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# Design and Construction of an Omni-Directional Soccer Ball Thrower

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# DESIGN AND CONSTRUCTION OF AN OMNI-DIRECTIONAL SOCCER BALL THROWER

by

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**of**

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# Design and Construction of an Omni-Directional Soccer Ball Thrower

## Honors Thesis by Andrew Marquette

Project complete through the Mechanical and Aerospace Department design sequence.

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## Introduction

We are ODST the Omni-Directional Soccer Ball Thrower team which designed the soccer ball launching machine. Working in direct correlation with the project sponsor John Meade from Athlonic Sports this is the report outlining the soccer ball thrower. John from Athlonic Sports came up with the overall project and initial project vision. There are soccer ball launching machines on the market but lacking mobility, not amiable and are heavy. The design needed to be mobile, amiable, lightweight, and have a soccer ball capacity incorporated into the machine. This will allow coaches to repeatability place the soccer ball in certain location to improve the soccer player skills.

### Background

Anyone who has played soccer can tell you how hard it is to consistently kick or throw a ball in the same manner when performing routine drills. Soccer ball launchers are the solution to the inconsistency. They help make practice both more potent and efficient, while also opening up the possibility for new drills and practice techniques. Currently, a variety of soccer ball launcher designs exist. But the portability both on and off the field has been a large challenge. The goal of this project was to create a design that allowed for ease of transportation to the field, as well as use on the field, increasing the marketability of its use.

## Project Requirements

Design requirements were defined by Athloinc sports in which the design would be constrained to. These constraints are displayed in Table 1.

**Table 1: Design Requirements**

| |
|---|
| Launch High School League sized soccer balls |
| Launch balls every 3 seconds with manual trigger |
| Launch 1 ball at a time |
| Capable of 180-degree horizontal aim and 0-45 degree vertical aim |
| Control covers so goalie cannot see and anticipate curvature of shot |
| Hold up to 8 soccer balls |
| Capability of spinning ball for horizontal curvature |
| Launch up to 70mph |
| Maximum weight of 75 lbs. |
| Wheels that won't damage or scuff soccer balls |
| Capable of breaking down to fit in UPS-shippable box |
| Total material cost under $1400 |

## Solution

The solution we came up with can be seen in Figure 1. A critical feature that can be seen is that it uses two wheels to launch the balls. The ball is pushed between the two wheels where the friction along the surface accelerates the ball to launch it. The wheels are independently controlled by two potentiometers, allowing for varying speeds of each wheel to change the speed and curve of the ball.

**Figure 1: CAD Design of the Soccer Ball Launcher**

## Mechanical Design

### Base

The highest loads on the entire frame are on the base of the launcher between the two wheels, so this section needed to be carefully designed to withstand the stresses of launching thousands of soccer balls. In addition, it was desired that deflections under load be minimized in order to reduce loss of efficiency during launch. Originally, a large plate with flanges was the design. It could be bent from sheet metal, making manufacturing inexpensive. However, finite element analysis showed that local deformation occurred between the flanges, requiring that the design be built from .25" aluminum to meet the deflection requirement. The resulting part weighed 25lbs, which was unacceptably heavy if the weight requirement was to be met.

A new base was designed that utilized an aluminum C-channel to withstand the high bending loads imparted by the launching wheels. Rails for guiding the ball and braces for mounting the spine of the launcher to the base could then be welded to the C-channel to create a single-piece base that the remaining launcher components bolted onto. Because the base was designed to be built from aluminum, which doesn't experience infinite life in fatigue like steel, fatigue failure needed consideration. Assuming a maximum of 500 balls are shot during a practice session, and practice occurs five times per week, the lifetime of the part was calculated to be 20 years with a safety factor of 2. This is far greater than the expected life of the product and is not considered to be a significant contributor to wear and tear on the machine. Figure 2 shows the final base design.

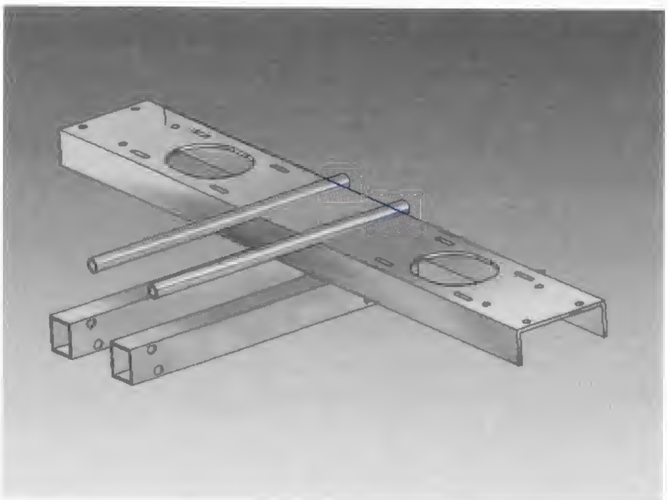

**Figure 2: Base Design**

## Actuator Mechanism

One of the requirements was that the machine prevented more than one ball from being launched at the same time. Another required that a manually operated trigger, such as a button, launch the balls. A mechanism was designed that meets these requirements. It involves the use of a solenoid and a lever to press the ball into the spinning wheels when a button is pressed. The lever is in the shape of a half-moon cradle that prevents the ball from rolling forward into the wheels when the solenoid is in its resting position. Figure 3 shows this mechanism.

