DISC GOLF THROWING ROBOT
PRELIMINARY DESIGN REPORT

WRITTEN BY

Sydney Lewis
Slewis11@calpoly.edu

Rachel Greenberg
Rgreen09@calpoly.edu

Erick Daza
Eedaza@calpoly.edu

Nevada Schultz
Nsschult@calpoly.edu

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo
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PREPARED FOR

Potential Sponsors

ABSTRACT

As a disclaimer, the following report is based on requirements set out by a previous sponsor that is no longer affiliated with this project. The design team has decided to maintain the goals and requirements listed in this document of their own accord.

Disc golf is a disc throwing sport that has increased in popularity over the past few decades. Disc manufacturers need a way to test the flight characteristics of their discs. The scope of this project is to create a disc throwing robot that can throw a driver disc a distance of 500 feet to 600 feet. Research shows that multiple disc throwing products exist; however, none of them meet the requirements set out by the design team. In order to prepare for the robot design and build, analysis on disc flight and different launching methods has been conducted. It was found that spin, speed, and release angle will affect the disc's flight and should be manipulated. The final product will incorporate the necessary elements to successfully fulfill the design team's vision.

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1 INTRODUCTION

Disc golf is a sport in which players throw discs into a target called a basket. The sport was established in the 1970s and has since grown in popularity over the past few decades.

1.1 Problem and Key Stakeholder

Currently, disc manufacturers test their discs by manually throwing them. This process is taxing on the human body when attempting to throw a disc at pro-level distances. In addition, fatigue can affect flight data and accuracy. To test top-of-the-line discs, the design team was tasked to create a disc throwing robot. The robot should throw a driver disc 500 feet to 600 feet to emulate a full power throw of a professional disc golf player. To maximize the efficiency of the disc flight, the team has been encouraged to manipulate the release angle, rotation, and speed of the disc. The robot must also be accurate, precise, and easy to operate.

1.2 Design Team

The team taking on the design challenge consists of four mechanical engineering students. Nevada spearheaded the project with a decade of disc golf experience and specializes in welding, machining, and prototyping. Sydney is a mechatronics expert and an experienced drone builder. Rachel has a background in robotics design and manufacturing processes. Erick is geared up with programming knowledge in MATLAB, Python, and SolidWorks to make the disc golf robot a reality.

1.3 Document Overview

Within this document, the “Disc Golf Robot” team will illuminate details associated with the completion of the project. Throughout the following sections, the reader should walk away with a deep understanding of the problem at hand and how the design team will take on the challenges. Section 2 provides a detailed background of the project. From project needs and wants, to disc golf statistics, similar designs, and technical challenges, the reader will understand all the factors the team has taken into consideration thus far. In section 3, the reader will learn about the objectives, and learn how the design team frames the many requirements into a feasible and workable project. The blurred lines around what the team can and cannot control will be clarified, and a series of engineering specifications will be laid out. Section 4 will highlight the steps taken to come to a design decision: ideation, prototyping, and evaluation. Section 5 rounds out the preliminary design review by showing a detailed plan of how the design team will accomplish upcoming tasks. With a clear approach to each milestone, the reader will see that the disc golf robot has provided a great challenge to the design team, but the challenge is within reach of the team’s capabilities. Lastly, the conclusion section will summarize the entirety of the document.

2 BACKGROUND

Survey based blogs indicate the average disc golf player throws between 300-350 feet. Pro level athletes reach distances up to 600 feet. This robot aims to emulate a pro-level athlete, consistently delivering the farthest throw possible.

2.1 Determining Stakeholder Needs

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The primary task during the initial stage of research was to identify stakeholders and their needs. Research showed that the market for disc golf is rapidly increasing. In 1975, the first disc golf course in the US was installed. By 2020, there were over 9,000 [1]. The number of active members in the PDGA doubled over the last four years; showing 35,000 active members of the Professional Disc Golf Association (PDGA) in 2016, to 71,000 in 2020. Additionally, the Pro Purse has doubled in last decade, with 2020's prize coming in at a whopping $4,082,653 [1].

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Based on the team's knowledge of the current disc golf market, this product has potential to generate great demand; the primary stakeholders being disc manufacturing companies. With disc golf's increasing popularity, manufacturers are in prime position to capitalize on its growth. A machine like the disc robot would greatly improve the quality control of discs and serve as a strong marketing selling point for customers.

Prior to setting up a meeting with the team's previous sponsor, the team formulated needs based on the limited introductory information given. The team came up with a list of parameters it deemed the stakeholder would like to manipulate, such as disc speed, distance, rotation, cost, size, and launch angles. Based on the team's research, it was assumed acceptable for the product to launch a disc approximately the distance an average disc golf player can launch. That distance, as shown in Figure 1, is between 300 and 350 feet.

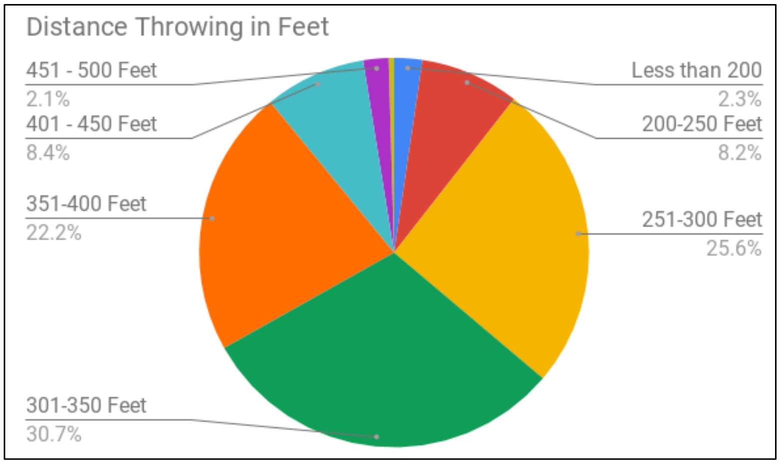

Figure 1. Typical Disc Golf Throw Distances [2]

Once the team conducted the interview with the former stakeholder, there was much more clarity regarding the company's needs. The key takeaway from the meeting was that this company was not as concerned about independent control parameters such as translational velocity or rotational speed, rather they were mainly in need of a product that can launch a disc within 500-600 feet.

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Other crucial takeaways from the meeting were that this robot needs to be accurate, with the capability of launching different types of discs. Furthermore, the primary reason for the robot is for quality control and investigating how changes in quality effect flight.

With a greater understanding of this company's needs, the team worked on formulating a concise problem statement as part of the preliminary steps in the design process. There were recurring themes that each team member individually formulated such as:

- The need to replace human disc testing with automated disc testing.
- The ability to launch a disc at pro-level distances.
- The ability to isolate variables such as speed, release angle, and rotational speed.

The problem statement, which is more formally presented in the objectives section of the , was derived from the listed recurring themes stated above.

2.2 Similar Products

It was a challenging task to find products like a disc throwing robot. There are certain projects, which will shortly be discussed in further detail, that can launch frisbee discs. However, most machines or contraptions on the market are not designed to launch a disc; rather, they launch other objects, such as sports balls and clay shooting targets. The following is a brief overview of projects and products that can potentially aid in the ideation process.

Figure 2 demonstrates a project that has the capability of launching frisbee discs in a fast and sequential manner. The disc is given the initial momentum by the rotating disk located at the center and is guided by the side rails. The guiderails are also what generates the spinning motion of the disc, which may serve as a reference in terms of how to generate spin for the team's design. This design does possess the basic ability to launch a disc and seems like a feasible project. However, based on the videos, it does not appear to meet the distance criteria of throwing a disc 500 to 600 feet. Rather, this seems to possess the ability to only throw a disc up to 40 feet. This may be simply because the machine was not intended to launch far distances, or because it is not capable of launching long distances.

Figure 2. Frisbee Track Launcher [3]

Figure 3 demonstrates another project which can launch only one disc at a time. The disc is given rotational speed by a separate motor and suction cup. The spinning suction is attached to a throwing arm that spins, giving the disc linear velocity. This design also meets the criteria of launching a disc with control of different parameters such as rotational and translational velocity, but it fails to meet the main criteria which is launch distance. From the video, it appeared to only be able to launch the disc 60 feet. The problem may be that due to the nature of how the machine grips the disc, it does not possess the ability to generate enough thrust force. It therefore seems that it would be best to avoid any type of grip, such as the one shown below, that would impair the ability to impart a large thrust force.

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Figure 3. Suction Cup Swing Launcher [4]

Figure 4 represents an existing product in the market which is a non-automated contraption that can launch a disc. This is like the target launching product because they both function in a similar manner. One key takeaway of this product is the gripping mechanism, which may certainly be used as a reference for any potential future design. This product demonstrated that a stronger grip on the disc may lead to a further launch distance, which will be considered regardless of whether the design is modeled after this product. This product does appear to be able to launch at approximately the desired distance of 500 feet, however, it takes human power to throw the object. A design which utilizes a robotic arm instead can potentially be modeled after this product. This product is similar in nature to the patent "Disc Launching Mechanism" [5].

Figure 4. Non-Automated Disc Thrower [6]

Figure 5 is an existing product with a major drawback. It does not have the ability to launch discs but could potentially be used in the ideation process to generate a design that meets the stakeholder's criteria. A great feature of this machine is that it can launch projectiles at high velocities and therefore large distances, but it is not known exactly how fast or how far it could launch a disc. Another positive feature is that, unlike a robotic arm, it would not need a sudden braking impulse to impart thrust onto the disc.

If a design such as the one in Figure 2 is used, it may be beneficial to model it after a design like this where there are two wheels acting on the disc as opposed to one. A patent, "Contacting Wheels Type Football Throwing Device" [7] describes this design in more detail.

Figure 5. Automatic Football Launcher [8]

Figure 6 demonstrates a design that can generate a tremendous amount of thrust force by utilizing pneumatics. The pneumatics could also be replaced by springs or elastic chords capable of generating large thrust forces. The issue with this design is that it was unable to generate rotational motion of the disc and consequently failed to launch more than 50 feet. If the team can figure out a way of generating rotational motion, this design has potential to offer the largest distance due to its ability to generate a great amount of thrust force relative to the other previously mentioned products. The key takeaway is that if the team cannot generate enough spin on the disc, no amount of thrust force, regardless of design, will be able to launch the disc far enough.

Figure 6. Pneumatic Disc Launcher [9]

2.3 Patents

Patents that could directly aid in the ideation process were scarce. Almost all the patents found were determined to be helpful based on certain components that they contain. Most of the patents not shown in this report are identical to the products demonstrated above, while others are only similar in nature. Other patents do not represent any of the products above but were still chosen due to the extrinsic value they may provide to the project. An example of such a patent is the robotic arm patent [10], which may be useful should the team deem it optimal to utilize a robotic arm as the mechanism for launching discs. A list of useful patents is in the References section of this report.

2.4 Technical Challenges

As described above, there are few existing products to launch frisbee discs; the ones that can, leave much to be desired in terms of distance. Research on throwing biomechanics shows that the largest power contribution results from horizontal shoulder adduction, providing nearly all the work done to increase translational velocity of the disc. [11] One of the challenges is not only to generate enough power, but also enough spin so that the disc has angular momentum. Angular momentum is crucial for long disc flight. Figure 6 demonstrates a pneumatic device that encapsulates this rotational challenge. The disc was launched with high power but tumbled to the ground shortly after releasing due to the lack of spin. The biomechanics of a human arm are extremely difficult, if not impossible, to replicate exactly. Coordination in the hands and wrist are integral in producing a concentric throw, as shown in Figure 7 below. Hands and wrist are technically advanced mechanical devices that are difficult to replicate. If a grip between the robot and the arm can be effectively accomplished, then research suggests it may be possible to design a flexible robotic arm.

