Final Report
EZ – Emergency Zipline

Submitted to:

Professor Haifa El-Sadi

Date: 8/9/2023

By

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WENTWORTH INSTITUTE OF TECHNOLOGY
MECH-5000-01

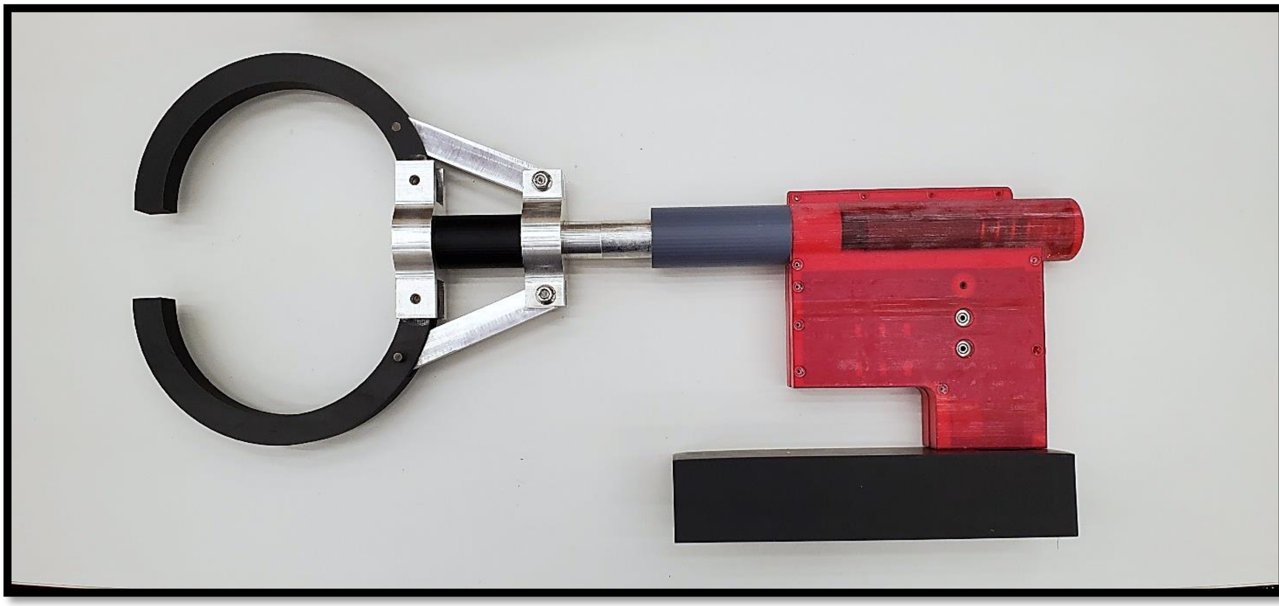
Mechanical Capstone Project

Summer 2023

ABSTRACT

Throughout this semester, our team has dedicated substantial effort to the development of a Zipline-Launcher combination mechanism using the traditional engineering design process. This endeavor has had a series of crucial stages including preliminary designs, mechanical analyses, and the creation of rapid prototypes. The fundamental objective behind this mechanism is to establish a highly versatile solution that can find practical applications across a spectrum of scenarios. Our vision is to provide a mechanism that empowers individuals to swiftly traverse challenging terrains or reach otherwise inaccessible locations with ease and efficiency. The system works with a grapple-hook style projectile attached to a steel wire being fired out of an electronic powered launcher. The brushless motor spins a set of carbon-steel gears and compresses a spring attached to a firing cylinder. When the gear completes a full cycle and the spring releases, a powerful air-burst fires the grapple-hook projectile. The team has conducted calculations, FEA tests and CFD analysis to fully realize the potential of our proposed system.

FINAL PROTOTYPE



The team successfully produced and assembled a built-to-spec prototype of the launcher and grapple hook projectile. We believe that with more development time and project budget the system could perform the original goals set by the team.

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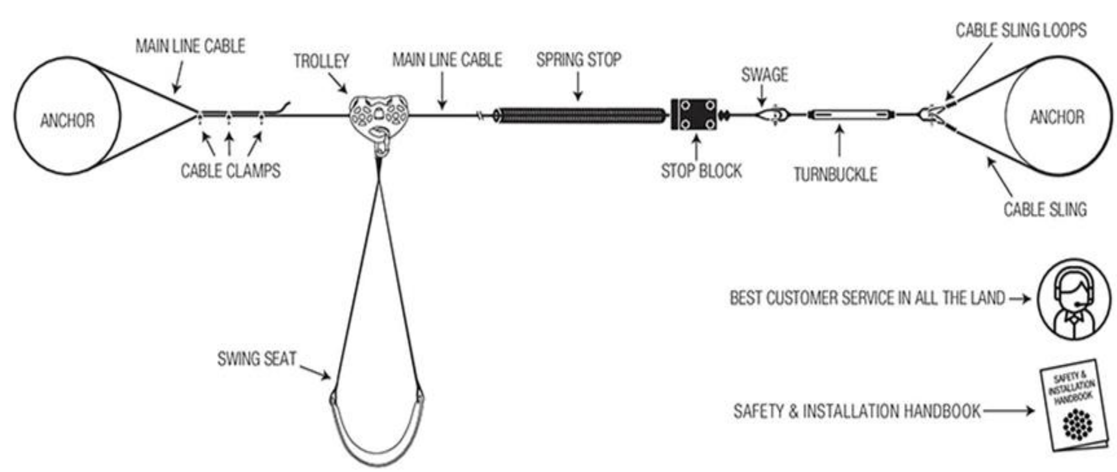
Problem Definition

Our team made this mechanism for people who find themselves in a vertically challenging situation. The purpose of the zipline is to transport a payload from a stable high elevated area to an available lower elevated area some distance away via the force of gravity. Our team believes this concept can be useful in an urban emergency evacuation or to help individuals traversing natural terrain escape from elevated areas to safety.

Background Research

Zipline

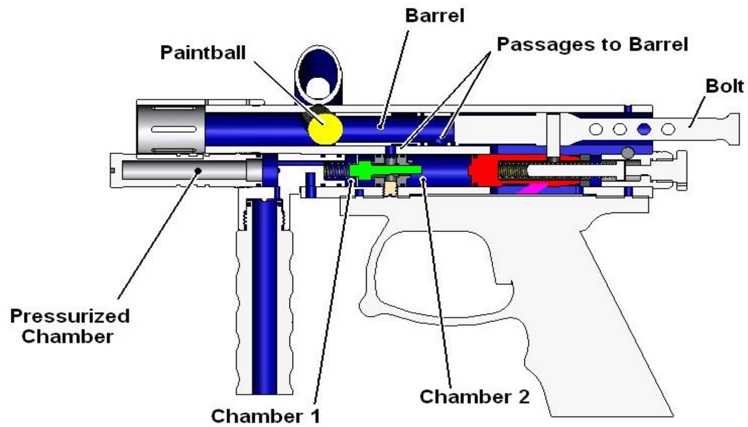
- The team conducted specific research to help us better understand what makes an effective zipline system. The system typically includes a steel wire cable, an anchor, a trolley, a seat, and a stop block (shown below).
- The custom grapple hook projectile functions as our anchor. The team will use a standard stop block, trolly, and seat as the firing mechanisms were made to be compatible with each. The team chose to do this for design convenience and to help us get a better idea of



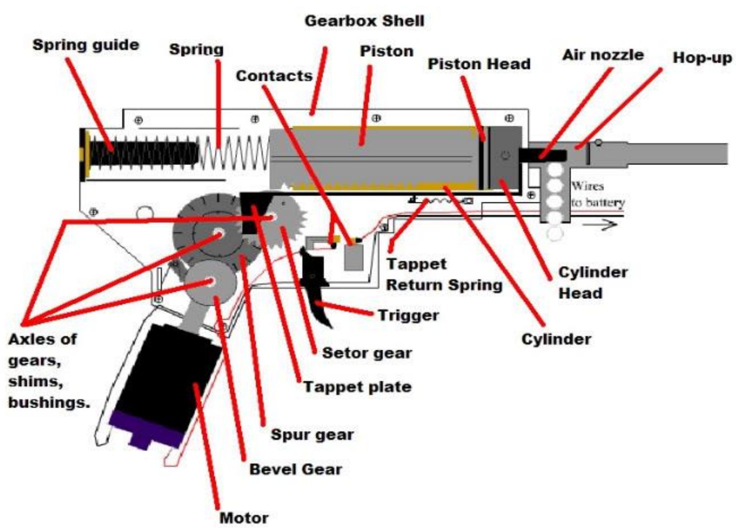
the overall project budget.

Launchers

- The team took design inspiration from airsoft and paintball equipment. The pneumatic system is based on a traditional paintball gun. A pressurized chamber will create a powerful burst of air to launch the custom projectile (shown below).



- Our system has been simplified to a pressurized chamber, a barrel, and a butterfly valve to release pressure. The team values the system for reliability and mechanical simplicity. The team is concerned about usability and mobility for the end users.



- The electronic system is based on a traditional airsoft gun. A battery powered motor spins a set of gears connected to an airtight spring system. When the spring releases it creates a powerful burst of air to launch the custom projectile (shown below).

- Our system has been modified to launch a larger projectile. The team values the compact design and ease of use of the system. The team is concerned about the reliability of the system.

Project Objectives

1. Design and analyze a custom grapple hook projectile to carry and secure a traditional zipline wire.

2. Design and analyze two comparable firing mechanisms that will launch a custom projectile at a target range of at least 80'.

3. Choose one firing mechanism to physically produce using rapid prototyping and design refinement.

4. Source raw materials and specific mechanical parts to accommodate the outlined manufacturing process.

5. Successfully staying within the project timeline and budget.

The team has agreed to the above points as the critical objectives to address the original mission statement for the zipline launcher project.

Project Plan

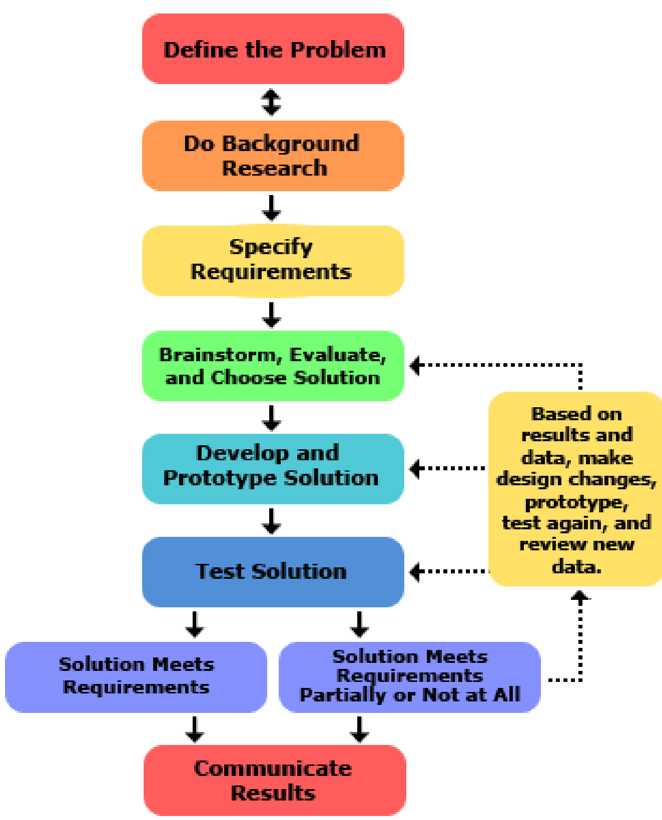
- Team members & Qualifications –
  Chris Belloli – BSME undergraduate
  Shannon Cullen – BSME undergraduate
  Francesca Ferrell – BSME undergraduate
  Eduardo Meza - BSME undergraduate
  Logan May - BSME undergraduate, manufacturing minor

- Support personnel requirements –
  We plan on utilizing the manufacturing lab faculty and Professor El-Sadi for assistance as needed. Most of the prototyping process will be carried out by the existing capstone team.

- Facilities, labs or equipment are required to accomplish project plan –
  The Team plans on using the general mechanical lab as well as the manufacturing lab as needed for prototyping. Test areas and other aspects of project assembly is accessible off campus as well.

- Detailed Gantt chart – (see below)
- Cost estimate / budget – (see below)

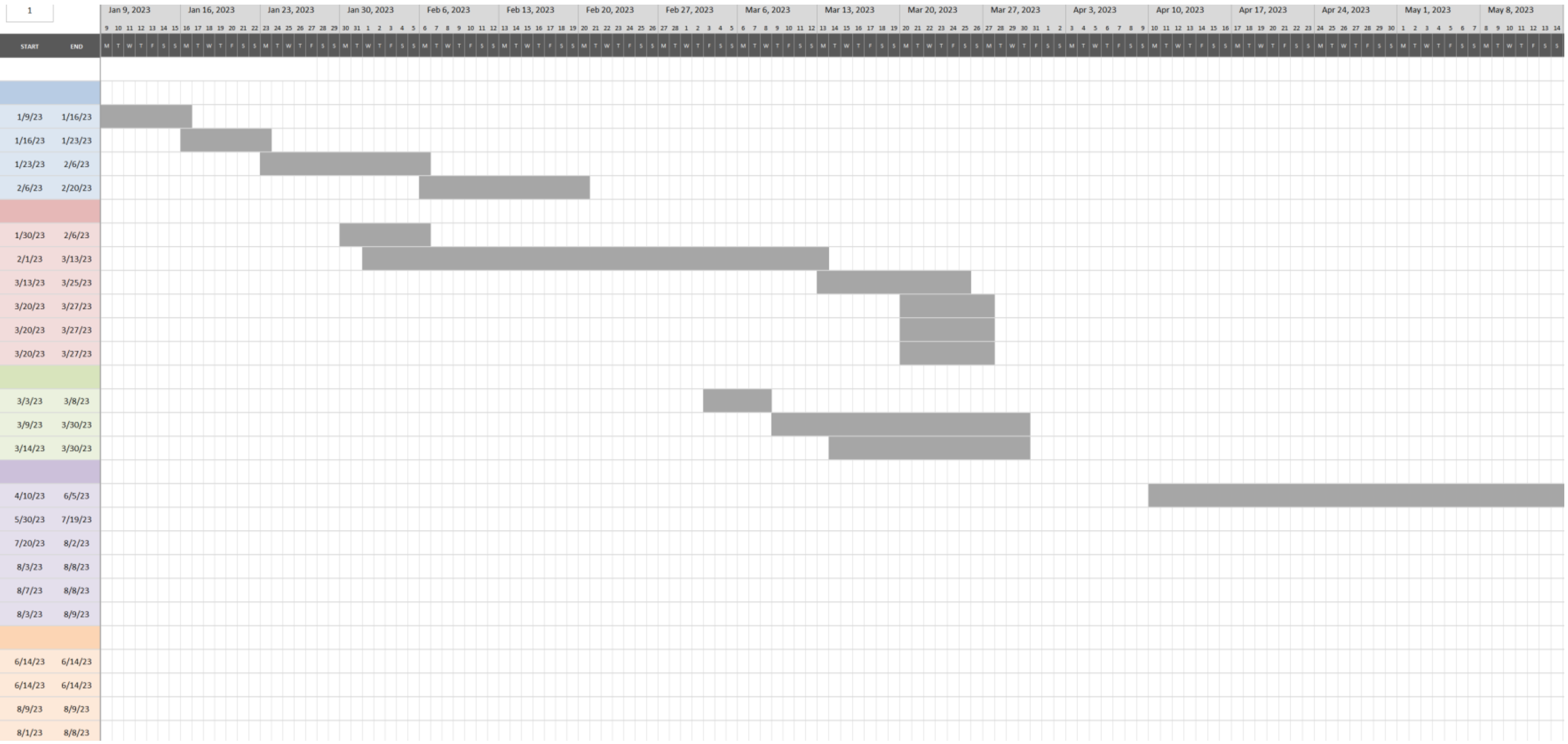
- How the project will be graded must be identified –
  The team firmly believes that the most important part of the project is following the standard engineering design process. In order of steps this is generally defined as:



At the end of the Capstone project, we wish to be graded on how well we considered and executed each one of these steps. We believe the functionality of the final prototype is an incidental objective compared to the overall design process.