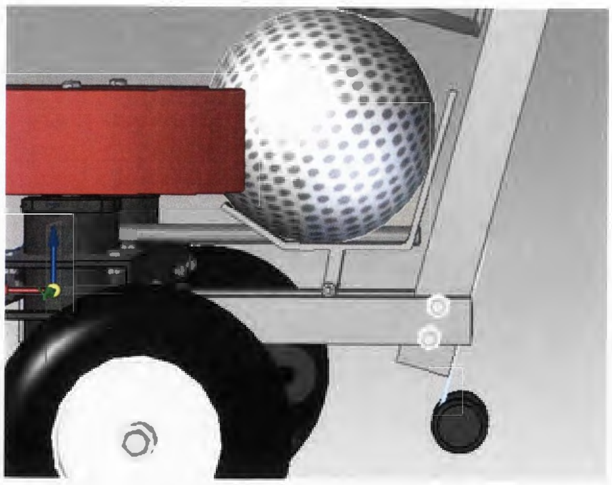

**Figure 3: Actuator Design**

## Maneuverability

The two-wheel support system allows full 360° rotation and permits the user to move with and maneuver the launcher without difficulty. In order to accurately mimic a ball being kicked, it's important that the launcher be as low to the ground as possible. Unfortunately, this prevented the launcher from being aimed above a 30° angle. In order to meet the requirement of a 45° angle of launch, a pair of smaller 4" wheels was added to the back of the launcher, which can be seen in Figure 4. Theses wheels serve a dual-purpose. They allow the launcher to be aimed at angles greater than 30° as well as providing a way for the launcher to stand on its own so the operator can walk away from it without having to lay it down.

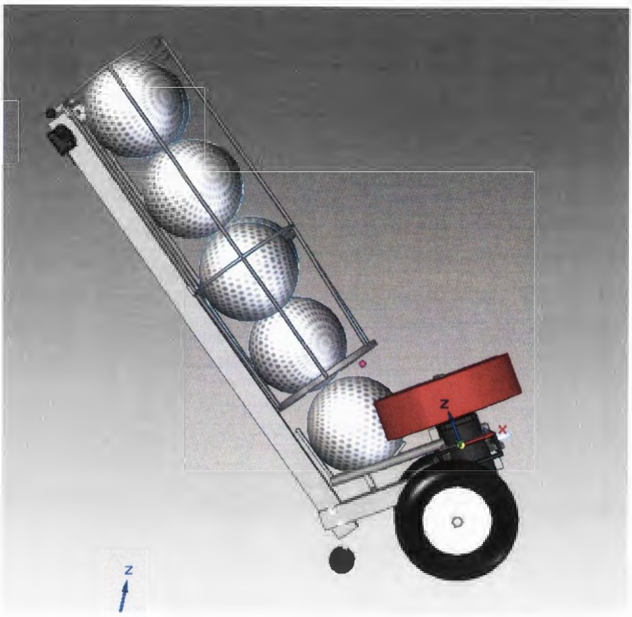

**Figure 4: Maneuverability of the Machine**

## Spine Design

The back bone in which the handle bars and ball rack are mounted to is called the spine (Figure 5). Throughout many design iterations and consultations with Athlonic Sports the final design was agreed upon to fulfill the design requirements (see figure 3).

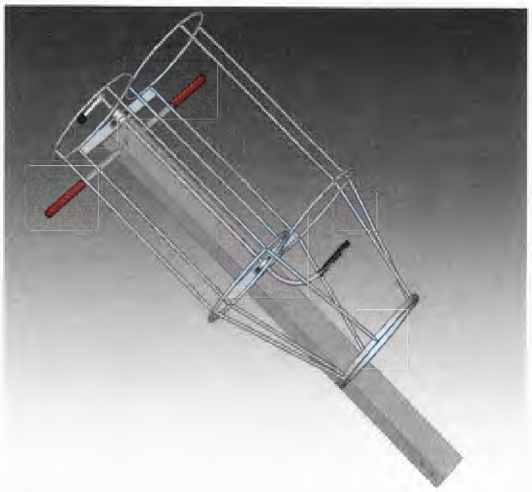

**Figure 5: Design of Spine Assembly**

Design requirements that directly impacted the design of the spine are seen below

- **Launch High School League soccer balls**
- **Capable of 180-degree horizontal aim and 0-45 degree aim**
- **Control covers so goalie cannot anticipate soccer ball**
- **Hold up to 8 soccer balls**
- **Maximum weight of 75 lbs.**
- **Capable of breaking down to fit in UPS-shippable box**
- **Total material cost under $1400**

