Introduction:

➢ Problem statement

The goal of this project is to develop a catapult system that can be used to throw a squash ball the farthest distance and to be able to have some degree of accuracy with the mechanism. In order for this project to be successful at all, the catapult must at least work and actually through the ball. The degree of success will be determined by how accurate and how far we can get the catapult to through the ball.

The design of the catapult mechanism has several design constraints placed on it. First the mechanism used for this catapult system must use at least a four-bar mechanism to accomplish the task. It may have any number of bars in the mechanism as long as it is greater than or equal to four. The catapult mechanism will use only one specified motor to power the system. Another constraint on the catapult mechanism is that it must be made entirely from wood. This mechanism cannot start with any potential energy stored in the system before the motor is turned on. The motor may be used to build up potential energy but may not be run for more than 30 seconds before actually firing the catapult system. Finally, the entire mechanism has to meet a space constraint of 2’ by 2’ and cannot leave that space while in operation.

The following is a list of the project rules:

- The squash ball can be hand-loaded during the competition. However, after loading, teams will be permitted only to turn on the switch connecting power to the motor.

- Distances will be measured from the edge of the table (Start Plane) to the point of impact in centimeters. Each team will get three tries and the sum of the three distances (measured in cm) will serve as the team’s score. A rematch may be
required to settle the decision in case of a tie (which will be solely at the discretion of Dr. Krovi)

- All parts should be taken from student’s houses/apartments/garages, machine shops, scrap yards, etc. Purchases need to be kept minimal, if any.

- All devices will undergo strict safety inspections prior to the competition. If anyone in the MAE machine shop or Dr. Krovi feels that the mechanism is unsafe, it will not be allowed to compete – no exceptions.
➢ Idea Generation

The first action we took as a group was to hold a brainstorming session to generate as many ideas as we could. Everyone came up with their own ideas for how to design the catapult system. We then met and went over the design ideas and evaluated how well we thought they were. After going through the initial concepts we considered and focused on three different designs for this mechanism.

The first design is a system of springs that are stretched using a four bar setup. The four bar setup has a string connected to it which is wound onto a pulley by the motor. The springs store the potential energy as the string is wound onto the pulley. The ball is placed in front of a spring loaded platform that is pulled back and loaded by the four-bar mechanism. Once the string is released the spring’s contract and the ball is fired.

Figure 1
Another design that we considered is a design that resembles a BB gun. The motor is connected to a four bar-slider mechanism. When the input link is rotated by the motor, the four bar-slider mechanism compresses a spring. This preloads the mechanism by storing potential energy behind that platform. Once the mechanism releases, the spring forces the platform up and fires the ball.

**Figure 2**

Design concept 3 is an earlier version of the design that we decided to use for this mechanism. We have since decided to move the location of the motor and string loading the system. This version of our four-bar catapult uses a rubber band to store the potential energy of the mechanism. The string is connected to the throwing arm and then wound onto a pulley by the motor. By rotating the throwing link through a determined angle, a load is placed on the input link by the rubber band connected to it.

**Figure 3**
Our fourth and final design was similar to the third. We decided to place the motor at the other end of the mechanism. The new configuration is rotated in the opposite direction to through the ball. This setup was used so that longer links could be used and still meet the size requirements. The longer links would give the mechanism more leverage and therefore place more force on the ball.

Figure 4
**Project Development**

Our group decided to use a four-bar mechanism to construct the catapult. The motor will be used to load a spring connected to one of the links. The motor setup will use a pulley system with a “shaft” to wind the string onto. Once the link connected to the spring is rotated through a predetermined angle, the system will be triggered to release the string that is loading the mechanism and the mechanism will fire.

The construction of the mechanism started after the preliminary analysis was completed. This analysis provided us with the position and lengths of all the links needed.

a) Four-bar construction:

The complete structure was made from wood. We used 1” x 2” pieces of hardwood for all of the links. All of the links were first cut to their predetermined lengths. The ends of the links were rounded and drilled for the pins to connect them together. The bases that connect the links to the platform were formed from blocks of pine and then screwed to the platform. The platform that the mechanism was mounted to was made from a piece of 1” pine. Since we wanted to have some versatility and control of how far the mechanism would shoot, several holes were drilled in the firing arm. This allowed us to change the amount of force and acceleration that the arm generated.

b) Spring setup:

