison data and the actual drop data. The first was an error present in the Drop 1 data, which included two extra header rows about 50 and 70 lines into the file. These were manually removed, and no similar errors were found in any other data files. The second was a lack of time indexing in the two drop data files. Since each example drop data used a time step of 150 ms, the same was assumed for both actual drops and a time column was added to each dataset for indexing.

Additionally, since the only relevant data was during the drop at the end of the dataset, each was trimmed to only the final 40 seconds. This is especially important as acceleration early in the dataset (that wasn't related to the drop itself) had more time for velocity and displacement to compound and would become more significant than the actual drop data's velocity & displacement.

Filtering

All datasets contained a significant amount of noise in the raw data, which made it difficult to ascertain the actual motion of the payload beyond determining that "something" was happening during a particular period. A wide (sigma = 5) Gaussian filter was applied to each dataset to smooth the acceleration for magnitude generation and event detection, since this allowed individual high/low points to still influence the overall trend but not appear as sudden changes in acceleration.



<fig 20>, Plots of the z-axis acceleration from Drop 1, before and after applying a gaussian filter.

Based on the videos of the drop, there is (unaccounted for) a significant portion of acceleration that occurred laterally and rotationally. These accelerations are included in the overall acceleration magnitude below, and increase the calculated velocity and displacement. This is very pronounced in the second dataset, where after reaching a velocity plateau, the velocity later continues to drop during the descent. This rotational acceleration was not removed in this analysis. Supplementary analysis could be done to remove it with a fourier transform and low pass filter.

As the final correction before analyzing the data, the overall acceleration magnitude was reduced by its median. It was noted that the acceleration magnitude was ~10 m/s^2 for most of the recorded datasets (except during the drop and other detected events). This is due to earth's constant gravitational influence, and if taken at face value indicates that the accelerometers were falling unopposed for most of the duration of the recording (a total distance of about 8 km for the 40-second example datasets and about 400 km for the 300-second actual datasets). Since this gravitational factor was the recorded acceleration magnitude for most of the drop, the median (which is this factor) was subtracted from the overall magnitude, effectively shifting the graph by 9.8 m/s^2.

<u>Magnitude Generation</u>

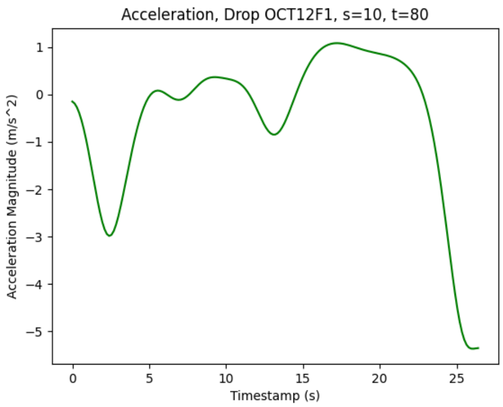
Since the payload was (by nature of the design) not upright during descent, the actual downwards acceleration is not represented by a single axis of the accelerometer. Taking each accelerometer axis to be orthogonal vectoral components of the net acceleration (from the payload's reference frame), the magnitude of the acceleration was calculated and is plotted below. If the payload were an inertial reference frame relative to a grounded reference frame, it would be trivial to transform between the two and determine the actual descent velocity/distance. However, the payload began rotating even before release, and since no rotational information is known (such as from a gyroscope), we cannot transform between the descent in a grounded reference frame and the accelerometer's reference frame. Thus the components of acceleration due to the revolution of the lander under the parachute remain unaccounted for. Without this correction, the magnitude data below is a significant overestimation of the actual descent acceleration, velocity, and displacement.

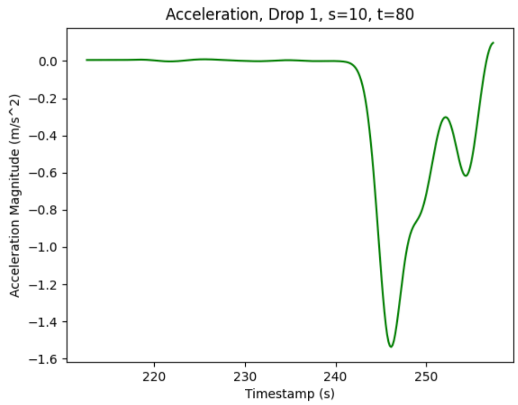
Event Detection

Since the data was smoothed, significant rapid changes in acceleration will only be recorded when there is an actual significant change in the motion of the payload. The change in acceleration for each time step was calculated and values above a threshold were flagged as “events,” such as parachute deployment or ground contact. These are plotted below the acceleration data.

Velocity Magnitude & Displacement Estimations

Numeric integration was performed on the acceleration magnitude to generate rough estimates for the change in velocity magnitude throughout the descent. The same process was performed on velocity magnitudes for an estimate of displacement magnitudes. The uncorrected rotation during the drops is the result of the increased velocity and displacement at the end of the plots.


