DESIGN AND MANUFACTURE OF AN INDOOR PADDLEBOARD TRAINER

By:

Sami Kafeety

Diljot Pannu

Omer Abbasi

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Faculty Advisor: Johan Fourie

Program Head: Mehrzad Tabatabian

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(Author's Declaration)

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Abstract

Paddle boarding is an exciting sport adored by millions of people around the world. Cruising on a paddle board may consist of a cruise across a crystal clear lake or a thrilling battle against the currents of a breathtaking river. Unfortunately, paddle boarding is hindered by weather patterns. It is an activity that is mainly enjoyed in the summer, as the conditions for the sport are not favorable throughout the year. Therefore, a demand for an indoor paddle board trainer exists.

The project commissioned by DOS Watersports requires a development of a functional prototype of an indoor paddle board trainer. Some of the requirements for the paddle board trainer included inertia and variable resistance. The scope of the project was focused solely on the paddle motion and not the user's ability to balance on the paddle board. The form of resistance was open ended, as well as the budget for the paddle board trainer.

Before the development of any project, an intensive market research is critical. This provides the design team with knowledge of existing products and competition. The market research conducted by the team resulted in two products that appear on the opposite side of the spectrum. Priced at $100, the *Paddle Power Trainer* utilizes resistance bands to provide resistance to the paddle motion. This rather cheap solution is not ideal, as the motion does not feel natural. On the opposite side of the spectrum lies a *Stand-Up Paddle Board Training Machine* sold by VASA. The base price of the product is $1549.00 USD and could potentially cost $2250.00 with add-ons.

To determine the specifications of the paddle board trainer, the team visited the BCIT recreational center accompanied by an experienced paddle boarder. At the recreational center, the team determined that an ideal paddle board trainer should provide a variable resistance from 5 – 25lbs. Discussions with the project sponsor determined additional specifications such as an average stroke length of 2 meters and approximately 40 strokes per minute.

With the market research and project specifications at hand, the team brainstormed various forms of resistance that could be implemented in the paddle board trainer and narrowed them to down to six. The six forms of resistances included springs, wind, water, hydraulic systems, pneumatic systems, magnets and pulleys. Concepts for the paddle board trainer were generated utilizing the forms of resistances above. After several iterations, a concept consisting of resistance bands, magnets, bicycle wheel, roller and a flywheel was chosen for further development.

Consequently, a SolidWorks model was created for the chosen concept and discussed with the project the sponsor. The feedback from the project sponsor was considered and the necessary changes to the CAD model were made. A parts list for the alpha prototype was made once the design team felt confident in their design. Parts were obtained via Inside Ride and McMaster Carr. The team utilized BCIT's facilities to manufacturer the prototype after the parts had been delivered. Some of the manufactured parts included UHMW drums, aluminum brackets, spacers, steel plates and a wooden paddle.

Difficulties and problems arose when the team had completed the alpha prototype. One of the problems being the constant force spring not functioning as intended. Due to the opposing forces, the constant force spring failed to retract once it had been wound onto the secondary UHMW drum. However, the team swiftly recognized the problem and replaced the constant force spring with resistance bands. Also, the team encountered drum slippage on the shaft during the action and retraction strokes. Drum slippage was solved by a key slot on the drum and shaft.

In conclusion, the design team was successful in their attempt to design and manufacture a functional paddle board trainer. The prototype met all the requirements set by the sponsor and several avid paddle boarders claimed that the prototype felt natural and closely resembled the paddle boarding motion. For future work, gears and electrical components such as a display screen need to be implemented to transform the prototype into a marketable product.

Acknowledgements

The design team would like to thank our project sponsor, Johan Fourie, for his insight and assistance during the conceptual design phase, as well as throughout the manufacturing and final assembly phases of the project. His guidance has proved to be valuable to the design team, as it progressed the project work more effectively and efficiently than it would have alone.

The design team would also like to thank Mohammad Alemiardakani and the rest of the Manufacturing Department for the assistance and guidance during the manufacturing phase of the project.

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1 Introduction

The following section will introduce the project to the reader, provide background information as well as an overview of the problem at hand.

1.1 Project Background

Paddle boarding is a popular water sport enjoyed by many people around the world. It involves standing on a board located in a body of water, and using a paddle to propel yourself forward. Paddle boarding can be done leisurely as a summer activity, or competitively in various regional competitions all over the globe.

Paddle boarding provides a user with many benefits. For starters, paddle boarding allows a user to get more in touch with nature, while reducing stress mainly from being surrounded by water. Also, it provides a full body workout since all the muscles of the body are used at some point during the paddle boarding motion. This also leads to increased balance, strength, and cardiovascular health for the user.

With all the benefits that paddle boarding provides, it is a shame that it cannot be enjoyed every day of the year. Since paddle boarding is an outdoor watersport, it is heavily permitted by weather patterns. In geographical locations of the world where rain occurs during most of the year, such as in Vancouver, British Columbia, there are only select times of the year where paddle boarding can be enjoyed. This poses as a problem for enthusiasts of the sport as they are not able to train their skills during the off-seasons.

1.2 Problem Statement

Due to the unfortunate lack of appropriate weather in many areas of the world, paddle boarders are missing their opportunities to get exercise related to paddle boarding. Aside from going to the gym, there is a need for a device, which can allow paddle-boarders to train their skills during the off-season.

DOS Watersports has recognized this problem, and requested the expertise and technical knowledge of an engineering company to produce an indoor paddle board trainer which can solve this issue, as outlined in the Request for Proposal located in Appendix A. The requested device would be focussed solely on training the paddle motion, as the training the users stability is outside the scope of the project. The device would provide training through a form of resistance, which can be achieved through various types of methods.

1.3 Objective

The team at OSD Solutions has responded to the request from DOS Watersports with a proposal for an indoor paddleboard trainer, which is believed to solve the current issue. The proposed design would provide the necessary resistance to the user's paddling motion, and would do so in a completely mechanical way. The end-result of this group project is to develop a functional prototype which will act as proof of the chosen concept and serve as a solid platform for which the design team, as well as future design teams, will be able to elaborate on and optimize to achieve a more elegant product.

2 Detailed Description of the Current Status

This chapter will discuss the market research that took place to determine the current competition for the design team's product, as well as what technologies are being used. It will also discuss the specifications of the project and all the assumptions that were made moving forward throughout the timeline of the project.

As defined in the scope of the project, the team's sole focus for the paddle board trainer is to train the **paddle stroke motion** of the user. This means that the aspect of balancing on the board and the simulation of water motion is not of concern to the design team, as it falls outside of the project scope. For this purpose, the team conducted research and conceptual design based on forms of resistance which can be incorporated in the trainer.

2.1 Market Research

Market Research was conducted to find indoor paddle board training devices that are currently available in the market. This was done to determine an appropriate price point as well as discover different technologies available to ensure the production of an efficient and effective trainer.

The market research yielded two products, one product is simple in design and low in price, but doesn't provide inertia. The second product provided the necessary inertia but the price point was very high. Each of the researched products represent opposite sides of the overall market spectrum in terms of paddle board trainers. With many other products in between these, in terms of pricing and functionality, the design team had adequate room to work with in developing their product.

2.1.1 Paddle Power Trainer

One the lowest side of the spectrum is the Paddle Power Trainer [5]. This device consists of dual resistance bands that attach to the top and bottom of the paddle. The resistance bands are meant to provide resistance to the paddle stroke motion of the user. A unique element of this device is that it can be reversed to provide resistance in both, action and retraction, stroke. The price of the Paddle Power Trainer is approximately $100.00 USD, providing a relatively cheap solution to a rather complex problem. After researching the product thoroughly, an issue was discovered that the resistance applied by the bands is not constant, but rather it increases throughout the duration of the stroke. As well, inertia does not exist to provide a natural sensation during the strokes.

Figure 2.1 Paddle Power Trainer

2.1.2 Stand-Up Paddle Board Training Machine

The second product from the market research was the Stand-Up Paddle Board Training Machine created by VASA [1]. Also known as the SUPErg, this item has an initial cost of $1549.00 USD. However, the total cost increases if a consumer wants to include options such as a power meter, priced in total at $1749.00, or a paddle board base, costing $2249.00 altogether. The machine is wall mounted and uses a fan as its form of resistance, and includes seven different damper settings. The optional power meter measures the device's RPM, wattage, time, distance, and pace. Although the SUPErg contains many amazing features, the overall price is relatively high to be valuable to an average consumer.

Figure 2.2 Stand-Up Paddle Board Training Machine

2.2 Project Specifications

Specifications for the project had to be determined to allow for adequate designs and appropriate calculations. The specifications were used to select suitable concepts to be further analyzed.

The design team and an avid paddle boarder visited the BCIT gym to determine what range of weight would mimic the resistance of water the best and the length of an average paddle stroke. The design team and the project sponsor discussed the appropriate rate of paddle strokes and mechanical power dissipations to aid in calculations.

Table 2.1 below summarizes all the assumptions and specifications for the project, which will be referred to throughout the project duration in order to select conceptual designs.

Table 2.2.1: Project Specifications

High Resistance [lb]	15 – 25
Low Resistance [lb]	5 – 15
Comfortable Weight [lb]	10
Average Strokes per Minute	40
Average Stroke Length [m]	2
Power Dissipation [W]	150

3 Theoretical Background

The following section will discuss the research conducted to determine different types of resistances, concept generation and the final concept chosen.

3.1 Technical Research

The initial market and technical research was used to brainstorm any form of resistance, whether or not suitable for the product, to determine any potential methods that could be applicable for the trainer. This would allow the design team to combine multiple methods to produce an optimal concept. The research concluded the following resistance methods:

1. Sand
2. Water
3. Free weights
4. Resistance bands
5. Springs
6. Wind
7. Hydraulic Systems
8. Pneumatic Systems
9. Electric Motor
10. Magnets and Flywheel
11. Pulleys and Flywheel
12. Gear Box
13. Water resistance/fan
14. Body weight (gravity)

Once the list of various resistances was generated, the design team determined suitable forms of resistance that could be applied to the indoor paddleboard trainer. To determine suitable resistances to move forward with into the conceptual design phase, project requirements were considered. Inertia was determined to be the most important design requirement so that the paddle motion would feel as natural as possible. Because of inertia and other functionality, several forms of resistances such as sand, water, free weights, resistance bands, electric motor, gear box, and body weight were eliminated.

The following list names all the remaining methods of resistance after preliminary elimination.

1. Springs
2. Water Resistance
3. Air resistance
4. Hydraulic Systems
5. Pneumatic Systems
6. Magnets and Flywheel
7. Pulleys and Flywheel

The design team's next focus was to develop conceptual design sketches for the remaining resistive methods listed above. Shown in the following section are the six conceptual designs.

3.2 Primary Conceptual Design Phase

The following sections discusses the initial conceptual design phase of the project.

The design team took the items listed in the previous section and produced a series of conceptual designs to better represent the resistive methods in a visual format. Certain methods, such as wind and water resistance were combined as they can be modelled similarly.

3.2.1 Pneumatic System

The design team's first concept includes utilizing a pneumatic system to provide the necessary resistance for the trainer. The following circuit below in Figure 3.1 shows the potential design for this concept.

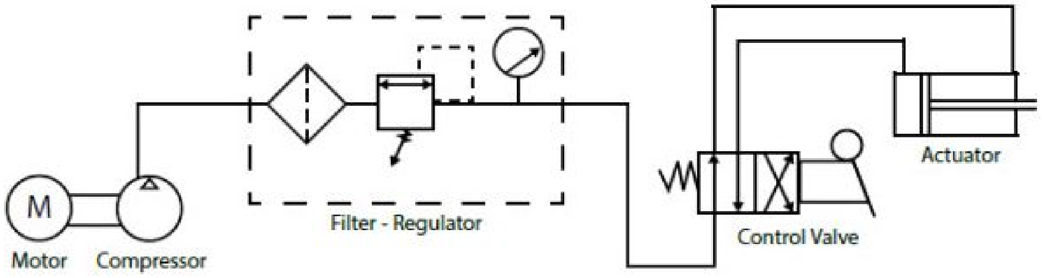

Figure 3.1 Pneumatic System Circuit

The system shown above includes a linearly actuated cylinder, a two-way flow control valve, as well as the basic components of any pneumatic circuit which include a filter, pressure regulator, motor and compressor unit. The system utilizes a rod attached to a double acting cylinder, which would extend during the action. The differential pressure within the cylinder on each side of the piston act as the resistance. The flow control valve dictates the flow of the compressed air and would retract the piston in the default configuration shown in Figure 3.1 above.

3.2.2 Hydraulic System

The design team's second concept includes utilizing a hydraulic system to provide the necessary resistance for the trainer. The following circuit in Figure 3.4 shows the potential design for this concept.

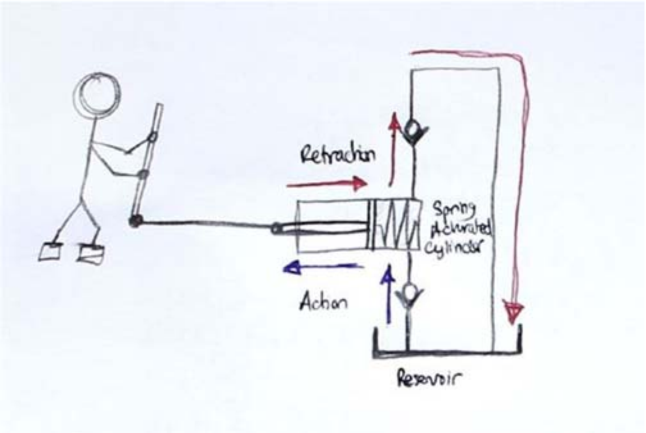

Figure 3.2 Hydraulic System Circuit

The design team's previous experience working with hydraulic circuits allowed for the creation of the tentative hydraulic circuit as shown as Figure 3.2 above. The circuit includes a spring actuated cylinder and two one-way flow control valves. During the action stroke, the hydraulic fluid is drawn from the reservoir through the one-way flow control valve into the cylinder, as indicated by the blue arrows. Once the action stroke is complete, the spring in the cylinder forces the cylinder to return to its home position, ejecting the hydraulic fluid into the reservoir to begin the next action stroke.

3.2.3 Magnets and Flywheel System

The third conceptual design utilizes magnets and a flywheel as part of the resistance factor. The following sketch in Figure 3.3 shows the design proposed by the design team for this concept.

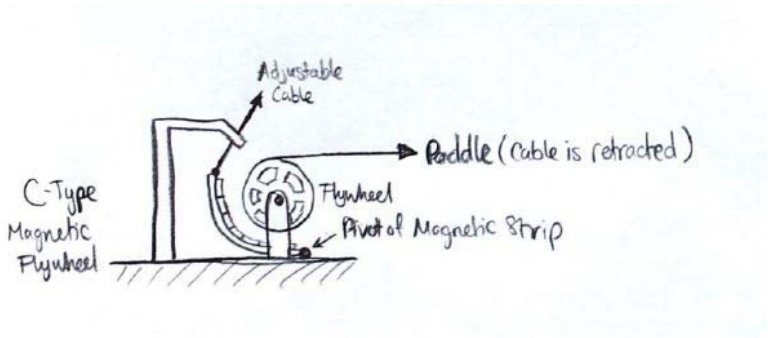

Figure 3.3 Magnet-Flywheel System

This system contains a flywheel and a C-type magnetic strip which fits the contour of the flywheel and rotates around a pivot on the ground. This system works using the principle of Eddy Currents. Below in Figure 3.4 is a diagram describing Eddy Currents.

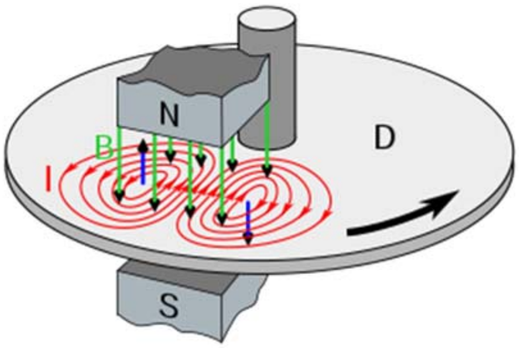

Figure 3.4 Eddy Current Diagram

Eddy Currents are induced in the rotating disk, such as the flywheel, from the magnetic field of the C-type magnetic strip. This induced current produces a secondary magnetic field in the rotating disk that counters the magnetic field of the magnets. The opposing magnetic fields repel each other, which provides resistance to the rotation of the disk. Therefore, the closer the magnet is to the rotating disk, a stronger resistance to motion exists.

3.2.4 Flywheel and Pulley System

The following conceptual design utilizes a flywheel and pulley system. Figure 3.5 below shows the conceptual system design.

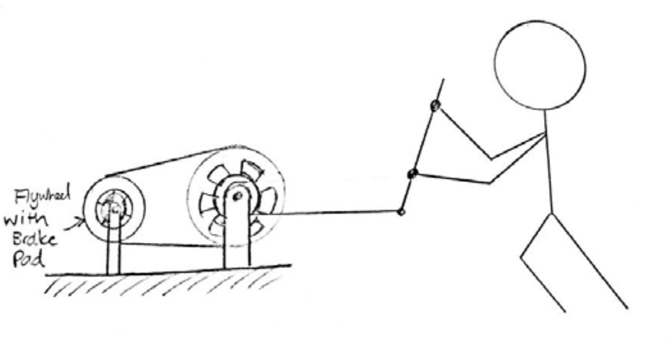

Figure 3.5 Flywheel and Pulley System

This system includes a flywheel with a brake pad, and two different sized pulleys. The rod, attached to the smaller radius pulley, would cause the larger radius pulley to rotate during the action stroke. The motion of the larger pulley, attached to the flywheel via belt, would cause the flywheel to rotate. The brake pad is present to add resistance to the flywheel's motion.

3.2.5 Water/Air Resistance

The fifth concept generated comprises of water and air resistive methods. They have been paired together because they are similar in design and method at applying resistance to a system. Figures 3.6 and 3.7 below show the concepts of water and air resistance.

Figure 3.7 Water Resistance System

Figure 3.6 Air Resistance System

As shown in Figure 3.6 and 3.7 above, the team utilizes the same principle and features as rowing machines that use both air and water as forms of resistance. Details of how these machines function were scarcely found during the research phase, but having used these devices previously, the team is able to speculate on how the resistance is achieved and how the system really works. A similar system shown below is intended to be implemented in the paddle board trainer.

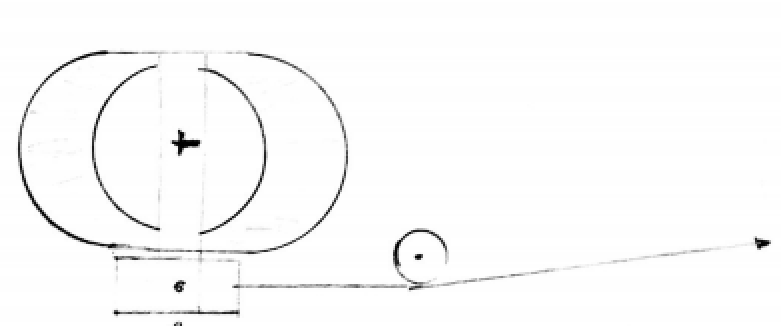

Figure 3.8 Water resistance concept

3.2.6 Spring and Pulley System

The sixth concept utilizes a spring and pulley system. Below in Figure 3.9 shows the design team's conceptual design for this type of system.

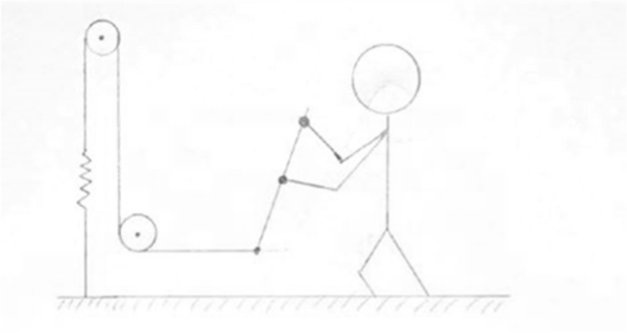

Figure 3.9 Spring and Pulley System

This system is extremely simple and contains a single spring and two pulleys. The rod would be attached to a cord that is wound through the pulleys and attached to the spring at one end. The spring provides resistance to the action stroke and the pulleys are present to reduce the space needed for this trainer.

3.3 Secondary Conceptual Design Phase

The six conceptual designs from the Primary Conceptual Design Phase were further investigated by the team, and after thorough discussion and analysis, the six conceptual designs were used to generate four conceptual designs which utilize the aspects of the concepts stated above.

