STYMBappé Robot Arm Analysis
Yahya Mirza

MAE 3 – Section B02

Department of Mechanical and
Aerospace Engineering

Instructor: Huihui Qi

Section Teaching Assistants: Juan Pablo Viaux, Richard Vallejo, Grant Luu

Team 25: Sherwin Salemi, Taylor Donnan, Yahya Mirza, Miles Talbert

University of California, San Diego

Section 1: Robot and Arm Introduction

Team 25's football robot, "STYMBappé," has three main components focused on mobility and dynamic scoring capability:

1. Drivetrain: All-wheel drive with each of the four wheels directly-driven by a geared motor.

2. Flywheel Kicker: Two-stage pulley system with a 1:9 gear ratio that spins a specially designed flywheel module in order to kick footballs into the goal. Powered by a non-geared, high speed motor.

3. Arms: A pair of curved swiper arms angled at 20° relative to the horizontal that allows for the robot to knock boundary footballs into (or out of) the playing field.

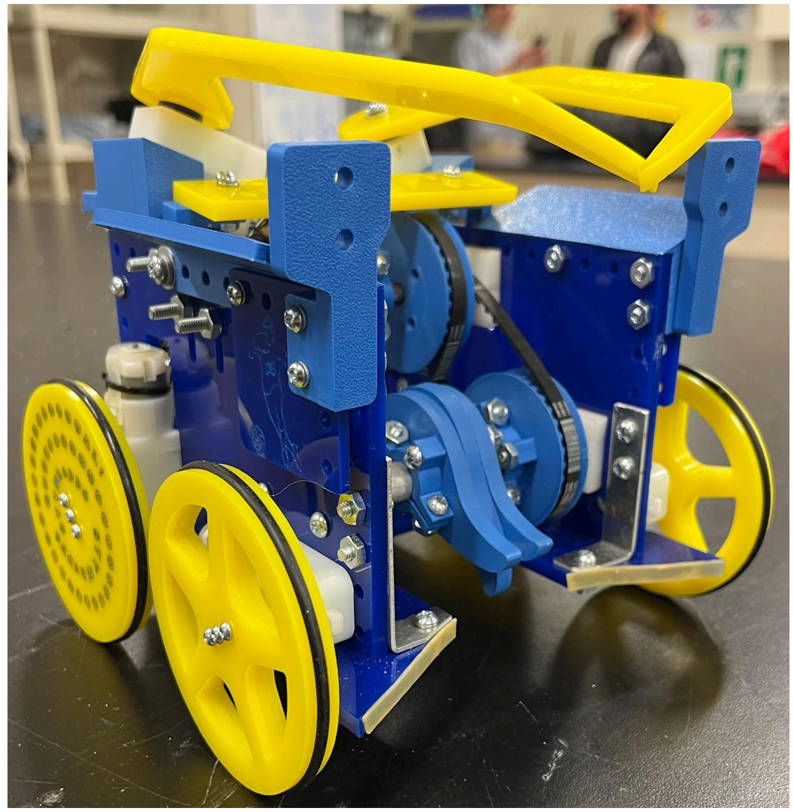


Figure 1: **Photo of finished robot**

Arm Introduction:

This report will focus on the arm module for our robot. The module is a critical component of our robot that allows us to effectively knock balls from their staring positions into the field. Within the competition field, there are eight total footballs located at the top of the boundary walls. The center of each football lies at a height of 9" above the field ground with the robot containing an 8" height limit. In order to score the eight boundary footballs, a component must be designed to meet these functional requirements:

- **(1):** Reach a height of 9" from a starting height of anywhere between 0" to 8"
- **(2):** Reliably bring boundary footballs into the playing field
- **(3):** Make sure the footballs do not roll towards the opponents goal, preventing own goals

In order to meet these functional requirements, a subassembly of a 3D printed mount, 90° Geared Motor, and an acrylic swiper arm profile was prototyped and manufactured. The 3D printed mount allows for two things: (1) the interface between the geared motor and the chassis, and (2) the angle of the output shaft of the geared motor to be at an angle of 20° relative to the horizontal.

