Innovative Robotic Designs For VEX U Challenge "Nothing But Net"

ABSTRACT- The design, construction, and programming of robots that can primarily execute a partner robot elevation and launch objects accurately to a target are experimented in this project. The objects in question are 4-in diameter balls that are scattered over a stationary perimeter. The robots will be able to locate the balls autonomously with the use of navigating sensors and lift a partner robot over twelve inches off of the ground. A ball pitching mechanism will be investigated to launch balls from any position to a target that is forty inches above the ground. The elevating mechanism is designed for rapid lifting of a load under twenty-five pounds. The mechanism will use tension in order to lift the robot. The tension is stored as potential energy through pneumatic pistons where upon the actuation of the pneumatic pistons, the potential energy will change to kinematic energy. The momentum and the force exerted by the rubber bands which creates the tension, will be enough to lift the partner robot off the ground at a target time of two seconds or less. The launcher used on both robots will be able to launch accurately and rapidly, having a fire rate of about 4 balls per second (bps). This is done using a single flywheel launching system that utilizes a 3d-printed heavy wheel in order to conserve momentum while spinning, being minimally affected with each ball launched. This report will therefore outline the process of selecting wheel size, weight and how the launcher, transmission and lift are all investigated to generate efficient robots.

Keywords: Robotics, Programming, SOLIDWORKS, CAD, Autonomous, Sensors.

I. INTRODUCTION

Every year, VEX Robotics provides a challenge that immerse problem solvers in the areas of Science, Technology, Engineering and Math (STEM) using robotics platforms and engineering processes. This year challenge is called 'Nothing But Net [1].' The challenge is played on a 12'x12' square field where two alliances (one "red" and one "blue") design, build and program robots to compete in matches consisting of a forty-five second autonomous period followed by one minute and fifteen seconds of driver-controlled manipulation. There are ninety-four (94) polyurethane foam balls and ten (10) bonus balls, available as scoring objects on the field. Some scoring objects begin in designated locations on the field, while others are available to be entered into the field during the match. Each robot begins a match on one of their alliance starting tiles. Each alliance has one 'High Goal' and one 'Low Goal' to score objects into. Alliances also earn points for 'Low' and 'High Elevating' one of their robots upon the other. A bonus is awarded to the alliance that has the most total points at the end of the autonomous period.

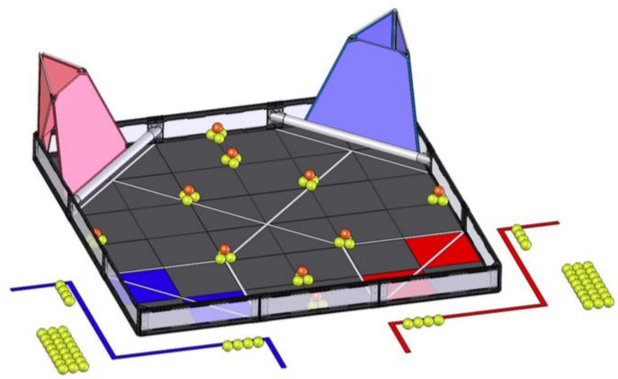


Figure 1: Field and Game Set Up

A. Objective

The primary objective of this project is to design, build and program 1. a robot that has an effective and rapid elevation mechanism that also complies with the limitations and constrains of the challenge and 2. a robot that can launch balls consistently and rapidly from any location on the field. To accomplish the first objective, it is necessary to produce a force that overcomes the weight of the partnered robot and the force of gravity acting upon the partnered robot. This requires a robust and stable drive train to be able to withstand and maintain stability when adding additional weight. To accomplish the second objective, the feeding mechanism that loads balls into the launcher needs to run quickly and lag just behind the recovery of the launching mechanism. This enables both robots to launch efficiently, expending as little time as possible.

B. Related Background

Lift: Similar to the deploying ramp, this system can be actuated with either pneumatics pistons or DC motors. Since the pneumatic piston-actuated process is faster, we will only consider this type of actuation. In a four-bar lift, as shown in [1], energy for movement is stored in rubber band tension. A pneumatic piston holds the tension until the piston is retracted allowing the four-bar lift to go up quickly. A platform is used to hold the partner robot. The platform will always keep a parallel position to the ground even in the elevated position.

A major problem about this lift mechanism is the concentration of weight at one point of the robot. This creates destabilization because the center of mass is shifted almost outside of the boundaries of the robot rapidly. Another problem to this lift is the amount of tension needed to bring up a desired load. The more load the more difficult it is for this type of lift to move. Bending and torsion might be experienced in some parts of the structure of the robot.