Acceleration, Drop OCT12F1, s=10, t=80
Acceleration Magnitude (m/s^2)
Timestamp (s)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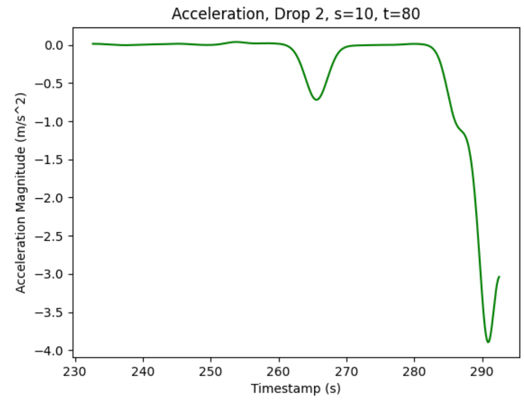
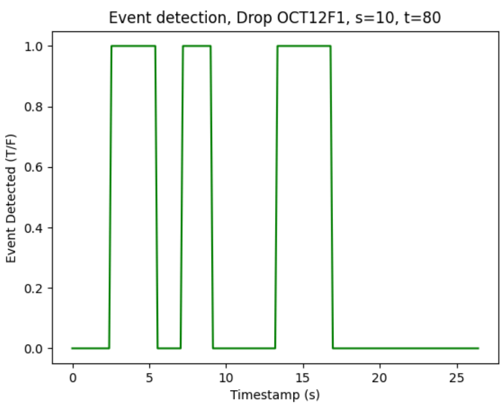
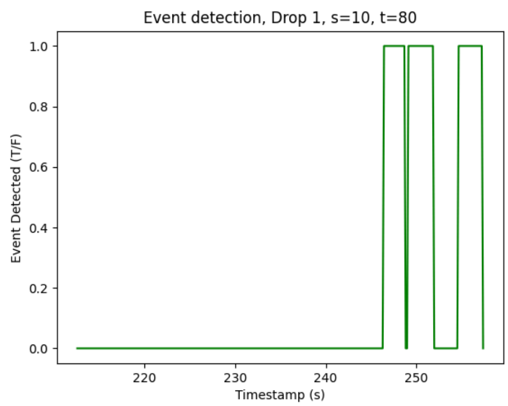
Acceleration Magnitude (m/s^2)
Timestamp (s)


Acceleration, Drop 2, s=10, t=80
Acceleration Magnitude (m/s^2)
Timestamp (s)


Event detection, Drop OCT12F1, s=10, t=80
Event Detected (T/F)
Timestamp (s)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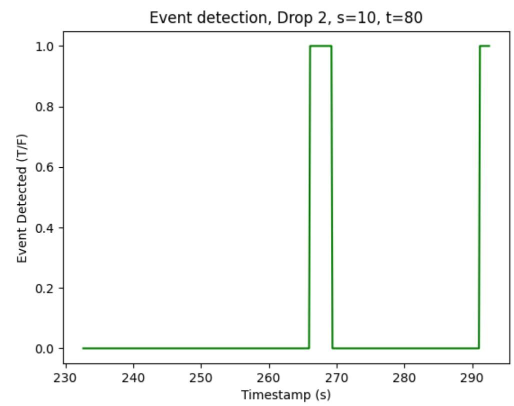
Event Detected (T/F)
Timestamp (s)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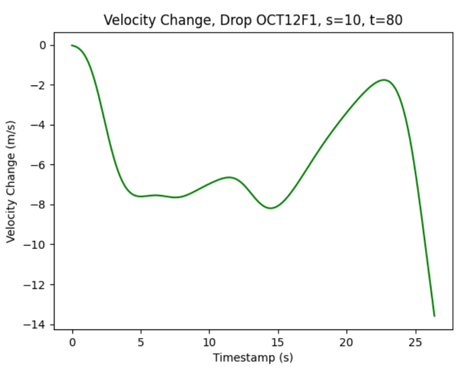
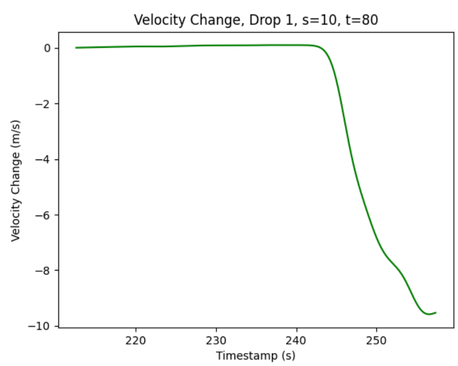
Event Detected (T/F)
Timestamp (s)


