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DroneBack
Preventing Casualties via Rapid Counter-Drone Launching System

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ABSTRACT

Drone warfare is becoming increasingly effective and cost efficient through the use of First Person-Viewer drones. These drones can carry payloads, capable of eliminating enemy combatants. To counter these drone assaults, current solutions are mostly non-kinetic. They use electronic and cyber solutions such as altering a drone's GPS location, known as spoofing. Other techniques include: jamming, which masks control signals, and the total takeover of a drone's electronic control unit, known as hijacking. These non-kinetic solutions require highly trained operators and specialized equipment. The Drone40 shows promise in being used as a kinetic solution for hostile drones when paired with Anduril's Lattice software, an autonomous AI software solution. This software is automated to detect hostile drones and intercept without requiring user input/control. These small and modular drones are easy to use, capable of autonomous flight, and are highly modular. Current deployment methods such as 40mm grenade launchers and/or vertical takeoffs require less training than non-kinetic solutions but require several minutes of setup time. The objective of the DroneBack team is to provide a functional and portable drone launcher that is 1. compatible with the Drone40 and other similar drones, 2. mechanically driven, 3. capable of rapid drone deployment and 4. easily integrates with standard issue plate carriers and backpacks. Stakeholders of this project include all soldiers in the modern-day battlefield.

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1 INTRODUCTION

The objective of this project is to design and construct a functional and portable counter-drone launcher capable of being implemented into modern-day warfare for under $500 by May 1st, 2025. The deliverables for this project are as follows:

- Functional Drone Launcher Prototype (Compatible with the Drone40 and Viper40)
- Engineering Calculations and Simulations
- ASME Y14.5 Compliant Drawings
- Project Report
- Project Presentation and Poster

The stakeholders of this design project include soldiers who are engaged in conflicts that see drone warfare regularly. Since this design aims to protect soldiers who are exposed to drone warfare, these individuals are more likely to employ a DroneBack launch system. The motivation behind this project is to provide troops with an additional layer of protection from drone attacks. This design gives the user the potential to evade an attack by rapidly deploying a counter-drone to intercept incoming threats.

1.1 BACKGROUND

Soldiers fighting in conflicts such as Israel and Ukraine provide key insight into the damage drones can inflict. The development of military defense systems has allowed countries to successfully defend their respective airspaces. To combat this, various regions are working to create more agile solutions to counter long-range missile technology. The solution that countries such as Ukraine and Russia have been employing is first-person view (FPV) drones. These FPV Drones provide increased maneuverability compared to mortar fire or other long-distance anti-personnel weapons, while minimizing detectability due to their small scale [10]. These drones can function as “kamikaze drones”, meaning they are for one time use and destroyed on impact. FPV drones can be used as precise small-scale artillery [9]. An article from Kyiv Independent reports that many casualties and injuries in the last 6 months are the results of FPV drone strikes [4]. These drones are also being reported to be used due to their “low cost and ability to drop hand grenades on targets” [6]. The ability to outfit off-the-shelf drones with payloads has created a new frontier for unmanned aerial combat. Countries that use FPV drones keep production costs low while also retaining incredible strike precision and minimizing the exposure of infantry units. Reports out of Israel have also made note of the devastating effects of FPV drones and have stated that “Battles now include not only the space around ground troops but also the spaces above them, creating minefields in the air” [5].

The solution to this issue may very well lie within drones themselves, The Drone40 and Viper40 are both grenade-launch mini loitering systems compatible with standard 40mm grenade launchers [7,8]. These drones are capable of autonomous flight and threat identification like the technology of automated air defense systems. When deployed, these drones can track and move to permanently intercept hostile drones. Both drone systems are designed to be conveniently stored in standard combat vests where they can be accessed for loading into a grenade launcher or hand deployment when needed. While these options are effective, they require the user to have adequate time to identify and react to threats. The DroneBack design reduces the time to launch by implementing a pack-mounted launcher that will deploy these counter drones in an instant. This design will rely on mechanical components which will decrease the detectability and possibility of jamming.

1.2 STATEMENT OF PROBLEM

Drone warfare has become a dominant strategy in modern conflicts. Soldiers and civilians involved in recent conflicts in the Middle East and Europe have given firsthand testimony to the lethality and effectiveness of drones, especially FPV drones. While large drones can be susceptible to air defense systems, small drones are difficult to detect, have increased maneuverability, and are not a cost-effective use of expensive military systems [9]. Because of this, cost-effective counter-drone solutions are being developed to help provide soldiers with the protection they need in the field. An example of an FPV drone is shown in Figure 1. Currently, there are no solutions to counter these FPV drones. Promising solutions to this issue include jamming, spoofing, and swarming technology. These can be effective defenses against FPV drones but are not currently being used for personal defense. This issue, if left unsolved, will lead to more casualties. The reality is that drone warfare makes the cost to wage war low, and the loss of human life high.

Figure 1: FPV Loitering Munition Drone

This is a First Person View Loitering Munition Drone with a mortar shell rigged to the underside. This drone has been wired and is ready for launch. One soldier must hold the drone while another (in the background) is responsible for controlling its take-off by remote control.

1.3 *CONCEPT OF OPERATIONS*

The DroneBack design aims to provide operators in the field with a rapid counter-drone deployment system. This is achieved through a four-step process. The initial step is that the operator detects a hostile drone in their immediate area. This can be achieved by hearing the drone, visual contact, or other external equipment that is able to detect its electronic signature. Upon detection, the operator then decides that the situation is life-threatening and pulls the brake release, causing the DroneBack to launch the Drone40 directly above the user. This is considered step two. The third step in this process is that the Drone40's operating system turns on, deploys its propellers, and transitions into flight mode. The Drone40 then uses its advanced software to scan the area and move to intercept any hostile drones. The final step is that the Drone40 intercepts the hostile drone and disables it by using one of its countermeasure tactics. The Drone40 has kinetic and non-kinetic countermeasures at its disposal. Kinetic countermeasures include explosive detonation after physically contacting a hostile drone and a non-kinetic countermeasure includes electronic warfare tactics such as spoofing and jamming. Regardless of the countermeasure method, a rapid deployment of a Drone40 gives the operator in the field an opportunity to evade the area and potentially save their life. These steps are broken down into their individual function shown in Figure 2 on the next page.

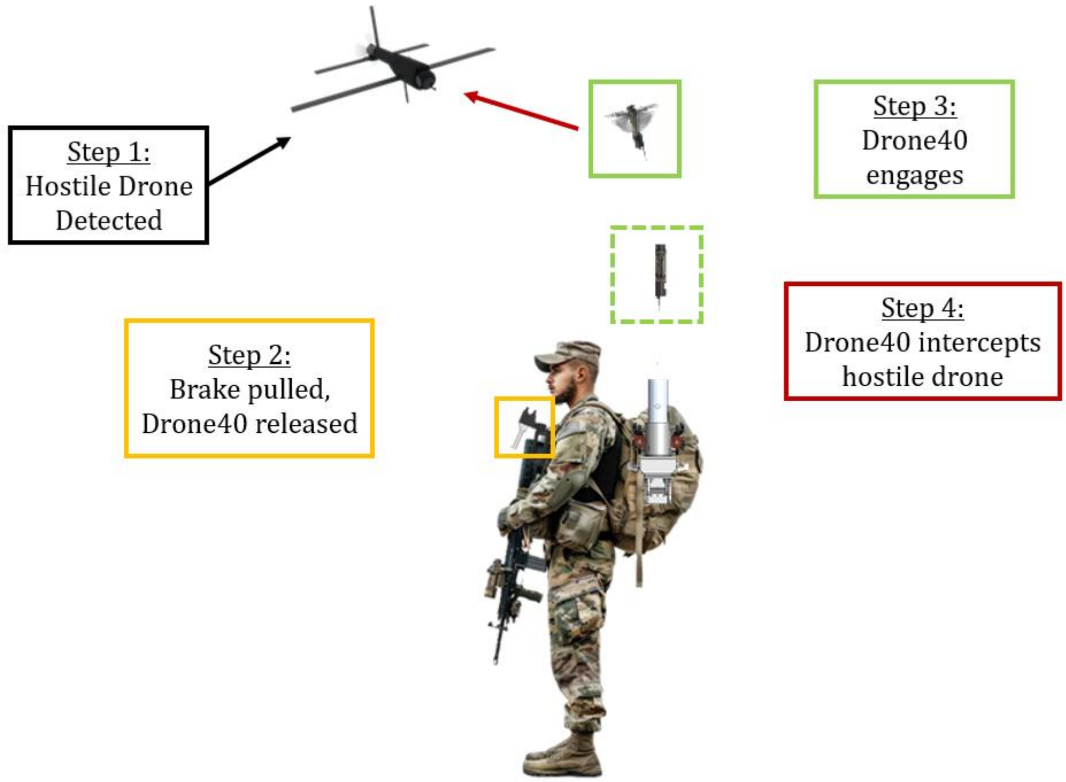


Figure 2 : Concept of Operations

This is a breakdown of DroneBack function in a step-by-step process. Step one is that a hostile drone is detected. Step two is that the system is actuated, causing the Drone40 to be released. Step three is that the Drone40 turns on, transitions to flight mode, and moves to engage the hostile drone. Step four is that the hostile drone is intercepted and disabled by the Drone40.

1.4 *REQUIREMENTS*

The concept of operations led the team to develop requirements that outperform the existing Drone40 launch methods. The requirements for the DroneBack project are shown in Table 1. The first column is the requirements, and the second column is the performance measure. To create a product that would be adopted for the military or private sector, this design must outperform existing solutions while offering modularity and durability for diverse implementation.

Table 1: Project Requirements

Requirement	Performance Measure
1. Instantaneous Launch	$Time\ to\ Launch < 1\ sec.$
2. Drone Deployment Height	$Launch\ Height \geq 15\ ft.$
3. Mechanically Driven	System energy stored in spring
4. Launcher Weight	$Total\ Weight < 6\ lbf$
5. Variable Launch Adjustment	$Angular\ Adjustment \geq 180^{\circ}$
6. Project Cost	$Project\ cost < \$500$
7. Outer Tube Strength	$\sigma_{max} < \sigma_{yield}$, $FOS \geq 1.5$
8. Modularity	Compatible with MOLLE Webbing

The current methods of launching the Drone40 include 40mm grenade launch and hand deployment. Images of these two methods of launching are shown in Figure 3. Both launching methods require setup time. The grenade launcher would either be on a sling, attached to a backpack, or an armor vest and not always loaded with a Drone40. Grenade launchers also use a combustible propellant to function, leaving a detectible heat signature. This could lead to an operator being detected while in a covert section. Hand deployment would require removing the Drone40 from storage and letting it take off from the user’s hands requiring significant setup time.

The first requirement is that the DroneBack be capable of instantaneous launch. This means when the user pulls the release the drone will exit the tube in less than one second. This design requirement was created to improve upon the current launch methods time to launch.

A. B.

Figure 3 : Existing Drone40 Launch Methods

In A is the M79 40mm grenade launcher. This is an example of a standard issue 40 mm grenade launcher that could be used to launch the Drone40. In B is an image of a marine launching the Drone 40 via hand deployment.

Since the Drone40 is a proprietary product, the exact height at which a Drone40 is launched is not available to the public. However, a video shows U.S. Marines launching a Drone40 [11]. The team estimated from this video that it achieved a height of about 15 ft. after launch. This demonstration led the team to develop the second design requirement for the DroneBack project. This requirement being that the Drone40 must launch at least 15 ft. in the air above the user. Since the Drone40 has the capability of being pay loaded with an explosive element, proper deployment height minimizes the safety risk to personnel.

Thermal detection equipment is becoming more advanced and is increasing in availability. Soldiers in modern warfare implement thermal detection on their rifles, handheld scanners, and tanks. To mitigate detection, the DroneBack design needs to limit the heat signature produced upon launch. This led the team to establish the third requirement that the DroneBack must be mechanically driven. This means that there cannot be any electrical or combustion systems. Additionally, a mechanically driven system does not employ combustion to launch the Drone40 and mitigates the possibility of the payload detonating while inside the tube.

The fourth requirement is that the DroneBack must weigh less than 6 lbf. Soldiers already carry 68 lbf of gear on average. Any significant addition to that load would cause the soldier to become fatigued [2]. A standard issue M79 40mm grenade launcher weighs about 6 lbf [12]. To outperform the M79 in weight, the DroneBack design must weigh less than 6 lbf.

Military personnel use many different configurations of gear that are specific to their individual mission such as backpacks and plate carriers. The DroneBack needs to be adjustable to meet these configurations. This led to the fifth requirement for the project being the DroneBack needed to be capable of adjusting the angle of launch. The performance measure is the capability of being adjusted 180 degrees in one plane of motion. The reason for this requirement is to ensure a safe launch by having the capability to angle the DroneBack away from the user.

The University of Southern Indiana allotted a budget of $500 for the DroneBack team to design and construct the project. Additionally, the team wanted to provide soldiers with a cost-effective solution that could be adopted by the military for standard issues.

The DroneBack needs to be strong enough for a soldier to fall directly on it without jeopardizing the integrity of the Drone40 that is housed inside. Standard issue military equipment is designed to be robust and survive adverse environments. The team wants the DroneBack design to be comparable to standard issue military equipment. The performance measure for this requirement is that the Outer Tube needs to have a factor of safety of greater than 1.5. The loading situation is that of a soldier and their gear falling directly on the Outer Tube. This would amount to a 252 lbf point load on the tube since the average weight of a soldier plus their gear is about 252 lbf [2,3]. The Drone40, housed inside the Outer Tube, may be pay loaded with an explosive element and if the tube yielded it could cause an explosion posing a serious threat to the user's safety.

The DroneBack needs to be capable of being mounted to standard military equipment easily. This will be accomplished by using the MOLLE (Modular Lightweight Load-Carrying Equipment) webbing that comes on all standard issue military equipment such as backpacks and armor plate carriers. MOLLE webbing is a looping system that allows different pack and pouch configurations.

It uses nylon webbing that provides a convenient and quick attachment point for soldiers to customize their gear based on preference. This creates a snug and sturdy attachment that can be quickly attached or detached. A diagram of how the MOLLE webbing functions is shown in Figure 4. A plate carrier with MOLLE webbing attached to the outside is shown in Figure 4.

A) B)

Figure 4 : MOLLE Webbing Diagram and Plate Carrier

In A is a Diagram of the function of MOLLE Webbing. A soldier could thread the strap through the MOLLE webbing and snap it into place. In B is an armor plate carrier with MOLLE webbing.

Overall, the requirements were designed to outperform the existing launch methods while providing an effective solution. Safety and functionality were the main concerns that influenced the design requirements.

2 CONCEPTUAL DESIGN

The design contains four major subsystems: the Tube Assembly, Release Assembly, Interface Assembly, and the Cocking Mechanism. The concept is to have a modular launch system that can be attached to a standard issue plate carrier or backpack, depending on how the operator has their gear setup. Some field operations only require a plate carrier, while others require more storage and opt for a backpack. Regardless, field operations are a fluid situation and equipment carried must be easy to attach and detach. The system needs to be attached to MOLLE webbing so that it can easily be equipped with a variety of operator setups. This design will use an adjustment mechanism, giving the operator the ability to adjust the launch direction as needed. The launch system will be a mechanically driven system that can propel a 40mm Drone or equivalent above the operator. The concept for this system is to use helical compression springs that are controlled by the release mechanism which controls the drone launch. The release mechanism is to be ambidextrous and able to equip MOLLE webbing to be compliant with a variety of configurations and users. Additionally, the Tube Assembly should encase the launch components and provide adequate protection for diverse implementation in the field.

2.1 *Final Concepts*

The DroneBack Assembly consists of four major subsystems: The Tube Assembly, Release Assembly, Cocking Mechanism, and the Interface Assembly. Each subsystem was designed for seamless cohesion with each other while maintaining the ability to be easily repaired and operated. The DroneBack Assembly Subsystem breakdown is shown in Figure 5.

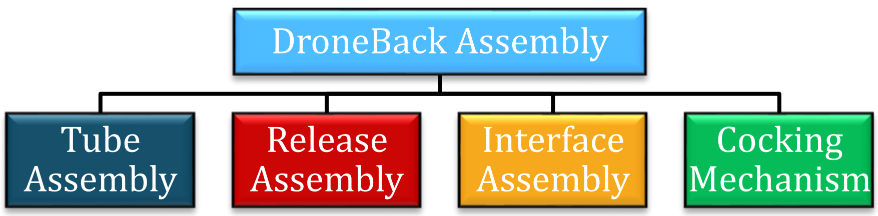


Figure 5 : DroneBack Subsystem Breakdown

This is the subsystem breakdown for the DroneBack Assembly is shown. The four main subsystems are the Tube Assembly, Release Assembly, Interface Assembly, and Cocking Mechanism.

Most of this assembly was manufactured via 3D printing using Polylactic acid (PLA) materials. Polylactic Acid is a common 3D printing material that is easily accessible and very effective for prototyping. For mass production, injection molding of the PLA pieces and the extrusion of the barrel is recommended. A model of the entire DroneBack assembly is shown in Figure 6.

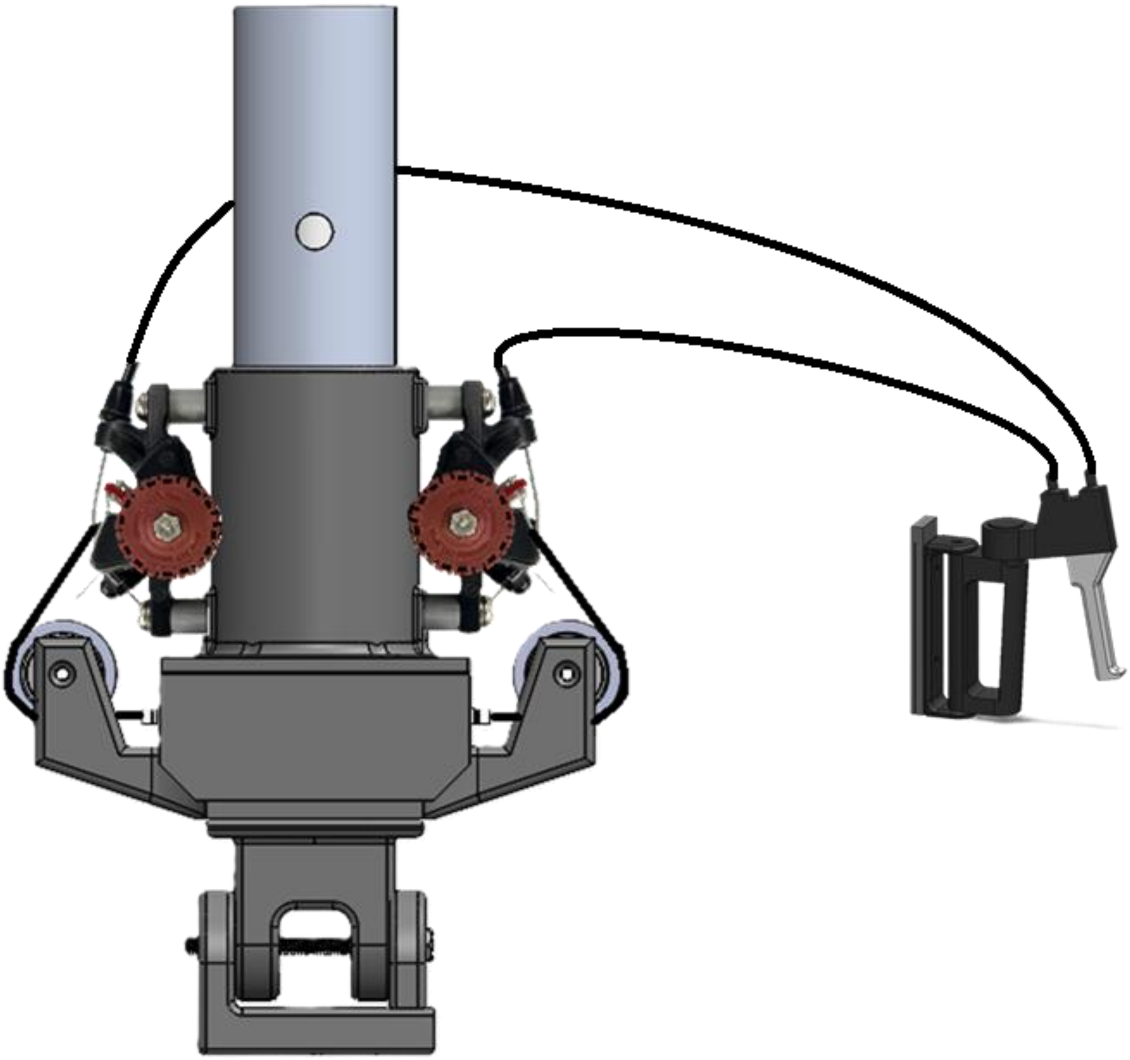


Figure 6 : DroneBack Assembly Model

This is the entire DroneBack model generated using SolidWorks.

2.1.1 Tube Assembly

The Tube Assembly consists of an Outer Tube, Inner Tube, Plunger, Propulsion Spring, and Mock Projectile. This assembly's purpose is to house and protect the Drone40 and store energy for the launch. Its tubular design allows for trajectory alignment to ensure user safety and an effective launch. The cross-section and subsystem breakdown are shown in Figure 7.