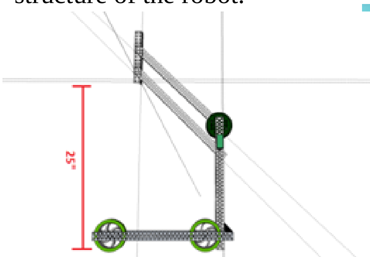
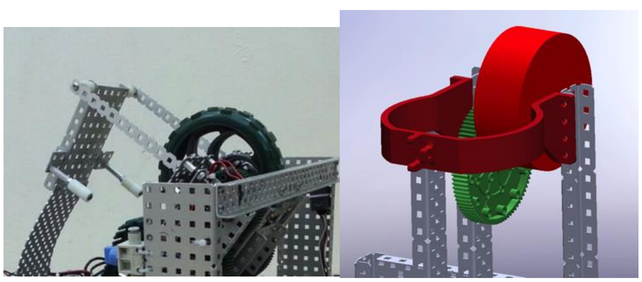


Figure 3: Four-bar in the up position

Figure 2: Robot positioning with a 4-bar lift

Single Fly Wheel: Fire Rate: 600ms Bps (4 Motors Full Court)
A Single wheel launcher uses the same concept as a double flywheel. One wheel spins at a very fast RPM, when a ball comes in contact with a fixed wall as the spinning wheel the ball is launched as a projectile.



Figures 4: Single flywheel launcher (Physical and CAD model) respectively

On refference [3] a video of a single wheel launcher is presented. This single wheel launcher is used to rapidly score points for skills. The high Arc and consistant launch delivers a high skills scores for the team.

II ENGINEERING REQUIREMENTS

Versatile: The machine needs to able to perform different operations rapidly and efficiently. This involves the lift, launcher, and intake/feeding.
Portable: Easy mobility of the robot allows effective readiness before and after matches.
Controllable: Robot must be programmed to allow easy manipulation via remote control.
Durability: Robot must be built strong. A robust robot will decrease the error factor while interacting with other robots during a match.
Reliability: Robot must contain an effective balance of hardware and software for the proper and constant operation of the machine.

III HARDWARE DESIGN

A. Elevation Robot

When deciding how the lift would be designed, it was foreseen that it had to be wider than the partnered robot whose constraint is 15”. The design that will be implemented will be a four bar lift as shown and described in Figure 5. A Plexiglas with a thickness of 1/16”, reinforced by aluminum bars was used to create the platform where the partnered robot will drive on. This platform is 16” wide and about 16” in length. Being limited with sizing constraints, the lift had to be further optimized to account for the skill of the partnered robot driver.

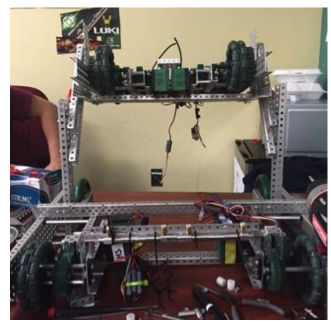


Figure 5: Early elevation prototype

For optimization, the back wheels were placed on the outside rather than the inside. This gave more room than before. Next, the design of guides that will aid in giving better accuracy will be created in SOLIDWORKS 2015. This design will increase the effectiveness of the lift because in the worst-case scenario, the partnered robot must still be able to drive onto the platform where it would be elevated off the ground.

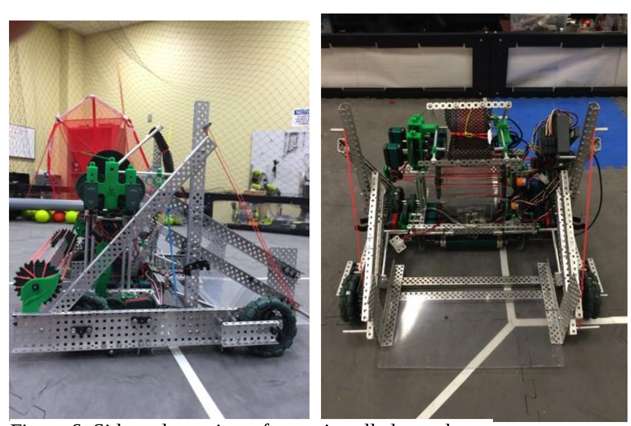


Figure 6: Side and top view of ramp installed on robot.