Velocity Change, Drop OCT12F1, s=10, t=80
Velocity Change (m/s)
Timestamp (s)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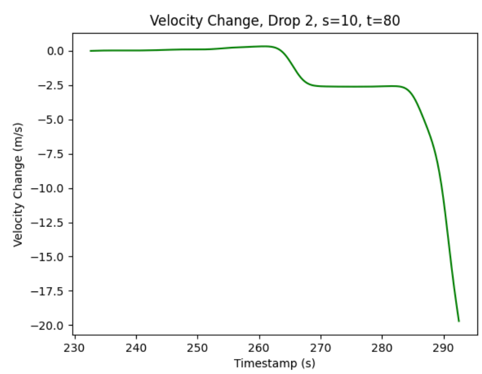
Velocity Change (m/s)
Timestamp (s)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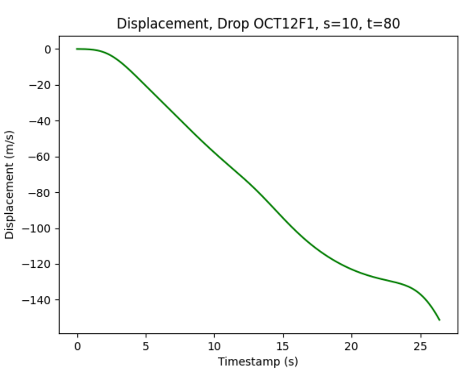
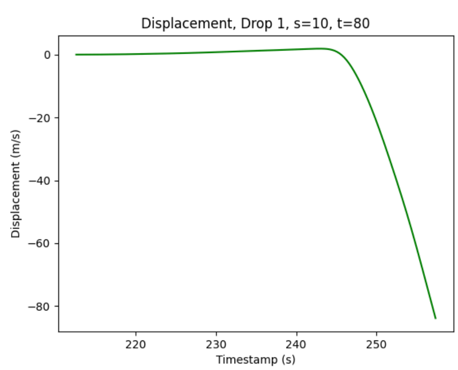
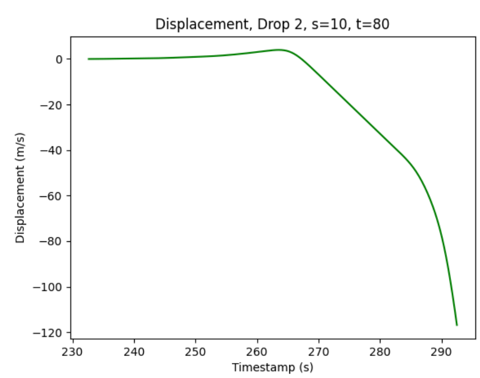
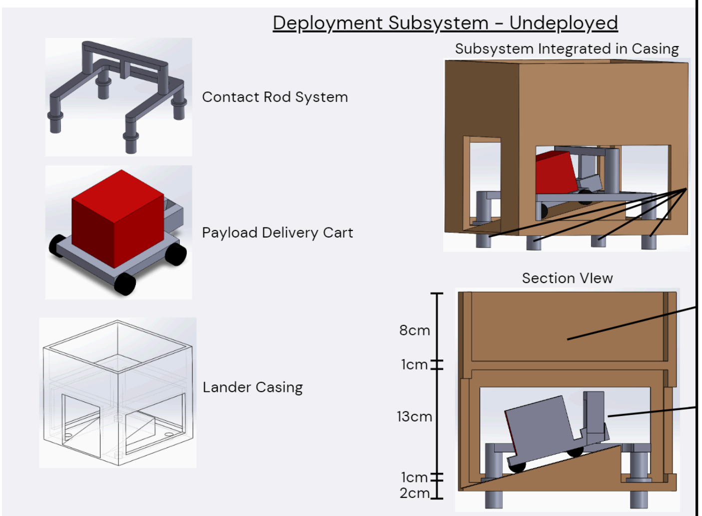
Velocity Change (m/s)
Timestamp (s)


Displacement, Drop OCT12F1, s=10, t=80
Displacement (m/s)
Timestamp (s)


Displacement, Drop 1, s=10, t=80
Displacement (m/s)
Timestamp (s)


Displacement, Drop 2, s=10, t=80
Displacement (m/s)
Timestamp (s)

4. Design Evolution



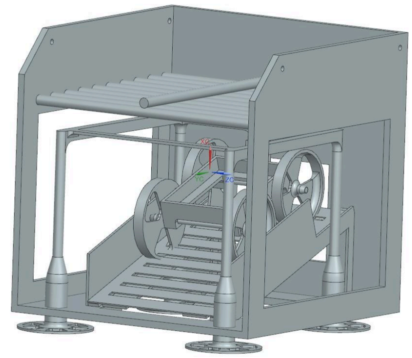
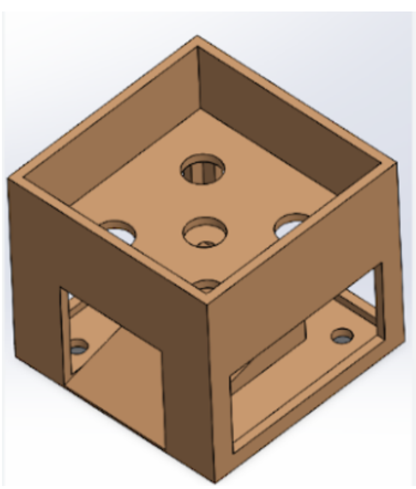


Fig 21. PDR Lander Design	Final Lander design

Since the PDR, the design has not been changed to create a whole new system of deployment. Once the building began, changes were made to be practical to make, make the design simpler, or to reduce the weight.



