Northrop Grumman Umbilical

Final Report

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EXECUTIVE SUMMARY

The 2021-2022 NAU Northrop Grumman Capstone team was challenged with designing a new umbilical retraction system (URS). The current technology for a URS is a bungee cord which attaches to the umbilical and nearby tower. The bungee cord is loaded in tension producing a side force on the vehicle which has the potential to cause complications during launch but allows a very quick retraction of the umbilical once the vehicle launches. Northrop Grumman tasked our team with the development of an URS with an imposed side force of less than ten pounds without losing the retraction speed of six feet per second. The system must be durable enough to withstand the launch conditions, cost effective, highly reliable, and easily maneuverable. In terms of safety, our device must have a one-hundred percent success rate to avoid causing complications during launch. Further, our design must be safe from electrostatic discharge (ESD Safe) meaning our device can not interfere with the electrical signals being transferred to and from the vehicle. With client requirements in mind, the team developed a variety of design concepts. These design concepts were evaluated using tools such as a Decision Matrix and Pugh Chart until one design concept was left. The design was called “Dog Leash” and resembled a winch system. With a design concept selected, the team began researching components of the design such as the motor, the cable type, and the materials to be used for the base and wheel, to determine the best options for the final design. The prototyping process started with the creation of a 3D model using a computer aided design software. Our first prototype was 3D printed on a small scale to map out the general components of the device. The second prototype iteration was built on a slightly larger scale out of wooden materials, again giving our team a visual of the general components and functionality of the device. Manufacturing of our final device included outsourcing laser cut steel plates used for the base plate, wheel plates, and side plates. The side plates were welded onto the base plate. The team used a lathe and mill to machine the rotation shaft and inside wheel. An electrical circuit was created to connect our power supply to the motor control and the motor control to the motor. Upon completion of manufacturing our device testing could begin to see if our final device met or did not meet our customer and engineering requirements. The team performed five tests: rotation speed, cable type, environmental conditions, side force, and retraction speed. All the tests except retraction speed were successful and approved by our client. Due to an error when calculating the necessary diameter of the inner wheel, our final device retraction speed averaged 4.22 ft/s. We are confident if this error were remedied by implementing a large diameter in the inner wheel, the 6ft/s requirement would be met resulting is partial approval from our client. Further, our team experienced issues with our actuation system functioning 100% of the time causing our success rate engineering requirement and our high reliability customer requirement to be partially approved as well. All other design requirements were met and approved by our client. If allotted more time the team would implement a larger inside wheel, develop a more robust actuation system, and enclose our device in a heat shield.

ACKNOWLEDGEMENTS

Kaitlyn Barr – Sponsor for our project and direct contact from Northrop Grumman. Kaitlyn was a big help in getting us in the right direction and providing valuable feedback that we were able to apply to our project.

David Willy – Not only was David the professor but he also provided great suggestions on our project.

TABLE OF CONTENTS

Contents

1 BACKGROUND

1.1 Introduction

Northrop Grumman tasked our team with designing, prototyping, testing, and delivering a new umbilical retraction system. We were given engineering requirements and customer specifications our design must meet upon completion. The current technology Northrop Grumman is using is a tension loaded bungee cord. This current design has room for improvement and redesign due to the life cycle of the system being a one-time use. This leads to increased costs caused by the replacement need for the system. This project is important to Northrop Grumman and the aerospace and defense industries because umbilical cables provide many different things, such as electrical power, communications, or pressurized gases, to vehicles before launch. Consequently, it is imperative the umbilical is retracted to avoid becoming damaged under launch conditions.

1.2 Project Description

Our client representative, Kaitlyn Barr, presented the following project description to our team:
"The objective of this project is to design an umbilical retraction system. The umbilical retraction system will be designed to pull cables/hoses away from the vehicle after they are released to avoid damage to the launch vehicle. The retraction system needs to be easily installed and removable. It cannot exert excessive force on the umbilical prior to separation with the launch vehicle. In addition, it needs to be reliable for mission success and durable to withstand launch environments. Further improvements may also be made to the system at the discretion of the team such as protection of the umbilical against thermal and shock environments."

1.3 Original System

The original system has been in use for many years and is the standard for Northrop Grumman umbilical release devices. The system is a bungee cord loaded in tension which is released upon launch. The specifications are not widely let out. Most companies, including Northrop Grumman, our team's client, do not allow information outside of their building due to it being classified. Given this, in-depth understanding will not be possible, but the overview of the system can be broken down.

1.3.1 Original System Structure

The original system structure consists of an umbilical cable which is detached from the vehicle. The cable is detached by the retraction bungee which separates from the vehicle at launch. The umbilical cable is attached to an umbilical boom, but for Northrop Grumman's larger scale vehicles, the umbilical cable will be attached to a tower. During launch, the umbilical cable will be detached and retracted out of the way to prevent any permanent damage from the launch conditions. The retraction bungee will incinerate and will need to be replaced for the next launch. Figure 1 below illustrates Northrop Grumman's current umbilical retraction system design.

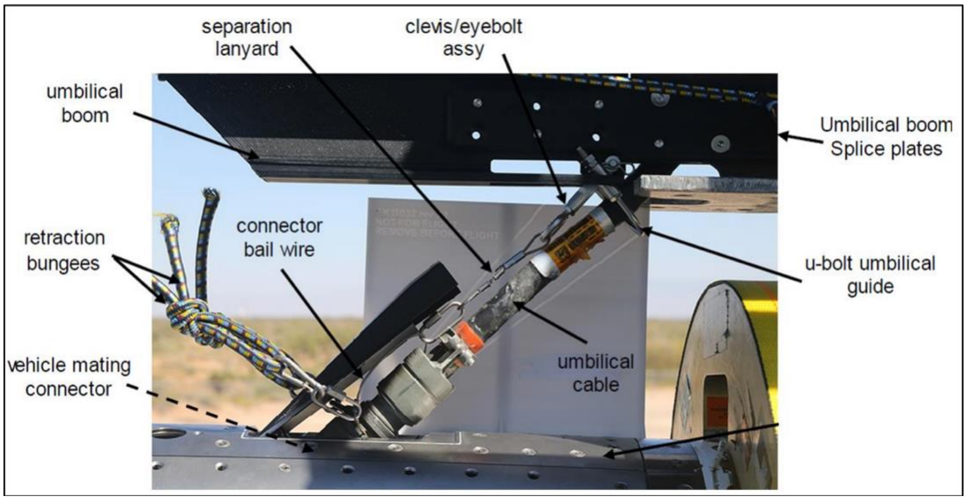


Figure 1: Current Umbilical Retraction System

1.3.2 Original System Operation

The original system of the umbilical cable is illustrated in Figure 2 below. The umbilical cable is attached to the right of the image, while the umbilical cable goes to the left. The attachment process is where the lanyard release connector is linked to the receptacle. The retraction bungee is pulled at an angle which creates a side force on the rocket. This is all the information given to the team from Northrop Grumman that describes the design aspects.

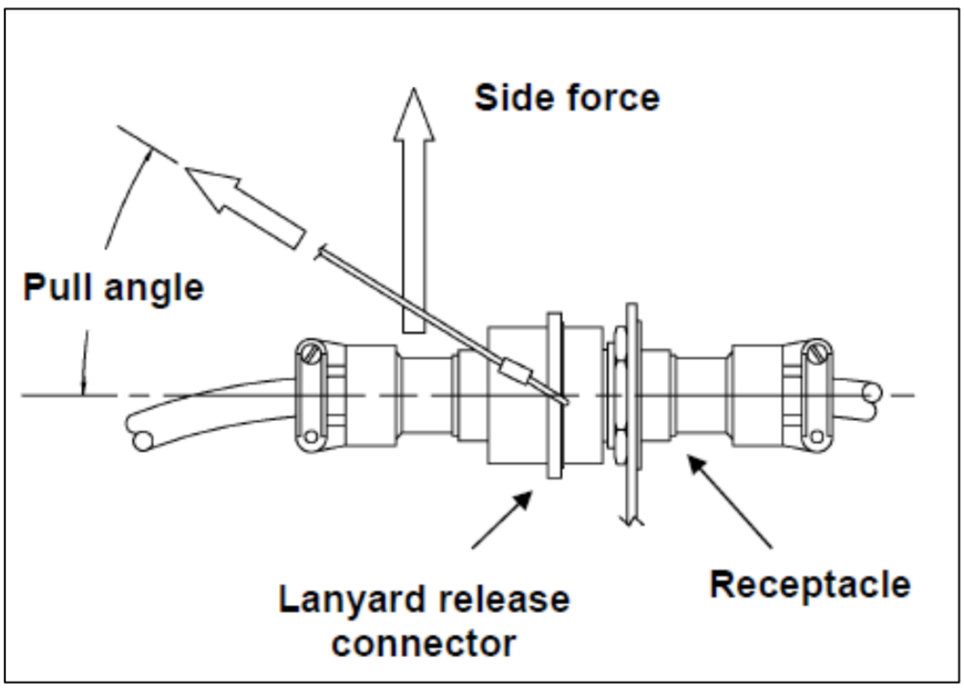


Figure 2: Umbilical Diagram

1.3.3 Original System Performance

The performance of the bungee retraction system used for most umbilical cable applications is highly successful. Information about umbilical cables is limited due to the secrecy associated with the defense industry. So, any exact details on the launch vehicle along with the umbilical cables are low. Further, because the launches are not easily replicated, gathering data as a team is not practical. So, at this point our performance understanding of the original system is low.

1.3.4 Original System Deficiencies

The design of an original system made of a bungee retraction system is a consistent design that has low deficiencies. The most important deficiency is the side force. The side force is emphasized by our client, which returns an important customer requirement. The original system is currently reliable but would not meet the one-hundred percent success rate. Creating a design that will minimize the side force will lead to a higher success rate due to a near minimal side force caused by the bungee attachment. The failure analysis performed on unsuccessful umbilical releases, done by the companies themselves and released to the public, found the side force initiated the failure. The other customer requirements would be highly rated and would not carry a need for improvement due to its low correlation. An engineering requirement that could be improved from the original system is the success rate. The success rate is an issue due to the minor part of the retraction cable which melts away during each launch, that becomes lessened by the cost.

2 REQUIREMENTS

One of the first things we did was meet with our client and determine what requirements our design would have to meet. The following sections detail these requirements starting with the client given customer requirements then moving into the subsequent engineering requirements that we came up with.

2.1 Customer Requirements (CRs)

The customer requirements given to us during the client meetings follow as such. The design must have a low-cost while being durable and manufacturable. The cost must be less than the current system, which is around $12000 per launch. The durability of the system, at a minimum, must withstand two launches, whereas the current system is single use. Therefore, the design will save the company $24000 for every couple of launches. Our client expects the umbilical retraction system to have a one-hundred percent success rate. This means our design needs to be extremely reliable with no possibility of malfunctioning because then the vehicle could become damaged and worst-case result in a vehicle explosion. Other customer needs given to our team were to have a design that could be easily removed and installed to varying in size vehicles. Further, our design needs to be electrostatically discharged safe (ESD), so the vehicle does not short circuit during disconnection.

2.2 Engineering Requirements (ERs)

The following engineering requirements were provided to us by the client. Ideally, the design will remove all force acting on the side of the vehicle (side force) before and during liftoff, but we are allotted to have a side force that does not exceed ten pounds of force. As the current standard puts a hefty side force on the vehicle, our model must eliminate this aspect as much as possible and ideally, all together. The speed of retraction is the next crucial factor of the design. In detaching from the vehicle, the umbilical must move six feet in one second, which is comfortably obtainable through bungee cords, but designs that do not use this system may be more difficult to create and may result in a higher cost to manufacture. Another requirement is our design must not cost over five thousand dollars because this is the budget sponsored by Northrop Grumman to the team for this project. Weight is an important aspect of the design because our design must be easily removable and have a quick installation. If it is heavy and awkward to move, then the installation process will be slower. The device must be able to withstand brief moments of extreme temperature and must not change its reliability due to different air temperatures. As stated above, ensuring our device has a one-hundred percent success rate is of the utmost importance.

2.3 Functional Decomposition

The Function Decomposition section is used to picture the flow of energy sources within the system the team will be designing. From the beginning, these two models have been live documents and have gone through different changes as our design evolved. These changes as well as the current state of each model are described within their respective sections below.

2.3.1 Black Box Model

The purpose of creating a Black Box Model is to identify the main function of our project deliverable, an umbilical retraction system. Our team decided the main function is to retract the umbilical. Once the main function was identified, the team evaluated the overall material, energy, and signal flows into and out of the system. The materials which flow into and out of the main function are depicted with a bolded line. The energy flows are represented by a normal font size line and the signal flows are represented by a thin line. After evaluation of our previous Black Box Model and current design solution, our team determined updates did not need to be made. The material input and output flows of the main function remain as follows, human hand, umbilical retraction cord, and a motor controller. The energy flows into the main function remain unchanged as well being human energy and electrical energy. These energy flows are translated into thermal energy and mechanical energy as an output of the main function. The actuation of the umbilical retraction device still requires and input and output signal determining when the device is on and when the device is off. This model of flows helped the team begin the manufacturing process because it required us to implement design aspects that correlate and ultimately assist in the main function of the device. For example, we determined how to convert the electrical energy supplied by our power supply into rotational mechanical energy of our motor. The flows were confirmed when we began the testing process of our device.

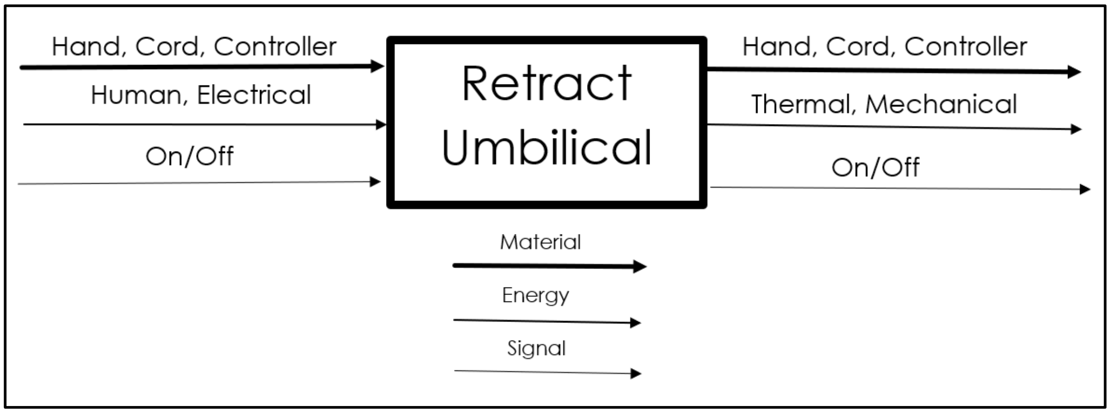


Figure 3: Black Box Model

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

Our functional model shown in Figure 4 took the inputs from our Black Box Model shown above and analyzed the paths each input would take throughout our system. On the left of the model shown below, we have the inputs from our Black Box Model each being imported to the system. Next, these inputs are either transported or manipulated to accomplish our final goal of retracting the umbilical. The model allowed us to better analyze and create our design concepts. By further understanding the material, energies, and signals going through our system, we were able to better visualize how these pieces would interact with each other.

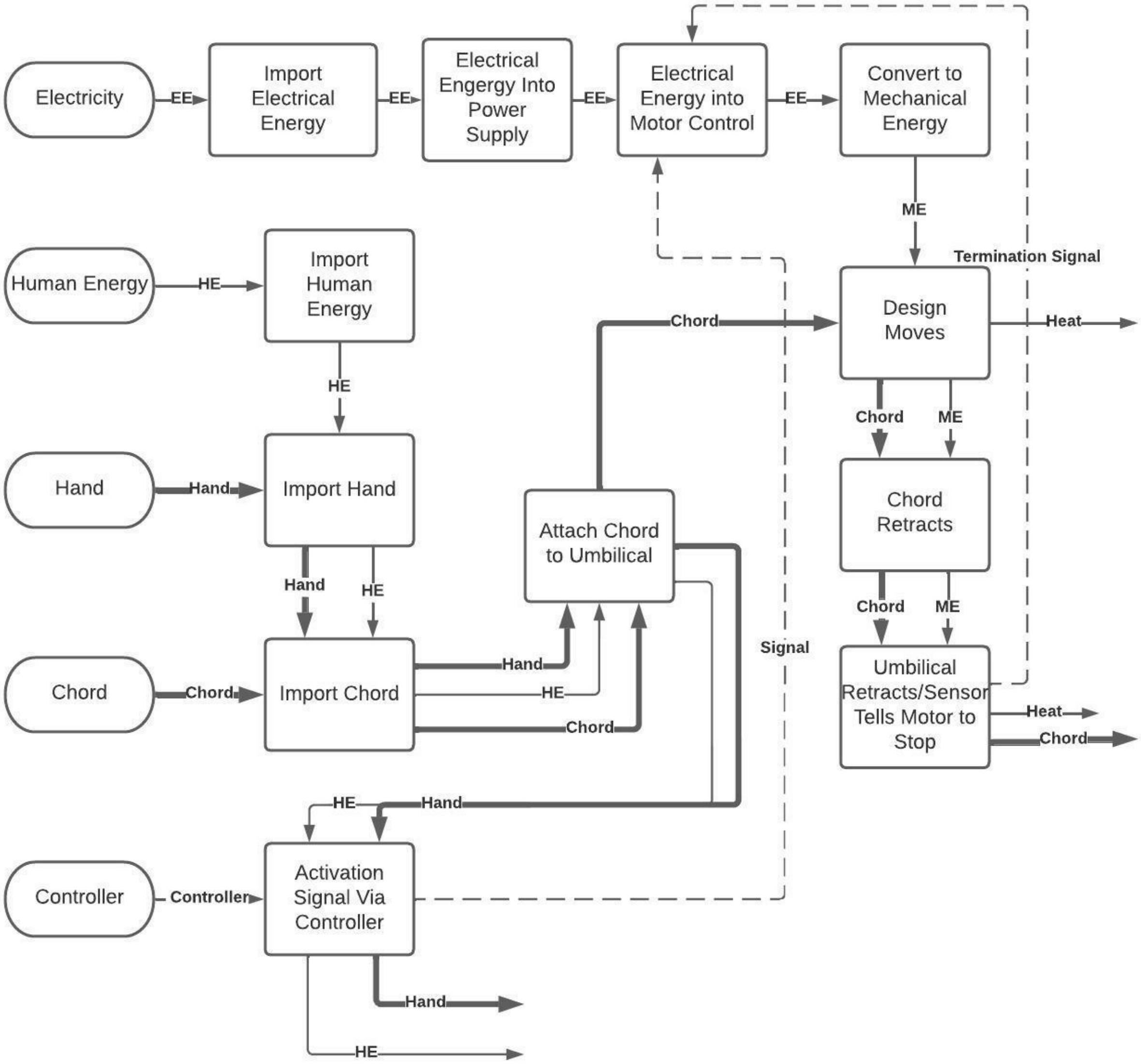


Figure 4: Functional Decomposition

As our design has evolved throughout the course of this semester, so too has our functional model. Proper upkeep of our functional model is essential as it allows us to map out how our system will work and how new components or changes will affect the overall flow of the device. One notable change to our system and subsequently the functional model was the addition of a motor controller to manage the power input and motor speeds. Within the functional model, signals are both inputted and outputted from the motor controller which then go on to activate different sections of our design. Another change recently made from the preliminary design was the way that the signals were inputted into the system. To ensure that we maintained proper control over the design's speed and activation/deactivation cycles, we implemented a switch which will be human operated that will send the activation signal to our motor control. These two changes were made to address one of the main failure concerns within our design which were the actuation systems. Initially, we planned on utilizing a braking system to stop our design which the functional model reflected. However, after testing we concluded that the gears within the motor were strong enough to stop the system.

2.4 House of Quality (HoQ)

The House of Quality is split up into different tables. **Error! Reference source not found.** depicts a comparison between the engineering requirements against themselves. This table will show the reader how each engineering requirement will be affected by the others and is rated on a qualitative scale ranging from 0, 1, 3, and 9. Intuitively, a weak relationship is given a zero and a strong relationship is given a nine. Shown in

is the rest of the Quality Function Deployment which compares the engineering requirements to the customer requirements along with the customer requirements to the benchmarking. It also should be noted that on the QFD, on the temperature, retraction speed, and side force categories, are the labels of the test procedures these will correspond to their proper testing procedure. The engineering requirements against customer requirements show the most important aspects of the design are the success rate, speed of retraction and side force acting on the vehicle. Additionally, these were the most important aspects discussed with the client. The other aspects, although important, were not raised to the highest concern of the client. These include the weight, length, cost, and temperature rating of the design. The benchmarking in the customer option survey is defined by the legend shown in **Error! Reference source not found.** where it was decided that the NASA Kennedy tower and the WWII German V2 tower were the most adept design to what the team was looking to compare against. This is justified as the Blue Origin design seemed overly bulky and from literature reviews did not seem to be the best design. Later in the report the decision matrix will be discussed, the ratings from the absolute technical importance row comes into play here where the designs were added up and placed out of one hundred and divided by the total to make a comparable rating system to rate against the concept generations.

Table 1: Engineering Requirements Vs. Engineering Requirements

1	Cost							
2	Side Force	3						
3	Retraction Speed	3	9					
4	Temperature	1	0	1				
5	Weight	9	9	3	0			
6	Umbilical Length	0	9	9	0	9		
7	Success Rate	9	3	9	9	1	3	

Table 2: Customer Option Survey Legend

Legend	
A	NASA Kennedy
B	WWII German
C	Blue Origin

Table 3: Lower Section of the House of Quality

			Technical Req.							Customer Option Survey				
	Customer Needs	Customer Weights	Cost	Side Force [T.P4]	Retraction Speed [T.P 2]	Temperature [T.P 3]	Weight	Length	Success Rate (%)	1. Poor	2	3. Average	4	5. Good
1	High Manufacturability	3	3	0	0	0	3	1	3		A		C	B
2	High Reliability	5	3	9	9	3	3	1	9		C		B	A
3	Easily Installed/Removed	4	1	0	0	0	9	3	3	A	C		A	B
4	High Durability	4	9	9	9	9	3	9	9	B				AC
5	ESD Safe	3	1	1	3	3	0	0	1					ABC
	Tech Req.Units		Dollars($)	Pounds (lbs)	Speed (ft/s)	Fahrenheit (F)	Force (lb/ft)	Feet (ft)	Success Rate (%)					
	Tech Req. Targets		5000	<10	6ft / 1s	-30F to 160F	1lb / 1ft	2ft to 6ft	100					
	Absolute Tech. Importance		67	84	90	60	72	56	105					
	Relative Tech Importance		5	3	2	6	4	7	1					

2.5 Standards, Codes, and Regulations

Table 4 below shows a list of the standards and codes that the team will have to keep in mind when designing the prototypes and final design. These regulations are set in place to make sure quality and safety service is met through all means of design.