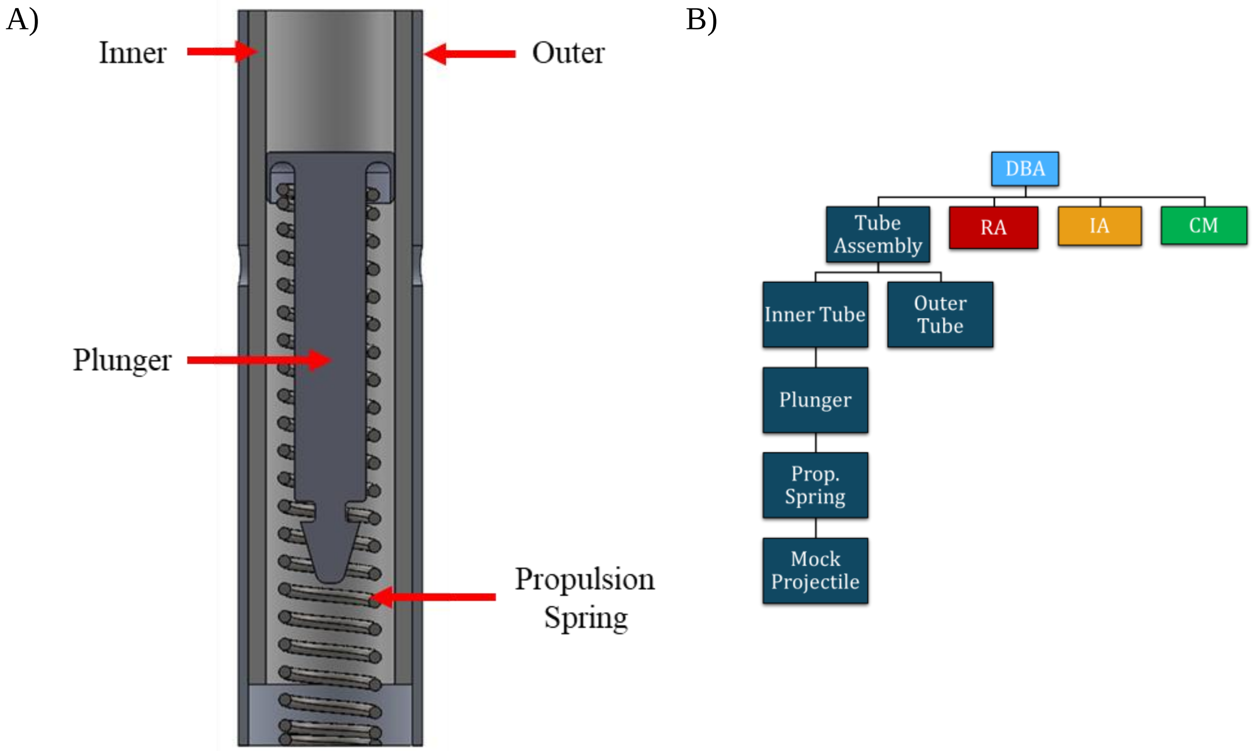


Figure 7 : Tube Assembly

In A is a cross section, generated by SolidWorks, of the Tube Assembly that shows how each component fits inside the Outer Tube. In B, the subsystem breakdown of the Tube Assembly by component. This shows how the Tube Assembly connects to the rest of the DroneBack Assembly.

The Outer Tube serves as a hard shell to protect the drone from any impact. The Outer Tube material is fabricated from 6061-T6 aluminum. This material is selected for its lightweight nature and strength. The diameter of the Outer Tube is designed to allow enough room for an Inner Tube to fit inside, this feature adds modularity and allows the operator to change Inner Tube diameters, allowing for a wider range of projectile sizes. A dimensioned image of the Outer Tube is shown in Figure 8.

The Inner Tube serves as a barrel for the projectile and is fabricated from schedule 40 polyvinyl chloride (PVC). The Inner Tube is slightly shorter than the Outer Tube by 0.75 inches. This was intentionally designed to mesh with the hub assembly. This feature adds strength by giving the Inner Tube material to be fixed around.

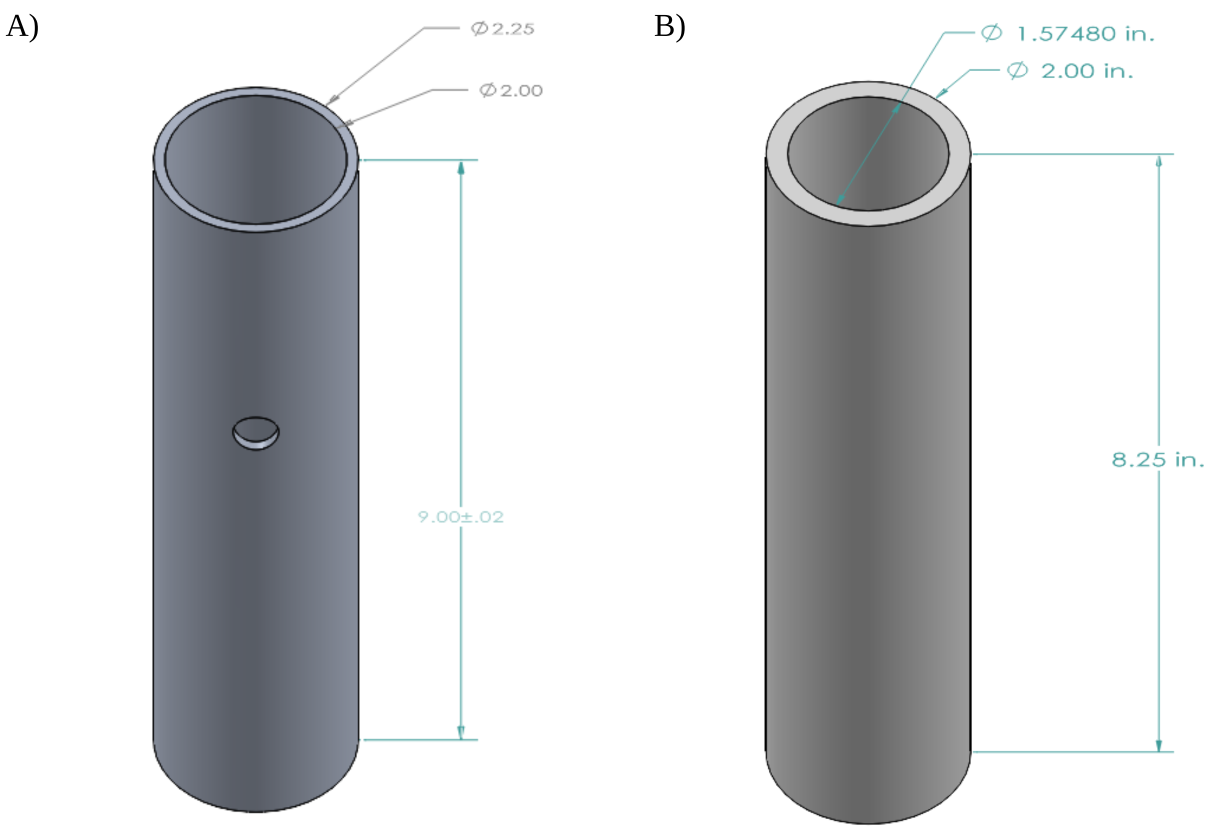


Figure 8 : Inner and Outer Tube Models

In A is a SolidWorks model the Outer Tube fabricated from 6061-T6 Aluminum. In B is a SolidWorks model on the Inner Tube fabricated from 6061-T6 Aluminum. The dimensions are shown for both models.

The Plunger is shown in Figure 9. The prototype was 3D printed using polylactic acid (PLA). The extruded lip at the platform's top was designed to increase stability and is used as a mounting point for the Propulsion Spring. The slotted groove near the base of the Plunger, and the Plunger tip geometry allows a seamless interface with the Release Assembly. These design features allow for a smooth loading cycle and decrease stress on the Release Assembly while loading. It should be noted that Aluminum and Lexan were considered as materials for the final design. The team performed finite element analysis and strength testing using the Instron ElectroPuls to confirm that PLA material would be strong enough to withstand the loading it would undergo for a prototype model.

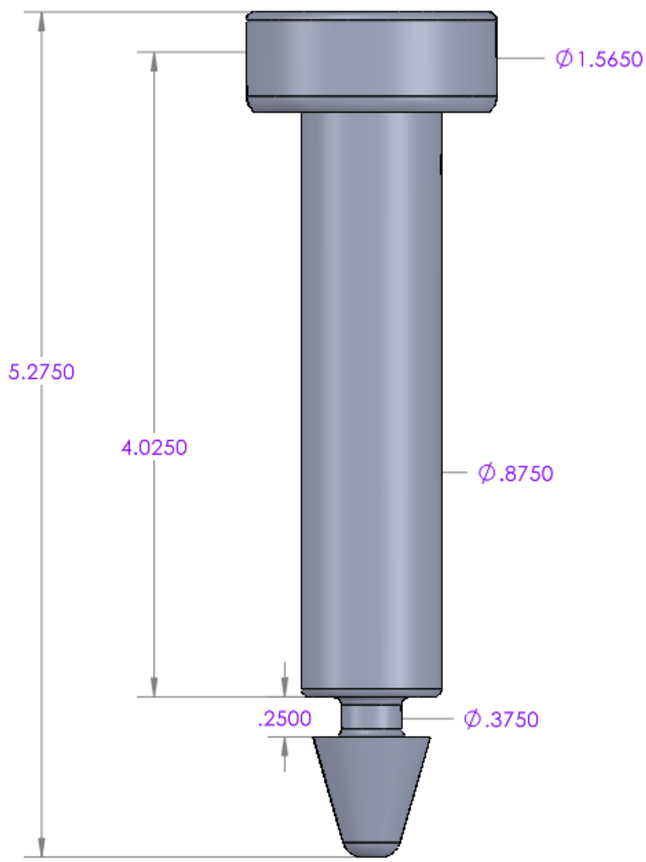


Figure 9 : Plunger Model

This is a SolidWorks model of the Plunger. The dimensions are shown in purple.

The Propulsion Spring was selected by first calculating the energy needed to launch the Drone40 15 ft. above the user. Then this was set equal to the potential energy stored in the spring, determined by its spring constant and travel. The physical dimensions of the spring were crucial to the system success as it needed to be less than 40mm in outer diameter to fit in the tube. Throughout the Propulsion Spring design process, it was determined that selecting a spring based on travel would have a greater impact on the amount of acceleration provided. Since the term for spring travel is squared in the equation for potential energy of a spring it impacts the amount of energy stored more than the spring constant. The Propulsion Spring was a commercially available compression spring purchased from The Spring Store and is shown in Figure 10.

Figure 10 : Propulsion Spring

This is a SolidWorks model of Propulsion Spring made of 302 SS

The mock projectile was designed to model the Drone40 by its dimensions and weight. To achieve this a 3D model was created with a height of 180 mm and a diameter of 40 mm. The Drone40 is capable of being pay loaded so its weight will vary based on configuration. To achieve the most accurate representation of the varying weight the team decided to create a hollow shell with a snap fit lid which can be seen below in Figure 11. This design offers the user to add weight inside the mock projectile to achieve a simulation of a pay loaded or non-pay loaded launch.

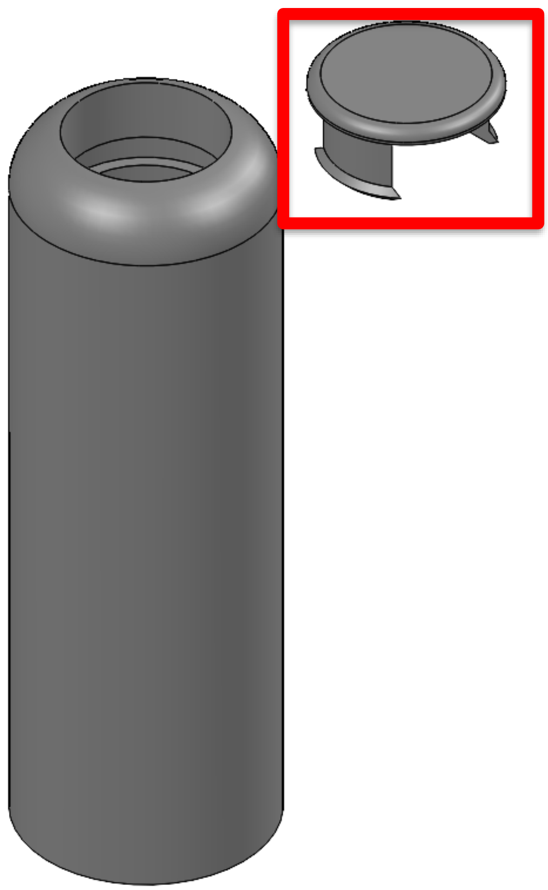


Figure 11 : Mock Projectile Model

This is a SolidWorks model of the mock projectile. Boxed in red is the snap fit lid that securely fits in the hole on the body of the mock projectile. This feature allows for the mock projectile to be filled with mass to achieve the pay loaded mass of 300g of the Drone40.

2.1.2 Release Assembly

The Release Assembly consists of the Housing, Release Clamps, Release Springs, Cable System, Brake Cable, and Brake Lever. This subsystem's primary function is to ensure a secure hold on the Plunger while loaded, and to allow for an instantaneous and reliable release of the Plunger initiating the drone launch. The subsystem breakdown and the Release Assembly components are shown in Figure 12.

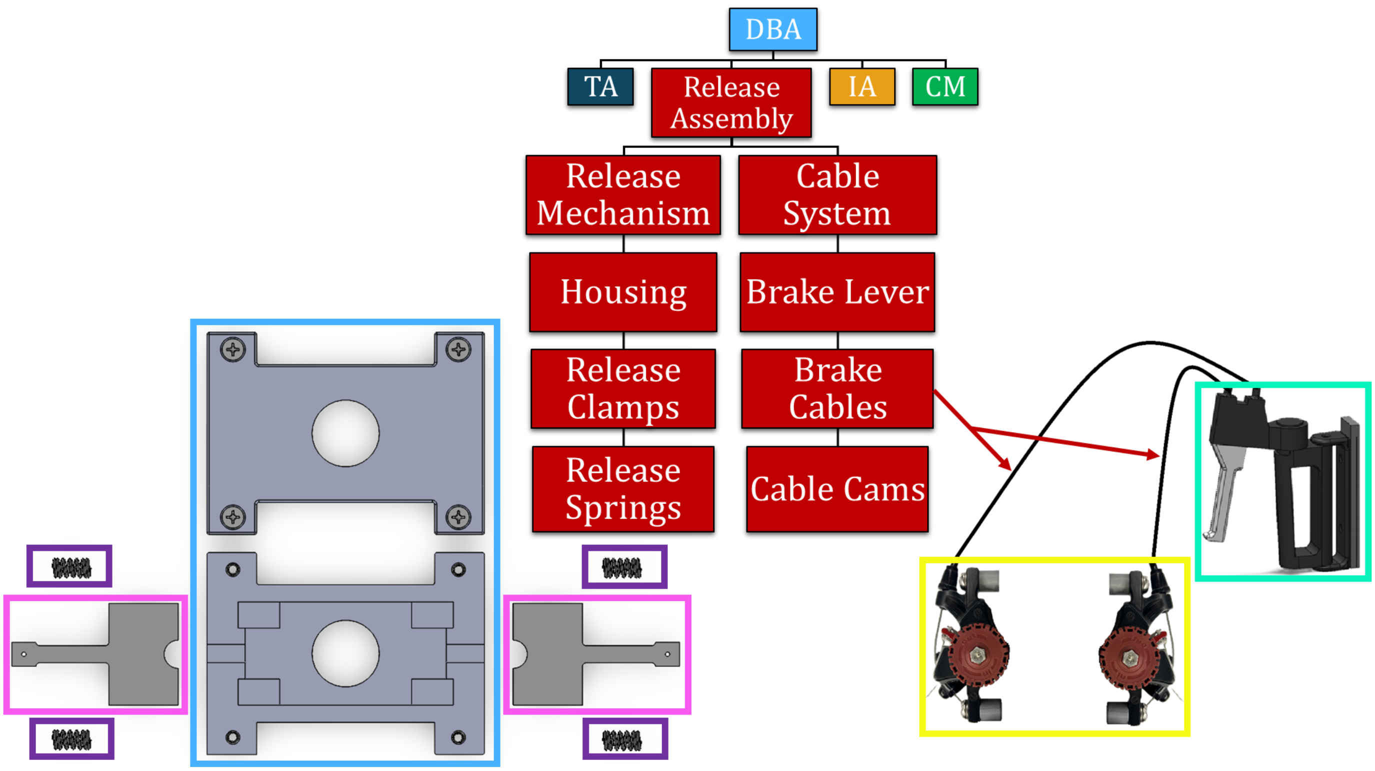


Figure 12 : Release Assembly Component Breakdown

This is a breakdown of the components of the Release Assembly. The Housing is outlined in blue, Release Clamps in pink, Release Springs in purple, the Brake Lever in green, the Brake Cables at the red arrows, and the Cable Cams in yellow.

The Release Housing shown in Figure 13 is entirely 3D printed PLA and weighs 0.35 lbs., making this design lightweight and easy to manufacture. Both housing pieces have identical internal layouts and were designed to only allow internal components to be placed in the operating orientation.

The internal faces of the release housing utilize recessed pockets and channels allowing the internal components to move without binding and eliminating the need for permanent spring and clamp fixtures. Once assembled the housing can be placed into the sub-system interface in with either half being the “top” or “bottom” these descriptive labels are solely for fastener orientation and do not reflect the assembly’s ability to be operated in any orientation.

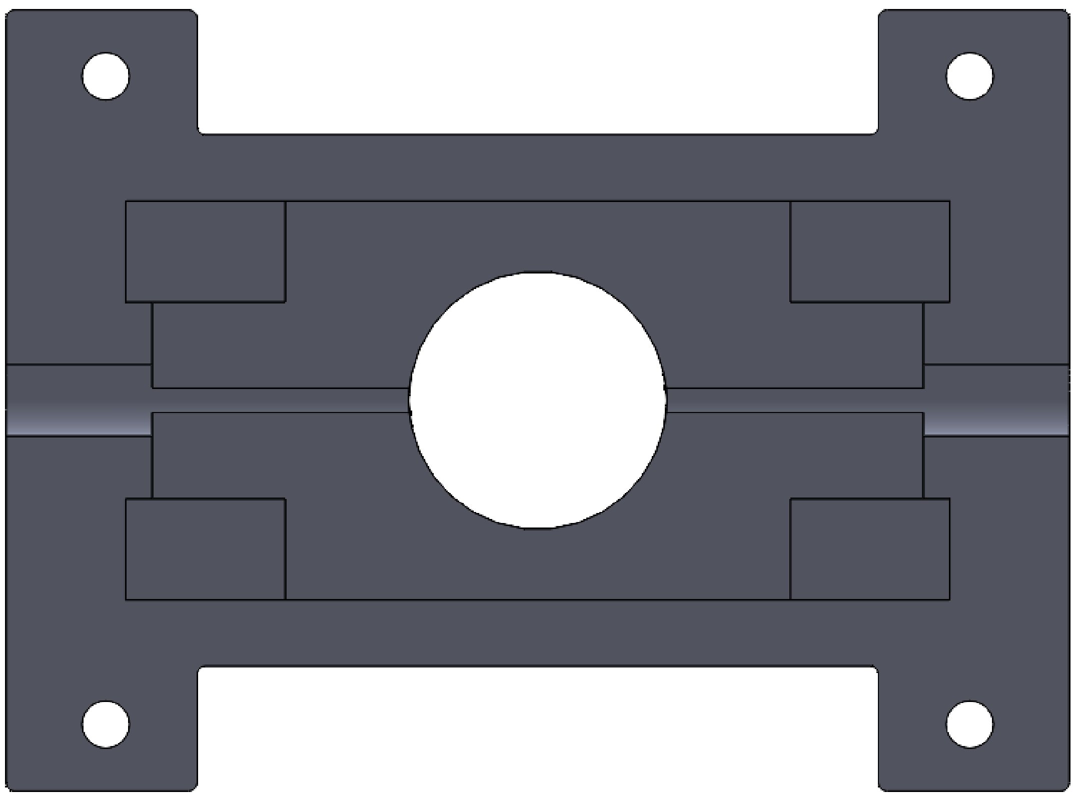


Figure 13 : Release Housing Internal Model

This is a SolidWorks model of release housing internal design.

The Release Clamp design is shown in Figure 14. The design evolved from the original detent pin design into a spring-loaded clamp design. This design offers more stability and more evenly distributes the load from the spring across a larger surface area rather than a single contact point. The 360 degrees of contact the can be obtained with this design decreases the possibility of Plunger misalignment.

The increased surface area of the clamp increases the contact area of the clamp with the housing and decreases the possibility of binding throughout the loading and release cycle. These clamps were originally modeled and manufactured with 3D printed PLA, but ultimately were machined from 6061 Aluminum, increasing product durability and life.