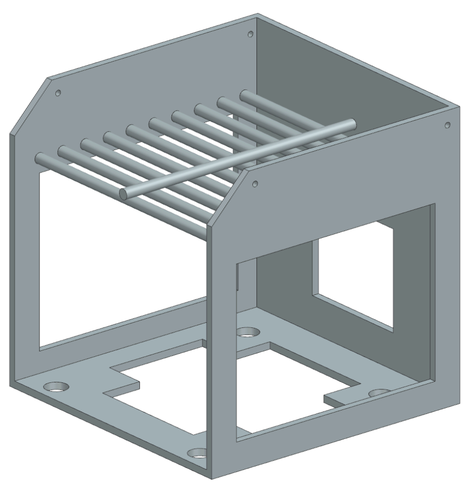


Fig 22. PDR Chassis	Final Chassis

Beginning with the chassis, many changes were made to the design, most of these changes were made for weight reduction and airflow. The cutouts from the side and back walls were increased, this was determined during the construction of the body. Once assembled, the cutouts were slowly increased until the body began to flex slightly. These areas were then slightly reinforced which offered a great trade between weight reduction and airflow. Also in the building phase, it was discovered that the payload deployment subsystem had done a great job in keeping the payload steady and oriented straight forward that a front wall was unnecessary. Once again allowing for a large amount of weight reduction and greatly increased airflow. Once the ramp model was created and built, it was suspended off the bottom of the lander which was then used for more airflow and weight reduction. The last change was to the parachute compartment, this was mainly changed to rods as they were readily available and lightweight. This greatly reduced the weight and added lots of strength as well as points for the parachute to be connected to.

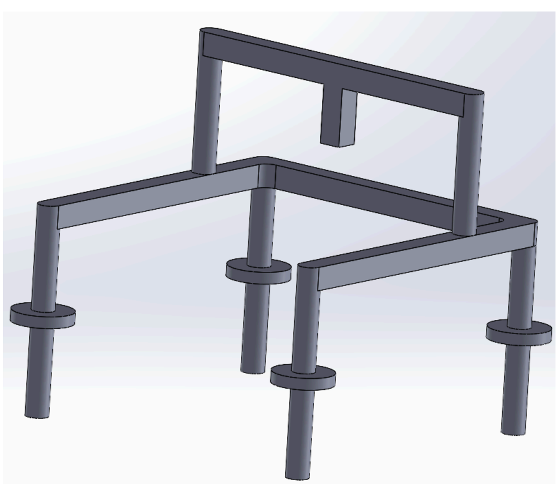
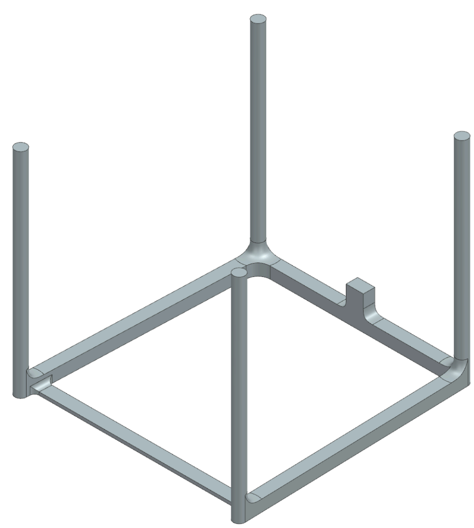
	

Fig 23. PDR Contact Rod	Final Contact Rod

The initial contact rod design had the pin slightly behind the center to hold the cart, as well as rings around the legs to stop the legs from falling down. In an attempt to continue bringing the pin further back to allow for more room for the cart to gain velocity, the design was changed to having the pin on the frame of the rods themselves. The rest of the changes were made for manufacturing reasons. The initial design was a very difficult object to print, took a long time to print, and required lots of support which added to prototyping costs. Although the Second design may have been slightly more weight in the end, the simplicity of the design made it very easy to print many copies of and required no support which reduced the time greatly. This change made it possible to do a very large amount of testing as new parts could be remade in just a few hours.