Table 4: Standard, Codes, and Regulations

Standard Number or Code	**Title of Standard**	**How it applies to Project**
AGMA Table 1	Equations for gear rating	The equations for gear rating will be useful in our calculations for our motor.
AISI M 1-4	Design for Fatigue	The final design includes parts made of steel, so fatigue understanding aided the design.
ANSI B.1	Procedures	The standard helped understand the procedures that go into designing.
IEEE: ESD 6.0	ESD Control Program	The standard for ESD will help with the wiring of the electronics in our device.
ASME Y14.5	Geometric dimensions and	This standard was used to develop the computer

GD&T	tolerances	aided designs of our device

American Gear Manufactures Association was used to understand the gear rating of motors. The analysis was completed for the gear rating to manipulate our motor. Each of the symbols within the gear rating is paired with an equation that we used to better understand the changes we could make to the motor such as gear ratio factor and reliability factor.

The American Iron and Steel Institute was useful for the team's design. Steel was used in our final device. The sections M1-4 explained the understanding of fatigue on steel. Section M4 goes into bolts which were used to mount our device to the mounting part. The mounting part will be 12' by 12' where the device will attach. Understanding the fatigue capability for our steel parts was helpful in the development of our final design

The Institute of Electrical and Electronics Engineers was important during the creation of our device because of the importance of electronics. Our client Northrop Grumman supplied some information on the topic of electrostatic discharge but gathering more resources and specific standards for ESD aided our team when finalizing our designs electronic aspect.

The American National Standards Institute create standards including the procedures for engineering while designing. The section picked detailed the procedures engineers must take and how provisions can occur during a project. The standard detailed how changes to the procedure can affect future aspects of the process of designing. Accommodating for those changes will need to be compiled.

The American Society of Mechanical Engineers Y14.5 provides the complete definition of geometric dimensioning and tolerancing. This provided guidance on proper use of symbols and engineering drawing standards for our computer aided 3D software designs.

3 DESIGN SPACE RESEARCH

This section provides an outline of the in current systems, and ideas the team came across while going through the brainstorming process. Here it will be shown what other systems are relevant in today's world and how they are implemented, and how the team can use/ improve of them.

3.1 Literature Review

The team was tasked with performing a literature review from each team member. Each member researched a different topic to make a more robust device. By understanding more aspects of the project, the team was more efficient in research and design changes. Our teams first benchmark was the Nasa Kennedy Launch Complex where research was completed online. The source described how the umbilical system is run and the types of processes that go into the retraction of the umbilical cables. The next benchmark was for the German V2 rocket. The source was again from the internet and gave a breakdown of how the launch vehicle interacts with an umbilical system. The final benchmarking was on the Blue Origin New Shepheard. This benchmarking was also performed online but was not an article but a video. The team was able to see how the umbilical retraction system works for Blue Origin. The findings from our benchmarking helped the team understand the importance of our device as well as how the current umbilical retraction system works. The aerospace industry is very protective of information, so the first two benchmarks were from older systems.

3.2 Benchmarking

To establish a better idea of what we were trying to accomplish, we studied some of the other umbilical retraction systems which are currently in use by other organizations. Through this research, we hoped to better understand our problem at hand, and we hoped our research would help us create a more conclusive designs that would not only improve upon our client's current system, but also fix many of the other issues found in other space system vehicles.

One of the issues we encountered when researching these systems was many details are not publicly available. Initially, our search results only brought up umbilical retractions systems from much older programs such as WWII rockets and the Apollo program. Therefore, we resorted to watching videos of more recent launches such as those achieved by NASA and Blue Origin and attempted to deduce what types of mechanisms were in use on their umbilical retraction systems. Furthermore, we researched other cable retraction systems that were not necessarily used for rocket umbilical cables, but instead are used in various other industries. The following sections highlight our findings.

3.2.1.1 System Level Benchmarking

As previously stated, details on current umbilical retraction systems are not readily available online. Because of this, we studied videos of various rocket launches from different companies and did our best to determine what kind of system was in use based on the mechanism that was visible, as well as the behavior of the umbilical. We analyzed three different systems, one used by the NASA Kennedy Launch Complex, one used by old German WWII V2 missiles, and one used by the Blue Origin rocket New Shephard.

3.2.1.2 Existing Design #1: NASA Kennedy Launch Complex [20]

The first design that we looked at was the system that is in place at the NASA Kennedy Space Center's Launch Complex in Florida seen in Figure 5.

Figure 5: NASA Kennedy

Here, they utilize a series of swing arms and secondary retraction systems to not only pull their umbilical cables, but also walkways. Whilst the swing arms are quite self-explanatory, the secondary retraction systems seemed to include a motorized system that would pull away the connection from the launch vehicle which afterwards would get pulled away by the swing arm it was attached to. Recent videos showcasing the Artemis mission's umbilical retraction systems [21] give an excellent view of this system in action.

Relating this to our project, we determined this type of system would not meet the requirements of having high manufacturability and being easily installed. Despite these systems being more complex than what we hope to achieve, they allow us to observe different methods of cable retraction for space systems.

3.2.1.3 Existing Design #2: German V2 Missile [22]

This second design was used on the German A4-V2 rockets back in WWII. This design was very simple and included a tall tower that would fall over away from the missile pulling the retraction cable with it. This is pictured in Figure 6 where the tower can be seen to the left of the V2 rocket holding the umbilical cable suspended. This cable was detached using explosive bolts which would then allow gravity to pull down the tower. Despite the simplicity of the design, many complications arose from this system. Few fail-safes were put in place so if the explosive bolts failed to go off, then the tower would pull the rocket into a dangerous trajectory.

Figure 6: German V2

The review of this design proved to be less useful since we would be unable to design a tower that would work for both the large and small Northrop Grumman launch vehicles. In fact, for the Antares rocket used by Northrop Grumman, it makes use of a "falling" tower that pulls the umbilical cable and tower away after launch once the umbilical cables are pulled by some other secondary retraction system.

3.2.1.4 Existing Design #3: Blue Origin New Shephard [23]

One of the last systems we reviewed was the recent launch of the New Shephard rocket. By watching the many videos of Blue Origin's recent launch, we were able to deduce that the umbilical cables are pulled back to the tower via chords which are attached to a motorized winch. Looking at Figure 7 we can see the umbilical attached towards the top of the rocket with multiple chords going up from the bottom of the tower to the umbilical.

Figure 7: Blue Origin New Shepperd

Once the launch begins, these chords are retracted which in turn pulls the umbilical downwards and back towards the tower. This system seemed the most feasible for our project and would go on to be one of the inspirations for our designs.

3.2.1.5 Subsystem Level Benchmarking

After analyzing the three existing designs mentioned above, we broke down our umbilical retraction system into three main components: cable retraction, connection, and actuation. Cable retraction is the mechanism that will be used to impose a force onto the umbilical and get it away from the launch vehicle. Connection is how our device will attach to the umbilical. Actuation is what will tell our system to begin retracting the umbilical. For this part, it is crucial that whatever actuating device we use be reliable and near instant.

3.2.1.6 Subsystem #1: Cable Retraction

This subsystem focuses on the mechanism that will impose a force onto our umbilical to pull it away from the launch vehicle. Our main problem we were looking to solve with this section was how could we store up enough potential energy to pull the umbilical without having an initial tensile force. Three concepts we produced that could solve this issue were a pneumatic system, a motorized system, and a spring-loaded system.

3.2.1.6.1 Existing Design #1: Pneumatic Piston

This subsystem design features a pneumatic piston that relies on air pressure differentials to move a piston rod within a cylinder. Figure 8 shows an example of this design that can be found on the market [24].

Figure 8: Pneumatic Piston

This design would allow for high-speed retraction depending on how well we could seal off the inside and how high of a pressure differential we could accomplish. One of the key issues we predicted with this subsystem concept was the range of motion of the piston rod. To move our umbilical, the necessary six feet, we would need a very long and heavy cylinder and piston rod. Furthermore, designing a product of this size that would be able to hold a vacuum would also be very difficult and could possibly lead to complicated maintenance or constant failures.

3.2.1.6.2 Existing Design #2: Motorized System/Winch

This design heavily resembles a winch you would find on the front end of an off-roading vehicle. The main difference being that most winches emphasize high torque but slower speeds. Since our pulling weight will be so low, we had to focus on designs that put retraction speed over torque. Figure 9 showcases a product we found like what we were looking for [25].

Figure 9: Motorized Winch

This product uses a motor to wind and unwind a spool of cable very quickly. With this concept, we would have to determine how we would actuate the system as well as what size motor or subsequent gear ratio we would need. Some issues we foresee with this subsystem design mostly originate from installation issues which may include difficulty attaching to preexisting launch surroundings or the fact that the system will require power in the form of electricity.

3.2.1.6.3 Existing Design #3: Spring Loaded System

This subsystem design utilizes a coil spring to retract the cable. This is very similar to what one would find within a tape measure or retractable dog leash. Besides these two examples, applications of this design do exist within the industrial setting. Figure 10 shown below is one example that is available for purchase [26].

Figure 10: Spring Loaded

While these products meet the retraction speeds we are looking for, they are unable to handle heavier loads. Although the weight we will be moving is not particularly heavy, it still is too high for all the products that we have found that use this subsystem design. This is mostly due to the coil springs themselves which are unable to pull back heavier loads.

3.2.1.7 Subsystem #2: Attaching Chord to Umbilical

This subsystem focuses on how we will attach our retraction mechanism to the umbilical itself. This is a crucial component as without proper attachment, our system could fail and not pull the umbilical away from the launch vehicle.

3.2.1.7.1 Existing Design #1: Carabiner

One option for this subsystem is to use a simple carabiner to attach our retraction system to the umbilical. The carabiner would be placed on the end of the chord of our system then attached to the umbilical via a mounting point. According to our client, such a thing exists currently although we were not able to obtain details.

3.2.1.7.2 Existing Design #2: Knot

This option would have us simply tie a knot around the umbilical cable. This option has the potential for failure if we do not properly secure the knot. Furthermore, tying the knot may prove to be difficult depending on the flexibility of our chosen cable. Another idea would be to have a type of slip knot at the end of our cable that could then be wrapped around the umbilical and tightened.

3.2.1.7.3 Existing Design #3: Clamp

A clamp is a possible candidate for properly securing our retraction system to the umbilical. The clamp would be fastened at the end of our retracting cable and would clamp around the umbilical itself. This option is like the carabiner but may prove to be less secure.

3.2.1.8 Subsystem #3: Actuation

The actuating subsystem will be responsible for starting and possible stopping our design. This portion of the design is crucial as we will need something that is near instantaneous and highly reliable. Since we are not simply relying on an initial tensile force like the current design, this actuation will also be responsible for starting the system which will apply this force.

3.2.1.8.1 Existing Design #1: Arduino

By using an Arduino board, we could easily actuate our device both on and off and do it wirelessly if needed. There are plenty of systems which use Arduino as an actuating device so getting started would not be too difficult. One foreseeable issue would be that we would have to somehow match the retraction of the umbilical cable with the detachment/launch of the vehicle. This would either require a fast trigger finger or some sort of sensor that will tell the system when detachment has occurred.

3.2.1.8.2 Existing Design #2: Raspberry Pi

This iteration of our actuation subsystem is very similar to the Arduino board mentioned in the previous section. Instead of using an Arduino board, we would replace it with a Raspberry Pi computer. While this option is a bit more expensive than the Arduino option, Raspberry Pi computers are far more powerful. A Raspberry Pi computer would allow for further expansion of our system into things such as force and temperature sensors or better automation.

3.2.1.8.3 Existing Design #3: Pull-Pin

This iteration is much simpler than the previous two and simply has a pull pin being used to actuate our system. This pull pin would be used to either disengage a brake or in the case of the pneumatic piston, release a piston. The main issue with this design is that it would require manual operation which may be impossible due to the conditions surrounding the launch. Furthermore, timing could be an issue as both an early and a late actuation can lead to catastrophic failure.

4 CONCEPT GENERATION

4.1 Full System Concepts

4.1.1 Full System Design #1: Piston

The piston design will be split into two different subsections which is discussed in a later portion of this report. The piston will use some form of mechanism to remove the umbilical. It will be split into a vacuum or spring-loaded system to retract the umbilical.

4.1.2 Full System Design #2: Swing Arm

The swinging arm design utilizes a boom as the mechanism to hold the umbilical, this design is shown in Figure 11. The boom will be placed into tension by ropes connected to both sides of the boom, the ropes to one side of the boom will be stretched in tension whereas the other side will be pulled by the opposite rope in tension. As the mechanism will start, the ropes that are being pulled in tension will release or cut, and the ropes on the other side will pull the boom away ripping out the umbilical out of the rocket and moving out of the path of the rocket swiftly. The advantage of this design is that it would work very well at moving out of the way quickly and keeping a steady hold on the umbilical. There are many faults with the design though in that it might be heavy, hard to install, but most importantly it is only feasible to larger rocket designs.

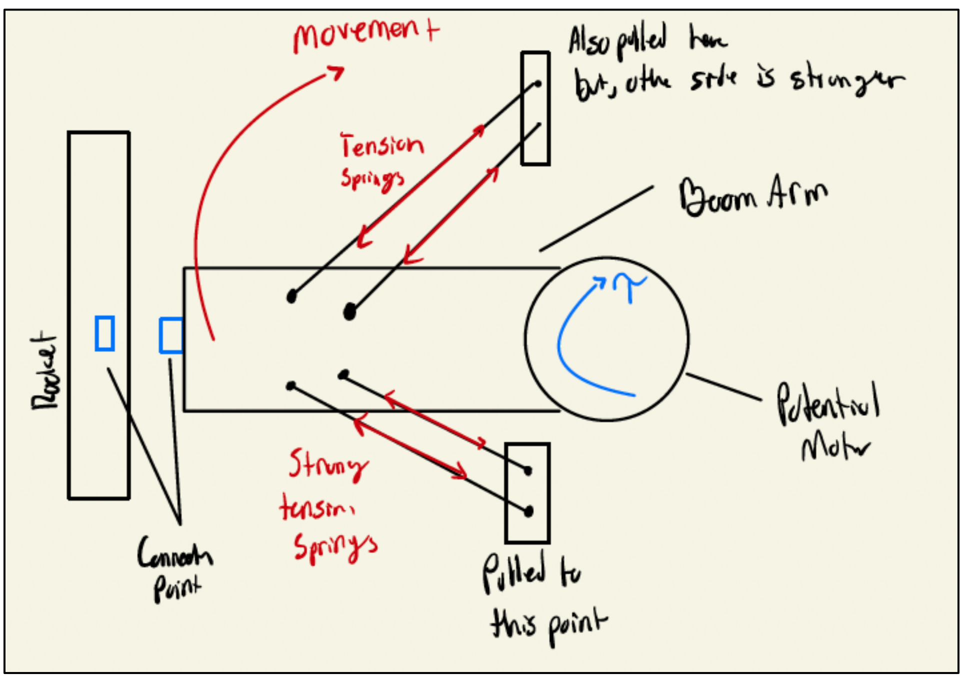


Figure 11: Swing Arm Design Concept

4.1.3 Full System Design #3: Crossbow

The crossbow design acts as a reverse draw crossbow as the mechanism that pulls the umbilical cord. A compound crossbow works by adding potential energy to a string by pulling it back to a locking mechanism. The string that it is connected to is attached to limbs at the front of the device, these limbs are pulled into the device creating large amount of potential energy that is stored in the string. The locking mechanism can then be released which allows the string to move freely and the limbs of the crossbow to extend launching the string with extreme velocities. A reverse draw crossbow works in the same manner but instead of the limbs being pulled into the back of the device while being attached at the front, they are instead attached at the end of the device and pulled in towards the front end. This same mechanism could potentially be used in the umbilical retraction system. It would work with immense speed and power, but it has a major default in the amount of moving parts in the device that could very much fail over time and cause extreme damage to the rocket and nearby structures. Figure 12 and Figure 13 show the crossbow design before and after the mechanism is released showing the transfer of energy through the system.

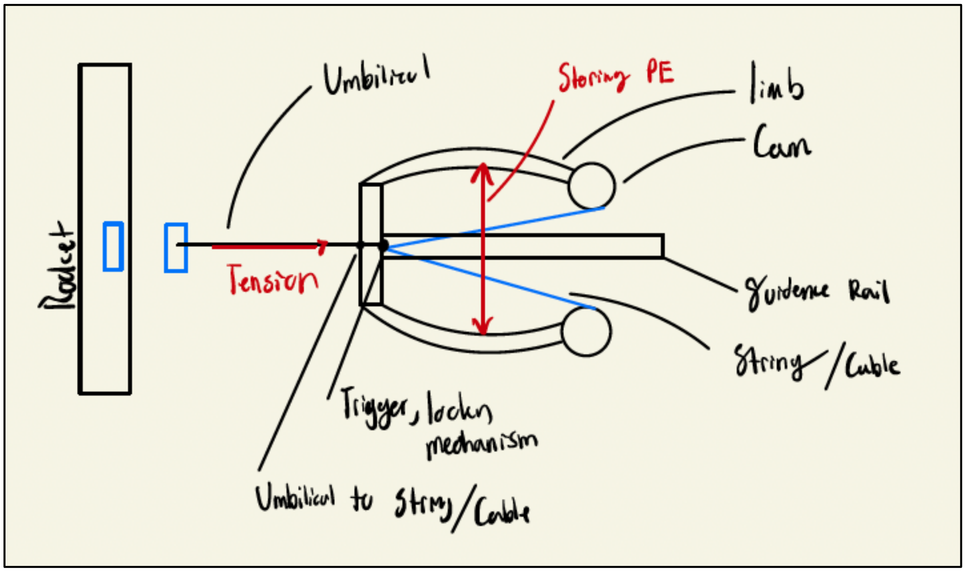


Figure 12: Crossbow Design Concept

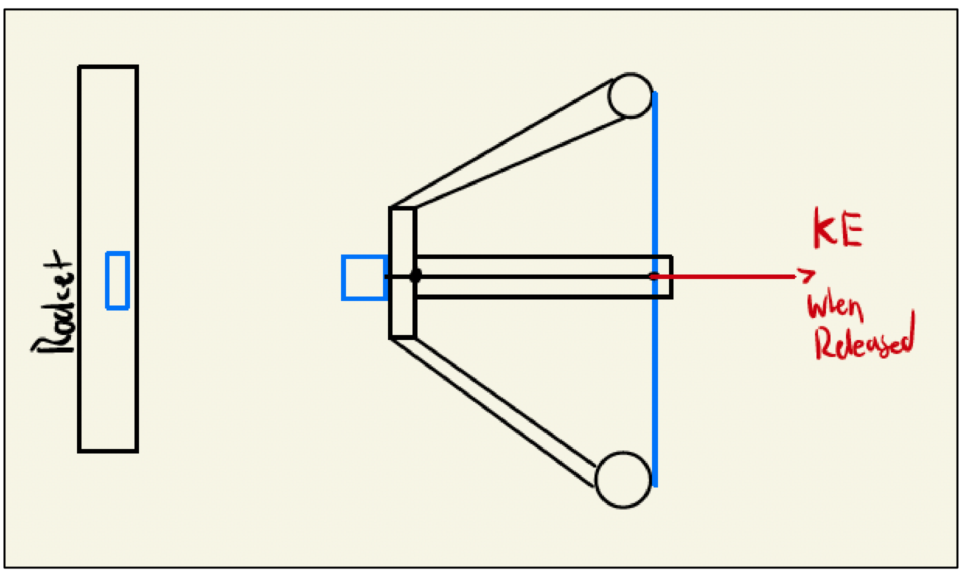


Figure 13: Crossbow Design after Actuation

4.1.4 Full System Design #5: Slingshot

The slingshot design incorporates two bungee cables connected to a spring positioned on the other side of a flat plate. The bungee cables are fed through the flat plate to attach to either side of the umbilical, which loads them in tension. Since the bungee cables are connected to the spring when pulled to the umbilical, the spring becomes compressed against the flat plate toward the vehicle. When actuated, the spring and bungee cables will revert to their unloaded positions retracting the umbilical away from the launch zone. This design will meet the retraction speed requirement due to the tension and compression forces supplied by the bungee cables and spring, but there is a possibility the umbilical becomes damaged from the collision with the flat plate after retraction. Another consideration is the variability of the force provided by the spring due to the variation of the spring constant based on launch conditions, such as temperature and weather.

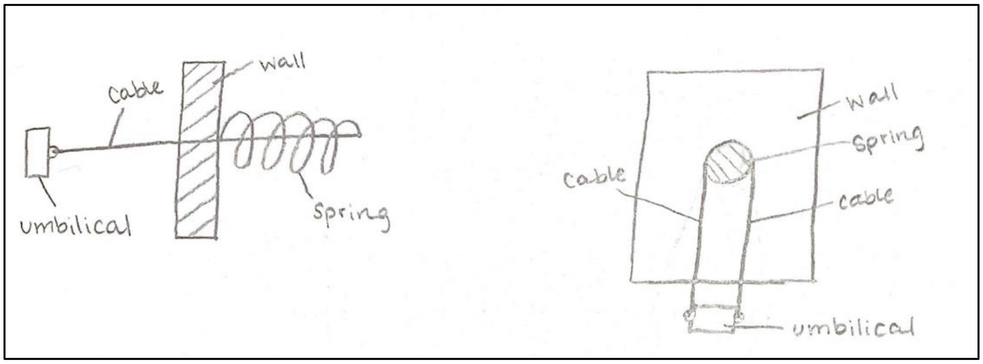


Figure 14: Slingshot Design Concept

4.1.5 Full System Design #6: Two Arms

This design features two parallel arms that when actuated collapse which pulls the umbilical back with them. These arms fold by the joints placed between them as shown in Figure 15 below. This design is like the retraction systems found in the Artemis system although this system does not have them retract this far. Due to the high range of motion, we need for our system, this design may lose stability and begin to slouch whilst extended. Furthermore, to reach our desired retraction speed, we would have to get the joints to move very quickly, which may not be easy.