The lift mechanism was modified to obtain a different arrangement and placement on the rubber bands. It was determined that the current prototype had the tension working on a really small angle. In order to get the most energy from the tension elements, the force needed to be drawn perpendicular to the bar. In other words, the effective angle from bar to tension force needed to be close to 45 degrees. With the current version, the effective angle was only 12 degrees. Even after extending the bars a little longer to allow the rubber bands to stretch more and retain more potential energy, the effective angle was still the same, therefore, there was minimal improvement.

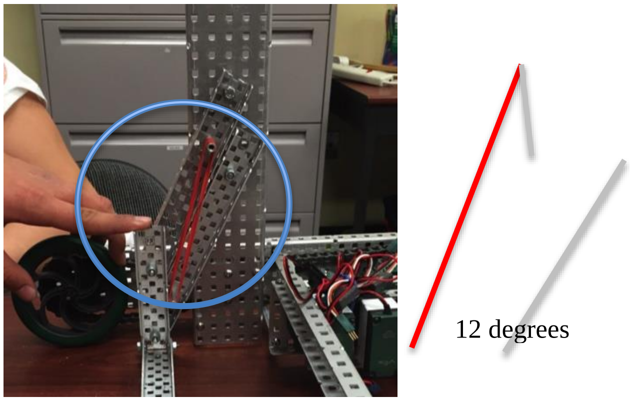


Figure 7: 15-degree angle tension direction

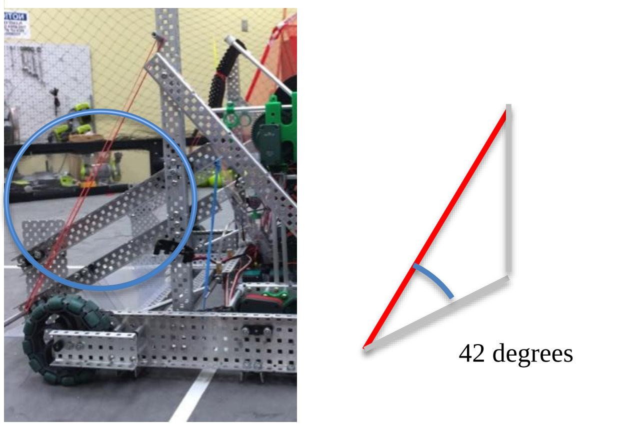


Figure 8: 42-degree angle tension force direction

An angle of 42-degree was obtained by changing the location of the tension elements and the pivot point locations. The results were greatly favorable. Based on table 1, prototype 3 with the highest angle was able to obtain more elevation with less tension. At 12 rubber bands (6 on each side) the lift was able to bring the load up to 12 inches off the ground. 12 rubber bands produced 67 pounds of force being enough to achieve our goal of 12 inches of height. This amount of tension also reduces stress and strain on the bolts and structural components.

A.1. Testing

Table 1. Lift Test Comparison

	Load (lbs)	Height (in)	Tension (lbf)	# of Rubber Bands
1st Prototype (Small 4-bar Lift)	14.9	5	63	16
	14.9	9	85	20
	14.9	10	91	24
	14.9	10	93	26
2nd Prototype (Long 4-bar Lift)	14.9	4	65	12
	14.9	8	71	14
	14.9	10	81	16
	14.9	13	99	20
3rd Prototype (Modified 4-Lift/Different Pivot Points)	15.4	9	55	8
	15.4	10	60	10
	15.4	12	67	12
	15.4	13	74	14

The third prototype was, by far, the most favorable mechanism. It produces the most height with small amounts of force from the rubber bands. This is convenient due to the fact that the more tension in our system, the more bending experienced by the supporting bars. Excessive bending can permanently modify the structure and even fracture after a certain amount of cyclic loading. This prototype allows the lift to reach the required height using only 74 lbf from the rubber bands.

Figure 9: Rubber Band Tension Test

The tension from the rubber band was experimentally obtained using a fish scale. As shown in figure 9, a set of rubber bands were stretched the same length as the ones from the lift and measured with a tape measurer. The fish scale was attached to the other end to obtain the pounds of force when the rubber bands were pulled. This was done for every set of rubber bands on every prototype.