Team Gantt Chart

TASK	START	END
Ideas		
Making topic list	1/9/23	1/16/23
Refine topics	1/16/23	1/23/23
Final topics	1/23/23	2/6/23
Research final topic generate idea	2/6/23	2/20/23
Models		
Initial design	1/30/23	2/6/23
Rough Design	2/1/23	3/13/23
Final Design	3/13/23	3/25/23
Material Lists	3/20/23	3/27/23
Manufactoring Lists	3/20/23	3/27/23
Mechanical Drawings	3/20/23	3/27/23
Calculations		
Kinematics	3/3/23	3/8/23
FEA	3/9/23	3/30/23
CFD	3/14/23	3/30/23
Manufactoring		
Purchase/Received Materials	4/10/23	6/5/23
Rough Model	5/30/23	7/19/23
Tests	7/20/23	8/2/23
Modifications	8/3/23	8/8/23
Final Test	8/7/23	8/8/23
Final Model	8/3/23	8/9/23
Miscellaneous		
Presentation 1	6/14/23	6/14/23
Term 2 Mid-term Report	6/14/23	6/14/23
Term 2 Final Report	8/9/23	8/9/23
Poster	8/1/23	8/8/23



Team Gantt Chart

1

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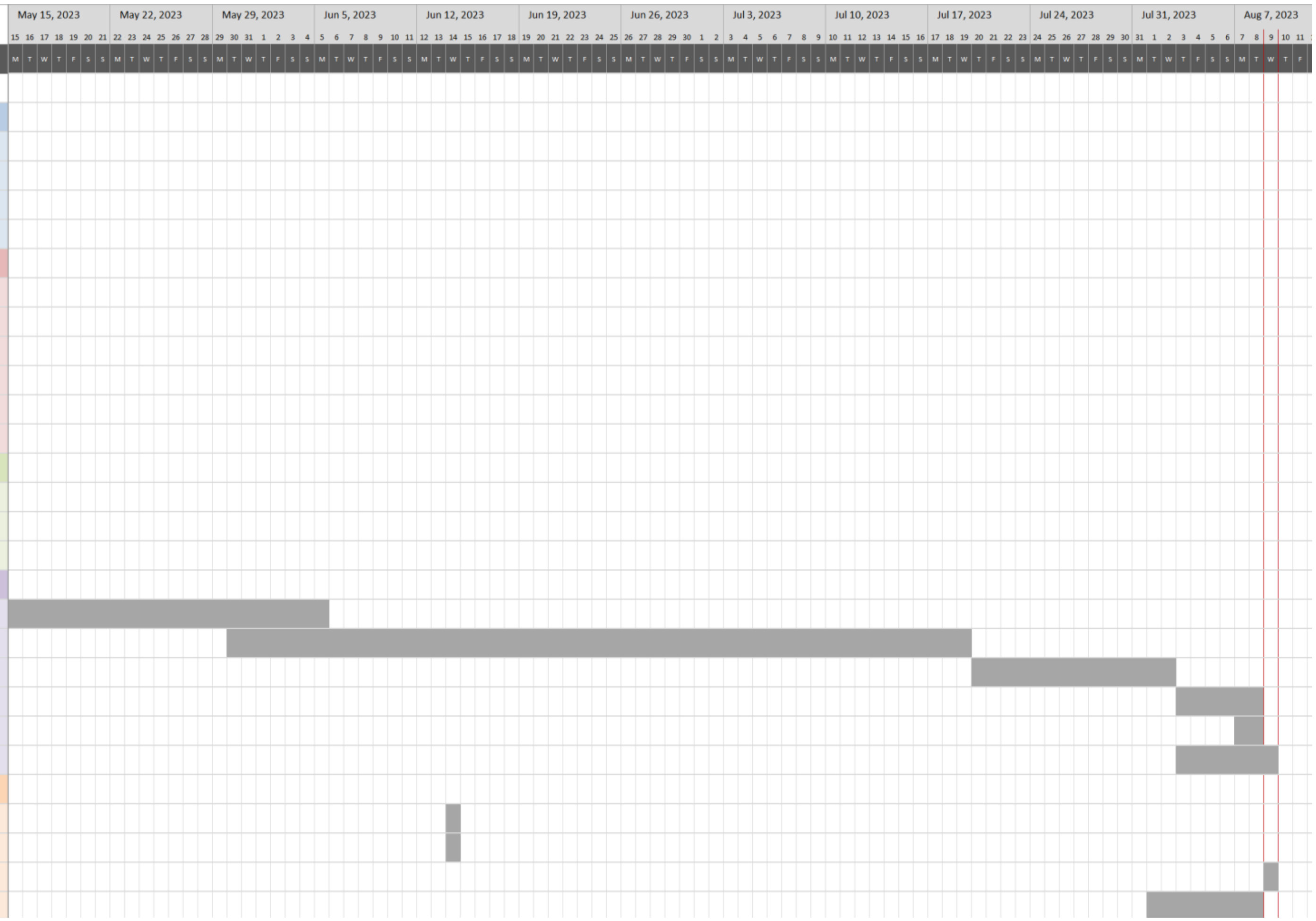


Project Cost Total

Name	Cost	Needed/Ordered	How many received?	Where to Buy
Firing Mechanism				
Gears and Bearings	106.36	3 sets	3 sets	https://www.evike.com/products/27806/ ||| https://www.evike.com/products/12499/
Motor	45	1	1	https://www.evike.com/products/29144/
Springs	35.9	2	2	https://www.mcmaster.com/catalog/129/1495/9657K467
Battery / Charger	30	1 each	1 each	3S4QC/ref=emc_b_5_t ||| https://www.amazon.com/Valken-Airsoft-Li-po-Battery-Charger/dp/B00T54BHEA/ref=sr_1_4?keywords=valken+airsoft+s
Electronics	19.49	1 set	1 set	https://www.pishop.us/product/raspberry-pi-zero-2-w/?src=raspberrypi
Hardware	18.28	1 box	1 box	https://www.mcmaster.com/products/screws/stainless-steel-slotted-rounded-head-screws-for-sheet-metal/length~1/
Grapple hook				
1 x 2 x 24 Aluminum Bar Stock	44.12	1		https://www.grainger.com/category/raw-materials/aluminum/aluminum-bars-rods-discs/aluminum-flat-bars?attrs=Thickness%7C0.5+in&filters=attrs
1 x 24 aluminum circlular stock	16.2	1		
8x8x.75 aluminum bar stock	104.56	1		
Spring (locking)				https://www.mcmaster.com/products/springs/compression-springs-7/
Pins				https://www.mcmaster.com/catalog/129/3764/98381A542
D-Ring/ Carabiner				-6621521?pd_rd_w=DaEsz&content-id=amzn1.sym.26a5c67f-1a30-486b-bb90-b523ad38d5a0&pf_rd_p=26a5c67f-1a30-486b-bb90-b523ad38d5a0&pf_rd_r
Zipline Parts				
Zipline Harness		1		
Zipline wire	35.63	1		https://backyardziplines.com/products/1-4-cable?variant=2405298110487
3" PVC Pipe		1		https://www.lowes.com/pd/Charlotte-Pipe-3-in-dia-x-10-ft-L-260-PSI-PVC-Pipe/3135451
Cement Fill		4-5 bags depending on bag weight		https://www.lowes.com/pd/Sakrete-60-lb-High-Strength-Concrete-Mix/3093929
Trolley		1		
	Total Cost	455.54		**Given Budget from School : $400**

Project Results

Produced Prototype

Launcher System:

The Launcher design is comprised of 2 sides of a housing unit made from Vero plastic, an electrical box with a sliding door made of PLA plastic, and a PLA plastic barrel that helps keep the two sides together.

The inner mechanism is comprised of a brushless motor, three carbon steel gears with a ratio of (26:1), a 5'' spring with a spring rate of 22.16 lbs/in, and 4 custom firing parts printed from the Onyx carbon 3D printer.

Inside the electrical box includes the 11.1V lithium "nun chuck" battery, a pico-board loaded with python code and a motor controller.

Grapple Hook Projectile:

The grappling hook design is meant to wrap around a 5-inch vertical pole. It is made from aluminum stock as well as carbon fiber reinforced nylon. It is held together with alloy steel pins and metric nuts and bolts. The grappling hook consists of claws, a shaft and base, an adjustment piece, and two connecting rods.

The shaft is an inch in diameter, while the hole in the adjustment piece is a little bit larger than that so it slides up and down the shaft in a slip fit fashion. The grappling hook should be launched so that the bottom surface of the shaft collides with the target, and the force exerted on the shaft will cause the adjustment piece to slide and the claws to shut.

- **Custom grapple hook projectile design, analysis, measurements**

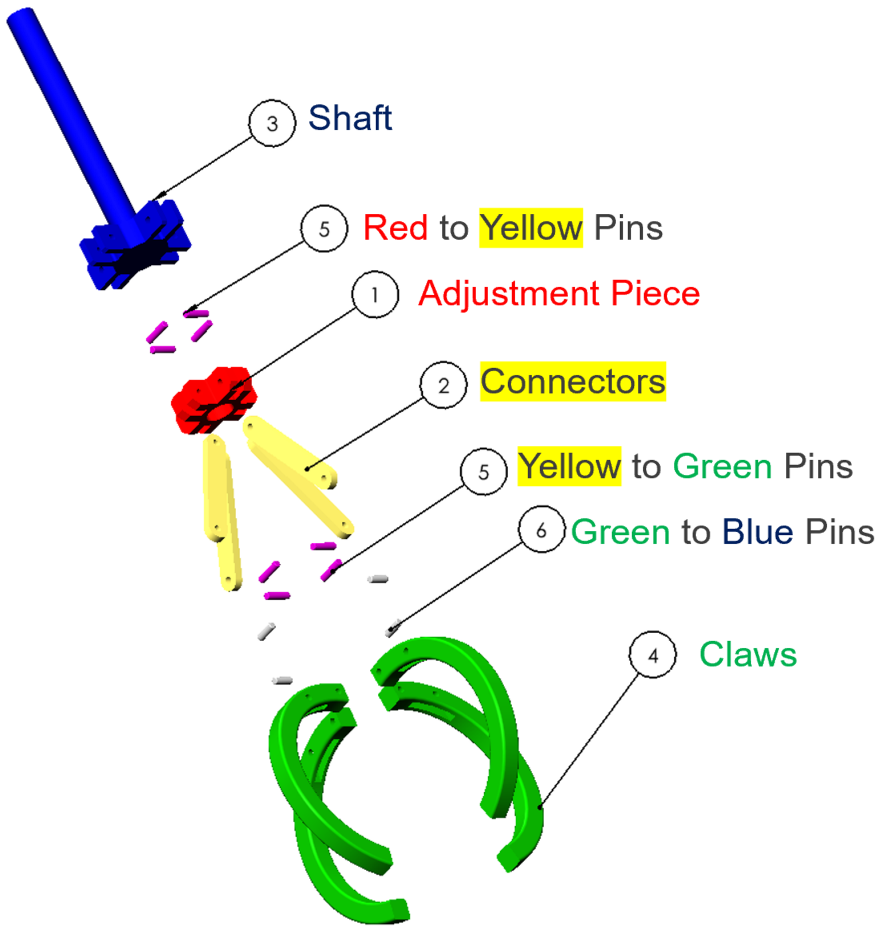


Figure 1 Grappling Hook Exploded View

In the image above, we see the exploded view of our base grappling hook design. We see that the hook is composed of 4 significant parts, including the shaft, the slider, the connects, and the claws, along with 3 sets of pins. The reason this design was chosen is because it provides a form of locking the hook in place on impact rather than relying on a trigger function of some sort. The idea is to launch this hook and once the center of the hook hits the target pole, the momentum of the slider and the claws will cause the slider to move down the shaft and close the claws to lock in place.

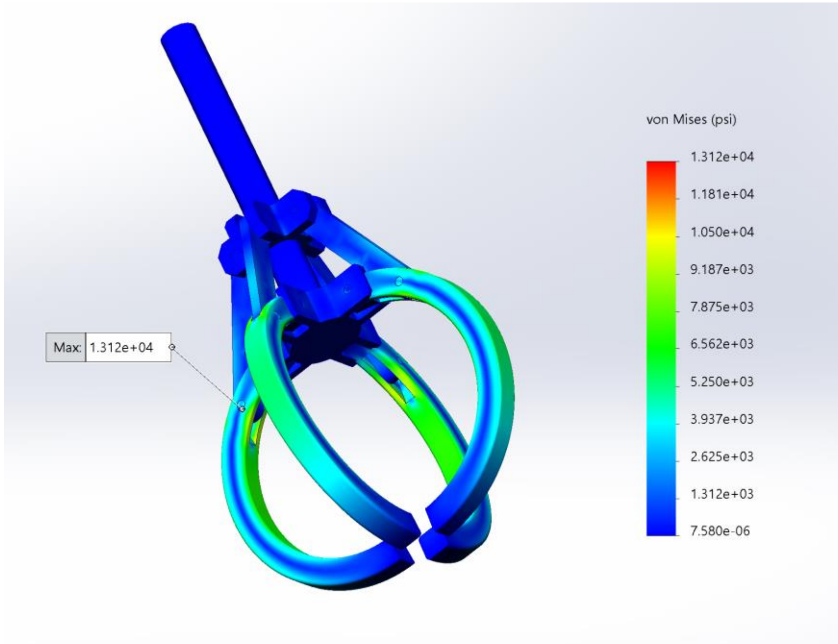


Figure 2 Four Claw FEA Simulation

In the image above we see the von mises stress plot after applying a 120-pound force on the front end of the 4 clawed hook. This helps us simulate the weight of a 120-pound person pulling on the hook while attached to a pole. We also see the maximum value for the von mises stress which is 13,120 psi and occurs on one of the pins holding the hook together. We are able compare this value to the yield strength of the alloy steel pin and conclude that the 4 clawed hook will not fail.

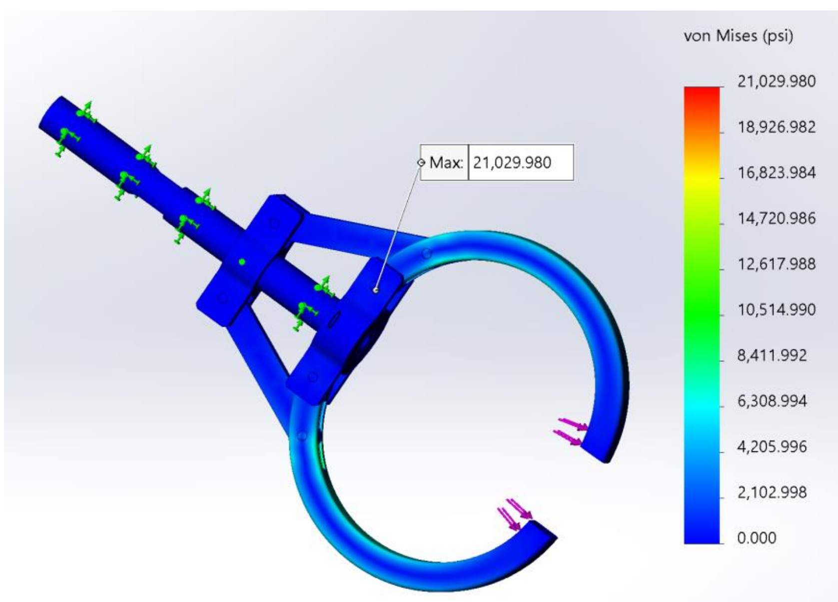


Figure 3 Two Claw FEA Simulation

In the image above we see the von mises stress plot after applying a 120-pound force on the front end of the two clawed hook. This simulates the weight of a 120-pound person pulling on the hook while attached to a pole. We also see the maximum value for the von mises stress which is 21,029.98 psi and occurs on one of the pins holding the hook together. We are able compare this value to the yield strength of the alloy steel pin and conclude that the 2 clawed hook will not fail.