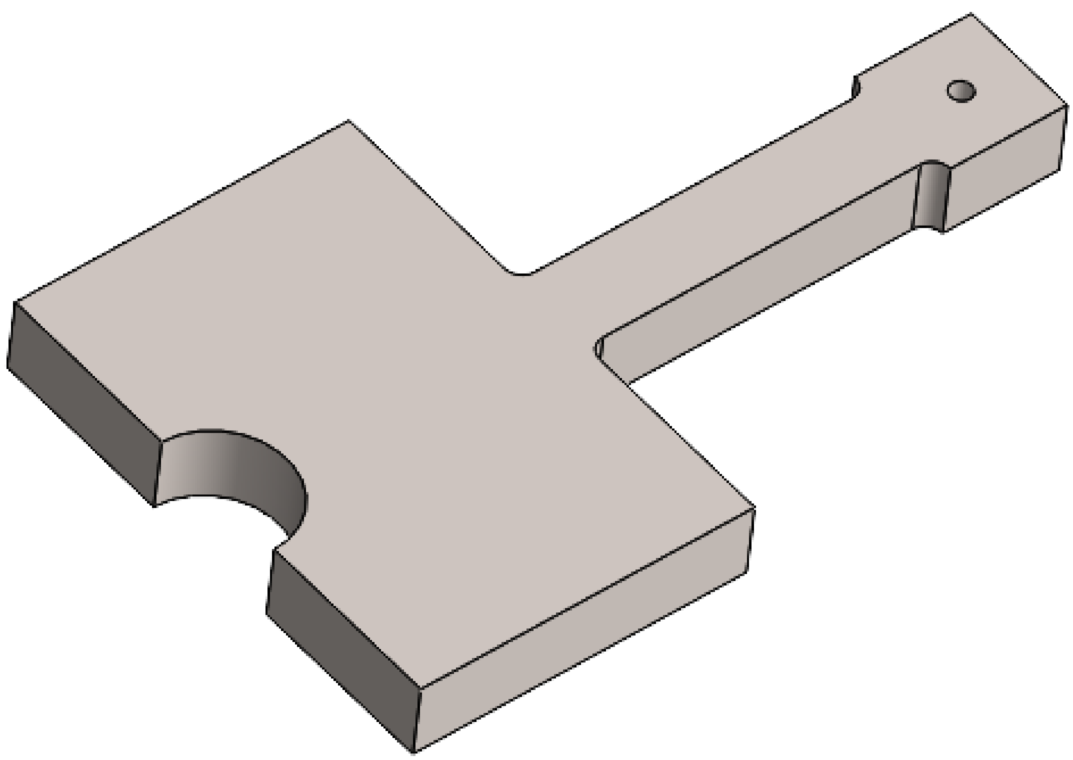


Figure 14 : Release Clamp Model

This is a SolidWorks model of a Release Clamp. There are two release clamps in the Release Mechanism. This part was designed to be fabricated from 6061 T6 aluminum.

For ease of use a recycled bike brake system was chosen to actuate the release clamps. This subsystem consists of a standard Brake Lever, Brake Cable, and ambidextrous MOLLE adapter. The Brake Cables are fed through the eyelets on the Release Clamps, and once the Cable Lever is engaged, the release clamps are actuated, initiating the lunch sequence. A prototype of the Brake Lever, and MOLLE adapter is shown in Figure 15.

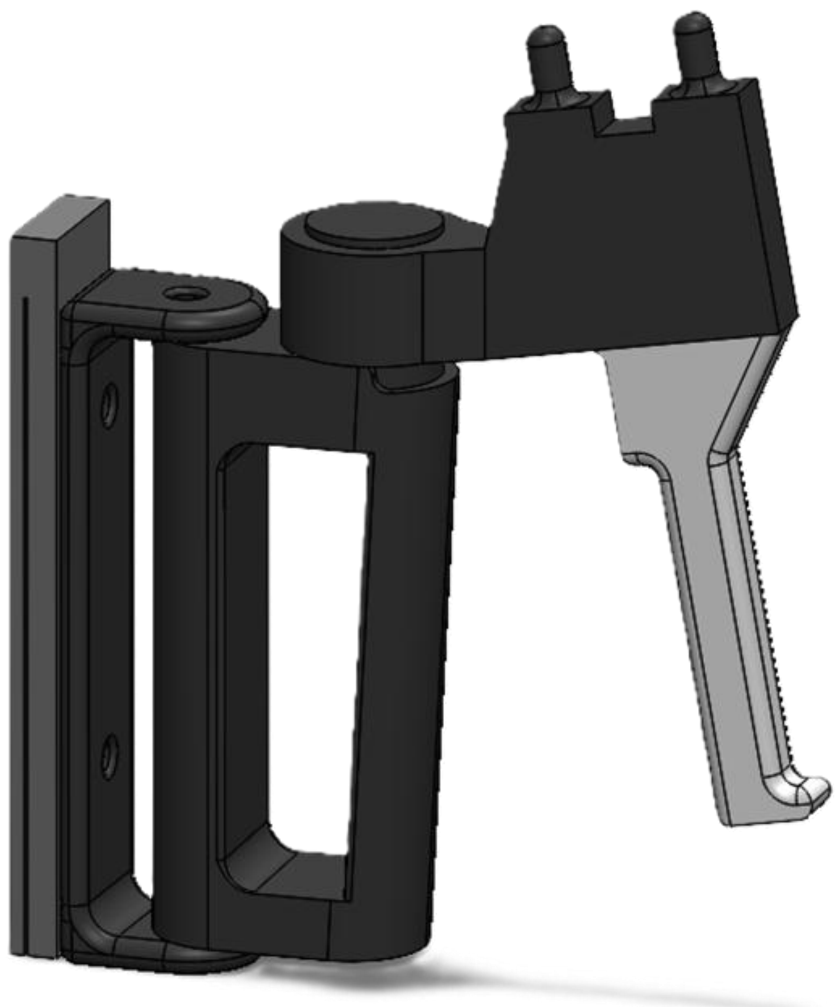


Figure 15 : Bike Brake Lever Model

This is a SolidWorks model of the Brake Lever assembly.

The final assembly configuration of the Release Mechanism assembly is shown in Figure 16. The final design was inspired by spring-loaded detent pins commonly found in trailer hitch pins, construction equipment, and modern weapon systems like the AR-15. The Release Mechanism consists of 4 identical springs, 2 identical clamps, and 2 housing halves. This design requires no permanent fixtures for internal components simplifying the assembly process and allowing for quick in-field repairs or maintenance.

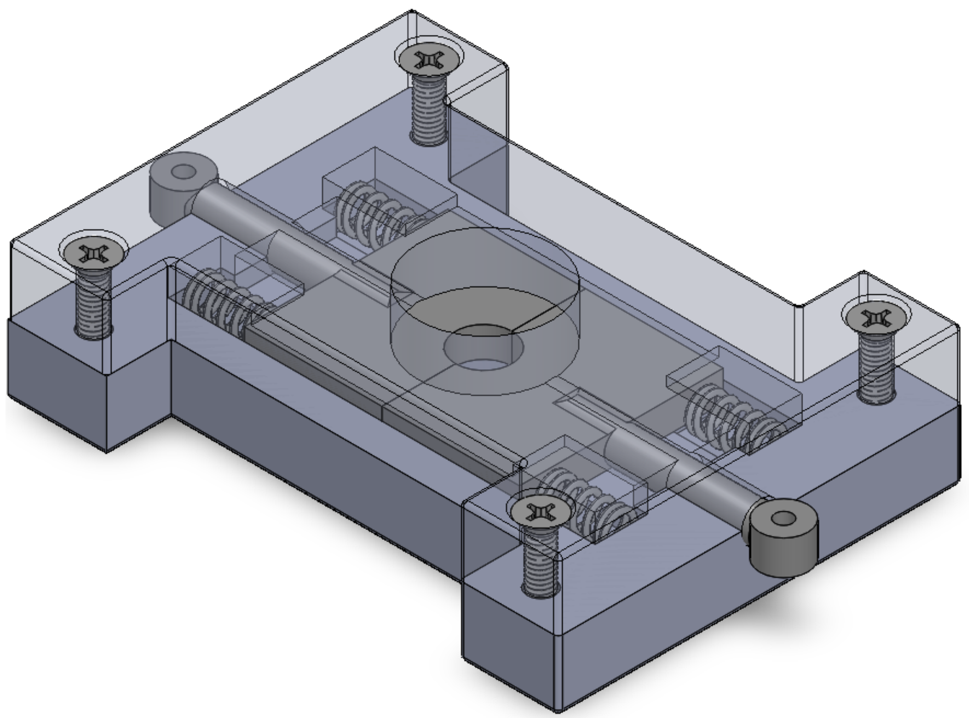


Figure 16 : Complete Release Assembly Model

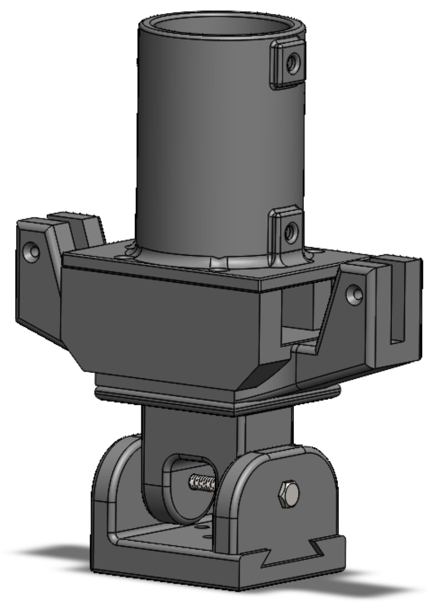
This is a SolidWorks model of the Release Assembly with transparent top to show internal components.

The final Release Assembly shown in Figure 16 was designed for reliable operation and incorporates a failed closed design, meaning that in the event of system failure the release mechanism will always remained engaged, this ensures that no misfires occur by having the internal springs always in compression these springs also increase the force required to actuate further decreasing the odds of accidental release.

2.1.3 Interface Assembly

The Interface Assembly provides an area for the entire assembly to be mounted. It is the heart of the DroneBack, allowing the Tube Assembly and Release Assembly to be fixed together. The Interface Assembly is made up of two main components: the Assembly Hub and the Variable Launch Hinge. A picture of the Interface Assembly and a breakdown of its components are shown in Figure 17.

A)



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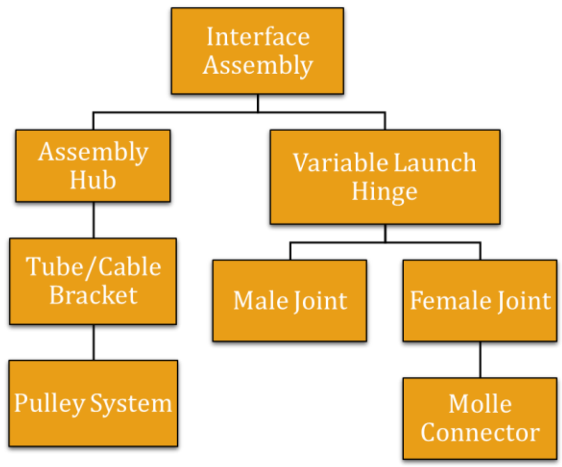


Figure 17 : Interface Assembly Model

In A) is the final assembly for the Interface Assembly. It features both the Assembly Hub and Variable Launch Hinge connected. In B) is the subsystem breakdown for the Interface Assembly.

The Assembly Hub is a component that addresses the need to house the various subassemblies. It houses the Release Assembly and connects to the Variable Launch Hinge. The Assembly Hub is defined by two components: the Tube/Cable Bracket and the Pulley System. This component is shown in Figure 18.

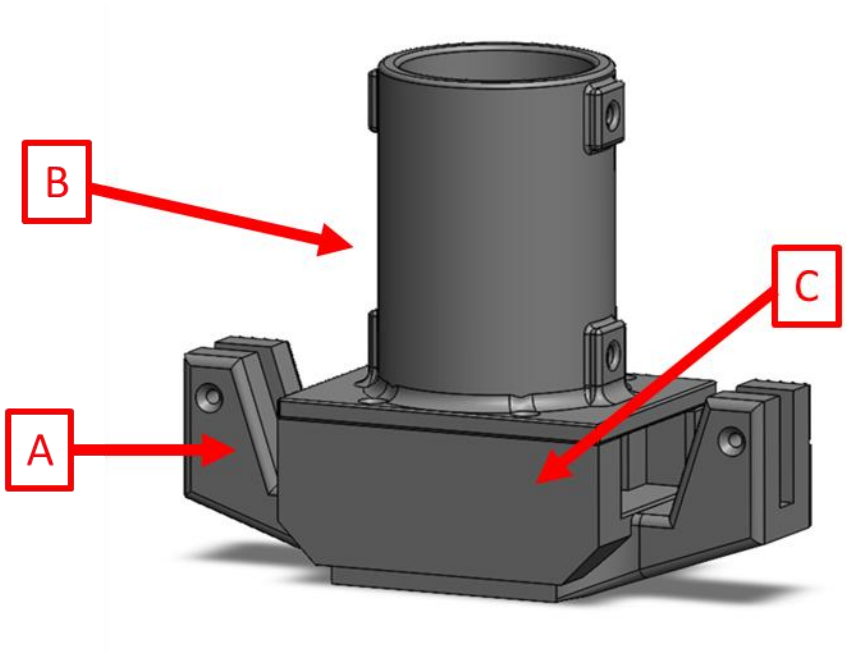


Figure 18 : Assembly Hub Model

This is the final concept for the Assembly Hub. It features all the components of the Assembly Hub including the Tube/Cable Bracket, and the Pulley System. The red arrows on the Figures indicate the specific parts of the Assembly Hub. The arrow marked, A, is the pulley system, the arrow marked, B, is the Tube/Cable Bracket, and the arrow marked, C, is the Assembly Hub itself.

The Assembly Hub provides the Release Assembly with a protective housing and mitigates exposure to foreign debris in the field. Figure 19 shows the Assembly Hub shown in gray and the Release Assembly in black from the top view. This shows how the two subsystems are mated together. The Assembly Hub has an internal cavity that the Release Mechanism can be placed in, fully seated, and held in place once the Tube/Cable Bracket is attached on top.

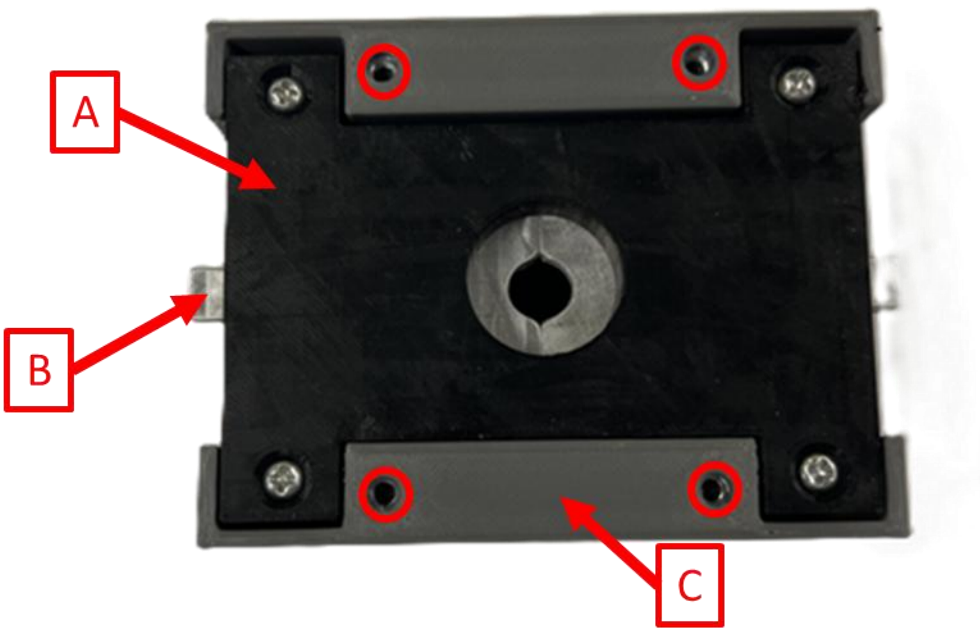


Figure 19 : Assembly Hub with Release Mechanism

This is the Release Assembly fully seated inside the Assembly Hub. This shows how these two components mate. Arrow A shows the Release Assembly and is marked in black. Arrow B shows the aluminum Release Clamps and Arrow C shows the Assembly Hub. The red circles indicate where the Tube/Cable Bracket attached via four fasteners.

The Assembly Hub was modeled on SolidWorks and was 3D printed out of PLA. This component was designed to house the Release Assembly and be mated to the Tube/Cable Bracket. Both the Assembly Hub and the Tube/Cable Bracket provide a location to mate the Release Mechanism, Cable Cams, and Tube Assembly. Once the Assembly Hub and Release Assembly are combined, the Tube/Cable Bracket is attached to the Assembly Hub via four fasteners. These fasteners are marked by red circles shown in Figure 20. Once the Tube/Cable Bracket is attached to the Assembly Hub, the Tube Assembly can be slid into place. The Tube Assembly slides into the top of the Tube/Cable Bracket until the bottom is reached.

Figure 20 : Side View of Cable Cams

This shows a side profile of the Tube/Cable Bracket with the Cable Cams attached via the two fasteners indicated by the red circles. This shows how the Cable Cams are mounted onto the Tube/Cable Bracket

The Tube/Cable Bracket cover has two small holes on each side. This was the location where the bike brake clamps would eventually be mated. The Tube/Cable Bracket cover was originally going to be achieved with multiple parts but was ultimately designed as one component to simplify construction, minimize part count, and increase the overall strength of the assembly. Figure 21 shows the final concept for the Tube/Cable Bracket as a single piece, with the Cable Cams attached.

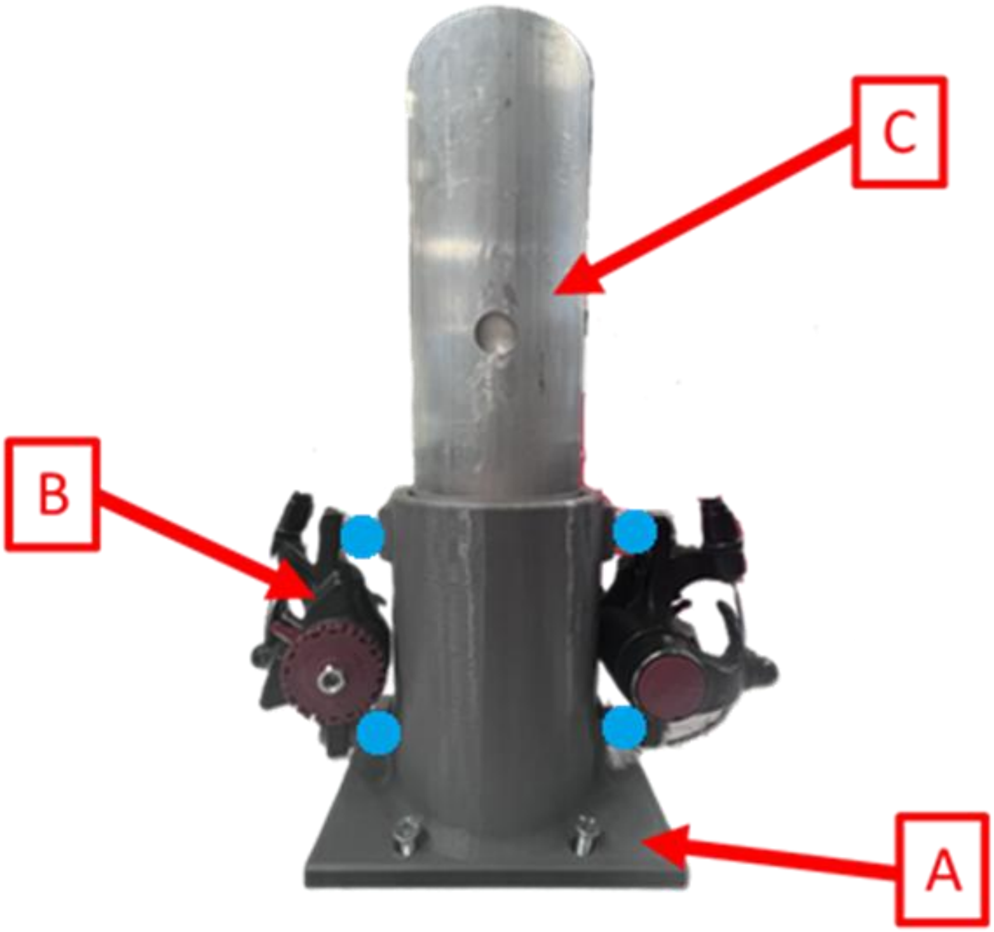


Figure 21 : Tube/Cable Bracket Cover

This is the Tube/Cable Bracket cover. This component attaches to the Assembly Hub and is indicated by the red box marked A. The Cable Cams are indicated by the red box marked B and are mounted onto the side of the bracket via four fasteners indicated by the blue dots. The Tube Assembly is indicated by the red box marked C.

The design for the Cable Cams mounting system served two purposes, giving the team a way to mount the Cable Cams vertically, and fixing the Tube Assembly in place. The Cable Cams were fixed with four fasteners as shown in Figure 21 marked in blue. Once the Cable Cams are connected, they are fixed with four fasteners shown in Figure 20 and Figure 21. These fasteners extend through the Tube/Cable Bracket and contact the Tube Assembly. These fasteners were tightened such that they acted as set screws on the Tube Assembly, keeping it fixed in place.

The final component of the Assembly Hub is the Pulley System. This is an incredibly important component to the function of the DroneBack system. The Pulley System can be seen below in Figure 22. The Pulley System allows the Cable Cams to actuate the Release Mechanism.

In addition to its redirection ability, the Pulley System mates both the Variable Launch Hinge and the Assembly Hub. The Assembly Hub is connected to the Pulley System via four fasteners. The Pulley System is then connected to the Variable Launch Hinge via four additional fasteners.