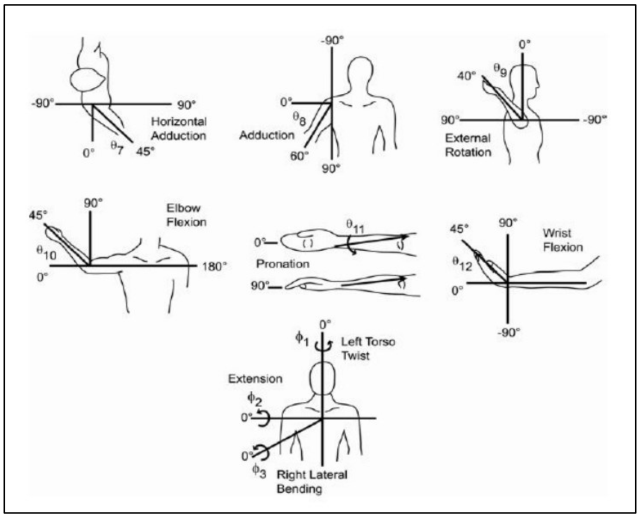
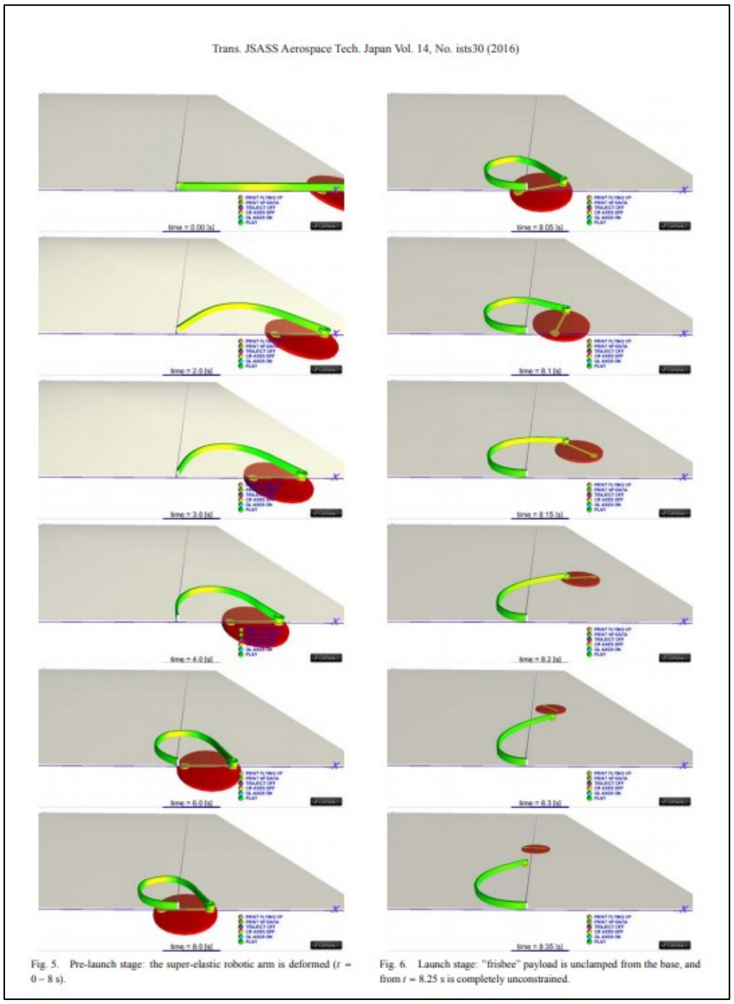


Figure 7. Biomechanics of a Human Arm Throwing a Disc [11]

A robotic arm may utilize linkages in a variety of configurations. The International Astronautical Congress published an article describing robotic manipulators as a type of mechanical catapult that achieves “not only desired ejection velocity of the payload, but also its required spin.” [12] The difficulty in the practical use of these systems is their highly non-linear nature, making the behavior difficult to model. Figure 8 shows a diagram of the super-elastic robotic arm, outlining the trajectory from windup to release.



Trans. JSASS Aerospace Tech. Japan Vol. 14, No. ists30 (2016)

Fig. 5. Pre-launch stage: the super-elastic robotic arm is deformed (t = 0 – 8 s).

Fig. 6. Launch stage: "frisbee" payload is unclamped from the base, and from t = 8.25 s is completely unconstrained.

Figure 8. Mechanical “Frisbee” Catapult Using a Flexible Arm [12]

The type of material used in this design is a key issue. Research suggests a material with a high modulus of elasticity, low mass density, and high structural damping as the solution to most problems of flexibility. [13] It could be advantageous to circumvent the complexities of a mechanical arm by separating the translational and rotational velocity with two different mechanisms (i.e., spinning up, then launching.) The challenge with this idea is interfering with the isolated velocity and losing energy on the interaction.

For a disc to have consistently good flight characteristics in terms of speed, glide, turn, and fade, it is important to control the angle, spin rate, and translational velocity. Technical journals have identified two key parameters that affect flight performance: aerodynamic efficiency (a unitless ratio of lift to drag, *CL/CD*) and more importantly, coefficient of pitching moment (*CM*). The coefficient of lift, *CL*, is directly influenced by spin, causing a greater lift force and longer flight time, especially so if the crosswind is aligned. In a wind tunnel, where the previous stakeholder indicated they were planning to use the robot, these coefficients have potential to be free from environmental influence other than the motion imparted by the robot itself. Drag coefficients do vary from disc to disc; as an example, the drag coefficient of a putter is larger than that of a driver at typical angles of attack. [14] Both the aerodynamic efficiency and coefficient of pitching moment directly affect the distance a disc can travel. [15] The pitching moment influences the tendency of the disc to yaw from its intended path, and the aerodynamic efficiency influences the disc's flight time. [16]

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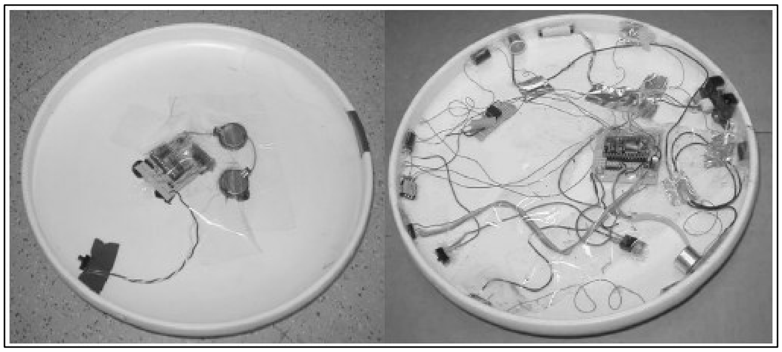


Figure 9. Frisbee Mounted with Sensors [14]

Real-time Frisbee flight data can be obtained by mounting pressure, infra-red, accelerometer, and magnetometer sensors underneath the cavity of a disc as shown above in Figure 9 [14]. From the source that performed this experiment, inconsistencies in drag and pitching moment were captured, likely due to the wobble effect of the disc weighted down with sensors. However, this data combined with other sources in the scholarly report suggested a linear relationship between launch speed and range rather than quadratic (which would be expected for an ideal point-mass projectile with negligible drag). The conclusion of this research was that disc ejection speed is an extremely important parameter to control; possibly more so than spin (as it does not decay at the same rate as linear velocity during flight.)

3 OBJECTIVES

This section defines what the team can and cannot control. Here, the engineering specifications are laid out for the reader.

3.1 Problem Statement

Disc manufacturers need an automated way to consistently launch discs at pro-level distances, while ideally being able to isolate and change variables such as speed, release angles, and rotation. Surprisingly, human testing is the most prominent method for testing disc flight characteristics.

3.2 Boundary Diagram

Figure 10 was used to define the scope of the problem by determining which factors the team can control. Elements that are included in the red circle are within the control of the design team. For example, the disc distance can be achieved by many methods such as spinning wheels, pneumatics, and flexible arms; it is therefore within control of the design team and circled in red. The type of power supply and the robot itself are also inside the circle as the design team can manipulate those variables. Outside the box are variables the team cannot directly control such as disc parameters and weather conditions.

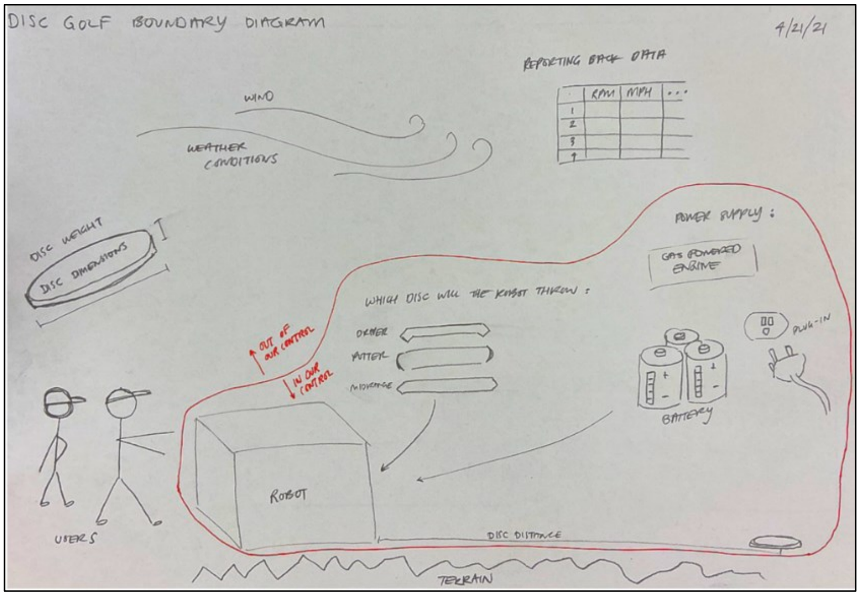


Figure 10. Boundary Diagram

3.3 Stakeholder Wants and Needs

After consulting with the previous sponsor and negotiating a hierarchy of their requests, a concise list of the stakeholder's needs and wants was created. In no particular order, the wants and needs for the disc throwing robot can be seen in Table 1.

Table 1. Summary of Customer's Needs and Wants

Needs	Wants
500-600 feet of distance	Throw any distance by 100-foot increments
Throw a distance driver	Throw all types of discs
Easy to operate	Fast to reload
Minimal in size	Easy to transport
Somewhat accurate	More accurate than a human
Realistic speed and spin to perform flight	Control over speed and spin

3.4 Description of QFD Process

The quality function deployment (QFD) gave the design team a way to define the problem based on a rated tier system of needs and wants. The QFD, shown in its entirety in Appendix A, shows the relationship between who, what, how, how much and now. These categories help to define the importance of a specification to the stakeholder. Within the QFD, the key needs of the customer are stated and weighted to show the importance of each need. In addition, engineering specifications relate to the customer's needs to signify if the design is "over-designed" or "under-designed." Lastly, current products are listed and are rated against the needs of the stakeholder. Together, these categories reveal that there are no existing products that fully satisfy the wants and needs identified. It also highlights areas that have been heavily developed and others that will require more research. By creating the QFD, the design team has cultivated a deeper understanding of the problem and is better prepared to acknowledge every need in the design of the disc golf robot.

3.5 Engineering Specifications

Table 2 displays the order of importance, from most important to least important, of many engineering specifications. The main priority of the robot is to project a driver disc 500 - 600 feet. The higher importance items have an "H" for high-risk. A high-risk status indicates that without this parameter, the robot may not be considered successful. There is also a high-risk that we will not be able to accommodate all the different disc shapes. All the disc distances are within a tolerance of about 50 feet. These distances are all testable. In addition to throwing a multitude of discs, it is important that one person can operate the robot. Ideally, the team does not want excessive hands-on involvement beyond one person loading the robot. The robot also needs to be a relatively portable size; smaller than 40 cubic feet and requiring no more than three people to transport.