The following section discusses the design team's Secondary Conceptual Design Phase of the project. Each of the concepts listed below will be accompanied by a conceptual drawing, a list of advantages and disadvantages, and a brief explanation of the essence of the design and its functionality. As well, a referral to Appendix E follows each concept in regard to hand calculations which were done to quantify average power output, as well as mechanical aspects such as torque and rotational speed. These calculations were done based on the project specifications stated previously in Chapter 2.

3.3.1 Concept 1

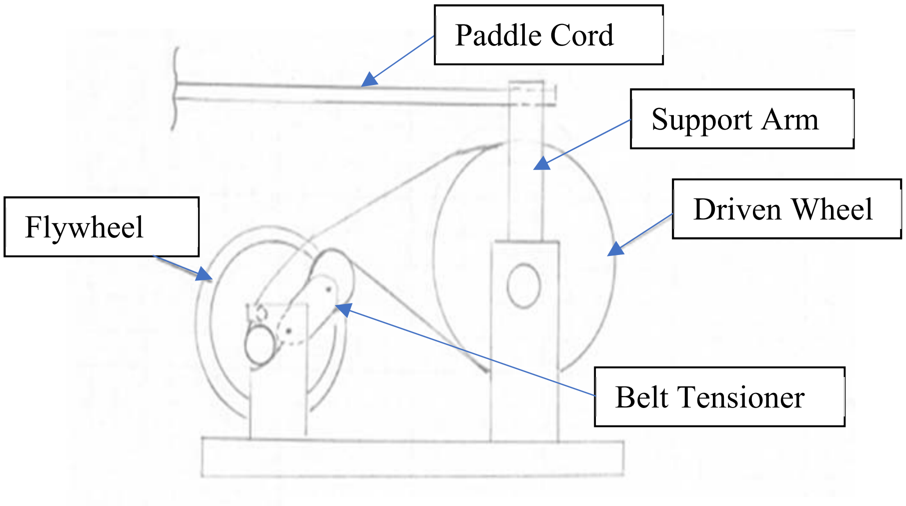

Figure 3.10 Concept Design 1-a

This concept consists of a driven wheel, flywheel, support arm, belt tensioner, and a paddle cord. The support arm connects the driven wheel to the paddle via the paddle cord. The support as seen in the front view below in Figure 3.10 is a bracket that is attached to both side of the driven wheel on a moving shaft. The driven wheel is attached to the flywheel via a belt and includes a belt tensioner to keep the belt tensioned.

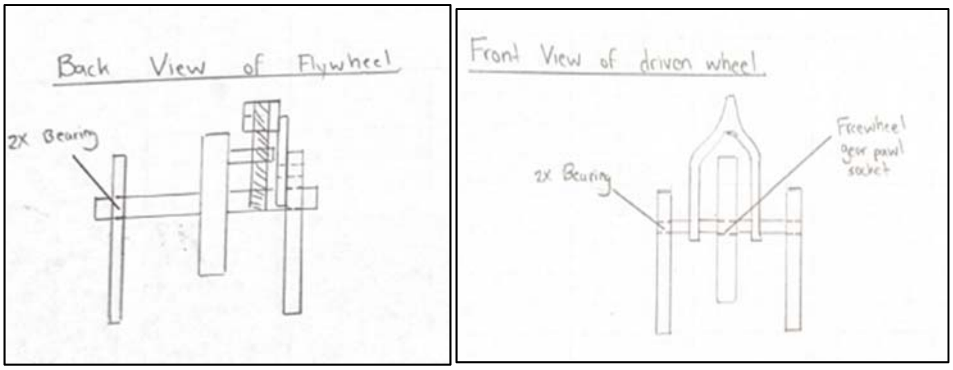

Figure 3.11 Front and Back Views of Concept 1-a

As seen in Figure 3.11 below, the magnets are encased in the flywheel. This is meant for compactness as well as to have the ability to move the magnets further and closer to the flywheel based on required resistance.

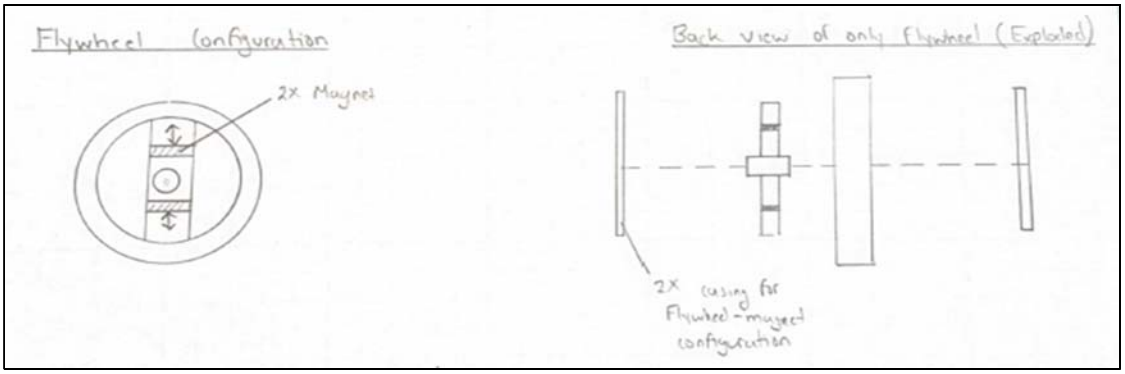

Figure 3.12 Flywheel Configuration of Concept 1-a

Another orientation for the magnets and flywheel can be viewed in Figure 3.12 below. The magnets are arranged in a "C" shape which fits the contour of the flywheel. The magnets move closer and further away from the flywheel based on user preference of resistance. This concept is inspired by stationary bike machines that can be found in most gyms. The same idea applies as in Concept 1-a, where the intensity of resistance to motion is dependant on the proximity of the magnets to the rotating wheel.

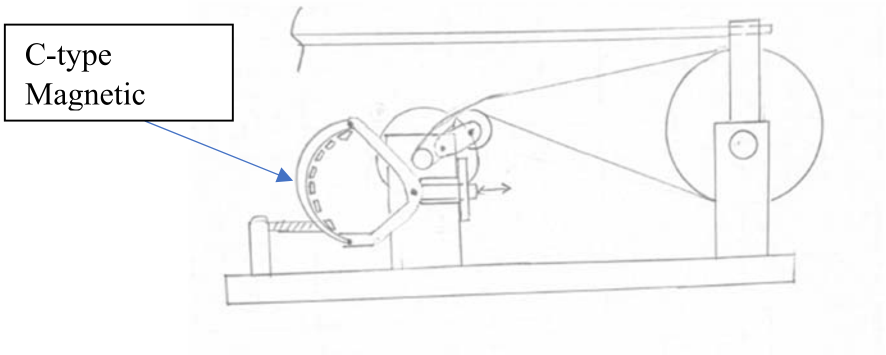

Figure 3.13 Concept 1-b

Calculations for this design can be found in Appendix E.

3.3.1.1 Advantages and Disadvantages

Table 3.1 below lists the advantages and disadvantages of the design team's first concept.

Table 3.3.1: Advantages and Disadvantages of Concept Design 1

Advantages	**Disadvantages**
No mechanical wear because the magnet makes no direct contact with flywheel. Therefore, it will have a long shelf life	The current design needs a variety of pulley systems to account for the high velocity ratio

Cheap and readily available. Magnetic flywheel systems can be purchased online	The arm would have to be relatively large to account for the ~2m pull of the user but because the length of the arm greatly affects the speed of the driven shaft it can't be too long.
Not many complicated or moving parts, therefore it is easy to implement	Learning curve when learning and implementing eddy current system

3.3.2 Concept 2

The second concept shown below comprises of a spring and mass system to meet the desired requirements.

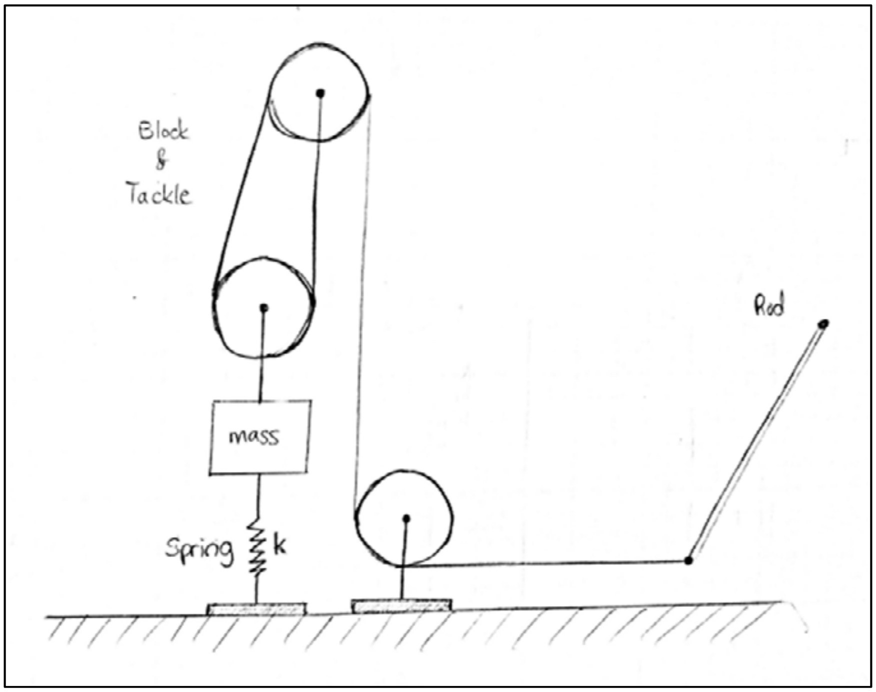

Figure 3.14 Concept Design 2

For the configuration shown above in Figure 3.13, the design team developed a system where the rod is attached to a series of pulleys which are connected through a block and tackle system to a mass and spring. The resistance to the motion of the paddle is sourced at the mass, which includes the spring force and gravity force.

3.3.2.1 Advantages and Disadvantages

Table 3.2 below lists the advantages and disadvantages of the design team's second concept.

Table 3.3.2: Advantages and Disadvantages of Concept Design 2

Advantages	Disadvantages
Block and tackle allows for proportioned movement of mass vs stroke length	Spring force will increase throughout the stroke of paddle
Simple system	Will need some sort of barriers around mass to restrict movement
Spring returns mas to home position	Minimal inertia (slight amount with acceleration of paddle stroke)
Smooth motion of action and retraction strokes	
Minimal manufacturing required (just for pulleys and base)	

Calculations for this design can be found in Appendix E.

3.3.3 Concept 3

The concept shown below uses a pendulum action to use the center wheel to drive the flywheel. The sketch below presents two different illustrations denoted by the numbers 1 and 2. The stroke action causes the center wheel to rotate which in turn drives the flywheel. The concept uses a magnetic strip as a form of resistance.

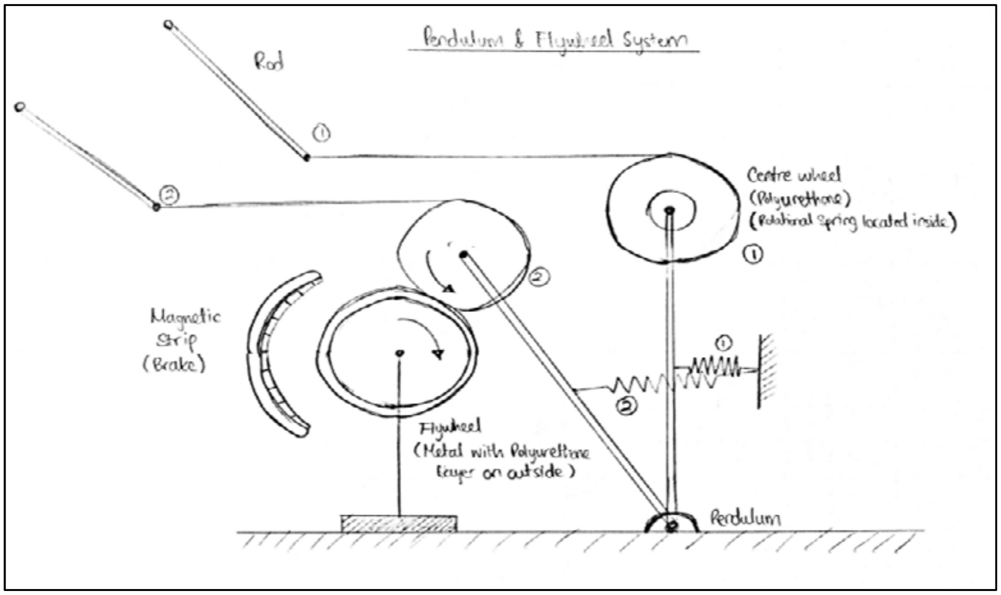

Figure 3.15 Concept Design 3

3.3.3.1 Advantages and Disadvantages

Table 3.3 below lists the advantages and disadvantages of the design team's third concept.

Table 3.3.3: Advantages and Disadvantages of Concept Design 3

Advantages	**Disadvantages**
• Spring returns center wheel to home position	• Complex system
• Rotational spring for auto-retraction of cord	• Chance of unsmooth flow during action stroke
• Wheels made from a "grippy" material such as polyurethane or rubber (less cost)	• Flywheel must be metal with a layer of "grippy" material
• Flywheel retains its spinning until brake is applied	• Magnetic brake will induce heat generation due to Eddy currents and friction
• Inertia is present	• User must pull hard enough to overcome spring force and to turn flywheel

3.3.4 Concept 4

The design team's fourth and final conceptual design was presented by the project sponsor during the conceptual design phase. Figure 3.15 below shows the concept.

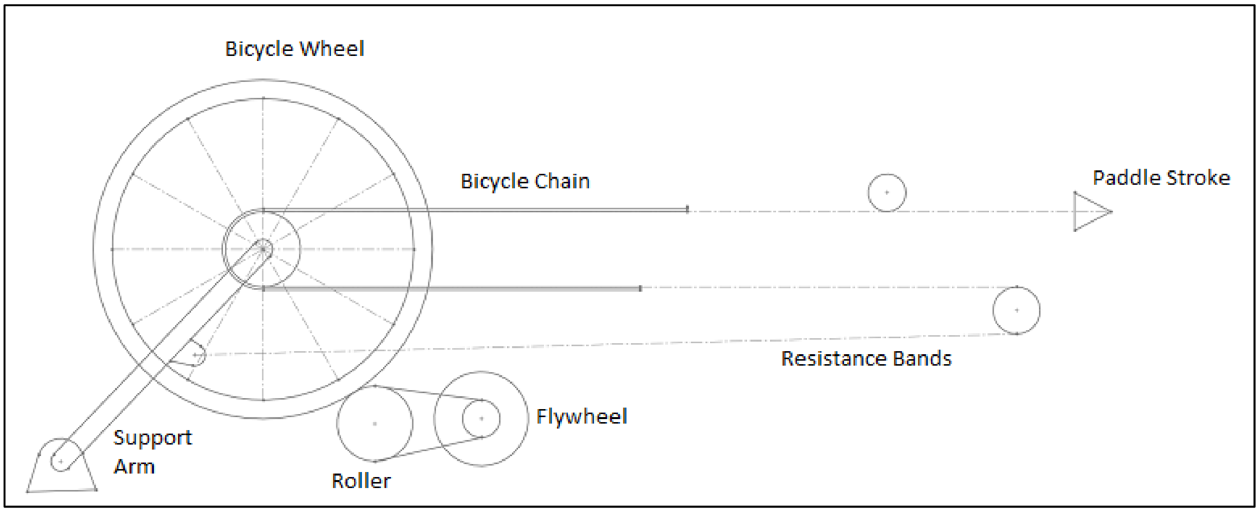

Figure 3.16 Concept Design 4

This concept takes advantage of previously tested and proven concepts and modifies them to meet the project requirements. The concept originates from the E-Motion Roller Trainer for bicycles, where a bicycle wheel rests upon a roller connected to a flywheel. The motion of the bicycle wheel would cause the roller to rotate, in turn causing the flywheel to rotate. A magnet, with several configurations, connected to the flywheel would act as a form of resistance. However, if a higher level of resistance is desired, bicycle gears can be implemented to add to the resistance supplied by the magnet.

3.3.4.1 Advantages and Disadvantages

Table 3.4 below lists the advantages and disadvantages of the design team's fourth concept.

Table 3.3.4: Advantages and Disadvantages of Concept Design 4

Advantages	Disadvantages
• Easy to implement as it relies on proven concept (bicycle)	• Not compact, as the design would require approximately 4-5 meters to function properly
• Simple and easy to manufacture	
• Consists of off-shelf products	
• Able to achieve the flywheel speed without using many pulley ratios.	

3.4 Final Chosen Concept

The design team compared the advantages and disadvantages of each concept from the Secondary Conceptual Design phase and. A Preliminary Design Review was held amongst the design team's colleagues where constructive feedback was given on the conceptual designs. Following the design review, a thorough analysis and comparison of the individual concepts was conducted. Ultimately, concept 4 was selected for further development.

Concept 4 was chosen was because of its advantages compared to other concepts. It was easier to implement and it relied on previously proven concept of a bicycle trainer. The concept includes a flywheel which would provide the required inertia. As well, the majority of the main components could be purchased online which would reduce manufacturing cost and time. Due to the disproportionality of the resistance band, a constant force spring was implemented to retract the paddle to maintain a constant motion throughout the stroke of the paddle by the user.

The main components of the system, such as the bike wheel, the support arm, the roller, the flywheel, and the spring, were either provided by the project sponsor or purchased online. The flywheel wheel assembly and constant force spring were purchased from Inside Ride and

McMaster-Carr respectively. The bicycle wheel and the support arms were taken from an old bicycle. All the components will be discussed further in Chapter 4.

The next task was to create a 3-D model in SolidWorks of the indoor paddle board trainer. Aluminum T-slot extrusions were used to build the frame of the paddle board trainer due to their high strength to weight ratio. Arbitrary pseudo-models of the wheel, flywheel, and roller were made mainly to visualize their locations on the design, and to adjust when necessary. Figure 3.16 below shows the design team's first model design iteration.

3.4.1 SolidWorks Model Iteration #1

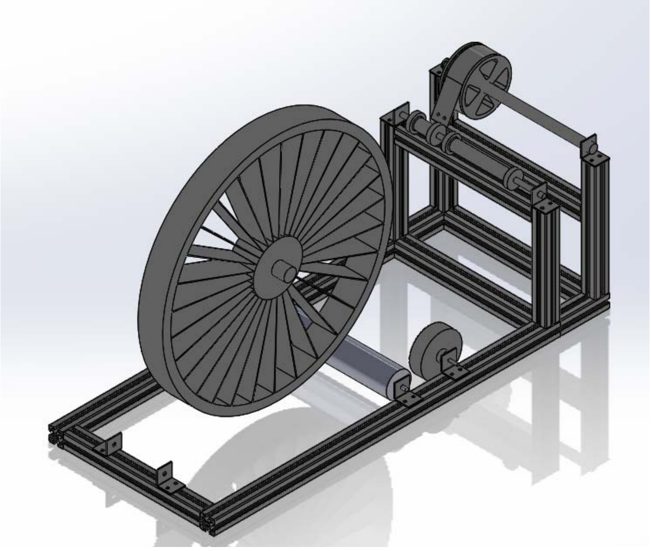

Figure 3.17 SolidWorks Model Iteration #1

As shown in Figure 3.16 above, all the necessary components are placed together in a way to achieve the desired motion caused by a paddle stroke. This first iteration comprises of two shafts with press fitted drums. The constant force spring is intended to wound onto the smaller during the action stroke. The right drum on the front shaft is meant to house a bicycle chain. 90° aluminum brackets are used to hold the shafts, flywheel, and roller. The design team realized that the extra length of the secondary shaft, as well as the extra T-slots needed to hold the shaft would prove to be unnecessarily, expensive and consume extra space. This caused the design team to re-iterate the design to overcome these minor issues.