To meet the design requirements different materials, geometries and sizes were considered. The actual overall length of the spine was determined through geometry as well as ergonomics. The Centers for Disease Control and Prevention provided the average male height of 69.5 inches (Center for Disease Control and Prevention). Through simple geometry with a 15 degree mounting angle from vertical and contributions from support wheels an over length was determined. A reasonable assumption for the head to shoulders of an adult was 20.5 inches with support wheel contribution of 4 inches. The following equations 3.3 and 3.4 are used to calculate the overall length of the spine

$$Spine\ Height = Average\ male\ height - Head\ to\ shoulders - Support\ wheel\ contribution.\quad (Eq. 3.3)$$

$$Cos(15°) = \frac{Hieght\ of\ Spine}{Length\ of\ Spine}\quad (Eq. 3.4)$$

The length in which was required human ergonomics was 45 inches roughly 3.75 feet.

Once the overall length of the spine was determined the actual shape of the spine could now be designed. Many considerations went into choosing the shape of the spine. The design needed to be able to with stand the forces the spine would experience while still being cost effective. We will have forces applied at the handle bars as well as interface between the spine and base connection. The spine also would need to carry the load of the ball rack structure as well as the 8 soccer balls. Every shape under the blue moon was considered but ultimately for moment of inertia considerations we decided upon rectangular cross section. The moment of inertia directly impacts the stress within the member.

Some of the cross sections that didn't satisfy the design were circular, oval and square. Each cross section was evaluated for ease of attainability, the associated cost, ergonomics, moment of inertia, and ascetics. The rectangular cross section met more criteria such as moment of inertial, associated cost to name a few.

The spine was designed with the highest regard to safety in mind. The mounting to the base was accomplished through the use of 0.5 inch bolt. Through analyzing the forces that would be applied a factor of safety of 340 was determined. This is 340 times the shear strength of the bolt which shows that the spine will not detach from the base. The mode of failure in the spine design is plastic deformation of the spine cross section. We as a team realized the possible outcomes if any other component of the design failed before the spine. Therefore we designed the spine to yield before any other mechanical failure was experienced. Yielding of the spine for the applied loads and moments has a safety factor of 4. There is no possibility that the user would lose control of soccer ball thrower through any other mechanical means. The spine will yield plastically before shearing of mounting bolts or handle bars. Refer to the attached appendix for all calculations performed.

Materials for the spine are aluminum due to the inherent aspect of aluminum being lightweight. Aluminum can be easily attained and is lightweight with considerable cost. Steel, aluminum, composite materials were all considered in the design of the spine. Steel has a great weight associated with it as compared to aluminum and composite materials. The composite material was approximately 1.5 times the cost of aluminum for a similar part.

The handle bars are mounted on the spine with the availability for detachment. The design didn't incorporate and bends or fancy geometries due to cost restrictions. The handle bars aid in allowing the user get a 180 degree horizontal aim. The handle bars have grips attached to them to give the user a comfortable experience. The electronic controls to launch the soccer ball and control wheel speed will be mounted to an electronics box (Figure 6). The electronics box has an inherent feature of consoling the controls thus fulfilling a design requirement.

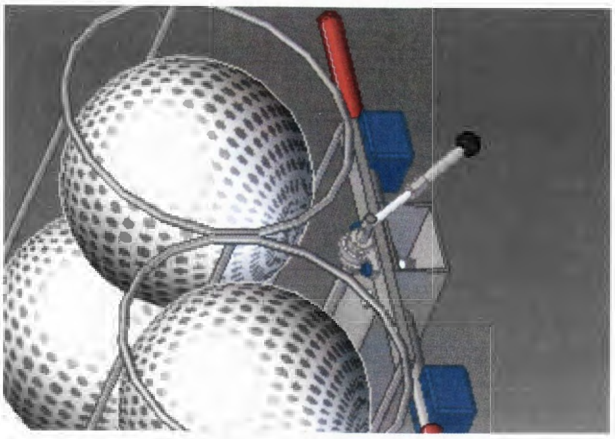

**Figure 6: Handle Bar Design**

## Ball Rack (Hopper)

One of the design factors and one of the requirements was that of being able to hold eight balls. At first the team had the design of a hopper (ball rack) that was just one column. This was nice but it was too tall and would sit too high and would be inconvenient to put the balls in the rack due to the fact of not being able to be reached. One would have to simply tilt the machine down and insert the balls. So as a team we came up with some ideas. Some of the ideas consist of a zigzag design and would roll the balls down kind of like a cascade. Another is having a collapsible hopper so that it can be reduced down to the desired height and also have the ability to fit in a UPS shipping box.

Now we'll talk about the zigzag design. This design was a good idea but had some complications to it. Some of the complications is that of the collapsibility. This would have too many parts and would cost too much for what our budget could hold. Also, the hopper having a zigzag design was too bulky and would take up too much space.