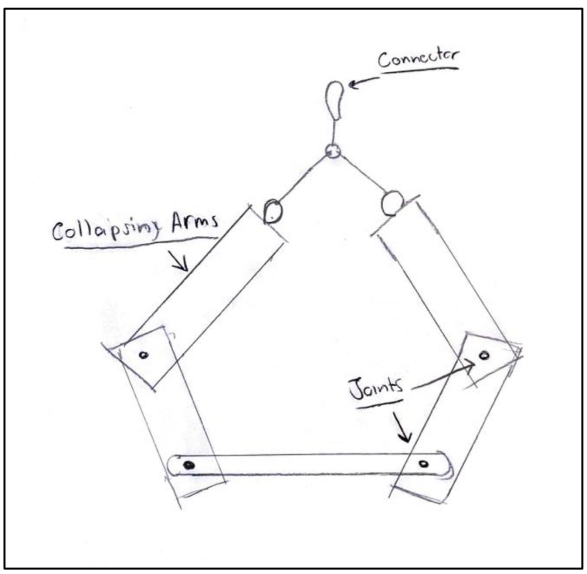


Figure 15: Collapsing Arm

4.1.6 Full System Design #7: Dog Leash

The dog leash concept features two separate designs which use different subsystem concepts. The main idea behind both is a reel of chord will be extended and retracted to first, hook onto the umbilical, then, pull it back.

4.1.7 Full System Design #8: Dead Weight

This concept utilizes a pulley system to retract the umbilical. On one end of the pulley, the chord is attached to the umbilical. On the other end, the chord is attached to a weight suspended by a trapdoor. When actuated, this trap door will open thus dropping the weight and pulling the umbilical back. Due to the many moving parts of this system, it may be too bulky to implement. Furthermore, since we are relying on gravity for our acceleration, there may be a delay in the time between the weight beginning to fall and the chord being in tension.

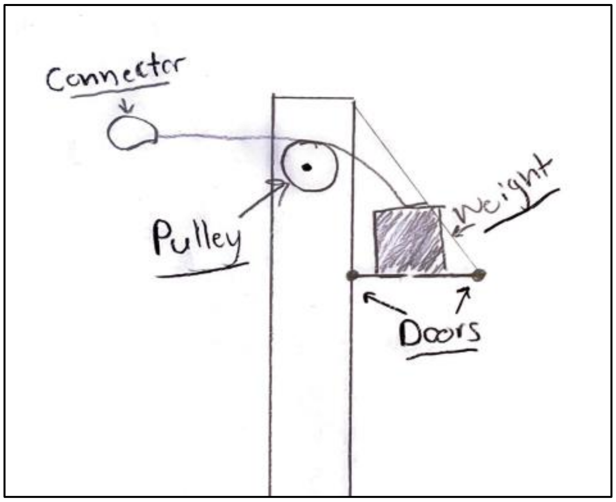


Figure 16: Dead Weight Design Concept

4.1.8 Full System Design #9: Two Tower

The next concept was a two-tower retraction design. The focus was to pull the umbilical cables away from the rocket but from different points. Having more retraction points for a single umbilical cable will allow for a more successful retraction.

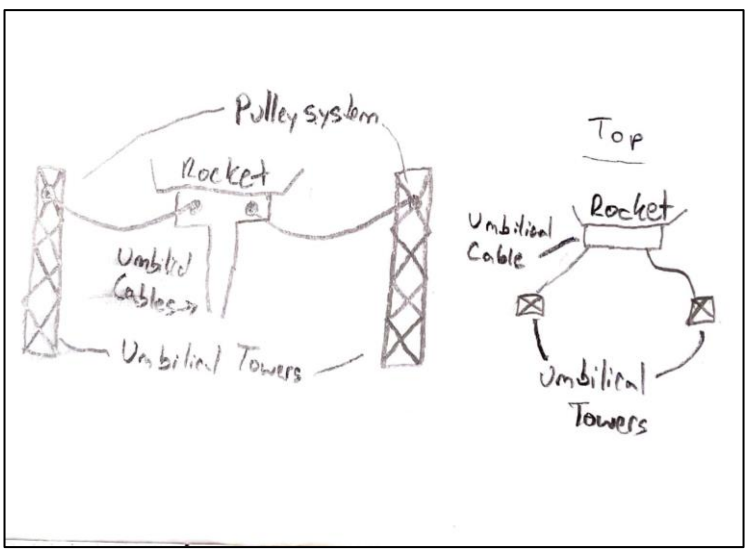


Figure 17: Two Tower Design Concept

4.2 Subsystem Concepts

4.2.1 Subsystem #1: Piston

The piston concept will be split into the two subsystem concepts of a vacuum piston and spring piston. Both designs have their pros and cons which will be discussed in their individual sections.

4.2.1.1 Design #1: Vacuum Piston

The vacuum piston design utilizes a vacuumed as the working motion to retract the umbilical; it is shown below in Figure 18. The system would consist of a pump, piston rod, and a piston cylinder along with various other parts to control flow rates. The piston rod will be placed inside of the canister such that when fully extended, a seal would create from the piston rod to the end of the canister. Air will then be vacuumed out from the free space of the canister such that when the umbilical needs to retract, back pressure will be applied to the piston rod, and a pin mechanism will release collapsing the piston down retracting the umbilical. With this design a form of air will need to be entered into the opposite side of the piston rod such that the pressure does not equalize in the canister preventing the full actuation. This design would be extremely fast and efficient, but there are many areas that will cause the design to fail such that as the seals not working properly, the bumper on the piston rod failing over time causing a system malfunction, bad disconnections, and inefficient pressure outtake from a vacuum.

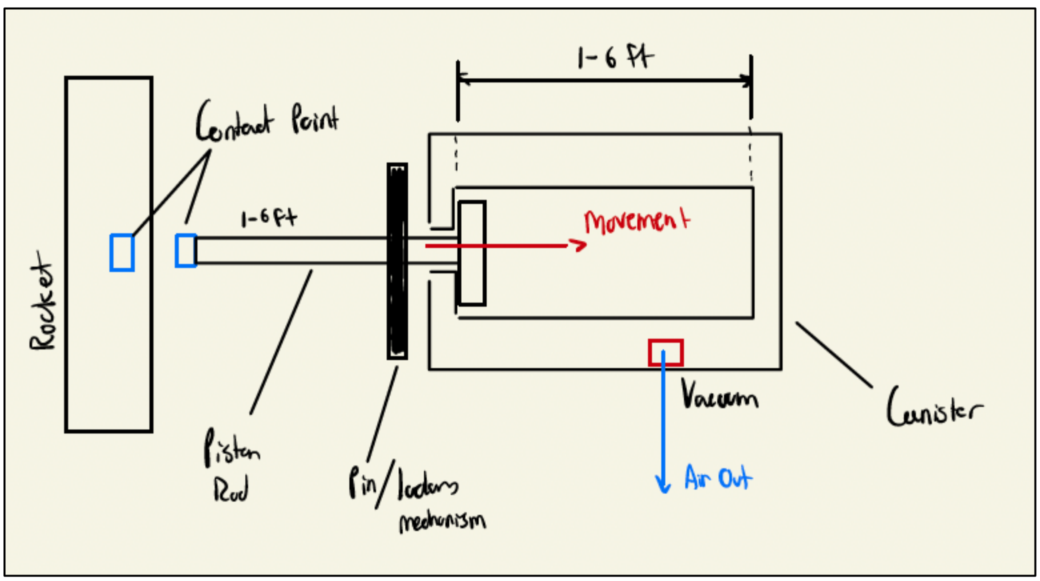


Figure 18: Vacuum Piston

4.2.1.2 Design #2: Spring Piston

The spring piston design relies on a spring attached to a shaft. The shaft extends to the umbilical where they are connected by a cable. The spring is loaded in tension toward the vehicle so when actuated the spring will recoil away from the launch zone. The spring and shaft would be incased in a protective shell to reduce the launch zone effects on the spring. This casing would be implemented to reduce variation in performance due to the spring constant varying based on temperature and weather. The need to regulate the launch conditions as much as possible to normalize the spring constant to ensure functionality is a downside to this design. Another thing to consider with this design is the life cycle of the spring. A new spring will retract faster than a spring used multiple times, so to meet the retraction speed and one-hundred percent success rate requirements, eventually the spring will need to be replaced, especially under varying launch conditions.

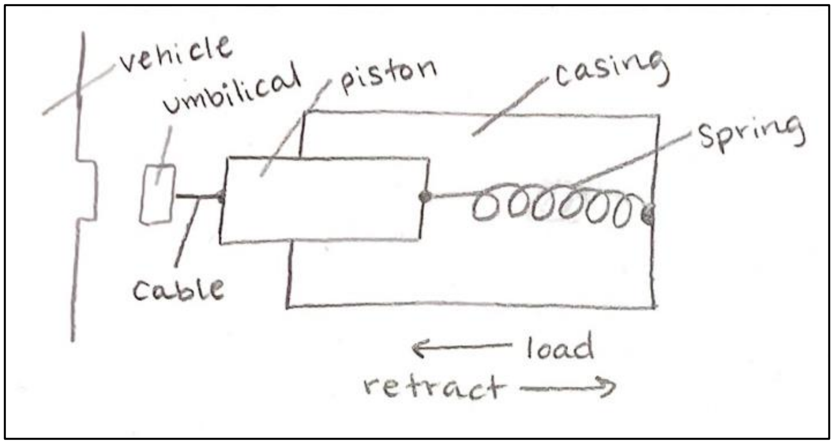


Figure 19: Spring Piston

4.2.2 Subsystem #2: Dog Leash

Below are the different subsystem design concepts for the Dog Leash. There is both a spring assisted, and motor assisted 'leash' discussed in these sections below.

4.2.2.1 Design #1: Spring Assisted

The spring assisted dog leash features a flat coil spring within a housing that will be used to extend and retract a chord. This idea is like the mechanism found within a tape measure or a retractable dog leash. Based on some preliminary calculations we did; the flat coil spring may not be strong enough for the weight of the umbilical. Further research into more powerful flat coil springs will be needed before this concept can be proven or disproven for our needs.

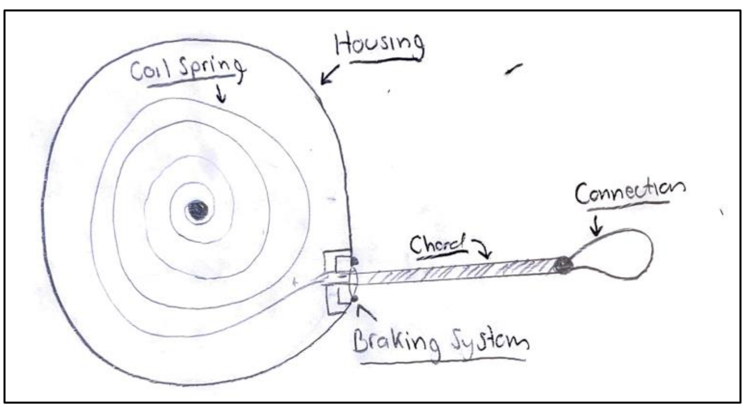


Figure 20: Spring Assisted Leash

4.2.2.2 Design #2: Motor Assisted

The motor assisted dog leash utilizes a motor to extend and retract a reel of chord. This concept is like that of a winch but instead of pulling with a high torque, we plan to spec ours out to pull at a high speed. As of now, this is one of our higher rated concepts due to its simplicity and the fact that it would meet all our requirements so long as we choose the correct motor.

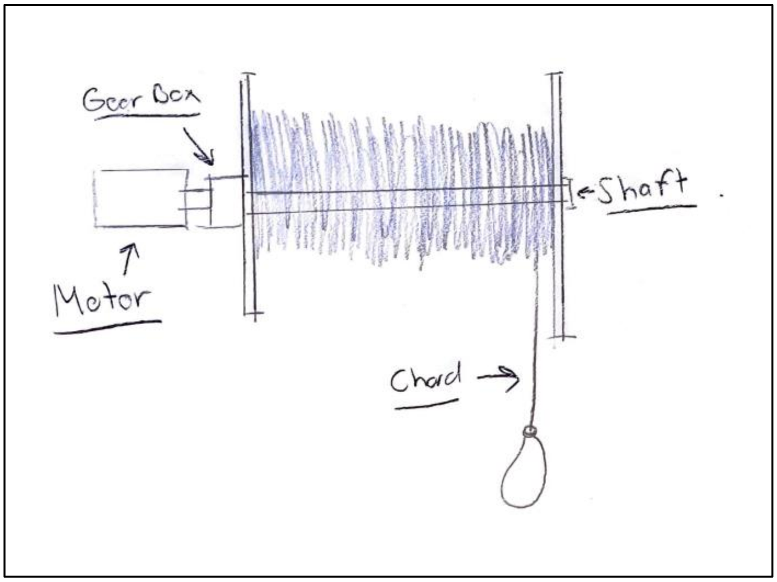


Figure 21: Motor Assisted Leash

5 DESIGNS SELECTED – First Semester

Chapter 5 of this document compiled all the concept generation, data from the Quality Function Deployment, and benchmarking to tell the team what designs are most probable and overall, the best fit for the client. The Decision Matrix in **Error! Reference source not found.** shows the top designs compiled against the engineering requirements, whereas the entirety of the designs against engineering requirements are shown in the appendix. **Error! Reference source not found.** will show the Pugh Chart which takes the top designs from the Decision Matrix and compares it to a datum along with the customer requirements. The design chosen will come out of the Pugh Chart.

5.1 Technical Selection Criteria

5.1.1 Decision Matrix

The Decision Matrix below in **Error! Reference source not found.** is an abbreviated version of the full decision matrix which is placed in the appendix. The abbreviated version covers the top choice designs which were the Vacuum Piston, the Spring Piston, the Dog Leash, and the Two Arms designs. The designs were scored against the engineering requirements discussed in Section 2.2. The weights in the matrix come from the Quality Function Deployment where each engineering requirement was weighted and placed out of a sum of one hundred and divided to get its proper weight. All the scoring was based off light calculations along with which designs had the most realistic working probability. For instance, the crossbow design scored low in the decision matrix because the mechanism is extremely complicated and has many sources of error compared to the other designs. The results show that the Vacuum Piston fit the requirements the most with the Dog Leash and Two arms design coming next. The reason the Spring Piston did not score as closely to the Vacuum Piston is because the mechanism can vary greatly on temperature and size of umbilical needed.

Table 5: Decision Matrix

		Vaccum Piston		Spring Piston		Dog Leash		Two Arms	
Engineering Reqs.	Weight	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Cost	12	4	0.48	3	0.36	4	0.48	3	0.36
Side Force	16	3	0.48	3	0.48	4	0.64	4	0.64
Retraction Speed	17	4	0.68	3	0.51	3	0.51	3	0.51
Temperature	11	5	0.55	4	0.44	2	0.22	4	0.44
Weight	14	3	0.42	3	0.42	2	0.28	2	0.28
Adjustability	10	4	0.4	2	0.2	4	0.4	4	0.4
Success Rate	20	3	0.6	4	0.8	5	1	3	0.6
Total	100	26	3.61	22	3.21	24	3.53	23	3.23

5.1.2 Pugh Chart

The completion of the Decision Matrix helped our team narrow our ten design concepts to the top five. We set the current technology Northrop Grumman is using, the bungee cord retraction system, as the datum our five designs would be compared against. As a team, we discussed whether our design would perform better than, worse than, or the same as the datum based on specific criteria. Better was denoted by a green box and plus sign, worse was denoted by a red box and minus sign, and the same was denoted by a blue box and capitalized s. The criteria for comparison were pulled from our House of Quality combining the most important customer and engineering requirements representing qualitative and quantitative specifications. The results of our analysis were not as helpful as we would have liked. As shown in **Error! Reference source not found.**; Design 1: Vacuum Piston, Design 2: Spring Piston, and Design 4: Dog Leash, have the same total of better, worse, and same marks. Because of this, our team evaluated each design concept against each other to see what aspects of the designs could be implemented or combined to improve the comparison against the datum.

Table 6: Pugh Chart

	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Key	
Criteria	Vac. Piston	Spring Piston	Slingshot	Dog Leash	Two Arms	Bunjee	+	Better
High Durability	+	+	S	+	+	D	-	Worse
High Manufacturability	-	-	S	-	-		S	Same
Easily Installed	+	+	S	+	S	A		
Success Rate (100%)	-	-	S	S	+			
Cost ($)	+	+	+	+	+	T		
Retraction Speed (6ft/1s)	S	S	S	-	-			
Weight (1lb/1ft)	-	-	S	-	-	U		
Side Force (<10lbs)	+	+	+	+	S			
Size	-	-	S	-	-	M		
Sum +	4	4	2	4	3			
Sum -	4	4	0	4	3			
Sum S	1	1	7	1	2			

5.2 Rationale for Design Selection

The top two designs the team decided to go with were the Vacuum Piston along with the Dog Leash in variations. The Vacuum Piston was chosen due to the ability it must work under temperature which the Spring Piston would change depending on the temperature due to the spring constant changing. Also, the Vacuum Piston would be able to adapt to multiple lengths and have many different adjustable settings in how the pressure difference will work. It would be able to speed up or slow down the retraction depending on how fast the client needs it to be while at the same time change how far it will have to retract. The only other failure that would be common in the Vacuum Piston would be the fact the seals may wear over time and could potentially be difficult to replace, and if there was a leak in the system there could be dire consequences as the vehicle could explode during launch. The Dog leash was the next top design. Like the Vacuum Piston it would be easily adjustable if a motor would be used to retract the umbilical. If a spring coil variation were used in this, then there could be changes in the retraction spring just like the Spring Piston. In conclusion, because the Dog leash has less errors than the Vacuum Piston, the Dog Leash will be the design pursued by the team. The client is happy with the Dog Leash design and the team believes it would be able to make a successful system involving this mechanism.

This next section will discuss the design the team has selected and how it will be created and what iterations it will go through over time. The first ever concept of a design the team thought of was a vacuum piston, but after harsh consideration it was decided that that design would have to many errors such as leaks and pressure problems. Therefore, a new concept had to be chosen, this was the Dog leash, winch, design. Over the course of this semester two concepts will be created for the winch, the first one will be made by a 3D printer over what the team thinks a rough design will look like. The second one will be created after getting feedback from the client after the team's presentation with them on Monday November 15th. The current design is shown below in 5.1 in further detail but the base model for what the team is doing is based off a winch design.

5.3 1st Semester Design Selection

A winch design is conceptually simple, it includes a motor which is connected to a shaft inside of a wheel that can windup a road or chord to give tension or pull on an object. The 1st prototype as described above is a simple 3D printed model to see how feasible the design is and to give a good visual of where the weak points and stresses on the design lay. Figure 22 below shows what the first concept of the design looks like. In this assembly, the position where the motor lays are off to the right. The wheel is held in place by a shaft that runs in between two solid plates to secure its movement to only on axis. As part of the challenge that was given to use by the client; the device must be mounted on a 12X12 square tube that is vertical from the ground. The holes to the side of the device would be a positioned mounting place for the tube.

5.3.1 3D Print model

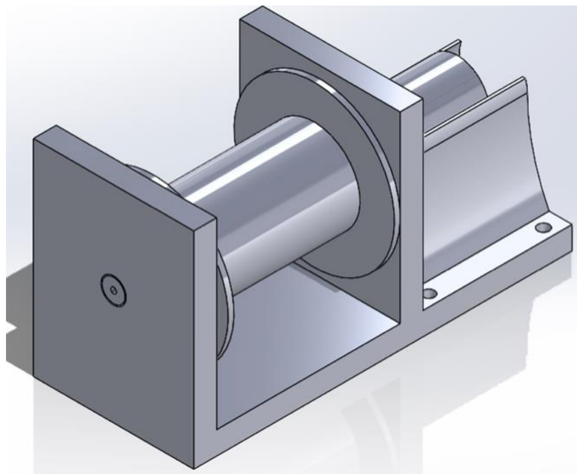


Figure 22: First Prototype

This first design showed a proof of concept by seeing the wheel spin. With it proving it would work, there is a mountain of problems within it that needs to be shown in future designs. A couple for instance, there needs to be bearings in place for the shaft to reduce friction on the plates. The motor needs to be optimized for the design as the motor for the prototype had almost no torque, that was to be expected though. Additionally, there needs to be positioning holes throughout the design as the four holes placed to the end of the design would create a moment on the design which is not ideal as it could break over time. The biggest issue with this design though is that it would never work for an ideal world as it was 3D printed the assembly process was ignored a little bit, and in the future, there needs to be a better process for assembly.

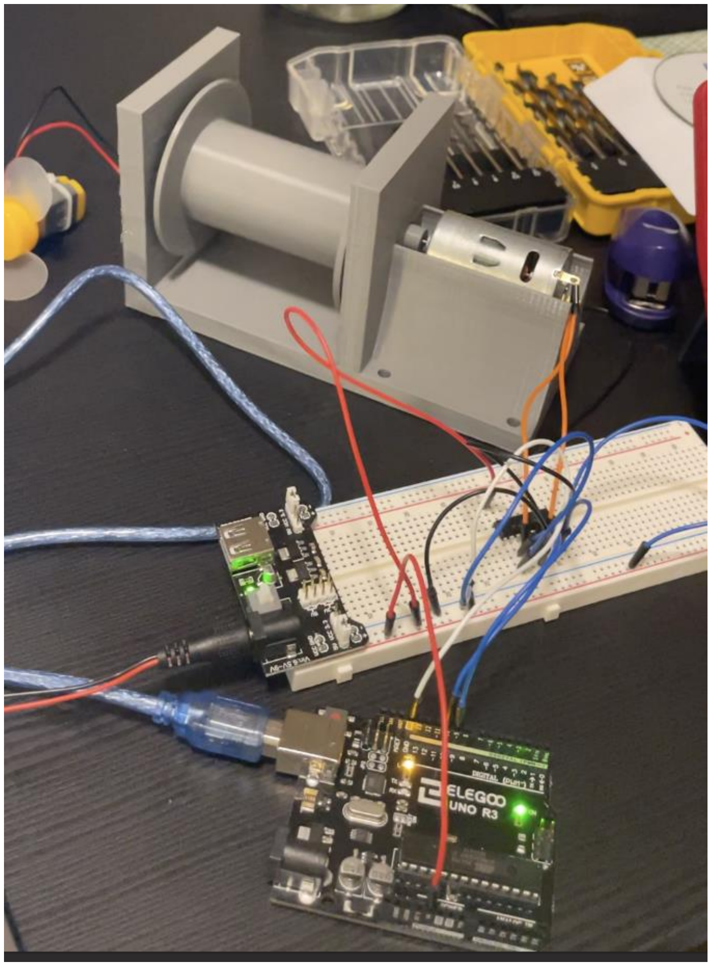


Figure 23: First Prototype with Electronics

Figure 23 above shows the entire model of the 1st prototype. It was connected to a simple Arduino to control the features, but as seen when running the device, this can be unreliable. To solve this problem a full-scale motor controller will be needed. The actual motor used for this design was extremely small and was no able to pull that much force although it spun the wheel decently fast. The 1st prototype as depicted in *Figure 23* much proved to show that the speed and pull force it had were too low. The next prototype though will still utilize a smaller motor but should hopefully be able to meet the requirements listed below.