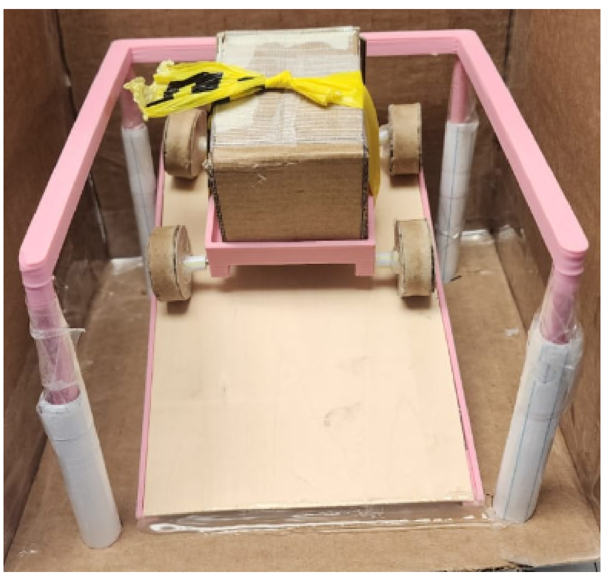
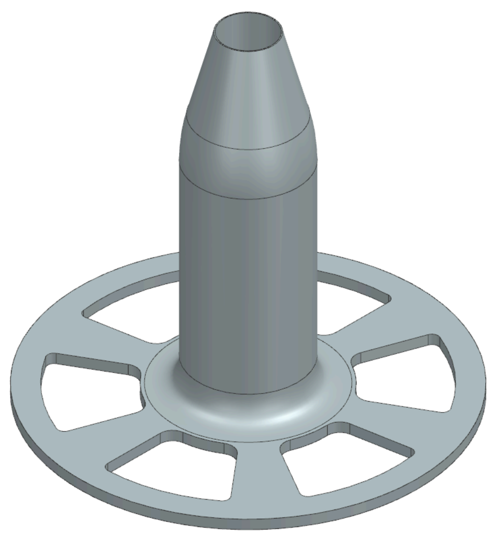
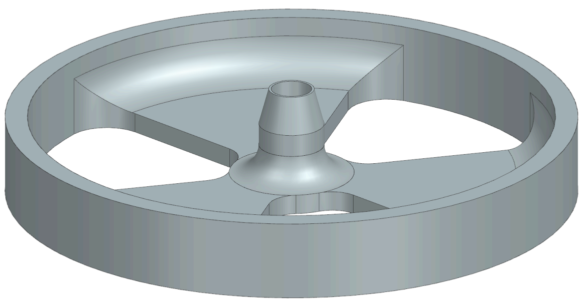
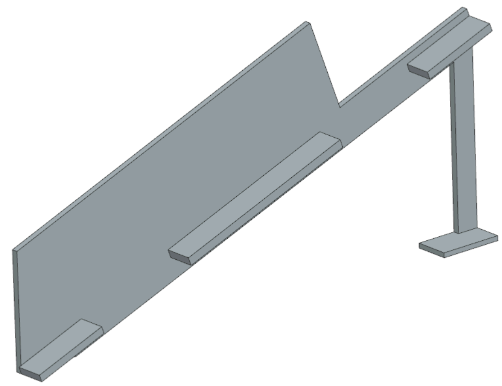
	

Fig 24 Prototype Lander	Final Lander Feet

During the testing phase, the thin legs of the rods would deploy very quickly and the force when touching down was so large the cart would be ejected rather than rolling. This led to a quick fix of wrapping the legs with paper to increase the diameter and add some friction to increase the time the force is applied and hopefully allowing for a smoother deployment. This worked very well in testing and was then incorporated into the design of the landing feet.

<table>
<tr><td></td><td></td></tr>
<tr><td>Fig 25 Final Lander Wheels</td><td>Final Lander Ramp Frame</td></tr>
</table>

From the same prototype lander, the makeshift wheels can be seen at entirely different angles which caused very sporadic movement and often would fall off the ramp or get stuck on the legs of the contact rods. This difference in angles was mainly due to imperfections when attempting to make proper spacers for the wheels. Because of this, the spacer design was directly incorporated into the wheel.

Additionally, a guide rail was added to the ramp frame. Although the new wheels rolled very smooth and straight, once the assembly was completed, the lander was still underweight. The guide rails, though unlikely to be needed, were added as a redundancy to ensure proper deployment.

By Creating almost every part via 3d printing, this allowed for a very large amount of testing. Not only was it quick to print, the reliability of the printer allowed for each replacement part to have the same angle, weight, and withstand the same forces. Extra parts were brought to testing days as well as final drop day.