A.2. Gear Design

In order to minimize friction on the launcher and optimize performance, a gear needed to designed. For instance, a 1:9 gear ratio was necessary to obtain the desired velocity of 7.4 m/s. This gear ratio provided a frequency of 1440 RPM with a high-speed configured motor (160 RPM). The only way to obtain this ratio, given the VEX platform, was by compounding gears. However, compound gears required more mechanical parts causing more energy loss in terms of heat and noise. As a result, our team decided to design a gear so that there was no need to use compound gears. The gear was, then, 3D printed.

To get an output of 1440 RPM, a driver gear with 108 teeth was needed to spin the twelve-tooth pinion. With this, a desired gear ratio of 1:9 was obtained. The gear was designed in CATIA software. In order to design such gear, the team had to research about all the important aspects of a gear design like the pitch diameter and angle of pressure.

Equations:

N = 108

P = 24 (value obtained from vex 84T gear) - Diametral Pitch

D=N/P=4.5 in−Pitch Diameter

A=1/P=0.0416 in −Addendum

B=1.157/P=0.0482 in −Dedendum

OD=(N+2)/P=4.583 in −Outside Diameter

RD=(N−2)/P=4.416 in−Root Diameter

CP=3.14D/N=3.14/P=0.589 in −Circular Pitch

BC=D∗cos(P*A)=4.499 in −Base Circle

T=3.14D/2N=1.57/P=0.0654 in −Circular Tickness

WD=2.157/P=0.0898 in −Whole Depth

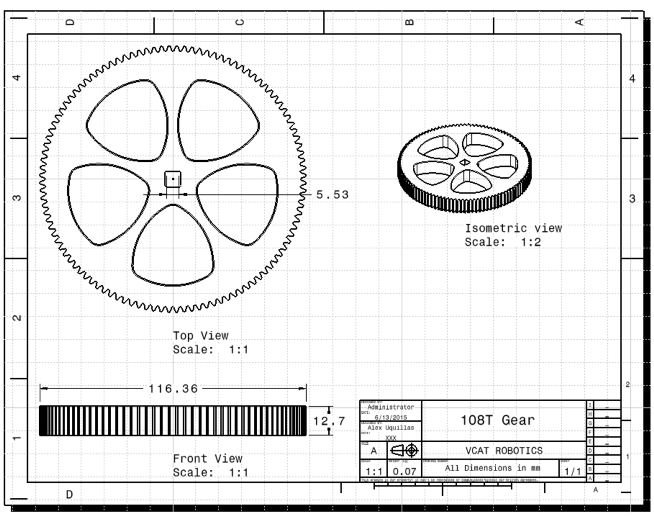


Figure 10: Gear Design Technical Drawing

B. Partner Robot

A major issue for the smaller robot is space constrictions. Due to this, many designs were made as compact as possible to fit different mechanisms, allowing them to work concurrently without flaws. The smaller robot was designed around a transmission drive train and a single flywheel launcher.

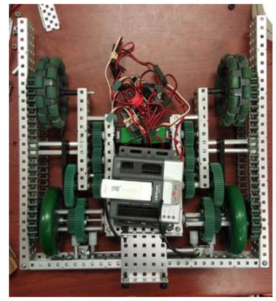


Figure 11: Initial transmission design

The idea of the transmission is to shift from a low speed (high torque) to high speed (low torque). This enables us to be both faster and stronger than other players/robots during competitive environments. The shifter can be seen in the figure to the left. The shifter consists of a double acting pneumatic piston, which retracts and extends based on the driver or autonomous routine. The drive train consists of 6 motors that work concurrently. Each motor is configured for high speed (1:6 or 160rpm) with a transmission that switches from 60:36 to 36:60

Torque Calculation:	Speed Calculation:
Torque configuration: (36:60) x 6(motors) x 9.2 lbs 1.67 x 6 x 9.2 = 92 lbs Speed Configuration: (60:36) x 6 x 9.2 lbs = 0.53 x 6 x 9.2 = 33 lbs	Torque configuration: (36:60) x 160rpm = 96 rpm Speed Configuration: (60:36) x 160rpm = 266 rpm

Table 2. Transmission rpm/force calculation

B.1. Single Flywheel

The launcher design on the robot consists of a single flywheel system, which, as its name implies, consists of a single wheel. The wheel itself has a base weight of approximately 350 grams and is powered by a total of 4 DC motors with a high-speed internal gear configuration (1.6:1 or 160rpm). The outer ratio consists of a 25:1 gear reduction for an even faster rpm. The accuracy and launch rate are very high using a control algorithm and a stable mechanical design. The design itself consists of 3d-printed parts to emulate a metal frame. The purpose of this launcher is to project balls at various locations on the field and as quickly as possible.