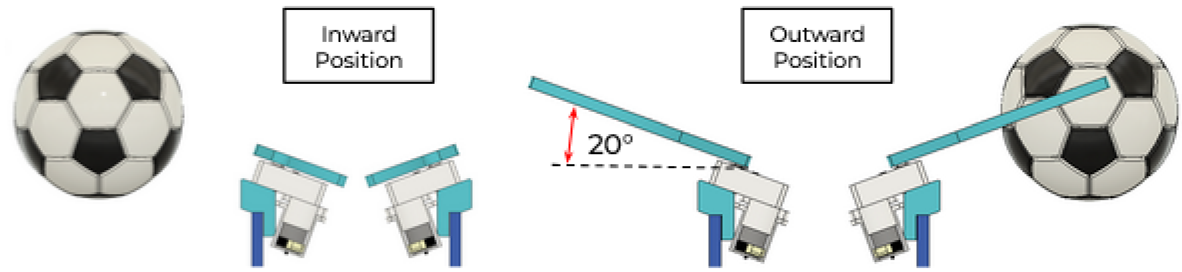
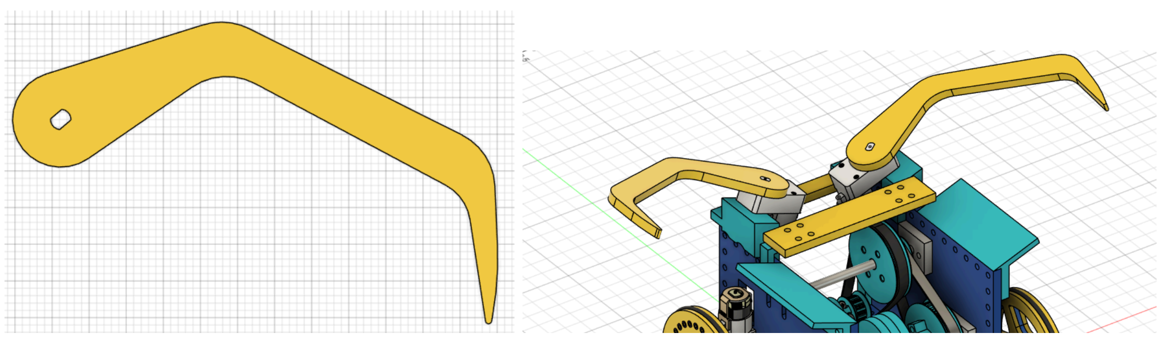


Figure 2: **Arms in their inward and outward positions. The football is placed at the height that the boundary footballs would be located. The 20° angle allows for the arm to reach the proper height required to knock the boundary footballs down.**

The swiper arm contains a scythe-like shape, allowing for effective hooking of the boundary footballs into the field.



(a) (b)

Figure 3: **The scythe shape of the arm (a); an isometric view of the swiper arms (b)**

Via empirical analysis, the pushing force of the arm resulted to be a strength of 2N, well beyond the minimal pushing force required to knock the boundary balls into the playing field. This means that when the arm swipes down to knock a given boundary ball, it can apply a linear force of 2N to the ball, overcoming the friction between the mounting plate and allowing the ball to roll into the playing field. In addition, the swiper arm profile allows for the footballs to be hooked in and dragged towards the center of our robot, which is where the flywheel kicker module lies. This allows for the robot to swipe then immediately kick footballs towards the goal. The measured pushing force makes sense as the calculated pushing force of the arm is 1.8N, yielding a 10% error. The difference of 0.2N can be attributed to poor reading of spring scales or an improper measurement of the stall torque of the geared motor.

Section 2: Analysis of Swiper Arms – Maximum Pushing Force

Problem Statement:

This analysis will determine the **maximum pushing force** of an individual swiper arm, with the goal of making sure that the maximum pushing force overcomes the 0.1N linear force required to knock the boundary footballs from their starting positions.