At first, we were going to use rubber bands to store potential energy in the mechanism. We later decided against this and chose to use springs instead. The switch to springs was made because we felt that the springs would be more reliable and consistent. Rubber bands would be more likely to weaken and therefore cause variations in the amount of potential energy stored and also be more likely to break. An eye screw was screwed into the bottom side of the input link to connect the spring too. It was placed close to the follower link so that the spring would be stretched the maximum possible amount. The other end of the spring was connected to another eye screw that
was screwed into the platform. For versatility and more control over the amount of force stored by the spring, several eye screws were placed in a line on the platform. This would allow us to vary the amount that the spring was stretched when the mechanism is fired. We used one spring and eye screw distance combination for maximum distance and another spring and eye screw distance combination for shooting 20 feet in the accuracy competition. The spring setup can also be seen in Figure 6.

c) Motor, Pulley, String setup:

The motor is set up to use a system of two gears that drive a shaft for the string to wind onto. The motor is mounted to the platform using screws. We then mounted a shaft through a block of wood. The output shaft of the motors gearbox is connected to the shaft used to wind the string onto by a system of two gears and a belt to link them. The gears used form a 2:1 ratio so that the torque output of the motor is doubled. This allowed us to be able to store more potential energy by using a stiffer spring. The end of the shaft opposite of the gear has a hole drilled in it so that the string can be tied to it and then wound around the shaft.

**Figure 5**
d) Release Mechanism

The next major part of our catapult design is the release mechanism. We need a way to release the string from the throwing arm when it reached a predetermined position. This was accomplished by using a pin and a wedge. The pin and put through a loop at the end of the string and the placed into a whole at the end of the throwing arm. The pin was made so that it has a tapered wedge at the one end of it. We then made another tapered wedge out of a 2” x 4” piece of pine. This larger wedge was cut to the height needed and then mounted to the platform. When the motor is turned on, the string winds onto the shaft. Once the string pulls the throwing arm back to the release position, the wedge on the pin and the large wedge mounted to the platform push against each other. This causes the pin to pull out of the throwing arm, firing the mechanism.

Figure 6
e) Ball holder:

The ball holder was made from a coffee scoop. The coffee scoop used was a perfect size to hold and through the ball. The handle of the coffee scoop was mounted to the front side of the throwing arm. The scoop of the coffee scoop was bent back around the end of the throwing arm.

Figure 7

f) Power supply, switch setup:

The power supply consisted of a large 6-volt battery. We chose to use such a large power supply because we did not want to have to worry about smaller batteries wearing down and causing us to go over the allowed time constraint. The battery was connected to the motor through a small 12-volt switch. Both the power supply and the switch were mounted to the platform.
Project Optimization

After we had our initial design idea set up and agreed upon, our group then began the task of modifying and optimizing our four bar mechanism. This was accomplished throughout the length of the project up until our competition. The first stage we did was to begin with the solid model constructed on Pro Engineer. This was done to ensure that the parts would fit before prototype construction. These Pro Engineer drawings are located with the simulations and photographs.

Our initial analysis included placing a spring or a series of springs to provide forces and accelerate the links and throw the squash ball. We tested different springs to see what kind of forces the motors could store. The first problem was where to put the spring for optimal distance, yet controlled shooting. Link three was chosen because it was ideal from our initial design to fit a spring there and it acts as a driving link for the whole mechanism quite nicely. The spring was fastened by loops at the ends of the springs attached to I hooks in the base and link 3.

The next stage in optimization was then testing the springs with our motors. We ended up testing the motor with increasingly higher voltages until our ideal spring was pulled back. This Voltage turned out to be 6 Volts. The motor took 28 seconds to pull back at this power output. A simple on-off switch controlled the motor. With 4.5 volts this turned out to be 35 seconds, a bit too long. The high torque gear was used inside our motor throughout testing. We found it to be able to pull the larger springs back, while the higher speed gear, or the smaller one, just couldn’t handle the bigger springs.

The next part our team proceeded to optimize was to transmit this power from the motor as efficiently as possible. We started out by building a gearbox, with a pulley and belt to convert the motors power to our spring. Our gearbox was basically a drilled out 2 by 4 chunk with a journal bearing type of friction affecting a steel shaft. This friction was reduced by the use of lubricating grease and it played a small role with little energy losses. This steel shaft transmits power to wind some fishing line on one end and be driven by the belt and pulley from the motors torque on the other end. The end of the shaft was kept in place by the inclusion of a spring to keep our pulleys aligned properly.
The fishing line was a 25 lb line, and we found that this snapped in testing once, but was generally OK. The gearbox was held in with two screws on the bottom of our base, which provided adequate stability. This concluded the power transfer development of our project.