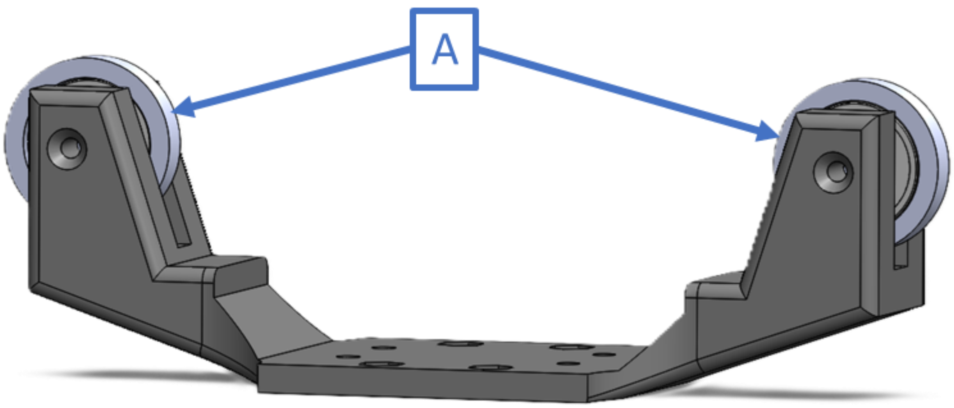


Figure 22 : Pulley System Model

This is a SolidWorks model of the Pulley System. It is attached to the Variable Launch Hinge and Assembly Hub via four separate fasteners. This component features two bearings that allow the DroneBack cables to be redirected to a horizontal force. The bearings are indicated by the blue arrows marked, A.

Since the Cable Cams were mounted parallel to the launch tube, the displacement of the brake cables was perpendicular to the Release Assembly. This meant the vertical displacement needed to be translated into a horizontal displacement to actuate the Release Mechanism. This was achieved with a pulley redirection system shown in Figure 23.

The direction of force on the pulley system is shown in Figure 23. This shows the direction of the force as the Bike Lever is pulled. The vertical force of the Cable Cams is turned into a horizontal force using the Pulley System. The flow of this redirection is marked in red.

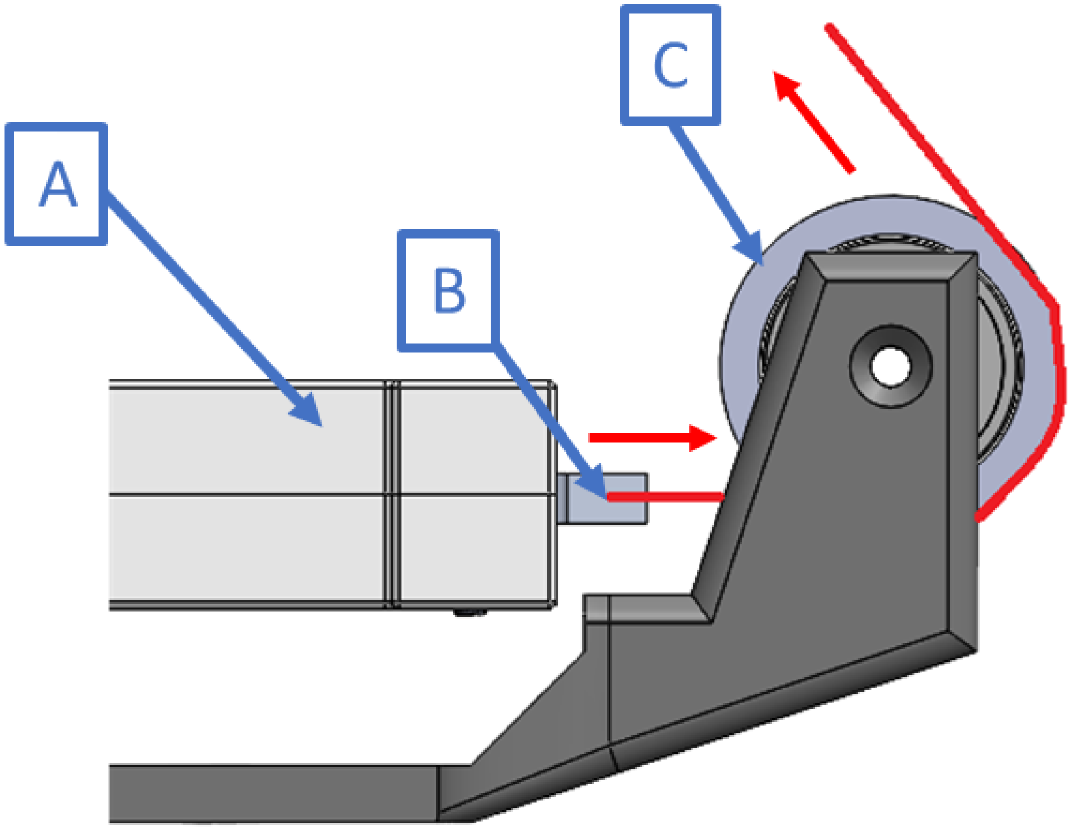


Figure 23 : Pulley System Force Diagram

This diagram demonstrates the direction of flow for the Pulley System. The red line represents the main cable, attached to the Cable Cams. The red arrows indicate the input force being redirected by the Pulley System. The blue arrows indicate the different components that interact with the pulley system. Arrow A shows the Release Mechanism, arrow B shows the Release Clamp, and arrow C shows the pulley bearing.

The Variable Launch Hinge allows users to orient the launcher into the desired orientation while providing a perpendicular mounting surface to interface with off-the-shelf MOLLE webbing adapters. The Variable Launch Hinge is made of 3D printed PLA and has both a Male Joint and Female Joint in addition to the MOLLE Connector. The Variable Launch Hinge is shown in Figure 24.

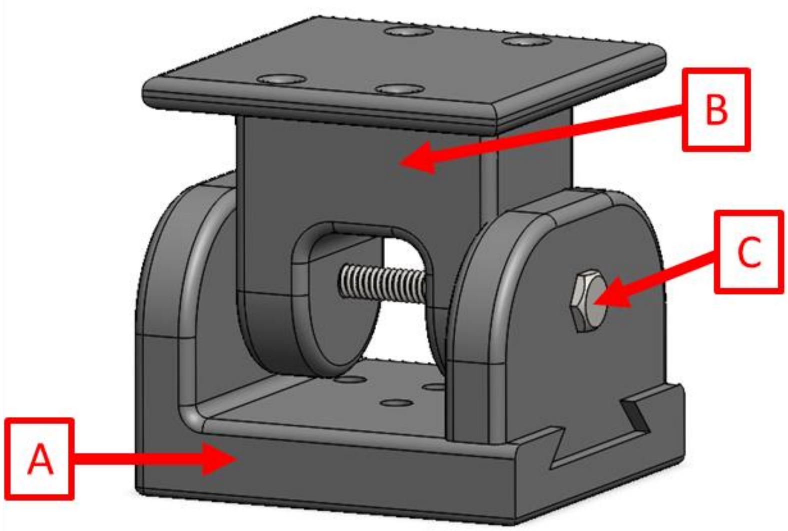


Figure 24 : Variable Launch Hinge Model

This is the Variable Launch Hinge and its components. The arrows indicate the various components in the Variable Launch Hinge. Arrow A shows the Female Joint with its separated base, arrow B shows the Male Joint, and arrow C shows the threaded rod that mates the hinge.

Initially, the Variable Launch Hinge was designed to be machined out of aluminum. While this would be ideal for increased strength, it was not necessary for a functional prototype. The Variable Launch Hinge needed to support the rest of the DroneBack assembly, which weighs less than 5 lbf. Machining the hinge out of aluminum was ultimately abandoned after strength testing was conducted. The strength tested performed on the Instron ElectroPuls showed that the PLA Variable Launch Hinge could support roughly 125 lbf (140 lbf for Male Joint and 110 lbf for Female Joint), which was more than sufficient for a prototype. The Variable Launch Hinge is an important component within the DroneBack assembly.

Standard issue MOLLE webbing comes on military plate carriers, backpacks, and other equipment. As per the project requirements, the final design needed to incorporate a MOLLE adapter to attach the DroneBack to standard issue plate carriers and backpacks. This would allow the final DroneBack design to be easily deployed in the field. In addition to the modularity project requirement, the team wanted the design to have the ability to adjust its orientation.

The project requirement states the design must have a variable launch adjustment of 180 degrees. In addition to this requirement, the DroneBack must be mounted parallel to the user for an effective launch. These requirements led the team to use an adjustable hinge that allowed the DroneBack to be mounted parallel to the user while also allowing for variable adjustment. The purchased adapter is shown below in Figure 25. The MOLLE adapter purchased uses two separate pieces, A housing that permanently attaches to MOLLE webbing using spring loaded clamps, and a disk that has a series of fastener positions to be used with various equipment. The two components can be easily separated with the use of a quick release system, making it an attractive option for those in the field.

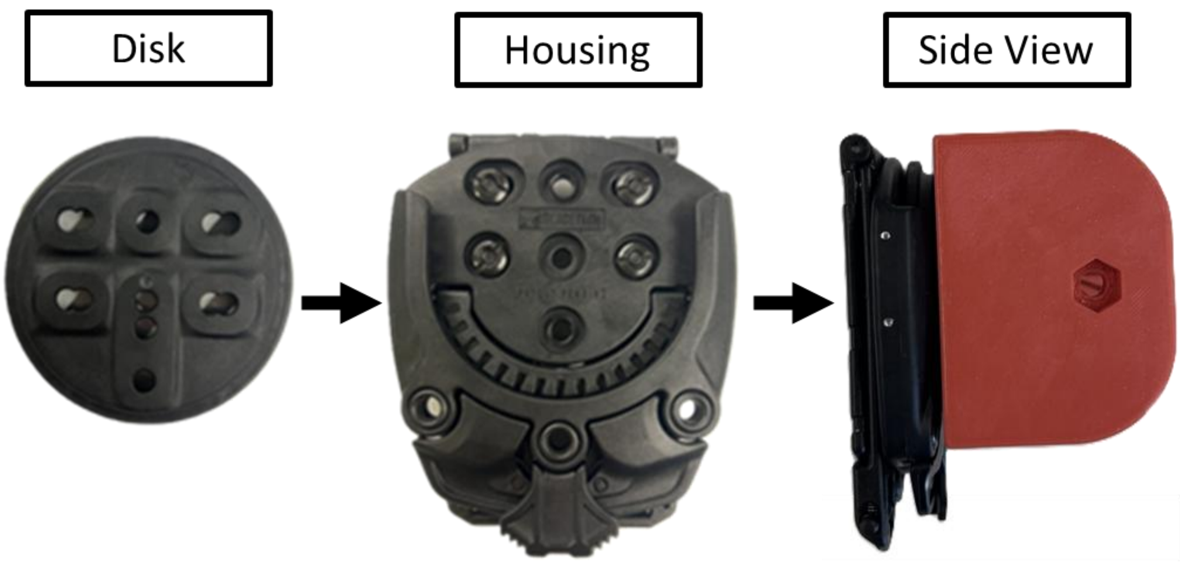


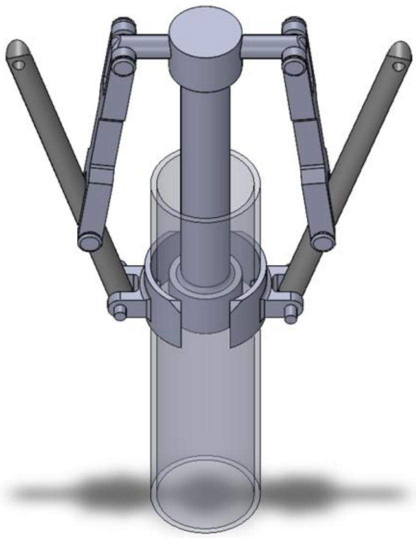
Figure 25 : Base MOLLE Adapter

This shows the MOLLE connector separated into its two components. From left to right; the disk is the component that the Female Joint of the Variable Launch Hinge is attached to, the Housing is the component that is permanently attached to the MOLLE webbing on a plate carrier or backpack. Figure 25 also shows a side view of the Variable Launch Hinge attached to the Disk and inserted into the Housing.

2.1.4 *Cocking Mechanism*

The Cocking Mechanism, shown in Figure 26, serves the purpose of reducing the force required to compress the spring, allowing the user to easily cock the launcher. The Cocking Mechanism reduces force required by the user to compress the Propulsion Spring from 78 lbf to 4 lbf per Crank Arm, 8 lbf in total. For risk mitigation and ease of use a slider crank mechanism was designed.

A)



B)

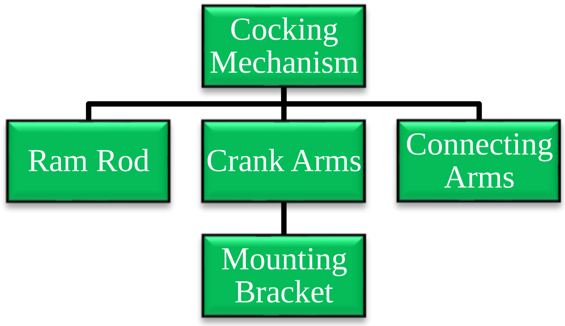


Figure 26 : Cocking Mechanism Breakdown

In A is the Cocking Mechanism attached to the Outer Tube. In B there is the subsystem breakdown of all components of the Cocking Mechanism.

The Ram Rod is 3D printed out of PLA and directly interfaces with Plunger fitting inside the Inner Tube. The two Crank Arms provide a location for the person loading the DroneBack to input force. These two Crank Arms are fabricated from aluminum. The two Mounting Brackets are permanently fixed to the Outer Tube with a hose clamp. The Connecting Rods were 3D printed out of PLA and connect the Ram Rod to the Crank Arms. An exploded view of these components is shown in Figure 27.

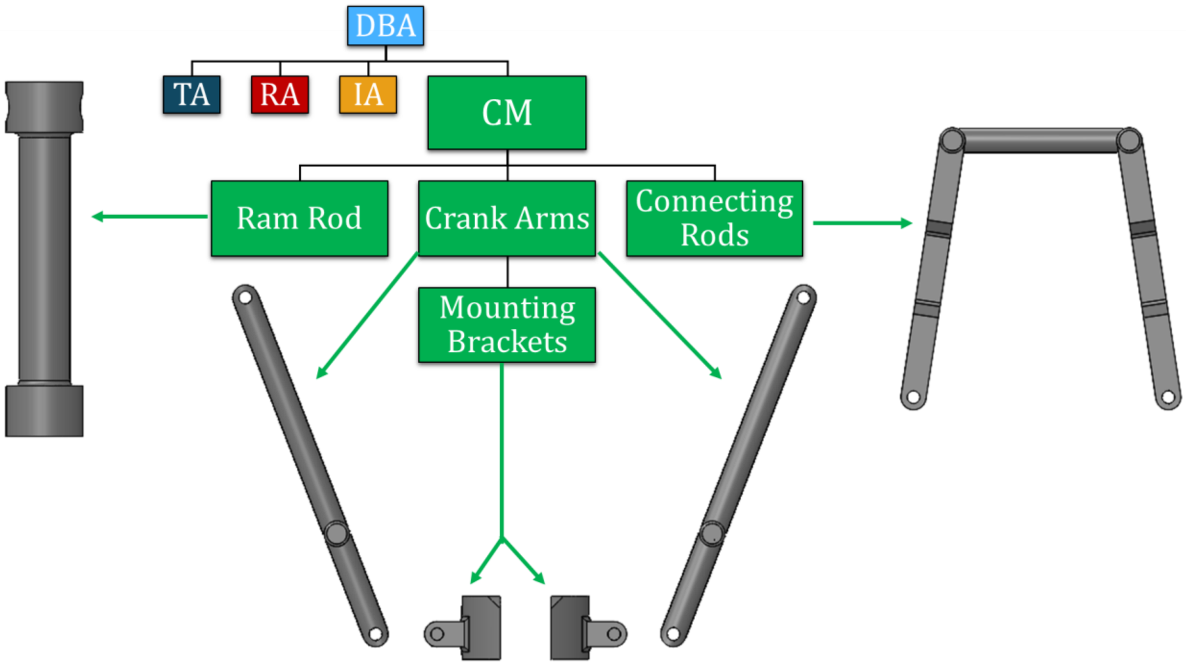


Figure 27 Cocking Mechanism Exploded View

This is an exploded view of the Cocking Mechanism with the green arrows indicating what each component is.

3 ENGINEERING DESIGN

This section describes the calculations and decisions made to select and design critical components such as the Propulsion Spring, the Outer Tube, the Plunger, the Release Mechanism, and the Variable Launch Hinge to ensure the DroneBack meets all functional and technical requirements.

3.1 SYSTEM ENERGY CALCULATION

The first calculation performed was a system energy calculation. This calculation will dictate the spring parameters required to meet the design requirement of launching a drone 15 ft. in the air. Friction and drag will be ignored thus simplifying the system energy calculation. Using the maximum mass of a Drone40 with a payload (300g), the required energy for the system was found to be just over 119 in-lbf. The complete system energy calculation is shown in Appendix G. A diagram that shows the setup for the system energy calculation is shown in Figure 28.

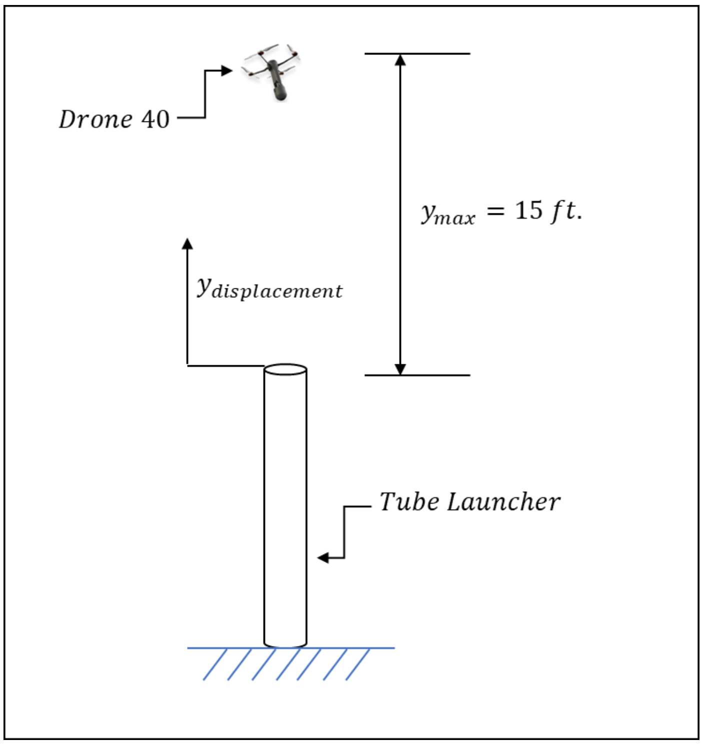


Figure 28 : System Energy Diagram

This diagram shows the situation that sets up the amount of energy required. It allows for simplification of the calculations and a good understanding of what the calculations means to the system.

Once the kinetic energy was obtained a preliminary spring constant of $27\ \frac{lb}{in}$ was found by assuming a travel distance of three inches. This design assumption allowed the team to determine a potential spring constant and adjust values as needed. The Propulsion Spring needed to fit inside the 40mm Inner Tube. The spring purchased from The Spring Store and all its associated parameters can be found in Appendix G. The key parameters were a constant of $21.638\ \frac{lb}{in}$ and a maximum travel of $3.646\ in.$ storing $143.82\ in \cdot lb$ of energy. This was more than the required $119\ in \cdot lb$ of energy needed launch the Drone40 15 ft.

3.2 TUBE DESIGN

The initial calculations done for the outer aluminum tube were done using values shown in Table 2. The dimensions in this table were for commercially available aluminum tubing meeting the dimensional criteria required for the Drone40.

Table 2 : Outer Tube Material Properties
Material*: 6061 T6 Extruded Aluminum*
Yield Strength *= 40 ksi*
Young's Modulus *= 100 ksi*
$\boldsymbol{D_o} = 2.25in$
Length *= 9in*
$\boldsymbol{D_i} = 2\ in$
$\boldsymbol{I_{hollow\ cyclinder}} = \frac{\pi}{64}\left({D_o}^4 - {D_i}^4\right) = 0.4727\ in^4$

The data shows that the most severe loading situation for the Outer Tube to undergo would be that of a soldier falling on the tube with all their body weight plus the weight of their gear. The average weight of a soldier and their gear is 252 lbf [2,3]. Using SkyCiv software, the team modeled the tube as a cantilever beam, with a 252 lbf load at the end, this simulates the average weight of a soldier in full-service gear falling on the tube. The loading scenario is shown in Figure 29. The shear diagram is shown in Figure 30, shear diagram, and bending diagram are shown in Figure 29.

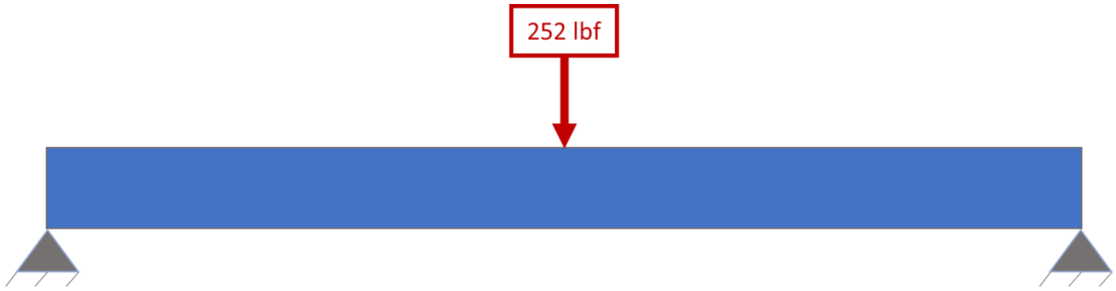


Figure 29 : Outer Tube Loading Condition

This is the loading condition for the Outer Tube. The loading considered is a 252 lbf load applied on the center of the outer tube in blue.