Assumptions:

- The weight of the arm is negligible (i.e. there is no moment caused by the arm onto the system)
- Quasi-static
- No air resistance
- The effective moment the swiper outputs contains a radius that is equal to the straight line between the center of rotation of the motor shaft and the endpoint of the arm (FBD provided below for further clarity)
- Arm is rigidly connected to motor shaft (i.e. no internal friction between shaft and arm)

Free Body Diagram of Individual Swiper Arm:

Table 1: **List of Key Variables and Equations Used in the Analysis**

Variables	
$\mathbf{T_m}$	Individual Geared Motor Torque
$\mathbf{R_e}$	Effective Radius of swiper arm
$\mathbf{g}$	Acceleration due to gravity
$\mathbf{F_N}$	Normal force
$\mathbf{F_p}$	Pushing force

Equations for individual arm:

$$\tau = F \times R$$

$$\Sigma F_x \approx 0$$

$$\Sigma F_y \approx 0$$

$$\Sigma M \approx 0$$

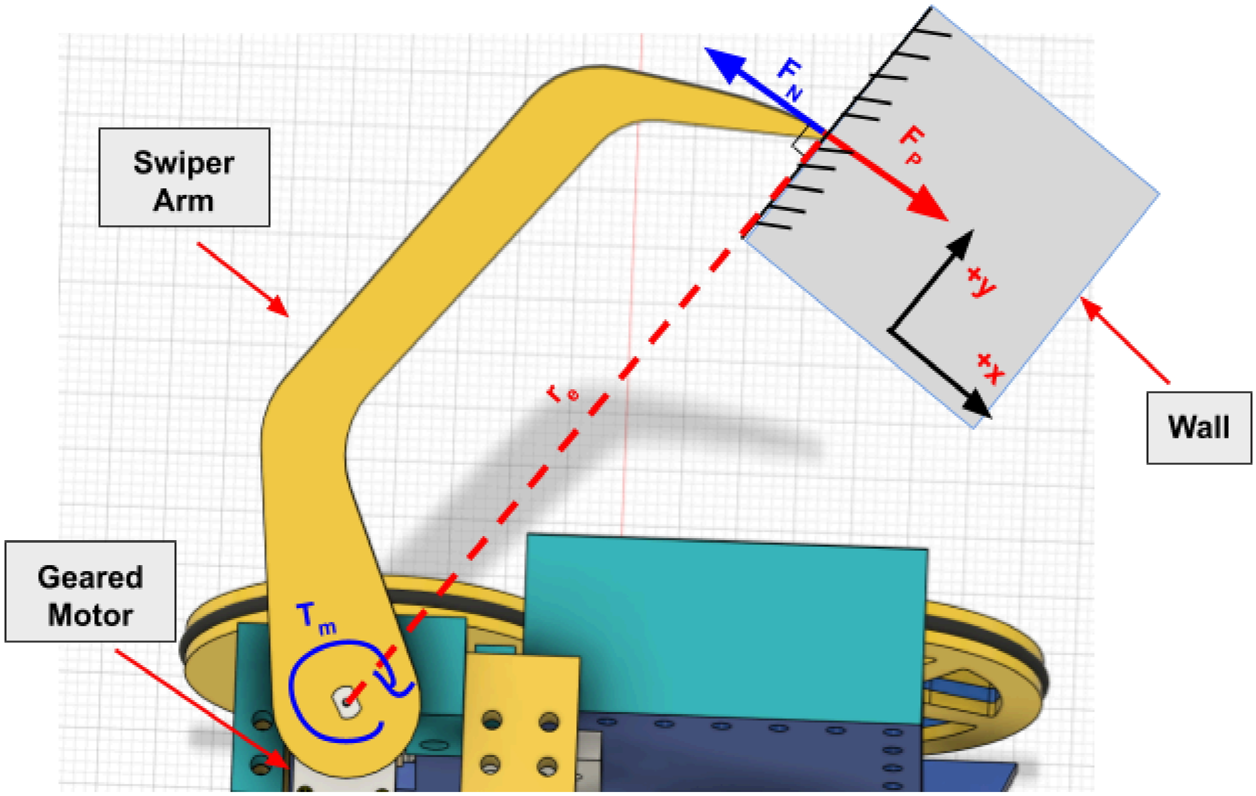


Figure 4: **Free Body Diagram of the Swiper arm hitting a wall. The motor will be running at the stall torque and we will assume a quasi-static analysis. Forces from the arm onto the wall are marked in red. Forces onto the arm are marked in blue.**

Pushing Force Derivation:

$$\Sigma M = \tau_m - F_N R_e = 0 \quad (1)$$

$$F_N = F_P \quad (2)$$

$$F_P = \frac{\tau_m}{R_e} \quad (3a)$$

$$\Sigma F_y = 0 \quad (4a)$$

$$\Sigma F_x = \frac{\tau_m}{R_2} - F_N = 0 \quad (4b)$$

$$F_N = \frac{\tau_m}{R_2} = F_P \quad (3b)$$

Calculating Theoretical Pushing Force:

In lab, we empirically determined the stall torque of each of our available motors along with other relevant data. Below is a diagram showing the experimental setup along with a table listing the acquired data for both the geared and non geared motors.