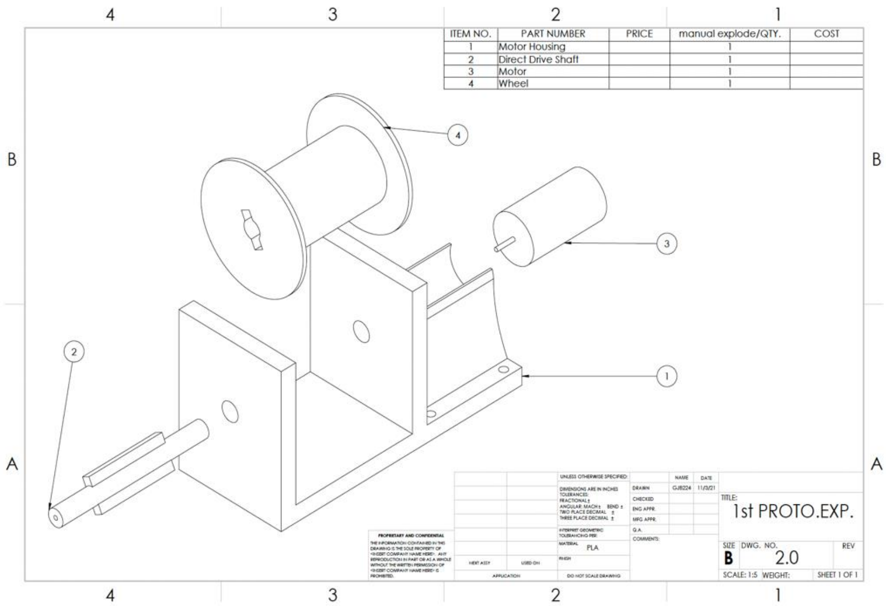


Figure 24: First Prototype Drawing

Eventually over the course of the year leading into the Spring semester, the actual requirements will be met. All the numbers shown for the 1st prototype were tested experimentally by seeing how much force it was able to pull and how fast it was able to move by a tachometer. The 2nd prototype numbers come from educated guesses based off the motor the team plans on getting, calculations for this are currently in the process of being done, they are just not completed now for professional validation. The last portion that needs to be checked is if a gear ratio will need to be created. This will be done with the 2nd prototype as for the first one would have shown it to be useless but give a bigger motor that would be able to supply the power for a gear ratio, it might be a valuable resource to easily control the motor speed on the winch. If the gear ratio shows to not be important for the upcoming prototype, then it will not be implemented in the final design.

5.3.2 Wooden model

A second design iteration was presented at the end of ME 476C which recreated a full-scale model but built out of simpler materials and had cheap components to it. This model had a sole purpose to see if the design would be able to handle the stresses that would be present on launch conditions. If the design held up, then it can be reasoned that a version made from medal will be even stronger. The device was built of out plywood and was fixed together using screws and wood glue. A drill was attached to the end to see if the inside would spin which it could.

Figure 25: Second Prototype Assembly

Figure 26: Second Prototype Side View

Figure 27: Second Prototype Other Side View

The figures above show the wooden model, and although it looks very rudimentary, it teaches the team a lot. It shows us that the design is possible, has strength to its construction, and can turn a wheel which means continuation of this design concept can proceed.

Figure 28: Thin Wheel for Second Prototype.

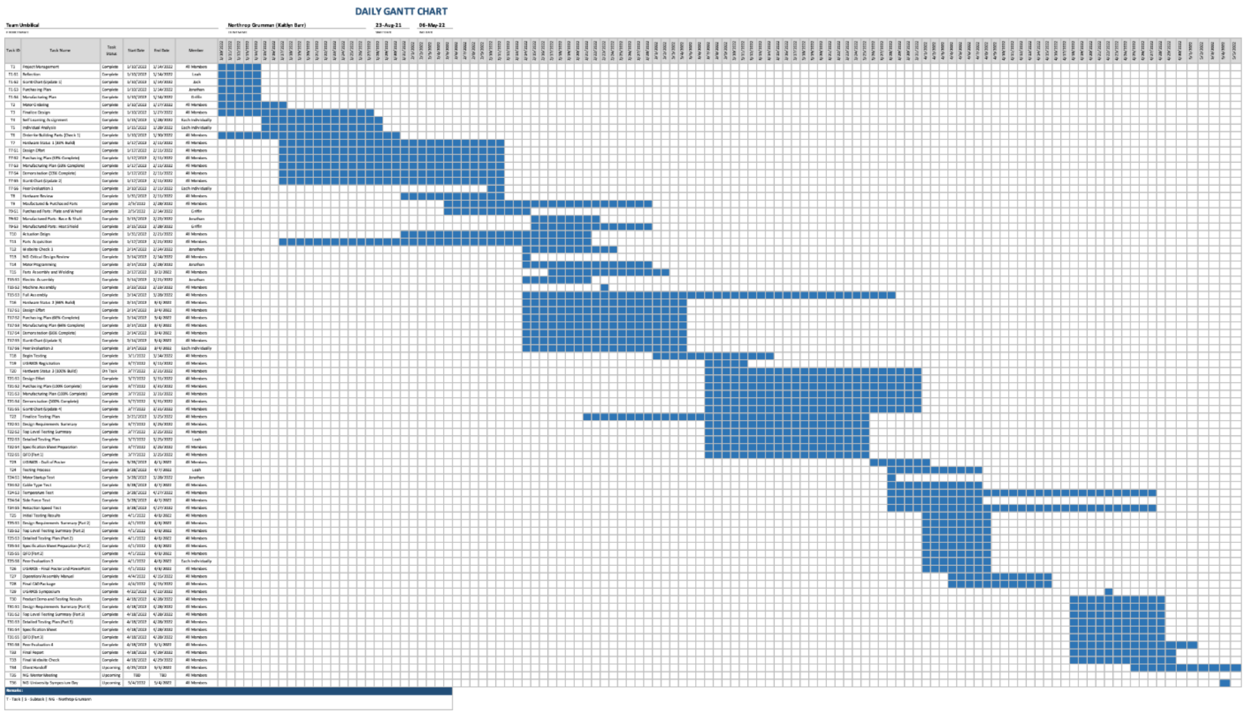
Figure 29: Thick Wheel for Second Prototype

The above 2 pictures Figure 28 and . Figure 29 show two different design iterations. The top one being a small winch to wrap a cable on over itself, and the second one, a wide wheel to ideally move the cable along the length of the wheel such as a fishing reel. The team though that it might be in interest to make it move across the wheel so there is no entanglement in the cable so it is easier wound and unwound, but at the end of the tests the team decided to use the version that spools onto of itself so that there couldn’t be a chance of entanglement, and for an easier mechanism.

6 Project Management – Second Semester

6.1 Gantt Chart

Table 7: Gantt Chart



The team used a Gantt chart to keep the team on path. Maintaining a consistent schedule made it easier to understand, where we are and where were with the project. For the first half of the ME486C the team was easily on track and met the requirements for the project management assignment. Which lead us to our first hardware review for the 33% build. During that time the team had to begin the purchasing process and create a manufacturing plan for when those purchases arrive. The team also had the first website check and a critical design review with our client Northrop Grumman. This next section is where hurdles arrived. We were on great pace for the manufacturing overall but when it came to assembly it was more tedious than originally planned. The team being behind caused the 66% build to be less developed that hoped causing a slight grade drop. Between then and the 100% build, the team was able to finish manufacturing the last few parts as well as complete the assembly. The next big task for the team was testing. Which led us to our initial testing results. Throughout the semester the team had been building out testing plans. Our initial testing was completed on time as expected. Our teams next big task was U-grads where we presented our project missing only the final testing. Our team also had a poster where we would give a brief overview of our project with as much detail as possible. Once U-grads was completed the team finished the testing phase. Those tests were the retraction speed and temperature test. Once the testing was complete, we presented those final testing result, which completed our time in class for ME486C. The final report was our next task and was completed the next day. Our team will be presenting our poster to our client for a Northrop Grumman Symposium Day and eventually give the device for our client handoff. Improvement in the Gantt chart and further scheduling could have been completed more efficiently to use a website which it's much more accessible for all the members. The Gantt chart file we used as a team was buried under the amount of file in our Microsoft teams. Creating a weekly Gantt chart and emailing the members to prepare for the week could have improved our efficiency.

6.2 *Purchasing Plan – Jack*

Table 8: Purchasing Plan

Part / Assembly	Part #	Quantit	Price	Total Pric	Statu	Supplier	Manufacture	Start/Order Dat	Finish/ Receive Dat
Cord	KIT110-2	1	$ 64.00	$ 64.00		Wes Spur	Wes Spur	12-Nov	10-Jan
Motor	A128-150-G8	1	$ 529.00	$ 529.00		AmpFlow	AmpFlow	17-Nov	3-Feb
Motor Controller	MCP266	1	$ 269.00	$ 269.00		AmpFlow	AmpFlow	17-Nov	3-Feb
Power Supply	S-1000-24	1	$ 199.00	$ 199.00		AmpFlow	AmpFlow	17-Nov	3-Feb
Speed Adjuster	MCP DM Controller	1	$ 20.00	$ 20.00		AmpFlow	AmpFlow	17-Nov	3-Feb
Bearing 1"	5913K74	2	$ 12.77	$ 25.54		McMaster-Carr	N/A	1-Feb	10-Feb
Bearing 3/4"	5913K73	2	$ 11.90	$ 23.80		McMaster-Carr	N/A	1-Feb	10-Feb
Machine key	90164A655	2	$ 7.22	$ 14.44		McMaster-Carr	N/A	3-Feb	10-Feb
Left Disk Cut and Tapped	NA	1	$ 40.98	$ 40.98		SendCutSend	SendCutSend	5-Feb	14-Feb
Right Disk Cut and Tapped	NA	1	$ 41.05	$ 41.05		SendCutSend	SendCutSend	5-Feb	14-Feb
Left Side Plate Cut and Tapped	NA	1	$ 40.55	$ 40.55		SendCutSend	SendCutSend	5-Feb	14-Feb
Right Side Plate Cut and Tapped	NA	1	$ 41.66	$ 41.66		SendCutSend	SendCutSend	5-Feb	14-Feb
Base Plate	NA	1	$ 123.97	$ 123.97		SendCutSend	SendCutSend	5-Feb	14-Feb
Tool Replacement Cord 14/3	342-576	1	$ 14.47	$ 14.47		Home Depot	CerroWire	7-Feb	7-Feb
Southwire Cord 1.66/ Ft	12/3 300 Volt	3	$ 1.66	$ 4.98		Home Depot	Gardner Bender	7-Feb	7-Feb
16-14 AWG Ring Terminals 15 pack	15-104	1	$ 2.95	$ 2.95		Home Depot	Gardner Bender	7-Feb	7-Feb
12-10 AWG Ring Terminals 15 pack	15-107	1	$ 3.61	$ 3.61		Home Depot	Gardner Bender	7-Feb	7-Feb
22-18 AWG Spade Terminal 6 Pack	15-111	1	$ 2.40	$ 2.40		Home Depot	Gardner Bender	7-Feb	7-Feb
D-Sub Serial Adapters	DB15 RS232	1	$ 12.99	$ 12.99		Amazon	Jienk	21-Feb	1-Mar
Enclosure	O791778468009	1	$ 161.99	$ 161.99		Amazon	YUEQING QILI ELECTRICAL	21-Feb	1-Mar
Toggle Switch	69196O8793716	1	$ 7.19	$ 7.19		Amazon	HiLetgo	21-Feb	1-Mar
Power Socket w Switch Fuse	B082ZFRV1B	1	$ 8.99	$ 8.99		Amazon	MXRS	21-Feb	1-Mar
External Cooling Fan	B009OWVUJ0	1	$ 18.99	$ 18.99		Amazon	AC Infinity	21-Feb	1-Mar
Cable Gland Pack	O752771026917	1	$ 16.49	$ 16.49		Amazon	Cable Gland	21-Feb	1-Mar
40A Inline Circuit Breaker	B07KF2PV6V	1	$ 16.99	$ 16.99		Amazon	Y-SOLAR	21-Feb	1-Mar
Wire Connector Kit	B01LCG52C6	1	$ 13.99	$ 13.99		Amazon	EL-SKY	21-Feb	1-Mar
Hot Rolled Plate Gusset	B00YWBSR94	1	$ 12.99	$ 32.37		Amazon	IMS	21-Feb	1-Mar
Gusset with Hole	B009Q73QMM	1	$ 12.25	$ 12.25		Amazon	Allstar Performance	21-Feb	1-Mar
Lathe Stock	B01F80WG1W	1	$ 29.99	$ 29.99		Amazon	Stoner Metals	21-Feb	1-Mar
Chassis Mount for Connectors Sets	HS-4	1	$ 11.99	$ 11.99		Powerwerx	Powerwerx	21-Feb	1-Mar
Aluminum Material	NA	1	$ 27.93	$ 27.93		Home Depot	Home Depot	26-Feb	26-Feb
Scrap Wood & Bolt, Nut, and Screw Kits	NA	1	$26.14	$ 26.14		HomeCo	HomeCo	3-Mar	3-Mar
Side Plate and Disk	NA	1	$30.62	$ 30.62		SendCutSend	SendCutSend	7-Mar	28-Mar
Final Price				$ 1,890.31					

The teams purchasing plan began early in the semester where we started the purchasing with our chord set from Wes Spur which was used later in our cable testing. The next was the biggest purchase from the team which was the motor, motor controller, power supply and speed adjuster all from AmpFlow. This purchase took a lot of time to complete because of the motor decision and comparing multiple options. Bearing from McMaster-Carr were out next purchase where the team purchased a couple options to find the exact bearing. Our teams next purchase was from SendCutSend a company that laser cuts parts with extremely high tolerances. That purchase included a left and right-side disks and plates for our spool and housing. The team had a couple of reimbursements during the semester one being parts from Home Depot which included nuts and bolts for our device. The next reimbursement came later and was aluminum material from Home Depot. Our net big purchase was from Amazon which included all the electrical parts. The parts were a serial adapter, enclosure, power socket with fuse, cooling fan, cable glands, inline circuit breaker, wire kit, gusset, and a lathe stock. The total cost from the Amazon purchase wasn't high but was extremely important in our electronics setup and wiring. The also purchased a chassis mount for connectors from Powerwerx so the team would be able to house the electronics. Our team final purchase was a second purchase from SendCutSend where we ordered an additional set of plate and disk that were slightly adjusted from the previous purchase.

The difference from the original purchasing plan was large. Our original purchasing plan was a breakdown for each potential prototype. From there our estimates were way over our actual cost. One potential improvement that could've been implemented at the start would be more research into specific parts and maybe estimate certain parts that we expect. The actual original plan was also based off the two previous Northrop Grumman capstone projects that spend around $2100. From that information we were able to make assumptions for our team's potential cost.

6.3 *Manufacturing Plan – Griffin*

Below is out posted manufacturing plan which shows every item that has been manufactured for our device, along with the assembly dates to when the entire device is ready to use.

Table 9: Manufacturing Plan

Part / Assembly	Part #	Quantity	Price	Total Price	Status	Supplier	Manufacture	Start/Order Date	Finish/ Receive Date
Left Disk Cut and Tapped	NA	1	$40.98	$40.98		SendCutSend	SendCutSend	5-Feb	14-Feb
Right Disk Cut and Tapped	NA	1	$41.05	$41.05		SendCutSend	SendCutSend	5-Feb	14-Feb
Left Side Plate Cut and Tapped	NA	1	$40.55	$40.55		SendCutSend	SendCutSend	5-Feb	14-Feb
Right Side Plate Cut and Tapped	NA	1	$41.66	$41.66		SendCutSend	SendCutSend	5-Feb	14-Feb
Base Plate	NA	1	$123.97	$123.97		SendCutSend	SendCutSend	5-Feb	14-Feb
Welding, R/L Plate to Base	N/A	1	N/A	N/A		N/A	Machine Shop	25-Feb	25-Feb
Inside Wheel	N/A	1	N/A	N/A		Home Depot	Jonathan/ Machine Shop	25-Feb	4-Mar
Shaft	N/A	1	N/A	N/A		Home Depot	Jonathan/ Machine Shop	25-Feb	4-Mar
Electrical Layout	N/A	1	N/A	N/A		N/A	Jonathan	4-Mar	11-Mar
Machine Assembly	N/A	1	N/A	N/A		N/A	Griffin/ Machine Shop	7-Mar	30-Mar
Electrical Assembly	N/A	1	N/A	N/A		N/A	Jonathan/ Machine Shop	7-Mar	29-Mar
Full Assembly	N/A	1	N/A	N/A		N/A	Team	14-Mar	30-Mar

6.3.1 Send-Cut-Send

Going thr**ough this list above, the first five parts listed were outsourced to a laser cutting company called SendCutSend. This company as advertised gives a resolution for 0.005 inches, had the ability to tap holes, was able to deliver parts in a week (took 1.5 weeks to receive) and could cut in a variety of different materials. The price for the components was aggressive compared to other manufactures and purchasing the material and building the parts ourselves. Outsourcing our parts to them made manufacturing much easier and relieved quite a bit of stress from the team. Once the parts were received, the Left and Right plates were sent to the machine shop to get them welded so that the entire assembly could be finished.**

6.3.2 Machine Shop Parts

There were then two parts left that were to be built in the NAU Machine Shop. These parts were the Inside Wheel and Shaft. Each part took a couple weeks to build as the team needed a reminder of how some of the equipment worked due to it being a couple years since the last time we were in the shop, as well as the parts needed to be under high precision to build and therefore hours were added to make sure all requirements were met. The first photo below shows the shaft to run from the motor to the other side of the plate. This part was cut down from aluminum stoke, and then was put on the 4-Axis mill to make the keyway.

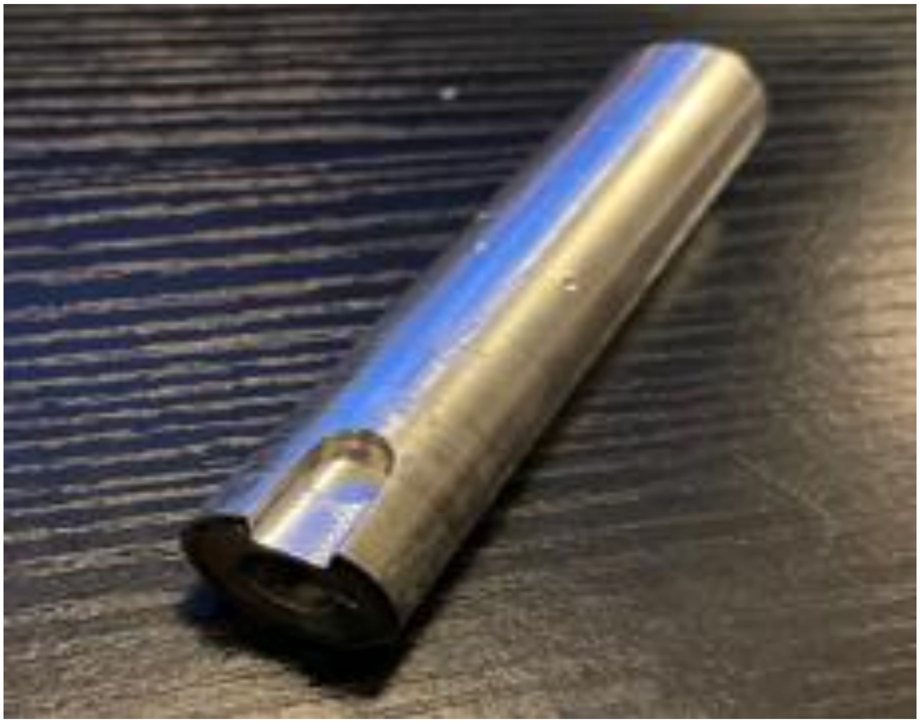


Figure 30: Machined Shaft

The next part that was manufactured was the Inside Wheel as shown below. This part was mostly done by hand using the lathe and mill. The team ran into trouble when building the keyway for this part because the broaching set needed for it was unavailable and hard to find, so therefore some of the CAD work was changed to allow the HAAS to cut the part in its entirety which gave a very accurate and very well-built part.

Figure 31: Machined Inside Wheel

6.3.3 Assembly

Once the parts had finished being made, the machined parts could come together for their assembly. Along with that the electrical assembly could begin as the team had figured out the wiring diagram and had all the parts for the electrical components. The electrical assembly is shown below as Figure 32. This picture shows the power supply (top) leading out the right side to be plugged into an outlet, as well as leading to a 40 Amp inline fuse (far left) which then connects to the motor controller (bottom left) which has a toggle switch attached to it for our actuation system.