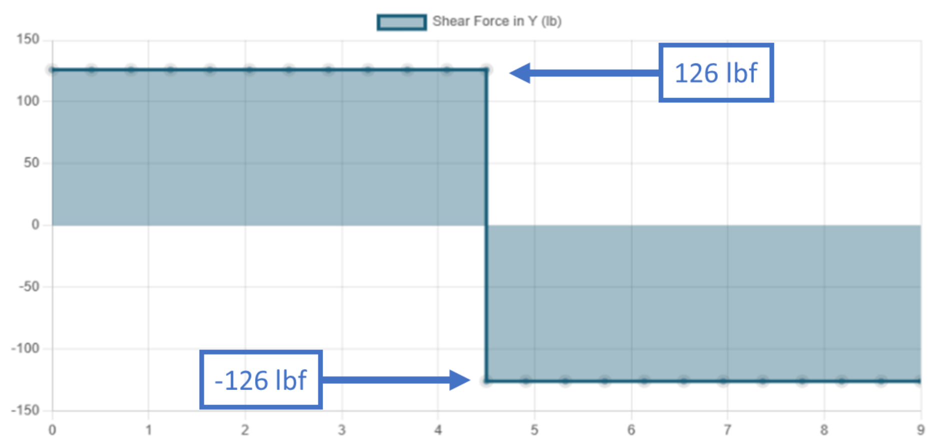


Figure 30 : Outer Tube Shear Diagram

This is a shear force diagram. Outlined in blue are the maximum and minimum shear force locations.

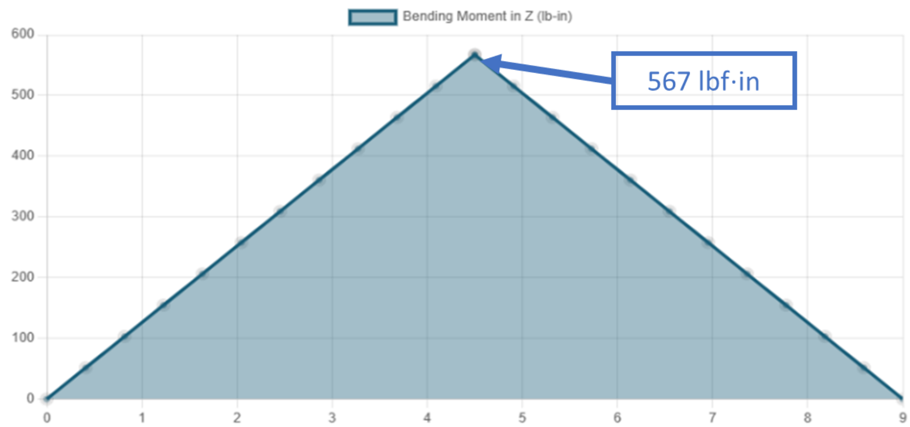


Figure 31 : Outer Tube Moment Diagram

This is the Outer Tube moment diagram. This diagram was generated using SkyCiv software.

The maximum shear force that occurs on the beam is 126 lbf and the maximum moment was found to be 252 in-lbf. These values were then used to calculate the maximum bending stress that the tube will experience. The calculation for this stress can be found in Appendix O. The bending stress that the tube will experience in this loading condition is just under 1350 psi. Since the material selected has a tensile strength of 40,000 psi, the outer aluminum tube has a safety factor of about 29.6. With the max stresses being well within the safety and performance parameters set by the team, an aluminum tube with the dimensions from Table 2 was purchased and chosen for the final design.

3.3 *PLUNGER DESIGN*

The Plunger was designed using dimensions from the Tube Assembly as limits for dimensions such as length, shaft diameter, and platform diameter. See Table 3 for the dimensions.

Table 3 : Plunger Dimensions	
Overall Length	≥ 3.25 in.
Shaft Diameter	≤ 0.956 in.
Platform Diameter	≈ 1.57 in.

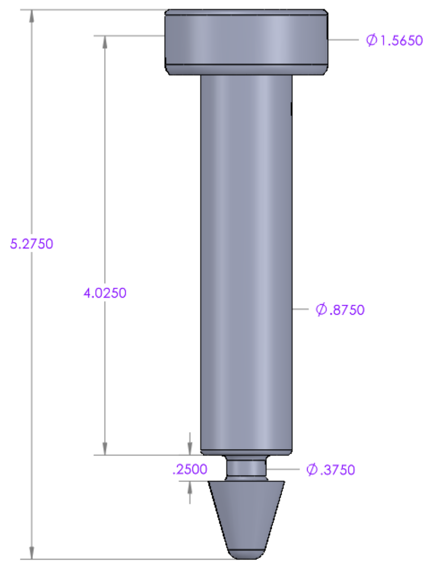


Figure 32 : Dimensioned Plunger Model

This is a SolidWorks model of the Plunger fully dimensioned.

This design shown in Figure 32 features reduced diameter allowing smoother interface with the Inner Tube and Propulsion Spring. Shown in Figure 32 the platform features an extruded lip; this helps to keep the Plunger aligned during release and provides more surface area to secure the Propulsion Spring. This design was tested with the release clamps, Tube Assembly, and Propulsion Spring and meshed well with all assemblies, becoming the final Plunger design. With a finalized Plunger design the team began the design of the Release Assembly. Design parameters for this system included smooth interface with the Plunger during loading and release, along with the strength and durability to undergo multiple cycles and extended periods of load stress.

3.4 *Release Design*

The Release Assembly was one of the most critical components in the DroneBack Assembly, as its function was to ensure instantaneous launch, and a secure hold of the Plunger until launch was initiated. The trigger force required to actuate the mechanism was required to determine the overall functionality and feasibility of the design and was found using the MATLAB code in Appendix E, this was calculated to be 30 lbf. While this number seemed high, the addition of lubricant reduced frictional resistance, while still requiring high enough forces to actuate reducing the probability of an unintentional launch. During model fit test, and component dry runs, the PLA clamps withheld forces and functioned properly. Once the Propulsion Spring was inserted and the clamps underwent loading, the eyelets began to tear out and fail. This was a remedied by making the clamps from 6061 Aluminum.

3.5 VARIABLE LAUNCH HINGE DESIGN

The Variable Launch Hinge was designed to have 180 degrees of rotation. This was a requirement the team set to make the DroneBack capable of varying orientation. The inspiration behind the Variable Launch Hinge was a simple door hinge. These use a male and female end with a pin connecting them. The Variable Launch Hinge was constructed in a similar fashion, using a male and female joint, and a ¼-20 threaded bolt as a connecting pin. A SolidWorks model of the Variable Launch Hinge is shown in Figure 33 with some basic dimensions in inches.

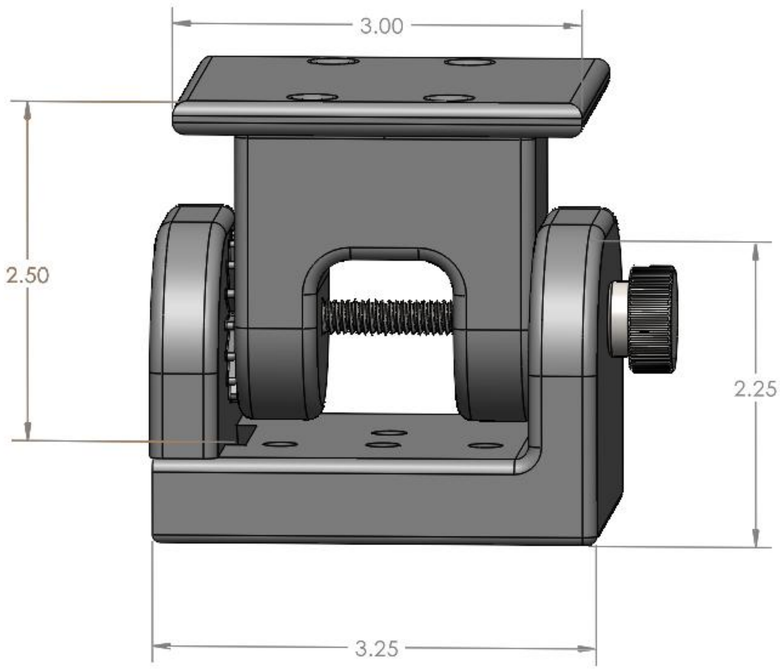


Figure 33 : Final Variable Launch Hinge

This is a SolidWorks model of the final Variable Launch Hinge with applicable dimensions. This hinge acts as an anchor because it bridges the subassemblies to the MOLLE adapter. It is important to make a rigid hinge that can also be adjusted easily all while keeping a low footprint. There were no specific area requirements that the team established, however the MOLLE adapter that was procured had an outer diameter of 2.80 in, making the total area of 6.16 in^2. This was used as a guide to estimate the size of the Variable Launch Hinge. A simple CAD model was created using SolidWorks and was revised by 3D printing prototypes out of PLA.

The Female Joint of the Variable Launch Hinge is separated into two pieces and connects via a small cavity that acts as a track. This allows the Variable Launch Hinge to be compressed fully once the threaded rod and knob are attached. Figure 34 shows the Female Joint separated.

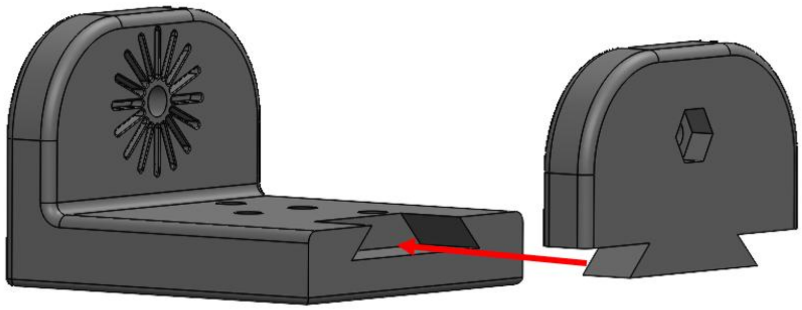


Figure 34 : Female Joint Compression Feature

This is the Female Joint of the Variable Launch Hinge separated into its two pieces. The separated component fits into the cavity track shown by the arrow in red. These two pieces are compressed together onto the Male Joint and held in place by the threaded rod and knob.

The 180 degrees of variable launch requirement was met using the Variable Launch Hinge and its adjustable grooved wheel. The grooved wheel is shown in Figure 35. This grooved feature is cut into the walls of the Female Joint and extruded onto the walls of the Male Joint. This feature can be seen on the Male Joint in Figure 36. This allowed the Variable Launch Hinge to be compressed together and lock in certain positions. These specific positions are dictated by the grooved feature and are set every 22.5 degrees.

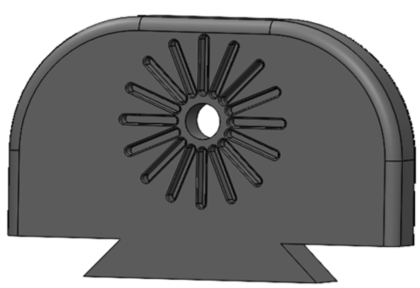


Figure 35 : Female Joint Grooved Feature

This is the separated piece of the Female Joint and highlights the grooved wheel feature. These grooves help lock the Variable Launch Hinge in place at certain orientations. The grooves are set every 22.5 degrees.

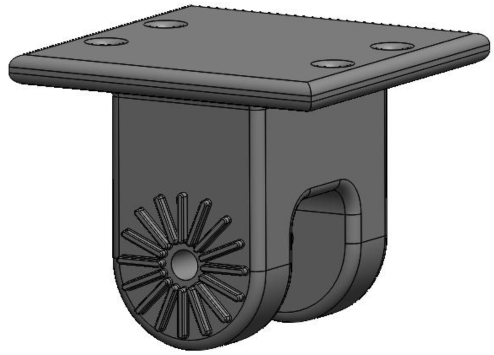


Figure 36 : Male Joint Grooved Feature

This model highlights the grooved feature on the Male Joint of the Variable Launch Hinge.

4 FABRICATION

The DroneBack was fabricated using the resources and equipment supplied by USI such as the design lab and the applied engineering center. Fabrication of each component was divided up into their associated subsystem. The processes involved in the fabrication are outlined in the sections to follow.

4.1 TUBE ASSEMBLY

The Outer Tube and Inner Tubes were purchased off the shelf from the Online Metals website and Home Depot. The Outer Tube was purchased in a 3ft. section and cut to length using the horizontal bandsaw. The holes for the Mounting Bracket were drilled out using a vertical endmill. The Inner Tube was also cut to length using the horizontal bandsaw, after which it was placed in a lathe and the length was turned down to 8.25 inches. The horizontal bandsaw did not provide tight enough tolerance so the team opted to use the lathe for a higher level of precision. Photographs of these processes are shown in Figure 37 and Figure 38.

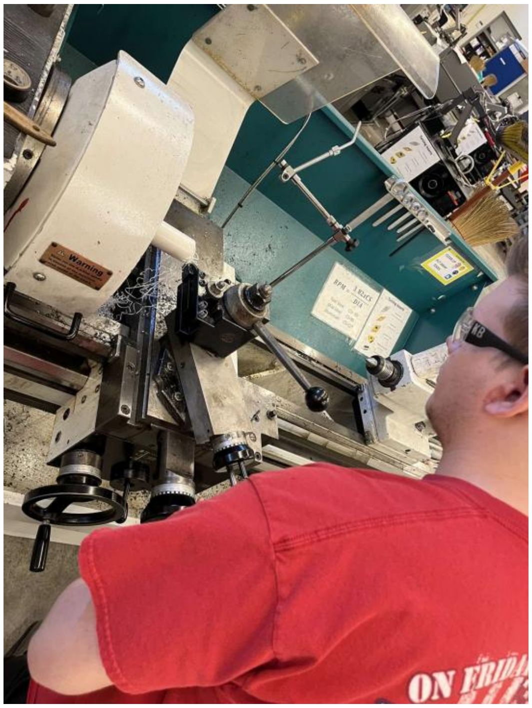


Figure 37 : Inner Tube Milling Process

Team member Klay Brown uses the lathe to turn down the length of the Inner Tube to the correct length of 8.25 inches.

Figure 38 : Outer Tube Horizontal Bandsaw Operation

This shows the Outer Tube being cut to length on horiztonal bandsaw operation.

The Mock Projectile was fabricated from PLA using the prusa 3D printer with a 15% infill. A snap fit lid was also 3D printed to contain the weights used to achieve the weight of a pay loaded Drone40 (300g). An Image of the mock projectile can be seen in Figure 39.

A)

B)

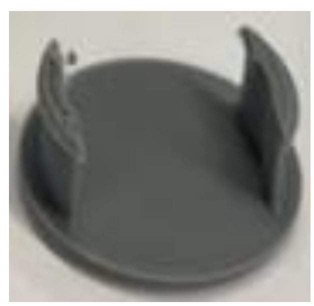


Figure 39 : Mock Projectile Physical Prototype

In A is the mock projectile used for testing. This projectile was 3D printed PLA. The hole in the top is where weight was added to achieve a mass of 300g for testing. In B is a zoomed in image of the snap fit lid that snaps into place to ensure the weight used to model the Drone40 is securely kept inside.

The Plunger was fabricated from PLA material using the Prusa 3D printer with 25% infill. The Plunger undrewent many different revisions. The versions of the Plunger were changed to accommodate for size throughout the design and construction phase. For example, the Plunger was intitially too large in diamter and was getting stuck in the spring so it needed to be resized acoordingly. Additionally, the Plunger would break after launch upon hitting a hard surface such as concrete, so a higher infill was used.The revisions of the Plunger can be seen in Figure 40. The only design changes made were diameter of the Plunger and the length.

Figure 40 : Final Prototype Plunger

This shows the prototype Plunger in the upside down configuration to capture a detailed image of the Plunger. This was 3D printed at 25% infill using the Prusa Mini 3D printer.

4.2 *RELEASE ASSEMBLY*

The final Release Assembly was fabricated via 3D printing, waterjet cutting, and purchase of off-the-shelf fasteners. Polylactic Acid is an efficient, and affordable prototyping material. The Release Assembly underwent multiple iterations before the final prototype design, this design progression is shown in Figure 41. SolidWorks models are easily integrated with the Prusa software used for 3D printing, the decisions to prototype with PLA maximized time efficiency and minimized financial impact.

A) B) C)

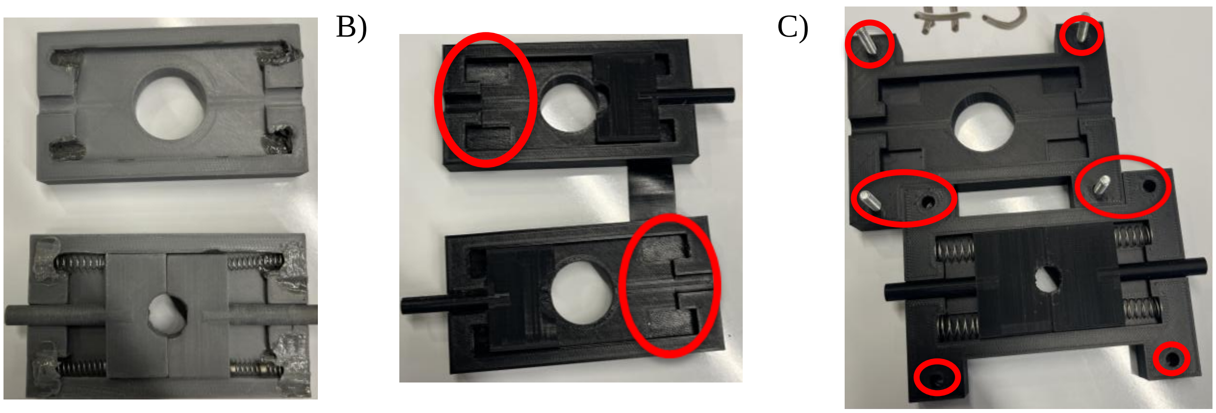


Figure 41 : Release Mechanism Progression

In A) release mechanism revision 1. In B) release mechanism revision 2 with recessed pockets added for spring retention. In C) release mechanism revision 3 with PLA release clamps, release springs and fixture mounts added to revision 2

Figure 42 shows a functioning 3D printed release mechanism prototype. This prototype was fabricated and assembled in under 24hrs. Final fabrication of the release clamps was completed using the AEC waterjet, and an endmill.

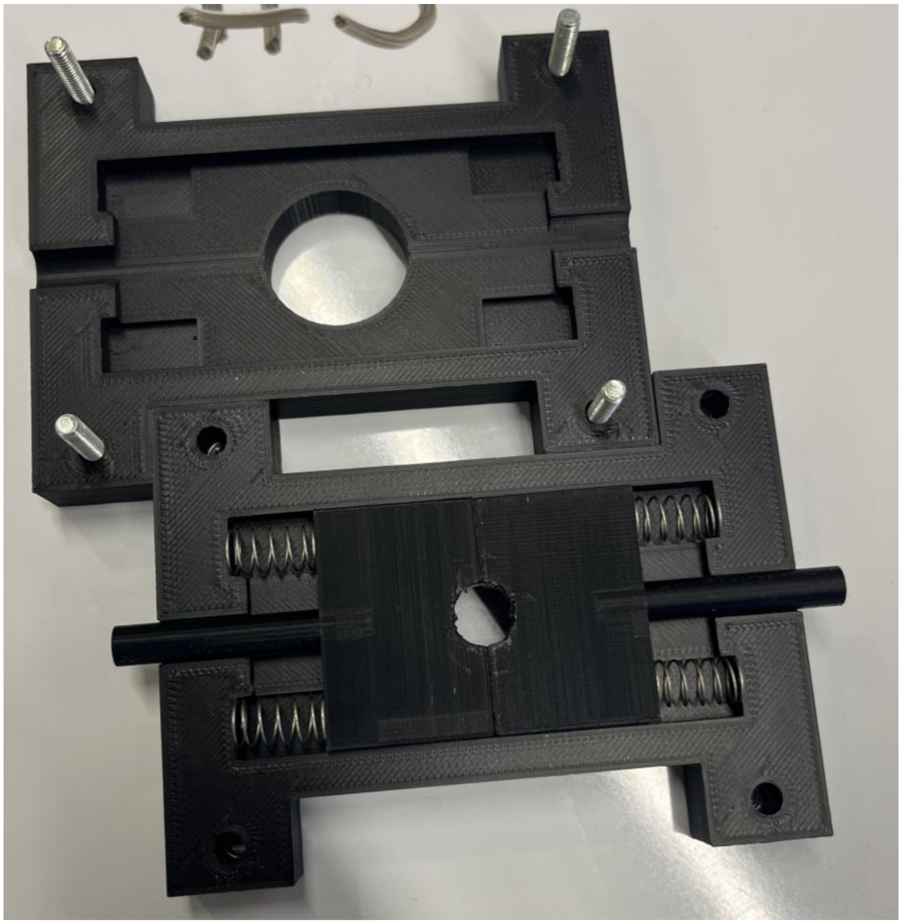


Figure 42 : Full Release Mechanism Assembly

This shows the full release mechanism assembly with PLA clamps, release springs, and fasteners. Cable System not shown.