3.4.2 SolidWorks Model Iteration #2

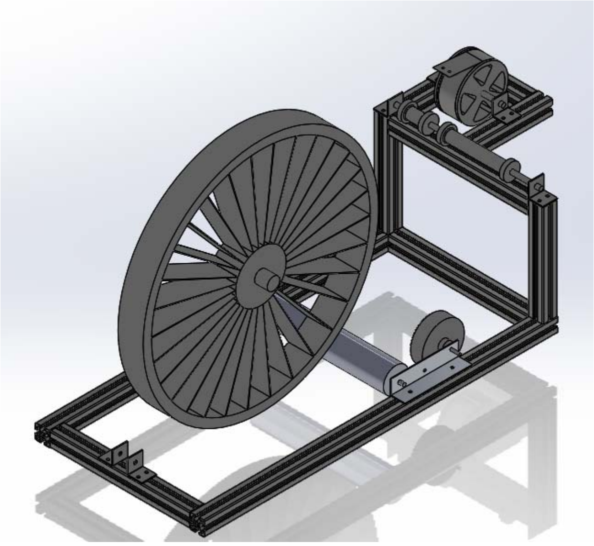

Figure 3.18 SolidWorks Model Iteration #2

Figure 3.17 above show the second iteration for the trainer design. Some important changes include the T slot assembly meant to house the constant force spring drum. The flywheel and drum are mounted onto a single 90° aluminum bracket. The bracket also incorporates the placement of the belt tensioner which ensures a tensioned connection between the roller and flywheel.

3.4.3 Decision

The design team determined that the second iteration was satisfactory and to proceed further with manufacturing of the paddle board trainer.

4 Description of the Project Activity and Equipment

The following section discusses the activities and equipment prepared for the project. A description of the project components will be discussed, which include both the manufactured and purchased components. Shop drawings of the manufactured components can be found in Appendix D.

4.1 Project Components

The following components were used for the alpha prototype:

- 2x Aluminum T-slots 45mm x 45mm, 42” long
- 3x Aluminum T-slots 45mm x 45mm, 16” long
- 4x Aluminum T-slots 45mm x 45mm, 12” long
- 1x Aluminum T-slot 45mm x 45mm, 8” long
- 10x Aluminum T-slot Inside Corner bracket
- 1x UHMW Drum, 6” diameter, 3” wide
- 1x UHMW Drum, 2” diameter, 7” wide
- 1x UHMW Drum, 2” diameter, 3” wide
- 1x Constant Force Spring
- 1x 90 Degree Aluminum Extrusion, 8” long, 2” wide
- 1x 90 Degree Aluminum Extrusion, 2” x 2” long
- 2x Spacers
- 2x Steel plate
- 1x Magnetic Flywheel Assembly
- 4x Bearing L-Brackets 2” x 2”
- 1x solid aluminum shaft, 22” long
- 1x solid aluminum shaft, 14” long
- 4x bearing and bearing mounts
- 3x Aluminum T-slot Outside Corner Bracket
- 1x Resistance band

4.2 Manufactured Components

The following section discusses the manufacturing of the various components.

4.2.1 Aluminum T-slot

Four different sizes of aluminum T-slots were used to build the alpha prototype of the paddleboard trainer. All the aluminum T-slots were cut to size using the circular saw and the faced off on the mill to achieve a smooth surface. The four different sizes of aluminum T-slots can be seen below in Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4.

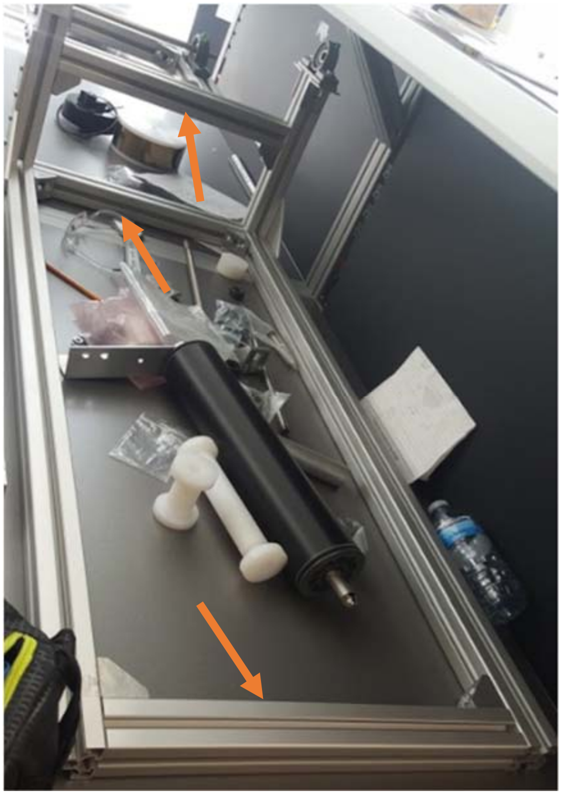

Figure 4.1 (3 x 16") Aluminum T-slot Extrusions

Figure 4.2 (2 x 42") Aluminum T-slot Extrusions

Figure 4.3 (1 x 8") Aluminum T-slot Extrusions

Figure 4.4 (4 x 12") Aluminum T-slot Extrusions

4.2.2 UHMW Drum

Three plastic drums were machined for the paddleboard trainer. Two of the drums were used for the constant force spring to assist in the retraction stroke. The third drum was used to house the bicycle chain. All three drums were machined to the desired size on the lathe at low rotational velocity, and drilled through their centers using the lathe. The three different sizes of UHMW drums can be seen in Figure 4.5, Figure 4.6 and Figure 4.7 below.

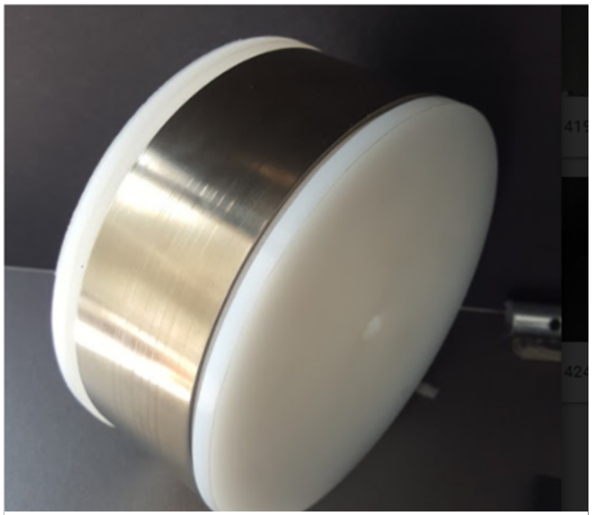

Figure 4.5 UHMW Drum, 6” diameter, 3” wide

Figure 4.6 UHMW Drum, 2” diameter, 3” wide

Figure 4.7 UHMW Drum, 2” diameter, 7” wide

4.2.3 90 Degree Aluminum Extrusion

Three different sizes of 90° Aluminum Extrusions were used to build the paddleboard trainer. Two of the 90˚ aluminum extrusions were used for the roller and the other extrusions were used to attach the bearings to the aluminum T-slots. All aluminium extrusions were cut from a stock piece that was approximately four feet long, with a 2”x 2” L-shaped cross section, and an approximate thickness of 1/8”.

4.2.3.1 Housing Bracket

The first of the Aluminum Extrusions was used to house the flywheel and one end of the roller. It was cut to size on the band saw and drilled according to the drawing shown in Appendix D using the drill press. The aluminum extrusion can be seen in Figure 4.8 below.

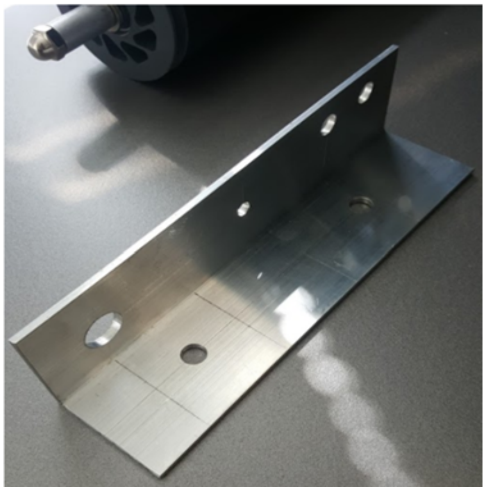

Figure 4.8 Housing Bracket

4.2.3.2 Roller Bracket

The second of the aluminum extrusions was cut on the band saw and drilled accordingly to the drawing in Appendix D using the drill press. Like the housing bracket above, this extrusion is used for the placement of the roller. The aluminum extrusion can be seen in Figure 4.9 below.

Figure 4.9 Roller Bracket

4.2.3.3 Bearing Block Plate Brackets

The last of the aluminum extrusions are used for the placement of the bearings and bearing blocks on the aluminum T-slots. All were cut using the band saw and drilled accordingly on the drill press. These extrusions can be seen in Figure 4.10 below.

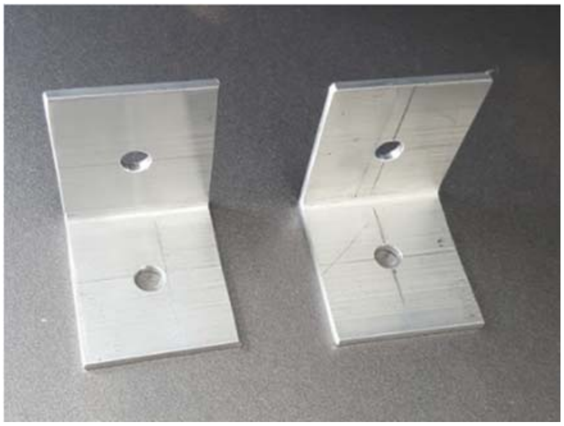

Figure 4.10 Bearing Block Plate Brackets

4.2.4 Spacers

Two spacers of the same size were used for the roller and to ensure that the ends of the drum would not rattle and fall out of place. The spaces are made from an aluminum rod and were machined and drilled on the lathe. One of the two spacers can be seen below in Figure 4.11.

Figure 4.11 Roller Spacer

4.2.5 Aluminum Shafts

Two aluminum shafts are used to aid in the movement function of the paddleboard trainer. They were found in the BCIT machine shop and cut to size on the band saw. The ends were sanded down on the lathe to ensure they would fit into the bearings well. The two aluminum shafts can be seen in Figure 4.12 below.

Figure 4.12 Aluminum Shafts for Bearing Blocks

4.2.6 Steel Plates

Two steel plates of the same size were manufactured to aid in the mounting of the two bearing blocks on the ends of the aluminum T-slots. They were both cut to size on the band saw from scrap pieces of steel plate and drilled on the drill press. One of the two steel plates can be seen in Figure 4.13 below.

Figure 4.13 Bearing Block Plate

4.2.7 Wooden Paddle & Handle Holders

A paddle is needed to simulate paddle boarding motion on the water, and therefore the design team decided to use a wooden rod as the paddle. The paddle was retrieved from the wood shop and each corner was bevelled so it would be easier to hold. Paddle handle holders were also added to one side of the prototype so that the paddle could be kept with the prototype after use. The assembly of the wooden paddle and holders can be seen in Figure 4.15 below. For a more appealing look, the paddle was sanded down and an espresso stain was applied, the finished handle can be seen in Figure 4.14 below.

Figure 4.15 Wooden Paddle & Handles

Figure 4.14 Espresso Stained

4.2.8 Bicycle Wheel Arms

The bicycle wheel arms are components of an old bicycle. The bicycle was found at BCIT and the arms were cut using a saw. The arms were then sand blasted to remove the original paint job, and then powder coated black to finish. The finished product can be seen below in Figure 4.17.

Figure 4.16 Bike Wheel Arms

4.2.9 Bicycle wheel bracket

Figure 4.17 Bike Wheel Bracket

The bike wheel bracket was used as the bracket for the bike wheel arms which are connected via Alan caps. The bracket was milled to size and contains two 3/8” holes on each side for placement on the back T-slot.

4.2.10 Eye Socket

The eye socket is used for guidance of the bike chain to ensure proper alignment of the bike chain on the bike sprocket. The eye socket base is made from sheet metal, which was initially cut to an arbitrary size, then two 3/8" holes were punched and it was bent 90 degrees and placed on the T-slot. The hole which the chain feeds through is a hook that was found at home and brought in for use.

Figure 4.18 Eye Socket

4.3 Purchased Components

The following section will discuss the various components the design team purchased online. These components were bought and used as is, they were not manufactured. All purchased components were either bought from McMaster-Carr or Inside Ride.

4.3.1 Aluminum T-slot Inside Corner Bracket

Aluminum T-slot corner brackets were used to secure the aluminum T-slots into place to ensure that the paddle-board trainer is rigid. They were used in all ten corners of the paddle board trainer. One of the ten corner brackets can be seen below in Figure 4.19.

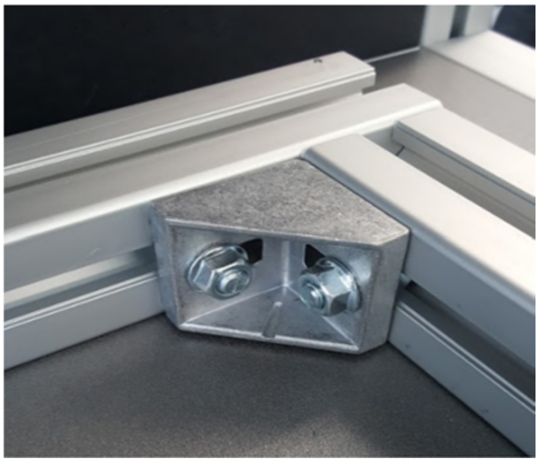

Figure 4.19 Inside Corer Bracket

4.3.2 Constant Force Spring

The purchased constant force spring was bought from McMaster-Carr. The purpose of the constant force spring is to apply a constant tension to the paddle boarder in the retraction stroke. The constant force spring can be seen placed on the drum in Figure 4.20 below.

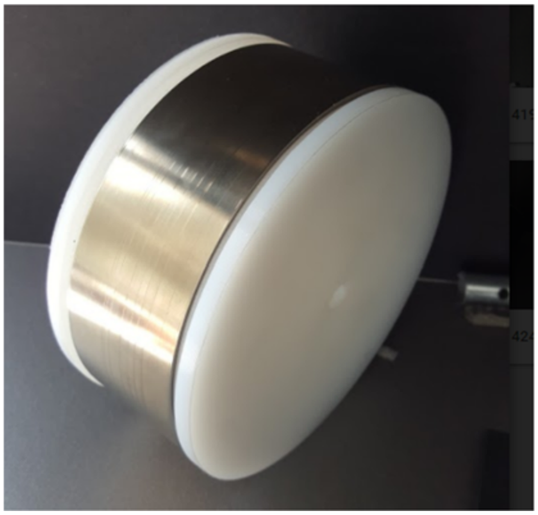

Figure 4.20 Constant Force Spring

4.3.3 Bike Drum Roller

The Bike Drum Roller was purchased from Inside Ride. This drum will work in unison with the magnetic flywheel and will allow the bike wheel to roll on it. The drum can be seen in Figure 4.21 below.

Figure 4.21 Bike Drum Roller

4.3.4 Magnetic Flywheel Assembly

The Magnetic Flywheel Assembly is responsible for the allowing the paddleboard user to feel a natural action and retraction stroke. It also has four different settings on the magnetic to allow for lighter or harder pull during the power stroke. The magnetic assembly contains the flywheel, belt tensioner, belt, and magnet. This assembly can be seen in Figure 4.22 below.

Figure 4.22 Magnetic Flywheel Assembly

4.3.5 Aluminum T-slot Outside Bracket

The outside corner brackets are a far more rigid than the inside corner brackets. They are used in locations that require more rigidity than what the inside corner brackets can supply. Since the inside brackets can only work on the inside of two aluminum t-slots, the outside brackets are needed for the outside of the aluminum t-slots. The outside brackets can be seen in Figure 4.23 below.

Figure 4.23 Outside Bracket

4.3.6 Bearings and Bearing Mounts

The bearings and bearing mounts were found in the BCIT machine shop and used for rotation at the ends of the two aluminum shafts. They will be placed on the aluminum T-slots using the steel plates and bearing 90 deg. aluminum brackets. Roller bearings were chosen because the system is lightweight and there are no misalignment issues. One of the four bearing and bearing mount assemblies can be seen below in Figure 4.24.

Figure 4.24 Bearing Block

5 Discussion of Results

Chapter five will contain four main subsections, these sections will include:

- The main issues and difficulties discovered after manufacturing and during testing.
- Discussion of the alpha prototype and its three main subassemblies
- Brief description of the results obtained from testing.
- Cost Analysis of the alpha prototype

5.1 Difficulties Encountered

The difficulties encountered during the duration of the project were the constant force spring not aiding in retraction, the UHMW drums slipping along the two metal shafts, adjustment of drum sizes on the two shafts to balance out torque, and the substantial noise produced by the bike chain on the eye socket.

5.1.1 Constant Force Spring

The constant force spring was initially implemented to aid in the retraction stroke for the paddleboard trainer. It was chosen because it would provide a constant force in the action stroke. However, the constant force spring failed to produce the necessary retraction force. This was due to opposing forces cancelling each other once the constant force spring had wound onto the secondary drum. Many different configurations were explored and discussed, but based on time constraints and the need to develop a proof of concept, the design team opted to use a resistance band. The resistance band chosen was an ultralight (5 Lbs.) pink band purchased from SportChek. It provided the appropriate retraction stroke and it worked exactly as intended.

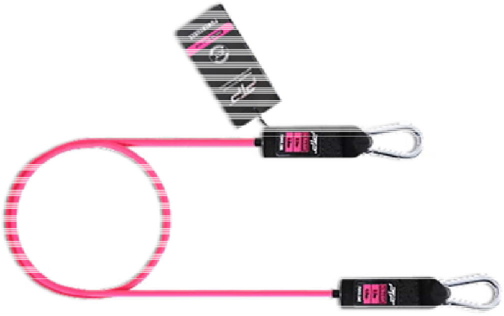

Figure 5.1 Ultralight Resistance Band

5.1.2 Drum Slippage

Because the UHMW drums have very low coefficient of friction they were slipping on the metal shafts, even after they were press fit using the arbor press in the machine shop [6]. This was problematic because if slipping occurred on the two drums that were used for the retraction stroke, retraction would not be possible. To combat this issue, both shafts and drums used a keyway system.

Figure 5.2 Keyway System

A 3/16" drill bit was placed into the milling machine and 10 cm of the shaft was drilled one third of the way in. A 3/16" stock rectangular bar was cut 10 cm on the band saw to be used as the key on the shaft. The cut rectangular bar was grinded down and contoured to fit the 10cm incision on the shaft creating a key on the shaft. The plastic was used as the keyway, which was created using a broaching tool and was cut using the arbor press. The shaft and the plastic drum were press fit using the arbor press. This process was used for the two drums containing the resistance band. The keyway system can be seen in Figure 5.2 above.

5.1.3 Changing Drum Sizes

Substituting the constant force spring for the ultra light resistance band resulted in difficulty with the resistance band. It provided a large resistance compared to the unravelling of the chain. It was found that when connecting the resistance band to the top drum, the top drum was approximately six times as large compared to the chain drum. Therefore, to unravel the chain drum, the paddleboard user would have to overcome 60 lbs. compared to the intended 10 lbs.

Thus, the top drum was then reduced in diameter to the same size as the chain drum. When the drum size was adjusted, the resistance band ravelled around chain drum and this ravelling was exactly proportional to the unravelling of the resistance band.

5.1.4 Noise from Bike Chain

After the addition of an eye-socket, it was realized during testing that the chain would rub against the hook of the eye socket and this metal-to-metal contact would be noisy and irritable to the paddleboard user and the nearby bystanders. The solution to this problem was cutting the chain short 1.5 meters and replacing it with nylon rope. The nylon rope moved into the eye socket and eliminated the loud metal-to-metal contact. Figure 5.3 below show the new configuration.

Figure 5.3 Eye Socket with Nylon Rope

5.2 Alpha Prototype Subassemblies

The following subsection will include a description of the three main subassemblies of the alpha prototype of the paddleboard trainer. These three assemblies include: the back tire assembly, the flywheel assembly, and the drum assembly.

5.2.1 Back Tire Assembly

Figure 5.4 Isometric View of Back Tire Assembly

Figure 5.5 Side View of Back Tire

The back tire assembly includes the bike wheel arms, bike wheel bracket, bike wheel, bike chain and the resistance band. The bike chain is attached to the sprocket side of the bike wheel and the resistance band is attached to the opposite side, hooked into one of the holes of the bike arm. The bike wheel arms are used to attach the bike wheel to the bike wheel bracket as seen above in Figure 5.4 and Figure 5.5. The bike wheel bracket is not rigid; it can be rotated 45 degrees from the positive x-axis to 45 degrees from the negative x-axis. The purpose of this subassembly is to ensure that the bike wheel remains in contact with the bike roller and its non-rigidity allows the configuration to be changed, for example to swap the sprocket to the other side if needed.