So what we ended up with is the simple design of a two column hopper that sat side by side, which can be seen in Figure 5. This allowed us to be able to hold eight balls and meet the requirement. There was only one problem to this though, and that was that we needed a device so that it would only feed one hopper at a time. By solving this problem, we added a ball stopper that extends from the top of the design to the bottom of one of the hoppers to be able to stop a column of balls. This is set in a convenient place so that the operator can easily access the mechanism.

The ball rack is made out of round stock 6061 Aluminum and weighs only 2.8 lbs. This was good that it was so light to help with one of the requirements which is to have the machine weigh 75 lbs. or less. The ball rack also has the diameter dimension of 10" inches so that a ball of size 5, which is the standard ball size of colleagues and high school athletes. So yet again it meets the requirement of holding a size #5 soccer ball. The raw material for this device was only $36.72 which is really cheap to help us stay in our budget range. So all in all, the design is efficient, cheap, light weight economic, and holds eight balls it is a great design for what we need in our Omni-Directional-Soccer-Ball-Thrower.

## Ball stopper

Moving on to the ball stopper, we wanted to come up with a simple design and that was user friendly. So what we came up with is the extended rod that runs down the center of the spine, which is seen readily in Figure 5 and Figure 6. This ball stopper is connected by two bearings to help it rotate easy and not get jammed up. At the end of the ball stopper is a cushion. This feature adds protection to the balls so that it won't mar them up nor poke or scratch the outside surface of the ball. One of the design problems that we ran into was that the ball stopper was just hanging loose on the spine and was free to flop around wherever. To solve this problem, we simply added clips to the top of the spine that are the size of the round handle so that it can clip in and be tight and secure so that when the machine is being ran that the ball stopper is bouncing around also allowing and defeating the purpose of stopping the hopper to be able to only feed one column at a time. This feature allows the user to launch all one side of the hopper and once he is done then he or she can lift the ball stopper and rotate it to the empty column and feed the machine with the column that is full.

## Launch Wheel

One of the more critical pieces to our launcher is the design of our launch wheels, which act as our main launching mechanism. The main purpose of the wheels is to contain enough energy to be able to successfully launch the soccer balls at the required speed. While one of our goals is to make our design as light as possible inside our financial constraints, the nature of the wheel's use requires them to have more weight. The solution to the restraints and our requirements will be accomplished by the use of a high moment of inertia in the wheels spinning axis and proper friction on the wheels surface to transfer energy into the ball.

The profile of the wheel is important, as geometrical differences can provide larger moment of inertia with less weight addition. Figure 5 shows the desired wheel profile chosen for our design.

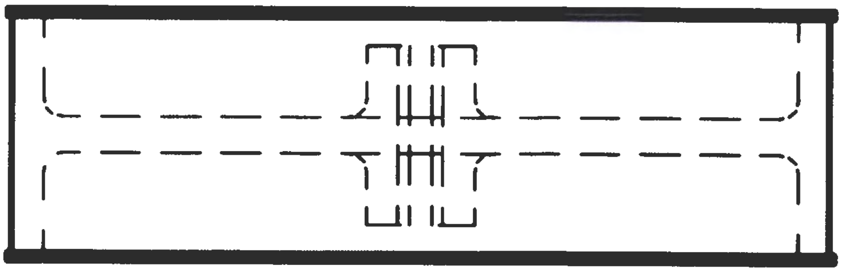

**Figure 7: Launch Wheel Profile**

The majority of the wheel's mass is on the outside edges of the wheel, to give it a larger moment of inertia, while keeping the overall weight of the wheel down. The wheel is to be made out of aluminum and can be machined and lathed to the appropriate shape.

The aluminum will provide the proper structure for our wheel, but not the best protection for launching the soccer balls. In order to achieve a surface that provides a better interface, we will be adhering polyurethane to the outside of the wheel. If properly bonded, the polyurethane will not only have sufficient frictional properties, but will be non-marring to the soccer ball. The adhesion process of the polyurethane is a critical factor, in that if the bond is not properly made, the polyurethane may not stay attached to the wheel at high RPMs. Using abrasive measures, chemical treatment of the aluminum, a factory bonding agent, and geometrical advantages, the polyurethane can be bonded securely to the wheel. If you refer to Figure 7, you will see that a small lip has been placed in the wheel profile near the top and bottom of the edges. This will provide a physical edge for the polyurethane to grip and help keep it from coming off of the wheel after it is molded on.

**Wheel mounts**

Another factor that was considered in our design was the distance between the launching wheels. Most wheel launchers have a static distance between their wheels, but we decided to make that distance variable to see where an optimum distance might be, if one exists. In order to achieve this, we have decided to create bolt holes in the frame that are elongated to allow the lateral movement of where the launching wheels will be bolted on. The launching wheels will be attached directly to the shaft of our motor, which will be welded onto a square motor mount. The motor mount will be what is directly attached to the frame, and can be mounted anywhere along the elongated bolt holes. Each side provides for one inch of movement, to allow for a two inch total movement between the wheels. This will give us a good range of motion between the two launch wheels and find out how that effects the launching of the soccer ball.