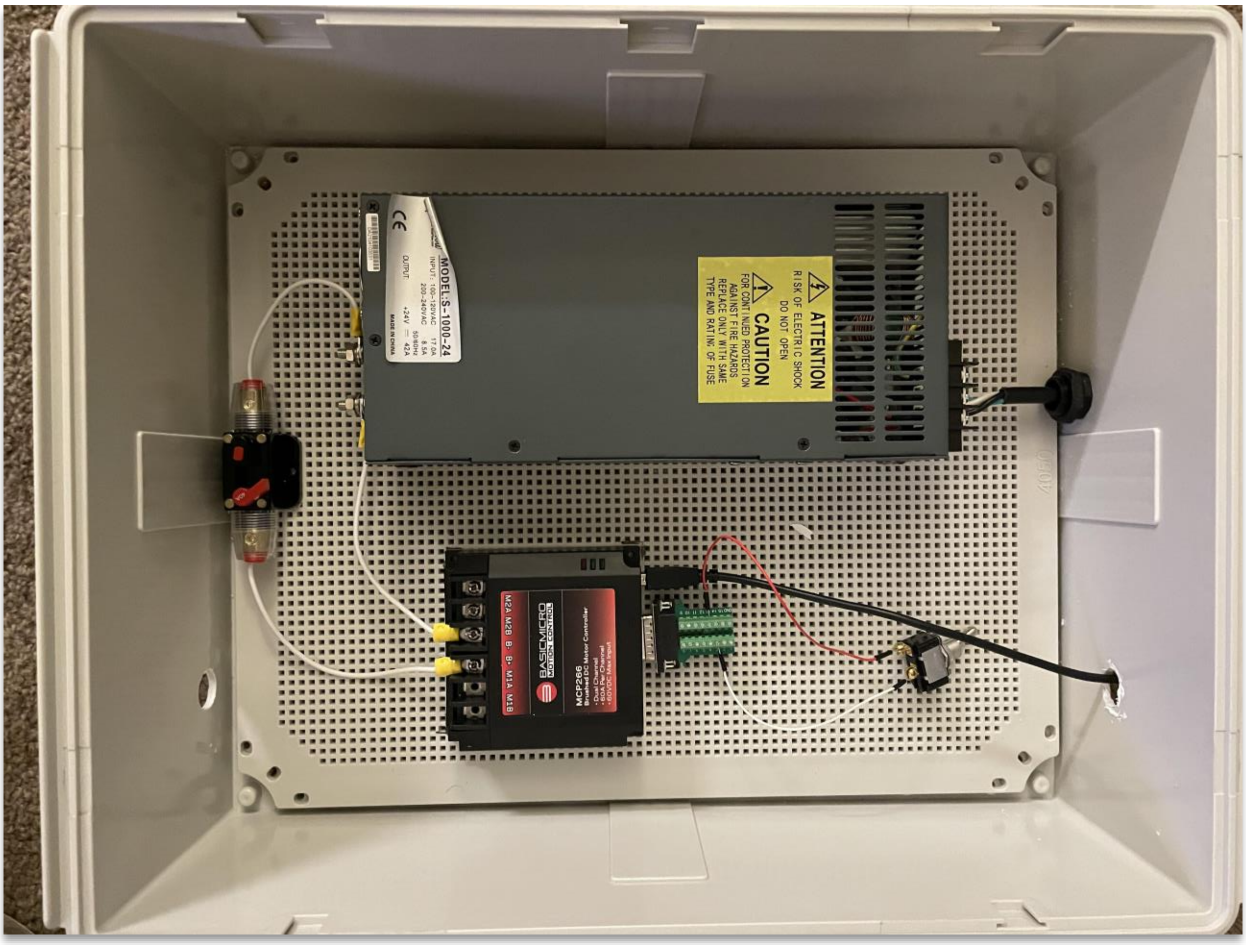


Figure 32: Electrical Assembly

Here we see the final mechanical assembly which has the two right and left plates welded onto a metal base which is standing on a 2X4 for ease of carry. From the plates, the entire wheel assembly lies within which is set in-between two bearings which hold the shaft from the motor, and the shaft running through the entire wheel. The entire wheel assembly is held together by screws and a key. The motor can be seen on the right of the photo with wires leading to the motor controller which is shown above. The motor screws into the right-side plate on 4 points to make a secure connection.

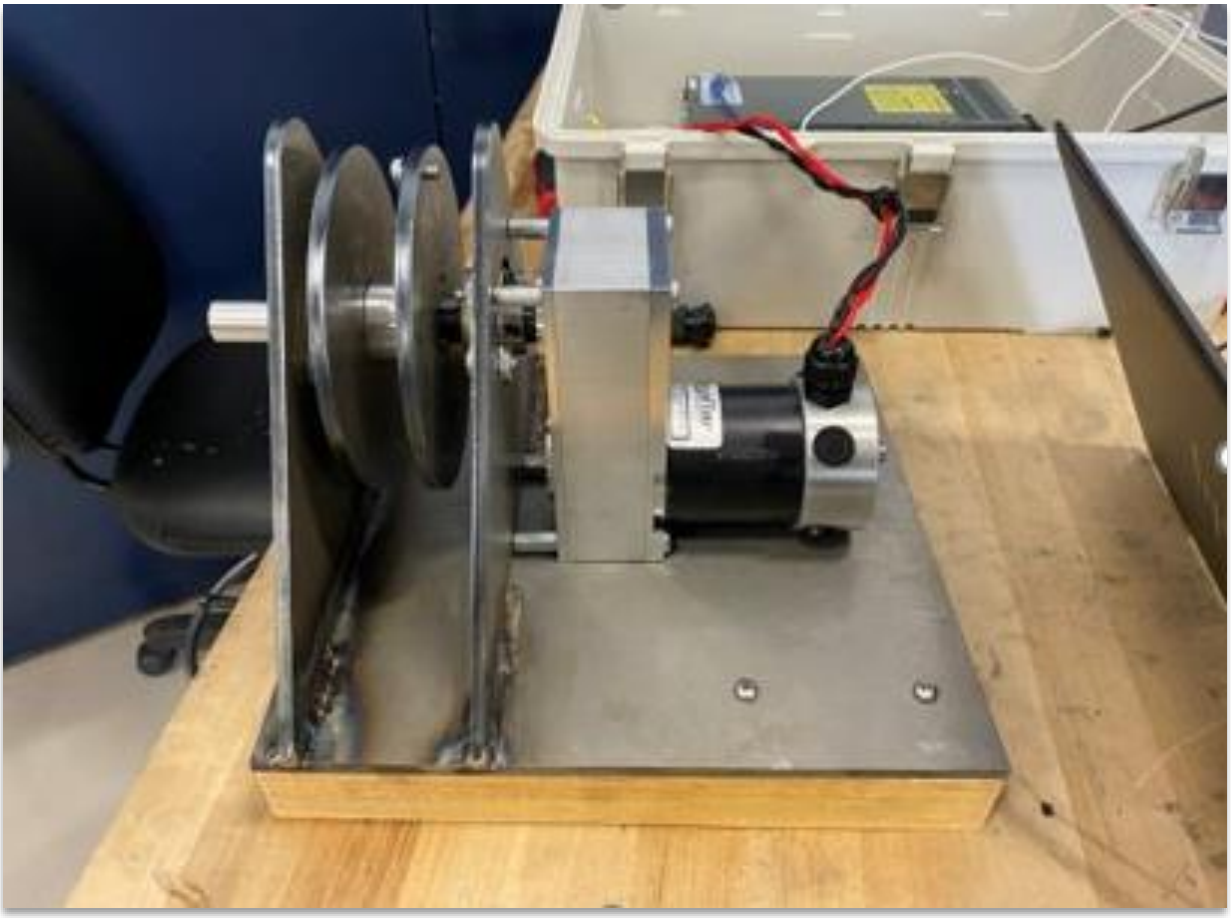
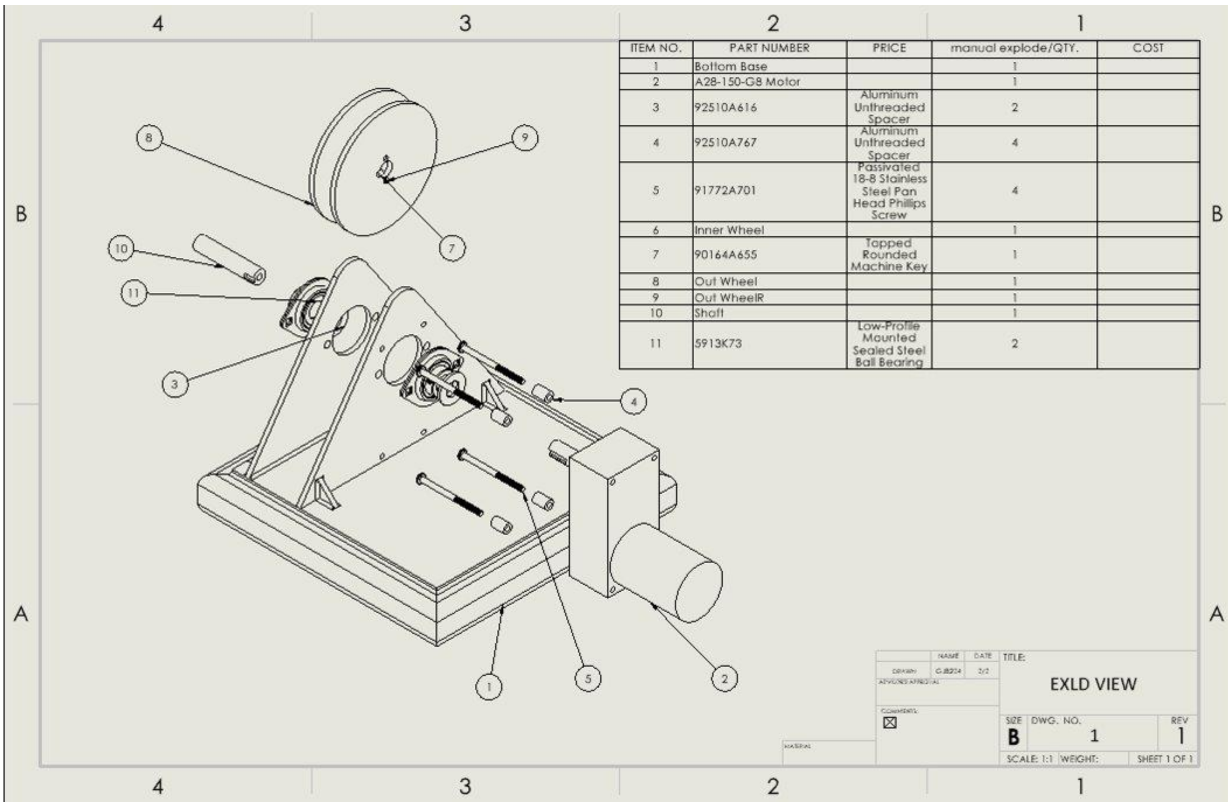


Figure 33: Machine Assembly

7 Final Hardware

7.1 Final Hardware

The first design from the second semester directly builds off the dimensions in mind from the last design from the first semester. The second design though does not include a cable guide as the team went with a thin wheel which reduces the need for one. The other big change were thinner walled plates because the wooden model has ¾ in. thick wood, which would be too heavy for the scope of this project and makes an unrealistic device.



ITEM NO.	PART NUMBER	PRICE	manual explode/QTY.	COST
1	Bottom Base		1	
2	A28-150-G8 Motor		1	
3	92510A616	Aluminum Unthreaded Spacer	2	
4	92510A767	Aluminum Unthreaded Spacer	4	
5	91772A701	Passivated 18-8 Stainless Steel Pan Head Phillips Screw	4	
6	Inner Wheel		1	
7	90164A655	Tapped Rounded Machine Key	1	
8	Out Wheel		1	
9	Out WheelR		1	
10	Shaft		1	
11	5913K73	Low-Profile Mounted Sealed Steel Ball Bearing	2	

Figure 34: Exploded View of Design

The design as shown includes a base for the entire model to sit on, two vertical plates to rest the wheel assembly and connect the motor too, a thin wheel design that holds a shaft which runs too one side of a motor to the other side which lays inside bearings to make a fluid motion. As shown in the design the vertical plates will be welded to the structure and all other parts will be assembled using screws. Drawings for each part and the assembly are shown in the appendix. One note is that in this view, the device is sitting on metal pipes, and this is because it was unclear to what our device will be mounted too so this was a basic design.

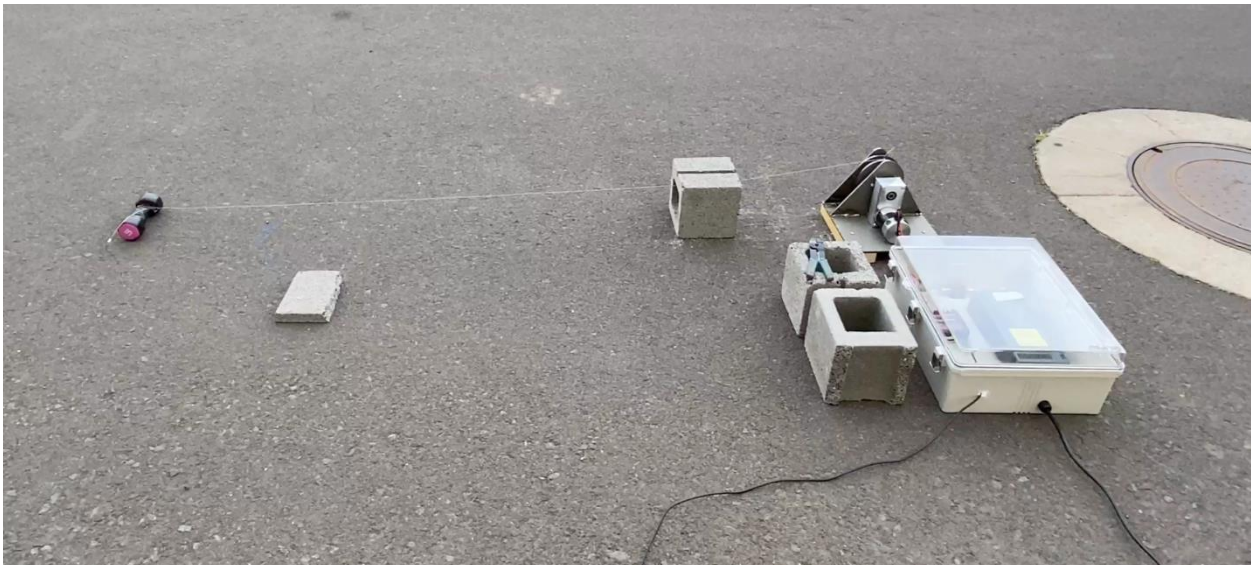


Figure 35: Full Assembly (At Testing Location)

When designing the device, the importance of being able to pull multiple cables, and different cable lengths was noted, so our final product has enough wheel space such that multiple cables can be pulled and can be wound on top of each other. The testing section of the document will outline and prove that the selected design has more than enough strength to pull more cables.

7.2 Challenges Bested

Compared to the first semester, our team did a much better job and creating milestones for our project in between our hardware checks. Because of this, we were able to provide ourselves with more time to troubleshoot and solve any problems that arose like the ones that will be listed in this section.

Manufacturing of the larger plates made of steel was simple as it was laser cut via a third-party company. However, when manufacturing our shaft and shaft housing, we ran into some issues regarding our keyways. We were initially told that the NAU machine shop had on-hand the proper broaching kit to cut out the keyways but when we went to do it, it turns out that was wrong. To get our keyways completed, we used the 4th axis mill to get the keyway on the shaft, and the Haas CNC machine to get the keyway on the shaft housing.

For the motor controller, our program went through multiple iterations. Because we did not use encoders, we were unable to get position or speed readings from our device. To compensate for this, we had to use different run-times to retract the umbilical different distances.

When doing our initial testing with our motor controller program, we noticed that the spike in current from starting the device at full speed was too much for our power supply to handle which would result in the motor running very slowly. To overcome this, we had to accelerate our motor in steps which affected our program that we were using for our motor controller.

8 Testing

8.1 Testing Plan

As mentioned above our client provided us with five customer requirements and seven engineering requirements. These requirements were related in our QFD and weighted on importance. Each requirement for organizational purposes was assigned a label, seen in Table 11. This label was used in our team's top-level summary, Table 10, to determine which requirement will be evaluated with each test. A few of our requirements do not have a specific test assigned to them due to evaluation being completed by other means. The customer requirement of being safe from electrostatic discharge was evaluated based on the properties of the materials used in our design. Again, our design was determined to be highly manufacturable and easily installed/removed based on our team's analysis of the time and expenses required to manufacture our device and the weight and mobility factor of our design. One of our engineering requirements which does not need an extensive test is cost. This engineering requirement can be evaluated by analysis of the number of parts needed for the design and material type used for each of the parts. Further, our client requires the design to have a one-hundred percent success rate. This will not require a specific test, but rather the testing procedures be completed multiple times to evaluate the overall performance of the design.

Table 10: Organization of CR's and ER's

Customer Requirements	Engineering Requirements
CR1 - High Manufacturability	ER1 - Cost
CR2 - High Reliability	ER2 - Side Force
CR3 - Easily Removable/Installed	ER3 - Retraction Speed
CR4 - High Durability	ER4 - Temperature
CR5 - ESD Safe	ER5 - Weight
	ER6 - Length
	ER7 - Success Rate

Table 11: Top-Level Testing Summary

Tests	Relevant DR
T1 – Rotation Speed	CR2
T2 – Cable Type	CR2, CR4, ER4, ER6
T3 – Environmental	CR2, CR4, ER2, ER3, ER4, ER5, ER6, ER7
T4 – Side Force	ER2
T5 – Retraction Speed	CR2, ER3, ER5, ER6, ER7

The rotation speed test was conducted to determine if our motor produced the desired torque corresponding to making our device reliable. The cable type test was conducted to determine if the cable could withstand launch conditions proving to be durable enough to be implemented into the final design. The environmental test was conducted to ensure our device would still operate under extreme temperatures and launch conditions. The side force test was conducted to prove our device will not impose a side force on the vehicle which would cause launch complications. The retraction speed test was conducted to determine the efficiency and reliability of our device.

8.2 Testing Results

Seen below in Table 12 and Table 13, is our teams specification sheet for our customer requirements and our engineering requirements. These tables are color coded based on our client's approval of our testing results, where red corresponds to not approved, yellow corresponds to partially approved, and green corresponds to approved. Our rotation speed test proved to be successful and reported torque values our team expected based on our motor calculations. The cable test resulted in our team selecting a steel cable due to its durability when exposed to launch conditions and how it performed under stress. The environmental test was successful, and our device functioned at temperatures of zero degrees Fahrenheit and one-hundred- and seventy-degrees Fahrenheit as adjusted by our client. The side force test was successful, and our device experienced less than one pound of force as expected because our device is not loaded in tension before actuation. The retraction speed test did not meet our engineering requirement of six feet in one second. Our team realized we made a calculation error when determining the necessary diameter of our shaft, but this result was partially approved by our client because if this diameter error is corrected by implementing a larger shaft our device would produce the required retraction speed. The engineering requirement, success rate, and the customer requirement, high reliability, are both partially approved by our client due to complications with our actuation system. When manually actuated our device is function one hundred percent of the time, hence the partial approval of success rate and high reliability.

Table 12: Customer Requirement Tesing Results

Customer Requirements	CR Met?	Client Approved?
CR1 - High Manufacturability	Yes	
CR2 - High Reliability	Yes	
CR3 - Easily Removable/Installed	Yes	
CR4 - High Durability	Yes	
CR5 - ESD Safe	Yes	

Table 13: Engineering Requirement Testing Results

Engineering Requirements	Target	Measured/Calculated Value	ER Met?	Client Approved?
ER1 - Cost	5000 ($)	1890.30 ($)	Yes	
ER2 - Side Force	<10 (lbs)	<1 (lbs)	Yes	
ER3 - Retraction Speed	6ft/1s	4.22 (ft/s)	No	
ER4 - Temperature	0 to 160 (F)	0 to 170 (F)	Yes	
ER5 - Weight	1lb/1ft	0.88 (lb/ft)	Yes	
ER6 - Length	2 to 6 (ft)	6 (ft)	Yes	
ER7 - Success Rate	100 (%)	100 (%)	Yes	

9 RISK ANALYSIS AND MITIGATION

Due to the nature of rockets, it was imperative that we properly determine and mitigate all potential failures in our system. Conducting a proper Failure Modes and Effects Analysis began very early on in the design process and evolved along with the design of our device. The next two sections highlight this evolution within our FMEA.

9.1 Potential Failures Identified First Semester

The following table is of the Failure Modes and Effects Analysis from the first semester of this project:

Table 14: Failure Mode and Effect Analysis

FMEA								
Part # and Functions	**Potential Failure Mode**	**Potential Effect(s) of Failure**	**Severity (S)**	**Potential Causes and Mechanisms of Failure**	**Occurrence (O)**	**Detection (D)**	**RPN**	**Recommended Action**
Baseplate - Where all components will connect to and what will be mounted to tower.	Impact Fatigue	Erratic Operation, vibrations	5	Assembly errors, poor maintenance	3	2	30	Ensure that proper estimates are made for load
Spool Carrier/Housing - Responsible for supporting axle and spool.	Plastic Deformation	Appearance, possible tangling of cable	3	Overloading	2	2	12	Select material with high surface hardness. Maybe look into a guiding system for the cable
Axle - Motor driven rod that our spool will rotate about.	Yielding	Possible system failure depending on severity offend	4	Overloading	4	1	16	Select material with high resistance to yielding
Motor - Used to convert electric energy to mechanical energy, in this case rotational	Burnout	Lots of heat, bad performance or even failure	7	Too little or Toomuc voltage/current, overloading	5	3	105	Properly size motor by calculating possible loads with a reasonable factor of safety.
Gear Box - Will allow us to increase or decrease rotational speed and torque coming from the motor. Ensures stress isn't put directly onto motor.	Contact fatigue, abrasive wear	Noise, lower performance, cracking	3	Overloading, improper maintenance	3	8	72	Ensure that proper maintenance is well defined. May need lubrication from oil based on operating temperatures and interference
Mounting Screw - These screws will mount our baseplate to the launch tower.	Failure from lack of locking mechanism, Fatigue	Erratic operation, vibrations	6	Overloading	2	4	48	Jack will perform shear analysis for our mounting screws with reasonable factor of safety

Arduino Board - Microcontroller for motor	Electrical failure	System will not operate	8	Improper connections, manufacturers error	4	6	192	Jonathan will test Arduino board and programming to ensure everything runs okay. Look into voltage supplies.
Motor Carrier - Responsible for holding motor in place	Release	Erratic Operation, vibrations	6	Faulty restraining systems, vibrations	4	5	120	Griffin will determine a way to fasten our motor to where little vibration is introduced into the system
L293D Motor Driver - Responsible for controlling the speed and direction of our motor.	Electrical failure	System will not operate	8	Improper connections, manufacturers error	4	6	192	Jonathan will test driver to ensure all points are working correctly
Bearings - Will be used to allow shaft to rotate, attached to spool carrier.	Fatigue Wear	Poor performance, erratic operation	4	Improper maintenance, Overloading	2	8	64	Ensure that proper maintenance is carried out. Possible lubrication. Ensure that correct loads are used.

The main takeaways from this were that careful consideration would have to be given to our motor selection and that we would need to complete thorough force analysis on the many parts of our device to prevent failure or yielding.

9.2 Potential Failures Identified This Semester

As the second semester progressed, we began to identify new issues that we would have to consider that came up as we changed our design. These issues included the motor controller, the power supply, and the cable that we chose.

9.3 Risk Mitigation

For the motor controller and power supply, we were mostly concerned with current spikes which are common which quickly starting or stopping a motor. To prevent any issues from this, we made sure to properly fuse our connections and we programmed the motor to accelerate in incremental steps to prevent a spike in current.

For the cable, we were concerned with possibly yielding due to our loads or from launch conditions. We took extra care in selecting our cable and performed thorough testing to make sure that these concerns were never an issue. Our full and updated FMEA can be found below in Appendix A.