5.2.2 Flywheel Assembly

Figure 5.6 Isometric View of Flywheel Assembly

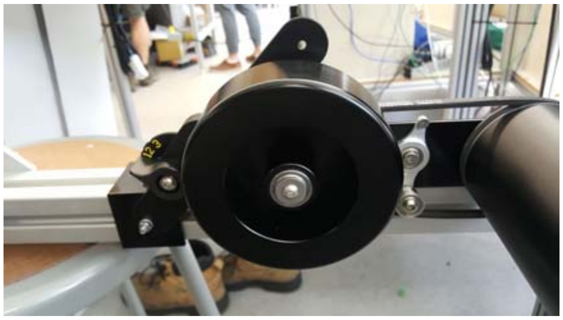

Figure 5.7 Side View of Flywheel Assembly

The flywheel assembly consists of the roller, belt, belt tensioner, flywheel, magnets and three brackets that house all the components. The objective of the roller is to transfer the motion, via the belt drive, to the flywheel, which produces the desired inertia of the system. The inertia produced by the flywheel allows for easier paddleboard motion as the user gets the flywheel to spin faster and faster. This spinning of the flywheel is intended to mimic the motion of the surfboard on water, which initially is relatively difficult, but as momentum is gained the paddling becomes easier. The magnetic settings, as seen in Figure 5.7 are labelled 0, 1, 2, and 3. Each number corresponds to different positions of the magnet, 0 being farthest from the flywheel, and 3 being the closest. The closer the magnet to the flywheel the harder it is for the flywheel to spin and therefore providing more difficult motion when paddling. The principle behind this is called Eddy Currents, which was elaborated on in Section 3.2.3 of the report.

5.2.3 Back Drum Assembly

The back drum assembly consists of the top shaft containing the retraction drum and chain drum, and the bottom shaft containing the guide drum and the two bearing blocks. The purpose of this assembly is to provide the shafts that allow for the action and retraction strokes. As the user pulls the paddleboard, the chain on the chain drum as seen in Figure 5.9 starts to unravel and the top retraction drum as also seen in Figure 5.9 starts to ravel. Because the two drums are the same diameter they will ravel and unravel at the same rate, therefore the distance pulled, which is measured by how much chain unravelled, will fully unravel back to its home position. This allows for continuous smooth motion of both the action and retraction strokes.

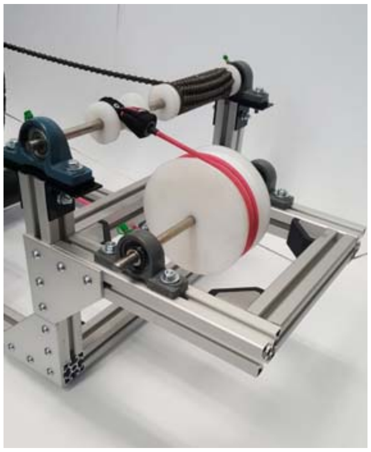

Figure 5.9 Isometric View of Back Drum Assembly

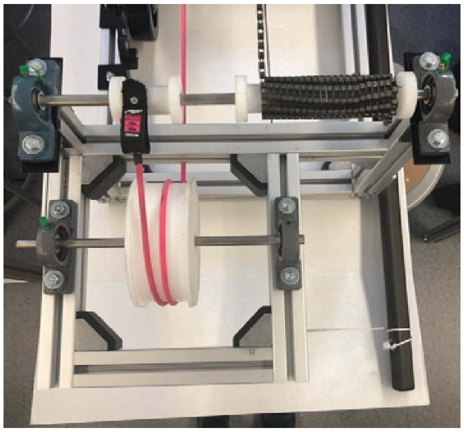

Figure 5.9 Top View of Back Drum Assembly

5.2.4 Final Indoor Paddleboard Trainer Assembly

The following two figures, Figure 5.10 and Figure 5.11 showcase all of the assemblies together, and representing the alpha prototype of the indoor paddleboard trainer.

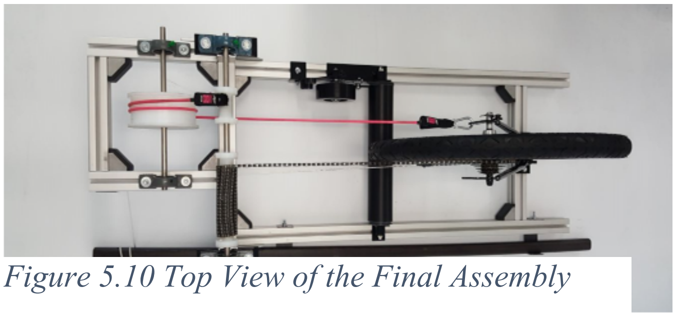

Figure 5.10 Top View of the Final Assembly

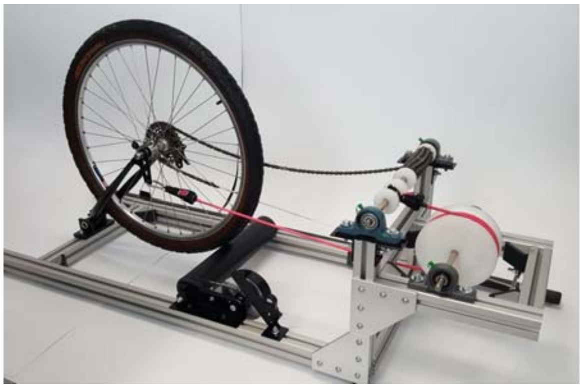

Figure 5.11 Isometric View of the Final Assembly

5.3 Results

An important objective of the project was to have variable resistance so the paddleboard user could adjust the variability of the trainer based on their skill level. The gears of the bike wheel as seen in Figure 5.12 and the adjustment of the magnetic relative to the flywheel as seen in Figure 5.13 achieved this variability. There are a total of 24 variable settings; each gear ranging from one to six is accompanied by position of the magnets, which range from zero to three. Therefore, each gear setting has four magnet settings giving a total of 24 variable settings.

Figure 5.13 Magnet Resistance Settings

Figure 5.12 Gear Resistance Settings

After showcasing the paddleboard trainer to the public at the MECH EXPO 2018 and receiving feedback from many frequent paddle borders, it was found that the motion of the trainer closely resembled the actual motion on the water. The tests were conducted at lightest possible gear and magnet setting and the feedback received was positive, indicating it was closely to that experienced on the water and therefore the implementation of the flywheel delivered the desired inertia for a natural feel. Also, it was found that at any setting beyond the lightest possible configuration, meaning the lowest resistance setting, the paddle motion was difficult and therefore would provide the intended "high resistance setting" set out in the project specifications in Section 2.2 of the project. The intended stroke length of two meters was also achieved; the paddleboard user can pull the paddle a total of 2.03 meters, which meets the intended project specification.

5.4 Cost Analysis

For the production of the alpha prototype, the design team purchased the following products.

Table 5.1: Cost Analysis of Alpha Prototype

Name	Description	Code	Size	Quantity	Price ($)	Total
UHMW Rods	Diameter 6in	9352K31	3in	**1**	23.75	23.75
UHMW Rods	Diameter 2in	8701K49	1ft	**1**	8.03	8.03
T-Slots	45mm	5537T103	5ft	**1**	30.50	30.50
T-Slots	45mm	5537T103	4ft	**2**	25.80	51.60
T-Slots	45mm	5537T103	1 ft	**4**	8.44	33.76
Corner brace		5537T196		**8**	8.24	65.92
Corner Surface Bracket		5537T965		**3**	14.78	44.34
90 Deg. Aluminum Extrusion	1.75in x 1.75in	8982K34	3ft	**1**	28.25	28.25
End feed fasteners	Packs of 4	5537T456		**5**	3.33	16.65
Resistance Bands	SportChek			**1**	10.99	10.99
KMC Z51 Bicycle Chain	Amazon			**2**	12.00	24.00
Flywheel Assembly	Inside Ride			**1**	150.00	150.00
Total						487.79

The total cost of the prototype was approximately $487.79. The bulk of the prototype cost is due to the aluminum T-slots and the flywheel assembly which costs $265.86. Although the prototype is more expensive the Paddle Power Trainer, it is significantly cheaper than the Paddle Board Trainer sold by VASA. Once the product is marketable, the price of the paddle board trainer can be drastically reduced by purchasing the components in bulk.

6 Conclusion

The objective of the project was to research different forms of resistance and produce several concepts implementing the resistance methods for the paddle board trainer. From the various concepts generated, one concept was selected for further development and a functional prototype was manufactured and assembled. Some of the requirements for the paddle board trainer were to incorporate inertia and automatically retract the paddle once the user had completed the action stroke. The selected concept consisted of a flywheel intended to meet the inertia requirement and resistance bands to retract the paddle.

Although the team faced unexpected challenges, the prototype was successfully developed. One of the critical unexpected challenges being the constant force spring not functioning as intended. The current prototype utilizes a magnet which acts as the primary source of resistance and meets all the specifications mentioned in the Section 2.2.

6.1 Future Work

Several modifications can be implemented to further optimize the alpha prototype into a marketable product.

6.1.1 Resistance Band

Currently, a resistance band acts as the primary component to retract the paddle. Although, the resistance band is more than capable to retract the paddle, it doesn't produce a constant resistance during action stroke. The resistance band produces a minimal resistance in the initial stages of the action stroke, however, the resistance increases significantly at the peak of the action stroke. Therefore, replacing the resistance band with another component which does not create a significant resistance difference and retract the paddle could be researched and considered in the future.

6.1.2 Constant Force Spring

A constant force spring was initially considered to support the retraction stroke. However, the constant force spring configuration was not ideal. Causing the constant force spring to wind onto another drum during the action stroke resulted in opposing forces. The opposing forces prevented the constant force spring to retract. Therefore, a different configuration for the constant force spring can be considered and implemented to retract the paddle.

6.1.3 Implement Gear Derailleur

Currently, a magnet producing eddy currents on the flywheel is the primary source of resistance in the paddle board trainer. A derailleur can be used to incorporate gears as a secondary source of resistance.

6.1.4 Electrical Components

Electrical components such as a display screen, tachometer etc. can be considered for the future to develop a user interface. The display screen can be used to provide the user with various information such as stroke rate, resistance, time etc.

6.1.5 Chain Tensioner

The chain connecting the bicycle wheel and drum tends to slack if it's not under tension. This results in chain derailment and nylon rope getting stuck into the gears; requiring the user to place the chain back onto the gears. The problem can be avoided by incorporating a chain tensioner to keep the chain tensioned and prevent derailment.

7 Bibliography

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A Appendix A – Request for Proposal

REQUEST FOR PROPOSAL

Indoor Paddleboard Trainer

October 24, 2017

Issued by:

DOS WaterSports

DOS WaterSports Representative:

Sami Kafeety

SamiKafeety@DOSWaterSports.net

604-491-3451

Background

DOS WaterSports was established in 1962 and has since been a world leader in water sport technologies. DOS specializes in several water sports including water skiing, jet skiing, boat racing, wakeboarding, paddle boarding and much more. We have recently developed a new division in our company that focuses on providing athletes with alternative training devices. An important area of focus of this division is to provide athletes with adequate training equipment in order to train in the off-season.

Purpose

Paddle boarding is an exciting water sport that is enjoyed by many across the world. It involves using your hands and a paddle to propel yourself forward to travel across bodies of water. Unfortunately, this sport can be limited by weather patterns. In the winter season, it is not ideal to indulge in the sport as it can be potentially life-threatening and can induce sickness. The need for a paddleboard simulator is on the rise for athletes wanting to train indoors and sharpen their skills during the off-season. We at DOS WaterSports are looking for new and innovative designs for an indoor paddle board trainer for paddleboard athletes to train all-year round.

Scope

The goal of the project is to produce a functional paddleboard trainer that focuses solely on paddle action and not the athlete's ability to balance himself on the paddle board. The scope of the project should is to design and develop a trainer that utilizes some form of a resistance(s). The resistance(s) may include but is not limited to gravity, spring action, aerodynamic, hydraulic, pneumatic, electric and magnetic. It would be in the best interest of the consumer to be able to store the trainer within a confined.

Deliverables

Upon the successful completion the project, the contracted company is expected to provide conceptual designs, a detailed drawing of the final approved design, a working prototype and a technical report including the steps taken to reach the final stages of the design process.

Budget

DOS WaterSports will be providing a budget of $5000 for this project. As this is a guideline, bidders with exceptional designs will be eligible for a reevaluation of the provided funding, given that the request for additional funding is justified.

Terms of Contract:

All proposals in response to this Request for Proposal must be submitted no later than November 7, 2017 at 5:30 pm. After the submission deadline, DOS WaterSports team will evaluate the submitted proposals and select the top three choices. The bidders of the winning proposals will be notified and invited to negotiate a tentative contract. After negotiations, one bidder will be awarded the contract.

The duration of this project will be from November 7, 2017 until May 11, 2018. Winning bidder is required to submit weekly reports to the project sponsor with the project sponsor. By the end of the project duration, the outlined deliverables must be presented forward in completion.

Proposal Requirements

The bidders are requested to submit a PDF copy of the proposal via e-mail. All proposals must include the following:

- Executive Summary
- Company History and Background
- Problem statement and requirements
- Proposed Solution(s)
- Estimated Cost
- List of resources
- List of key team members and experience
- References

Evaluation and Awards process

The proposal evaluation and awards processes are not strictly limited to the estimated cost of the project. A panel of the stakeholders of the company would evaluate the proposal based on the proposed solution and company.

DOS WaterSports will be rating proposals based on the following criteria in order of importance:

1. Adherence to the requirements set forth in this Request for Proposal
2. The bidding company's credibility, field experience, as well as reputation.
3. Creativity in design
4. Technical expertise of bidding company
5. Total cost of the proposed design(s)

Proposals can be submitted by email to: HRteam@DOSWaterSports.net

Project Deadlines

November 7, 2017: Proposal submission
November 14, 2017: Proposal Presentation (illustrating design concepts)
March 18, 2018: Final design concept confirmation
May 11, 2018: Final Prototype & Report Submission

Contact information

Questions or concerns can be directed to the contact listed below:
Name: Sami Kafeety
Title: Project Sponsor
Phone: +1 (604) 491-3451
E-mail: SamiKafeety@DOSWaterSports.net

B Appendix B – Project Management

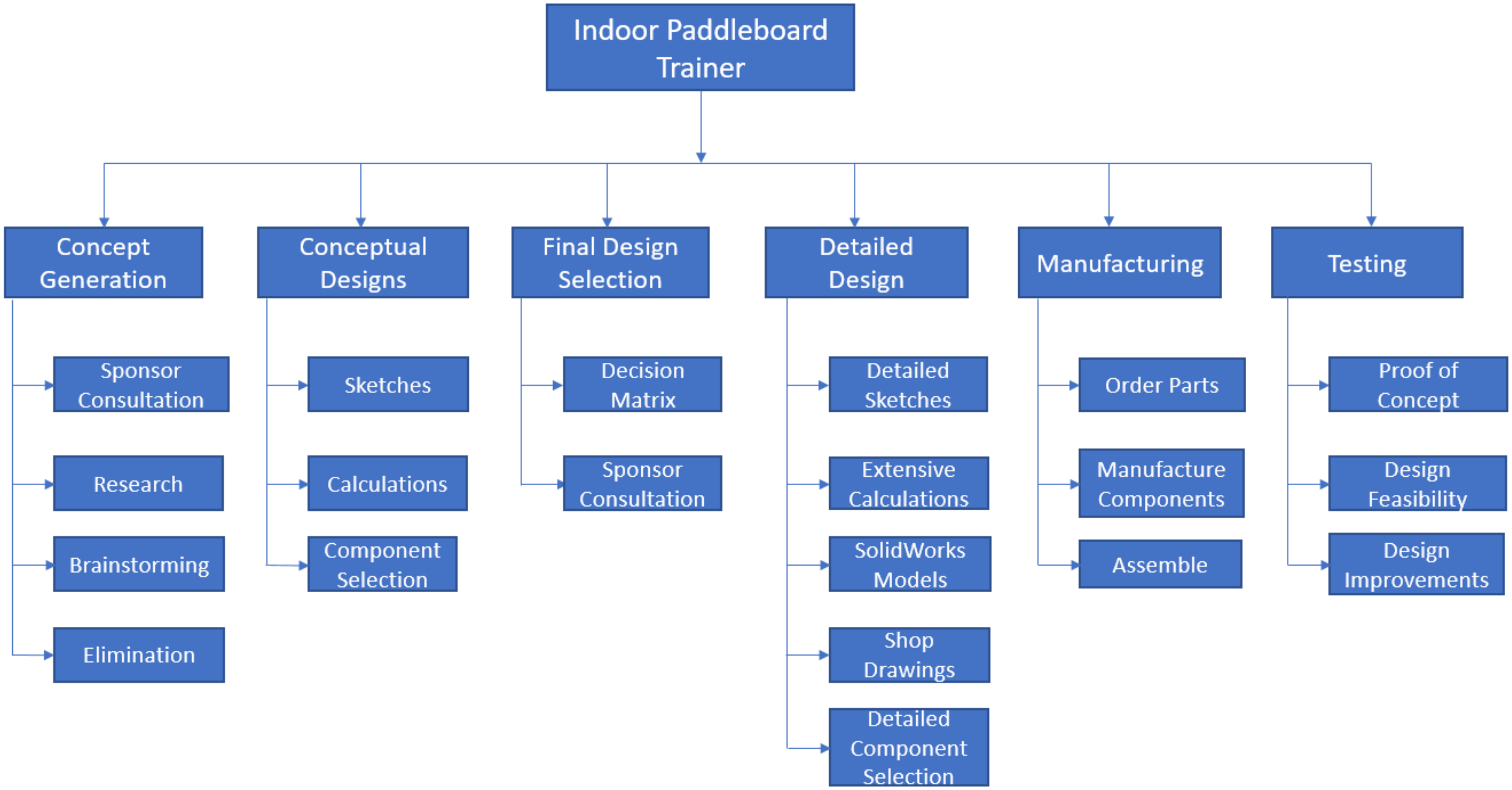
B.1 Milestone Schedule

	Activity Description	Calender Units (2 weeks)		Project Schedule Time Frame													
				December		January		Feburary		March		April		May	
Milestone															
1	Gather Technical Specifications	◆	◆	◆											
2	Six Concept Choices and Calculations							◆							
3	Six Concept Designs								◆						
4	Final Design Decision								◆						
5	Detailed Design										◆				
6	Manufacturing Start											◆			
7	Testing and Results												◆		
8	Working Prototype													◆	
9	Technical Report														◆

B.2 Technical Requirements

High Resistance [lb]	15-25
Low Resistance [lb]	5 – 15
Comfortable Weight [lb]	10
Average Strokes per Minute	40
Average Stroke Length [m]	2
Power Dissipation [W]	150