Number of Claws	Force Applied (lb)	Von Mises Stress (psi)	Yield Strength of pins (psi)	Failure
2 Claws	120	21,029	104,982	No
4 Claws	120	13,120	104,982	No

With the FEA simulations completed for the 2 and 4 clawed hooks complete, we can conclude that neither of the hooks will fail under the load of a 120-pound person. The project will be focusing on the 2 clawed hook for a couple of reasons. Reason 1 being that the 2 clawed hook results in a smaller weight making the required launch force to be smaller. Another reason the 2 clawed hook is more beneficial than the 4 clawed hook is that the 2 clawed hook is more likely to hit the target with its center face, allowing it to lock into position.

Hook Initial Velocity and Force

$$h = 28.86\ ft \ \ L = 80\ ft$$

$$t = \sqrt{2 * 28.86 * \frac{1}{32}} = 1.338\ s$$

$$V = \frac{80}{1.338} = 59.79\ ft/s$$

$$F_i = \frac{2.5 * 59.79}{32.2 * 0.1} = 46.42 \text{ lbs}$$

Force of the line

$$L = 80\ ft \ \ w = 0.11\ lbs/ft$$

$$W = 80 * 0.11 = 8.8\ lbs$$

$$r = 5.092\ in. \ \ \mu = 0.05$$

$$F_w = 8.8 * 0.05 * 5.092 = 2.24048$$

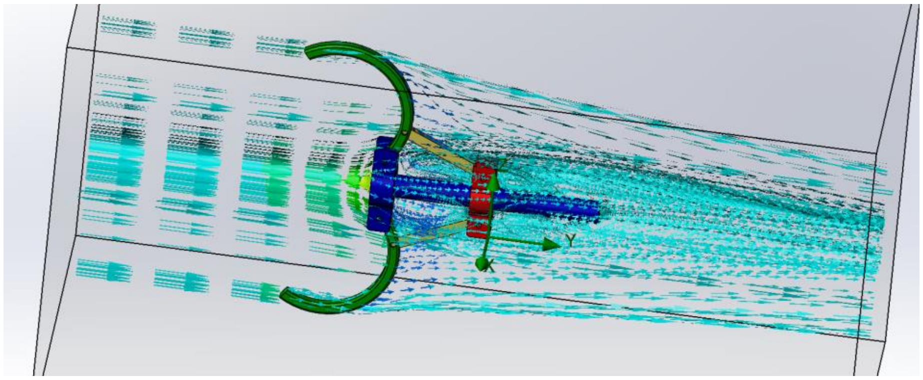


Figure 4 Grappling Hook Flow Simulation

In the image above, we see the velocity vectors for air as the grappling hook is launched into the air. The goal of this simulation is to obtain a value for drag force in order to calculate the total force required to launch the grappling hook to our desired target.

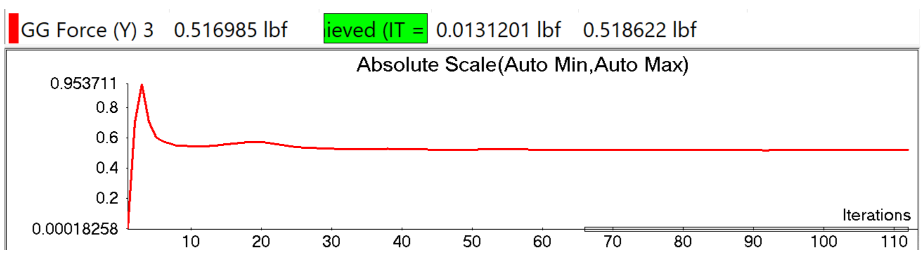


Figure 5 Drag Force Convergence Graph

In the image above, we see plot for simulated drag force. It is clear that as the number of iterations increases, the value for drag force converges to about 0.5186 lbf. With the required drag force, we are able to calculate the final force which is the sum of drag force, force of the line, and the initial calculated force. We result in a total launch force of about 55 pounds and will be using this value to determine the dimensions of the launching mechanisms required to launch the grappling hook.

- **Pneumatic firing mechanism design, analysis, measurements**

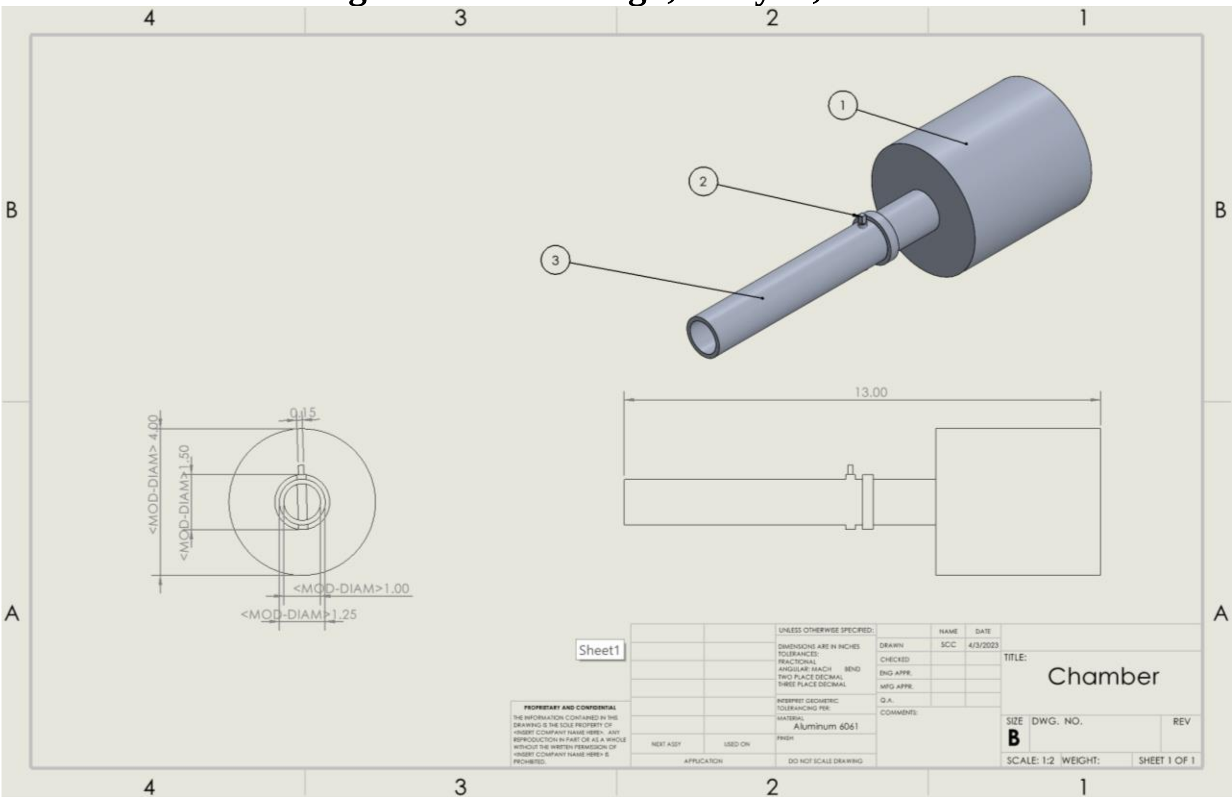


Figure 6 Final design of the Pneumatic firing mechanism

The chamber went through multiple iterations of designs with its' original involving a concave funnel that transformed into the barrel. Due to manufacturing constraints the funnel was not believed to be possible this resulted in the chamber to be flat on the face and back. Running flow simulations on the new design did not change the results the other design reflected. Allowing for the new design to be equivalently effective.

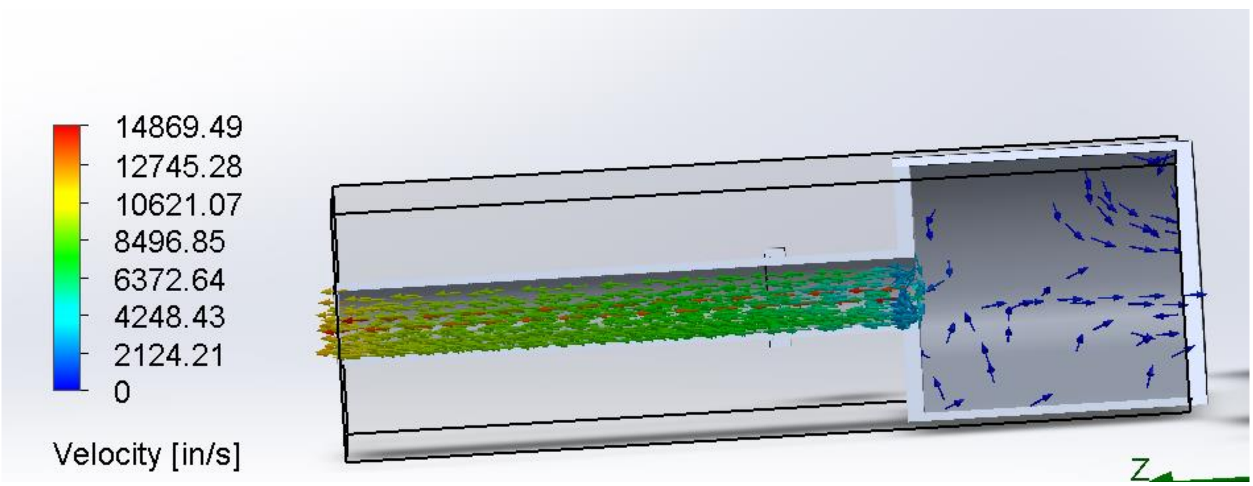


Figure 7 Velocity from the chamber through the barrel

The above image is a CFD simulation of the pressure chamber. This shows the change in velocity from the chamber through the barrel due to the change in pressure from the chamber to the pressure of the exit.

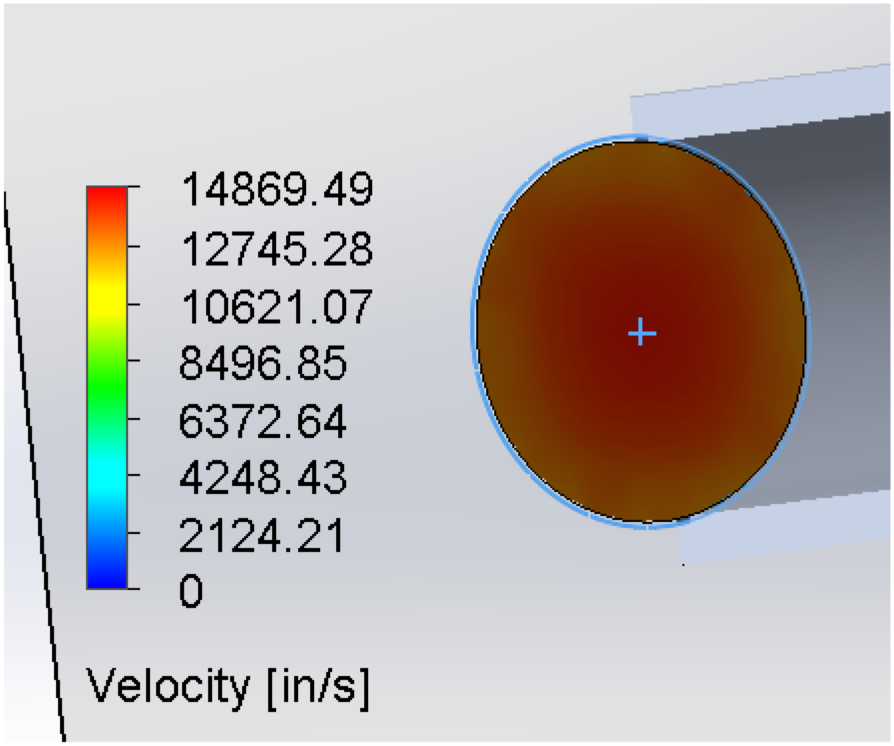


Figure 8 Velocity of air at the exit of the barrel

The above image shows the velocity in a cross-sectional plane, a similar cross-section that would be impacting the shaft of the hook when the projectile is getting launched.

The design of the barrel exiting the chamber assumes the inner diameter must be at least 1 inch. This is because of the claws shaft being also approximately 1 inch in diameter. This would create a seal that would allow the force of the air pressure to propel the claw forward. Based on the calculated force the claw requires to be launched and to counter act the force of the line being approximately 50 lb_f an assumed value of 55 lb_f was used. The reason for a higher assumed force was in case a counteracting force was not taken into consideration in the previous calculations.

The chamber pressure was calculated to be approximately 105 psi while the barrel pressure is supposed to reach around 70 psi to provide the force needed to launch the claw. This was calculated using Bernoulli's law assuming that the inlet equals a constant that also must equal the exit with the same constant. Allowing the inlet to equal the exit and assuming the velocity in the chamber before the releasing the pressure is equal to 0. The velocity of the exit needed to be calculated before the inlet pressure could be found which was solved using $F = \rho * A * V^2$ and with the given knowledge and assumptions the velocity of the exit can be calculated as shown on the next page.

Pneumatic hand calculations:

$$F = P * A$$

$$A = \pi * \frac{D^2}{4}$$

$$D = 1\ in = \frac{1}{12}\ ft$$

$$A = \pi * \frac{\left(\frac{1}{12}\right)^2}{4} = .005454\ ft^2$$

$$F = 55\ lb_f$$

$$P = \frac{F}{A} = \frac{55}{.005454} = 10{,}084\frac{lb_f}{ft^2} = 70.03\ psi$$

$$F = \rho * A * V^2$$

$$\rho = 2.369 * 10^{-3}$$

$$V = \sqrt{\frac{55}{2.369 * 10^{-3} * .005454}} = 2{,}063.2\frac{ft}{s}$$

$$P_1 + .5 * \rho_1 * {V_1}^2 = Constant$$

$$P_1 + .5 * \rho_1 * {V_1}^2 = P_2 + .5 * \rho_2 * {V_2}^2$$

$$V_1 = 0\frac{ft}{s}$$

$$V_2 = 2{,}063.2\frac{ft}{s}$$

$$P_2 = 10{,}084 + .5 * 2.369 * 10^{-3} * 2{,}063.2^2 = 15{,}126.17\frac{lb_f}{ft^2} = 105.05\ psi$$