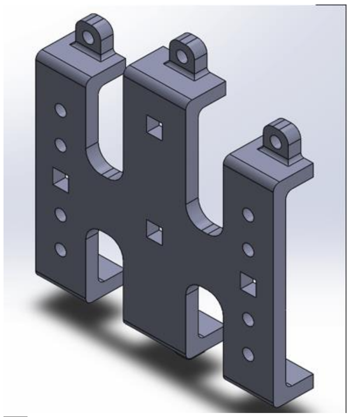


Figure 12: Launcher frame CAD

The design began by taking a concept of how to fit everything within sizing restrictions. The best way possible was by having a set of motors side by side, and opposite of each other in order to keep the points of contact to a minimum.

The initial launcher frame design can be seen on the figure above. The spaces account for the axles that will hold the gears. Note that this is the perfect spacing where gears mesh together. This spacing is determined using the sizing of the gear (supplied by VEX) and their corresponding CAD files that were imported into SOLIDWORKS. Using the spacing, a general outline can be created. The cutouts were made in order to save on material and hence weight. The material was cut out enough in order to reduce weight but not impact its' own structural integrity.

Keeping the same convention for the 3 parts on the launcher frame, the whole launcher can be created and mounted on the robot within minutes. The whole system is easy to attach and is sturdy.

This launcher is not only easy to implement, but launches balls consistently at a 45 degree angle.

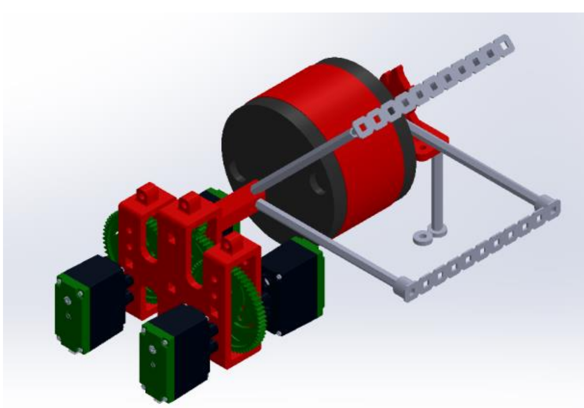


Figure 13: Launcher Assembly

B.2. Launcher Code

RPMCALC task is responsible for the calculation of revolutions per minute (RPM) on our single wheel launcher. In order to calculate RPM a Hall sensor or Tachometer is used. The sensor works by sensing magnets mounted on the wheel itself. As the magnets pass under the sensor the output signal of the sensor changes from High to Low, this change can be detected by code and allows us to accurately calculate the velocity of our wheel. The RPM task calculates how much time it takes for the sensor to read the magnets 5 times. There are two magnets on the wheel. Once the magnets have passed 5 times under the sensor this time is used to calculate the current RPM.

```
task RPMCALC()////////RPM CALCULATION TASK
{
  int count = 0;
  int status = 0;
  clearTimer(T1);
  while(1)
  {
    if (SensorValue[TAC] == 0 && status == 0)
    {
      count++;
      status = 1;
    } else if (SensorValue[TAC] == 1)
    {
      status = 0;
    }
    if (count == 5)
    {
      CurrentSpeed = (1000*5*30)/time1[T1];
      clearTimer(T1);
      count = 0;
    }
    if (time1[T1] > 500)
    {
      CurrentSpeed = 0;
    }
  }
}
```

The Algorithm works as follows: a target speed is set, the RPMCALC task calculates the current RPM and stores it in a global variable called CurrentSpeed. If the speed is less than the target speed it will send full power to the motors. This loop will be constantly executed until the current speed becomes greater than the target speed at which the control will spend a lower power to the motors. In simple words the algorithm is switching between high power and low power in order to maintain a constant target speed. The low speed is called BasePower, this is a power setting close enough to the target but not enough to be affected by battery voltage. The purpose of having a relative close BasePower to the target is to reduce the oscillation cause between the switching of the high power and the low power. Instead of switching between Full power and Zero power, it’s more efficient to switch between Full power and a BasePower closer to the target power.