.

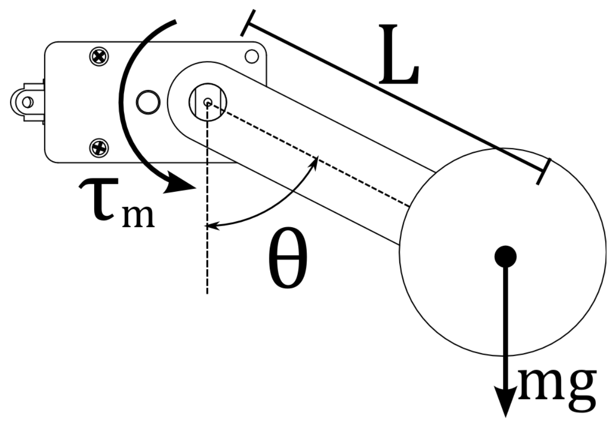


Figure 5: **Experimental setup used to find the stall torque of each motor. A mass of a known quantity was attached to the motor from a known length L away. The motor was turned on until the hanging mass was no longer moving. By recording the angle traveled, the stall torque can be calculated.**

***Table 2*: Acquired Data for Geared and Non-Geared Motors**

Quantity	Symbol	Geared Motor	Non-Geared Motor
Stall Angle (deg):	θ	52	9
Moment Arm Length (m):	L	0.13	0.065
Mass (kg):	m	0.2919	0.005
Stall Torque (Nm):	$\tau_{stall} = mgLsin\theta$	0.293	0.00767
No Load Speed (rad/s):	ω_{noLoad}	6.4114	201.06
Max Power (watts):	$P = \frac{1}{2}\tau_{stall} * \frac{1}{2}\omega_{noLoad}$	0.470	0.3855
Max Energy in 60s (J):	$E = P \cdot t$	28.18	23.132

Since the swiper arm utilizes a geared motor, the stall torque of the arm is 0.293Nm (*Table 2*).

Utilizing equation (3b), the theoretical pushing force is as follows:

$$F_P = \frac{\tau_m}{R_e}$$

$$F_P = \frac{0.293\ Nm}{0.162\ m} = 1.81\ N \tag{3b}$$

The theoretical pushing force from the swiper arm is 1.81 N. In order to verify this answer, we conducted an experiment in order to find the real pushing force of the arm. By using a spring scale held rigidly, we could simulate that as the wall that exists within the free body diagram. The arm was lined up such that the force of the arm was normal to the surface of the trigger of the spring scale.