### UPS Shippable

One of our requirements was to create a device that could be fit into a box that was shippable by UPS. The main factor in this consideration is the total size of a box. UPS has a max requirement that all boxes to be shipped must be 165 inches or less in combined length and girth. By creating a disconnect point at our designs spine, as well as removing the support wheels, we were able to orient the pieces and fit it into a box that meets the UPS specs. It should be noted that for our analysis, the disassembly of the launcher was kept at a minimum. There might be potential to disassemble the launcher further to fit into a smaller box, if it was found to be economically advantageous. However, as is, our design has met the shippable requirement.

## Electronic Design

### Motors

In order to meet launch speed and safety requirements and minimize cost/complexity, the launch wheels will be driven by two totally-enclosed 90V PMDC motors. Power analysis concluded that ¼ HP (4 Amps peak) rated motors would provide sufficient power to restore the lost energy between launches fast enough to meet the 3 second requirement. This size of motor is also attractive due to simplified NEC codes for motors rated at less than 6 Amps peak.

Another important specification for the motors is max RPM. This design calls for motors with a max speed of at least 3500RPM. This will allow the motors to operate efficiently and have sufficient available torque in the critical upper operating range of 1750-2500RPM.

Due to high torsional and bending stresses it is also necessary that the motor shaft diameter be a minimum of 5/8".

## Controller

The motors will be controlled using independent speed control circuits implemented with PWM-driven high-side MOSFET switching. The speed reference voltage is set by the operator using two potentiometers. Feedback functionality will be implemented using a low-cost PIC16F07 microcontroller. Feedback control is also used to limit each motor to a maximum current of 4 Amps. This is comfortably below the 6 Amp limit required by the NEC#430.39 when using a controller for overload protection.

## Enclosure

Preliminary designs called for an electronics enclosure with a NEMA 3R rating, but further investigation found that 3R enclosures are comparatively expensive, and allow overly easy access. For these reasons, the final design will use a die-cast aluminum NEMA 4x enclosure. This will ensure that even under the most severe operating conditions the electronics will be protected from the elements.

## Wiring

3 types of wiring will be used in this design. The largest is the flexible cable used to deliver power to the controller. As specified by NEC#430.24 and NEC Table#400.5, this cable will need to be 16/3AWG SJTW rated. For delivering power from the controller to the motors, 18AWG TW wire or larger is required. The wiring used to connect the controller to the handlebar switches only carries 5V and is not regulated by NEC standards. Any outdoor rated 8 conductor cable of 24AWG or larger will be sufficient.

## Switches/Controls

For simplicity and economy, the motor speeds are set with potentiometers rather than a digital input device. The solenoid will be triggered by two series-connected switches. Using series connected switches will aid in preventing accidental firing of the machine.

## Failure points

Ground faults/short circuit conditions can occur in any current carrying path of the controller circuit and can be caused by component failure or external tampering. This type of failure is protected against using fuses rated at 15 Amps. Individual motor currents are limited to 4 Amps to protect against failures that could be induced from locked-rotor currents or improper starting conditions.

# Construction

The construction took place at Athlonic Sports with the help and wisdom of John Meade, our project sponsor. Parts were purchased under him directly, and many of the materials and tools were found in house. A few items were created and modified using the Student Prototype Lab on campus, under the rule of Mike Morgan. And we want to give a special thanks to Terry Zollinger for helping create the wheels under pressure in the MAE machine shop.

**Figure 8: Constructed Soccer Ball Launcher**

## Wheel considerations

It became clear early on in the construction of the machine that the function and operation of the wheel is not only a highly critical device, but is also a difficult one to understand. While numerical values such as inertia and friction were considered, knowing how the harness and softness of the wheel material affected the throwing capability of the machine was truly only discoverable through testing.

## Testing Phase

Testing occurred over the period of a month, where design requirements and important parameters were tested for to understand the breadth and width of the machines capability in real world scenarios. It also became clear early on in the construction of the machine that the function and operation of the wheel is not only a highly critical device, but is also a difficult one to understand. While numerical values such as inertia and friction were considered, knowing how the harness and softness of the wheel material affected the throwing capability of the machine was truly only discoverable through testing. So the tests that applied were completed with three different sets of wheels: A set of pneumatic rubber wheels, a set of soft polyurethane wheels with aluminum hubs, and a set of hard polyurethane wheels with steel hubs. The testing descriptions can be seen in Table 2.