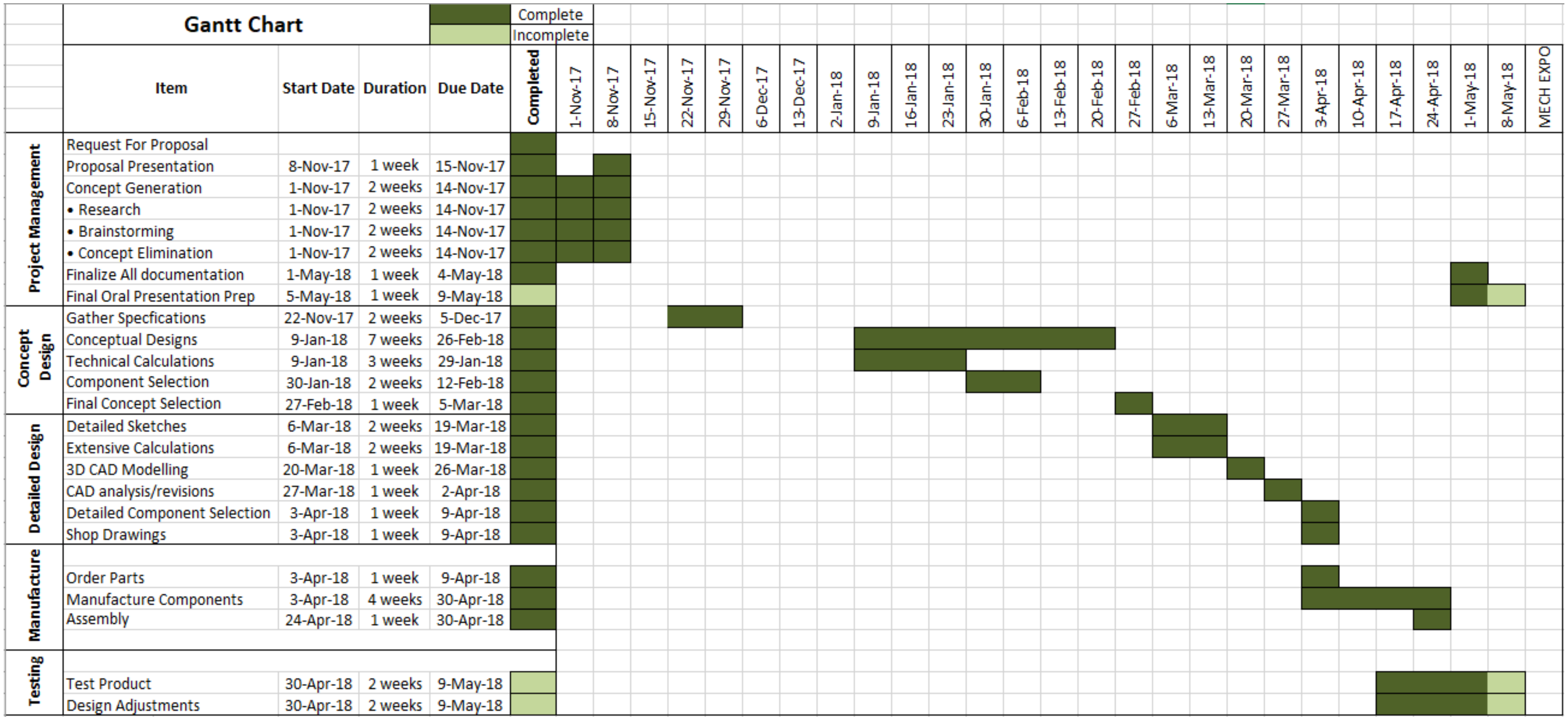
B.3 Project Work Breakdown Structure



B.4 Responsibility Assignment Matrix

Activity	Diljot Pannu	Omer Abbasi	Sami Kafeety	Johan Fourie
Concept Generation	R	C	C	C
Conceptual Designs	C	R	C	I
Final Design Selection	C	C	R	C
Detailed Design	C	C	R	C
Manufacturing	C	R	I	I
Testing	R	I	C	I

B.4 Project Schedule



Gantt Chart

■ Complete
□ Incomplete

	Item	Start Date	Duration	Due Date	Completed	1-Nov-17	8-Nov-17	15-Nov-17	22-Nov-17	29-Nov-17	6-Dec-17	13-Dec-17	2-Jan-18	9-Jan-18	16-Jan-18	23-Jan-18	30-Jan-18	6-Feb-18	13-Feb-18	20-Feb-18	27-Feb-18	6-Mar-18	13-Mar-18	20-Mar-18	27-Mar-18	3-Apr-18	10-Apr-18	17-Apr-18	24-Apr-18	1-May-18	8-May-18	MECH EXPO
Project Management	Request For Proposal				■																											
	Proposal Presentation	8-Nov-17	1 week	15-Nov-17	■		■																									
	Concept Generation	1-Nov-17	2 weeks	14-Nov-17	■	■	■																									
	• Research	1-Nov-17	2 weeks	14-Nov-17	■	■	■																									
	• Brainstorming	1-Nov-17	2 weeks	14-Nov-17	■	■	■																									
	• Concept Elimination	1-Nov-17	2 weeks	14-Nov-17	■	■	■																									
	Finalize All documentation	1-May-18	1 week	4-May-18	■																									■		
	Final Oral Presentation Prep	5-May-18	1 week	9-May-18	□																									■	□	
Concept Design	Gather Specfications	22-Nov-17	2 weeks	5-Dec-17	■				■	■																						
	Conceptual Designs	9-Jan-18	7 weeks	26-Feb-18	■									■	■	■	■	■	■	■												
	Technical Calculations	9-Jan-18	3 weeks	29-Jan-18	■									■	■	■																
	Component Selection	30-Jan-18	2 weeks	12-Feb-18	■												■	■														
	Final Concept Selection	27-Feb-18	1 week	5-Mar-18	■																■											
Detailed Design	Detailed Sketches	6-Mar-18	2 weeks	19-Mar-18	■																	■	■									
	Extensive Calculations	6-Mar-18	2 weeks	19-Mar-18	■																	■	■									
	3D CAD Modelling	20-Mar-18	1 week	26-Mar-18	■																			■								
	CAD analysis/revisions	27-Mar-18	1 week	2-Apr-18	■																				■							
	Detailed Component Selection	3-Apr-18	1 week	9-Apr-18	■																					■						
	Shop Drawings	3-Apr-18	1 week	9-Apr-18	■																					■						
Manufacture																																
	Order Parts	3-Apr-18	1 week	9-Apr-18	■																					■						
	Manufacture Components	3-Apr-18	4 weeks	30-Apr-18	■																					■	■	■	■			
	Assembly	24-Apr-18	1 week	30-Apr-18	■																								■			
Testing																																
	Test Product	30-Apr-18	2 weeks	9-May-18	□																							■	■	■	□	
	Design Adjustments	30-Apr-18	2 weeks	9-May-18	□																							■	■	■	□	

C Appendix C – Design Review Package

Indoor Paddle Board Trainer

Preliminary Design Review Package

Prepared For:

Johan Fourie, Project Sponsor

Mechanical Engineering Class of 2018

Prepared By:

Omer Abbasi,

Diljot Pannu,

Sami Kafeety

Date: February 7, 2018

C.1 Introduction

Paddle boarding is an exciting water sport that is enjoyed by many across the world. It involves using your hands and a paddle to propel yourself forward to travel across bodies of water. Unfortunately, this sport can be limited by weather patterns. In the winter season, it is not ideal to indulge in the sport as it can be potentially life threatening and induce sickness. The need for a paddleboard simulator is on the rise for athletes wanting to train indoors and sharpen their skills during the off-season. Therefore, we at ***OSD Solutions*** are currently working on designing new and innovative indoor paddle board trainer for paddleboard athletes to train all-year round.

C.2 Objective

The goal of the project is to produce a functional paddleboard trainer that focuses solely on paddle action and not the athlete's ability to balance himself on the paddle board. The scope of the project is to design and develop a trainer that utilizes some form of a resistance(s). The resistance(s) may include but is not limited to gravity, spring action, aerodynamic, hydraulic, pneumatic, electric and magnetic.

C.3 Research

C.3.1 Eddy Current Break Design

The concept of an eddy break as a form of resistance uses eddy currents to slow or stop a moving object by dissipating kinetic energy as heat. Eddy currents can be applied to a design for an indoor paddleboard trainer by using a flywheel as the moving disk to supply enough inertia so the user feels a natural stroke of the paddle (which mimics the actual motion) and then subsequently using magnets to produce changes in resistance so they user can adjust to their training preference.

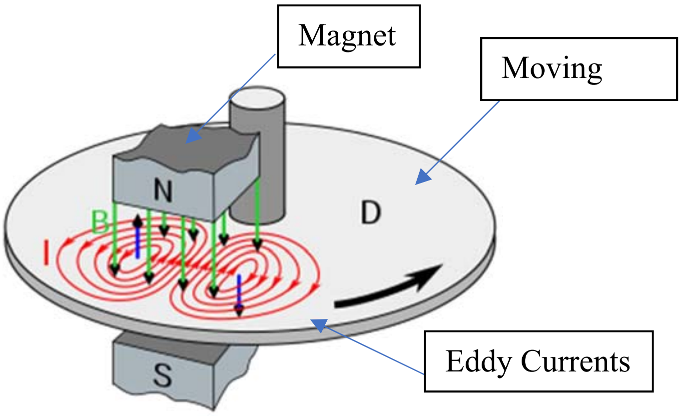


Figure 1 – Eddy Current

C.4 Product Specifications

The following section outlines the product specifications determined by the project sponsor and team members. The product specifications were found by visiting the local gym with an experienced paddle-boarder and determining what values of weight accurately represented the feel on the water. It is important to note that these values were used for the calculations of our designs.

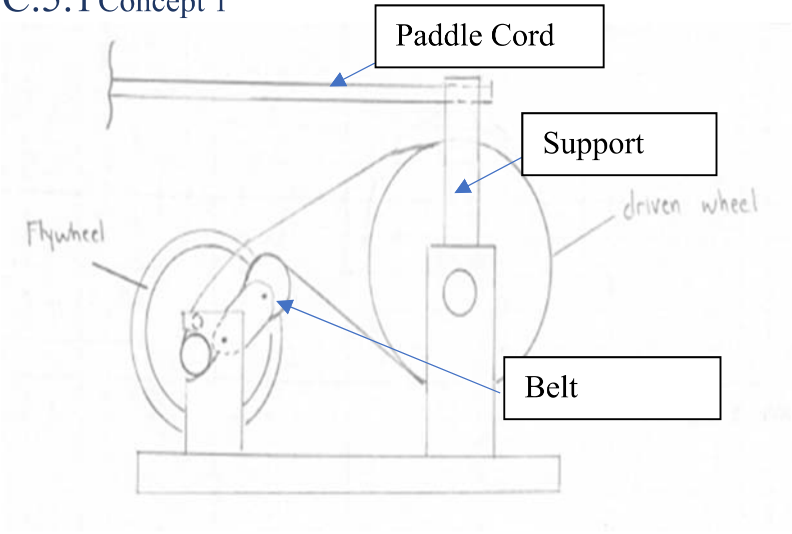
Table C.1 – Product Specifications

High Resistance (lb)	15 – 25
Low Resistance (lb)	5 – 15
Comfortable Weight (lb)	10
Average Strokes per Minute	40
Average Stroke Length (m)	2
Power Dissipation (W)	150

C.5 Concept Generation

The team spent adequate amount of time to research different forms of possible resistances and generated approximately 10 different concepts. The concepts consisted of resistance via the use of water, magnetic, spring, hydraulic and pneumatic systems. After a detailed discussion with our project supervisor regarding the feasibility, manufacturability of the concept, the design team decided to move forward with four concepts highlighted below.

C.5.1 Concept 1



The first conceptual design can be seen in Figure 2. The support arm connects the driven wheel to the paddle via the paddle cord. The support as seen in the front view is a bracket that is attached to both side of the driven wheel on a moving shaft. The driven wheel is attached to the flywheel via a belt and includes a belt tensioner to keep the belt tensioned.

Figure 2 – Side View of Design

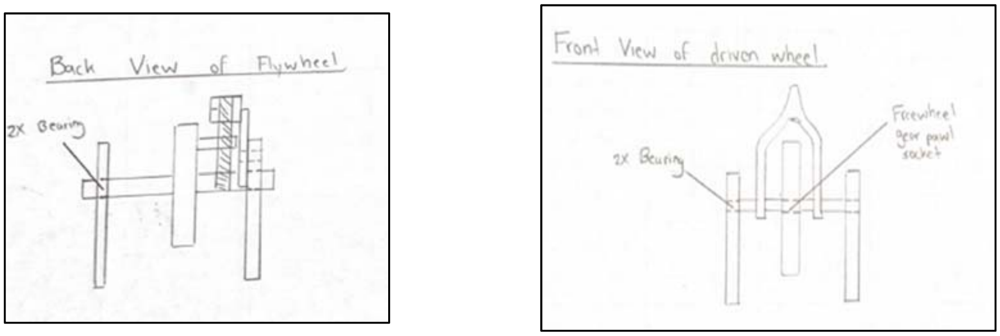


Figure 3 – Front and Back View of Design Concept 1-a

In this design, the magnets are encased in the flywheel, as seen in Figure 4 below, for compactness and to have the ability to move further and closer to the flywheel based on required resistance.

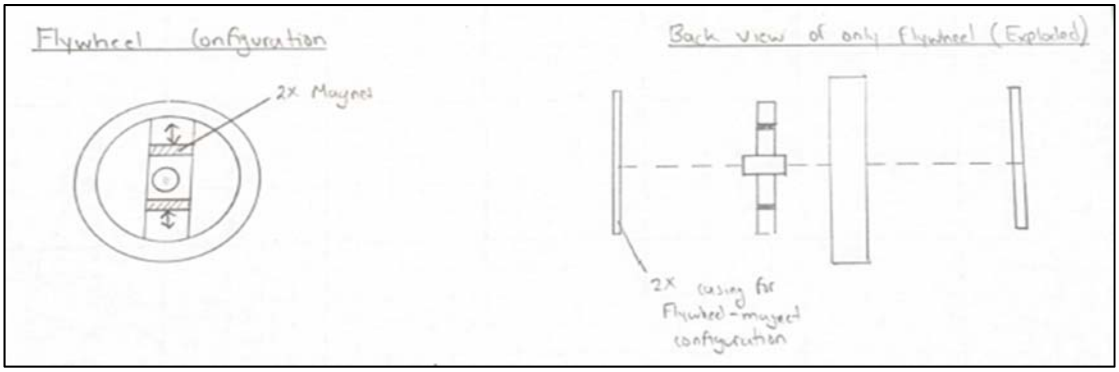


Figure 4 – Flywheel Configuration of Concept 1-a

In Figure 5 below, the magnets are arranged in a "C" shape which fits the contour of the flywheel. The magnets move closer and further away from the flywheel based on user preference of resistance.

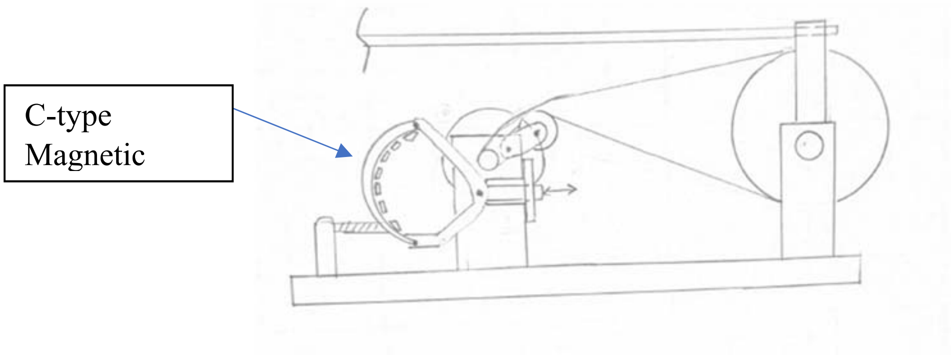
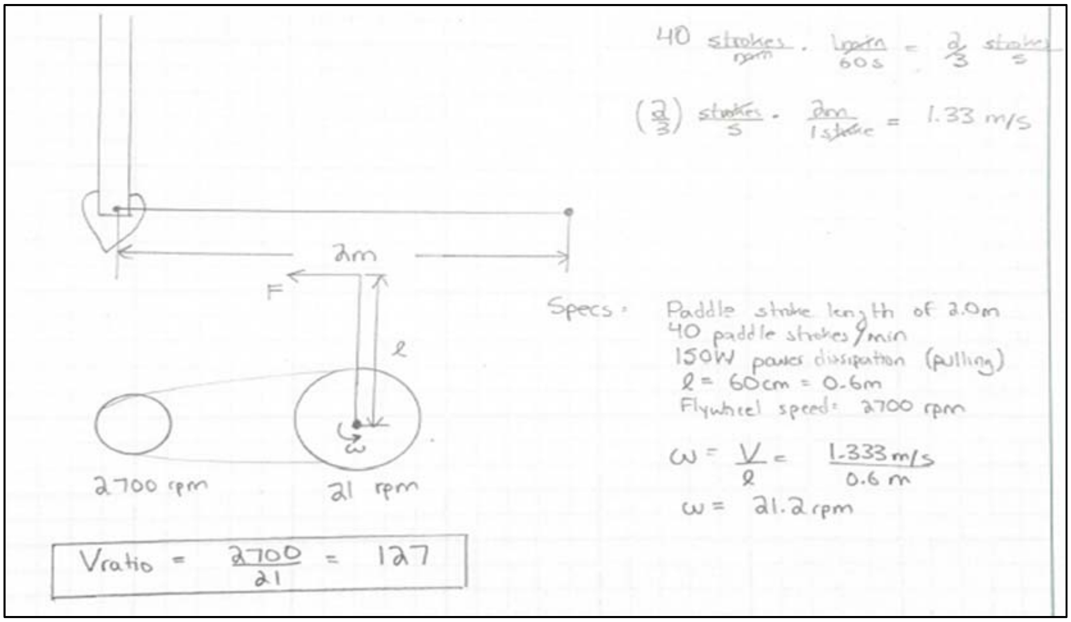


Figure 5 – Concept 1-b

C.5.1.1 Calculations



$40\ \frac{\text{strokes}}{\text{min}} \cdot \frac{1\text{min}}{60\text{s}} = \frac{2}{3}\ \frac{\text{strok}}{\text{s}}$

$\left(\frac{2}{3}\right) \frac{\text{strokes}}{\text{s}} \cdot \frac{2\text{m}}{1\text{stroke}} = 1.33\ \text{m/s}$

Specs: Paddle stroke length of 2.0m
40 paddle strokes/min
150W power dissipation (pulling)
$\ell = 60\text{cm} = 0.6\text{m}$
Flywheel speed: 2700 rpm

$\omega = \frac{V}{\ell} = \frac{1.333\ \text{m/s}}{0.6\ \text{m}}$

$\omega = 21.2\ \text{rpm}$

$\boxed{V_{\text{ratio}} = \frac{2700}{21} = 127}$

Figure 6 – Calculations for Concept 1

A high velocity ratio implies that we need a variety of pulley systems to achieve the necessary speed of the flywheel.

Table C.2 – Advantages and Disadvantages of Concept 1

Advantages	Disadvantages
No mechanical wear because the magnet makes no direct contact with flywheel. Therefore, it will have a long shelf life	The current design needs a variety of pulley systems to account for the high velocity ratio
Cheap and readily available. Magnetic flywheel systems can be purchased online	The arm would have to be relatively large to account for the ~2m pull of the user but because the length of the arm greatly affects the speed of the driven shaft it can't be too long.
Not many complicated or moving parts, therefore it is easy to implement	Learning curve when learning and implementing eddy current system

C.5.2 Concept 2

The concept shown below comprises of a spring and mass system to meet the desired requirements.