Table 2. Robot Specifications

Spec. #	Parameter description	Requirement or target	Tolerance	Risk	Compliance
1	Driver distance	550 ft	±50 ft	H	T
2	Hybrid distance	450 ft	±50 ft	H	T
3	Fairway distance	350 ft	±50 ft	H	T
4	Midrange distance	250ft	±50 ft	H	T
5	Putter distance	200 ft	±50 ft	H	T
6	Operation difficulty	1 person can operate	Max	M	A, T
7	Production Cost	TBD	Max	M	A, I
8	Overall Size	40 ft^3	Max	M	A, I
9	Transportability	3 people required	Max	L	T, A

4 CONCEPT DESIGN

To begin the concept design process, an exercise called "Ideation" needed to be completed. Ideation is a brainstorming and small prototyping procedure that aids in creative thinking and conceptualizing of design ideas.

4.1 Ideation

The first step in the team's ideation was called "Functional Decomposition." This exercise helped break down the goals of the design challenge into smaller pieces. The design can be separated into a main function that separates into subfunctions. The main function should reflect the goal of the challenge, while a subfunction should describe design considerations that will add up to accomplish this goal. Figure 11 shows the design team's functional decomposition tree that breaks down the Disc Golf Robot into main and subfunctions.

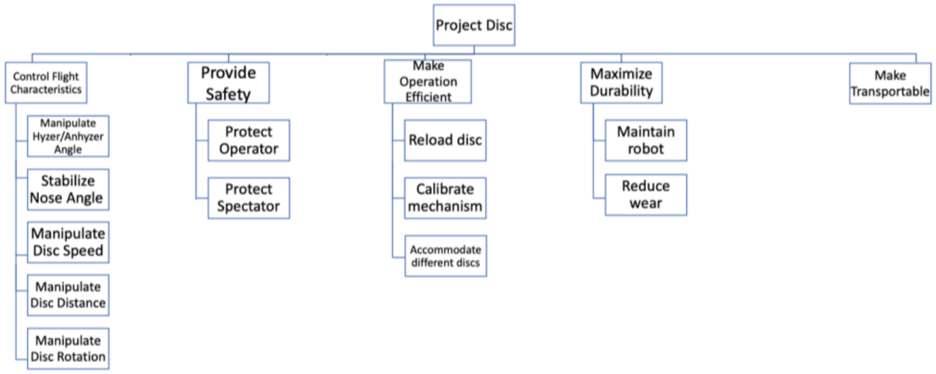


Figure 11. Functional Decomposition Tree

As the next step in the ideation process, the team chose to create "How Might We" questions. "How Might We" questions allow for brainstorming on how to achieve the subfunctions listed in the functional decomposition tree.

For example, the design team asked questions like, "How might we manipulate the hyzer and anhyzer angle?" or, "how might we reload discs into the robot?" For each "How Might We" question created, the team spent about 3 minutes individually brainstorming ideas to answer that question. When the brainstorming was complete, the team moved on to create ideation models.

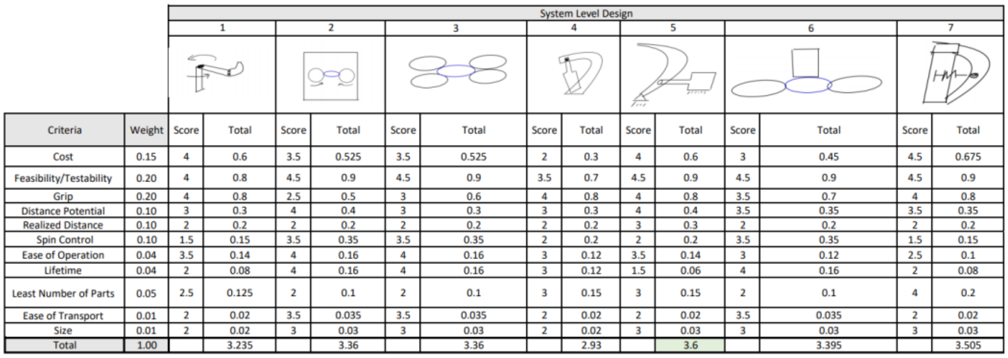
Five ideation models were created by each team member. Ideation models are small prototypes that take 20 minutes or less to make, representing one function that can be incorporated into a full system design. The model serves as a feasibility check for design ideas and helps to communicate the ideas to other members within the team. In Figure 12, one ideation model from each team member is shown.

Figure 12. Ideation Models

The function tested in the top left corner is an actuation mechanism. This model confirmed that an actuator-linkage assembly would be feasible and cause an arm to rotate 90° around a fixed pivot. The top right model tested the function of manipulating the hyzer angle; a gear assembly is shown surrounding the launching chute. On the bottom left corner, a disc is surrounded by four spinning wheels. The bottom right corner shows a launching mechanism utilizing an arm rotating 360°. After sharing each ideation model within the team, decision matrices were made to eliminate and narrow down the best ideas for each function.

4.2 Idea Selection and Refinement

To eliminate and refine designs, mathematical analysis, research on existing products, and decision matrices were utilized. Before the group performed collective design analysis, the team individually created Pugh matrices for specific functions to identify the strongest options. These matrices can be seen in Appendix B. After identifying the strongest functions, each member created two full-scale designs with the individual function options that were identified as the strongest. As a group, the team then rated each design against specific criteria with different weights. The criteria for the weighted decision matrix were determined from the stakeholder needs and wants identified by the QFD analysis; the weighted matrix can be seen below in Figure 13.



		System Level Design													
		1		2		3		4		5		6		7	
Criteria	Weight	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Cost	0.15	4	0.6	3.5	0.525	3.5	0.525	2	0.3	4	0.6	3	0.45	4.5	0.675
Feasibility/Testability	0.20	4	0.8	4.5	0.9	4.5	0.9	3.5	0.7	4.5	0.9	4.5	0.9	4.5	0.9
Grip	0.20	4	0.8	2.5	0.5	3	0.6	4	0.8	4	0.8	3.5	0.7	4	0.8
Distance Potential	0.10	3	0.3	4	0.4	3	0.3	3	0.3	4	0.4	3.5	0.35	3.5	0.35
Realized Distance	0.10	2	0.2	2	0.2	2	0.2	2	0.2	3	0.3	2	0.2	2	0.2
Spin Control	0.10	1.5	0.15	3.5	0.35	3.5	0.35	2	0.2	2	0.2	3.5	0.35	1.5	0.15
Ease of Operation	0.04	3.5	0.14	4	0.16	4	0.16	3	0.12	3.5	0.14	3	0.12	2.5	0.1
Lifetime	0.04	2	0.08	4	0.16	4	0.16	3	0.12	1.5	0.06	4	0.16	2	0.08
Least Number of Parts	0.05	2.5	0.125	2	0.1	2	0.1	3	0.15	3	0.15	2	0.1	4	0.2
Ease of Transport	0.01	2	0.02	3.5	0.035	3.5	0.035	2	0.02	2	0.02	3.5	0.035	2	0.02
Size	0.01	2	0.02	3	0.03	3	0.03	2	0.02	3	0.03	3	0.03	3	0.03
Total	1.00		3.235		3.36		3.36		2.93		3.6		3.395		3.505

Figure 13. Weighted Decision Matrix

The heaviest weighted criteria on the decision matrix were related to distance. The two outstanding designs were related to existing products that possess the ability to launch projectiles at high velocities and distances. One outstanding design concept was modeled after the Epec disc launcher. This product has been demonstrated, and tested by the team, to launch discs at distances within that of our target distance, approximately 350 feet. The second outstanding design was the spinning wheel robot, as it is modeled after an existing product with the ability to launch projectiles at high speeds. Distance potential was determined mathematically for two designs, including the pneumatic actuator throwing arm, and the spinning wheel robot.

4.3 Preliminary Analysis

For the actuator, a bore size of four inches was selected and the manufacturers data on force and stroke length was used to estimate ejection velocity. A simple geometry of a rod pinned at one end was used, and weight for the throwing arm was estimated by selecting realistic dimensions and calculating the mass with the density of carbon fiber. The goal of this analysis was to determine if the actuator is powerful enough to create speeds of 70 miles per hour at the end of a throwing arm. Using work and energy, the analysis revealed that our chosen actuator and arm would be capable of reaching speeds up to 165 mph, as shown by the Preliminary Analysis in Appendix C.

A preliminary analysis of the flight characteristics of the disc was done using the spinning wheels design as the launching mechanism. The angular and linear velocity was plotted against varying normal forces and varying coefficients of friction between the spinning wheels and the disc. The plot is shown below:

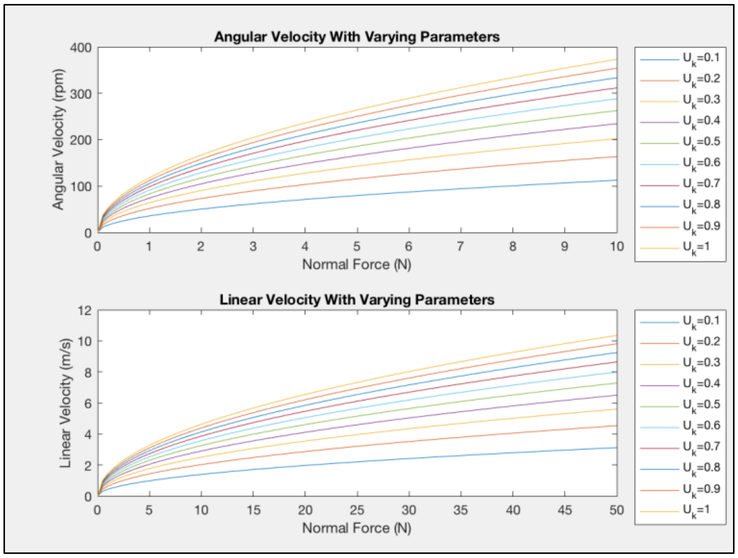


Figure 14. Flight Characteristics of the Spinning Wheel Disc

Figure 14 demonstrates that higher contact between the wheels and the disc along with a higher coefficient of friction will lead to a higher overall kinetic energy of the disc. One aspect of this analysis that was not taken into account was how much normal force could be applied to the disc without negatively impacting the flight characteristics. It is believed that compressing the disc to a great degree could cause the disc to momentarily contract and suddenly expand, causing a sudden unwanted motion that could affect the flight parameters upon release. The hand calculations for the formulas used to generate the plot as shown on Figure 14 is in Appendix D of this report.

Several other designs were eliminated due to lack of existing proof of concept. For example, the air cannon had great potential for launch power, but from existing videos showed great instability and an inability to spin the disc. For these reasons, the air cannon was deemed too risky and eliminated as a design option.

4.4 Concept CAD

Figure 15 below represents the basic functions of the throwing arm design. On the left, the actuator is retracted showing the loaded state of arm motion. The disc would fit directly into the EPEC grip as seen on the end of the arm. A powerful pneumatic actuator controls the arm, applying a strong moment when extended at high velocity. On the right of Figure 15, the lower actuators attached to the base plate of the arm are shown retracted, tilting the launching plate, causing the disc to be released at a negative angle with respect to the horizontal. In other words, the disc would be release at an anhyzer angle. With pneumatic pistons secured to the bottom of an adjustable plate, the disc can be released at a multitude of release angles.

Additionally, this design could be improved by mounting the two pistons that adjust the plate at a 45 degree angle, securing the plate to the vertical portion of the base seen below. This would allow for smaller actuators, and a larger range of motion for the plate.