For the bearings, proper analysis was done to make sure that they would handle our loads.

10 LOOKING FORWARD

The team has completed their build, but improvement is possible. Moving forward with the device we can include both future testing procedures and future iterations as well. The team has identified multiple improvements that can be made and broke those down into three iterations. First, increasing the diameter of the shaft to achieve the customer requirement of 6ft that the cable can pull. The next is building a heat shield to project the device from the elements. The final iteration would be to complete the actuation system. Future testing procedures would able be extremely useful in further development. One topic our client introduced as a potential stretch goal was to be able to pull multiple umbilical cables at once.

10.1 Future Testing Procedures

Future testing can be completed to further understand the device and its limitations. As stated above we noticed a possibility of increasing the diameter of the shaft. The next team can manufacture a new shaft that is larger in diameter and then re-test their shaft. The data they will receive should meet the engineering requirement of 6ft/s and even increase that rate if more weight is expected from the device.

Another potential test that was not a part of our scope would be to test pulling multiple cables and potential more than two or three at a time. Finding those values will be more useful for the client because they will be able to then place the cables in their specific way to maximize efficiency. When meeting with our client they mentioned the number of umbilical cables that are needed to support the launch vehicle that surpassed thirty cables for their larger rocket such as Antares. Meeting a larger retraction speed can allow this device to pull more umbilical cables.

10.2 Future Iterations

Make suggestions for iterations if this project was to move forward with another hypothetical team.

The next potential iteration is increasing the diameter size of the shaft. The team was not able to meet the retraction speed of 6ft/s. The team's highest retraction speed was 4.8ft/s. To increase the retraction speed, a simple fix is needed. Because of the limited time left in the semester the team was not able to create a larger diameter. There will be a couple options for moving forward with increasing. The first option is to rebuild the shaft at a larger size. To do so additional materials are needed and some time in a machine shop to get the size correct.

The next iteration is to build a heat shield for the device. Building a heat shield was a part of the design since our first semester in ME476C where we thought the best way to counter the elements would be to build a cover around the device as a heat shield. As the team moved onto the second semester and began manufacturing the device, we realized that our heat shield wasn't a part of the scope. The reasoning being the parts that we purchased earlier in the semester were rated to handle those temperatures. The biggest influence was changing cable types because it had the biggest change in temperature difference. We decided to go away from the nylon chords and use a steel cable. Because the team scrapped the heat shield later in the project there are preliminary CAD design for the heat shield. So, the incoming team wouldn't need to design any aspect of it and will just need to manufacture the heat shield.

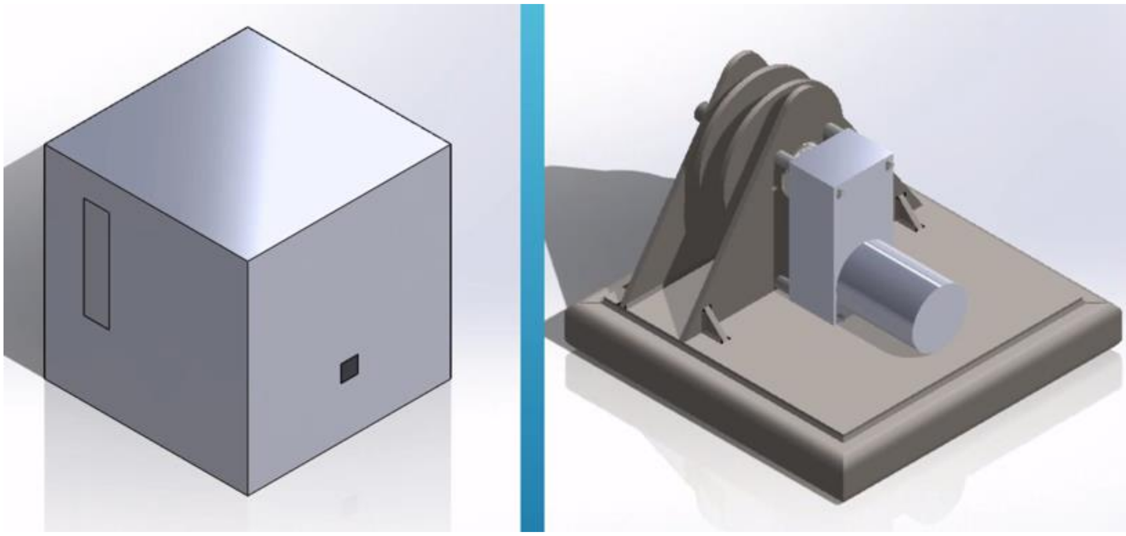


Figure 36: Potential Heat Shield Design

The final potential iteration would be to complete the actuation system. The actuation system first starts with the umbilical being in slack before take-off. The pull string will be taught and connected to the bail wire. The second step will occur during the vehicle take-off the umbilical cable will extend. Then the pull string will flip the switch and send a signal to the motor. In the third step the umbilical detaches from rocket naturally and the pull string will go with the bail wire. The fourth and final step the trigger is pulled and starts winding in the umbilical cable. The team ran into issues turning the switch on and was not able to finish that actuation. The team triggered the motor by the computer to start the code and pull the cable. To complete the actuation the future team will need to get the pull string to flip the switch.

11 CONCLUSIONS

This document outlines the current state of the 2021-2022 Northrop Grumman NAU Umbilical team design. The design project is to create a new umbilical that is just as successful and efficient as previous models with the added challenge of removing a side force created by the current retraction system of the umbilical. Over the course of the semester several design variants have been created, but the concept that the team felt solved the problem with the most ease was a winch design. The 1st model of the design was created using the SolidWorks package and gave a base for which the design will be created off. This 1st design was very rudimentary, and the team clearly saw which direction the next iterations need to go. There needs to be a better implementation of assembly involved in in the design, along with a larger motor and better motor control that are more reliable, and that can give the team results for testing. The testing procedures outlined that the cable, motor, structure, and thermal resistivity of the design will be experimented on to see where improvement can be made in future designs. Over the course of the next semester, the team will follow a tight schedule to make sure that the final product performs the tasks set to us by the client as well as coming in less than the budget allows.

11.1 Reflection

Through a long and arduous process, our team was able to successfully follow the engineering process to create a device that met most of our customer and subsequent engineering requirements. Along the way, we overcame multiple issues and were able to plan and iterate solutions to complete our device.

In the beginning, we had settled on a system that would use a spiral torsion string but after further analysis we decided on the motor driven system. This change in plans led to many other considerations that we had to consider such as power supplies, motor controllers, programming, and wiring. After further research, we were able to gather enough of an understanding of these components and in the end, everything worked together seamlessly.

At nearly $2000 under budget and all our customer requirements met, we are proud of the work we did and see this project as an invaluable opportunity to cap off our undergraduate studies.

11.2 Resource Wishlist

Going into the project it would have been helpful to have some real mechanical experience. For instance, machine shop training and better hand one mechanical assembly. I say the stuff about the mechanical assembly because the final design was not built with the greatest assembly in the world, and more experience with assembly would have helped. Along with that knowing what tools the machine shop has and knowing what they can do going into the project would have been helpful. The last thing that would have been beneficial to the team is a more hand on electrical course as EE188 was not sufficient in teaching us how to wire stuff, and to calculated energy outputs from the motor controller for instance learning about performance curves, and load cycles from the power supply was a learning curve.

11.3 Project Applicability

Jonathan Armijo – My biggest takeaways from this project were the skills and lessons I was able to acquire as project manager. I am very grateful for the work that my group did, and I deeply appreciate the trust that they put in me on certain decisions although overall the success of this project does not deserve to fall on any one person. I will be continuing my engineering career at TRAX International, a weapons and vehicle testing company that is contracted by the US Military where I will be working as a Test Engineer. I plan to utilize the skills I have acquired from this project to lead a multidisciplinary team with successfully and safely carrying out tests.

Griffin Brandt – As I aspire to become an Aerospace Engineer, hearing about the Northrop Grumman Capstone project piqued my interest. I hope that one day the lessons I learned in doing this project will help me in my future career in aerospace. My focuses right now are on Computational Fluid Dynamics and Fluid/ Thermal Systems so any class or project I can do now that will advance my knowledge in that field will help me. For this project specifically I loved learning about how the launch systems for large scale rockets work and why they are important. Seeing how subsystems that allow rockets to fly correctly work also inspired me to advance my career in aerospace.

Leah Blakney – The topic of this project does not align with my career interest of renewable energy systems, but I still found it valuable. This project applied knowledge and strategies I learned throughout my college courses and further developed my professional skills. This project required design concept generation and critical thinking and problem solving when our team hit roadblocks. This project provided professional development through working with a team on deliverables and giving presentations in front of a group of people.

William Shields - This project was a great learning experience and to get a glimpse into the aerospace industry. The aerospace industry is not my first choice but is a very interesting field. The project did aid me in employing my engineering bearings from previous classes into this project. For instance, during the literary reference, I was able to use the machine design book from class and apply the bearing equations. Using those equations, we were able to find tolerances from the dimension based from the CAD design. The symposium was a great end to the capstone class where connections were made.

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13 APPENDICES

13.1 Appendix A: FMEA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Detection (D)	RPN	Action
Baseplate - Where all components will connect to and what will be mounted to tower.	Impact Fatigue	Erratic Operation, vibrations	5	Assembly errors, poor maintenance	3	2	30	Ensure that proper estimates are made for load
Spool Carrier/Housing - Responsible for supporting axle and spool.	Plastic Deformation	Appearance, possible tangling of cable	3	Overloading	2	2	12	Select material with high surface hardness
Axle - Motor driven rod that our spool will rotate about.	Yielding	Possible system failure depending of severity of bend	4	Overloading	4	1	16	Selected material with high resistance to yielding
Motor - Used to convert electric energy to mechanical energy, in this case rotational	Burnout	Lots of heat, bad performance or even failure	7	Too little or too much voltage/current, overloading	5	3	105	Properly size motor by calcluating possible loads with a reasonable factor of safety.

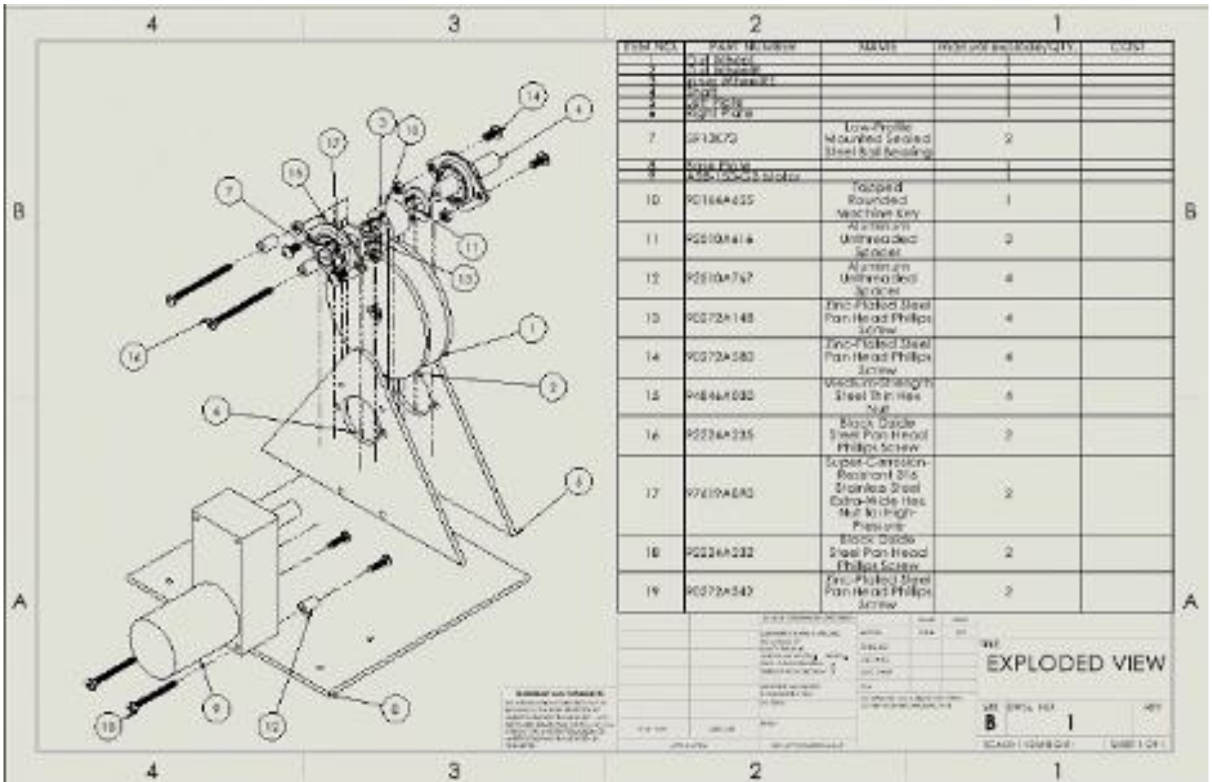
Gear Box - Will allow us to increase or decrease rotational speed and torque coming from the motor. Ensures stress isn't put directly onto motor.	Contact fatigue, abrasive wear	Noise, lower performance, cracking	3	Overloading, impropper maintenance	3	8	72	Ensure that proper maintenance is well defined. May need lubrication from oil based on operating temperatures and interference
Motor Carrier - Responsible for holding motor in place	Release	Erratic Operation, vibrations	6	Falty restraining systems, vibrations	4	5	120	Parts were welded to limit vibrations and other movements
Motor Controller - Receive power from power supply and supply power to motor. Run program to control motor	Electrical failure	System will not operate, components damaged	8	Improper connections, Overload of current	4	6	192	Motor programmed to accelerate in steps to prevent current spike. All connections secured. 40 A fused placed in series to power supply
Bearings - Will be used to allow shaft to rotate, attached to spool carrier.	Fatigue Wear	Poor performance, erratic operation	4	Improper maintenance, Overloading	2	8	64	Ensure that proper maintenance is carried out. Possible lubrication. Ensure that correct loads are used.
Power Supply - Will convert 120 VAC to 24 VDC @ 42 A	Electrical failure	System Failure, Components damaged, Electrical shock	8	Improper connections, Overload of current	4	6	192	Motor programmed to accelerate in steps to prevent current spike. All connections secured. 40 A fused placed in series to power supply

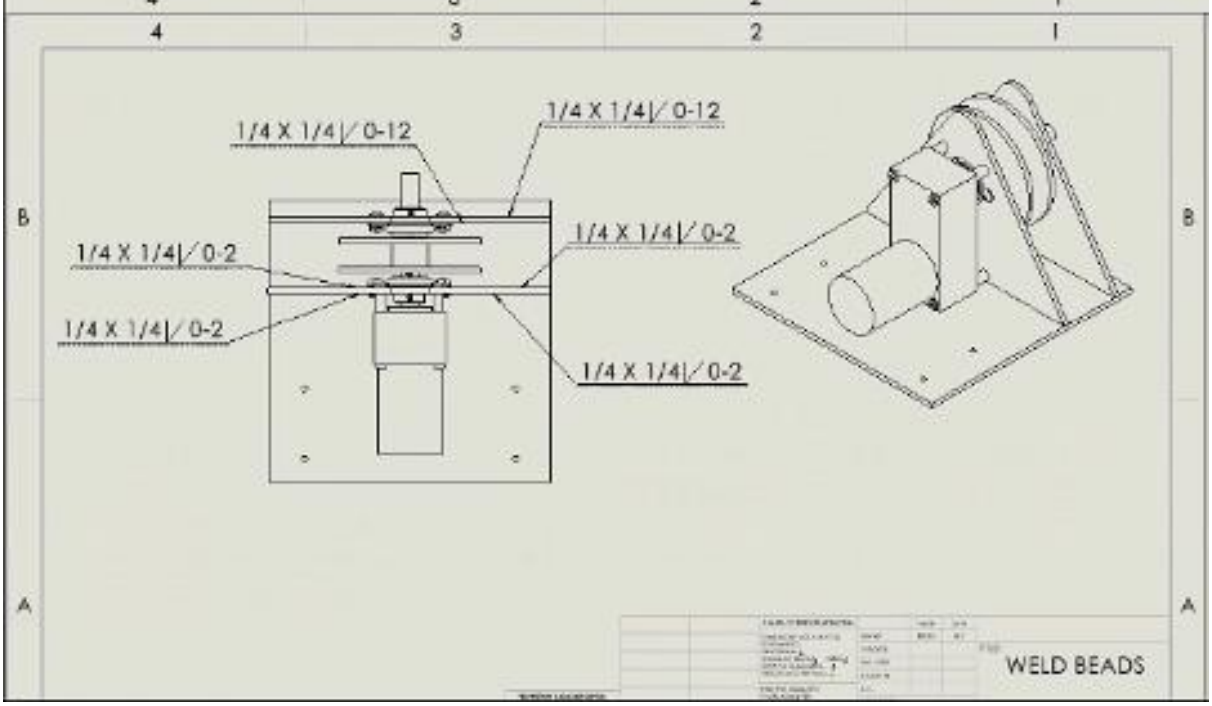
Cable - Will extend from device to umbilical	Deformation or breaking	Complete failure of system, unsafe conditions	8	Too large of a load, excess heat from environment	6	10	480	Thorough testing on our selected cable was done to determine if it would yield under expected conditions

13.2 1.1 Full B.O.M

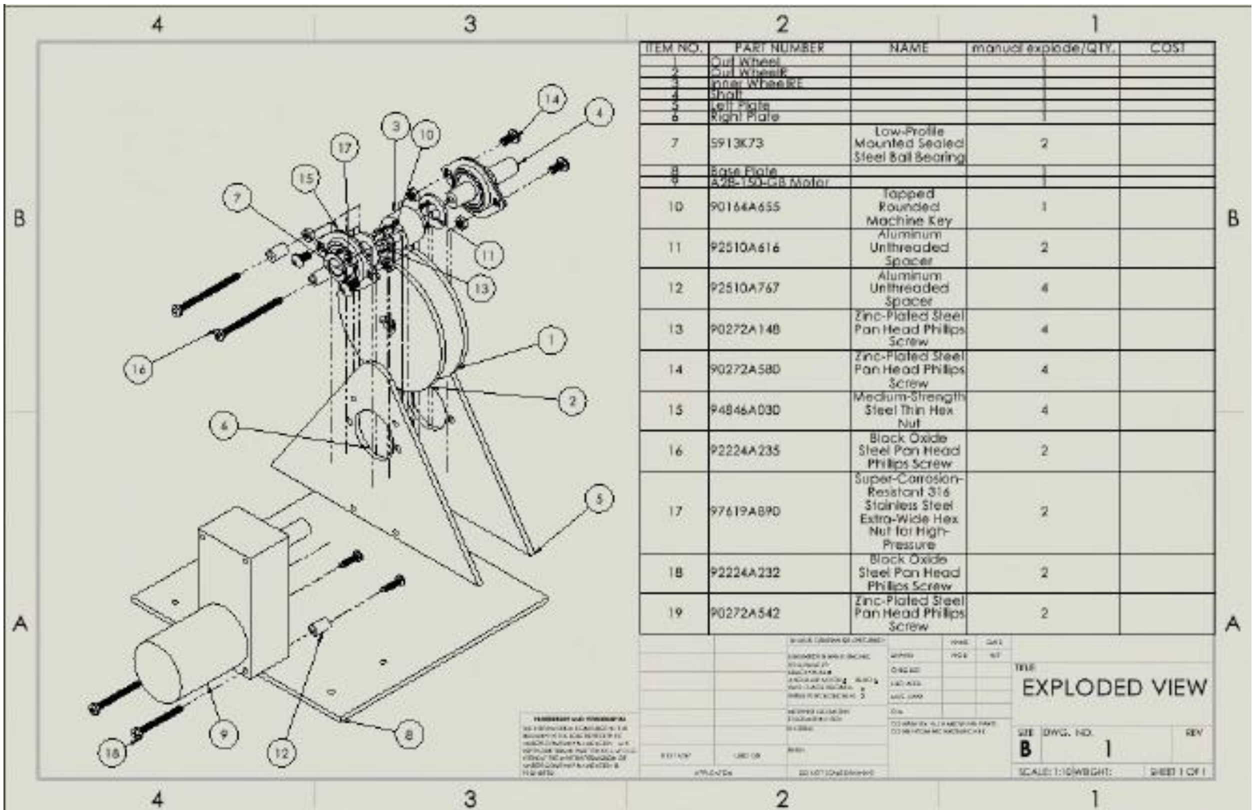
Part / Assembly	Part #	Quanti	Price	Total Pri	Statu	Supplier	Manufacture	Start/Order Dat	Finish/ Receive Dat
Cord	KIT110-2	1	$ 64.00	$ 64.00		Wes Spur	Wes Spur	12-Nov	10-Jan
Motor	A128-150-G8	1	$ 529.00	$ 529.00		AmpFlow	AmpFlow	17-Nov	3-Feb
Motor Controller	MCP266	1	$ 269.00	$ 269.00		AmpFlow	AmpFlow	17-Nov	3-Feb
Power Supply	S-1000-24	1	$ 199.00	$ 199.00		AmpFlow	AmpFlow	17-Nov	3-Feb
Speed Adjuster	MCP DM Controller	1	$ 20.00	$ 20.00		AmpFlow	AmpFlow	17-Nov	3-Feb
Bearing 1"	5913K74	2	$ 12.77	$ 25.54		McMaster-Carr	N/A	1-Feb	10-Feb
Bearing 3/4"	5913K73	2	$ 11.90	$ 23.80		McMaster-Carr	N/A	1-Feb	10-Feb
Machine key	92164A655	2	$ 7.22	$ 14.44		McMaster-Carr	N/A	3-Feb	10-Feb
Left Disk Cut and Tapped	NA	1	$ 40.98	$ 40.98		SendCutSend	SendCutSend	5-Feb	14-Feb
Right Disk Cut and Tapped	NA	1	$ 41.05	$ 41.05		SendCutSend	SendCutSend	5-Feb	14-Feb
Left Side Plate Cut and Tapped	NA	1	$ 40.55	$ 40.55		SendCutSend	SendCutSend	5-Feb	14-Feb
Right Side Plate Cut and Tapped	NA	1	$ 41.66	$ 41.66		SendCutSend	SendCutSend	5-Feb	14-Feb
Base Plate	NA	1	$ 123.97	$ 123.97		SendCutSend	SendCutSend	5-Feb	14-Feb
Tool Replacement Cord 14/3	342-576	1	$ 14.47	$ 14.47		Home Depot	CerroWire	7-Feb	7-Feb
Southwire Cord 1.66/ Ft	12/3 300 Volt	3	$ 1.66	$ 4.98		Home Depot	Gardner Bender	7-Feb	7-Feb
16-14 AWG Ring Terminals 15 pack	15-104	1	$ 2.95	$ 2.95		Home Depot	Gardner Bender	7-Feb	7-Feb
12-10 AWG Ring Terminals 15 pack	15-107	1	$ 3.61	$ 3.61		Home Depot	Gardner Bender	7-Feb	7-Feb
22-18 AWG Spade Terminal 6 Pack	15-111	1	$ 2.40	$ 2.40		Home Depot	Gardner Bender	7-Feb	7-Feb
D-Sub Serial Adaptors	DB15 RS232	1	$ 12.99	$ 12.99		Amazon	Jienk	21-Feb	1-Mar
Enclosure	0791778468009	1	$ 161.99	$ 161.99		Amazon	YUEQING QIU ELECTRICAL	21-Feb	1-Mar
Toggle Switch	691960B7931716	1	$ 7.19	$ 7.19		Amazon	HiLetgo	21-Feb	1-Mar
Power Socket w Switch Fuse	B0822FRV18	1	$ 8.99	$ 8.99		Amazon	MXRS	21-Feb	1-Mar
External Cooling Fan	B009OWVU10	1	$ 18.99	$ 18.99		Amazon	AC Infinity	21-Feb	1-Mar
Cable Gland Pack	0752773026917	1	$ 16.49	$ 16.49		Amazon	Cable Gland	21-Feb	1-Mar
40A Inline Circuit Breaker	B07KF2PV6V	1	$ 16.99	$ 16.99		Amazon	T-SOLAR	21-Feb	1-Mar
Wire Connector Kit	B01LOG52C6	1	$ 13.99	$ 13.99		Amazon	EL-SKY	21-Feb	1-Mar
Hot Rolled Plate Gusset	B00YWB5R94	1	$ 12.99	$ 32.37		Amazon	IMS	21-Feb	1-Mar
Gusset with Hole	B009Q73QMM	1	$ 12.25	$ 12.25		Amazon	Allstar Performance	21-Feb	1-Mar
Lathe Stock	B01F8OWG1W	1	$ 29.99	$ 29.99		Amazon	Stoner Metals	21-Feb	1-Mar
Chassis Mount for Connectors Sets	HS-4	1	$ 11.99	$ 11.99		Powerwerx	Powerwerx	21-Feb	1-Mar
Aluminum Material	NA	1	$ 27.93	$ 27.93		Home Depot	Home Depot	26-Feb	26-Feb
Scrap Wood & Bolt, Nut, and Screw Kits	NA	1	$26.14	$ 26.14		HomeCo	HomeCo	3-Mar	3-Mar
Side Plate and Disk	NA	1	$30.62	$ 30.62		SendCutSend	SendCutSend	7-Mar	28-Mar
Final Price				$ 1,890.31					