Table 2: Test Descriptions

| | |
|---|---|
| **Speed Test** | Set wheels to 1500 and 1550 RPM, and measure the launch velocity with a radar gun. |
| **Wet speed test** | Same as above, but use a spray bottle to wet the ball surface. |
| **Lamp Test** | By hooking up solenoid output to a test lamp, trigger bouncing can be easily detected. |
| **Goalie Test** | Ask goalie if he was able to anticipate control adjustments. |
| **Recovery Time Test** | After launching a ball, measure the time required to regain 95% of pre-launch RPMs. |
| **Curve Test** | Visually verify that by setting the motors to different speeds, a horizontal curve can be produced. |
| **Max Speed Test** | Set both wheels to their maximum setting and measure launch speed with a radar gun. |
| **Weight Test** | Verify that the machine weighs less than 75 lbs. |
| **Ball Marking Test** | Launch a new soccer ball and inspect for marks. |
| **Box Test** | Disassemble the machine and verify that it can fit in a UPS standard size box. |

## Tabulated Testing Results/Data

Table 3: Pass/Fail Testing Results

| Requirement | Date Tested | Result |
|---|---|---|
| **Launch only 1 ball at a time** | 11/6/2013 | **Pass** |
| **180 degree horizontal 45 degree vertical** | 11/9/2013 | **Pass** |
| **Hold 8 soccer balls** | 11/9/2013 | **Pass** |
| **Capable of horizontal curvature** | 11/9/2013 | **Pass** |
| **Goalie cannot anticipate shot** | 11/9/2013 | **Pass** |
| **UPS shippable** | 11/13/2013 | **Pass** |
| **Material cost less than $1400** | 11/13/2013 | **Pass** |

Table 4: Numerical and Wheel Specific Results

| Test | | Date Tested | Result | Std. Deviation |
|---|---|---|---|---|
| **Dry Speed test @ 1500RPM** (MPH) | rubber | 11/6/2013 | 48.2 | 1.03 |
| | polyurethane (aluminum) | 11/6/2013 | 47.7 | 1.83 |
| | polyurethane (steel) | 11/13/2013 | 48.4 | 2.99 |
| **Wet Speed test @ 1500RPM** (MPH) | rubber | 11/13/2013 | 38.4 | 8.26 |
| | polyurethane (aluminum) | 11/13/2013 | 34.3 | 4.19 |
| | polyurethane (steel) | 11/13/2013 | 36.5 | 6.22 |
| **Recovery Time** (Seconds) | rubber | 11/6/2013 | 4.34 | 0.24 |
| | polyurethane (aluminum) | 11/6/2013 | 3.04 | 0.44 |
| | polyurethane (steel) | 11/13/2013 | 2.87 | 0.81 |
| **Max Achieved Speed** (MPH) | rubber | 11/13/2013 | 70 | NA |
| | polyurethane (aluminum) | 11/13/2013 | **NA** | NA |
| | polyurethane (steel) | 11/13/2013 | **58** | NA |
| **Less than 75 lbs.** (LBS) | rubber | 11/13/2013 | 74 | NA |
| | polyurethane (aluminum) | 11/13/2013 | **76** | NA |
| | polyurethane (steel) | 11/13/2013 | **82** | NA |

Table 5: Ball Marking Results

| **Wheel Type** | **Marking** (deposits material) | **Scuffing** (removes material) |
|---|---|---|
| rubber | Deposits rubber on ball surface | None |
| polyurethane (aluminum) | None | Minor |
| polyurethane (steel) | None | Moderate |

## Discussion of Results

### Soccer Ball Size

Size 5 soccer balls were used in our testing. However, it should be noted that the balls were not all at the same internal pressure, which gave a variety or results for some of our tests. This is good for testing as it is analogous to balls used in an actual practice session. The results compiled above are the average values found from launching the different balls.

### Speed Test

The tests were completed for the varying wheels at the same RPM. A tachometer was used to ensure that the speeds were ± 10 RPM of target. The speed recorded in the table is the average speed value for 10 shots. All three wheel types operated well at these speeds.

### Wet Speed Test

The wetness test was used to compare how the performance of the soccer ball launcher changes when the ball are wet, which is analogous to a rainy day of practice. Methods were the same as the regular *Speed Test.*

### Lamp Test

This test was an easy way to test the output from the processor to the solenoid by hooking it up to a lamp. The lamp switching on an off represented one shot. And our attempts to break the code and get it to fire more than once in a one second window, meaning there was no double fires.

### Goalie Test

Marc, being a former soccer goalie, was put into a goal and was fired upon using different curves to see if he knew where they were going before the ball was launched. As a normal goalie would not know what sort of spin the ball would have until after a kick was made, so too did Marc not know which way the ball was spinning until after it took flight. This shows that the controls and operation of the machine is adjustable without the goalie knowing.

### Recovery Time Test

There is a time rise constant associated with the re-ramping of the wheels to their original speed after shots occurred. The electronic controls on the system have an over damped response to returning the wheels to their appropriate speed, meaning it takes a significant amount of time to return them. So we looked at the time it took to get to 95% of the original speed, as this was more realistic given our system. The lighter wheels exhibited larger times to recovery, as they lose a larger percentage of inertia when launching a ball and it takes them longer to recover.