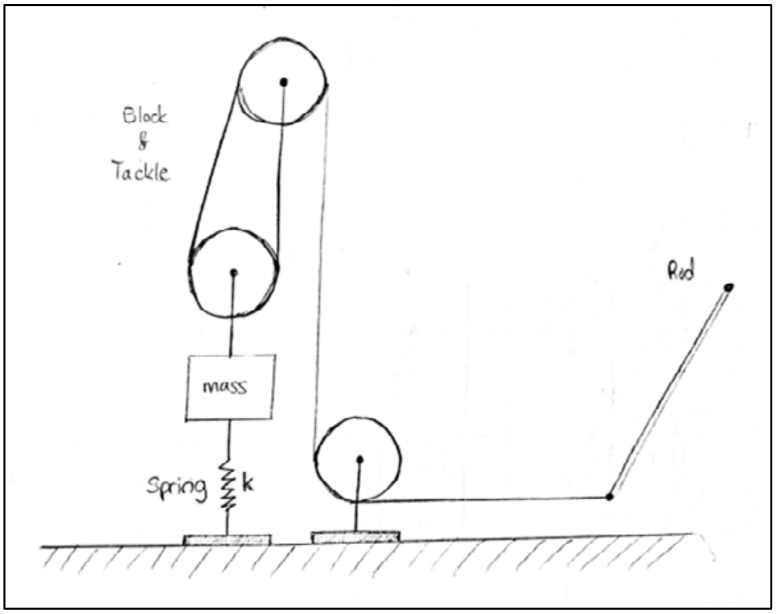


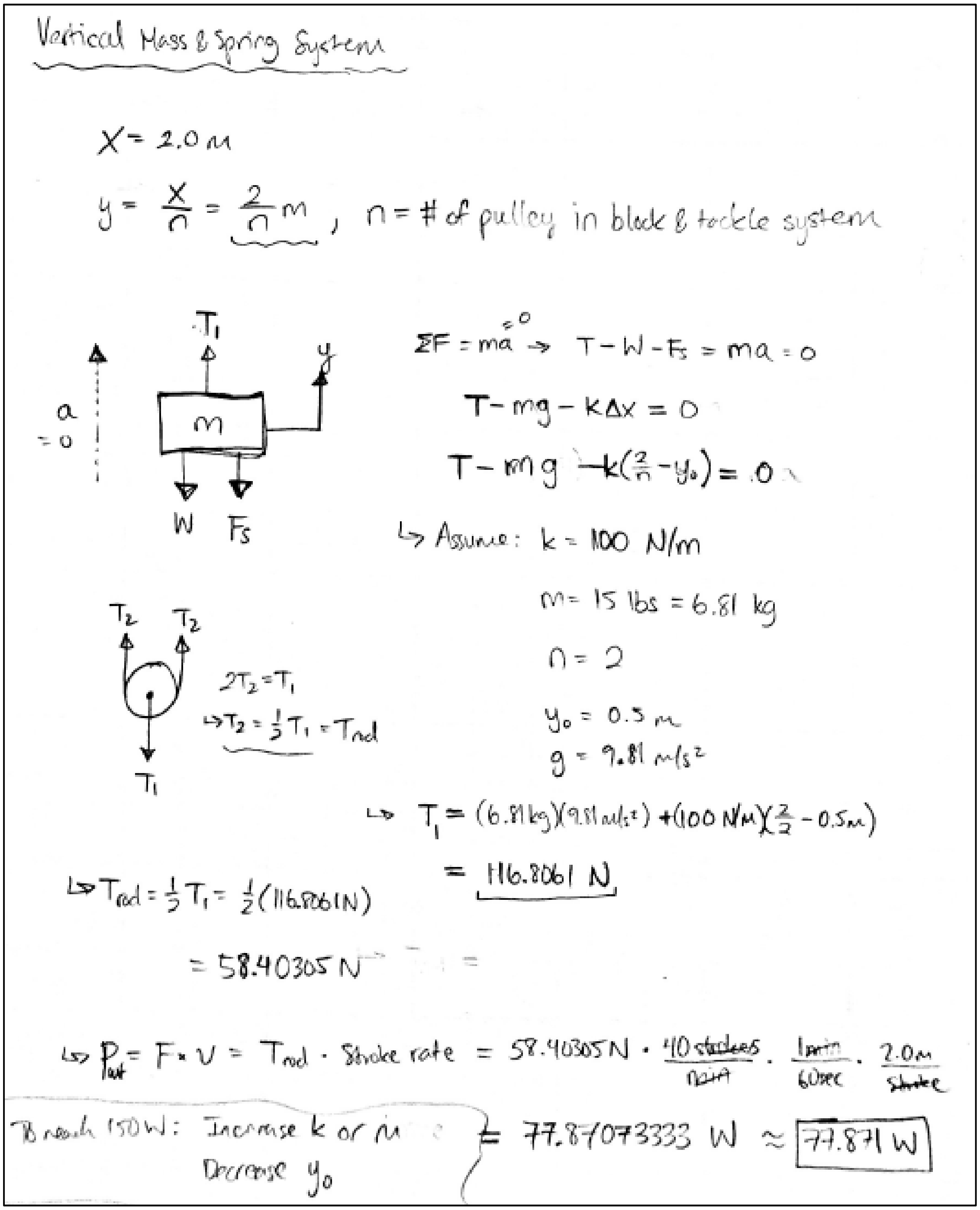
Figure 7 – Side View of Concept 2

For the configuration shown above, we developed a system where the rod is attached to a series of pulleys which are connected through a block and tackle system to a mass and spring. The resistance on the motion of the paddle is located on the mass, which includes the spring force and gravity force.

Table C.3 - Advantages and Disadvantages of Concept 2

Advantages	**Disadvantages**
Block and tackle allows for proportioned movement of mass vs stroke length	Spring force will increase throughout the stroke of paddle
Simple system	Will need some sort of barriers around mass to restrict movement
Spring returns mas to home position	Minimal inertia (slight amount with acceleration of paddle stroke)
Smooth motion of action and retraction strokes	
Minimal manufacturing required (just for pulleys and base)	

C.5.2.1 Calculations



Vertical Mass & Spring System

$X = 2.0\,m$

$y = \frac{X}{n} = \underbrace{\frac{2}{n}\,m}$, n = # of pulley in block & tackle system

$\Sigma F = m\overset{=0}{a} \rightarrow T - W - F_s = ma = 0$

$T - mg - k\Delta x = 0$

$T - mg - k(\frac{2}{n} - y_0) = 0$

↳ Assume: $k = 100\ N/m$

$m = 15\ lbs = 6.81\ kg$

$n = 2$

$y_0 = 0.5\ m$

$g = 9.81\ m/s^2$

$2T_2 = T_1$

↳ $\underbrace{T_2 = \frac{1}{2}T_1 = T_{rod}}$

↳ $T_1 = (6.81 kg)(9.81 m/s^2) + (100 N/m)(\frac{2}{2} - 0.5 m)$

$= \underline{116.8061\ N}$

↳ $T_{rod} = \frac{1}{2}T_1 = \frac{1}{2}(116.8061 N)$

$= 58.40305\ N$

↳ $P_{out} = F \cdot v = T_{rod} \cdot \text{Stroke rate} = 58.40305 N \cdot \frac{40\ strokes}{min} \cdot \frac{1 min}{60 sec} \cdot \frac{2.0 m}{stroke}$

$= 77.87073333\ W \approx \boxed{77.871\ W}$

To reach 150W: Increase k or m
Decrease y_0

Figure 8 – Calculations for Concept 2

C.5.3 Concept 3

The concept shown below uses a pendulum action to use the center wheel to drive the flywheel. The sketch below presents two different illustrations denoted by the numbers 1 and 2. The stroke action causes the center wheel to rotate which in turn drives the flywheel. The concept uses a magnetic strip as a form of resistance.

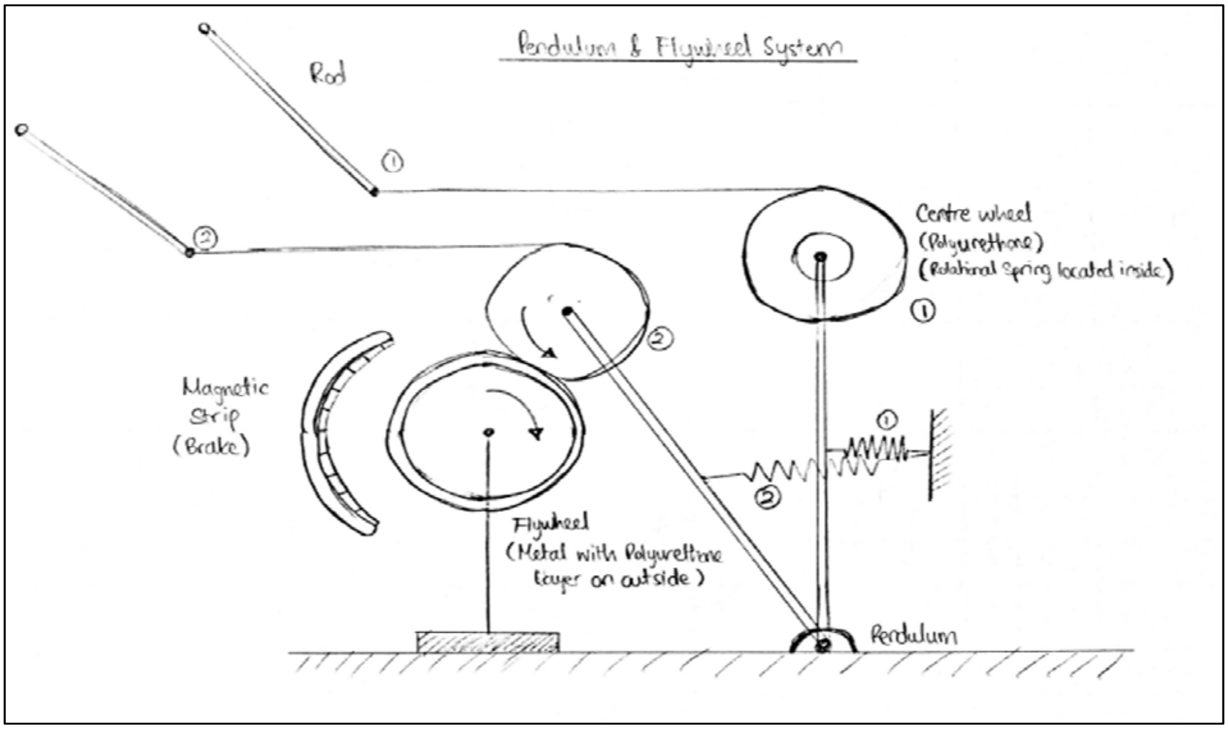
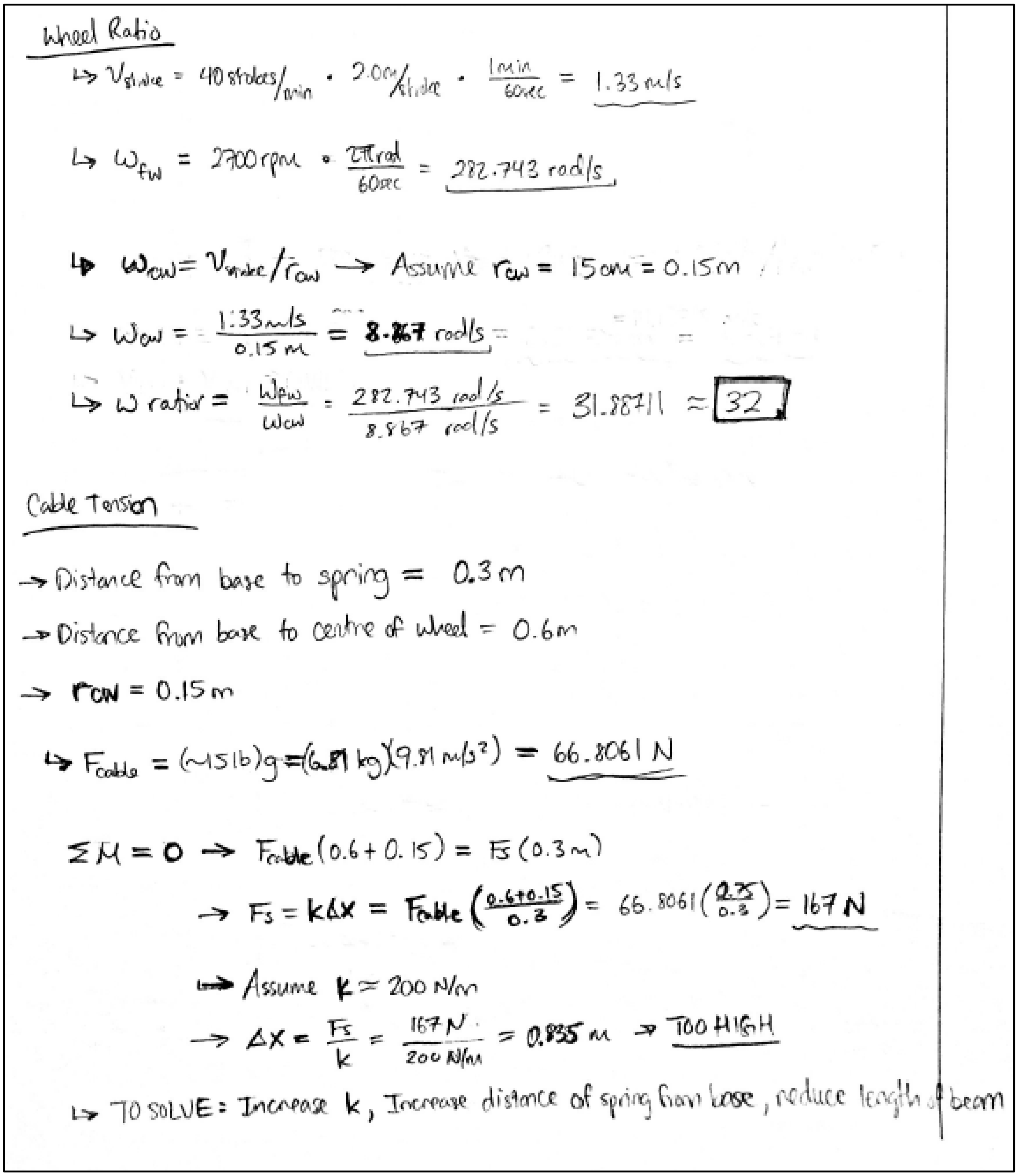


Figure 9 – Side View of Concept 3

Table C.4 – Advantages and Disadvantages of Concept 3

Advantages	Disadvantages
Spring returns center wheel to home position	Complex system
Rotational spring for auto-retraction of cord	Chance of unsmooth flow during action stroke
Wheels made from a “grippy” material such as polyurethane or rubber (less cost)	Flywheel must be metal with a layer of “grippy” material
Flywheel retains its spinning until brake is applied	Magnetic brake will induce heat generation due to Eddy currents and friction
Inertia is present	User must pull hard enough to overcome spring force and to turn flywheel

C.5.3.1 Calculations



Wheel Ratio

↳ $V_{stroke} = 40\,\text{strokes}/\text{min} \cdot 2.0\,\text{m}/\text{stroke} \cdot \frac{1\,\text{min}}{60\,\text{sec}} = \underline{1.33\,\text{m/s}}$

↳ $\omega_{fw} = 2700\,\text{rpm} \cdot \frac{2\pi\,\text{rad}}{60\,\text{sec}} = \underline{282.743\,\text{rad/s}}$

↳ $\omega_{cw} = V_{stroke}/r_{cw} \rightarrow$ Assume $r_{cw} = 15\,\text{cm} = 0.15\,\text{m}$

↳ $\omega_{cw} = \frac{1.33\,\text{m/s}}{0.15\,\text{m}} = \underline{8.867\,\text{rad/s}}$

↳ ω ratio $= \frac{\omega_{fw}}{\omega_{cw}} = \frac{282.743\,\text{rad/s}}{8.867\,\text{rad/s}} = 31.8871 \approx \boxed{32}$

Cable Tension

→ Distance from base to spring = 0.3 m

→ Distance from base to centre of wheel = 0.6 m

→ $r_{cw} = 0.15\,\text{m}$

↳ $F_{cable} = (\sim 15\,\text{lb})g = (6.81\,\text{kg})(9.81\,\text{m/s}^2) = \underline{66.8061\,\text{N}}$

$\Sigma M = 0 \rightarrow F_{cable}(0.6 + 0.15) = F_s(0.3\,\text{m})$

$\rightarrow F_s = k\Delta x = F_{cable}\left(\frac{0.6+0.15}{0.3}\right) = 66.8061\left(\frac{0.75}{0.3}\right) = \underline{167\,\text{N}}$

→ Assume $k \simeq 200\,\text{N/m}$

$\rightarrow \Delta x = \frac{F_s}{k} = \frac{167\,\text{N}}{200\,\text{N/m}} = 0.835\,\text{m} \rightarrow \underline{\text{TOO HIGH}}$

↳ TO SOLVE: Increase k, Increase distance of spring from base, reduce length of beam

Figure 10 – Calculations for Concept 3

C.5.4 Concept 4

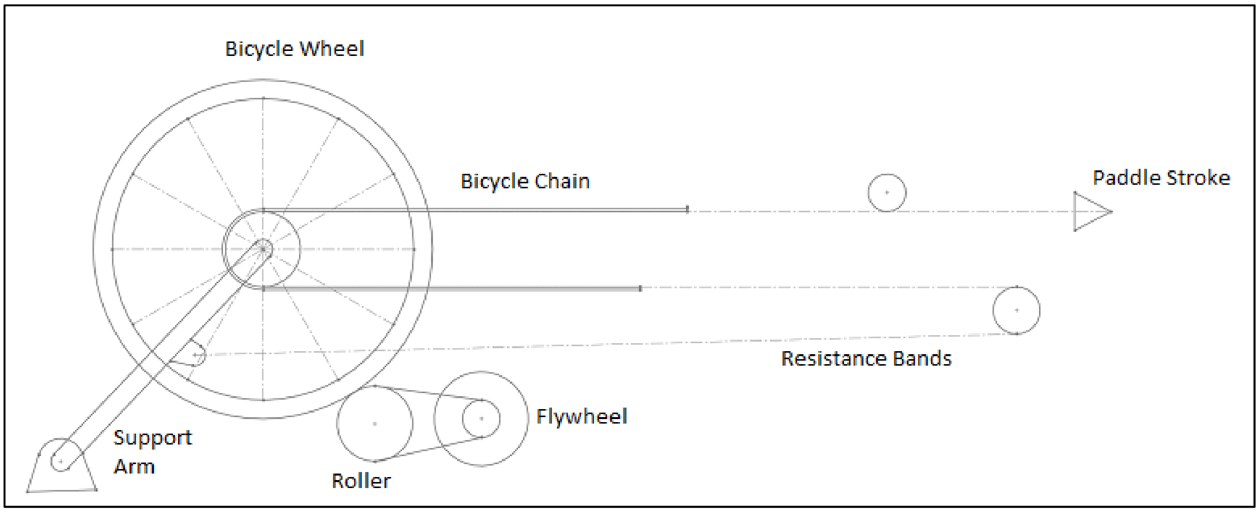


Figure 11 – Side View of Concept 4

This concept takes advantage of previously tested and proven concepts and modifies them to meet our requirements. The concept shown above originates from an E-Motion Roller trainer for bicycle where a bicycle wheel rests upon a roller connected to a flywheel. The motion of the bicycle wheel would cause the roller to rotate in turn causing the flywheel to rotate. A magnet, with several configurations, connected to the flywheel would act as a form of resistance. However, if a higher level of resistance is desired, bicycle gears can be implemented to add to the resistance supplied by the magnet.

Table C.5 – Advantages and Disadvantages of Concept 4

Advantages	**Disadvantages**
Easy to implement as it relies on proven concept (bicycle)	Not compact, as the design would require approximately 4-5 meters to function properly
Simple and easy to manufacture	
Consists of off-shelf products	
Able to achieve the flywheel speed without using many pulley ratios.	

C.6 Competitive Analysis

Currently there are two products, on the opposite side of the price spectrum, available on the market that can compete with our product. Aiming to keep the price of our paddle board trainer less than $500, the design team can edge the competition for giving the customers “a bang for the buck”.

C.6.1 Paddle Power Trainer

The Paddle Power trainer consists of dual resistance bands that are placed on top and bottom of the paddle. Priced at $100, the Paddle Power Trainer provides a relatively cheap solution to a rather complex problem. After researching the product thoroughly, the product is very hard to implement indoors. Also, the resistance applied by the bands isn’t constant and the sense of inertia does not exist.

Figure 12 - Paddle Power Trainer

C.6.2 Stand-Up Paddle Board Training Machine

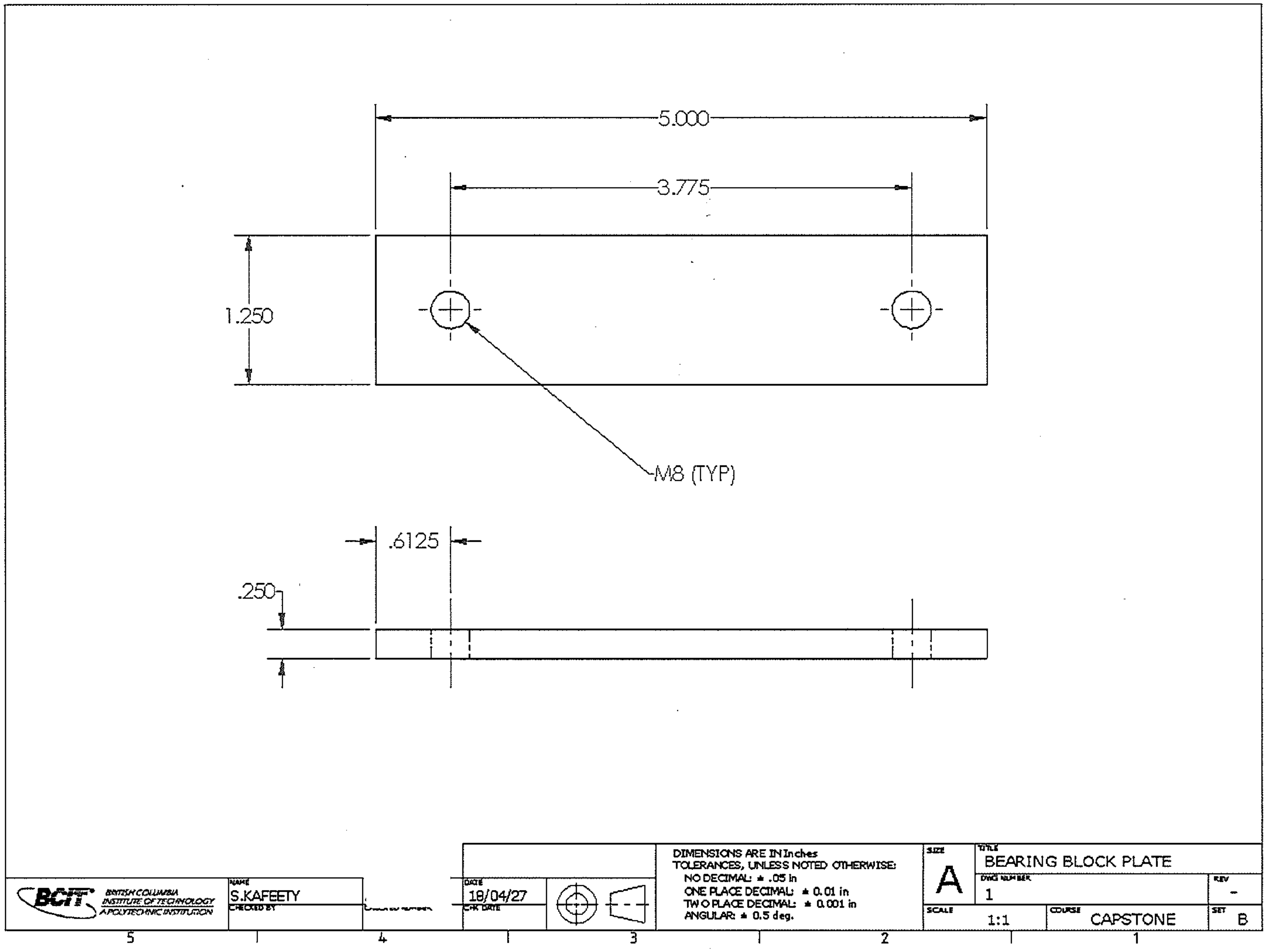
Supplied by VASA, a company based in USA, the stand-up Paddle Board Training Machine takes advantage of a variable wind resistance system to simulate the paddle board motion. However, starting at a price of $1549.00, the trainer sold by VASA tends to be very expensive.