4.3 *Cocking Mechanism*

The Cocking Mechanism was initially 3D printed using the Prusa 3D printer at 30% infill. The fixtures used were ¼-20 bolts and lock nuts purchased from Home Depot. The Crank Arms were initially 3D printed. However, after strength testing, the Crank Arms experienced a large amount of deflection. The team opted for aluminum Crank Arms to decrease the deflection. The aluminum Crank Arms were fabricated by using a band saw to cut the arms down to length. A grinder was then used to round off the edges. To ensure proper alignment of the holes a mill was used to drill the holes. An image of the 3D printed design is shown in Figure 3A. An image of the Cocking Mechanism with the aluminum Crank Arms can be seen in Figure 3B.

A)

B)

Figure 43 : Cocking Mechanism Physical Assembly

In A) is the Cocking Mechanism detached; the Crank Arms are 3D printed out of PLA. In B) is the Cocking Mechanism with the aluminum Crank Arms. The team chose aluminum to increase the strength of the Crank Arms.

4.4 INTERFACE ASSEMBLY

The Interface Assembly was entirely 3D printed out of PLA and used off-the-shelf hardware such as fasteners and hex nuts. The Assembly Hub was printed with eight captive hex nuts which allowed the team to use standard fasteners to mate the different components. These models were created using SolidWorks and were printed on the Prusa i3 MK3 and Prusa Mini.

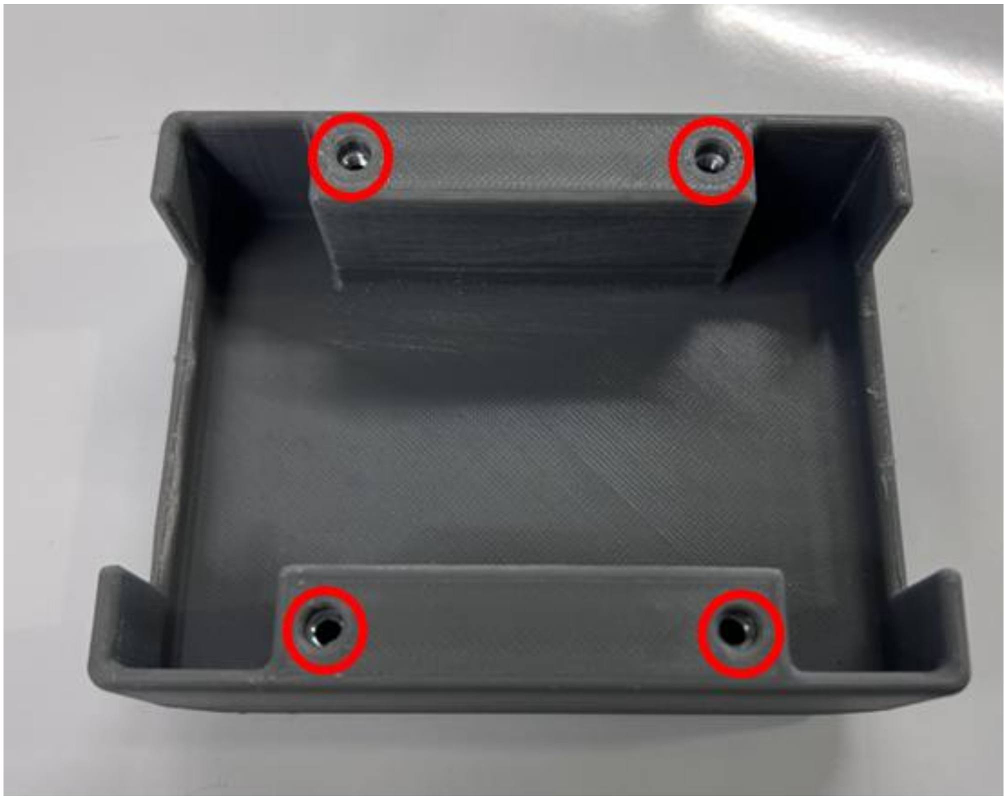


Figure 44 : Top View of Assembly Hub

This shows the top view of the Assembly Hub. The red circles indicate the four holes that have hex nuts 3D printed in place.

Figure 44 is a better look at the top view of the Assembly Hub and highlights the holes in which fasteners are threaded into. These four holes indicated by the red circles provide a location for the Tube/Cable Bracket to be mated. The #8-32 hex nuts were 3D printed into the Assembly Hub which made it easy to connect the Tube/Cable Bracket and Pulley System without needing to add threads to the models.

The Pulley System was 3D printed out of PLA and features a series of holes and hex nut cavities which made simplified assembly and allowed the team to use off-the-shelf #8-32 fasteners. Figure 45 below shows the Pulley System in its early prototyping stage, specifically when the team was developing the hole pattern that connected to the Variable Launch Hinge and then to the Assembly Hub.

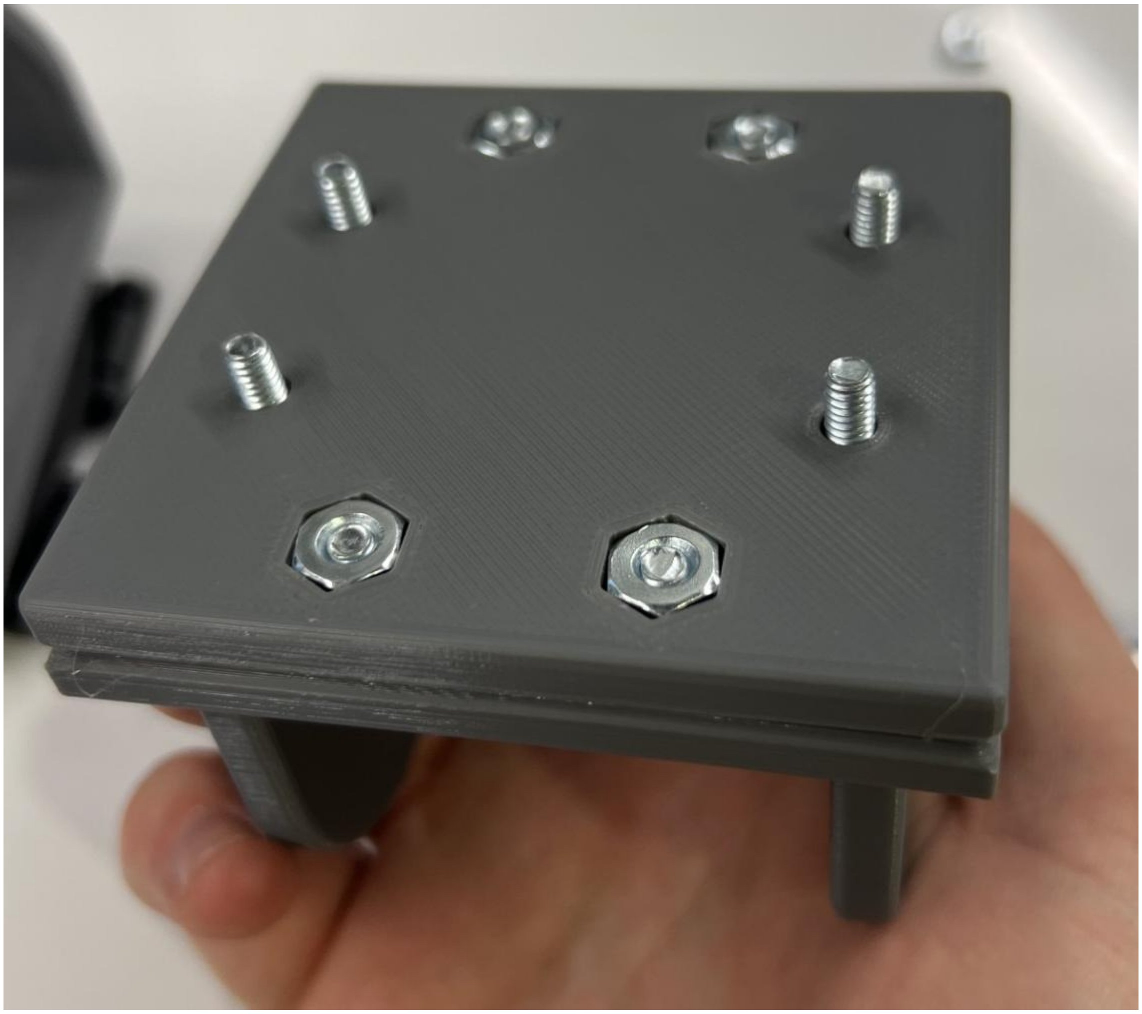


Figure 45 : Variable Launch Hinge Mating Bracket

This shows the early prototype for the Pulley System, specifically its bracket hole pattern. The Pulley System mates the Variable Launch Hinge to the Assembly Hub via the above hole pattern. This was achieved by 3D printing the component and using off-the-shelf #8-32 hardware.

5 TESTING & SIMULATION

A variety of testing was performed to ensure the components of the DroneBack would not fail while in use. These include strength testing and Finite Element Analysis. The strength testing was performed using the hydraulic strength tester (Universal Tester) and a pneumatic strength tester (Instron Electro pulse E10000). The Finite Element Analysis was accomplished using SolidWorks. The Finite Element Analysis was performed for all components that would undergo any type of loading during operation.

5.1 FINITE ELEMENT ANALYSIS

Finite Element Analysis is computer software that allows the user to test components for strength. The specific type of software the DroneBack team used was through SolidWorks. This testing is performed by modeling a part in a 3D space on SolidWorks modeling then applying loads and fixtures to simulate a loading situation. The parts simulated using FEA techniques were categorized by the associated subsystem. Results for these simulations were analyzed by displacement plots and stress plots. Stress plots show the areas of maximum stress that the part being tested undergoes during a loading situation. Displacement plots show the deflection a part undergoes during loading I.E. the scalar quantity a part is deformed down to compared to its undeformed state. These provide key insight into the components capability of supporting loading during operation.

5.1.1 Tube Assembly FEA

The components from the Tube Assembly that required FEA simulation were the Outer Tube and the Plunger. The Propulsion Spring, Inner Tube and Mock Projectile were not considered in this simulation because they will not be taking a load. The purpose of the Outer Tube is to protect the Drone40 from impact. The FEA simulation represented a loading a soldier falling directly on the tube. A mass distributed load of 252 lbf was applied to the top surface of the Outer Tube. It was found to have a maximum deflection of 0.0009 in. and had a maximum stress of 1.410 ksi. The yield strength of the material is 40 ksi resulting in a factor of safety of 28.4. This is well above the design requirement of a factor of safety of 1.5. Since the FEA simulation resulted in a FOS of 28.4 and the aluminum tubing material was limited, the team decided not to perform physical strength testing.

The FEA plots for both deflection and stress are shown in Figure 46 and Figure 47. The holes that accommodate for the Cocking Mechanism do not impact the overall strength of the Outer Tube, so they were not considered during FEA simulation and hand calculations.

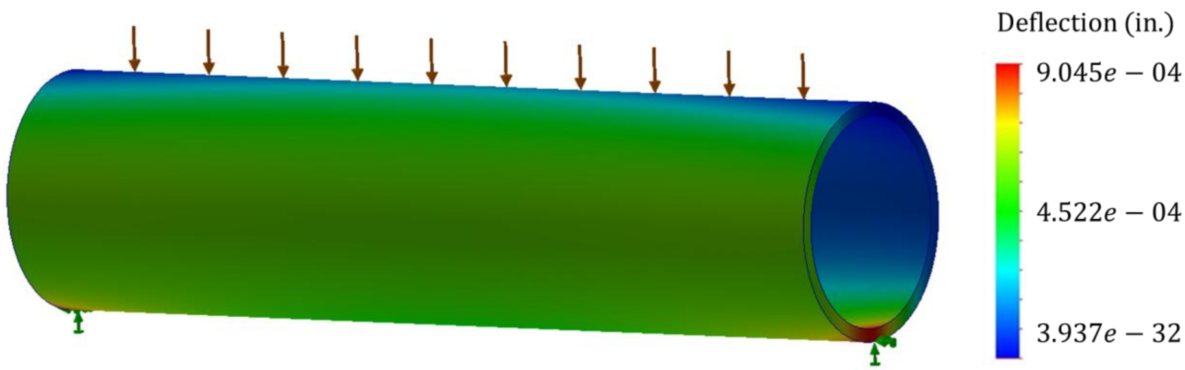


Figure 46 : Outer Tube Displacement Plot

This is a plot of a SolidWorks simulation of a 252 lbf mass distributed load being applied to the top surface of the aluminum Outer Tube. The maximum displacement was 0.0009 inches.

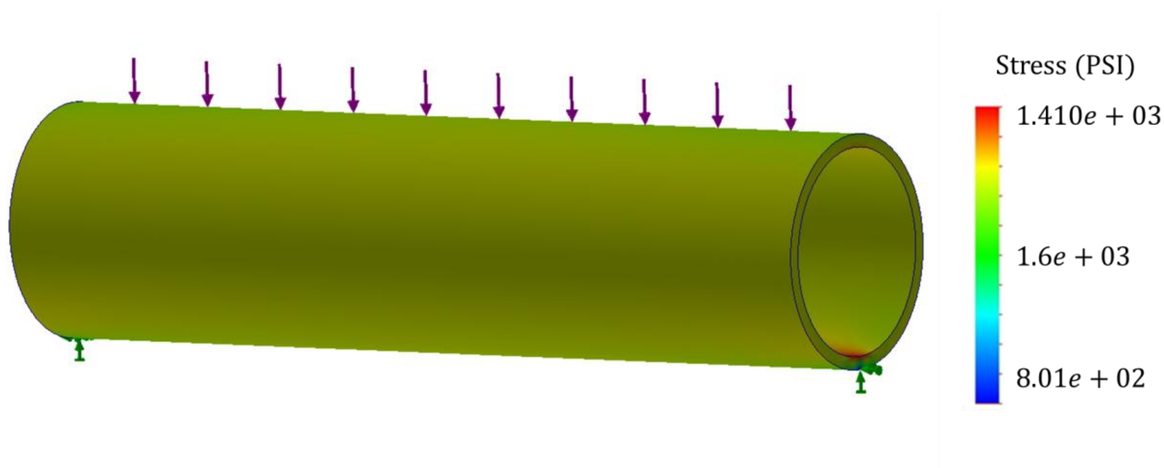


Figure 47 : Outer Tube Stress Plot

This is a SolidWorks simulation of a 252 lbf mass distributed load on the Outer Tube. This simulation was run using a 6061 T6 Aluminum tube with the a through hole to accurately model the Outer Tube with the current design. Under this loading situation the max stress was 1.410 ksi having a factor of safety of 28.4.

The hand calculations on the Outer Tube provided that under a load of 252 lbf the maximum stress was 1350 psi. This was very close to the FEA simulation for stress experienced by the Outer Tube of 1410 psi leading the team to be confident in the capability of the Outer Tube to support the loading outlined by the design requirement.

The Plunger is entirely 3D printed, and undergoes tensile loads from the Propulsion Spring, and the Release Assembly. These conditions gave the team reliability and performance concerns, and provoked thought for possible alternate materials such as Lexan or Aluminum. The use of alternate materials would require the team to spend considerable time and resources machining these parts to the proper sizes. To test the validity of these concerns FEA studies were conducted for the PLA Plunger and then compared with physical testing results. To properly simulate the loading conditions and interface, roller/slider fixtures were applied to the extruded lip of the Plunger, and an 80 lbf load to the bottom face of the release groove. The results of the studies can be seen in Figure 48 and Figure 49.

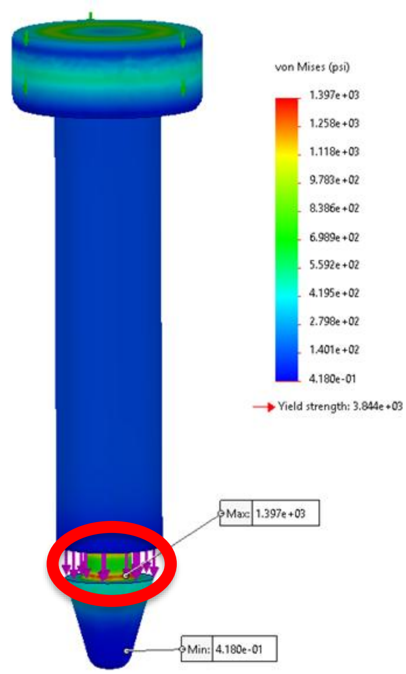


Figure 48 : Plunger Stress Plot

In Figure 48 is the stress plot simulated by the FEA program in SolidWorks. The maximum stress the Plunger underwent was 1397psi. Circled in red is the region with highest stress.

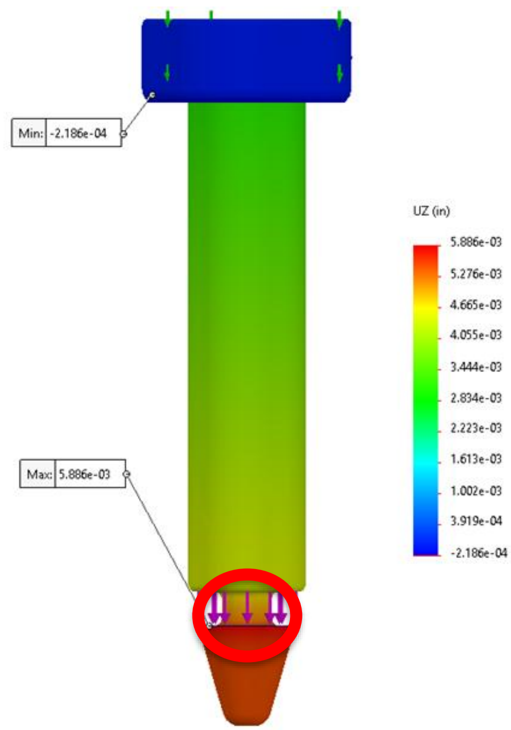


Figure 49 : Plunger Displacement Plot

In Figure 49 is an FEA simulation for the 3D printed Plunger fabricated from PLA. This plot represents the displacement from loading the plunger with 80 lbf of force. Circled in Red is the area that experiences the highest displacement.

The Von Mises stress for this loading condition was 1.397 ksi, when compared to the yield strength of PLA, a yield factor of safety of 2.75 was calculated. This met the team's safety requirement and led the team to believe the Plunger would not fail from yielding. The displacement of the Plunger was also analyzed, as plastic deformation may occur from high cycles, or misalignment of the Plunger could occur. The studies anticipated a maximum displacement of 0.0058 inches under these conditions. These results lead the team to believe PLA was suitable material and could proceed to physical testing.

5.1.2 Release Assembly FEA

The most significant points of failure in the Release Assembly are the release clamps. When engaged with the Plunger these clamps will experience approximately 80 lbf total load for extended periods of time. The most likely failure modes under these conditions would be binding from excessive displacement, or material yield at points of contact. Finite Element Analysis was employed to determine displacement, and the Von Mises stress of a 6061 Aluminum clamp and a Polylactic Acid clamp. From these studies the team was able to choose a suitable clamp material that is lightweight, safe, and reliable.

The first clamp prototypes were designed to be 3D-printed using PLA, as most of the assembly is 3D printed, and the team had easy access to equipment. These studies used an applied load of 40 lbf along the bottom edge and inside radius of the clamp face to simulate the force applied to clamps from the Propulsion Spring through Plunger interface. All other faces in contact with the release housing were fixed. The results of the studies can be seen below in Figure 50.

A) B)

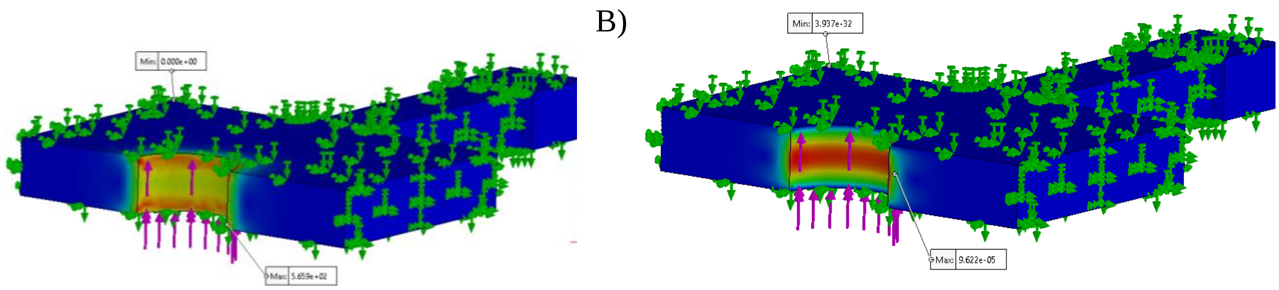


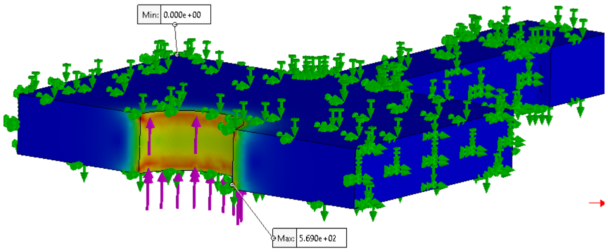
Figure 50 : PLA Clamp FEA Stress and Displacement Plots

In A) is the PLA Clamp FEA Von Mises Stress plot. In B) is the PLA Clamp FEA displacement plot.

Shown in Figure 50 is the Von Mises stress related to these loading conditions is 565.9 psi, when compared to the yield strength of PLA, 3844 psi, a yield safety factor of approximately 6 is found. Due to the tight tolerances of the Release Assembly for precision motion, deflection of the PLA clamps was of concern, The FEA results anticipated a deflection of only 0.096 mils, well within the acceptable range (≤ 0.005 inches). The team then prototyped with the PLA clamp design and were able to successfully complete multiple test launches, but the clamps began failing in fatigue.