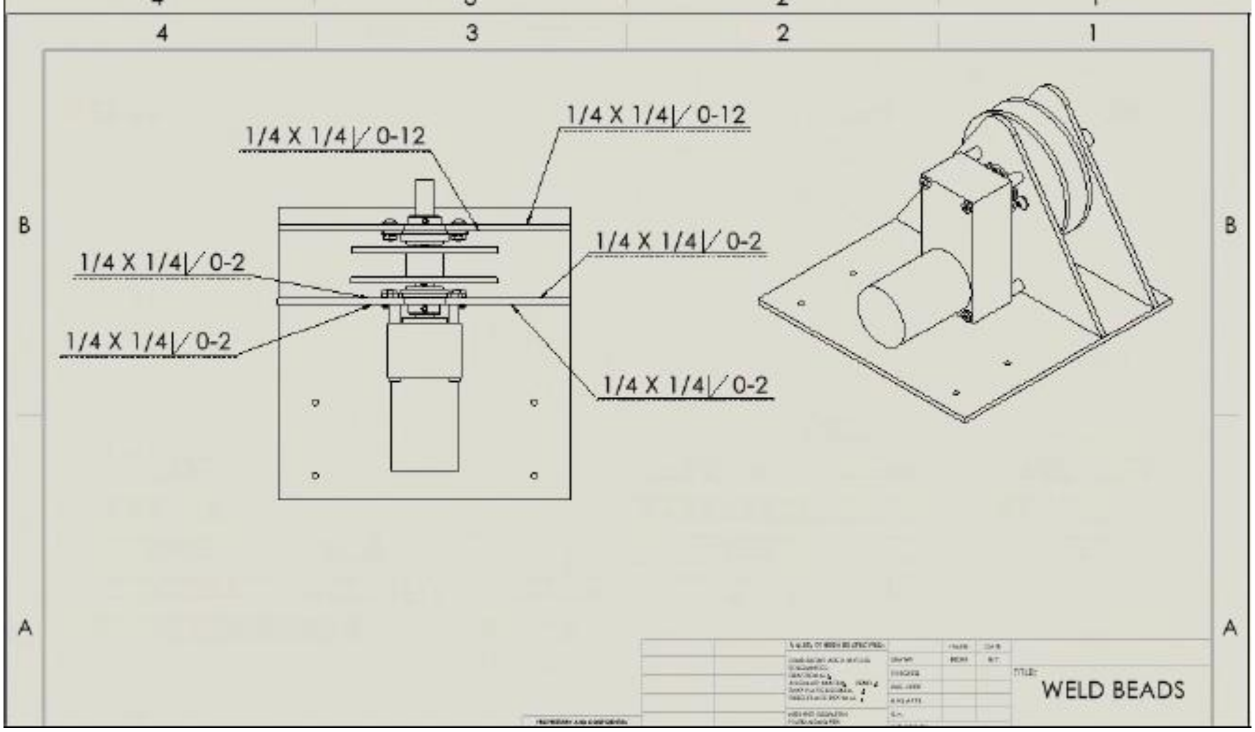
13.3 CAD Drawings

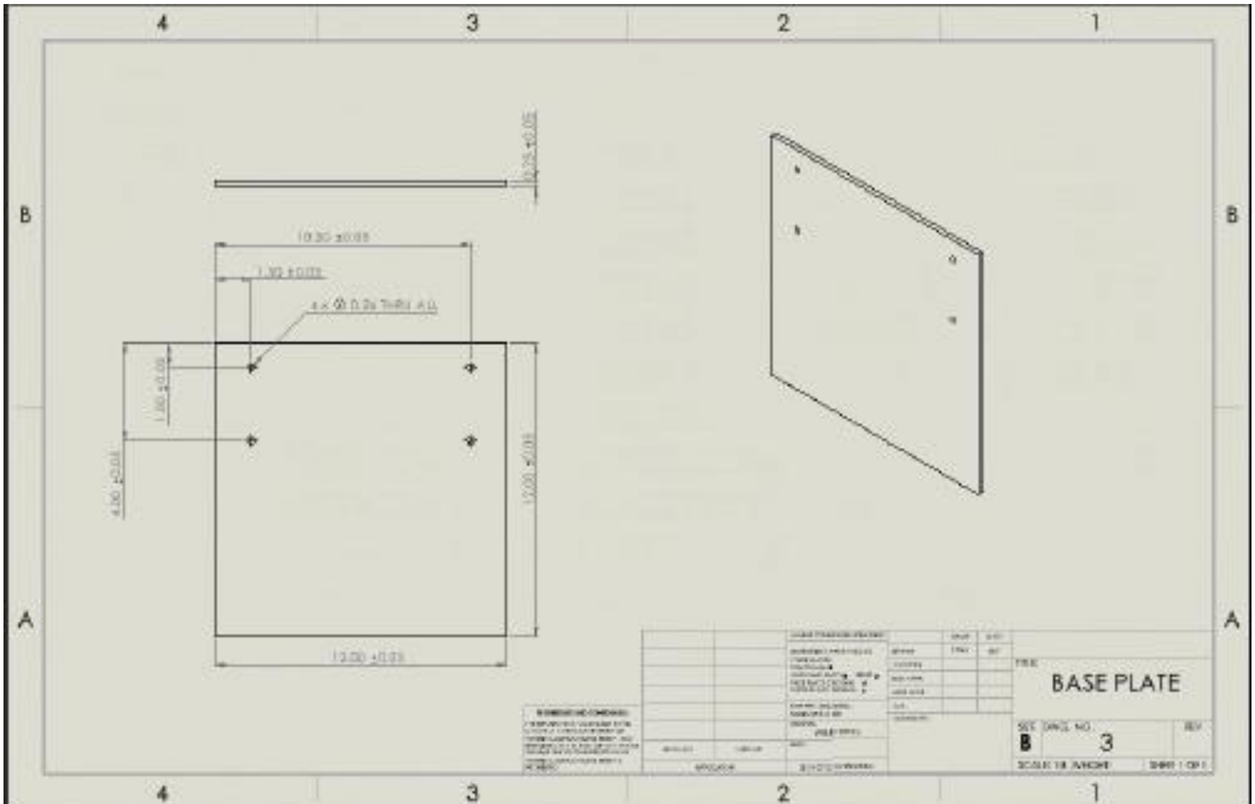




13.4 CAD Drawings



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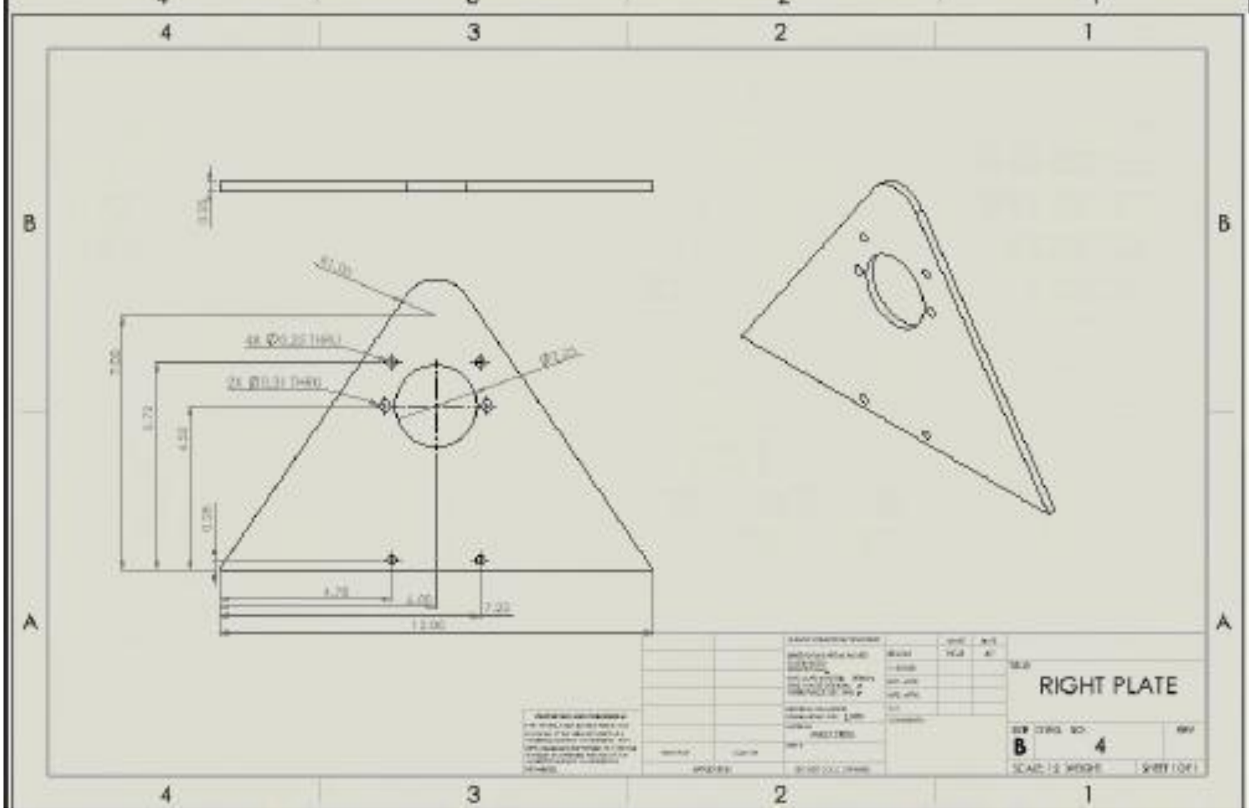
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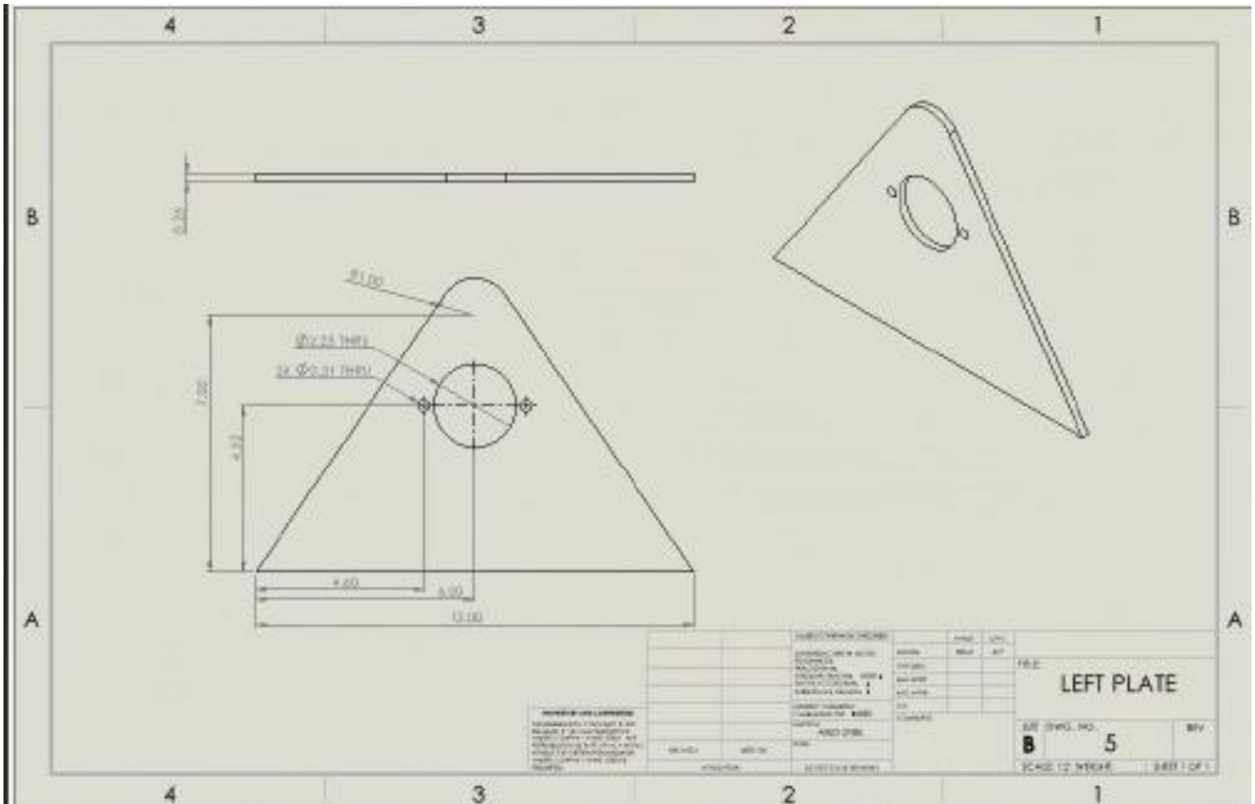
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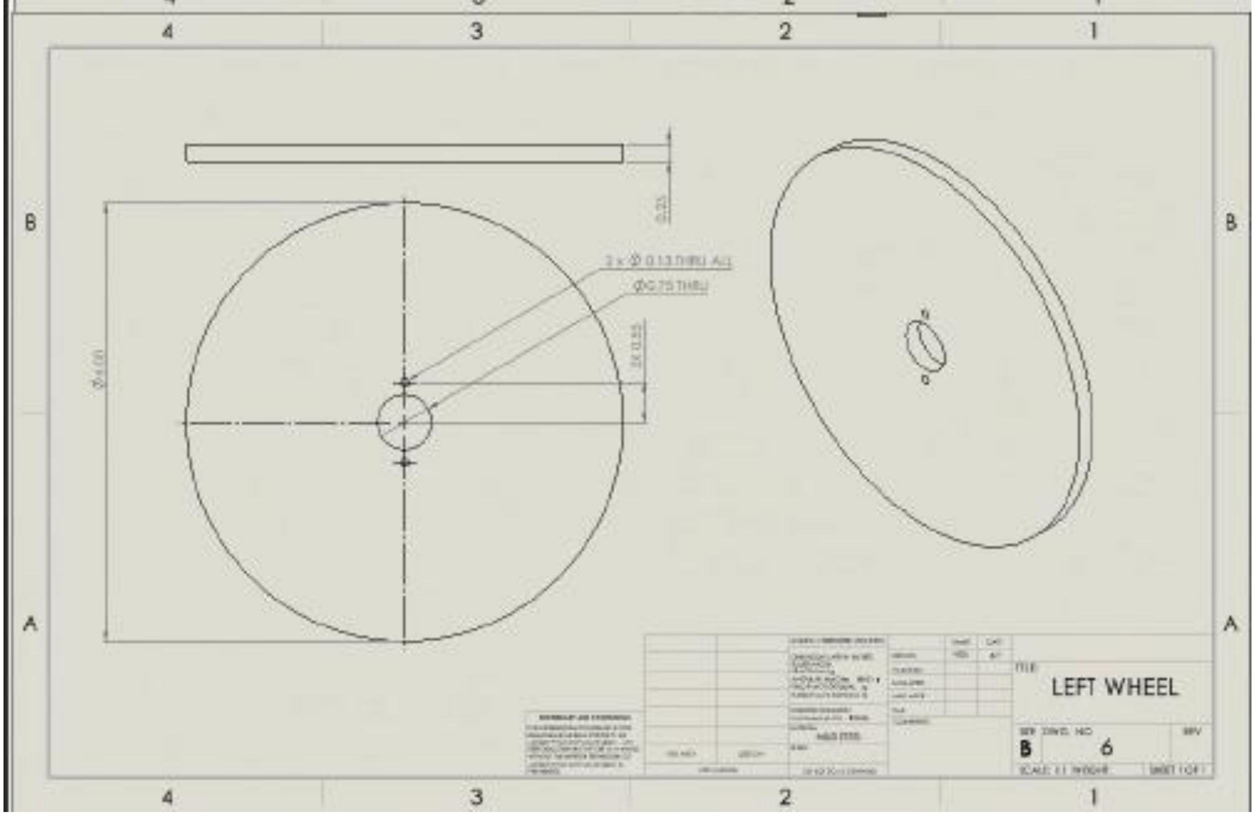
6.00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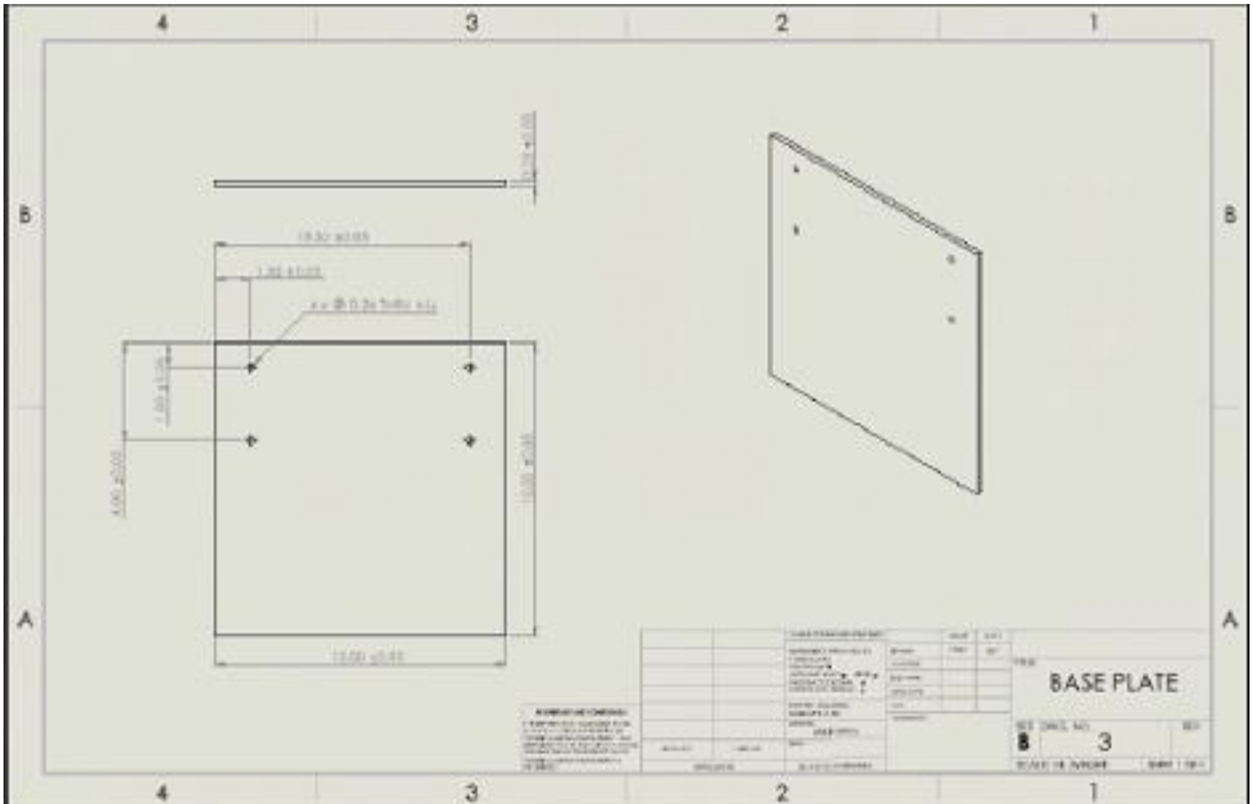
B
6
Ø0.75 THRU
0.25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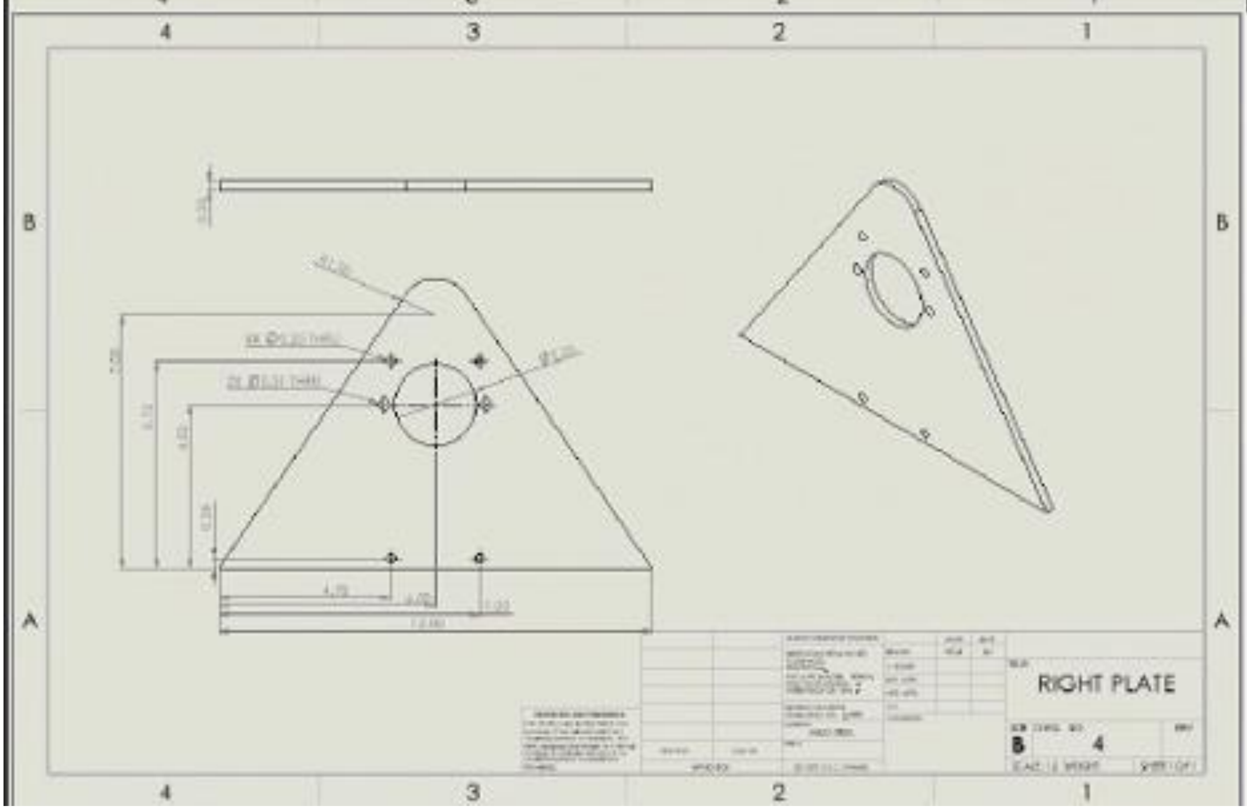