Shown with SurfSet's RipSurfer X
(not included)

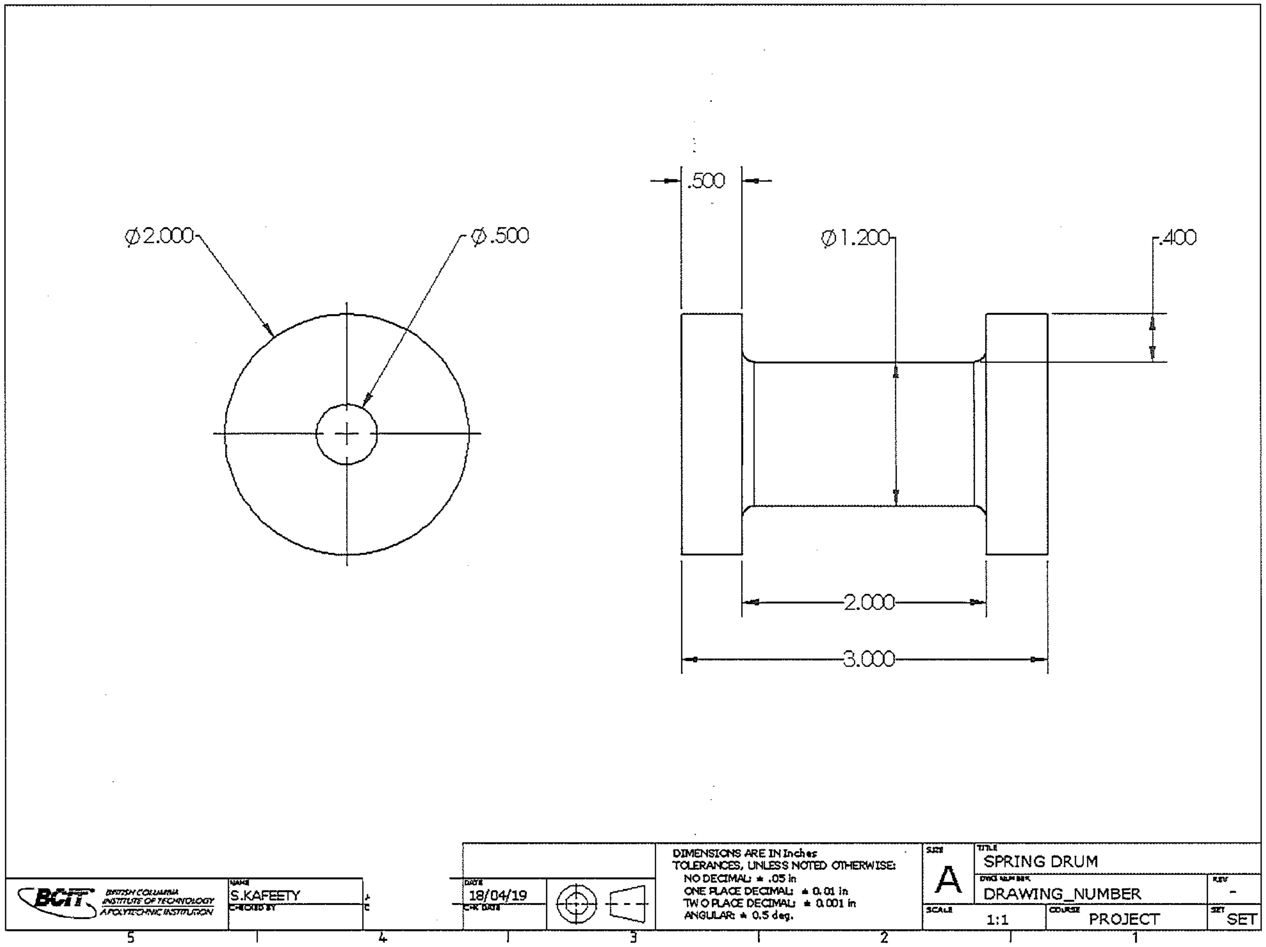
Figure 13 – Stand-Up Paddle Board Trainer

D Appendix D – Manufacturing Drawings

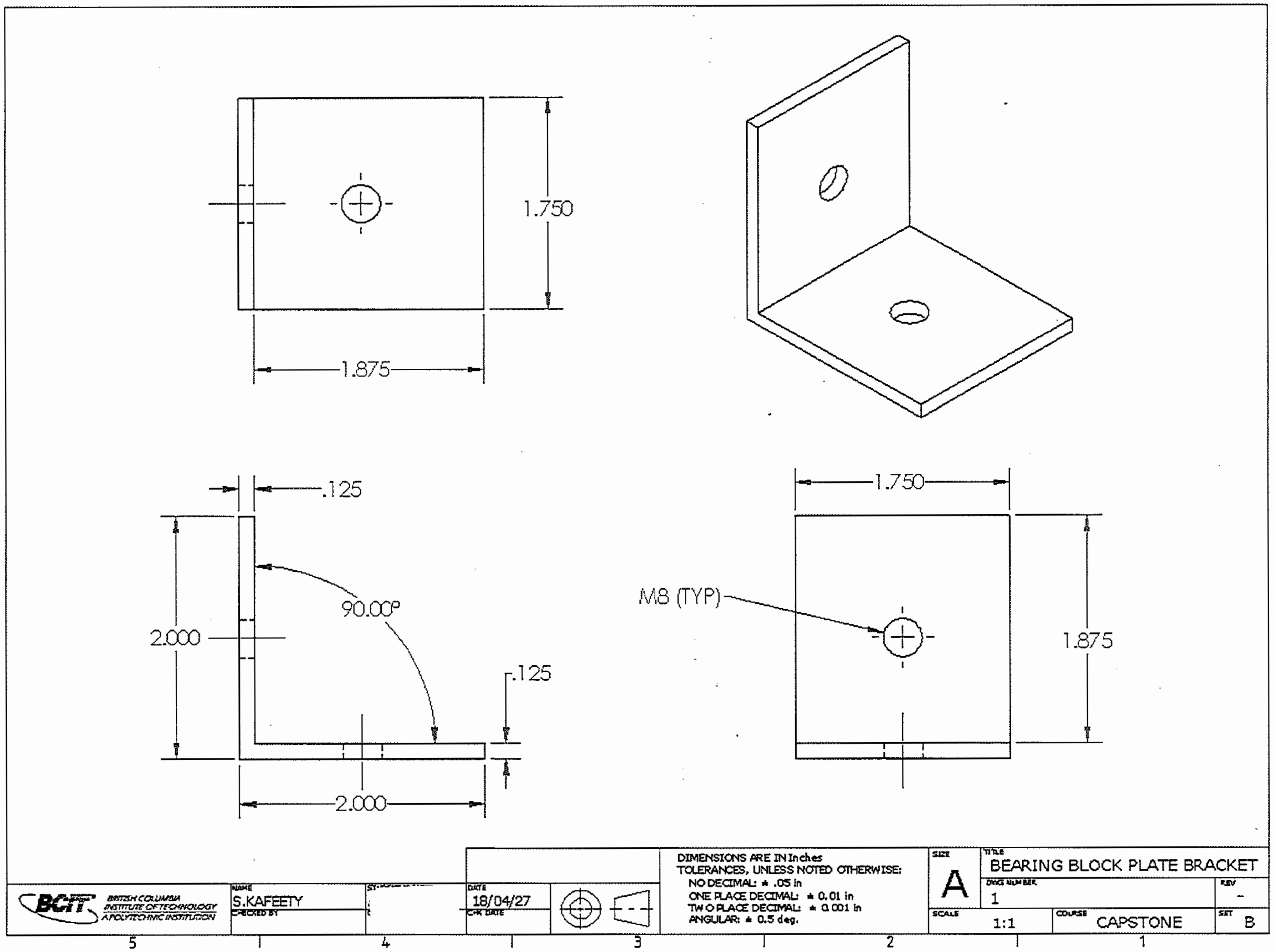
D.1 Bearing Block Plate



D.2 Spring Drum



D.3 Bearing Block Plate Bracket



BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY A POLYTECHNIC INSTITUTION

NAME S.KAFEETY

CHECKED BY

DATE 18/04/27

CHK DATE

DIMENSIONS ARE IN Inches
TOLERANCES, UNLESS NOTED OTHERWISE:
NO DECIMAL: ± .05 in
ONE PLACE DECIMAL: ± 0.01 in
TWO PLACE DECIMAL: ± 0.001 in
ANGULAR: ± 0.5 deg.

SIZE A

TITLE BEARING BLOCK PLATE BRACKET

DWG NUMBER 1

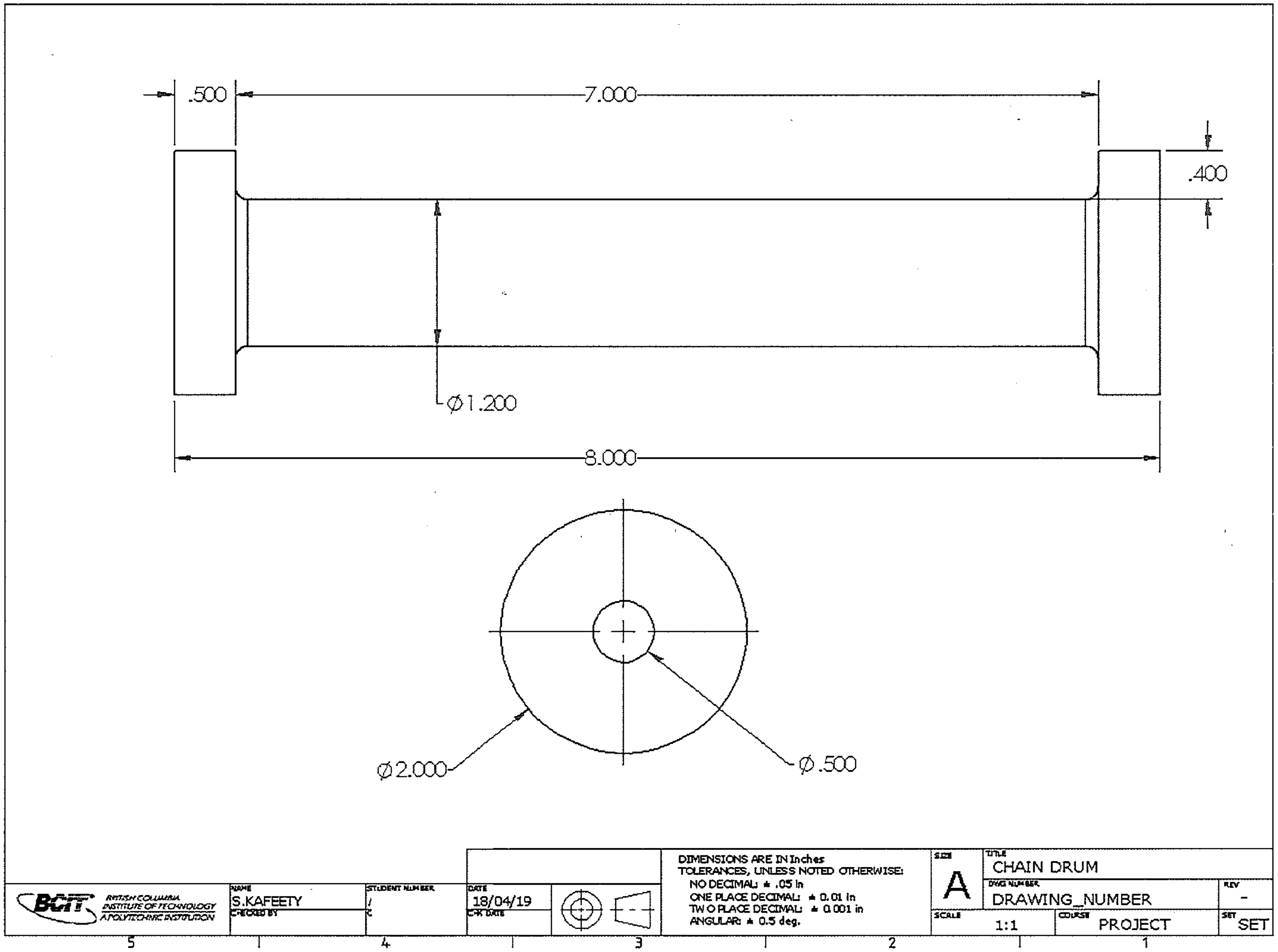
REV -

SCALE 1:1

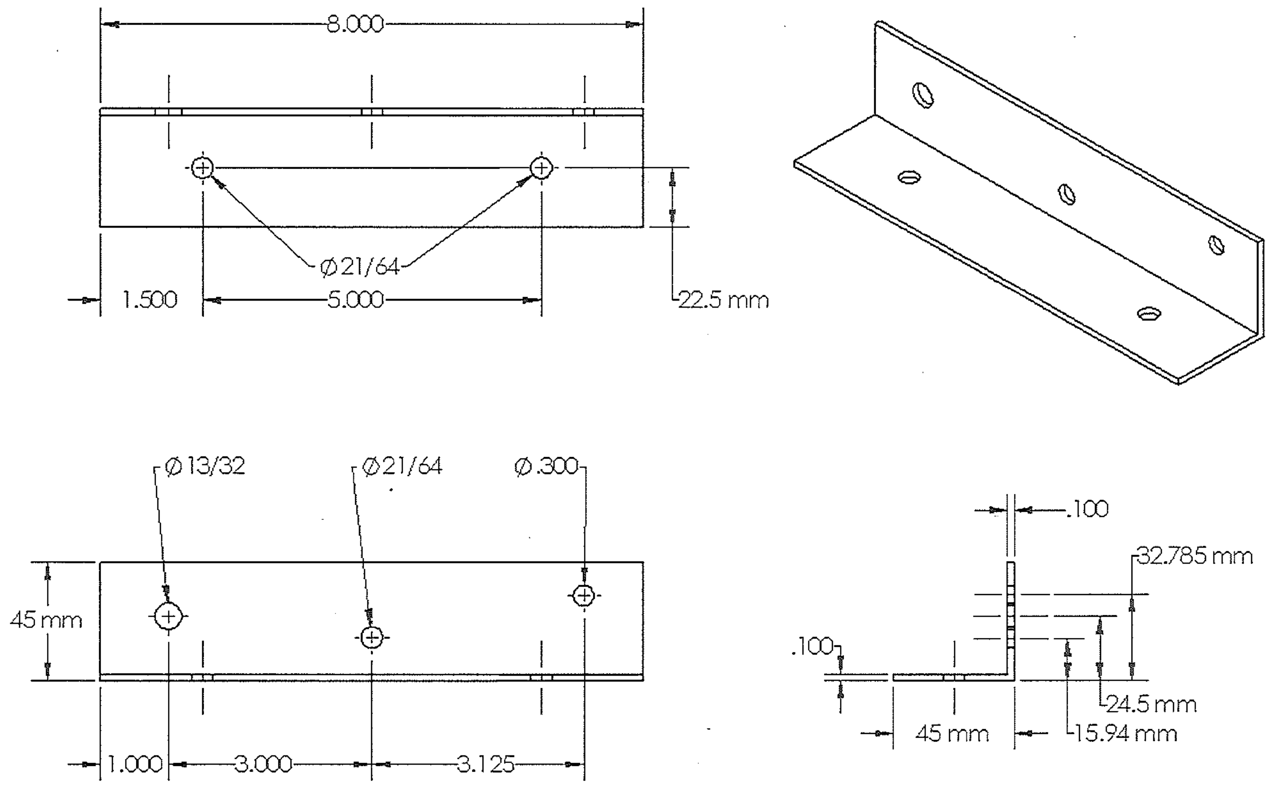
COURSE CAPSTONE

SET B

D.4 Chain Drum



D.4 Housing Bracket



All units are in inches unless otherwise specified

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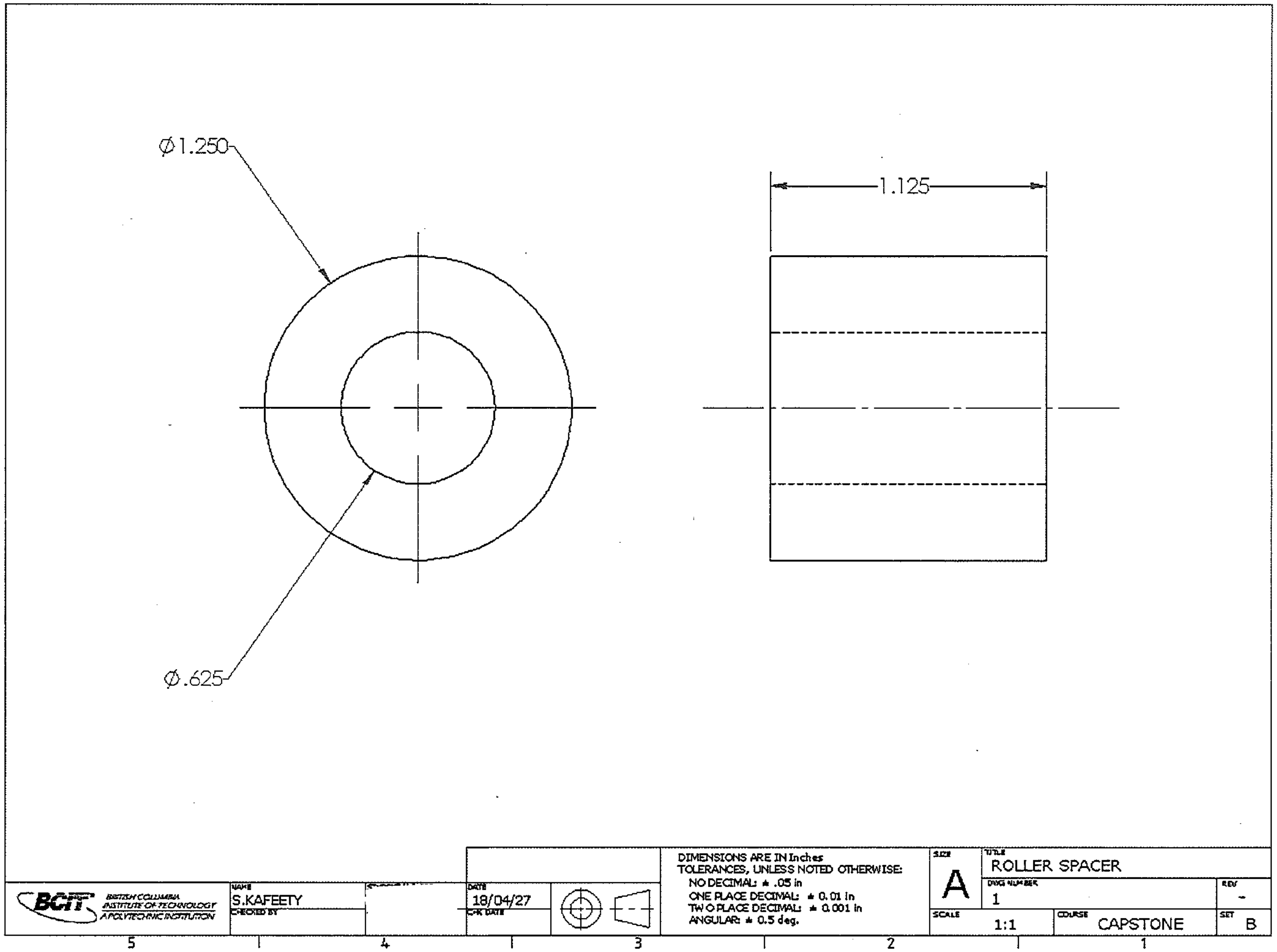
NAME S.KAFEETY
CHECKED BY
STUDENT NUMBER
DATE 18/04/30
CHK DATE

DIMENSIONS ARE IN Inches
TOLERANCES, UNLESS NOTED OTHERWISE:
NO DECIMAL: ± .05 in
ONE PLACE DECIMAL: ± 0.01 in
TWO PLACE DECIMAL: ± 0.001 in
ANGULAR: ± 0.5 deg.