- **Electronic firing mechanism design, analysis, measurements**

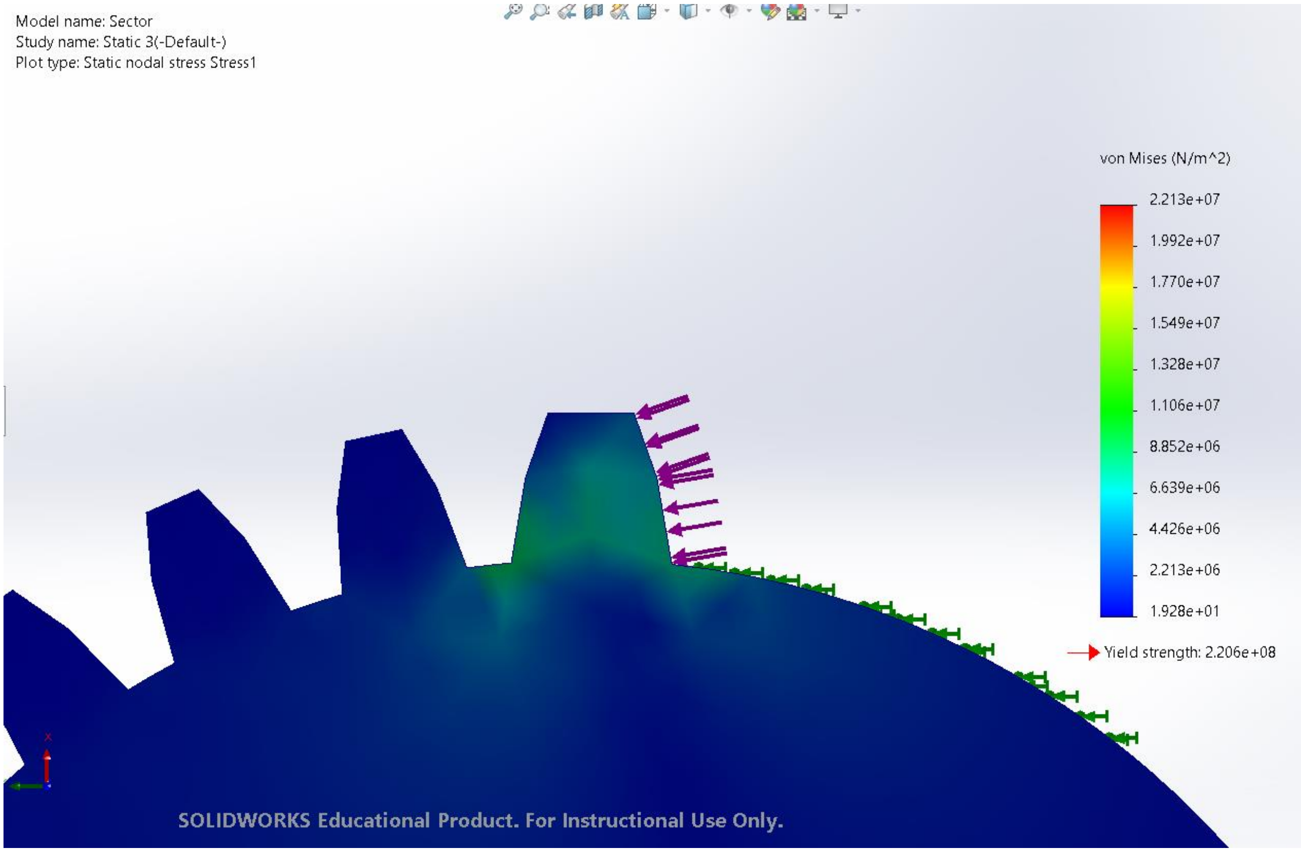


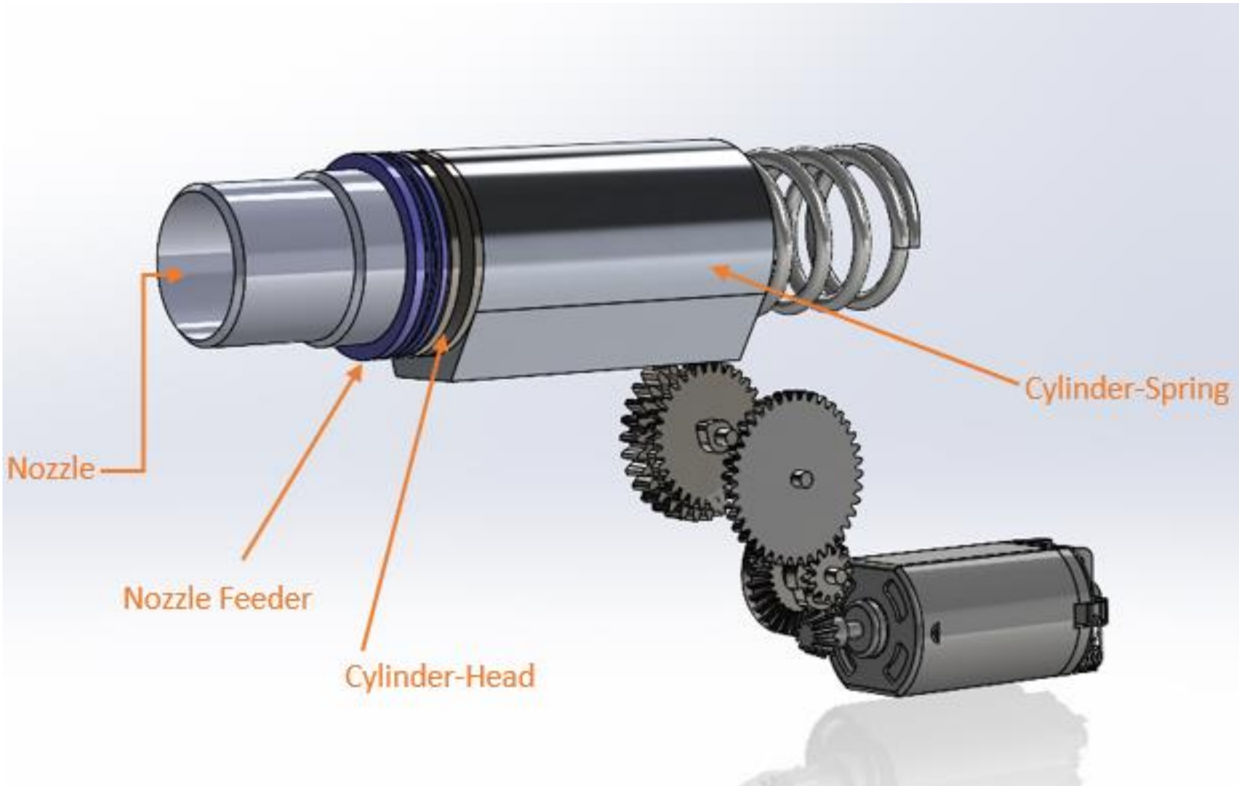
Figure 9 FEA of gear tooth

The sector gear is directly interacting with the spring mechanism and must be able to withstand force on the teeth being produced by the compression of the spring. The standard gear set will be made from plain carbon steel. (Pictured above) The maximum force of spring of 5.89 lb.-ft. is applied directly to the face of the gear tooth in a fixed position. The gears are the most critical part of the design because they translate power from an electric motor to the spring firing mechanism.

Property	Value	Units
Elastic Modulus	30457924.91	psi
Poisson's Ratio	0.28	N/A
Shear Modulus	11457981.28	psi
Mass Density	0.2817927981	lb/in^3
Tensile Strength	57989.8585	psi
Compressive Strength		psi
Yield Strength	31994.4547	psi
Thermal Expansion Coefficient	7.222222222e-06	/°F
Thermal Conductivity	0.000575114	Btu/(in·sec·°F)

Critical properties of Plain Carbon Steel

Figure 11 Firing Assembly



The full mechanism fits inside of a custom made, 3D printed, airtight housing unit that keeps the components in place and the tip of the Nozzle exposed so the required air burst can interact with the grapple hook projectile. Both the Cylinder-Spring and Cylinder-Head move with the spring (5'' spring used in final prototype) as the Sector Gear turns. When the Sector Gear runs out of teeth the spring will release and air will rush through the Nozzle Feeder and Nozzle providing approximately **1640 psi** of force directly to the projectile. The system resets itself after one full gear rotation.

Preliminary Calculations

Spring

Spring Rate [K] = 28.16 lbs/in
Compression Length [x] = 2.51"

Nozzle

Diameter = 1 in

Forces

Spring = 70.68 psi
Nozzle = 55.5 lbf

$$F = P * A$$

$$A_{nozzle} = \pi r^2 = .785\ in^2 = .00545\ ft^2$$

$$P_{spring} = K * x = 70.68\ psi = 10{,}084\ \frac{lbf}{ft^2}$$

$$\boldsymbol{F = 55.5\ lbf}$$

Mechanism Dimensions

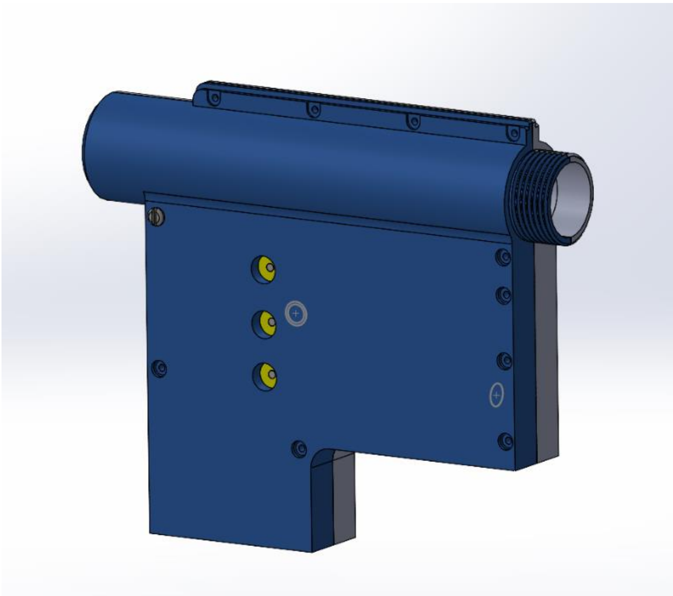
Length = 197 mm = 7.75 in
Width = 44 mm = 1.73 in
Height = 110 mm = 4.33 in

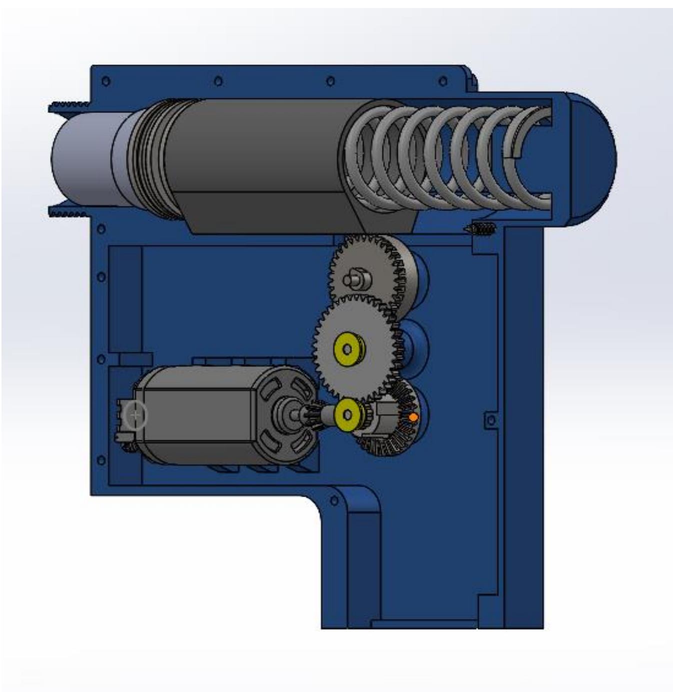
Theoretical Output from Produced Prototype

4"
Spring rate: 26.16 lb/in
Full compression: 1.5 in
Area of cyl head: 40.72 sqin
Full power: 1720 psi

5"
Spring rate: 22.25
Full compression: 1.81 in
Area of cyl head: 40.72 sqin
Full power: 1640 psi

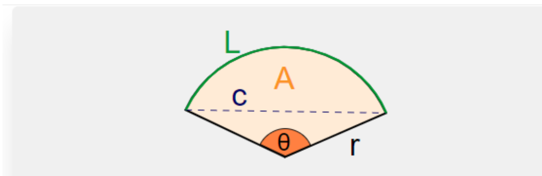
Figure 12 Housing Assembly





The housing design underwent six different iterations from the initial design and four full units were produced for testing. The early-stage units were 3D printed in PLA, but the final design utilized Vero plastic for strength, aesthetic, part fitment, and print accuracy.

Arc Length of driving teeth on Spur Gear



Central angle (θ)	183.4	deg
Radius (r)	13.6	mm
Diameter	27.2	mm
Sector area (A)	296.0224	mm^2
Chord length (c)	27.19	mm

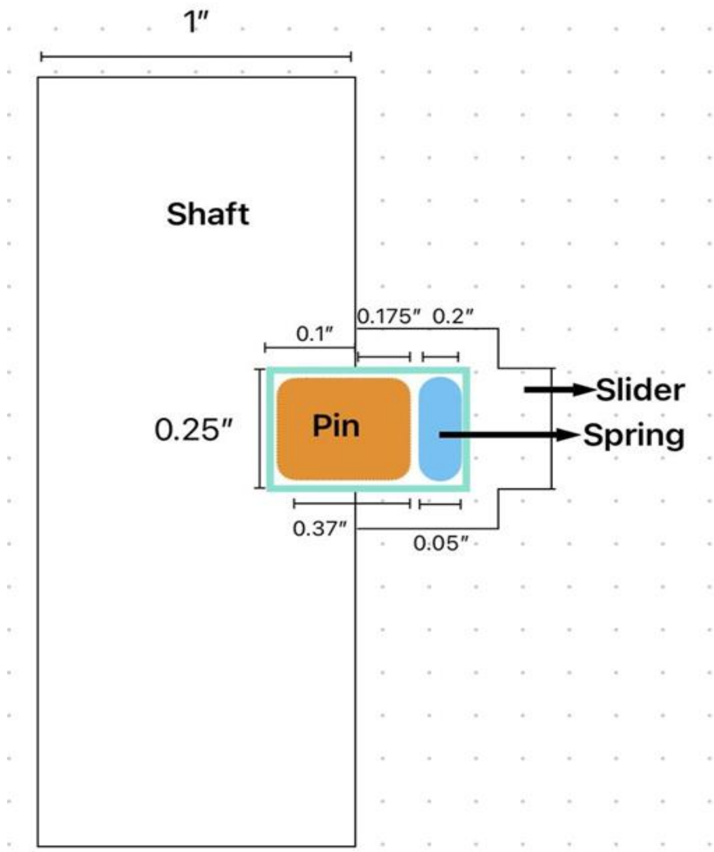
Arc length

Arc length (L)	1.713886	in

Spring Type	Compression
System of Measurement	Inch
Length	5"
OD	1.219"
ID	0.969"
Wire Diameter	0.125"
Compressed Length @ Maximum Load	1.81"

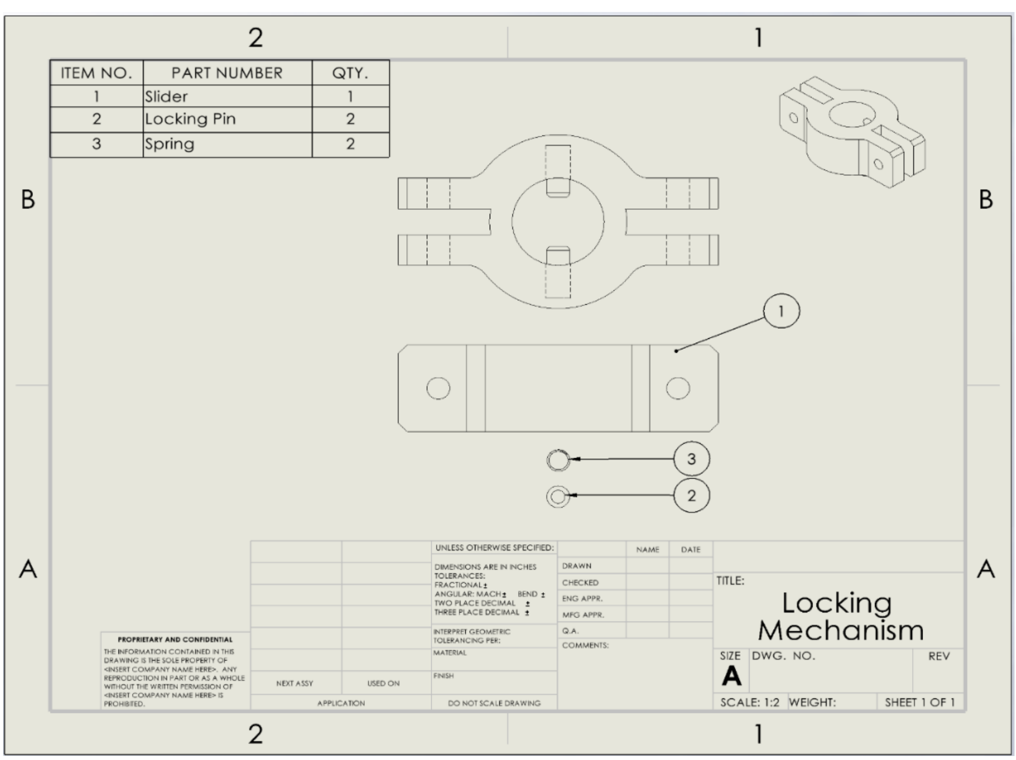
The system was engineered to ensure the driving teeth on the arc length of the gear could compress the spring far enough to achieve maximum load