### Curve Test

This test was performed to only verify that ball curvature was possible. Initial attempts to accurately quantify results were abandoned, as the results varied highly with balls of different pressure. However, at a regulation penalty kick distance of 12yards, a ball aimed at the center of the goal can curve roughly 5 to 10 feet horizontally before reaching the goalie.

### Max Speed Test

This test was designed to see if we could get the balls to shoot the designed 70MPH max speed. The pneumatic wheels did see a speed of 70MPH at about 80% power input. The aluminum hub wheels did not reach the goal as issues arose with the integrity of the polyurethane's adhesion to the wheel at high speeds, before it reached 70 MPH, and further ramping did not occur to avoid any potential high speed separation. The steel wheels did not reach the desired speed either. The harder polyurethane surface resulted in more slippage at the higher speeds, and at 58MPH, more input gave no more output.

### Weight Test

As noted in the table, the machine is over the specified weight requirement for two of the three wheels. However, the extra weight does not significantly increase the difficulty of moving and operating the machine, and it doesn't put the machine over the 150 lbs. weight limit for shipping.

### Ball Marking Test

Ball damage was found to occur in three ways. Marking occurs when the launch wheel material is deposited on the ball. Scuffing occurs when material is abrasively removed from the soccer ball surface. Transferring occurs when dirt from one soccer ball is left on the launch wheels and then deposited on subsequently launched soccer balls.

Our testing involved looking at the surface of a new soccer ball shot through the launcher and visually inspecting it for marks. The pneumatic rubber wheels marked the ball heavily, depositing significant rubber marks on the balls. The softer polyurethane did not deposit polyurethane on the balls, but did transfer dirt and rubber from marked balls to non-marked balls. The steel wheels with the harder polyurethane neither deposited nor transferred material. Both polyurethane wheel surfaces scuffed the balls, abrasively removing material from the surface. For all wheel types, the overall damage area was equal in height to the profile of the wheels (3 inches for the aluminum wheels; 4 inches for the rubber and steels wheels) and roughly 5 inches in length. Individual marks within the damage area varied in size, with the largest marks measuring 1-2 square centimeters in area.

### Box Test

We disassembled the machine as designed, and placed it into a mock box, of the appropriate dimensions for UPS shipping. The machine fit, and one inch dimensions were left on all sides for the inclusion of shipping foam.

## Future Design Considerations

For future designs we have made a few hindsight observations that we think would improve the design. The first is an increased speed to the actuator. At Athlonic while testing, we observed that the speed at which the balls entered the wheels affected the speed at which it exited. While this is not unexpected, we were sad to see that some of our wheels could not reach the 70 MPH benchmark. But increased the entry speed of the ball into the wheels might improve speeds significantly.

# Conclusion

The goal of our project was to create a soccer ball launcher that offered mobility and versatile use on the soccer field. Our testing has shown that we have a machine that will do the majority of what we want, and what a soccer coach will want. While there are certain tests that reveal that our machine does not meet the benchmark requirements outlined, we do believe that they do not represent critical failures. We are confident that we have a well working prototype of a soccer ball launcher, and that with minor adjustments; it can become a polished product with future iterations.

## Appendix A: Critical Calculations

**Wheel Material Calculations - Polyurethane**

Note: Vt=ω*r

Dimensions

$b := 6in = 0.152m$

$a := b - \frac{3}{8}in = 0.143m$

Density

$\rho := 1110\frac{kg}{m^3} = 1.11 \times 10^3 \frac{kg}{m^3}$

Poissons Ratio

$\upsilon := 0.48$

Angular velocity

$Vt := 90mph = 40.234\frac{m}{s}$

$\omega := \frac{Vt}{b} = 264\frac{1}{s}$

**Rotational Stresses**

$\sigma_{zz} := 0.0Pa$

$$\sigma_{rr} := \frac{(3+\upsilon)}{8}\rho \cdot b^2 \cdot \omega^2\left(1 - \frac{a}{b}\right)^2 = 3.053 \times 10^3 Pa$$

$$\sigma_{\theta\theta} := \frac{(3+\upsilon)}{4}\rho \cdot b^2 \cdot \omega^2\left(1 - \frac{1-\upsilon}{3+\upsilon}\frac{a}{b}\right)^2 = 1.156 \times 10^6 Pa$$

Yeild

$S_{ut} := 2000psi = 1.379 \times 10^7 Pa$

Approximate Sy at half Sut

$$S_y := \frac{S_{ut}}{2} = 6.895 \times 10^6 Pa$$

Principle stresses maybe? to find yeild criteria

$$\tau_{oct} := \frac{1}{3}\cdot\sqrt{(\sigma_{\theta\theta} - \sigma_{rr})^2 + (\sigma_{rr} - \sigma_{zz})^2 + (\sigma_{\theta\theta} - \sigma_{zz})^2} = 5.442 \times 10^5 Pa$$

$$S_f := \frac{\left(\frac{\sqrt{2}}{3}\cdot S_y\right)}{\tau_{oct}} = 5.973$$

**Energy**

Moment of Inertia Found in Solid edge

$I := 256.7lbm \cdot in^2$

wheel kinetic energy Initial

$$Ke_w := \frac{1}{2}I \cdot \omega^2 = 2.618 \times 10^3 J$$

mass of a ball

$m_b := 16oz = 0.454kg$

Ball Kinetic energy Initial

$$Ke_b := \frac{1}{2}m_b \cdot (Vt)^2 = 367.125J$$

Efficiency of energy transfer
from wheel to ball (e)