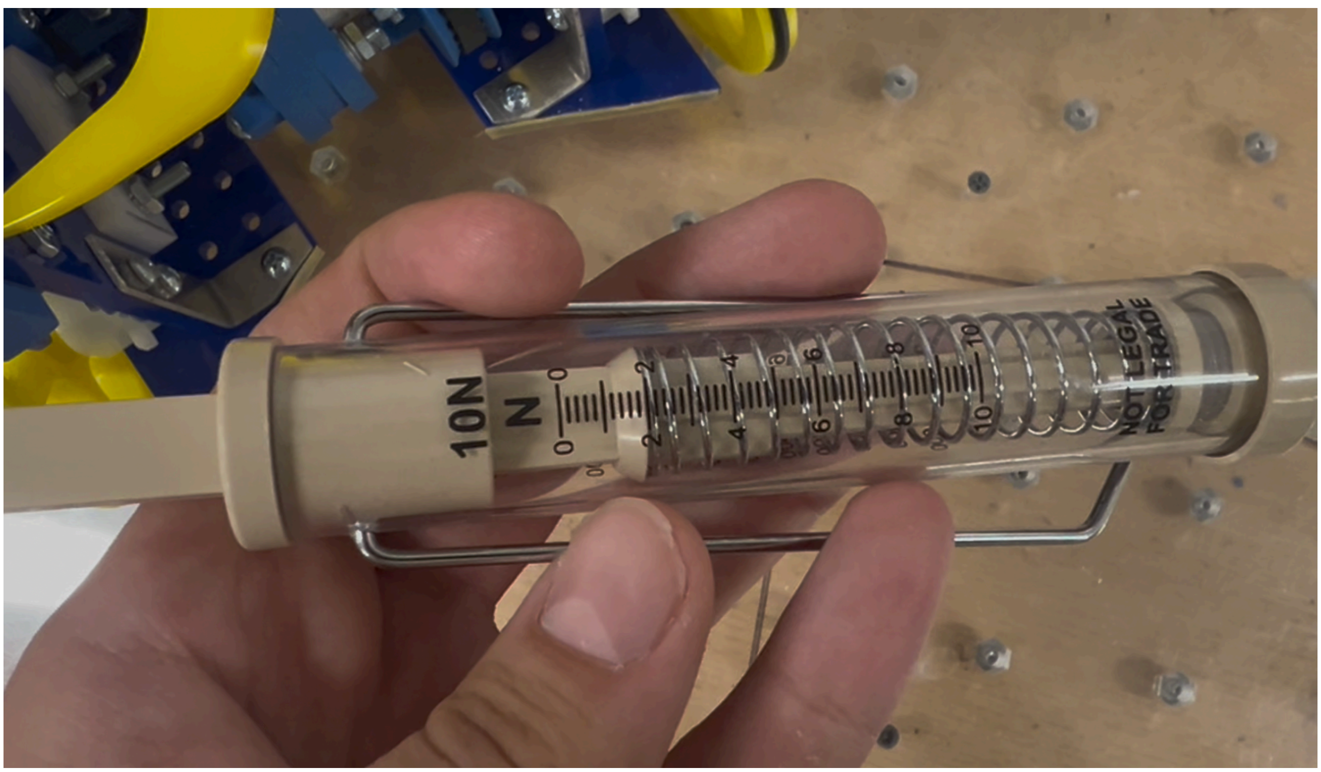


Figure 6: **Experimental setup used to find the pushing force of the arm. The arm was controlled such that the pushing force was applied collinear to the spring scale shaft.**

From our experiment, the actual pushing force yielded to be 2N (fig. 6), 0.2N higher than the theoretical value of 1.8N. Utilizing the empirically derived pushing force of the arm, we can calculate the factor of safety of the module by utilizing:

$$F.O.S = \frac{F_{Available}}{F_{Needed}} \tag{5}$$

Because the arm lies at an angle of 20°**,** our available linear pushing force is 2N×cos(20) = 1.88N. In order to knock the boundary balls into the field, a linear pushing force of around 0.3N is required. Therefore, via eq. (5), the factor of safety of the swiper arm module is:

$$F.O.S = \frac{1.88N}{0.3N} = 6.3 \tag{5}$$

With a factor of safety well beyond two, that means that the swiper arm provides more than enough linear force in order to knock the boundary footballs into the playing field. As a result, when the arms bring the balls down, a large impulse will be imparted, causing the footballs to not only be knocked down, but also have a relatively high velocity. A factor of safety of 6.3 indicates that it is unlikely for the arm to fail to deliver the required pushing force required to knock boundary footballs down into the field.

Overall Conclusions and Error Analysis

To summarize the findings of the analysis conducted on the swiper arm module of the robot, the theoretical pushing force was expected to be 1.8N. In practice, the actual pushing force resulted in 2N. With the 0.3N linear force required to move the boundary footballs into the field, a factor of safety of 6.3 was recorded, validating the mechanism of the swiper arm. Even with the successes in mind, there were still errors present in this analysis.

Because the theoretical calculation and derivation took an optimistic approach, the actual pushing force is expected to be lower than the theoretical pushing force. However, our actual pushing force is higher than our theoretical.

One explanation for this is that the measured stall torque of the motor was recorded to be lower than the true value, therefore yielding a lower than expected theoretical value for the pushing force. Another reason could be that the mass of the acrylic arm is significant, and because the arm is at a 20° angle relative to the horizontal, a component of its weight is applying a moment to the pivot point of the arm.