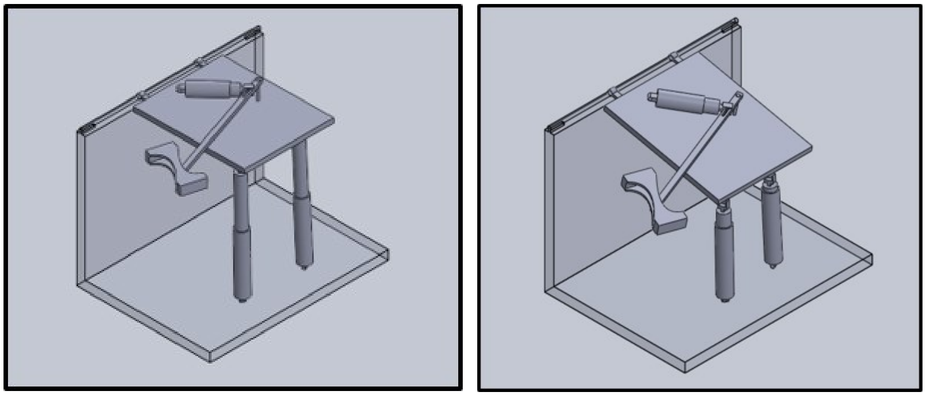


Figure 15. Pneumatic Actuator Launching “Epec” Disc Arm

The spinning discs is the other main concept that the team is taking into consideration. This concept will also be modeled after an existing product, which has the ability to launch footballs and baseballs at high speeds. It is believed that modeling the concept after this existing product will allow for the disc to be launched at high speeds which in turn will allow us to meet the distance criteria. The spinning discs would essentially be rotating about a stationary axis at a high rpm, and the discs would be inserted and launched by the rotating discs. This project was also deemed feasible and relatively cost effective given that there are already designs from which the team can draw inspiration. The spinning wheel design selected is shown in Figure 16.

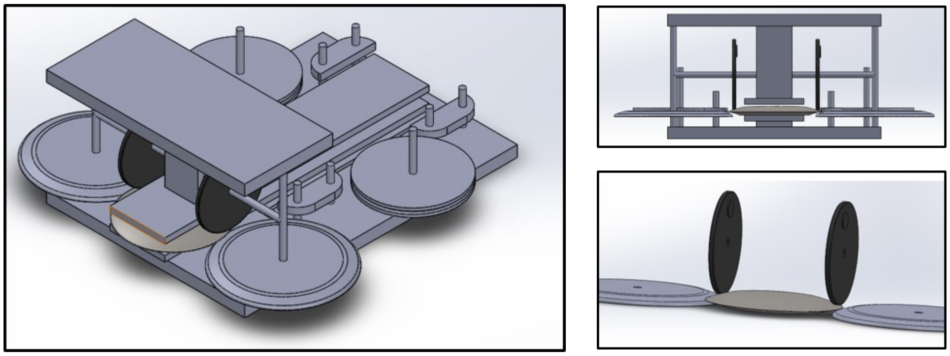


Figure 16. Spinning Wheels CAD Design

4.5 Concept Prototypes

The concept prototype demonstrated in Figure 17 is a model of the spinning wheels design. It has two wheels acting in the vertical position and four acting in the horizontal position. The wheels acting in the horizontal position are meant to add linear and rotational velocity to the disc. The wheels acting in the vertical position will add linear velocity to the disc and also control the nose angle of the disc. As mentioned, the overall kinetic energy of the disc will depend upon the coefficient of friction and the normal force between the disc and the wheels. If multiple discs are to be launched, it may be necessary to adjust the wheels in a way that allows for discs of multiple dimensions to be launched. In addition to allowing for the launching of multiple discs, having adjustable wheels may allow for the control of certain flight parameters as previously discussed.

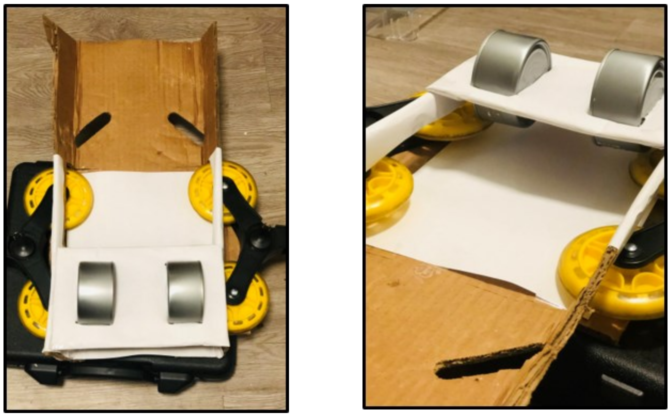


Figure 17. Spinning Wheels Concept Prototype

In Figure 18, the concept prototype for the actuator arm is shown. In this model, a pool noodle of 2.25 inches was used, representing the actuator bore. The bore selected for analysis was 4 inches, almost double the size shown in the image. The stroke length in the model is 6 inches, double the length of the analysis, but helpful for visualization. The wooden dowl was cut to 24 inches long, the same length of the carbon fiber model of the work and energy analysis. The arm would be wider and thinner, however it is representative of the actual design. The EPEC launcher is depicted by the party disc spinner rubber-banded to the top of the dowel.

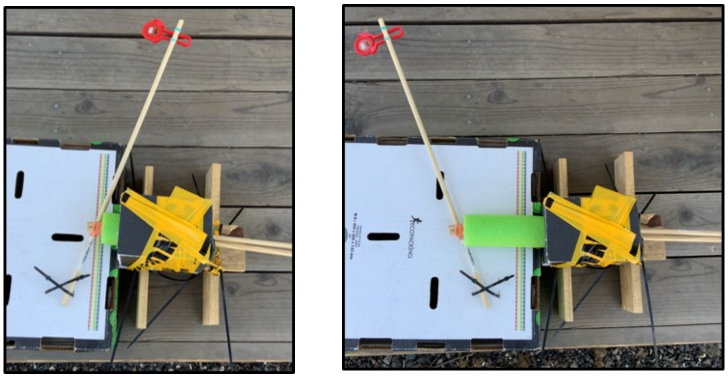


Figure 18. Launching Arm Concept Prototype

4.6 Design Hazards

With complex moving parts implemented in each design, there are a multitude of challenges and safety risks. A comprehensive list of each design risk and mitigation strategies can be found in Appendix E.

For the selected throwing arm design, the biggest hazard involves its fast moving and high force arm. If the operator were to stand within the arc of the throwing arm, it could cause serious bodily injury. This can be avoided by containing the system in an enclosure or having the operator stand behind safety guard rails. In addition, the arm would utilize pressurized air which, if handled incorrectly, could leak and trigger movement of the arm or blast the user with pressurized air. To avoid this, it is suggested to not only stand away from the machine when it is operating, but to also follow guidelines and use a pressure level under the rated load.

For the spinning wheel design, its unique hazards include its high-speed rotating parts. This causes a hazard as users could have hands and fingers pinched and injured. To avoid this, shields could surround the robot to guard the user from fast moving and rotating parts.

Both designs share a lot of other hazards as well. Both designs will be shooting a high velocity projectile and creating large forces. There is also the risk of accidental unsafe operation.

These can be avoided by following guidelines like keeping a distance from the robot and creating emergency protocols for robot operation.

Some challenges that accompany the chosen designs revolve around power generation and the realized distance of the machine. It is crucial that the disc be launched a distance of 500 to 600 feet. With the preliminary research done on existing products, it has been observed that the average disc or frisbee has not been thrown farther than approximately 350 to 400 feet. This will require the design team to utilize work energy, energy potential, and fluid mechanics in order to maximize the disc distance. Without a previous design to learn from, this is a challenge that is up to the design team to solve.

5 PROJECT MANAGEMENT

The design process is divided into three major sections: design, build, and test. This section describes the process in detail.

5.1 Design Process and Key Milestones

Table 3 shows the key deliverables for the design process. For a more detailed breakdown of the tasks and milestones, see Appendix F for the team Gantt chart.

Table 3. Key Deliverables

Date	Deliverable
05/04/21	Concept Models
05/18/21	Concept Prototype
05/25/21	Preliminary Design Review
09/28/21	Interim Design Review
10/12/21	Detail Drawings / Manufacturing Plan
10/19/21	Structural Prototype
10/26/21	Critical Design Review
11/30/21	Manufacturing and Test Review
03/08/22	Validation Prototype
03/15/22	Final Design Review

5.2 Next Steps

Although preliminary analysis has been performed, at this stage the group has not decided on a final design and is not committed to an actuator or wheel-based system. The next steps for the team involve finding funding for the project now that the primary stakeholder has backed out. The team intends to draft a cover letter to several manufacturers identified in Table 4.

If the team cannot find a new sponsor to pick up the project, there is $500 available from the senior project funds at Cal Poly and several grants to apply for. Crowd sourcing is another option. If necessary, the team will boot-strap the project and modify the design with cost as the primary design constraint.

Table 4. Potential New Sponsors

Company	Contact
Jennings Aeronautics	http://www.jenaero.com/
EPEC	Info@epecdisc.com
Legacy Disc	orders@legacydiscs.com
Innova West	proshop@innovadiscs.com
MVP Disc Sports	mvp@mvpdiscsports.com
DISCRAFT, INC.	discraft@discraft.com
Latitude 64	David@latitude64.se
Disc Golf Association (DGA)	Contact@discgolf.com
Daredevil Discs	info@daredevildiscs.com
Professional Disc Golf Association (PDGA)	(706) 261-6342

In the meantime, benchmarking tests with existing products are being conducted to test disc launching distance and grip mechanics using a handheld EPEC disc launcher [6]. A CAD model of a polymer disc has been created in SolidWorks with the intention to perform contact surface FEA analysis. More analysis needs to be conducted on both designs, including stress on the arm from the actuator impulsive force.

6 CONCLUSIONS

The design team was challenged to create a robot that tests the flight characteristics of their golf discs. Thorough research revealed disc speed, rotation, and release angle can be manipulated to maximize disc distance. The team's goal is to build a robot capable of throwing a driver disc a target distance of 500-600 feet to simulate a professional disc golf player's throw.

After reviewing the previous four sections, the reader should have a clear and accurate understanding of the design challenge. The needs include specifications on disc distance, the types of disc that must be thrown, and operational requirements for the robot itself. Research showed the range of similar products that solve similar problems. While none of the competitors' products solve the same set of requirements set out by the previous stakeholder, consulting the research will aid in robot brainstorming and design. Further researched brought to light many of the technical challenges of the project. To imitate the motion of the arm of a disc golf player throwing a disc, a flexible robotic arm would be ideal. However, achieving the desired distance from such a mechanical configuration would prove difficult. High speed wheels consistently launch discs, but those seem to fall short when it comes to disc distance.

The team has their work cut out for them. The next two quarters involve moving ahead with a project decision, but budget has become a primary concern that needs to be addressed before the team can fully move forward on one design. There is hope for new sponsorship on the horizon. In the meantime, the team will do their best to keep spirits up and progress steady.