- **Custom locking mechanism design ideas**



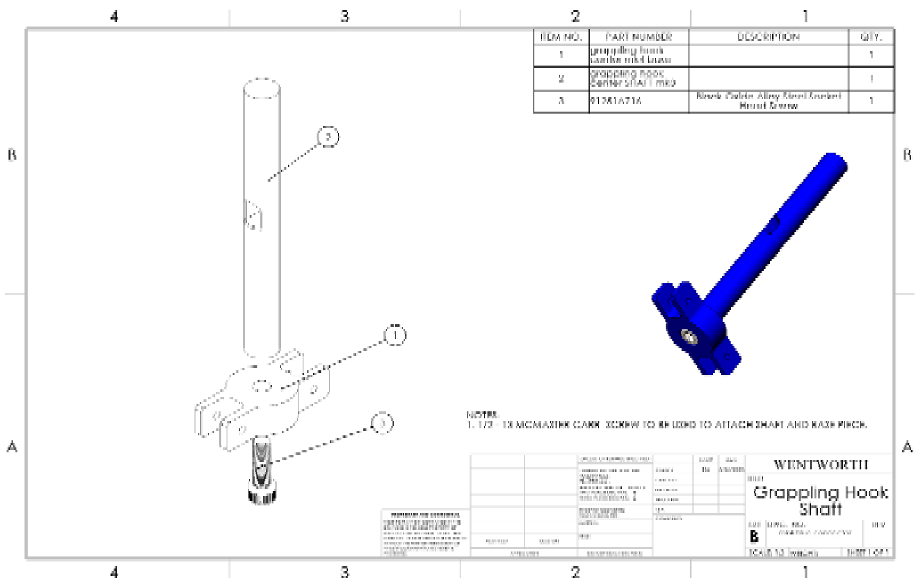
In the image (left) shows a preliminary idea of what could be a locking mechanism for the grapple-hook projectile. The parts include a pin, spring, slider and set screw.

The Locking mechanism is an integral part to the vision of the final design. the team lacked time and resources to incorporate this system into the final prototype.

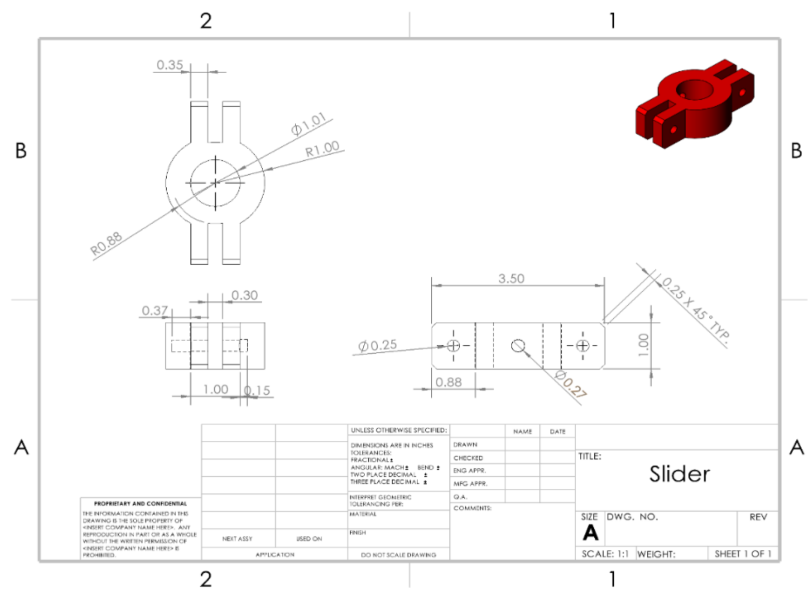


In the image (left) we have the assembly drawing of the locking mechanism. It utilizes a 0.25" diameter by 0.25" long and a pin that is 0.37" by 0.25".

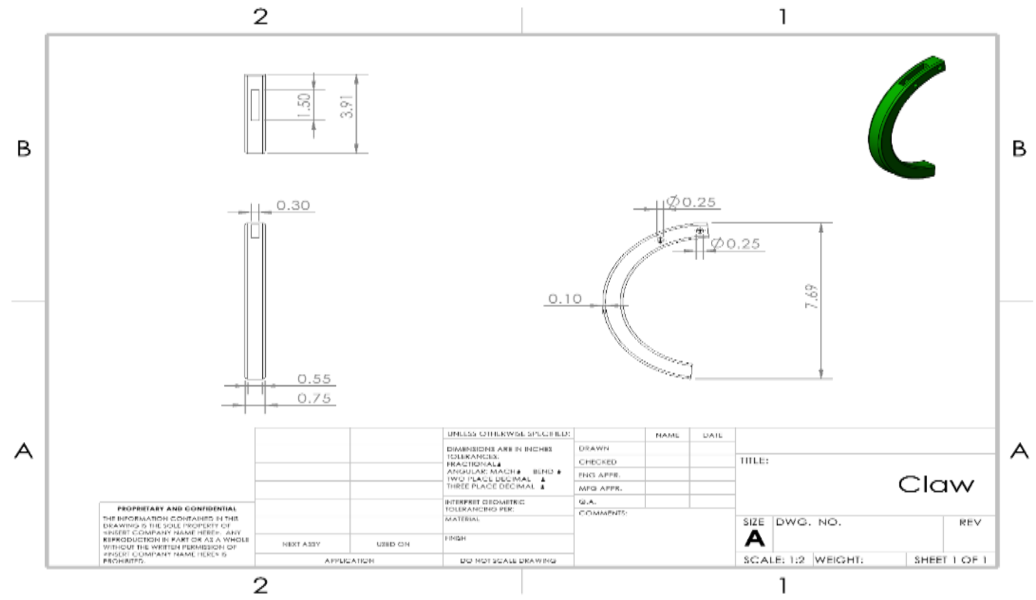
- **Assembly and Part drawings for use in manufacturing process**



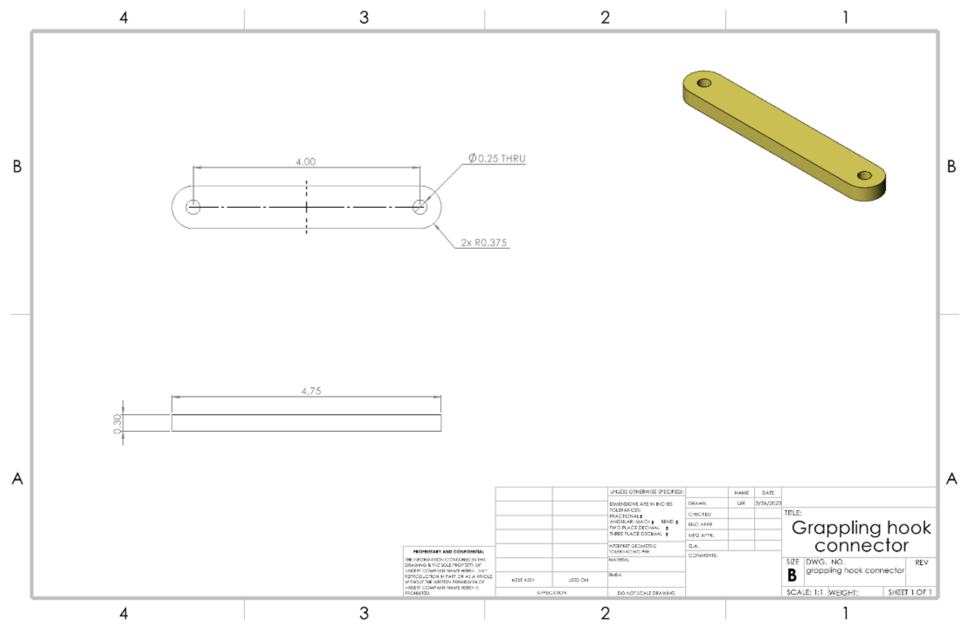
In the image above, the grappling hook shaft allows the adjustment piece to slide up and down to extend and retract the claws. The shaft is comprised of three different components. The shaft piece is screwed to the base piece using a ½-13 socket head cap screw. This greatly decreases the difficulty of manufacturing, as the shaft piece is completely circular, and the base piece can be cut in a way that is extremely like the red articulation piece. Both pieces could potentially be manufactured using the same fixture plate as well.



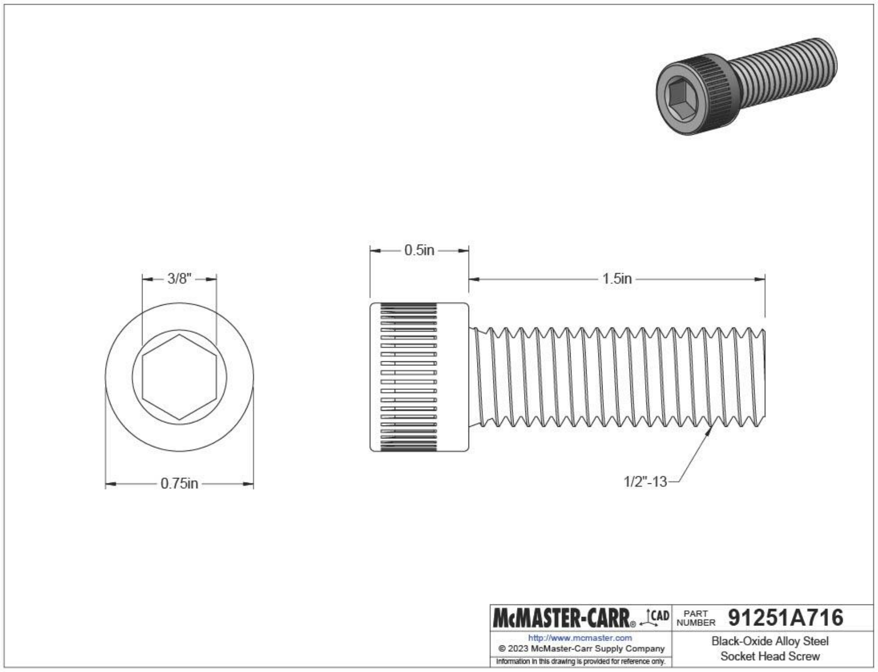
In the figure above, the red articulation/slider piece slides up and down the blue shaft piece. This sider is attached to two yellow connectors that will extend and retract the claws. The force of the blue base piece colliding with the targeted pipe will cause this slider to slide down the blue shaft and lock in place once the claws are fully retracted. The force of the collision is used to articulate the claws, so no motors/preloads will be needed to open and close the claws.



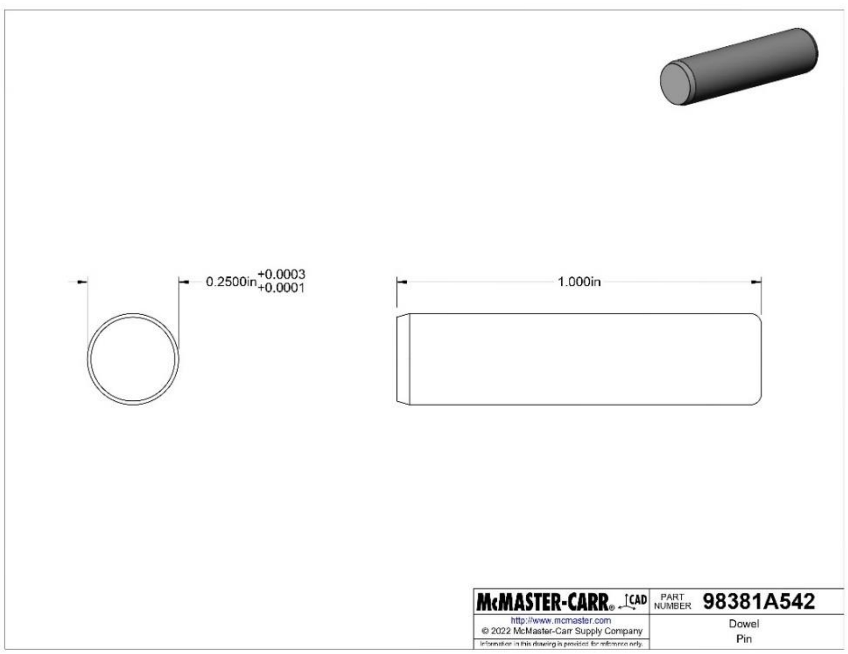
In the figure above, the claw is attached to the yellow connector and is designed in such a way that collision is avoided between any two claws. The claw has a rectangular slot that allows the yellow connectors to slide freely and articulate the claw smoothly. The claws may end up with a rubber cover towards the bottom of the claw, as adhesion to the target pipe may not be enough to ensure a tight grip. This claw is designed to surround a circular target pipe.



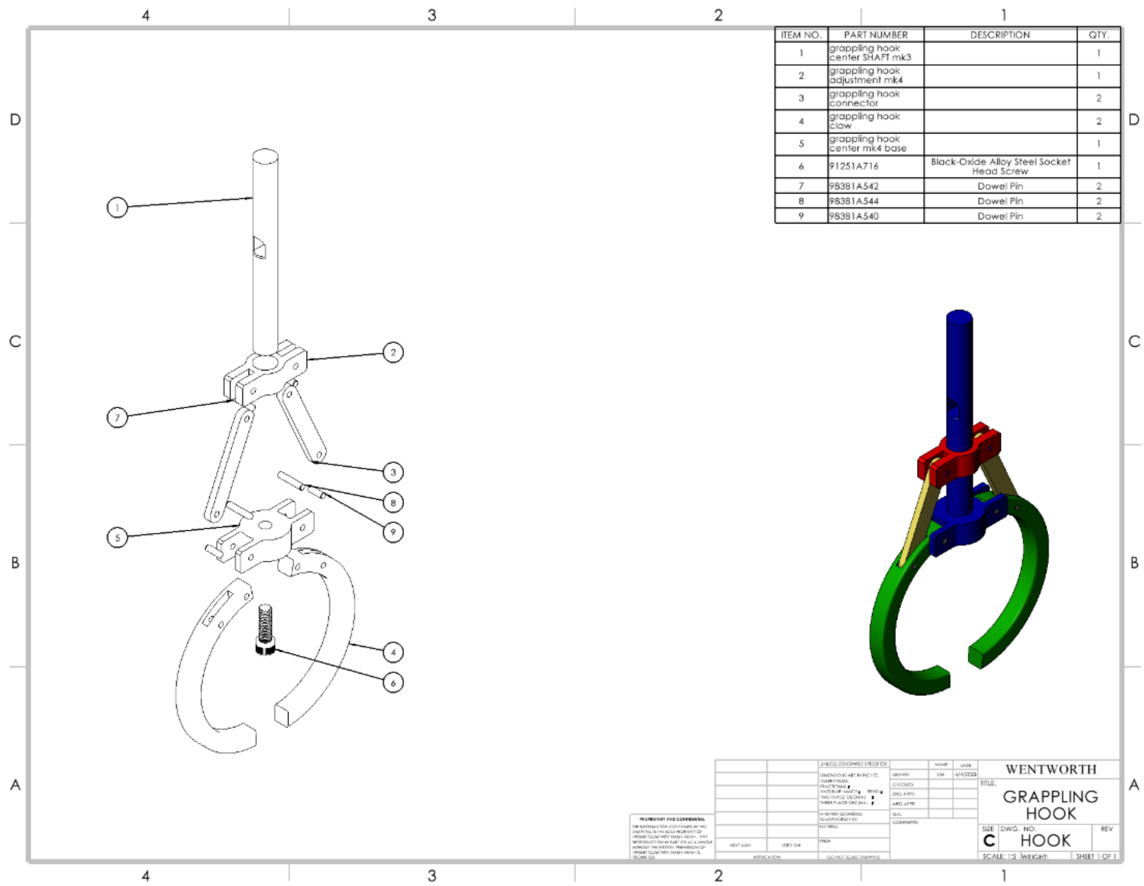
In the figure above, the yellow connector piece uses actuator motion to articulate the claws. The two connectors are connected to the red slider and the green claws. When the red slider slams inti the blue shaft piece, the connectors will move in such a way that the claws will close as far as they can without colliding with each other. The strength of the connector is crucial to claw articulation, so this piece was carefully designed in terms of thickness to ensure that it does not snap.