That being said, via testing the actual pushing force as well as the performance of the overall arm, all of the functional needs of the module were met. In terms of performance upgrades, the changes that were made were independent of the free body diagram analysis as we have confirmed that with the current radius and motor, the arm provides ample pushing forces to the boundary footballs. In order to better meet the functional requirements, the shape of the arm has changed from a hook shape to more of a scythe design. As a result, the footballs are now consistently knocked into the center of the flywheel instead of traveling in random directions.

With the given design, there are a couple limitations. For one, because the arm is routed onto the 3A terminal, the arm travels too fast for accurate positioning of the arm. In other words, despite using the geared motor, the excess current from the power supply causes the arms to move too fast for precise human controls. A small tap of the joystick causes the arm go rotate really far, and as we need to position the swiper arms precisely in order to knock down boundary footballs, it becomes difficult to pull off. Another thing is that when the arms collide with the wall, the normal force from the wall sometimes overcomes the stall torque of the motor, causing an arm to slip and making both arms go out of sync. To address both these issues at the same time, gearing down the swiper arms would not only make it slower, but it will also have a higher resistance to changes in position.

Personal Reflection

In terms of the overall robot project, the biggest technical lesson that I learned was the importance of chunking large problems into smaller ones. At first, we needed to dissect the competition rules and decide how we were going to score. From there, we split that into subcomponents and within those subcomponents each problem needed to be chunked down even more. By isolating each problem and having a top down approach, we were able to create a high quality robot that I am proud of.

This project was one that contained many challenges and struggles yet fueled amazing friendships and satisfaction. Going into office hours and prototyping with the friends that I made not just in Team 25, but in the rest of the class was something I always looked forward to. That being said, I still feel like I could have put in more time into this class and the project, but all that means is that I need to better manage my time and energy as I get involved with more project teams and classes. I am truly grateful for my time in this class, and I appreciate all the help and support that the team and I received.

Section 3: Design Process Essay – Risk Reduction Tests (1 Page Max)

Out of the three main components of our robot (drivetrain, flywheel kicker, arms), we needed to determine which of them was most relevant to perform a risk reduction assessment. Risk reduction in engineering is the process of identifying and solving potential design flaws before proper design work and integration is even started. This is to ensure that an idea is actually capable of meeting the functional requirements of any mechanical structure. We at STYMBappé conducted a logical analysis to determine the component for our risk reduction analysis.

The logic goes as follows: as our drivetrain is a four-wheel-drive system, if one wheel fails, we will still have three other wheels that allow us to drive. If our swiper arms break, even though we would not be able to knock down the boundary balls, we can at least go on the defensive and score the balls that our opponent is trying to score. Lastly, if the flywheel kicker breaks, we will be able to knock footballs down, but now we have no method of scoring. As a result, it became clear that our most critical component of our robot would be our flywheel kicker module.

Now to go into the iterative prototyping process, we decided that utilizing the high speed motor would be the way to go as we needed fast speeds and high input power. We made bushings out of Delrin and used one of our steel rods to serve as our bearing for our tooth profile. We designed a a belt-driven 1:3 gear ratio between the motor and flywheel shaft. With that setup we now needed to design potential tooth profiles that allowed for us to effectively kick the footballs at a launch angle of 45°.

Our first tooth profile was ineffective. It was too small and the tooth profile did not contain the proper curvature to scoop the balls. We noticed that the balls would “skim” and graze the ball. This tangential force caused the ball to rotate in place rather than move rather than kicking it. With our second iteration, we made the scoop more dramatic and increased the radius. This had a profound effect on the effectiveness of the kicker and we could now actually kick. The problem was that the flywheel was spinning too fast, reintroducing the skimming issue.

To counteract this, we cut the amount of teeth from two to one, effectively “reducing” the RPM by ½. We also geared the motor down even further to make it a 1:9 ratio. Then, as we watched the footballs begin to travel up into the air and into the goal from across the field, we knew that we needed the flywheel kicker in our final robot design. Spoiler alert, the kicker is the highlight of our STYMBappé robot!

For future design projects, my goal is to be able to better design in an assembly context with many moving parts and components. That is something I really struggled to wrap my head around this quarter because I wanted to do everything all at once.