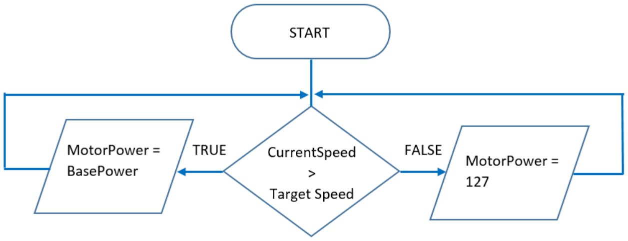


Figure 14: Flow chart for bang-bang code

Using the algorithm, the weight of the wheel needed to be selected. It is important to note that weight affects our angular momentum which is given by L=Iω, where I is the moment of inertia and ω is the angular velocity. L can also be calculated by (L)=M*V*R; where M = mass V = Velocity R = Radius [2]. The test used the control algorithm previously discussed. By varying the mass of the wheel, the velocity and radius were kept relatively constant. Looking at the angular momentum equation it can seen that by increasing the mass of the wheel, the resultant Angular momentum will also increase.

Angular momentum depends on two different factors: Wheel diameter or wheel weight. Because of sizing restrictions, the only choice was to increase the weight of the wheel by keeping a maximum diameter of 4in on the wheel. The performance of the system was tested by using four different weight settings on the flywheel; 200g, 300g, 350g, 400g. On each test, three balls were launched with the same velocity setting. Recovery time and velocity drop were both analyzed in order to determine the performance of the system.

```
task BANGBANG ()
{
  int MotorPower = 0;
  while(1)
  {
    //////SELECT SPEED
    if(ShootingMode == 1)//FULL COURT
    {
      TargetSpeed = 2800;
      BasePower = 38;
    }else if(ShootingMode == 2)//MID FIELD
    {
      TargetSpeed = 2400;
      BasePower = 30; //35
    }else if(ShootingMode == 3)//BAR SHOTS
    {
      TargetSpeed = 2150;
      BasePower = 30;
    }else if(ShootingMode == 5)//SKILLS
    {
      TargetSpeed = 2300;
      BasePower = 30;
    }else if(ShootingMode == 4)//LAUNCHER OFF
    {
      TargetSpeed = 0;
      BasePower = 0;
    }
    //////CONTROL
    if (CurrentSpeed > TargetSpeed){
      MotorPower = BasePower;
    }
    else if (CurrentSpeed < TargetSpeed){
      MotorPower = 127;
    }
    motor[m1] = MotorPower;
    motor[m2] = MotorPower;
    EndTimeSlice(); //OR DELAY 20 MILLI
    ////ERROR CALCULATION//
    rpmError = abs((TargetSpeed - CurrentSpeed)/10);
  }
}
```