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APPENDIX

A. House of Quality (QFD)

Correlations	
Positive	+
Negative	–
No Correlation	

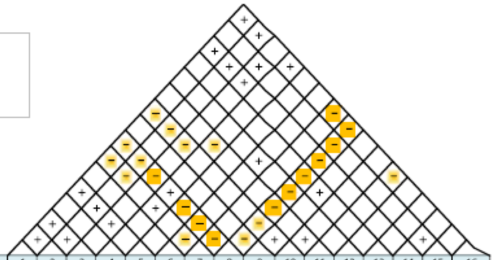
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

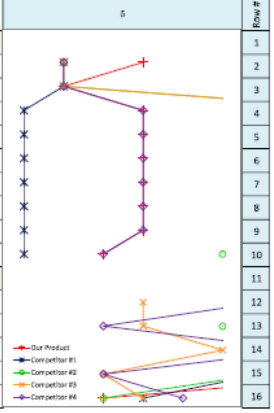
QFD House of Quality

Project: Prodigy Disc Golf Robot

Revision Date: 04/22/21



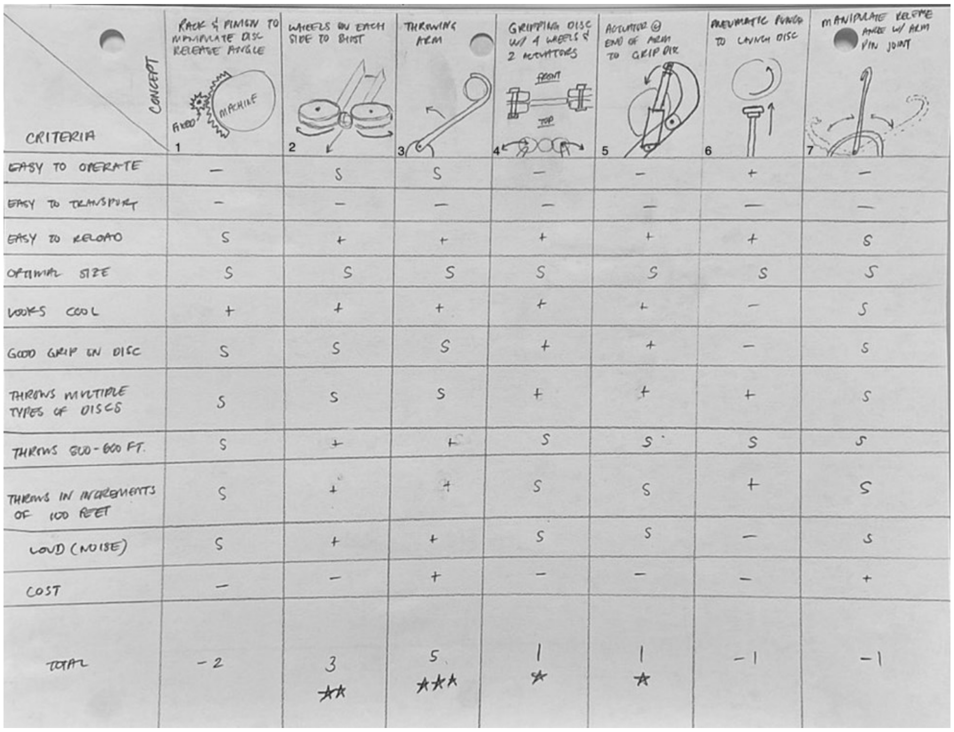
						Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
	WHO: Customers					Direction of Improvement	▲	▲	◇	◇	◇	▲	▲	▼	▲	◇	▲	▼	▲	▲	▲	▼	NOW: Curr. Products					
Row #	Weight Chart	Relative Weight	Manufacturer	Prodigy Disc	Maximum Relationship	HOW: Engineering Specifications (Tests) / WHAT: Customer Requirements (Needs/Wants)	Distance (ft)	Speed (mph)	Rotation (rpm)	Outlet Reliance (Yes/No)	Nose angle (deg)	Fire rate (discs/sec)	Lifespan (years)	Cost ($)	Visually Appeal (%)	Size (ft^3)	Ability to transport onto a cours	Time to reload (seconds)	Colors available (#)	Grip force on disc (N)	Grip diversity (#/6)	Sound (decibles)	Flexible Arm Thrower	Baseball Pitching Machine	Bike Wheel Frisbee Launcher	Rotating Frisbee Thrower (Sucti	Pneumatic Canon	Row #
1						Functional Performance																						1
2		35%	6	9	9	Throws Disc 500-600 Feet	●	●	●		○		○	●		▽	▽			○			3	1	1	1	1	2
3		20%	4	7	9	Throws in increments of 100 feet	●	●	○		○		○	●						○			1	1	1	1	1	3
4		8%	7	9	9	Throws a Driver Disc	●	●	○		●			●						○	○		3	0	9	9	3	4
5		4%	6	8	9	Throws a Hybrid Disc	●	○	○		●			●						○	○		3	0	9	9	3	5
6		3%	5	7	9	Throws a Fairway Disc	●	○	○		●			●						○	○		3	0	9	9	3	6
7		2%	4	6	9	Throws a Midrange Disc	●	○	○		●			●						○	○		3	0	9	9	3	7
8		2%	3	5	9	Throws an Approach	●	○	○		●			●						○	○		3	0	9	9	3	8
9		2%	2	4	9	Throws a Putter	●	○	○		●			●						○	○		3	0	9	9	3	9
10		5%	7	5	9	Good grip on disc	●	○	○		○		○	○						●	●		2	0	5	6	2	10
11						Human Factors																						11
12		7%	6	8	9	Easy to Operate				●		●	○	○				○				○	8	8	8	3	6	12
13		4%	5	4	9	Easy to Transport				●			○	○		●	●						9	7	5	3	2	13
14		5%	4	6	9	Easy to Reload						●	○	○				●					7	9	8	5	7	14
15		2%	2	3	9	Optimal Size								○	○	●	●						9	6	6	2	2	15
16		1%	1	2	9	Looks Cool								○	●				●				2	3	2	3	4	16



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	Disc launched 500 ft	Disc ejected at 50 mph	Disc can be rotated CW or CCW	Plug into outlet	Up to 89 degrees Hyzer and Anhyzer	At least 1 disc per minute	5 years	$10,000 (ask Prodigy)	51% Visual Appeal	<20 ft^3	51% Ease	<=1 minute	5 Colors	5 Newtons	Ability to throw all 6 disc types	Low Sound (<90 db)
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	Technical Importance Rating	300	200	140	60	140	20	10	20	10	10	10	10	10	30	20	10
	Relative Weight	30%	20%	14%	6%	14%	2%	1%	2%	1%	1%	1%	1%	1%	3%	2%	1%
Curr. Products	Flexible Arm Thrower	1	3	4	2	7	7	3	5	9	9	9	7	5	5	5	7
	Baseball Pitching Machine	2	3	5	1	9	9	9	6	4	3	5	9	9	5	5	6
	Bike Wheel Frisbee Launcher	3	0	4	5	7	9	9	9	4	5	4	8	5	5	5	8
	ting Frisbee Thrower (Suction cup)	4	1	5	4	1	5	4	4	9	2	3	3	5	9	1	6
	Clay Pigeon Launcher	5	5	2	1	2	9	9	7	9	8	9	7	9	8	5	9
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

B. Pugh Matrices

Criteria \ Concept	Robotic Arm	Rotating Discs	Air Cannon	Spring Cannon	Suction Cup Arm
Grip	S	-	-	S	S
Distance	S	S	+	S	-
Feasibility/Manufacturability	S	S	+	-	-
Cost	S	+	-	-	-
Cycles	S	+	S	S	S
Dimensions (weight/size)	S	S	-	-	-
Total	**0**	**1**	**-1**	**-3**	**-4**



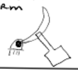
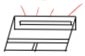
CRITERIA \ CONCEPT	1 RACK & PINION TO MANIPULATE DISC RELEASE ANGLE	2 WHEELS ON EACH SIDE TO BOOST	3 THROWING ARM	4 GRIPPING DISC W/ 4 WHEELS & 2 ACTUATORS	5 ACTUATOR @ END OF ARM TO GRIP DISC	6 PNEUMATIC PUNCH TO LAUNCH DISC	7 MANIPULATE RELEASE ANGLE W/ ARM PIN JOINT
EASY TO OPERATE	-	S	S	-	-	+	-
EASY TO TRANSPORT	-	-	-	-	-	-	-
EASY TO RELOAD	S	+	+	+	+	+	S
OPTIMAL SIZE	S	S	S	S	S	S	S
LOOKS COOL	+	+	+	+	+	-	S
GOOD GRIP ON DISC	S	S	S	+	+	-	S
THROWS MULTIPLE TYPES OF DISCS	S	S	S	+	+	+	S
THROWS 500-600 FT.	S	+	+	S	S	S	S
THROWS IN INCREMENTS OF 100 FEET	S	+	+	S	S	+	S
LOUD (NOISE)	S	+	+	S	S	-	S
COST	-	-	+	-	-	-	+
TOTAL	-2	3 ★★	5 ★★★	1 ★	1 ★	-1	-1

Commented [SML6]: Everyone add their own, also need to reference these appendices in our write up

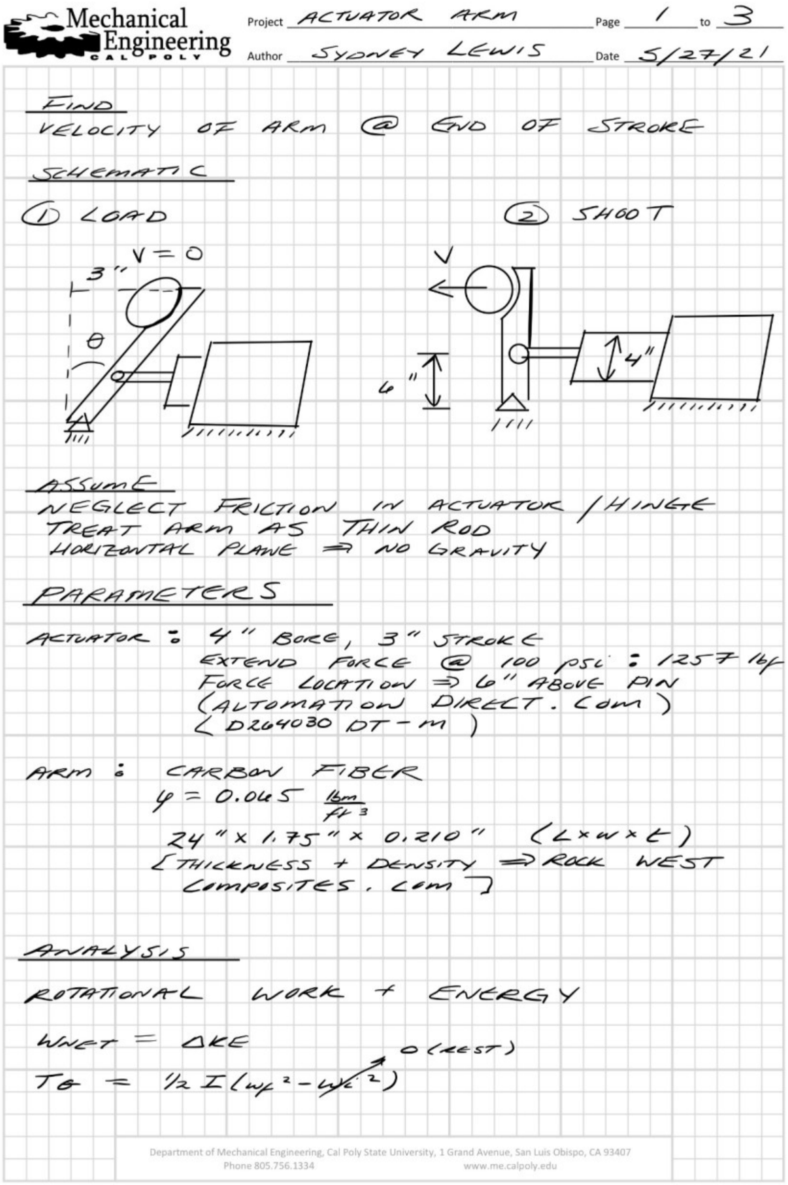
Commented [SML7R6]:

Pugh Matrix

Sydney Lewis
5/13/21
ME428-01

CONCEPT / CRITERIA	1. ACTUATOR ARM 	2. PNUEMATIC TANK 	3. Spinning Wheels 	4. ACTUATED SLING SHOT 	5. Rotating Arm 	6. EPEC LAUNCHER 
THROWS 500 ft	+	−	−	S	−	DATUM
THROWS IN ADJUSTABLE INCREMENTS	+	+	S	+	−	
THROWS MULT. DISC TYPES	+	+	+	S	+	
DISC GRIP	−	−	−	−	S	
EASY TO OPERATE	−	−	S	−	−	
EASY TO RELOAD	+	+	+	S	S	
EASY TO TRANSPORT	−	−	−	−	−	
TOTAL	+1	−1	−1	−2	−3	

C. Actuator Arm Work and Energy Calculations



Mechanical Engineering CAL POLY

Project ACTUATOR ARM Page 1 to 3

Author SYDNEY LEWIS Date 5/27/21

FIND

VELOCITY OF ARM @ END OF STROKE

SCHEMATIC

① LOAD ② SHOOT

ASSUME

NEGLECT FRICTION IN ACTUATOR / HINGE

TREAT ARM AS THIN ROD

HORIZONTAL PLANE ⇒ NO GRAVITY

PARAMETERS

ACTUATOR : 4" BORE, 3" STROKE

EXTEND FORCE @ 100 psi : 1257 lbf

FORCE LOCATION ⇒ 6" ABOVE PIN

(AUTOMATION DIRECT. COM)

(D264030 DT - M)

ARM : CARBON FIBER

$\rho = 0.065 \frac{lbm}{ft^3}$

24" × 1.75" × 0.210" (L × w × t)

[THICKNESS + DENSITY ⇒ ROCK WEST COMPOSITES. COM]

ANALYSIS

ROTATIONAL WORK + ENERGY

$W_{NET} = \Delta KE$

$$T\theta = \tfrac{1}{2} I (\omega_f^2 - \overset{0\text{ (REST)}}{\cancel{\omega_i^2}})$$

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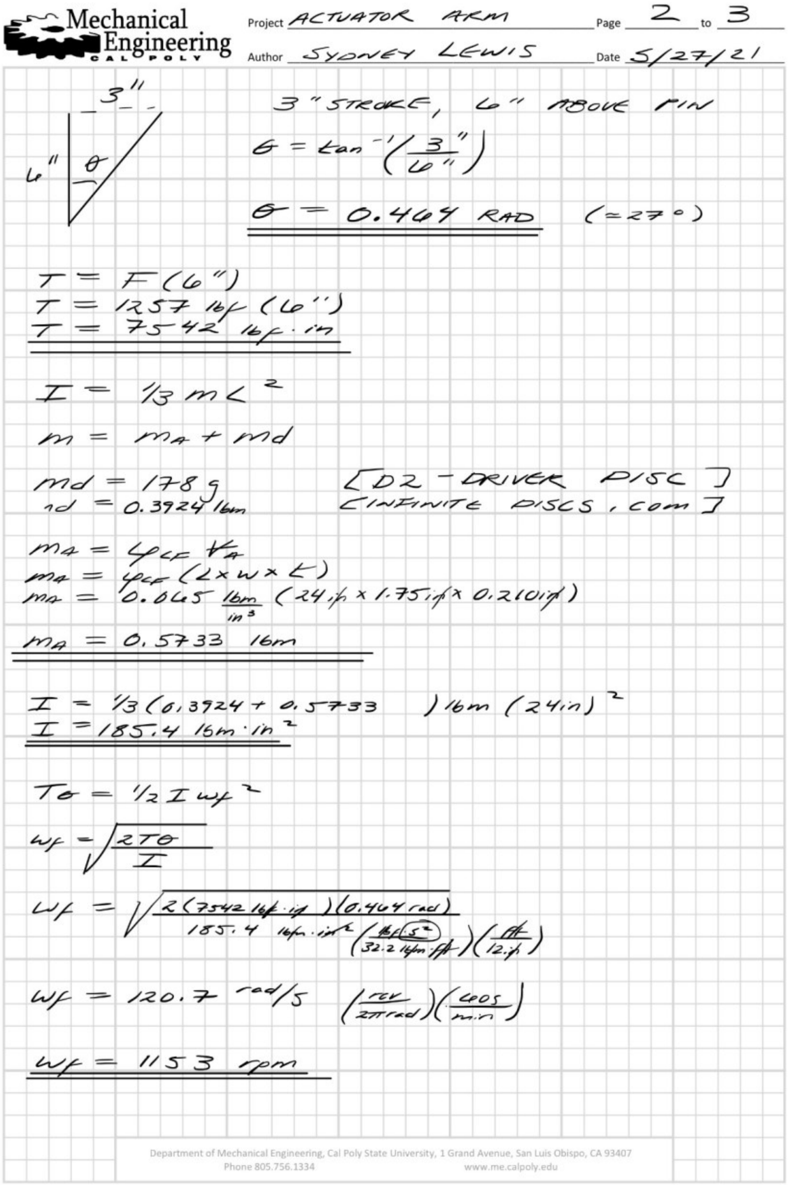
Phone 805.756.1334 www.me.calpoly.edu



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CAL POLY

Project ACTUATOR ARM Page 2 to 3
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3" STROKE, 6" ABOVE PIN

$$\theta = \tan^{-1}\left(\frac{3''}{6''}\right)$$

$$\underline{\underline{\theta = 0.464 \text{ RAD}}} \quad (\approx 27^\circ)$$

$$T = F(6'')$$
$$T = 1257 \text{ lbf} (6'')$$
$$\underline{\underline{T = 7542 \text{ lbf}\cdot\text{in}}}$$

$$I = \tfrac{1}{3} m L^2$$

$$m = m_A + m_d$$

$$m_d = 178 \text{ g}$$
$$m_d = 0.3924 \text{ lbm}$$

[D2 - DRIVER DISC]
[INFINITE DISCS.COM]

$$m_A = \rho_{CF} V_A$$
$$m_A = \rho_{CF}(L \times W \times t)$$
$$m_A = 0.065 \frac{\text{lbm}}{\text{in}^3}(24 \cancel{\text{in}} \times 1.75 \cancel{\text{in}} \times 0.210 \cancel{\text{in}})$$

$$\underline{\underline{m_A = 0.5733 \text{ lbm}}}$$

$$I = \tfrac{1}{3}(0.3924 + 0.5733) \text{ lbm} (24 \text{in})^2$$
$$\underline{\underline{I = 185.4 \text{ lbm}\cdot\text{in}^2}}$$

$$T\theta = \tfrac{1}{2} I \omega_f^2$$

$$\omega_f = \sqrt{\frac{2T\theta}{I}}$$

$$\omega_f = \sqrt{\frac{2(7542 \cancel{\text{lbf}}\cdot\cancel{\text{in}})(0.464 \text{ rad})}{185.4 \cancel{\text{lbm}}\cdot\cancel{\text{in}^2}\left(\frac{\cancel{\text{lbf}}\cdot\text{s}^2}{32.2 \cancel{\text{lbm}}\cdot\cancel{\text{ft}}}\right)\left(\frac{\cancel{\text{ft}}}{12 \cancel{\text{in}}}\right)}}$$

$$\omega_f = 120.7 \text{ rad/s} \left(\frac{\text{rev}}{2\pi \text{ rad}}\right)\left(\frac{60 \text{s}}{\text{min}}\right)$$

$$\underline{\underline{\omega_f = 1153 \text{ rpm}}}$$

Department of Mechanical Engineering, Cal Poly State University, 1 Grand Avenue, San Luis Obispo, CA 93407
Phone 805.756.1334 www.me.calpoly.edu

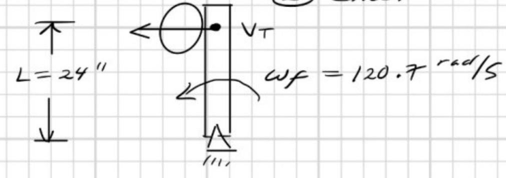
Mechanical Engineering CAL POLY

Project ACTUATOR ARM Page 3 to 3

Author SYDNEY LEWIS Date 5/27/21

TIP SPEED

② SHOOT



ASSUME SUDDEN STOP @ END OF STROKE EJECTS DISC @ ARM TIP SPEED, VT

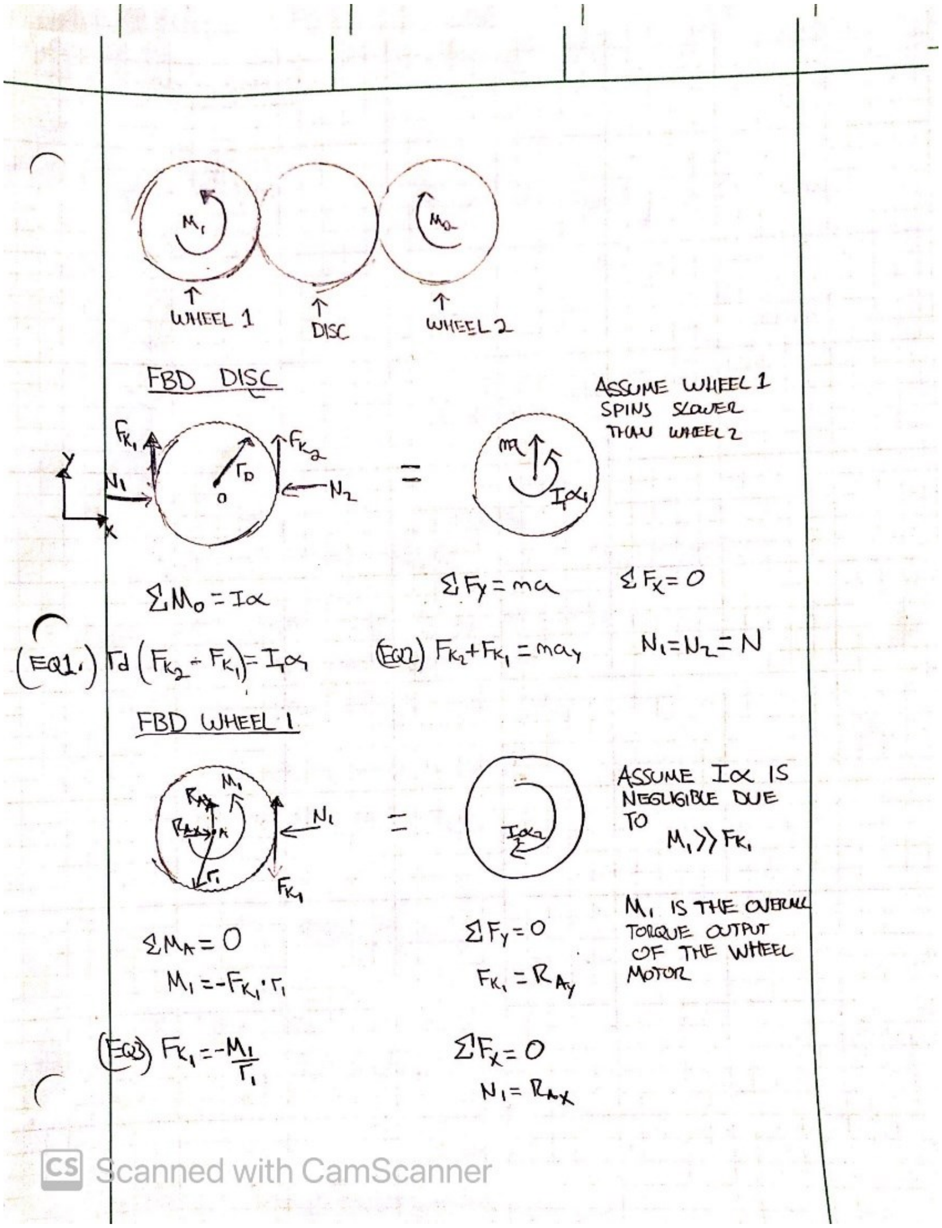
$V_T = L\,\omega_f$

$$V_T = 24''\left(120.7\ \text{rad}/\cancel{s}\right)\left(\frac{3600\ \cancel{s}}{hr}\right)\left(\frac{\cancel{ft}}{12\ \cancel{in}}\right)\left(\frac{mi}{5280\ \cancel{ft}}\right)$$