SIZE A
TITLE HOUSING BRACKET
DWG NUMBER 1
REV -
SCALE 1:1
COURSE CAPSTONE
SET B

5 4 3 2 1

D.5 Roller Spacer



BCIT BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY A POLYTECHNIC INSTITUTION

NAME S.KAFEETY

CHECKED BY

DATE 18/04/27

CHK DATE

DIMENSIONS ARE IN Inches
TOLERANCES, UNLESS NOTED OTHERWISE:
NO DECIMAL: ± .05 in
ONE PLACE DECIMAL: ± 0.01 in
TWO PLACE DECIMAL: ± 0.001 in
ANGULAR: ± 0.5 deg.

SIZE A

TITLE ROLLER SPACER

DWG NUMBER 1

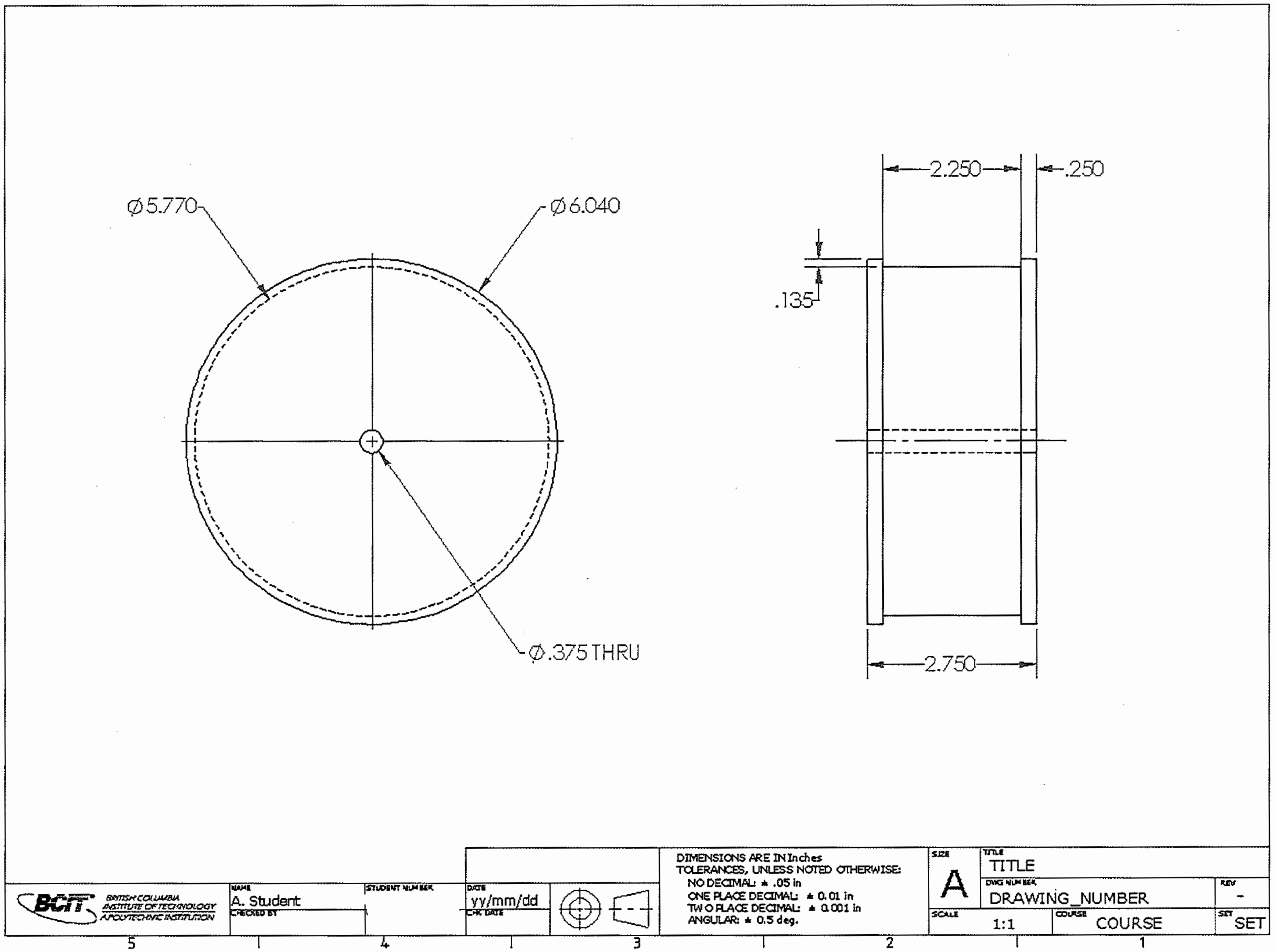
REV -

SCALE 1:1

COURSE CAPSTONE

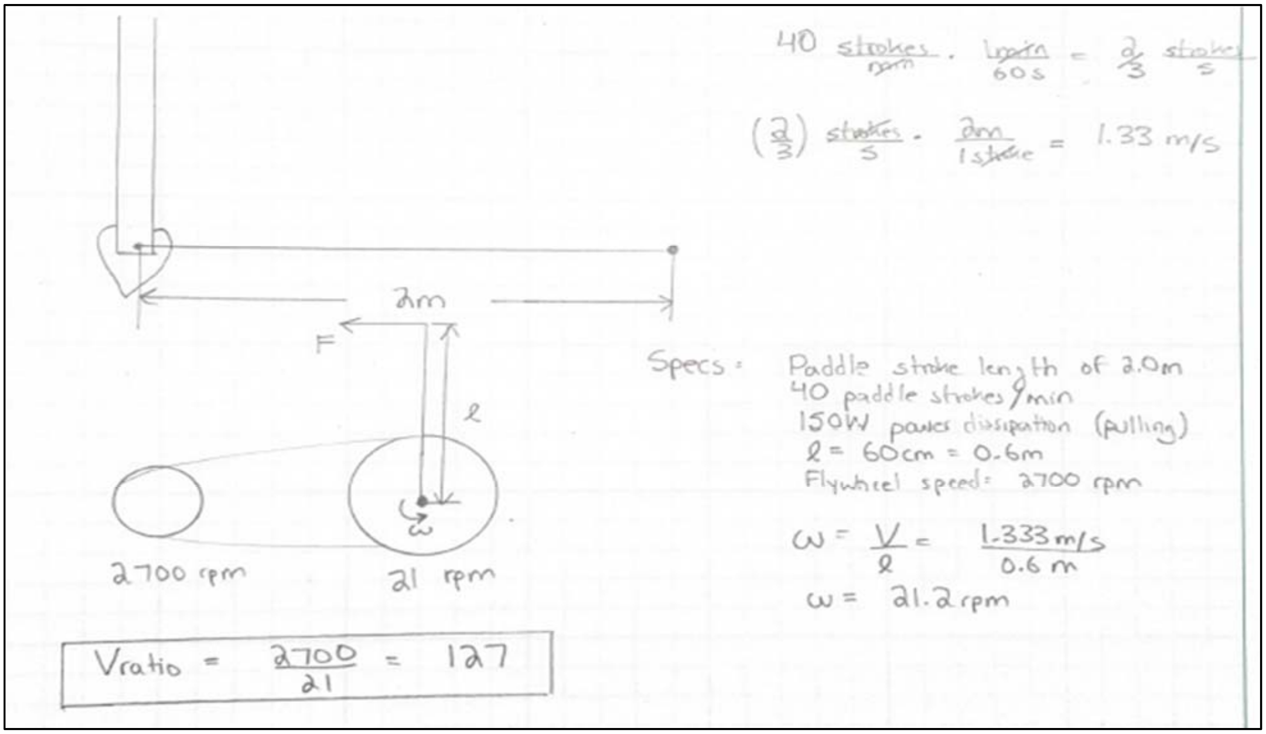
SET B

D.6 Spring Feed Drum



E Appendix E – Hand Written Calculations

E.1 Calculations for Concept 1



$$40\,\frac{\text{strokes}}{\cancel{\text{min}}} \cdot \frac{\cancel{1\text{min}}}{60\,s} = \frac{2}{3}\,\frac{\text{stoke}}{s}$$

$$\left(\frac{2}{3}\right)\frac{\cancel{\text{strokes}}}{s} \cdot \frac{2m}{1\,\cancel{\text{stroke}}} = 1.33\ m/s$$

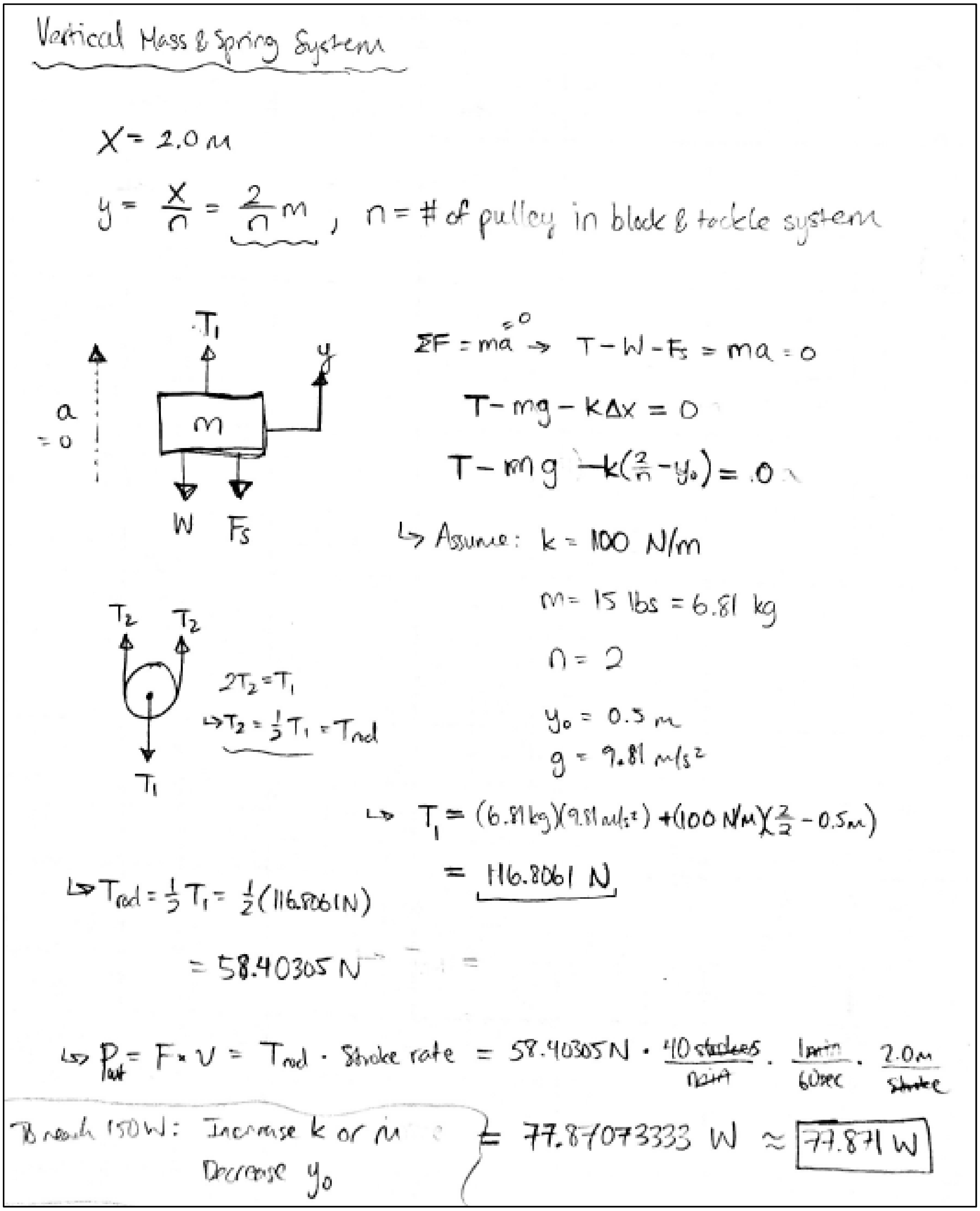
Specs: Paddle stroke length of 2.0m
40 paddle strokes/min
150W power dissipation (pulling)
ℓ = 60cm = 0.6m
Flywheel speed: 2700 rpm

$$\omega = \frac{V}{\ell} = \frac{1.333\,m/s}{0.6\,m}$$

$$\omega = 21.2\,\text{rpm}$$

$$\boxed{V\text{ratio} = \frac{2700}{21} = 127}$$

E.2 Calculations for Concept 2



Vertical Mass & Spring System

$X = 2.0\,m$

$y = \frac{X}{n} = \underbrace{\frac{2}{n}\,m}$, n = # of pulley in block & tackle system

$\Sigma F = m\overset{=0}{a} \rightarrow T - W - F_s = ma = 0$

$T - mg - k\Delta x = 0$

$T - mg - k(\frac{2}{n} - y_o) = 0$

↳ Assume: $k = 100\ N/m$

$m = 15\ lbs = 6.81\ kg$

$n = 2$

$y_o = 0.5\ m$

$g = 9.81\ m/s^2$

$2T_2 = T_1$

↳ $\underbrace{T_2 = \frac{1}{2}T_1 = T_{rod}}$

↳ $T_1 = (6.81kg)(9.81m/s^2) + (100\ N/m)(\frac{2}{2} - 0.5m)$

$= \underline{116.8061\ N}$

↳ $T_{rod} = \frac{1}{2}T_1 = \frac{1}{2}(116.8061N)$

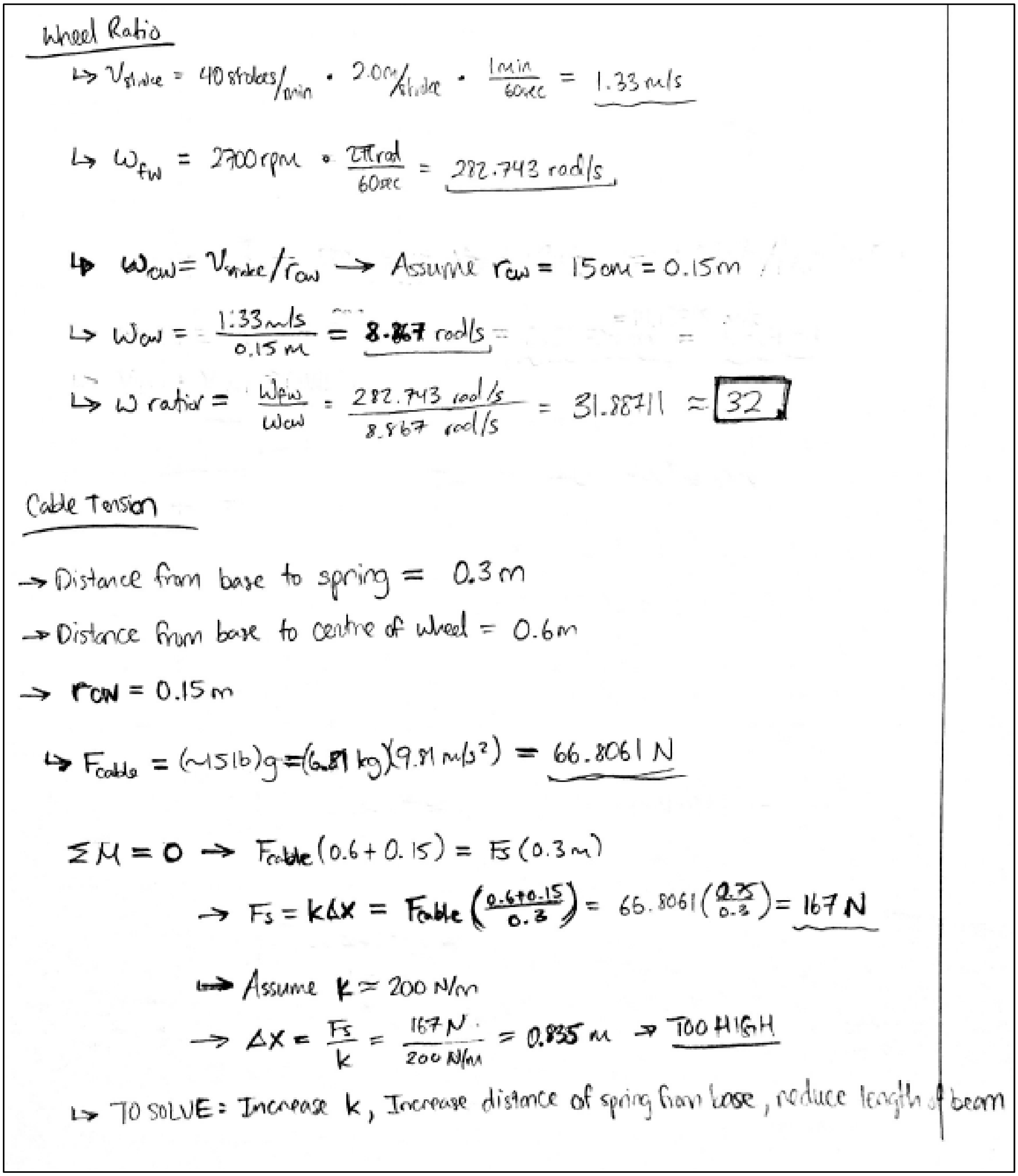
$= 58.40305\ N$

↳ $P_{out} = F \times V = T_{rod} \cdot \text{Stroke rate} = 58.40305N \cdot \frac{40\ strokes}{min} \cdot \frac{1min}{60sec} \cdot \frac{2.0m}{stroke}$

$= 77.87073333\ W \approx \boxed{77.871\ W}$

To reach 150W: Increase k or m
Decrease y_o

E.3 Calculations for Concept 3



Wheel Ratio

↳ $V_{stroke} = 40 \text{ strokes/min} \cdot 2.0\text{m/stroke} \cdot \frac{1\text{min}}{60\text{sec}} = \underline{1.33 \text{ m/s}}$

↳ $\omega_{fw} = 2700\text{rpm} \cdot \frac{2\pi\text{rad}}{60\text{sec}} = \underline{282.743 \text{ rad/s}}$

↳ $\omega_{cw} = V_{stroke}/r_{cw} \rightarrow$ Assume $r_{cw} = 15\text{cm} = 0.15\text{m}$

↳ $\omega_{cw} = \frac{1.33\text{m/s}}{0.15\text{m}} = \underline{8.867 \text{ rad/s}}$

↳ $\omega \text{ ratio} = \frac{\omega_{fw}}{\omega_{cw}} = \frac{282.743 \text{ rad/s}}{8.867 \text{ rad/s}} = 31.88711 \approx \boxed{32}$

Cable Tension

→ Distance from base to spring = 0.3 m

→ Distance from base to centre of wheel = 0.6m

→ $r_{cw} = 0.15\text{m}$

↳ $F_{cable} = (\sim 15\text{lb})g = (6.81 \text{ kg})(9.81 \text{ m/s}^2) = \underline{66.8061 \text{ N}}$

$\Sigma M = 0 \rightarrow F_{cable}(0.6 + 0.15) = F_S(0.3\text{m})$

$\rightarrow F_s = k\Delta x = F_{cable}\left(\frac{0.6+0.15}{0.3}\right) = 66.8061\left(\frac{0.75}{0.3}\right) = \underline{167 \text{ N}}$

→ Assume $k = 200 \text{ N/m}$

$\rightarrow \Delta x = \frac{F_s}{k} = \frac{167 \text{ N}}{200 \text{ N/m}} = 0.835 \text{ m}$ → TOO HIGH

↳ TO SOLVE: Increase k, Increase distance of spring from base, reduce length of beam