B.3. Wheel Selection

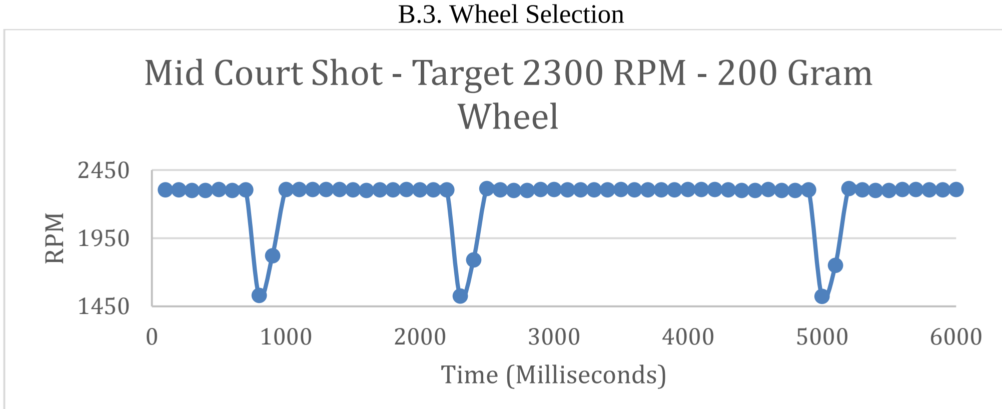


Figure 15: 200g Fly wheel, Angular Momentum: 0.1243

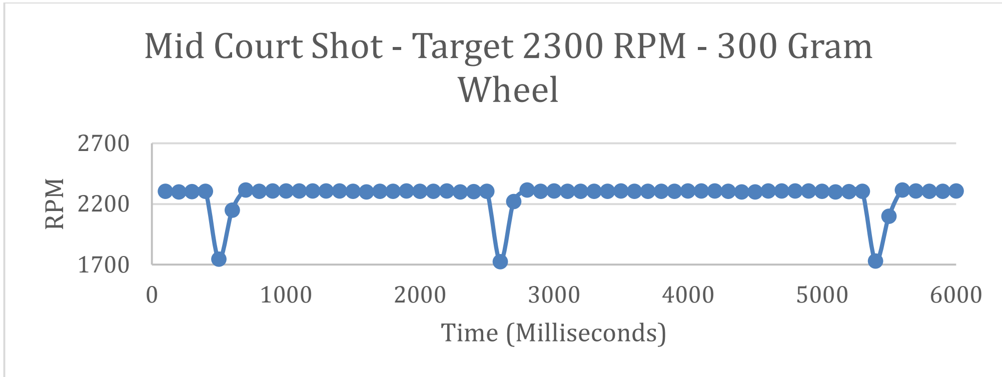


Figure 16: 300g Fly wheel, Angular Momentum: 0.1864

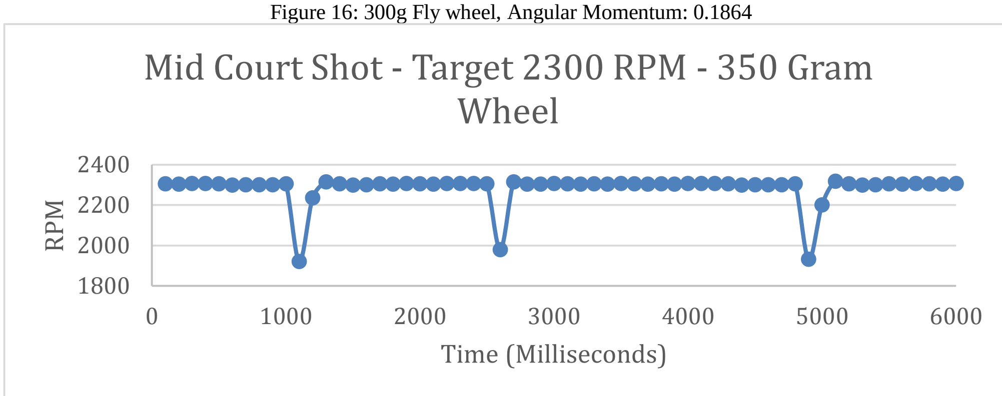


Figure 17: 350g Fly wheel, Angular Momentum: 0.2175

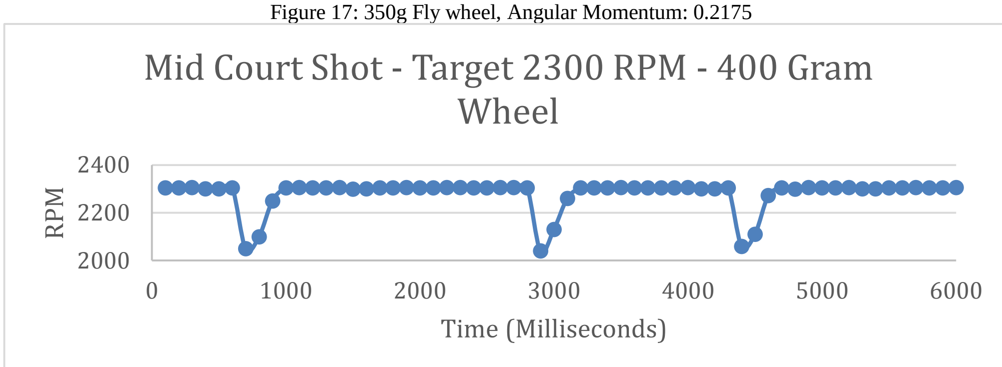


Figure 18: 400g Fly wheel, Angular Momentum: 0.2486

The calculations match the predicted results for 200g, 300g, and 350g 400g. From the graphs, it can be determined that the angular momentum increases as weight is added to the flywheel. This calculation can be seen in the drop in RPM as the ball is being launched. From the graphs above, the rpm drop and recovery time can be visualized. There is a smaller loss in RPM with the higher angular momentum on the 350g-wheel setting. Furthermore, loss of rpm is not as important as recovery time. It was noticed that recovery time improved from 200g to 300g and from 300g to 350g however it worsened from 350g to 400g. Through this data, it can be observed that the 400g-wheel was too much weight for the motors to handle. Thus, this means that 350g-wheel was the best candidate and produces the best results.