$V_T = 164.6$ mph

$\boxed{V_T \approx 165 \text{ mph}}$

D. Hand Calculations for Figure 14, Spinning Wheel



FBD DISC

ASSUME WHEEL 1
SPINS SLOWER
THAN WHEEL 2

$\Sigma M_0 = I\alpha$

$\Sigma F_y = ma$

$\Sigma F_x = 0$

(EQ1.) $r_d(F_{k_2} - F_{k_1}) = I_1\alpha_1$

(EQ2) $F_{k_2} + F_{k_1} = ma_y$

$N_1 = N_2 = N$

FBD WHEEL 1

ASSUME $I\alpha$ IS
NEGLIGIBLE DUE
TO
$M_1 \gg F_{k_1}$

M_1 IS THE OVERALL
TORQUE OUTPUT
OF THE WHEEL
MOTOR

$\Sigma M_A = 0$

$M_1 = -F_{k_1} \cdot r_1$

$\Sigma F_y = 0$

$F_{k_1} = R_{Ay}$

(EQ3) $F_{k_1} = -\dfrac{M_1}{r_1}$

$\Sigma F_x = 0$

$N_1 = R_{Ax}$

FBD WHEEL 2

ASSUME $I\alpha$ IS NEGLIGIBLE DUE TO

$M_2 \gg F_{k_2}$

M_2 IS THE OVERALL TORQUE OUTPUT OF THE WHEEL MOTOR

$\sum M_B = 0$

$M_2 = F_{k_2} \cdot r_2$

(EQ4) $F_{k_2} = \dfrac{M_2}{r_2}$

$\sum F_y = 0$

$R_B = F_{k_2}$

$\sum F_x = 0$

$N_2 = R_{Bx}$

(EQ 3) AND (EQ4) VALID ONLY IF NO SLIP OCCURS

IF SLIP OCCURS USE (EQ1) OR MULTIPLY INPUT TORQUE BY ESTIMATED COEFFICIENT δ

$\delta \equiv$ FRACTION OF INPUT TORQUE THAT IS TRANSMITTED

EQ1 : $r_d(-\mu_{k_2}N_2 + \mu_{k_1}N_1) = I_1\alpha_1$

$r_d \cdot N(\mu_{k_2} + \mu_{k_1}) = I_1\alpha_1$

$$\alpha_1 = \frac{r_d \cdot N \cdot (\mu_{k_2} - \mu_{k_1})}{I_1}$$

ASSUMING α IS CONSTANT AND $\omega_0 = 0$

$$\omega^2 = 2\alpha(\Delta\theta)$$

$$\boxed{\omega = \sqrt{\frac{2 \cdot r_d \cdot N \cdot (\mu_{k_2} - \mu_{k_1})\Delta\theta}{I_1}}}$$

FROM EQ2 $a_y = \frac{F_{k1}+F_{k2}}{m}$

$$a_y = \frac{\mu_{k1}N_1 + \mu_{k2}N_2}{m}$$

USING SAME PREVIOUS ASSUMPTIONS

$$a_y = \frac{2\mu_k N}{m}$$

ASSUMING a_y IS CONSTANT AND $V_0 = 0$

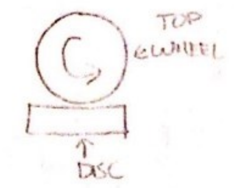
$$V^2 = 2a_y \Delta Y$$

$$V = 2\sqrt{\frac{\mu_k N}{m} \cdot \Delta Y}$$

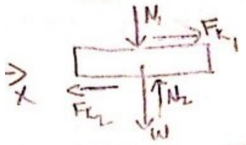
WHERE $\Delta Y = r_J \Delta\theta$

$$\boxed{V = 2\sqrt{\frac{\mu_k N}{m} \cdot r_J \Delta\theta}}$$

TOP WHEEL



FBD DISC



$$\sum F_y = 0$$

$$N_1 + W = N_2$$

ASSUMING NEGLIGIBLE WEIGHT

$$N_1 = N_2 = N$$

$$\sum F_x = ma_x$$

$$F_{k_1} - F_{k_2} = ma_x$$

$$\mu_{k1} N_1 - \mu_{k2} N_2 = ma_x$$

$$a_x = \frac{N(\mu_{k1} - \mu_{k2})}{m}$$

ASSUMING CONSTANT ACCELERATION

$$V^2 = V_0^2 + 2a_x \Delta X$$

$$\boxed{V_{FINAL} = \sqrt{V_0^2 + \frac{2N(\mu_{k1} - \mu_{k2})}{m} \cdot \Delta X}}$$

FOR SIDE WHEELS AT EXIT

$$\boxed{\omega_{FINAL} = \sqrt{\omega_0^2 + \frac{2 r_J N \Delta\mu_k}{I_1} \cdot \Delta\theta}}$$

E. Hazard Checklist Arm Design

Y	N	
Y		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
Y		2. Can any part of the design undergo high accelerations/decelerations?
Y		3. Will the system have any large moving masses or large forces?
Y		4. Will the system produce a projectile?
	N	5. Would it be possible for the system to fall under gravity creating injury?
	N	6. Will a user be exposed to overhanging weights as part of the design?
	N	7. Will the system have any sharp edges?
	N	8. Will any part of the electrical systems not be grounded?
	N	9. Will there be any large batteries or electrical voltage in the system above 40 V?
Y		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	N	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	N	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	N	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	N	14. Can the system generate high levels of noise?
	N	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
Y		16. Is it possible for the system to be used in an unsafe manner?
	N	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any “Y” responses, on the reverse side add:

(1) a complete description of the hazard,
(2) the corrective action(s) you plan to take to protect the user, and
(3) a date by which the planned actions will be completed.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Hazardous revolving / punch motion. The 24” arm intends to be set in motion by a quick, high force punch from an actuator, causing it to rotate potentially up to 90 degrees.	The revolving arm and actuator system will be contained within a physical enclosure, causing a human to be physically incapable of getting in the way of the arm motion or punch.	10/19/21	
The arm and actuation system will undergo high acceleration and deceleration.	The pneumatic actuator can either be upgraded by the manufacturer to contain an internal cushion, causing both the actuator and arm to decelerate at the end of the stroke. Or, a brake (springs/airbag) will be created by the team to lessen the deceleration of the arm after launch.	10/19/21	
The pneumatic cylinder is currently designed to supply 1257 lbf.	High force is the key element needed to meet our design goal of launching a disc 500+ ft. The force will not be corrected; however, several protective actions will be utilized: an enclosed system, physical indicators that warn the user launch is impending, such as lights and beeping sounds, a net around the immediate area to account for projected discs that may get launched incorrectly, loading and control buttons located behind the robot where the arm and projectile are physically incapable of acting.	10/19/21	

Disc launched at 50-100 mph should be treated like a projectile.	As mentioned above, projecting a disc 500+ ft is the design goal of this project. The projectile risk cannot be removed; however, many safety strategies will be incorporated as mentioned above. Enclosed area, warning lights/beeps to count down the launch, launch control located in a safe place on the robot (or ideally remotely, where the user can be at a safe distance away), stickers/ highly visible indicators to show where the projectile will be launching from, emergency stop button.	10/19/21	
Pressurized pneumatic cylinder designed at 100 psi.	Cylinder is rated up to 250 psi; minimizing risk by using a pressure well under the rated load.	10/19/21	
It is possible for the system to be used in an unsafe manner.	The outside enclosure of the robot will be designed as simply as possible to reduce risk of unintentional unsafe operation (2 buttons, 1 (3 position) switch: load, shoot, angle (hyzer, anhyzer, flat)). The shoot button will initiate a countdown before firing, giving the user an indicator incase it was accidentally pressed, allowing time for the user to stop the firing motion if needed. If budget allows, it is possible to use sensors (LIDAR) on the front of the robot for collision avoidance, allowing the bot to sense if someone is standing in front and prevent firing from occurring. This is an expensive mitigation option that reduces unsafe operation risk; however, it may not be possible to implement with our allowed budget.	10/19/21	

Y	N	
Y		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
Y		2. Can any part of the design undergo high accelerations/decelerations?
Y		3. Will the system have any large moving masses or large forces?
Y		4. Will the system produce a projectile?
	N	5. Would it be possible for the system to fall under gravity creating injury?
	N	6. Will a user be exposed to overhanging weights as part of the design?
	Y	7. Will the system have any sharp edges?
	N	8. Will any part of the electrical systems not be grounded?
	N	9. Will there be any large batteries or electrical voltage in the system above 40 V?
Y		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	N	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	N	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	N	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	N	14. Can the system generate high levels of noise?
	N	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
Y		16. Is it possible for the system to be used in an unsafe manner?
	N	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, on the reverse side add:

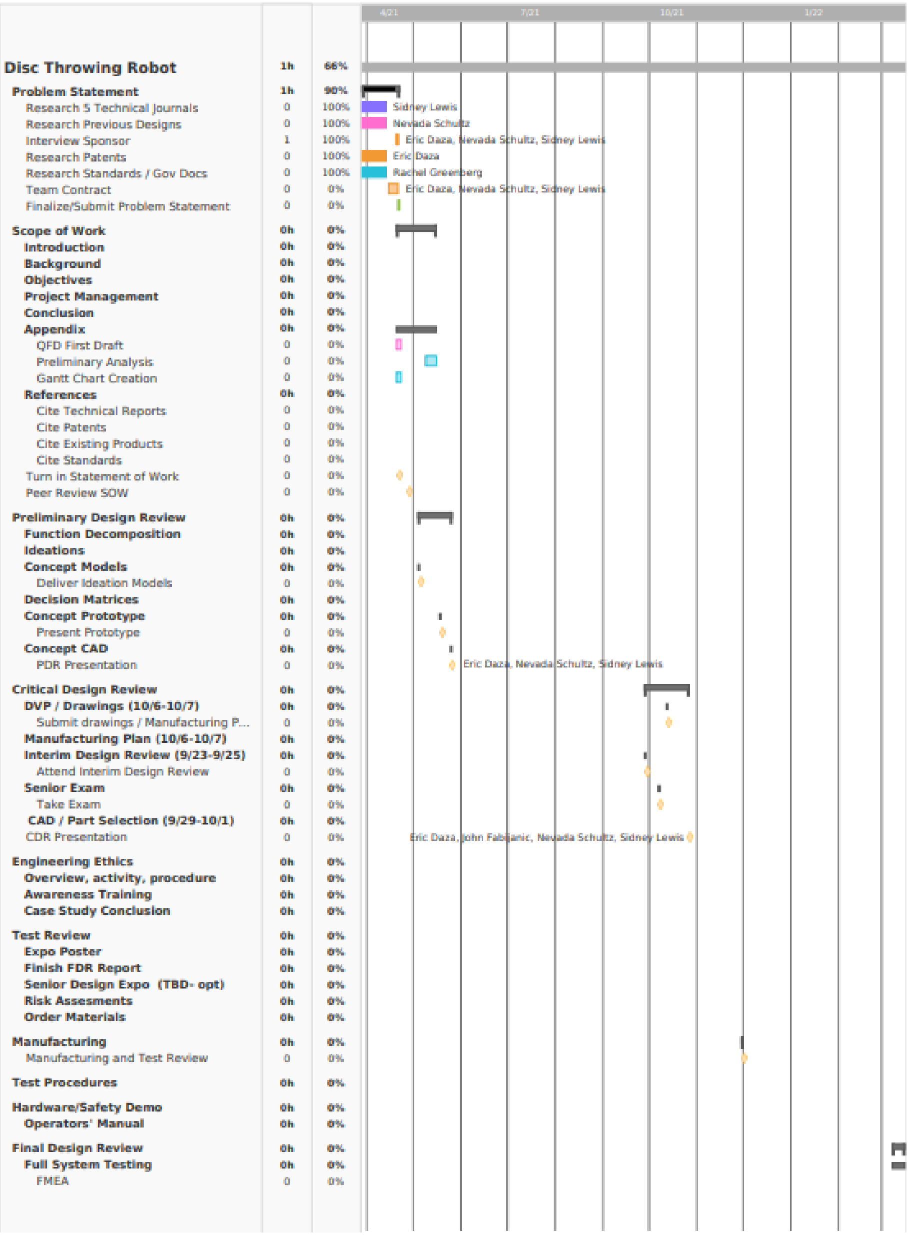
(1) a complete description of the hazard,
(2) the corrective action(s) you plan to take to protect the user, and
(3) a date by which the planned actions will be completed.