The figure above shows the screw that combines the blue shaft piece and the blue base piece.

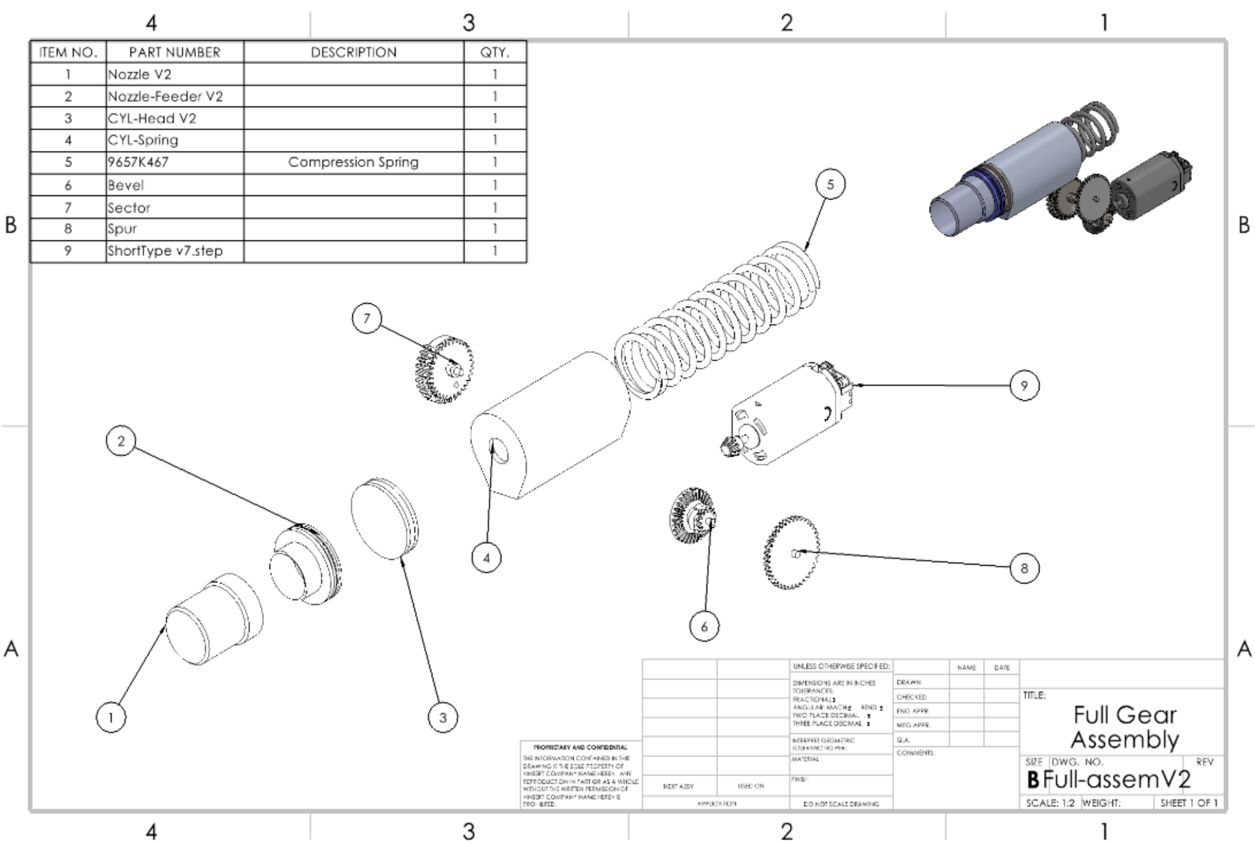


The figure above shows the alloy steel pins that will be used to connect the claw components. Alloy steel pins are crucial, as the tensile strength of alloy steel is much greater than aluminum. There will be 6 pin connections in total.



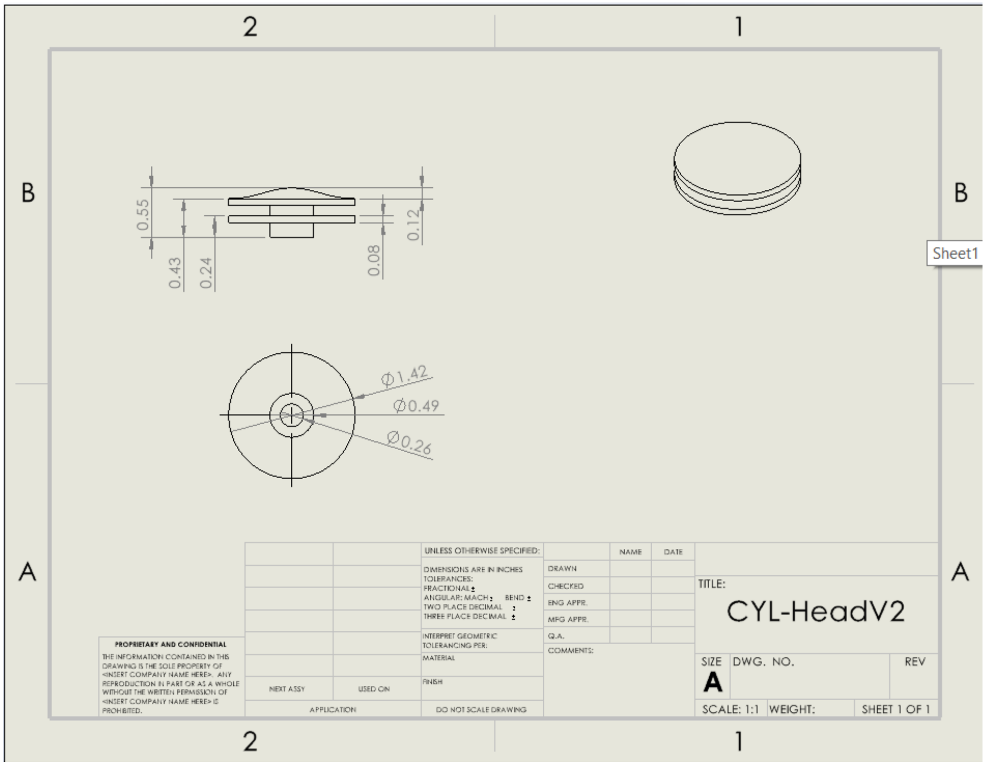
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	grappling hook center SHAFT mk3		1
2	grappling hook adjustment mk4		1
3	grappling hook connector		2
4	grappling hook claw		2
5	grappling hook center mk4 base		1
6	91251A716	Black-Oxide Alloy Steel Socket Head Screw	1
7	98381A542	Dowel Pin	2
8	98381A544	Dowel Pin	2
9	98381A540	Dowel Pin	2

(Pictured Left) An exploded view and bill of materials of the full grapple hook projectile assembly

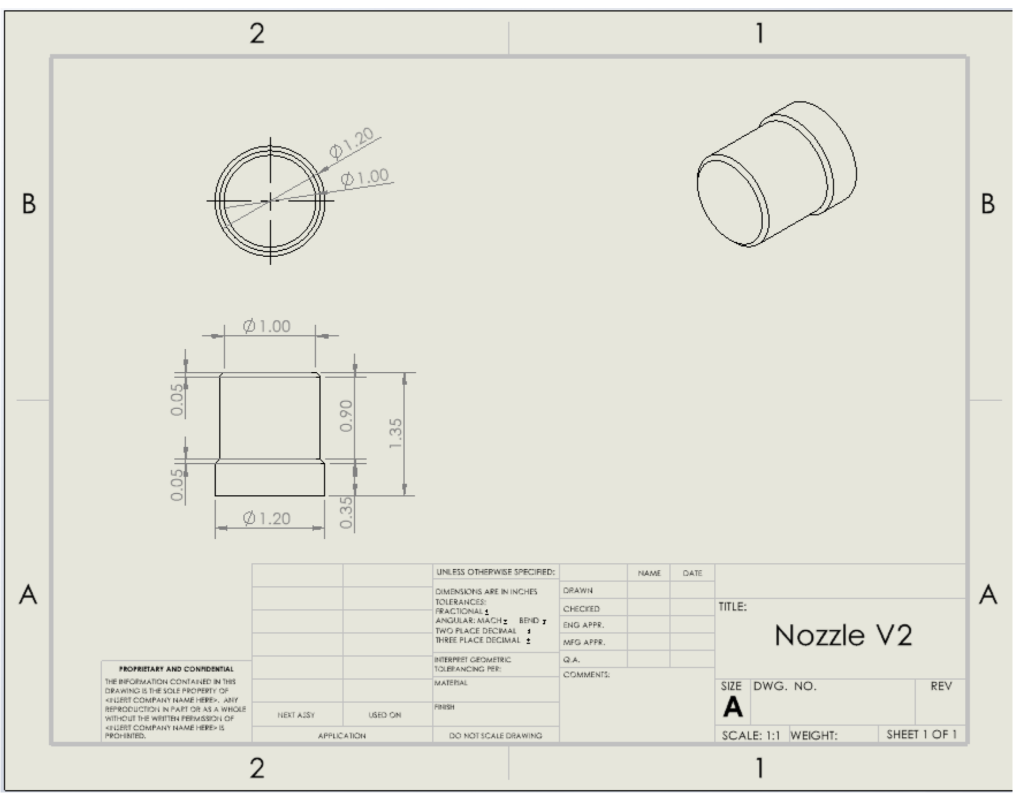


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Nozzle V2		1
2	Nozzle-Feeder V2		1
3	CYL-Head V2		1
4	CYL-Spring		1
5	9657K467	Compression Spring	1
6	Bevel		1
7	Sector		1
8	Spur		1
9	ShortType v7.step		1

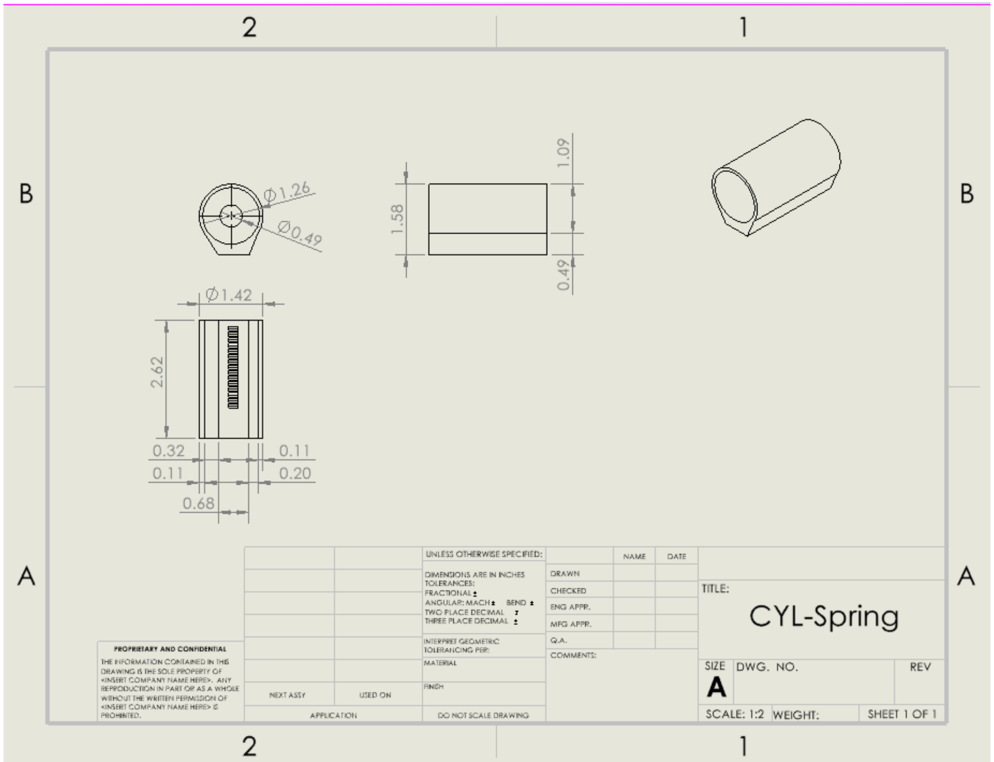
(Pictured Left) An exploded view and bill of materials of the full electronic mechanism assembly.



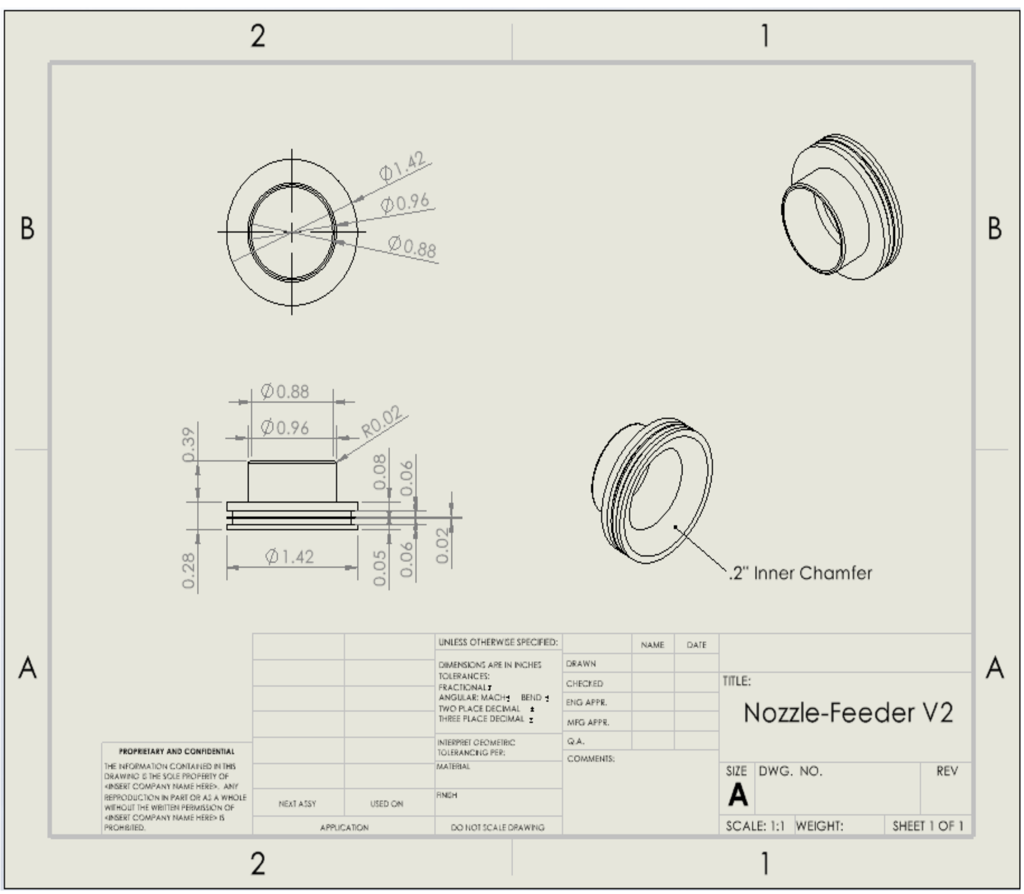
(Pictured Left) Engineering drawing showing critical dimensions of the Cylinder-Head piece. This part attaches to the end of the Spring-Cylinder to move air through the nozzle.