IV. CONCLUSION

The robots both include many different features in order to be efficient across the board. Both robots feature the same launcher. The launcher itself was strategically planned in terms of wheel weight, and maximum rpm to have a favorable fire rate and small recovery time. With control algorithms, the wheel is able to launch balls at varying locations away from the goal and fire them with pinpoint accuracy. Additionally, both robots feature the same drive train transmission in order to shift from a low speed/ high torque mode to a high speed/low torque mode to be faster and stronger than any robot on the field. This enables the driver to be defensive and offensive under different circumstances. The larger robot features a pneumatic acting lift, which lifts the smaller robot to a height above 12inches in 2 seconds. Overall, both robots have evolved into top class robots that can outperform any other in competitive environments.

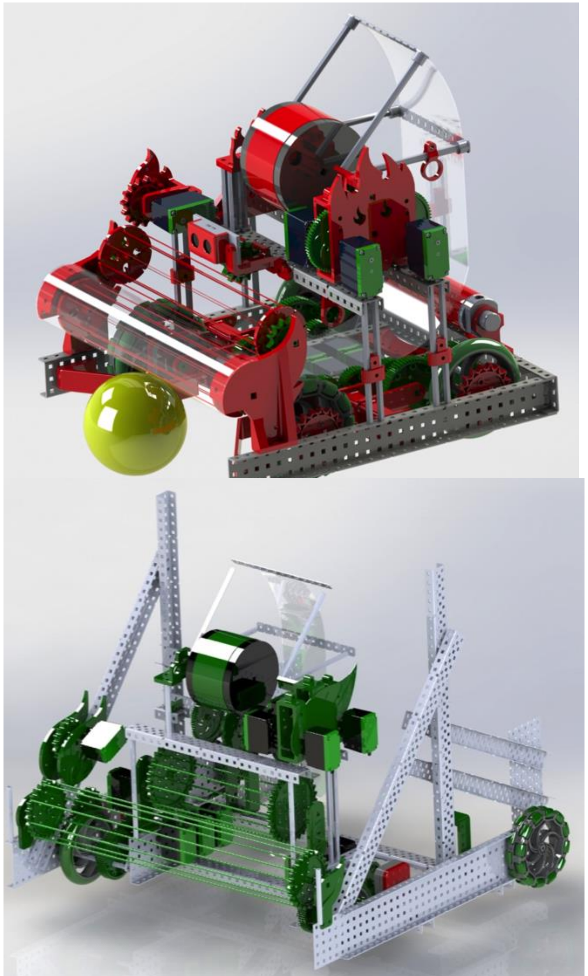


Figure 19: Final CAD designs

V. IMPLEMENTATION AND OUTCOME

From April 20-23, sixty national and international universities and colleges were invited to the 2016 VEX U World Championship in Louisville, Kentucky Freedom Expo Center. Invitation to the VEX U Robotics World championship will only be granted to a team that is a tournament champion or excellence award recipient of a regional competition.

The innovative robotics designs with fast launching velocity and advanced autonomous programing, allowed Vaughn's Robotics team to be 2015 tournament champion of the international congress of Technologies of Information and Communication (Cancun, Mexico), tournament champion of the Manchester Community College (MCC) Regional Qualifier, finalists in College of Southern Maryland (CSM) Regional Qualifier, recipient of Excellence award of Vaughn College Regional Robotics Competition and received invitation to participate in 2016 VEX U World Championship.

At the VEX World Championship, the largest robotics event in the world, these two innovative designs beat out a group from Mexico in the final round, and before that, many US institutions including University of Southern California, Worcester Polytechnic Institute, and George Mason University, among others. It was a series of terrific matches that was mainly possible by an outstanding implementation of engineering knowledge and skills. On Saturday, April 23, Vaughn College's Robotics team achieved the title of World Champions at VEX U beating out 60 other college teams! It is an incredible victory. In addition, the team also won Design Division Champion Award, as well as the Innovate Award and the Design Award of the VEX U World Championship.

Figure 20: VCAT robotics team posing after winning the World Championship 2016

ACKNOWLEDGMENT

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REFERENCES

[1] VEX Robotics, http://content.vexrobotics.com/docs/vrc-nothing-but-net/VRC-Nothing-But-Net-Game-Manual-20150612.pdf, accessed February 2016

[2] Wikipedia, http://ffden-2.phys.uaf.edu/webproj/211_fall_2014/Max_Hesser-Knoll/max_hesserknoll/Slide3.htm, accessed February 2016

[3] Team 7983G Centennial CyberHawks, https://www.youtube.com/watch?v=2MyrS_zcgdI, accessed February 2016