Description of Hazard	**Planned Corrective Action**	**Planned Date**	**Actual Date**

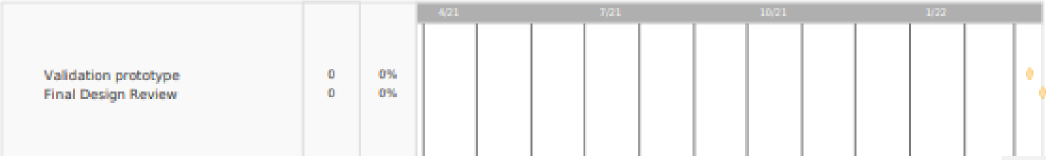
Wheels rotating at fast speeds. A larger wheel that feeds the disc into the robot will operate at low speed and may cause sheer.	The high-speed wheels will incorporate protective coverings and minimize wheel exposure to the direct environment. The feedings motor should be reduced to a minimal torque and speed. The operator must not interact with the robot from within a certain distance and without shielding. The operator must be able to hit, and emergency stop button at any moment.	10/19/21	
Parts or pieces from the outside, or from the robot could potentially be accelerated by the wheels. The wheels may also undergo acceleration upon launch or startup.	On startup and stop, the operator must be protected from the machine. He must be able to turn the robot on and off from a distance. There must be protective covering on the wheels, and there must be no loose flimsy pieces that could potentially break off and fall into the wheels.	10/19/21	
The feeder wheel will be rather large and constantly rotate. The primary spinning wheels are fast moving masses.	These fast-rotating wheels can cause damage if they collide with parts of the robot. The robot could inadvertently cause projectiles or clamping within the systems.	10/19/21	
Disc launched at 50-100 mph should be treated like a projectile.	As mentioned above, projecting a disc 500+ ft is the design goal of this project. The projectile risk cannot be removed; however, many safety strategies will be incorporated as mentioned above. Enclosed area, warning lights/beeps to count down the launch, launch control located in a safe place on the robot (or ideally	10/19/21	
The spinning wheels may be considered a flywheel.	As mentioned before, preventative actions around the spinning wheel include protective paneling, and operators far from the machine.	10/19/21	
		10/19/21	

It is possible for the system to be used in an unsafe manner.	The robot may be used unsafely as a weapon. The discs could be aimed towards people or animals and cause injury or loss of life.		

F. Gantt Chart



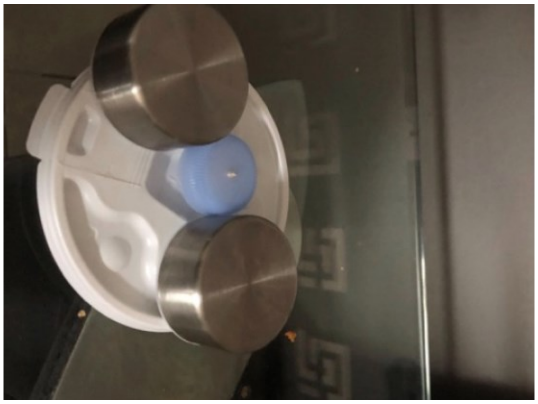
Disc Throwing Robot	1h	66%	
Problem Statement	1h	90%	
Research 5 Technical Journals	0	100%	Sidney Lewis
Research Previous Designs	0	100%	Nevada Schultz
Interview Sponsor	1	100%	Eric Daza, Nevada Schultz, Sidney Lewis
Research Patents	0	100%	Eric Daza
Research Standards / Gov Docs	0	100%	Rachel Greenberg
Team Contract	0	0%	Eric Daza, Nevada Schultz, Sidney Lewis
Finalize/Submit Problem Statement	0	0%	
Scope of Work	0h	0%	
Introduction	0h	0%	
Background	0h	0%	
Objectives	0h	0%	
Project Management	0h	0%	
Conclusion	0h	0%	
Appendix	0h	0%	
QFD First Draft	0	0%	
Preliminary Analysis	0	0%	
Gantt Chart Creation	0	0%	
References	0h	0%	
Cite Technical Reports	0	0%	
Cite Patents	0	0%	
Cite Existing Products	0	0%	
Cite Standards	0	0%	
Turn in Statement of Work	0	0%	
Peer Review SOW	0	0%	
Preliminary Design Review	0h	0%	
Function Decomposition	0h	0%	
Ideations	0h	0%	
Concept Models	0h	0%	
Deliver Ideation Models	0	0%	
Decision Matrices	0h	0%	
Concept Prototype	0h	0%	
Present Prototype	0	0%	
Concept CAD	0h	0%	
PDR Presentation	0	0%	Eric Daza, Nevada Schultz, Sidney Lewis
Critical Design Review	0h	0%	
DVP / Drawings (10/6-10/7)	0h	0%	
Submit drawings / Manufacturing P...	0	0%	
Manufacturing Plan (10/6-10/7)	0h	0%	
Interim Design Review (9/23-9/25)	0h	0%	
Attend Interim Design Review	0	0%	
Senior Exam	0h	0%	
Take Exam	0	0%	
CAD / Part Selection (9/29-10/1)	0h	0%	
CDR Presentation	0	0%	Eric Daza, John Fabijanic, Nevada Schultz, Sidney Lewis
Engineering Ethics	0h	0%	
Overview, activity, procedure	0h	0%	
Awareness Training	0h	0%	
Case Study Conclusion	0h	0%	
Test Review	0h	0%	
Expo Poster	0h	0%	
Finish FDR Report	0h	0%	
Senior Design Expo (TBD- opt)	0h	0%	
Risk Assesments	0h	0%	
Order Materials	0h	0%	
Manufacturing	0h	0%	
Manufacturing and Test Review	0	0%	
Test Procedures	0h	0%	
Hardware/Safety Demo	0h	0%	
Operators' Manual	0h	0%	
Final Design Review	0h	0%	
Full System Testing	0h	0%	
FMEA	0	0%	



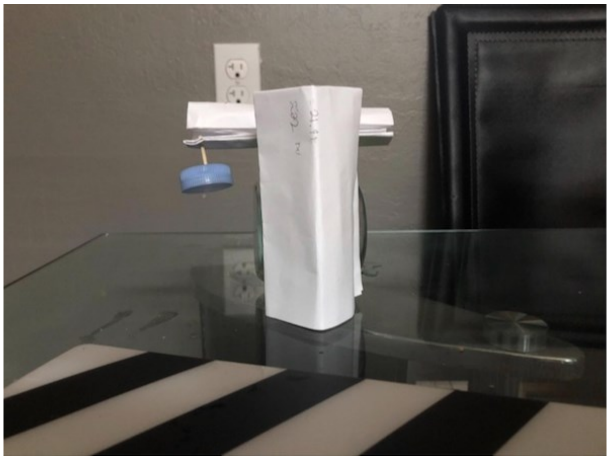
Validation prototype	0	0%
Final Design Review	0	0%

G. Function Concept Prototypes

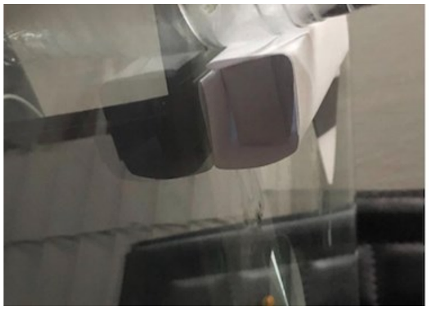
The way this prototype functions is as follows: the disc will sit on a spinning platform and that platform is on a rail guide. This platform is also being acted upon by either a sling or a spring which provides a thrust force. The two parameters (linear and rational velocity) can now be independently controlled.



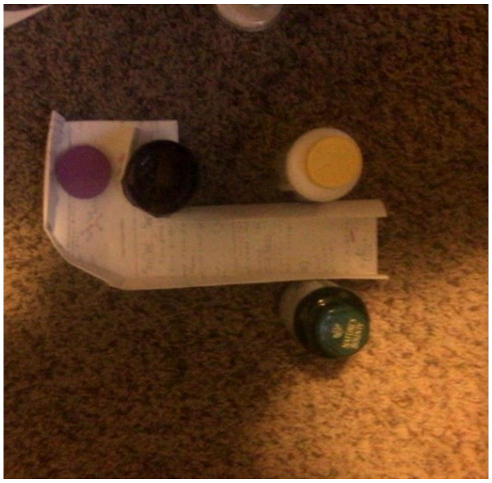
This prototype has two spinning wheels (the metallic discs) and the disc (the blue cap). The two spinning discs impart some of their energy to the smaller disc, thereby giving the smaller disc linear and kinetic energy.



The disc will be on a spinning platform which will provide rotational velocity, and the platform itself will be attached to an arm, which is attached to the main body of the robot. This arm can rotate about the robot, thereby imparting linear velocity on the disc upon release.



The prototype shown above has two images to demonstrate that the rear side should be completely shut while the front side is exposed to the atmosphere. The rear side will experience a sudden release of pressurized air, thereby imparting linear velocity onto the disc. The side of the inner part of the canon should generate rotational velocity.



This is a shoot that leads into a set of spinning wheels. The disc is shown by the purple circle. A spinning wheel accelerates the disc into the primary set of spinning wheels.

A spinning arm with an actuator positioned to balance the arm. The actuator causes the force in the wrist of the arm.

A coiled spring is used to generate rotation. A gear is shown that is used to ratchet the arm into the throwing position. This allows for automated reloading of the spring.

A four-wheel geometry is shown here. This has two wheels on both sides, and two wheels at the top and bottom.

A different four-wheel geometry. This causes a localized pinch at the top and bottom of the disc on both sides. There is a guided shoot that the disc slides on.

Figure 1. Actuator Linkage Throwing Arm

This confirmed the basic mechanics of having an actuator capable of extending and retracting connected to a curved linkage. The push/pull motion on the green stick causes a rotation in the red stick, up to almost 180 degrees.

Figure 2. Testing Pneumatics and Spin

This prototype illuminated challenges with using air to cause rotation in a disk. A blow-dryer was underneath pushing air through a hole up to the mini-disc. The arm on top was supposed to act like a record player arm and keep the disk down and cause it to spin. I realized another part is necessary to cause vorticity in the air (like a fan grate) and provide spin other than the arm.

Figure 3. Gripping Disc with Elastic Potential Energy

For this prototype, the goal was to test a gripping mechanism that used potential energy to grip multiple types of discs. Here a rubber band was used, but springs or other sources of potential energy could be used as well. The concept shows a flexible member contracting to the shape of the disc instead of being specially made to fit it exactly.

Figure 4. Actuator Extending to Manipulate Anhyzer Angle