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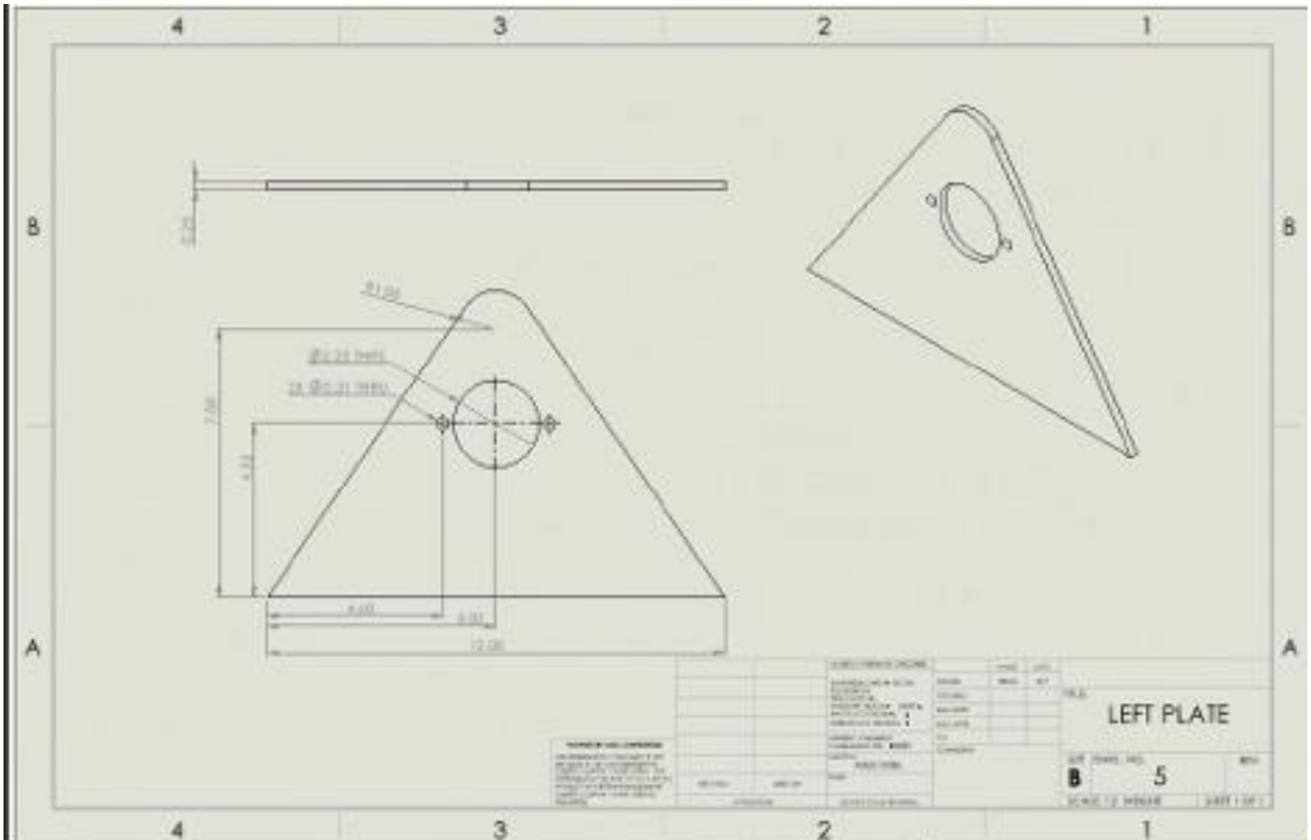
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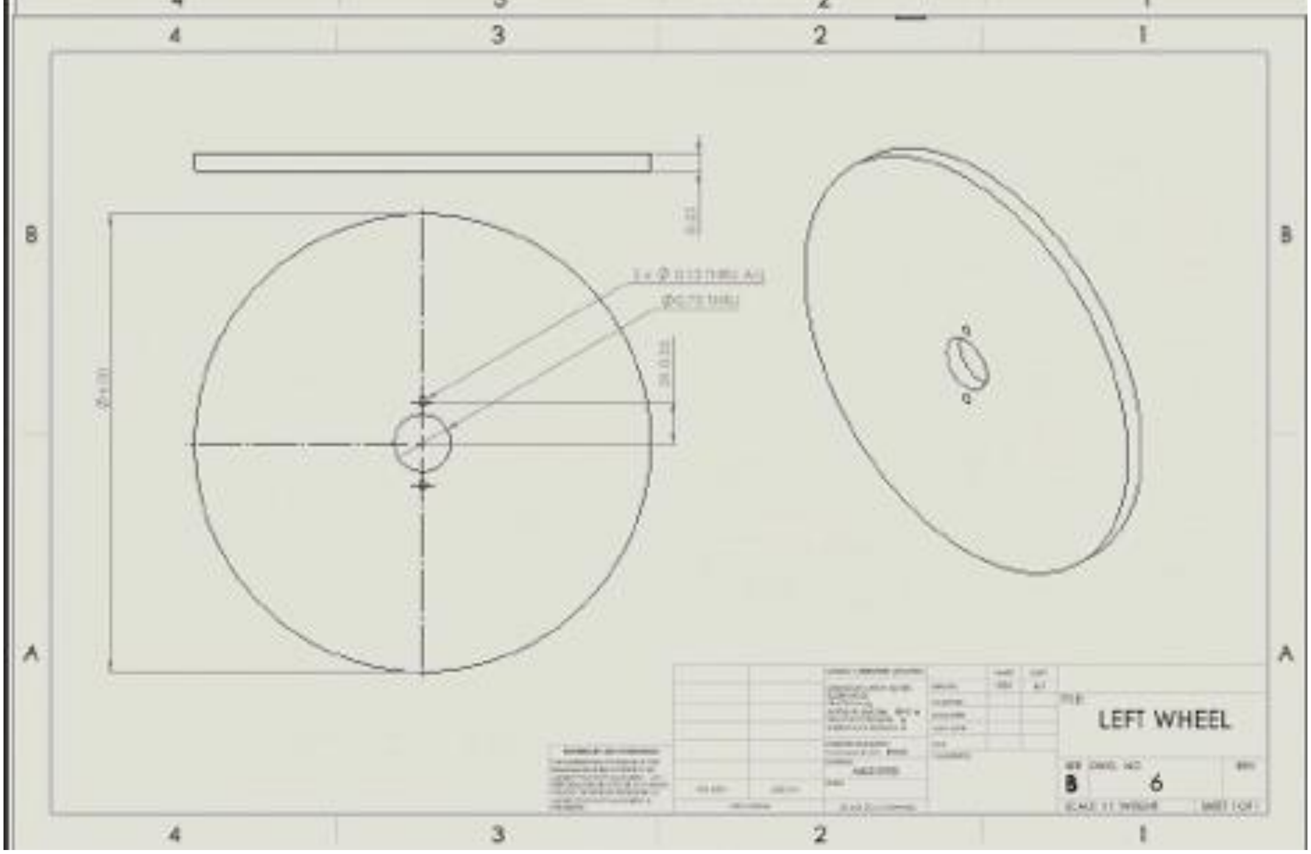
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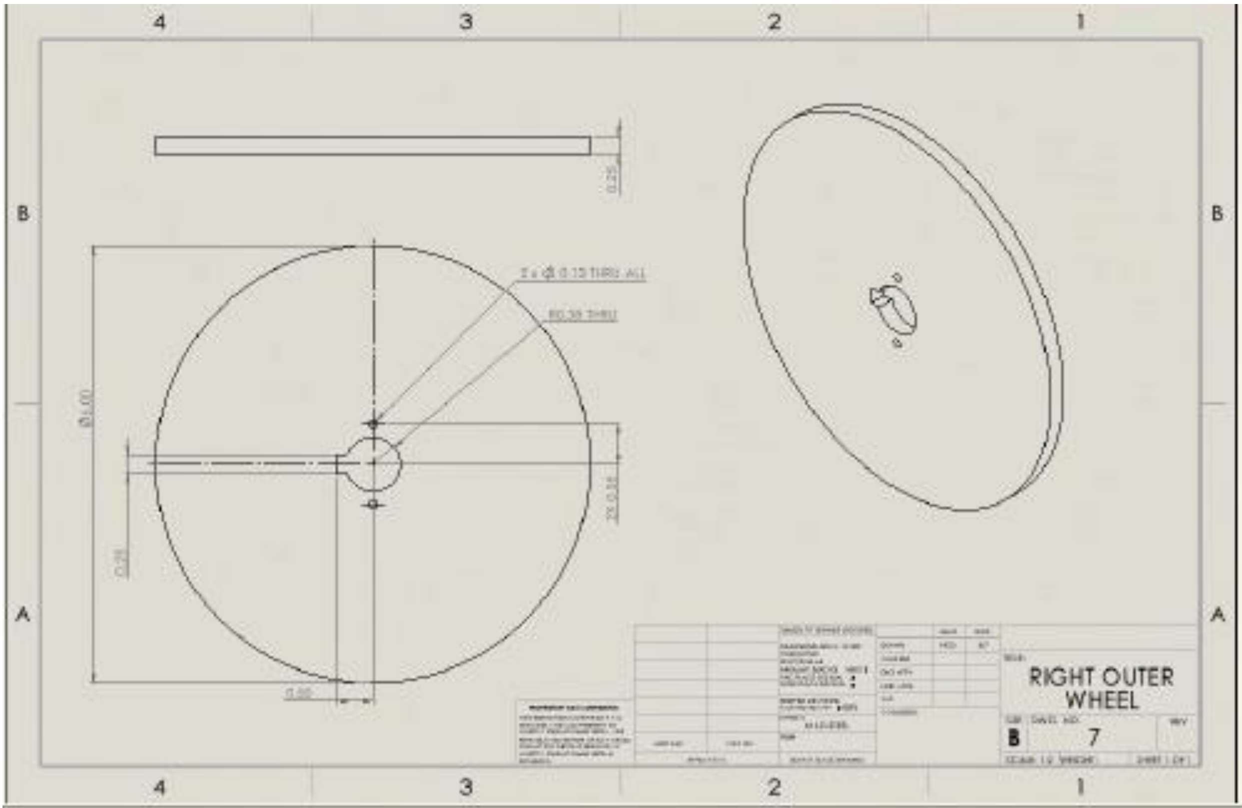
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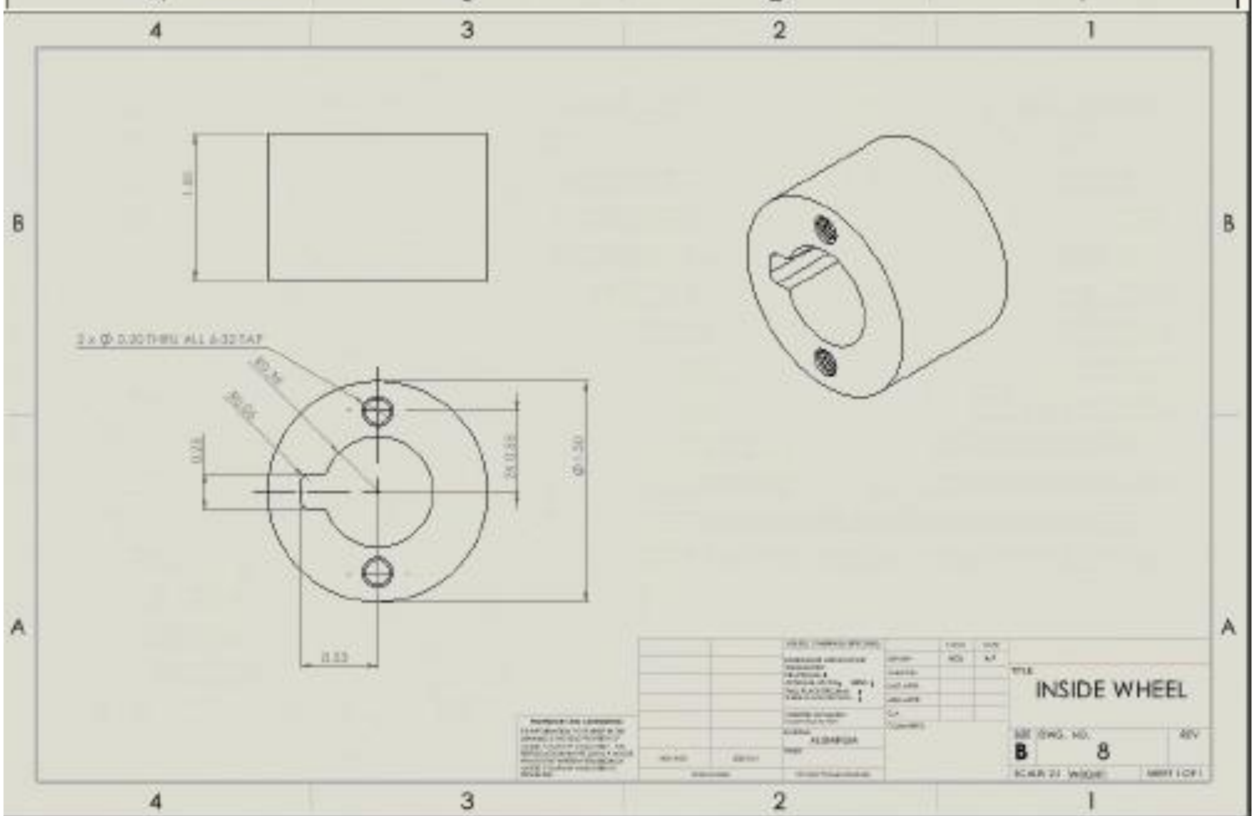
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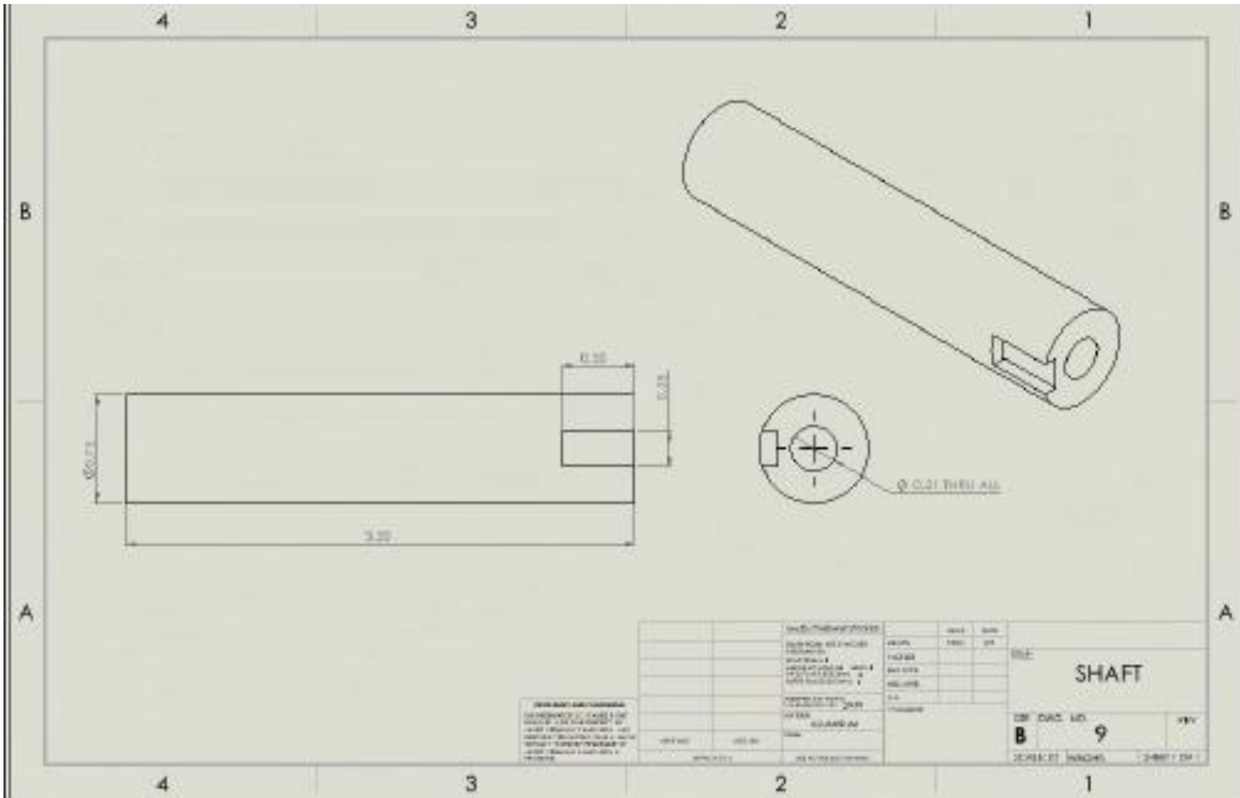
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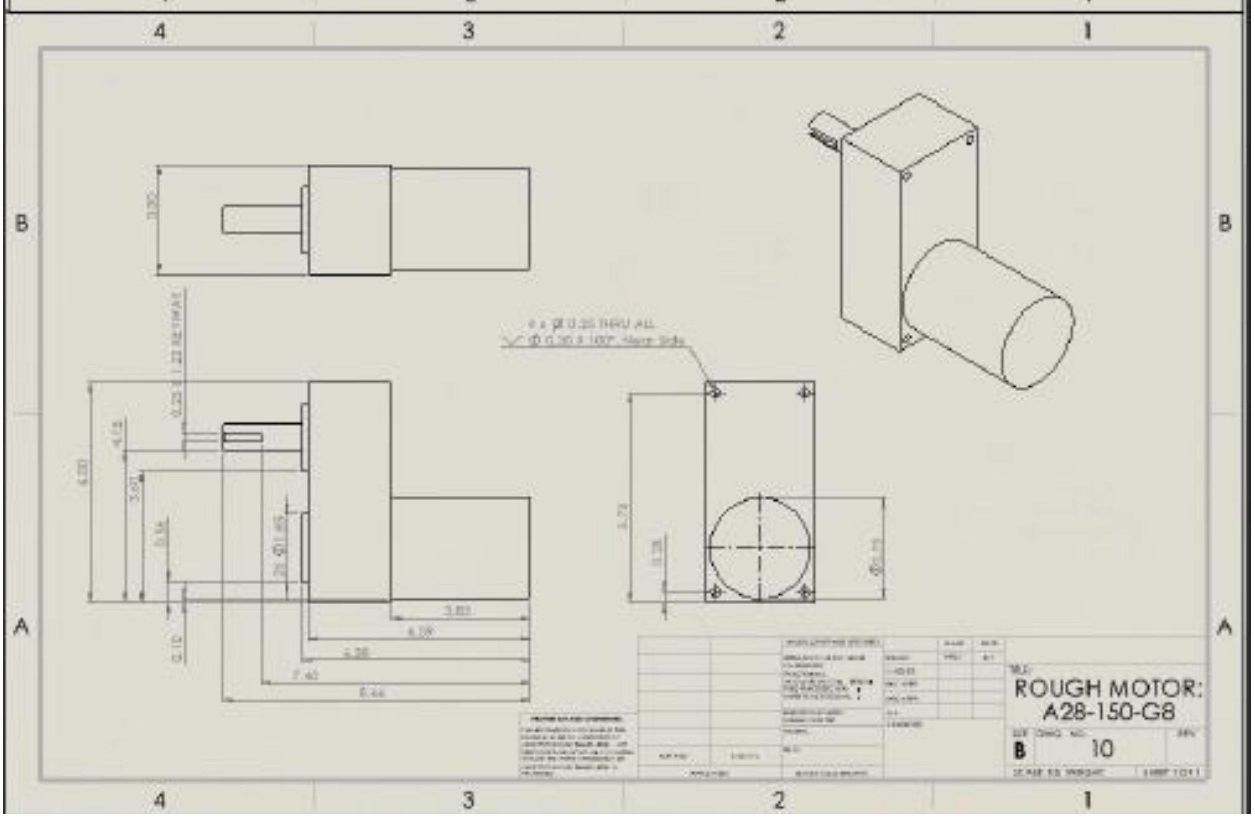
Ø 0.21 THRU ALL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