(Pictured Left) Engineering drawing of the Nozzle piece. The nozzle has been designed specifically to have a 1 in. exit diameter to apply the correct amount of air force to the grapple hook projectile.



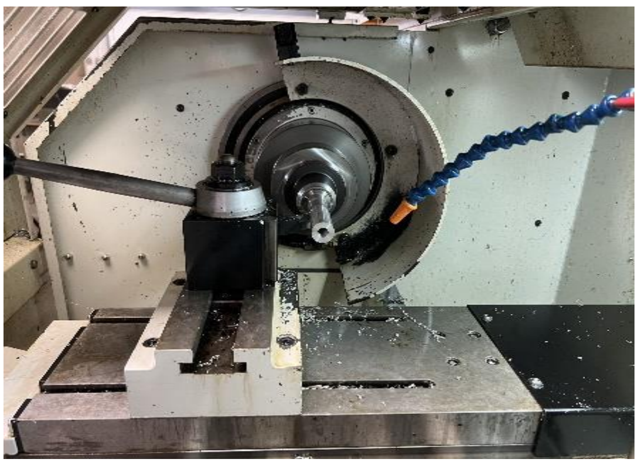
(Pictured Left) Engineering drawing of the Cylinder-Spring piece. The purpose of this part is to provide housing for the spring and mate the gear set via the teeth slots on the bottom of the part.

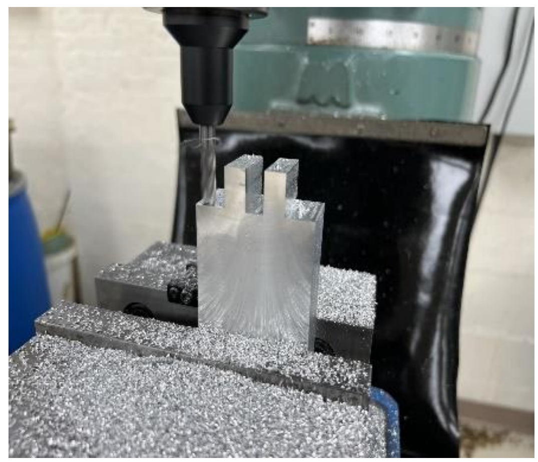


(Pictured Left) Engineering drawing of the Nozzle-Feeder piece. This part provides a channel for the air coming from the Cylinder-Head. The feeder keeps the Nozzle piece in place via press fit. The outer slots are for rubber O-rings to help make an airtight seal in the mechanism housing.

Manufacturing Process

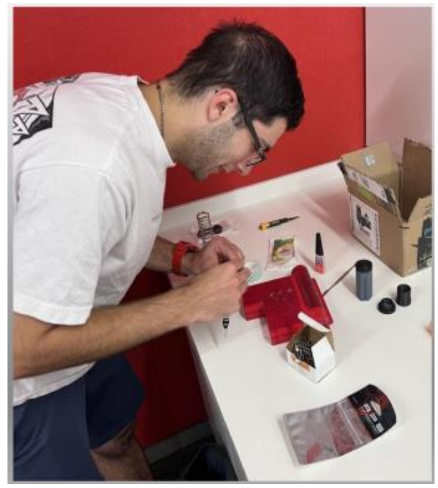
The grappling hook: The grappling hook was partially machined using CNC lathes and mills. The shaft, adjustment piece, and the connectors were machined out of aluminum, while the claws were 3D printed out of carbon reinforced nylon. The claws were originally planned to be machined of aluminum as well, but the cutting edge on the available end mills that Wentworth had available were only able to cut up to 1-inch pockets, while the claws needed a 1.8-inch pocket to be fully machinable. Nevertheless, the claws operated as intended, and were a great addition. The pin connections were purchased in alloy steel and were inserted into the aluminum and nylon pieces as needed. The adjustment piece, connectors, and shaft base were machined on the mill, and the circular shaft was machined on the lathe. Various hand tools were available to use in the manufacturing lab as well as measurement tools. The team purchased lots of stock for multiple attempts, but only one attempt was needed for each part.





The Firing System: 3D Printers were used to make the required custom parts. The nozzle, nozzle feeder, cylinder head, and spring cylinder were created with the ONYX printer in Carbon material. Other standardized parts (gears, motor, spring) will be purchased to complete the full firing mechanism assembly.

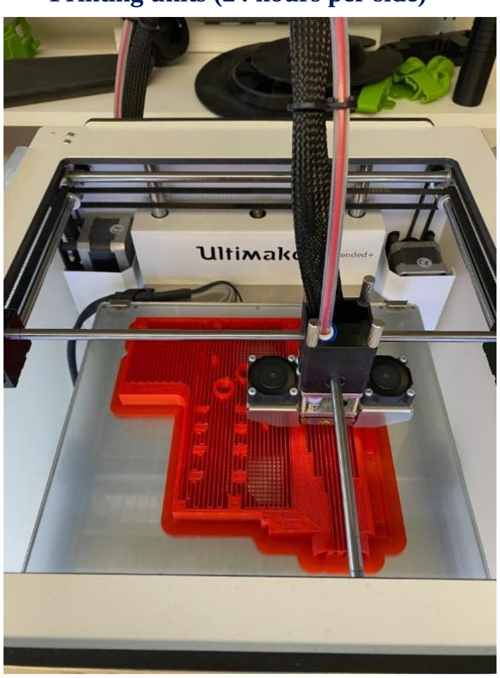
Onyx 3D Carbon Printer



Assembly of Firing system in final prototype

The Firing Housing: The Housing unit encompasses the brushless motor, set of gears, (5x) 8mm ball bearings, compression spring, firing cylinder, cylinder head, nozzle feeder, and firing nozzle. The early versions of the Housing unit were 3D printed in PLA to keep development costs low. This meant the printed supports were removed by hand and the parts were sanded down to ensure smooth operation. A total of **four** sets (Left and Right) units were produced over the semester to experiment with functionality and part fitment before the final prototype. There were noticeable improvements in operation performance and system refinement with every new iteration. The team has concluded that with more development time (and budget) a proper design could ensure the successful operation of a zipline launcher device.

Printing units (24 hours per side)

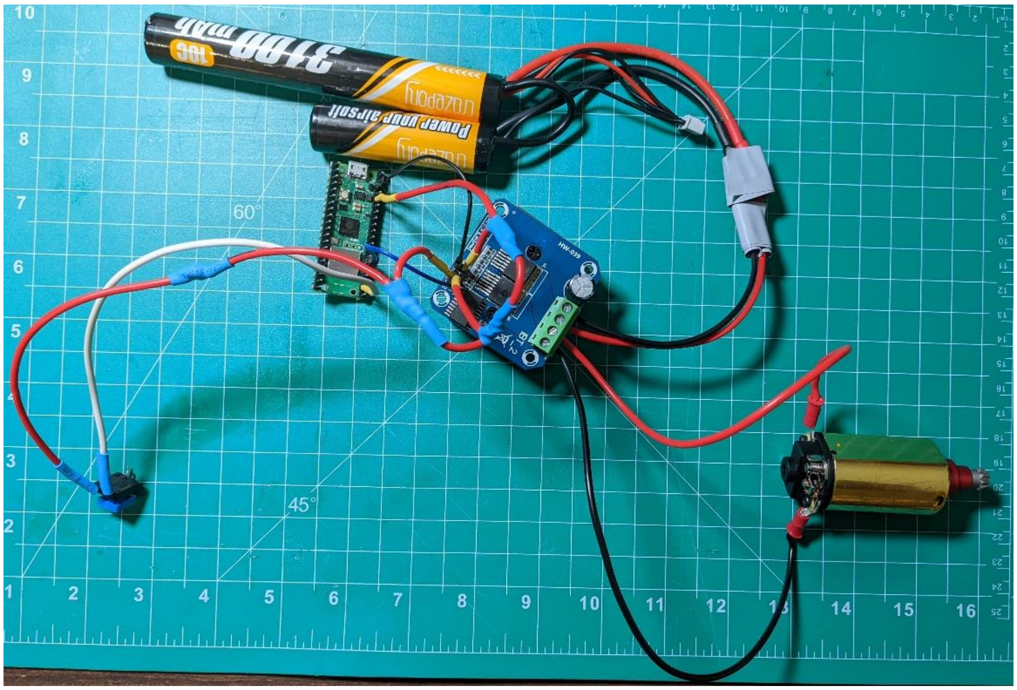


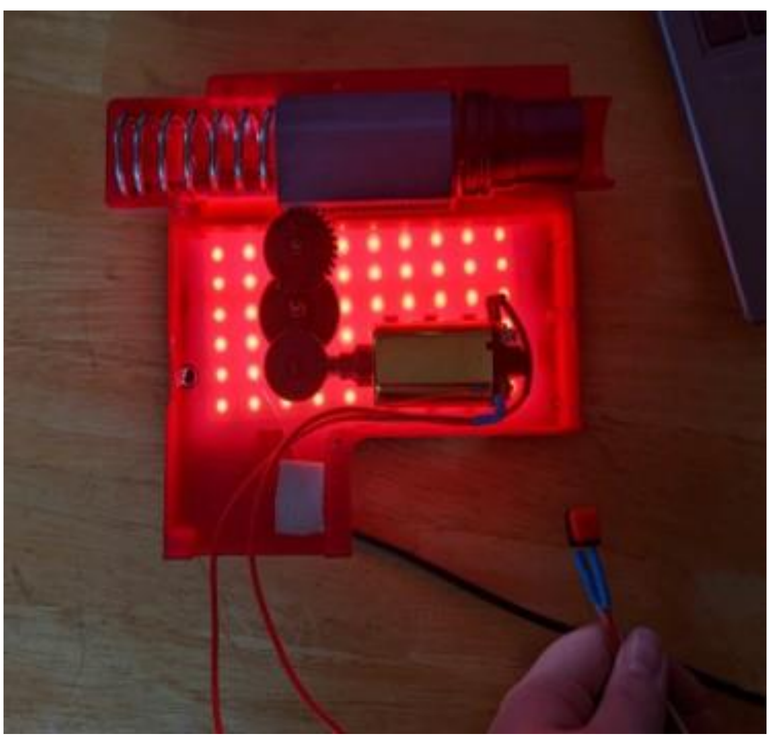
Sanding mechanism area (about 3 hours per set by hand)

Removing PLA support (about 4 hours per set by hand)

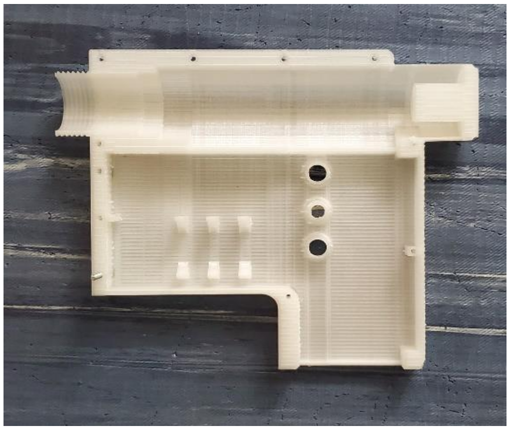
Electrical Component System: Initial thoughts for the electrical system of the project entailed just a battery, motor, and a switch. This just allows the motor to run directly from the battery when the switch is pressed. The downside to this system is no control over the speed of the motor along with no ability to add to the system such as an aiming and auto firing system for future advancements. This was immediately ruled out due to the fact of no control of the motor speed. Research into motor systems, the most common use of a motor system is in remote controlled cars built by hobbyists. The main components used were a micro controller that housed the code, and a motor controller or a motor driver that communicated with the micro controller to determine the amount of voltage that the motor used. Once knowing the very basic of the systems a Raspberry PI Pico board was purchased for the micro controller and a L298N was the motor driver. The first time setting it up the battery that was being used has 11.1 V and 3.1 A connecting that to the motor driver and accidentally connecting it to the Pico board caused both to overheat and fried the components within. Having a backup Pico on hand allowed for a quick switch but not realizing that the motor driver could not withstand the amperage means that more research had to be done to determine the correct motor controller this was also at the time where the final motor did not arrive yet. This led to the discovery of the final motor driver, which is the HiLetgo BTS7960 motor driver it can handle up to 43 A and 6-27V to control the motor. Once this was added into the system the Pico board was yet again fried because of current running back through because two wires that both provide current touched each other causing current to run back and fry the component. It was also discovered that a SEEED Xiao RP2040 was purchased. It is a micro controller and half the size of a Pico board, so it was decided to be used instead.

To set up the next version of the system the microcontroller needed to provide 3.3-5V to the motor controller for the motor controller to communicate with the micro controller. The micro controller receives power from the USB port on the computer when code is initially tested and from there it can send the voltage through the PMW ports on the micro controller or through the designated 3.3V or the 5V ports. With the enable pin on the motor controller needing to be provided 3.3V to allow for the motor to spin freely the 5V was used to power the board while the enables were given the 3.3V along with being connected to the firing button to run the motor when pressed. The whole system worked at this point being run off of the computer but for the system to be able to function in the handheld launcher the code needed to be downloaded onto the micro controller and run on a separate battery. Two separate issues occurred at the same time, the micro controller was being powered by a 9V battery causing it to overheat but not break along with it getting stuck in bootloader mode which sets it back to factory settings and would not except any code. This means that the board was no longer usable and a new one was required which brought the Pico board back in. In the end of the final system the power setup for the Pico board was not created due to lack of time, it just ran on computer power. The below circuit diagram is the fully flushed out circuit that was trying to be created but the only thing not completed was the 5V power supply. The power line running from the Pico board to the motor controller shows the power being sent to both enable pins and the power on the motor controller as well as the button being powered. The downside to the Pico board is the fact it only has a 3.3V providing port so the power for the motor controller had to be connected to the rest of the other power required components, this meant creating a bridge wire that allowed for no current to run back through which is significantly harder to create. In the end if the system is ever needed again, it can now be created quicker by having the knowledge and experience to go through this process.

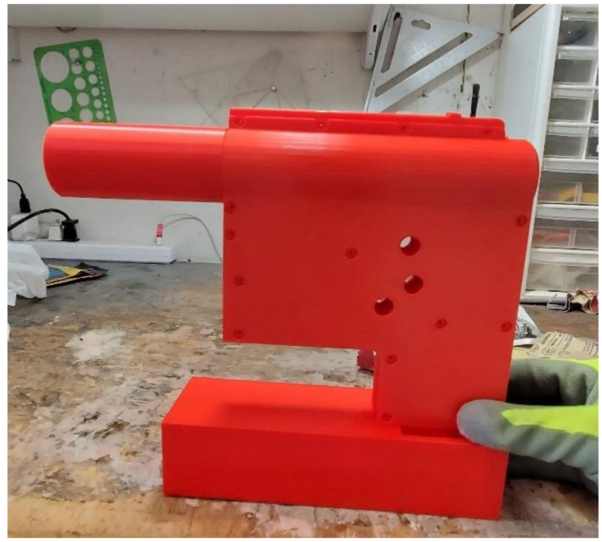




Additional Produced Components:



(Left) A print of the final "V6" version of the housing printed in clear PLA



(Above) A preliminary full assembly of the firing mechanism including the barrel, left and right sides and electrical box

(Right) An industry grade zipline (5ft) is attached to a 3D printed cylinder that fits on the end of the metal grapple hook. The line is rated for 120 lbs. of payload

(Below) 3D printed "test shots" were made in different shaft diameters to accommodate the barrel of the firing system

(Right) A Carbon 3D printed firing cylinder used for testing. The part had to be refined and re-printed to make better contact with the spur gear

(Above) The 3D printed electrical box is shown attached to the final prototype with the sliding door cracked open. Inside the box includes the battery, pico-board, and motor controller

(Above) The first set of gears acquired by the team. These gears have a lower ratio (18:1) and are made from plain steel. The team later upgraded to Carbon-Steel gears with a higher ratio (26:1) to better accommodate the firing system

(Left) An early version of the firing cylinder with the cylinder head attached. The cylinder head has a specific curvature on top to help force air through the nozzle

(Above) These versions of the launcher barrels all have slightly different inner diameters and thread styles. The correct version has .0625-11 inch thread and an inner diameter of 33.96 mm. The barrel correctly threads and fits to the final prototype with ease

(Above) A failed 3D print attempt at the “V3” version of the housing. The printer had overheated and canceled the print at this exact point

ABET Outcomes

Outcome 2	**Explain**
Public health	Our system has the potential to increase mortality rates for people who take part in extreme hiking and for people in vertical emergency situations.
Safety and welfare	The emergency zipline is to provide a safe route out of situations such as a burning building or other situations.
Global	The system can be standardized and easily implemented into office buildings or sold to outdoor supply retailers around the world.
Cultural	The system was influenced from cultural movies such as "Batman the dark knight" and "Mission impossible"
Social	Commercial access to a zipline launcher could inspire new modes of transporting people and objects more efficiently in the future.
Environmental	The system is battery powered which allows for the batteries to be charged on environmentally friendly means.
Economic factors	The tool can be used for multiple purposes other than emergencies such as providing transport for objects along with humans. Allowing for it to reach broader demographics and marketing approaches.