From the unsatisfactory performance of PLA during physical testing, the team began computer simulations to test Aluminum clamps of the same geometry and loading conditions. The results of this study is shown in Figure 51.

A)



B)

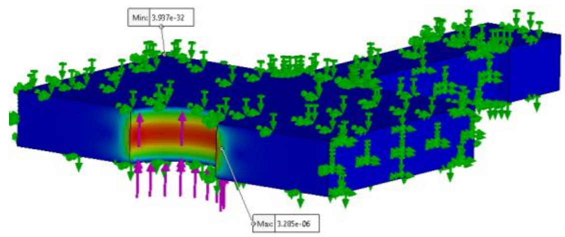


Figure 51 : Aluminum Clamp FEA Plots

In A) is the Aluminum Clamp FEA Von Mises Stress plot. In B) is the Aluminum Clamp FEA displacement plot.

The Von Mises stress was found to be 565.9 psi, which was expected from the previous PLA Study, when compared to the yield strength of 6061-O Aluminum which is 7999 psi. This results in a yield factor of safety of approximately 14. The anticipated deflection from this study was 0.033 mils, these results allowed the team to be confident in the performance of aluminum as the final prototype clamp material.

5.1.3 Interface Assembly FEA

A finite element analysis was performed on the Female Joint of the Variable Launch Hinge. A load of 252 lbf was applied to the outer walls to simulate the compressive loading it is expected to experience in the field. As shown, the maximum deflection experienced was found to be 0.03675 inches. This deflection was deemed minimal by the team since the Female Joint of the Variable Launch Hinge is already in compression initially and is prevented from yielding by the Male Joint that acts as a hard stop. This simulation was conducted with the material established as PLA. While this was helpful in simulating the expected loading, it assumes that the component is made of solid PLA. The components are made of 15-40% PLA depending on the 3D printer settings. Despite this assumption, the FEA gave the team confidence that a 3D printed Variable Launch Hinge would be adequate for a functional prototype.

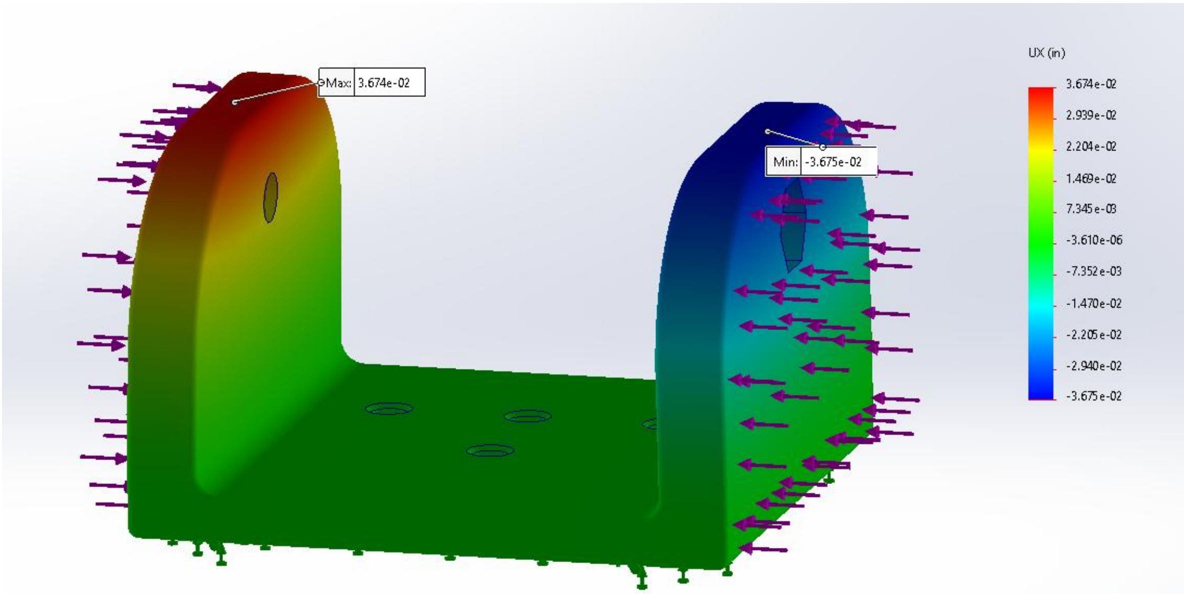


Figure 52 : VLA FEA – Female Joint

The FEA simulation for the Female Joint of the Variable Launch Hinge with applied load on outer walls is shown

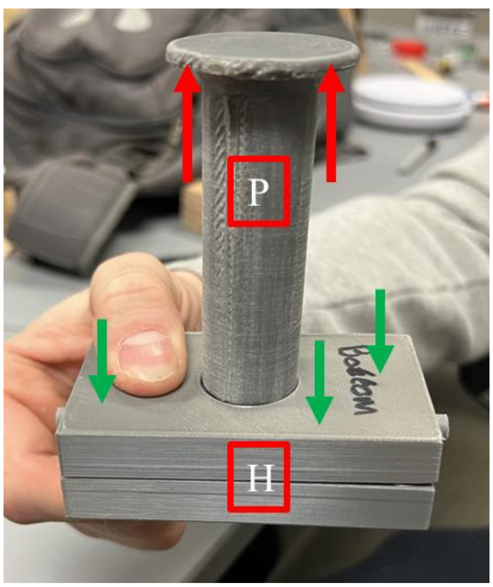
5.2 *STRENGTH TESTING*

Strength testing was a crucial factor throughout the design process. The team was able to perform strength testing with the help of Dr. Nelson and using the facilities provided by USI. It allowed the team to prototype components from each subassembly to ensure yielding would not occur. All 3D printed PLA parts were tested using the Instron Electro Pulse E1000. Each part was fixtured and loaded in tension or compression. The loading simulations were dependent upon how the part would undergo a load during operation.

5.2.1 Release Assembly Strength Testing

The only Tube Assembly component that was strength tested was the Plunger. The Plunger was tested at the same time as the Release Assembly. The strength testing configuration is shown in Figure 53. The machine used to strength test the Plunger and release mechanism was the Instron Electro Pulse E10000. The Plunger was loaded into the release mechanism and locked into place from the force provided by the release springs. Straps were attached to the top lip of the Plunger (P) which are indicated by red arrows. Toe clamps were then used to fix the release mechanism housing (H) to the base plate. A tension test was performed until the part yielded under a load of 150 lbf. Since the Propulsion Spring had a maximum compression force of 78 lbf, the factor of safety for the Plunger and release mechanism was 1.92. Although this was not a design requirement outlined by the team it was important for user safety and the function of the Release Assembly.

A)



B)

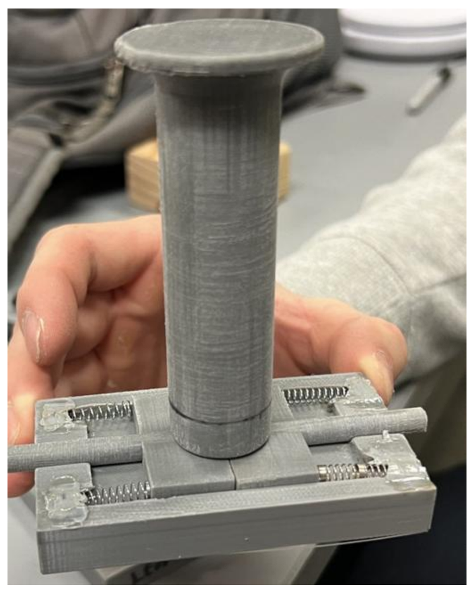


Figure 53 : Plunger and Release Mechanism Strength Testing Configuration

In A) is the loading configuration used during strength testing the Plunger and Release Mechanism. The red arrows indicate where the force was applied during a tension test. The green arrows are where the Release Housing was clamped during loading. The Plunger is indicated by (P) and the Release Housing (H). In B) is the same configuration without the top half of the housing.

5.2.2 *Interface Assembly Strength Testing*

The Interface Assembly was strength tested on the ElectroPuls Universal tester with assistance from Dr. Todd Nelson at USI. The Male Joint was set up for testing in the same position as the FEA study to simulate similar loading. The testing resulted in an average load of 125 lbf. The Female Joint, which was simulated using FEA, supported 110 lbf The Male Joint supported 140 lbf. This gave the team an average value of 125 lbf. While this was less than the simulated study, the strength tested components were 25% infill out of PLA. This meant they were significantly weaker than a solid piece of plastic. The loading setup for the Variable Launch Hinge Male Joint can be seen below in Figure 54. Despite the results being different from the FEA, the team was confident that 125 lbf would be more than sufficient for a functional prototype for the Variable Launch Hinge.

Figure 54 : Loading Setup for Male Joint on Universal Tester

This shows the loading setup for the Male Joint on the ElectroPuls universal tester. This component supported 140 lbf for this test.

5.2.3 *Cocking Mechanism Strength Testing*

The Crank Arm was tested using a tip-loaded cantilever setup. To ensure accuracy throughout the test clamps were used to hold down one side while a point load was applied to the other. The location of this point load was determined by estimating the surface area of where a person loading the DroneBack would place their hand while compressing the spring and cocking the launcher. Then place the load in the middle of that location to simulate a mass distributed load as a point load. In Figure 55 the testing setup is shown. This test was not meant to achieve an extremely precise analysis or simulation but to give the team confidence in the capability of the design. The Crank Arm supported a load of 24 lbf before plastic deformation occurred. Although this is less than the maximum cocking force calculation which can be found in Appendix D, it still underwent 2 in. of deflection. It is replaced with an aluminum rod to achieve less deflection and a higher yield strength.

Figure 55 : Crank Arm Strength Testing Setup

Crank Arm is shown being tested in the compression tester to simulate the loading it would undergo during the loading process. Boxed in red is the Crank Arm and ruler used to ensure the loading was in the correct position as it would be during use.

Shown in Figure 56 is the fully deformed Ram Rod. It had undergone strength testing using the Universal Tester under a compression load. Since this part of the Cocking Mechanism compresses the spring the force it needed to withstand without yielding is the max compression force of the spring which is about 80 lbf. However, after testing was completed the Ram Rod a 400 lbf load until plastic deformation occurred. This means that the Ram Rod would have a factor of safety of 5 giving the Team confidence in the design of this component.

Figure 56 : Ram Rod Plastic Deformation

The Ram Rod that failed under a compression test while using the Universal Hydraulic Tester is shown. The Ram Rod began yielding after a load of 400 lbf was applied. Since the working load is only 80 lbf this gave the Ram Rod a FOS of 5.

The broken Connecting Rod shown in Figure 56 failed during a tension test. The original design for the Connecting Rod was pinned using a 3D printed pin which failed due to bearing stress. Once the pin yielded tension was loaded through one side of the Connecting Rod thus causing that side to fail in tension after a 130 lbf load was applied. The Connecting Rod that failed is shown in Figure 57. Outlined in red is the 3D printed pin that failed.

Figure 57 : Connecting Rod Pin Failure

The Connecting Rod shown failed after a load of 130 lbf was applied. The 3D printed pin boxed in red yielded first causing the Connecting Rod to experience and asymmetrical load to one side causing it to fail prematurely.

Since the pin failed first it led the team in the direction of using a metal fastener to increase the load carrying capacity of the Connecting Rod. An image of this configuration post testing is shown in Figure 58. The Connecting Rod failed due to bearing stress under 246 lbf load. This is almost double the load carrying capacity of the configuration using the 3D printed pin. This led to the team using all metal fasteners in place of 3D printed pins for all the connections throughout the Cocking Mechanism.

Figure 58 : Connecting Rod Bearing Failure

The Connecting Rod after yielding to load of 246 lbf with a metal fastener. This fastener increased the load carrying capacity of the connecting arm from 130 lbf to 264 lbf

5.3 *PERFORMANCE TESTING*

Once the strength testing was complete performance testing was done to obtain values for launch height and time to launch. The team set up a pole with height measurements in increments of 5 ft. to measure the height of the Mock Projectile during launch trials. Slow motion video was used to analyze each trial and measure the height relative to the indicator. A still image taken from the slow-motion video shown in Figure 59 shows how the height testing was performed. This image also shows that the Mock Projectile reached a height of about 20 ft. After 20 consecutive launch trials were performed, the average time to launch was 0.16 seconds with an average height of 19.5 ft. The performance for groups of each trial is shown in Table 4.

Table 4 : Launch Trial Results

Trial #	Time to Launch	Launch Height
Trials 1-5 Average	0.16 sec.	20 ft.
Trials 6-10 Average	0.15 sec.	20 ft.
Trials 11-15 Average	0.15 sec.	18.5 ft.
Trials 16-20 Average	0.17 sec.	19.5 ft.
Overall Average	0.16 sec.	19.5 ft

The team focused on the DroneBack launching instantaneously (less than 1 second) to a height of 15 ft. In the still Image shown in Figure 59 the Plunger is also launched along with the mock projectile. Although it was not a design requirement for the Plunger to be fixed and not leave the Inner Tube upon launch, it did not impact the key technical requirements. The sample launch trial in Figure 59 is shown on the next page.

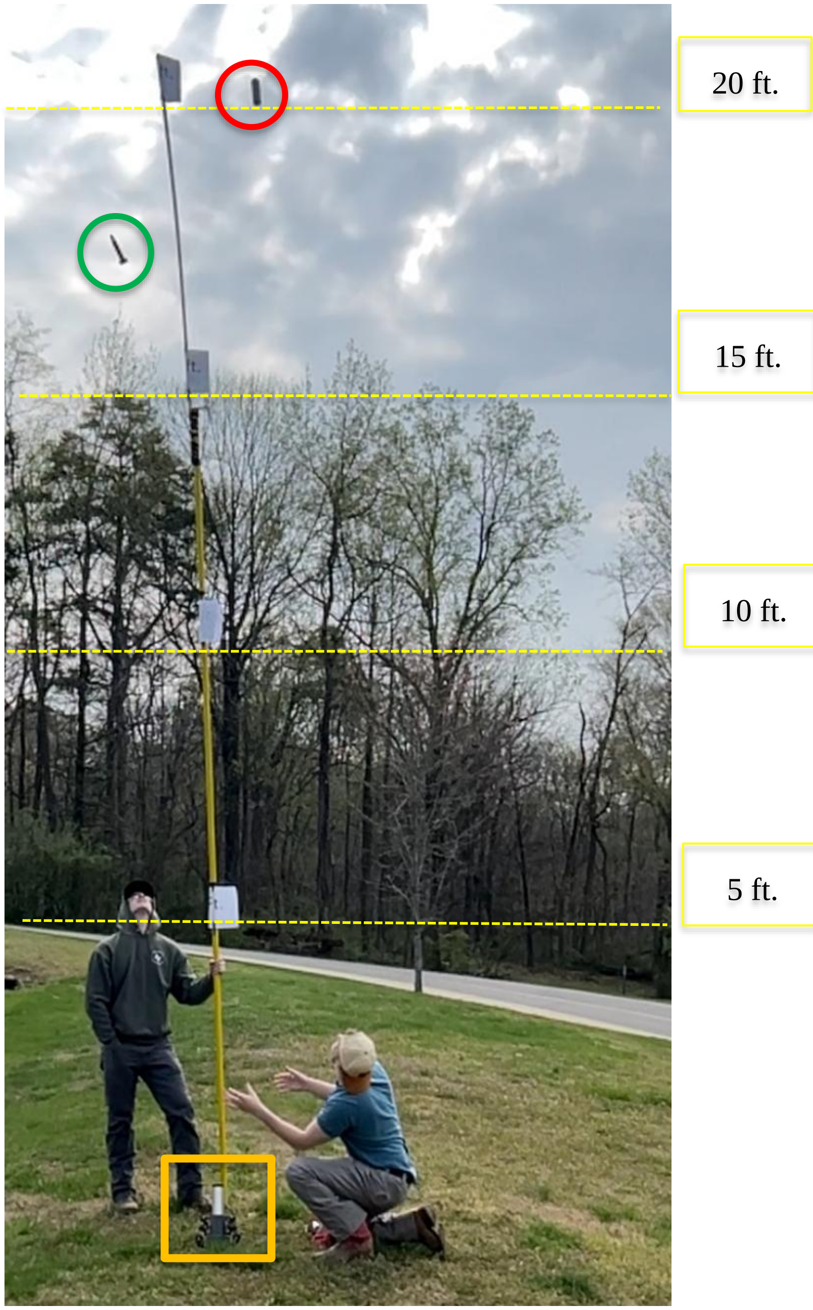


Figure 59 : Sample Launch Trial

This shows a still image obtained from a slow-motion video taken during a launch trial. Outlined in yellow is the DroneBack, outlined in red is the mock projectile, and outlined in green is the Plunger. The mock projectile reached a height of just over 20 ft.

6 ECONOMIC CONSIDERATIONS

This section outlines the time spent designing and constructing Drone40 along with the associated cost of materials and components within the final prototype. This section ensures that the DroneBack is not only technically sound but financially viable and sustainable.

6.1 COST AND LABOR

The overall protype resulted in an expenditure of $178 this is well under the project budget. The team spent approximately 25 hours a week designing and constructing the prototype. A visual breakdown of subassembly cost can be seen in Figure 60.

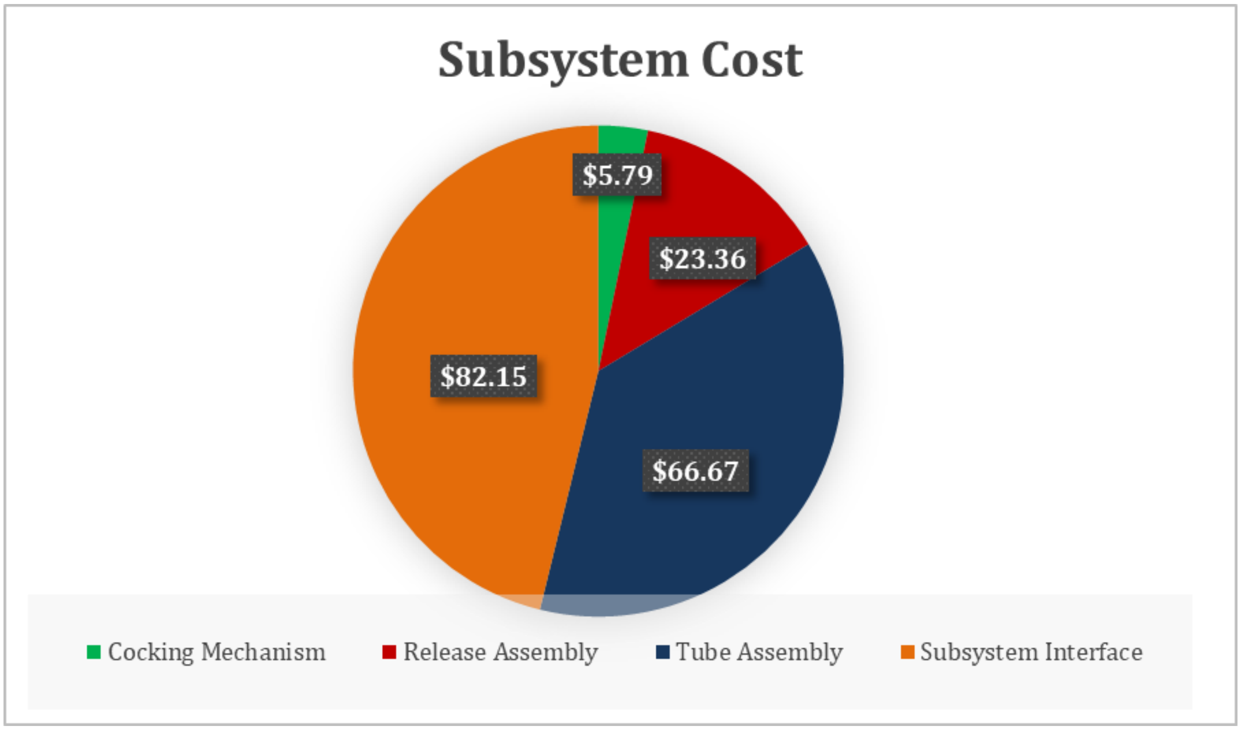


Figure 60 : Subsystem Cost Breakdown

This shows a visual breakdown of subsystem cost.

The Interface Assembly was the most expensive sub assembly. This is due to the purchase of the mobile connector, and the large quantity of PLA used to print. The Tube Assembly was the second most expensive sub-system, again this is due to the purchase of off-the shelf components such as the inner and Outer Tube. A breakdown of each individual component purchased for the full assembly is shown in Table 5.

Table 5 : DroneBack Prototype Budget

Component	Part Count	Cost
Propulsion Spring	1	$22.51
Release Spring	4	$0.80
Fasteners	22	$8.28
Inner Tube	1	$3.58
Outer Tube	1	$32.93
Adjustment Knob	1	$5.89
MOLLE Connector	1	$42.99
MOLLE Clip	1	$9.99
Polylactic Acid Spool (PLA)	2	$51.00
	Total Cost	$177.97

7 SYSTEM EVALUATION

Table 6 shows all the technical requirements that were met for this project.