5. Requirements

Requirements

Req #	Requirement	Rationale	Parent Req	Child Req	Relevant Subsystem	Req met?	Notes	Modifications after PDR
Level 1 (Project requirements)								
PR-1	Lander shall successfully land and deploy a payload within target area	Provided by Project requirements	Customer	TBD	All	Met	The lander successfully landed and deployed a payload within the target area and to achieve this an apex vent was introduced by the end to ensure that the lander do not drift in case of heavy winds	
PR-2	Lander shall survive a drop from 85 feet	Provided by Project requirements	Customer	DES-1, DES-2, PAY-3, PAY-4	Descent	Met	The lander successfully have withstood a drop of at least 85 feet, as nothing was damaged or out of position after the landing.	
PR-3	Lander shall successfully integrate to the provided release mechanism and payload	Provided by Project requirements	Customer	MECH-1, MECH-2	Payload, Mechanical	Met	The lander has succesfully integrated into the release mechanism and the payload forming one single system.	
PR-4	Lander shall deploy at least one descent/landing system following release	Provided by Project requirements	Customer	DES-1, DES-2	Descent	Met	Atleast one of the descent subsystems(parachute) was deployed after the release	
PR-5	Lander shall deploy at least one payload deployment system after touchdown	Provided by Project requirements	Customer	MECH-1, MECH-3	Mechanical	Met	Atleast one of the payload deployment subsystems was deployed after the release	
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	Met	The payload was secure and intact to the lander during the course of the descent and only deployed after touchdown	
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	Met	The bottom(wheels) of the payload was successfully in full contact with the ground	
PR-8	The payload shall have a clear view of the "sky"	Provided by Project requirements	Customer	PAY-1, PAY-2, PAY-5	Payload	Met	The payload rolled down the ramp and had clear view of the sky after the touchdown	
PR-9	The overall project costs should lie within $75	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Met	The project expenses lied within $75 dollar range	
PR-10	The lander(undeployed) should lie within 25cmx25cmx25cm	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Met	The volume constraints of the lander was met	
PR-11	The overall project mass(without the payload) should lie within 400grams	Provided by Project requirements	Customer	TBD	Payload, Descent, Mechanical	Met	The mass of the system(lander, payload amd parachute) together weighed under 400 grams.	
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	Met	The contact rod held the payload stable using a cart onto which the payload was mounted.	
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	Met	The contact rod was lifted and it detached itself from the cart onto which the payload was mounted on. The payload was therefore deployed successfully after touchdown	The idea of the pin was modified such that a small contact rod was added that clutched itself to the payload cart that had a deep vent (it was similar to what a ball and socket joint looks like)
MECH-3	The contact rod should be able to deploy the payload if the lander lands 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	Met	The contact rod was successfully able to deploy the poyload even though the lander landed at angles other than 90 degress to horizontal ground	
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	Met	The ramp had raised edges that prevented the payload cart falling off the rear or edges and it successfully slided all the way down straight	
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	Met	The contact rod did not interfere with the lander structure	
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	Met	The pin of contact did/will not damage the payload cart	The idea of the pin was modified such that a small contact rod was added that clutched itself to the payload cart that had a deep vent (it was similar to what a ball and socket joint looks like)
Level 3 (Subsystem/Component requirements)								
Descent Reqs								
DES-1	Descent subsystem will reduce the lander along with payload to a managable terminal velocity of (less than 3.5m/s)	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	Met	The parachute reduced the lander to a managable terminal velocity of 3.46 m/s	
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	Met	The parachute successfully deployed and reached its terminal veloicty before hitting the ground	
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	Met	The descent and landing subsustems were intact and contanied iwthin the constrained volume of the lander(25cm x 25cm x 25cm) at the time of the release	
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	Met	The descent /landing subsystem increased the total volume of the lander to greater than the initial volume(25cm x 25cm x 25cm)	
DES-5	Nothing shall remain attatched to the release mechanism once the lander is released	Provided by Project requirements	Customer	TBD	Mechanical	Met	Nothing was attached to the release mechanism once the lander was released	
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	Met	The lander touched down in an upright position initially in a way that the contact rod released teh payload cart to roll down completely.	

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	Met	The parachute lines remained untangled during and after the deployment	
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	Met	The parachute lines neither snapped not dislodged after deployment	
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	Met	The idea of the drogue chute was modified after the feedback from PDR and instead a parachute made of nylon was outsourced	The idea of the drogue shoot was modified after the PDR feedback which said that the shroud lines of the drogue might rip apart the apex vent of the lain parachute
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	Met	The idea of the drogue chute was modified after the feedback from PDR and instead a parachute made of nylon was outsourced	The idea of the drogue shoot was modified after the PDR feedback which said that the shroud lines of the drogue might rip apart the apex vent of the lain parachute
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	Met	The payload rolled down onto the ground and had full view of the sky and had full ground contact	
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	Met	The payload was able to travel the distance of shroud lines before the canopy touched the ground	
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	Met	The scientific payload withstood the force of landing	
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	Met	The payload cart withstood the force of landing	
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	Met	The payload cart successfully rolled on the provided landing mat	