$e := 0.75$

Wheel Kinetic energy after shooting a ball

$$Ke_{wpost} := Ke_w - \frac{1}{2 \cdot e}\cdot Ke_b = 2.373 \times 10^3 J$$

Energy needed to recharge each wheel

$$Ke_{recharge} := \frac{1}{2 \cdot e}\cdot Ke_b = 244.75J$$

Power for 3 second recharge

$$P := \frac{Ke_{recharge}}{3s} = 81.583W$$

Rotational and tangential speed of wheel after shooting a ball.

$$\omega_f := \sqrt{\frac{2 \cdot Ke_{wpost}}{I}} = 251.356 \frac{1}{s} \qquad Vt_f := \omega_f \cdot b = 38.307 \frac{m}{s}$$

$$251 \cdot \frac{60}{2 \cdot \pi} = 2.397 \times 10^3 \quad \text{RPM} \qquad 38.3 \cdot 2.23694 = 85.675 \quad \text{MPH}$$

**Motor**

Wattage needed to be applied to wheel at shaft

$$P = 81.583\ W$$

Motor Efficiency from 2100-2500 RPM
With High Torque

$$e_m := 0.65$$

Required electrical Power per motor

$$P_r := \frac{P}{e_m} = 125.513\ W$$

An NEC rated 1/4HP motor provides 360W peak power. This gives a safety factor of 2.8

**Friction for Wheel adjustability**

Washer Dimensions

$$ID := \frac{9}{32} in = 7.144 \times 10^{-3} m \qquad OD := \frac{5}{8} in = 0.016\, m$$

$$A := \frac{\pi}{4}\left(OD^2 - ID^2\right) = 1.579 \times 10^{-4} m^2$$

Force on wheel to be resisted LARGE

$$F := 50lbf = 222.411\ N$$

steel on steel static friction coefficien

$$\mu_s := 0.8$$

Force to be applied for necessary friction

$$F_f := \frac{F}{\mu_s} = 278.014\ N$$

Stress per bolt for force

$$\sigma_{bolt} := \frac{F_f}{4 \cdot \left(\frac{A}{3}\right)} = 1.321 \times 10^6 Pa$$

**Area divided by 3 for realistic contact area

Recommented Torque

$$T := 0.2 \cdot \frac{F_f}{4} \cdot 0.25in = 0.088\ J$$

Apply a safety factor of 5: $T_f := 5 \cdot T = 0.441\ J$

http://www.futek.com/boltcalc.aspx

$$lbfin := \frac{T_f}{0.11298 J} = 3.906$$

**Stresses on wheel shaft**

Dimensions

Assuming a force of

$d := \frac{5}{8}in$ $\quad l := 6in$ $\quad F := 50lbf = 222.411\,N$ $\quad P := \frac{1}{4}hp = 186.425\,W$

303 stainless steel $\quad S_{ut} := 87.3ksi = 6.019 \times 10^{8}\,Pa$ $\quad S_y := 35.0ksi = 2.413 \times 10^{8}\,Pa$

Bending Stress

$M := F \cdot l = 33.895\,J$ $\quad c := \frac{d}{2}$ $\quad I := \frac{\pi \cdot d^4}{64}$

$$\sigma_b := \frac{M \cdot c}{I} = 8.63 \times 10^{7}\,Pa$$

Torsional Stress

$T := 0.25 \cdot \frac{5252}{2500} \cdot lbf \cdot ft = 0.712\,J$ $\quad r := \frac{d}{2}$ $\quad J := \frac{\pi \cdot \left(\frac{d}{2}\right)^4}{2} = 6.235 \times 10^{-9}\,m^4$

*Torque found from below

$$\sigma_t := \frac{T \cdot r}{J} = 9.065 \times 10^{5}\,Pa$$

$$\sigma_{max} := \left[(|\sigma_b|)^2 + 3 \cdot (|\sigma_t|)^2\right]^{\frac{1}{2}} = 8.631 \times 10^{7}\,Pa$$ Von mises yeilding check

$$n := \frac{S_y}{\sigma_{max}} = 2.796$$ Safety Factor against yeilding

1. **POWER** (the rate of doing WORK) is dependent on **TORQUE** and **RPM**.
2. **TORQUE** and **RPM** are the MEASURED quantities of engine output.
3. **POWER** is CALCULATED from torque and RPM, by the following equation:

**HP = Torque x RPM ÷ 5252**

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