Table 6 Requirement

Requirement	Performance Measure	Met/Not Met	Value
Instantaneous Launch	≤ 1 sec.	Met	0.16 sec.
Mechanically Driven	Sys. Energy from Spring	Met	Met
Deployment Height	≥ 15 ft.	Met	19.5 ft.
Launcher Weight	≤ 6 lbf	Met	4.73 lbf
Variable Launch Adjustment	180° of rotation	Met	180° of rotation
Project Cost	≤ $500	Met	$178
Durability	Support 252 lbf load	Met	FEA

Instantaneous launch was met through the employment of the Release Assembly. The project met the mechanically drive requirement by using a Propulsion Spring to store the systems energy and relying on mechanical systems such as the cable system for mechanism actuation. The deployment heigh was met after a 20 test trials with an average launch height of 19.5 ft. The launcher's final weight was 4.73 lbf, well under the weight requirement, likely due to the mostly 3D printed parts. Variable launch adjustment was met through the Variable Launch angle hinge. Durability requirements were simulated using FEA and had a final safety factor of 3.9.

8 STANDARDS

Throughout the design process the DroneBack team aimed at designing and developing a system that could be adopted by the military. That led the team to create a system that was compatible with MOLLE webbing. MOLLE webbing stands for modular lightweight load carrying equipment. This system allows for the ease of attaching and detaching equipment from backpacks, armor plate carriers, and many other applications. The Pouch Attachment Ladder System (PALS) is the webbing system that is specifically tied to MOLLE. PALS is described as horizontal rows that are 25mm apart with the ability to interface with MOLLE equipment. The webbing commercial item description is listed as A-A-55301A. The team wanted the DroneBack design to be easily integrated into the MOLLE system that is already being used by the military. This was completed by using two off-the-shelf MOLLE webbing adapters. These adaptors were then attached to the base of the Variable Launch Hinge and the brake lever to allow soldiers using the DroneBack to equip it to their gear easily and securely.

The DroneBack team wanted the design to be compatible with the Drone40. Since the Drone40 is meant to be fired out of standard issue 40mm grenade launchers that are currently being used by the US military, the DroneBack design needed to as well. That is why the team designed the Inner Tube of the DroneBack to have an inner diameter of 40mm.

Standards met by this prototype include the launcher being compatible with standard issue MOLLE webbing for seamless implementation. Additionally, the Inner Tube being 40mm means that it is compatible with standard issue munitions used by the US military.

9 FUTURE CONSIDERATIONS

The DroneBack Design could be improved in a variety of different ways. The team considers two main avenues for improvement, component materials and design. In terms of component materials, the team focused on creating a functional prototype rather than a robust final product. While there were certain requirements the team established in terms of durability, the focus was on creating an initial prototype that functioned as intended. Future improvements to the design would include moving away from 3D printed components. While PLA parts have been helpful throughout the prototyping phase, a final product would likely need to be made of injection molded plastic or out of a lightweight metal alloy. This would improve the overall strength of the components and could potentially reduce the cost of manufacturing. In terms of component design, the team would improve the footprint of the DroneBack. The team did not establish assembly size as a priority for the functional prototype and sees reducing the DroneBack footprint as a future consideration. Currently, the DroneBack occupies a large area when equipped. This could be reduced by optimizing component thickness and reducing part count. As previously stated, some material choices could be improved which would allow the team to reduce component thickness without sacrificing strength. Additionally, the team sees the Plunger being permanently fixed to the Propulsion Spring so that it does not launch with the Drone40 upon release. This could be achieved by using an adhesive to mate the spring to the Plunger permanently.

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APPENDIX A: PRELIMINARY PROJECT SCHEDULE

The preliminary project schedule can be seen in Table 7.

Table 7: DroneBack Preliminary Project Schedule

Task Name	Duration	Start	Finish
Senior Design	**78 days?**	**Wed 1/15/25**	**Fri 5/2/25**
Droneback	**63 days?**	**Wed 1/22/25**	**Fri 4/18/25**
Order Parts			Wed 1/22/25
3d Print Parts			Wed 2/26/25
Test 3d Printed parts			Wed 3/5/25
Machine Metal Parts			Wed 3/12/25
Fabricate Design			Wed 3/19/25
Test Final Design			Wed 4/2/25
Final Design Prototype			Wed 4/16/25
Senior Design Report	**46 days?**	**Fri 2/28/25**	**Fri 5/2/25**
Draft 1 to Advisor			Wed 3/26/25
Draft Report 2 to Advisor			Wed 4/9/25
Final Report to Advisor			Fri 5/2/25
Final Report Submitted to Soar			Fri 5/2/25
Senior Design Presentation	**21 days?**	**Fri 3/28/25**	**Fri 4/25/25**
Design Presentation Draft 1			Wed 3/26/25
Design Presentation Review Complete			Wed 4/2/25
Presentation Slides to ENGR Laptop			Thu 4/24/25
Final Presentation Day			Fri 4/25/25
Poster	**44 days?**	**Mon 3/3/25**	**Thu 5/1/25**

APPENDIX B: BILL OF MATERIALS

The DroneBack Bill of Materials can be Seen in Table 8.

Table 8 : DroneBack Budget and Bill of Materials

DroneBack Prototype Budget			
Component	**Number of Parts**	**Cost**	**% Total Cost**
Propulsion Spring	1	$22.51	12.65
Release Springs	4	$0.80	0.45
Fasteners	22	$8.28	4.65
Inner Tube	1	$3.58	2.01
Outer Tube	1	$32.93	18.50
Adjustment Knob	1	$5.89	3.31
Molle Connector	1	$42.99	24.16
Molle Clip	1	$9.99	5.61
Polylactic Acid Spool	2	$51.00	28.66
	Total Cost	**$177.97**	

APPENDIX C: DRAWINGS

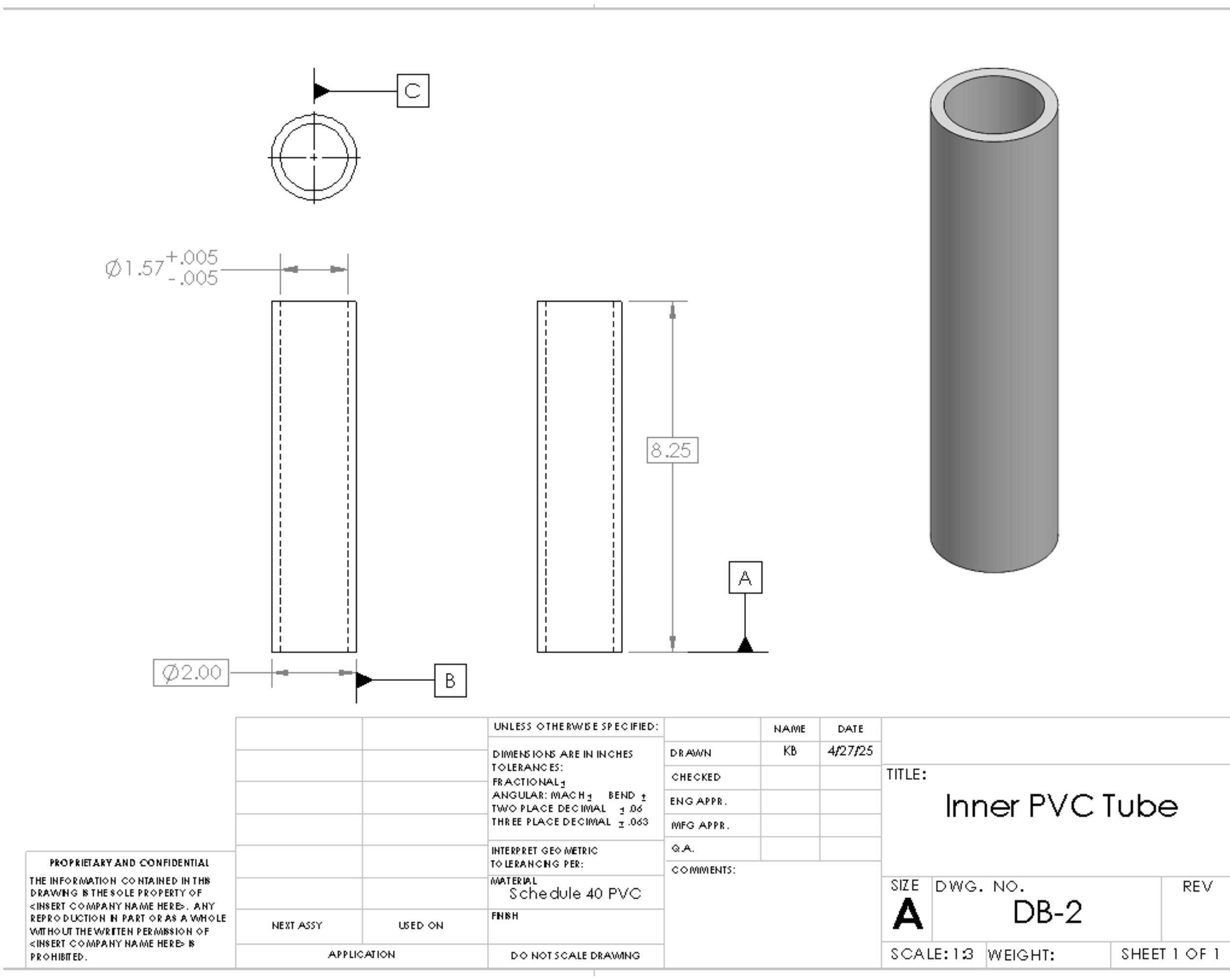

Figure 61: Inner PVC Tube ASME Y14.5 Compliant Drawing

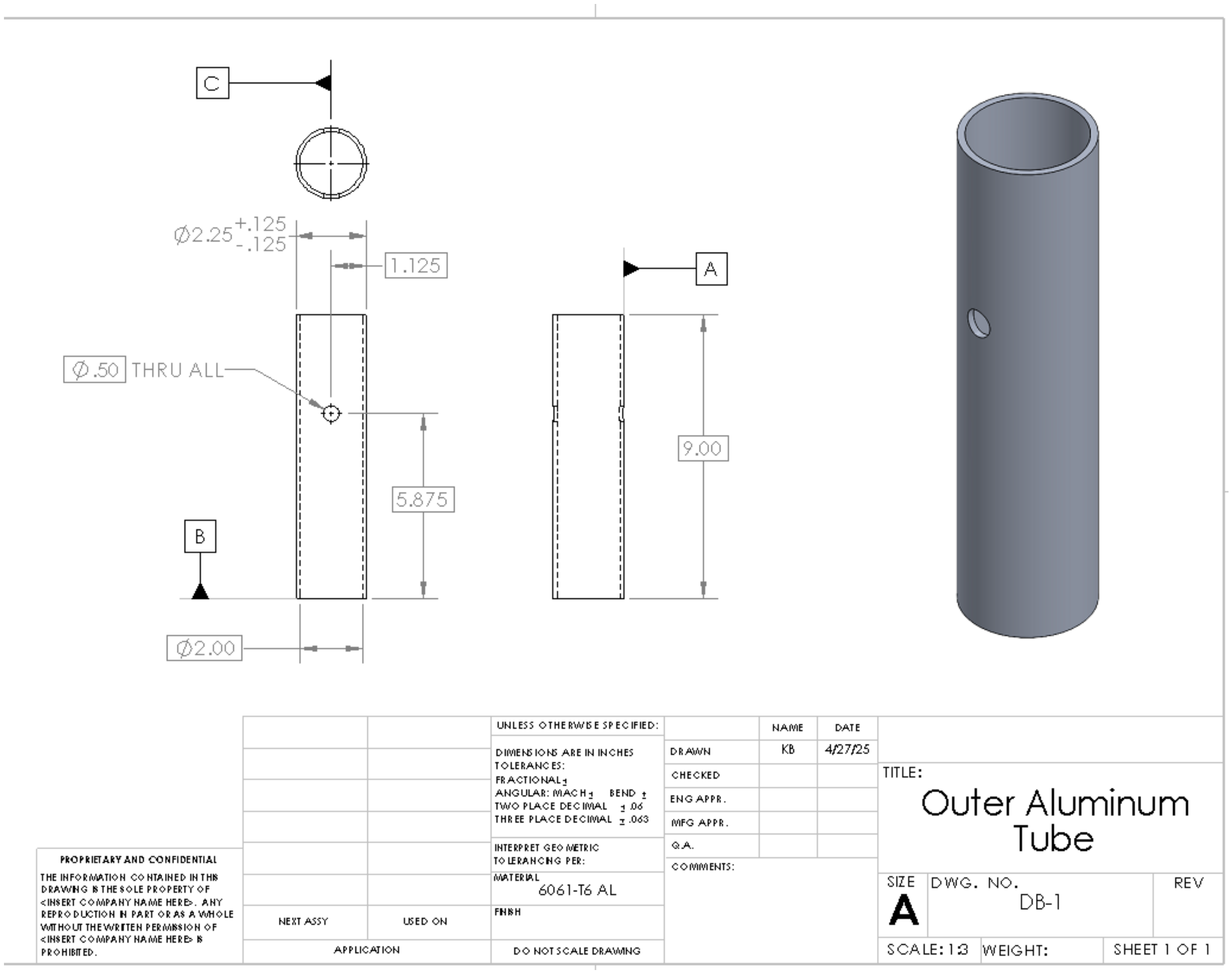

Figure 62: Outer Aluminum Tube ASME Y14.5 Compliant Drawing

APPENDIX D: MATLAB CODE

The MATLAB Code used to complete the Cocking Mechanism, and Trigger Forc Calculations Can be found below.

DroneBack Cocking Mechanism Code:

```
clc
clear
close all

%Constants

rad=pi/180;
ramdiam=1.5; % diameter of the Ram Rod
k=21.63829; % spring constant in lb/in

%Known Static Posistion

theta_2=25*rad; % angle between r2 and r1 in rad
theta_2_2=theta_2+(130*rad);
r_2=2.125; % CRANK ARM design variable
r_3=5.125; % CONNECTING ROD design variable
theta_4=asin(r_2*sin(theta_2)/(r_3)); % angle between r3 and r2 changes wrt pos B
theta_3=pi-theta_4-theta_2;
r_1_1=((r_2*cos(theta_2))+(r_3*cos(theta_4))); % r1 in pos 1
r_1_2=sqrt((r_3^2)-((sin(theta_2)*r_2)^2))-(cos(theta_2)*r_2); % r1 in pos 2
theta_4_2=atan2(sin(theta_2)*r_2,r_1_2+(cos(theta_2)*r_2));
theta_3_2=pi-theta_2_2-theta_4_2;

%Mechanical Advantage Calcs

x=linspace(0,r_1_1-r_1_2,50); % Displacement of Ram Rod
Fout=((k/2)*x); % force of half the spring force under full compression
lever=5; % Lever arm past connection
AC=r_2+lever; % Lever arm total
theta_290=linspace(theta_2,theta_2_2,50); % timestep of theta 2 through 130 deg. motion
MA=AC./-r_2*(cos(theta_290)-(sin(theta_290)/tan(theta_4))); % Mechanical advantage with changing
theta2
Fin=Fout./MA; % Force applied to lever arm based on angle theta 4 and displacement x

%Plotting Mechnaism Based on positon of D

[val1,idx1]=max(Fin);
[val2,idx2]=max(MA);
[val3,idx3]=max(Fout);

subplot(3,1,1)
plot(x,Fin,"g")
hold on
plot(x(idx1),Fin(idx1),'*r')
title('Applied Force Versus Spring Compression')
```

```
%Potting Continued
```

```
xlabel('Spring Compreesion (in)')
ylabel('Applied Force (lb)')
ylim([0,4.5])
yticks([0,1,2,3,4])
grid on

subplot(3,1,2)
plot(x,MA,"b")
hold on
plot(x(idx2),MA(idx2),'*r')
title('Mechanical Advantage Versus Spring Compression')
xlabel('Spring Compreesion (in)')
ylabel('MA')
ylim([0,20])
yticks([0,5,10,15,20])
grid on

subplot(3,1,3)
plot(x,Fout,"m")
hold on
plot(x(idx3),Fout(idx3),'*r')
title({"","Output Force Versus Spring Compression"})
xlabel('Spring Compreesion (in)')
ylabel('Output Force(lb.)')
yticks([0,10,20,30,40,50])
grid on
```

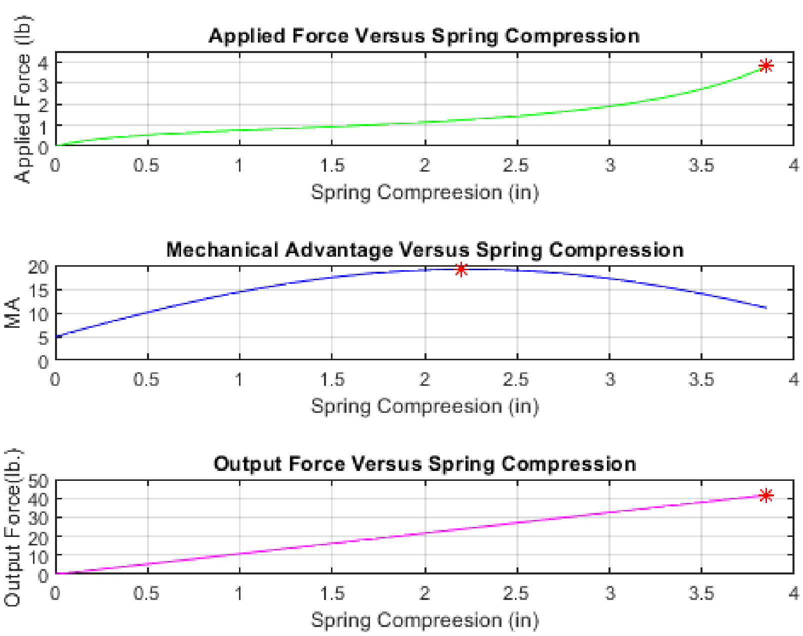

Figure 63 63: Cocking Mechanism Plots

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DroneBack Trigger Force Calculations

```
%Trigger Force Code

%Variables
L1= 0.12375 ;%inches
L2= 1.5 ;%inches
F_spring= 45 ;%lbs
F_release_springs= 1 ;%lbs
frict= 0.3 ;%coeffecient of friction

%Trigger Force Calculation
F_trigger=2*frict*F_spring*((L1+L2)/L2)+F_release_springs;= 30.2275 lbs
```

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APPENDIX E: DESIGN CONSIDERATIONS AND STANDARDS

The Droneback Design is compatible and compliant with the following standards.

A-A-55301: Item Description for Nylon Webbing

- PALS Grid Specifications and PALS Webbing Interface Spec: Any Clip or Strap must be conform to the 1" webbing grid with 1.5" spacing.

MIL-DTL-32439: MOLLE System construction, testing, materials, and interface requirements

ASME Y14.5: Geometric Dimensioning and Tolerancing

- The SolidWorks drawings shown in Appendix C show the Outer Tube and Inner Tube with ASME Y14.5 compliant drawings.

APPENDIX F: ABET OUTCOME 2, DESIGN FACTOR CONSIDERATIONS

ABET Outcome 2 states "*An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health safety, and welfare, as well as global, cultural, social, environmental, and economic factors*."

Table 9: Design Factor Considerations		
Design Factor	Page Number	Reason Applicable/Not Applicable
Public health, safety, and welfare	Page 5, Reference [4]	Many causulties in modern conflicts are the result of FPV Drone usage. This product aims to protect against FPV Drones.
Global	Pages 4-6	Intended for military use around the world.
Cultural	Pages 4-6	Results in safer environments around the battlefield.
Social	Pages 4-6	This product may lessen mortality rate.
Environmental	N/A	The DroneBack design consists heavily of PLA which is a biodegradable and recyclable material.
Economic	Page 11	Page 10
Ethical & Professional	N/A	The DroneBack design aims to save lives, not to take them, maintaining ethical and moral high ground.
Reference for Standards	Pages 71, Appendix E	These sections summarize the standards applied and how they were met.

APPENDIX G: EQUATIONS AND CALCULATIONS

The equations and calculations used throughout the Drone Back design can be seen below.

System Energy Calculation/Spring Selection:

- Design Variables
  - $m_{payloaded\ drone40} = 0.3kg \cong 0.6614lb$
  - $x_{travel} = \mathbf{3\ in}$
- Energy Calculation
  - $PE = mgy_{max} \cong 119.05\ in \cdot lb$
  - $PE = KE$
  - $KE = \frac{1}{2}kx_{travel}{}^{2}$
- Spring Constant Calculation
  - $k = \frac{2\text{KE}}{x_{travel^2}} \cong \mathbf{27}\,\frac{\mathbf{lb}}{\mathbf{in}}$

Table 10 : Propulsion Spring Properties

Physical Parameter	Value
Spring Constant	$21.638\,\frac{lb.}{in.}$
Free Length	$6.880\ in.$
Solid Height	$3.234\ in.$
Max. Spring Travel	$3.646\ in.$
Outer Diameter	$1.250\ in.$
Inner Diameter	$0.956\ in.$
Max. Load	$78.9\ lb.$
Kinetic Energy from Spring	$143.82\ in \cdot lb.$
Material	$302\ Stainless\ Steel$

Tube Bending Stress Calculations

$$\sum F_y = R_1 + R_2 - F = 0 \qquad Eqn.1$$

$$R_1 = R_2 = \frac{F}{2} = 126lb$$

$$\sigma_{max} = \frac{Mc}{I} = \frac{M_{max}\left(\frac{D_o}{2}\right)}{I_{hollow\ cylinder}} \qquad Eqn.2$$

$$\sigma_{max} = \frac{(567lb \cdot in)\left(\frac{2.25}{2}\ in\right)}{0.4727in^4} \cong 1349.4psi$$