Figure 26. Requirements

6. Risks
6.1. Risk Chart

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

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

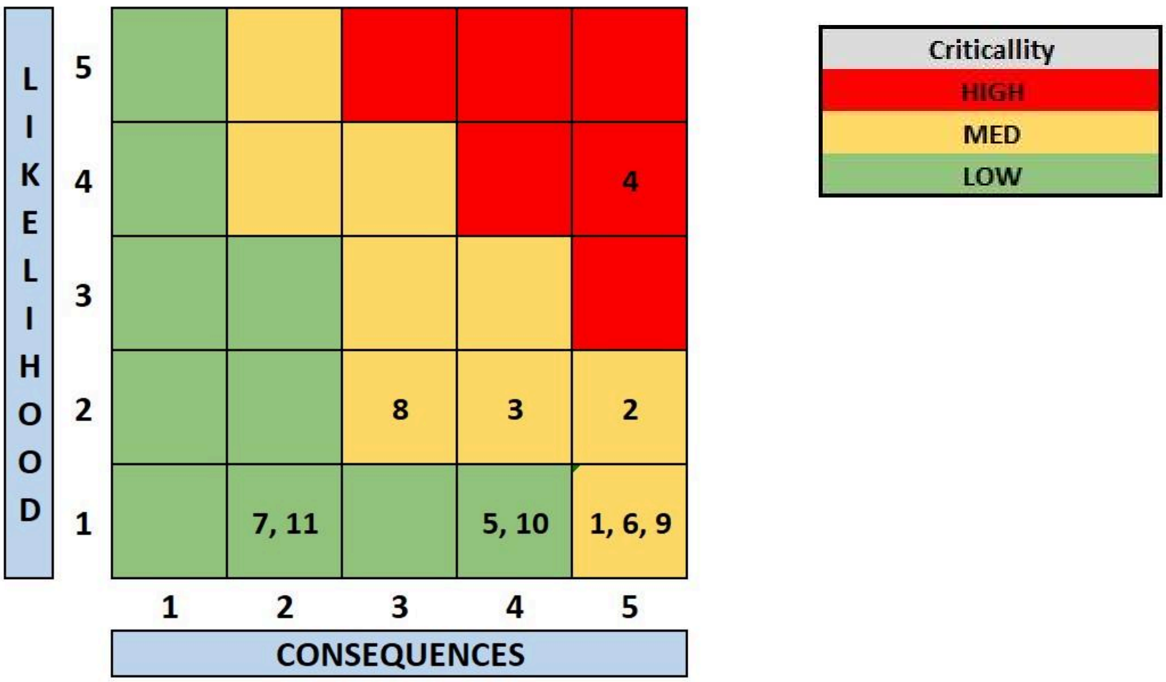


Fig 27. Risks

6.2. Risk Mitigation

Throughout prototyping and testing, various risks that could affect a successful descent and landing of the lander were identified. To acknowledge and monitor these risks, a chart was created to categorize the risks on their likelihood of occurring and the severity of the consequences in the case they were to occur. This categorization allowed for prioritization of specific design aspects during the building of the lander so that associated risks could be minimized.

A primary concern was the reliability of the lander's payload deployment subsystem. The system depends on a contact rod release mechanism which requires direct contact with the ground to initiate deployment. One of the greatest risks was that the contact rod would not make the first contact with the ground depending on how the lander fell. To mitigate the risk, longer rods were made so that, if the lander fell as intended, the rods would be the first to touch the ground. Circular “feet” were also attached to the bottom of each rod to provide stability upon landing so the lander would remain upright and the force could be pushed up through the rods. To release the contact rod from the cart which the payload rests on, the top of the rod structure has an extending pin that fits into a cavity in the cart. Another risk was that the pin would fail and the contact rod would not release the cart. To address this, when designing both components the pin and cavity were measured to fit each other snugly and the cavity was made to a depth so that the pin would be released by the impact force. This was ensured by testing multiple variations of the contact rod component with drop tests. These precautions also addressed risk 3: the case in which the pin released the payload prematurely. This would happen if the pin did not have a secure enough hold on the cart, so adding enough depth to the cavity and length to the pin mitigated this issue.

As one goal was to maintain the payload in an upright position from descent to landing, another risk was the payload becoming inverted either while it fell or upon impact. Measures taken to mitigate this were implementing a secure pin so that payload did not wobble, the addition of guard rails on the ramp so the cart could roll out straight, and maintaining an even weight distribution throughout the lander to reduce tilting. With uncertainty in the conditions of the drop-site during the design process, environmental considerations were also made. An identified risk was the possibility of the lander landing on a surface with obstructions, which could block the deployment of the payload. In an attempt to mitigate this, large wheels were used for the cart so that it could roll over possible obstacles and the ramp was built at a steep enough angle for the payload to be released at a velocity that could overcome getting stuck as it rolled out of the lander.

In addition to the payload deployment subsystem, the descent system came with its own risks. In relation to the payload, there was a possibility of the parachute getting stuck on the payload and not deploying reliably. To mitigate this, a “ceiling” was made that the parachute would rest on. It had bar features so that the parachute could not drape into the body of the lander but air could still flow into the parachute. Other risks were that the suspension lines could snap or tangle. This was mitigated by both the choice of parachute type and the method of packing the parachute. The parachute was outsourced by a rocketry company to enhance quality and reliability for the needs of the lander. By outsourcing the parachute, the integrity of the parachute was improved from what it would be with a hand-made parachute. By carefully packing the parachute so that it follows the placement of the suspension lines, the lines are less likely to become tangled.

7. Schedule
7.1. 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	11/27/24
5	End Item Data Package	12/6/24

Fig. 28 Mission Milestones

7.2. Gantt Chart

Project Name: SpaceWorks -1

Team Number: 1

Project Team Members: Hitul K, Emma C, Brenndon H, Harjot K, Liam N, Cas/Samuel S, Jordan E.