On the other end of our fishing line was the release mechanism. The release mechanism was the next part we tried to optimize. One of the team members had an idea from a brainstorming session that we use a wedge to provide a horizontal force using a vertical force to release our mechanism. This was the idea we chose to use as our release mechanism. Basically the fishing line wrapped around a peg with a wedged shape machined into it. The wedged shape was circular and the peg inserted into our throwing arm through a drilled hole with the fishing line looped around it. It was circular because when the arm was pulled back we wanted the other end of our wedge, which was attached to the projects base, to contact it at the desired release height and release the energy in the spring to drive the links and throw the ball. We had to optimize the height that our ground wedge stood at. This was done after the throwing arm wedge was constructed so we could just see how they fit together. Refer to the pictures section for a better look at this design.

The next stage of optimizations focused on getting our four-bar to be accurate, make some baskets, and fine tuning its performance. The first optimization includes our modification of the throwing arm for better accuracy. This was achieved by using a key slide in our throwing arm. This was not used for distance however; separate holes drilled into link one connected it to link two with a shaft. The first link was attached to our second link by an adjustable wing-nut type fastener. This angle that the two come together at and the effective link lengths could be changed by an adjustment of the wing nut. We also installed many different I hooks screwed into the base for different spring angles and positions. This modification is what actually helped us shoot 2 out of 3 baskets, although our team knows we should have hit 3. Another modification was the use of a coffee scoop for our ball holder. This helped the release of our ball be smooth by cradling the squash ball, but not too tight. Bending it to give our team the best-arched shot for our baskets optimized the scoop.
Solid Edge Motion Stages Simulation of 4 bar Mechanism

The starting position in the Figures is when the mechanism is fully loaded before release.
Prototype

- Solid Edge Velocity and Acceleration Link Analysis

Spring Stiffness (Ks) = 5 N/mm  
Force of Spring (Fs) = 20 N

Link 1:

Angular Velocity

Angular Acceleration

Link 2:

Angular Velocity

Angular Acceleration

Link 3:

Angular Velocity

Angular Acceleration
Future Improvements

A lot was learned by designing, constructing and testing our catapult. One of the important things that we realized and learned was how our design and setup could be improved. Given the time and opportunity to make improvements on our catapult mechanism, these are a few of the first changes that we would work on.

The first improvement that we would make would be to make full use of the 30-second time constraint. Our mechanism was taking an average of 24 seconds before releasing. If we utilized the full 30 seconds allowed, then we could store more potential energy and therefore launch the ball farther than we did. It was apparent that the motor had more than enough torque to accomplish this.

Another possible improvement that we could make to our mechanism would be to use lighter links. The lighter the links are, the higher the energy is that actually goes into throwing the ball instead of accelerating the links. Our links could either be made from thinner pieces of wood or slotted in the center to remove weight from them.

A final improvement that we could possibly make to our mechanism would be to adjust the height of the large wedge mounted on the platform. If the height of the wedge were a little lower or moved further back, then the throwing arm could be pulled even further back. This would cause the spring to stretch more and store more potential energy.
Conclusion and final Results

During the competition, our mechanism performed as expected. Although, on our first attempt at the furthest distance throw, the release pin came out too soon and resulted in a short throw. During the judging questions and evaluation we were asked how far we expected our mechanism to throw the ball. We predicted a longest through of 30 feet. Our longest through was on the second attempt and hit the 30-foot line. For our third attempt at a distance shot, we decided to use a combination of link and spring placement that we did not intend to. This combination produced a much larger amount of tension in the spring and caused the line to break.

We felt that our best accomplishment and a major portion of our design and testing effort was on the accuracy portion of the competition. We setup our catapult to through the ball into a garbage can 20 feet away. Our design turned out to be much more accurate and consistent that we even expected. The catapult threw the ball into the garbage can two out of three times. The only shot that missed the can was the first shot. The first shot was missed purely because of the initial aiming of the catapult. The ball missed the can by about 2 inches to the left but had perfect distance. After the initial miss, the platform was slightly rotated to compensate for the throw to the left of the can and the last two shots went right into the can.
Competition results

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With Group K that threw 60 feet, the average long distance throw was about 32 feet. This makes our longest throw about the average of all the groups. Our precision shooting on the other hand was tied for the best. Overall, we had a great time designing, building and competing with our catapult mechanism in this competition. This project does a good job at demonstrating the objective and usefulness of this course.