Team Conclusion

The team has yet to launch a physical projectile with the prototype. The team experienced setbacks with the motor function and hardware fitment. Correctly powering the motor has required multiple circuit configurations, multiple iterations of code and code languages, and experimenting with 2 different microcontrollers. As a team comprised of mechanical engineers, we feel this task would have been better suited to an electrical engineering discipline. The fitment of the gears and hardware varied between 3D print quality and material used. Refining the fitment of the hardware to this point took the entire semester and multiple test parts. Due to the experimental nature of the project the setbacks listed have prevented the prototype from a proper test. The team still firmly believes in the overall concept of the launcher and that given more time, budget, and refinement a functional launcher could be created. The team found success in the overall packaging of the device and final product produced. The project includes components made from plastic, carbon, steel, aluminum, and rubber.

Overall, the group put lots of time and effort into finalizing this proof of concept. Several concepts were thrown around in the earlier stages of the project that never made it to the final prototypes. These included a piercing-style grappling hook, a pneumatic launching system as opposed to a gear/motor powered system, and an aiming supplementary application. Parts were also purchased for a locking mechanism to be applied to the grappling hook, but this mechanism never materialized. Featured in the final prototype is six months of dedicated engineering design that will surely help the group in our future engineering positions.

References

"All About 4130 Steel (Properties, Strength, and Uses)." *Thomasnet® - Product Sourcing and Supplier Discovery Platform - Find North American Manufacturers, Suppliers and Industrial Companies*, https://www.thomasnet.com/articles/metals-metal-products/all-about-4130-steel-properties-strength-and-uses/.

"Grappling Hook Archives." *Small Boats Magazine*, https://smallboatsmonthly.com/article-tags/grappling-hook/.

"My Solidworks." *MySolidWorks - Official SOLIDWORKS Community*, https://my.solidworks.com/reader/swyoutube/ZpCLhK9dl98/gear-and-path-mates-with-cadman-grapple-gun.

"Solidworks Simulation Static Analysis of Crane Hook." *YouTube*, YouTube, 25 Jan. 2016, https://www.youtube.com/watch?v=USyR8QybSs0&ab_channel=KarthikR.

Team, Gabrian. "How Strong Is Aluminum? How Does It Compare to Steel?" *Gabrian*, 23 Mar. 2023, https://www.gabrian.com/how-strong-is-aluminum/.

Baker, Hannah. "How Do Airsoft Guns Work: The Mechanism of Spring, Electric and Gas Airsoft Guns." *Sharp Import*, 14 Mar. 2019, https://www.sharpimport.com/how-do-airsoft-guns-work-the-mechanism-of-spring-electric-and-gas-airsoft-guns.

Duthie, Andrew. "How Do Airsoft Guns Work? Everything You Need to Know: Airsoft Blog: Redwolf Airsoft." *AIRSOFT BLOG | REDWOLF AIRSOFT*, 14 Jan. 2021, https://www.redwolfairsoft.com/blog/how-do-airsoft-guns-work.

For Electronics

BTS7960 High Current 43A H-Bridge Motor Driver, www.handsontec.com/dataspecs/module/BTS7960%20Motor%20Driver.pdf.

"Getting Started with Raspberry Pi Pico." Projects.Raspberrypi.Org, projects.raspberrypi.org/en/projects/getting-started-with-the-pico.

"Xiao Introduction: Seeed Studio Wiki." Seeed Studio Wiki RSS, wiki.seeedstudio.com/SeeedStudio_XIAO_Series_Introduction/.

Stolting, Hans D. "Handbook of Fractional-Horsepower Drives." Google Books, books.google.com/books?id=VCHumncaeAAC&pg=PA134#v=onepage& q&f=false.

Appendix

Featured Document Figures

Team Resumes

Shannon Catherine Cullen

cullens4@wit.edu | 617-223-1991 | 576 Poplar St Boston, MA. 02131

EDUCATION

Wentworth Institute of Technology | Boston, MA — Exp Grad August 2023
Bachelor of Science in Mechanical Engineering
Aerospace Minor

SKILLS

Software: AutoCAD, SolidWorks, Revit, EES, Ansys, Java coding, G-code, Microsoft Office (Excel, PowerPoint, Word)
Engineering: Material testing, strain gauges, stress analysis
Manufacturing: CAM, CNC milling, Welding

EXPERIENCE

Commercial Construction Consulting, LLC | Boston, MA — Fall 2022
Mechanical Co-op

- Visited project sites and edited previous existing plans by locating all currently existing utilities (supply/return ducts, plumbing, and electrical)
- Generated 2-D or 3-D models from previous existing utility plans and from the locating plans
- Processed client information regarding the Building Emissions Reduction and Disclosure Ordinance to be approved by a certified engineer

Boston Water and Sewer Commission | Boston, MA — Fall 2021
Research & Customer Service

- Searched for and reviewed archives/database for information on history of properties, specifically water, rainfall, sewer, and fire systems.
- Responded to customer's requests for updates on approval process; ensured signing and proper retrieval
- Identified the exit drainage for emergency situations (i.e. oil leaks)
- Approved CAD drawings to match the site plans that were approved

PROJECTS

Emergency Zipline | Capstone — Spring-Summer 2023 (Current)

- 3-D rendered the pneumatic system
- Ran CFD and FEA on the pneumatic system
- Wired the motor and trigger mechanism to a raspberry pi and coded python onto the board
- 3-D modeling the housing for the firing mechanism

Trent 1000 Analysis | Gas Dynamics — Spring 2023

- 3-D modeled the diffuser in solid works to run simulations in Ansys
- EES coded to run calculations that allowed for a quick change in variables
- Python code was generated when certain variables were calculated using an iterative method allowing for a produced error less than 0.001%

ACTIVITIES/ LEADERSHIP

First Robotics Club, *Captain of Coding and Electrical Team* — 2016-2018

- Developed and managed the incoming coders and electrical team
- Created a robot to compete in First Robotics competition and achieved 2nd place

Middle School Robotics Club, *Counselor* — 2017-2018

- Taught troubleshooting for coding of Lego Mindstorms; developed knowledge of the innovation of robots

Christopher J. Belloli

bellolic@wit.edu | (508)-241-9995 | linkedin.com/in/Christopher-Belloli | Boston MA |

Education

Wentworth Institute of Technology | Boston MA ; Expected graduation: 2023

Bachelor of Science in Mechanical Engineering

Related courses: Mechanics of Materials, Engineering Thermodynamics, Engineering Fluid Mechanics, Machine Design, Engineering Dynamics, Differential Equations, Engineering Calculus, Circuit Theory and Applications, Engineering Physics

Engineering Work Experience

DePuy Synthes | Raynham, MA | Jan – Apr 2020

Shoulder Research & Development Team Engineering Co-Op

- Supported the design, research, and development for a next generation reverse fracture humeral implant
- Applied 3D design software for modeling and design accuracy through comparative dimensional analysis
- Designed mechanical part to improve the function of surgical instrumentation
- Conducted a dimensional analysis report to help complete the launch of a new product
- Performed surgical procedures in company laboratory using the products I was assisting with development
- Used digital documenting systems to organize and update the company product line as well as take inventory via data entry
- Conducted medical research to assist doctors in possible new shoulder procedures
- Presented multiple research-based meetings for the entire R&D shoulder team

SCA Development | Natick, MA | Sept 2020 – Present Day

Product Engineering & Company Development

- Constructed both scaled and full-scale prototypes of new products by method of 3D printing and assembly by hand
- Worked closely with company clients on engineering projects to ensure quality and completion in a timely manner
- Performed extensive research to ensure new products were competitive in industry and built to company specification
- Re-engineered existing products to meet changing demands of customers
- Conducted quality control and tolerance measuring procedures using mechanical tools and computer software
- Collaborated with co-workers overseas on multiple engineering projects at once
- Supported the launch of a B2C e-commerce company pertaining to the market of home/office ergonomics

Engineering Projects

Projectile Launcher | Engineering Design **Completed (2018)**

- Collaborated with a team of 5 and followed the engineering design process to create a kinematic based launcher

Single-Stage Gearbox | Machine Design **Completed (2019)**

- Developed a working single-stage gearbox to spec for small motorized vehicles using the machine design process

Skills

- **Software:** SolidWorks, Unigraphics NX, PTC Creo, EDMS, AutoCAD, MATLAB, Python, Microsoft Office
- **Engineering:** Design Process, Modeling and Drafting, Rapid Prototyping, Material Testing, Machine Operation, Stress Analysis, Applications of Calculus.

Logan May

Upton, MA 01568

774-462-8757 | logansmay2@gmail.com | Seeking employment upon August 2023 graduation

Education

Wentworth Institute of Technology, Boston, MA
Pursuing BSME full time with Manufacturing minor | Class of 2023

Blackstone Valley Regional Vocational Technical High School, Upton, MA
Manufacturing Technology | Class of 2019

Relevant Coursework

- Engineering Thermodynamics, Heat Transfer
- Strength of Materials, Engineering Statics, Engineering Dynamics
- Fluid Mechanics, Mechanical Vibrations, Simulation Based Design
- Engineering Graphics, Manufacturing Engineering, Industry Psychology

Career-Technical Skills & Experience

Manufacturing Technology

- CAD/CAM operations, computer aided design and computer aided manufacturing
- Creation of 3D models in Solidworks using CAD drawings
- 3D printing operations, slicing solid models into readable code
- CNC equipment operation including computer numerical control lathes, mills, plasma cutters, other methods of metal fabrication
- Finite Element Analysis, Kinematics
- Welding: Shielded Metal Arc, Metal Inert Gas, flat, overhead, vertical, horizontal
- Inspection of machined parts and quality control using high-precision measurement devices including calipers, micrometers, and optical comparators

Computer Skills/Certifications
Solidworks Modeling; Solidworks Simulation; AutoCAD; Blender; Microsoft Office Suite; Jira; Infor PLM; 3D Printing; Ultimaker Cura; Eiger; Marlin Firmware, G-code operations

Level 1 MACWIC Machining Certified; OSHA 10 Hour General Industry Certified; Solidworks Associate Certification (CSWA)

Work Experience

Solidworks Support Co-op, Physik Instrumente, Hopkinton, MA | Jan 2022-Dec 2022,
Provided general CAD support to design engineers over spring and fall semesters. Generated 2D CAD drawings from 3D solid model layouts. 3D printed various jigs/fixtures for large air bearing systems using Markforged 3D printers and Eiger software. Loaded design information into Jira, Infor PLM management systems. Assembled/wired air bearing components and pressure gauges.

EZ Grind Operator/Inspector, Tegra Medical, Franklin, MA | Jul 2018-Jun 2021
Inspected various needle components, razor blades, and other medical devices for dimensional inaccuracies. Adjusted multiple machines due to fluctuations in part dimensions. Worked with tolerances as small as +/-.0005inches. Developed into a leadership position with shift lead responsibilities.

Eduardo J. Meza-Ubeda

mezaubedae@wit.edu | (617) 301-1390 | Revere, MA

EDUCATION

Wentworth Institute of Technology **Expected August 2023**
Bachelor of Science in Mechanical Engineering
Minors: Aerospace Engineering and Applied Mathematics
GPA: 3.34/4.0

Boston College **January 2022- May 2022**
Part-Time student at Woods College of Advancing Studies
GPA: 3.8/4.0
Relevant Courses: Gas Dynamics; Simulation Based Design; Dynamics; Fluid Mechanics; Numerical Simulation and CFD; Heat Transfer; Thermodynamics I and II; Circuit Theory and Application; MATLAB; Statics; Mechanics of Materials; CAD and CAM; Graphics; Intro to Additive Manufacturing; Material Science

SKILLS

Design: SolidWorks Modeling; SolidWorks Simulation; SolidWorks Flow Simulation; OnShape; GrabCad Print, AutoCad, Visio
Programming: MATLAB; Python; Engineering Equation Solver (EES); R-studio
Software: ANSYS; Microsoft Office Suite, Google Suite
Certifications: Certified Dassault Systems Associate; OSHA 10, EDU Stratasys Additive Manufacturing Certification Level 1
Languages: English, Spanish

WORK EXPERIENCE

Schneider Electric – Hardware Design Intern **September 2022- December 2022**
Assisted in designing and coordinating Building Automation System (BAS) projects using AutoCAD and Visio. Tasks Performed included creating Electrical Installation Diagrams and Process and Instrumentation Diagrams, ensuring instrument approvals and specifications conformed to requirements, and verifying the accuracy of sequences of operation to meet project requirements. This experience provided valuable skills in teamwork, communication, and technical problem-solving.

Schneider Electric – Systems Application Engineer Intern **January 2022- May 2022**
Worked alongside the field team doing startup, programming, and functional testing of building automation controls systems on a lab/pharma client site. Learned to create, edit, and finalize floor plan graphics and unit graphics for consumer use. Learned and became proficient using Schneider's private software to work on these graphics as well as check the status of controls systems.

125 NUTRONS FIRST Robotics Team – Mentor **2020 – 2022**
Mentored students from multiple schools and backgrounds around Massachusetts. Assisted the head of program with all club needs. Consulted with the students and answered questions about college and robotic design.

TECHNICAL PROJECTS

Vertical Axis Wind Turbine **Summer 2022 – Spring 2023**
Collaborated on a team project studying Vertical Axis Wind Turbines (VAWTs). Designed and tested four blade designs in a wind tunnel, selecting the highest drag force design for building VAWTs with 3-6 blades. Evaluated the performance of each design to determine the most effective one. Presented the project at AIAA student conference to present findings to judges and peers.

Turbofan Engine Analysis **Spring 2023**
Analysis of a V2531-E5 turbofan engine using Ansys Student Version, Python, and EES. Overcame challenges related to complex aerodynamic interactions and large amounts of simulation data, ultimately generating results that closely aligned with actual performance data.

Emergency Zipline Launching System **January 2023 - Present**
Collaborated on a capstone project to design and analyze a grappling hook launching system, utilizing SolidWorks FEA and flow simulations to validate the design. Examined existing spring and air systems to launch the hook and verified that the design met the project goals. Moving forward, we plan to build and test a prototype of the grappling hook system.

AWARDS AND HONORS

Wentworth academic scholarship (2019-2022); Dean's List (2020, 2023); Mathematics Excellence (2018); Computer Programming Excellence (2018)

Conferences/Proceedings

[1] Massimiliano Orfanini, Eleonora Orfanini, **Eduardo Meza Ubeda**, Emily Sievers, "Studying the Efficiency of Various Wind Turbine Designs Through CFD Simulation and Numerical Testing", AIAA New England, Region I, university of Buffalo, New York, 2023