Project Start: Mon, 9/2/2024

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	Margin
1	**Subsystem Concepts**		100%	9/2/24	9/24/24	23	2
1.1	Conceptualize Ideas	Whole Team	TRUE	9/2/24	9/16/24	15	
1.2	Deciding on the Payload Subsystem	Whole Team	TRUE	9/16/24	9/16/24	1	
1.3	Deciding on DL Subsystem	Whole Team	TRUE	9/16/24	9/16/24	1	
1.4	Bringing those Ideas On paper (Drafting)	Whole Team	TRUE	9/16/24	9/23/24	8	
1.5	Trade Studies	Whole Team	TRUE	9/16/24	9/23/24	8	
1.6	Schedule Margin		TRUE	9/23/24	9/24/24	2	
1.7	◆ Deciding on a Project Design Concept		TRUE	9/24/24	9/24/24	1	
2	**PDR**		100%	9/23/24	10/9/24	17	3
2.1	Risks and Requirements	Brenndon, Harjot	TRUE	9/23/24	9/24/24	2	
2.2	Mission Sucess Criteria	Brenndon	TRUE	9/24/24	9/30/24	7	
2.3	ConOps	Liam	TRUE	9/24/24	9/30/24	7	
2.4	Lander Overall Design	Whole Team	TRUE	9/30/24	10/5/24	5	
2.4.	CAD Drawings	Liam	TRUE	9/30/24	10/5/24	5	
2.5	Possible Design Changes	SubTeams	TRUE	9/30/24	10/5/24	1	
2.5.	Make a Prototype	SubTeams	TRUE	10/4/24	10/5/24	5	
2.6	Conclude PDR (Profreading and Formatting)	DPMR + PM	TRUE	10/5/24	10/7/24	2	
2.7	Create Presentation Slides	Whole Team	TRUE	10/6/24	10/6/24	1	
2.8	Practicing	Whole Team	TRUE	10/7/24	10/7/24	1	
2.9	Schedule Margin		TRUE	10/7/24	10/9/24	3	
2.a	◆ PDR Completion and Presentation		TRUE	10/9/24	10/9/24	1	
3	**Functional Individual Subsystems**		100%	10/9/24	11/4/24	27	4
3.1	Budget / BOM (Individual Subsystems)	Brenndon + SubTeams	TRUE	10/9/24	10/15/24	7	
3.2	Procurement (Individual Subsystems)	Brenndon + SubTeams	TRUE	10/15/24	10/23/24	9	
3.3	Integration (Individual Subsystems)	SubTeams	TRUE	10/23/24	10/31/24	9	
3.4	Testing (Individual Subsystems)	SubTeams	TRUE	10/23/24	10/31/24	9	
3.5	Schedule Margin		TRUE	11/1/24	11/4/24	4	
3.6	◆ Functional Models of Subsystem		TRUE	11/4/24	11/4/24	1	
4	**Assembling Entire Lander & Final Submission**		100%	11/4/24	11/27/24	24	3
4.1	Assembling Both Subsystems Together	SubTeams + ATLO Eng.	TRUE	11/4/24	11/15/24	12	
4.2	Testing Lander	ATLO Engineers	TRUE	11/15/24	11/20/24	6	
4.3	Risks Mitigation	Whole Team	TRUE	11/20/24	11/24/24	5	
4.4	Last Minute Tests and Changes	Whole Team	TRUE	11/20/24	11/24/24	5	
4.5	Schedule Margin		TRUE	11/25/24	11/27/24	3	
4.6	◆Lander Submission		TRUE	11/27/24	11/27/24	1	
5	**Post-Drop Analysis**		100%	11/27/24	12/6/24	7	
5.1	Lander Debrief		TRUE	11/27/24	11/28/24	2	
5.2	Data retreival and analysis		TRUE	11/28/24	11/29/24	2	
5.3	Final EIDP report		TRUE	11/29/24	12/5/24	7	
5.4	Schedule Margin		TRUE	12/5/24	12/6/24	2	
5.5	◆End Item data Package		TRUE	12/6/24	12/6/24	1	

8. Conclusion

The team would classify the mission as a Partial Success. Two drop attempts were made.

For the first drop, the lander was attached to four shroud lines connected to the drone. The lander was then dropped from approximately 70 feet. The Descent/Landing subsystem performed perfectly; the parachute opened and deployed as intended. However, due to the wind, the lander gained significant horizontal velocity and landed on one of its edges. Although it tipped over to its side, it was still able to deploy the payload cart. Unfortunately, the cart was also tipped, resulting in no clear view of the sky and no direct contact with the ground.

For the second attempt, we followed the same procedure to drop the lander, but this time we chose a period when the wind was somewhat more stable than during the previous attempt. Although the wind was considerably lower, it still caused the lander to tilt during descent. Despite this, the lander successfully landed on the target site and deployed the payload in the correct orientation. However, it tipped onto its side after the successful deployment. This time, the payload cart was deployed correctly and made direct contact with the ground.

If we had more time or additional attempts to carry out this project, we would have conducted further testing. While we did test sufficiently, it was only in ideal situations. We could have explored more possible scenarios, such as wind effects or rotation during descent. Additionally, we could have made further accommodations to the lander to better handle these conditions while still ensuring successful functionality.