Catapult Project

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Machines and Mechanisms II

Group H
Adam Miess
Michael Miscione
William Mitchell
Shane Mockbee
Greg Moritz
Jason Morski
Charles Nasca
Joel Nashett
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Introduction:

For this project our group is faced with the challenge to design and develop a catapult system incorporating a four-bar mechanism and a small electric motor to drive the mechanism. This project is challenging because we have a large time constraint, size constraints and method constraints. We need to work together as a team and collaborate our efforts to devise a competitive device that we can analyze mathematically using our knowledge of this course.

There are many constraints for this project that we needed to take into consideration. The most difficult constraint was keeping the mechanism within the specified 2X2X2-foot cube and still has an effective device. We found that by miniaturizing our efforts, we were not able to generate as much power as we would have liked. Using a four-bar mechanism also created a design challenge where we had many ideas that would have been effective using a non-four-bar mechanism. Using the small motor that was required to power our system also posed limitations. We had to find an effective way to use the work produced from the motor to optimize the power input to our mechanism. Several other constraints on our device included the stipulation that it had to be constructed out of wood, there could be no preloaded energy and it must have a built in release mechanism.

Breaking down the problem into parts that we have covered in theory is very critical in designing a four bar mechanism that is going to be able the throw
a squash ball at a preferred distance. Major analysis that needs to be simulated is positions, velocity and acceleration.

The position of where the squash ball is going to be placed is going to be effected differently when using maximum velocities and accelerations. We need to find the ideal position when accounted for the velocities and accelerations when we test the 4 bar mechanism with the attached spring. The position of the configuration needs to be set so a synthesis outline can be used for optimal performance. For example, when using the first position, angles are set so a dyad process can be made. We can edit angles or lengths to create and a position that gives us a desired velocity.
**Idea Generation:**

To accomplish the task of completing this project our group has met and discussed the topic of this project and brainstormed many ideas. These ideas were discussed and examined to determine how we should best go about finding an applicable solution. To accomplish the task of completing this project after we had come up with an idea, we have regimented our group into several sub-groups with different tasks. One group will be writing up the final paper, one group will be building the actual machine, one group will be performing a dynamic designer/solid edge simulation, and one group will be performing a MATLAB simulation. By dividing up the project, we can more efficiently make use of a short amount of time allotted for this large project.

The fundamental strategy behind our device would be to incorporate many of the aspects that we have discovered in class. We incorporate a four-bar into the actual throwing device similar to ones we have talked about in this course. We decided that using a four-bar, rather than other mechanisms just using a four-bar for some trivial part of the device only to satisfy the requirements would allow us to use our knowledge of the four-bar analysis techniques that we have acquired throughout the course.

A four-bar would also be much easier to analyze than a more complicated mechanism requiring many pulleys, or compressors, or trebuchet type designs. We also believe that using the motor to its fullest potential would best be done by using a means of storing the energy. After much discussion, we decided on storing the energy in a spring(s) that would be stretched slowly over the allotted
time by the motor. The spring(s) would be attached to one of the elements of the four-bar, and upon release of the spring(s), the longest member of the four-bar will acquire an angular acceleration, which will propel the point of interest (holding the ball) at a high velocity and launch the ball. The motor, a take-up reel, a spring, and possibly a pulley, and the four-bar are the only mechanisms that will be used in this project.

Some of the other device ideas that our group has considered to use in the model of the project were mass pulleys, springs, pressure pistons and a trebuchet. We analyzed each device to see if there were positive and negative qualities that would affect the distance the squash ball would be thrown.

The mass pulley was a good idea to generate some potential energy to the four bar mechanism. The pulley would be attached to the four-bar, while being wound up by the electric motor. Tied to the end of the pulley would be a mass that would be released when then motor stopped. This would then create a potential force due to the mass. We did not decide to put this in our model because there are frictional spots between the pulley and the grounds. When the motor would come to a halt, there would be much friction between the pulley and where it traveled through. We did try to use this method as an experiment and found that out spring system propelled the ball about 1000% further.

Using pressure pistons was a brainstorming idea that was supposed to be used to create potential energy for the four bar mechanism. The four bar mechanism would have an electric motor placed on the hinge of the same side of where the pressure piston was located. For example, if we designed a pressure
piston against the 2nd arm, then the motor would be placed between the first arm and the base. We did not actually go through with this design because it looked awkward and physically unstable. We believed that the pressure piston would create too much of a skip or jolting force to the four-bar mechanism resulting poor, inaccurate throw of the squash ball.

The trebuchet was another possible idea that we would have used but didn’t due to time and not enough space for the built in dimension constraints. The trebuchet would be used to throw the squash ball. So the 4 bar mechanism would be used to create some sort of force to the trebuchet to release the squash ball. If we used this design, we would probably find that this would be the optimal design method because of the mechanical advantage a trebuchet has over a rigid four-bar. All of our ideas were carefully considered and examined before discarding or incorporating them into our final design. Because of this brainstorming, we believe we have made a good decision in our final design using a spring system to provide a potential energy for our system that upon release will fire the ball a significant distance.
Description of the Mechanism:

Our 4-bar mechanism is a double crank.

The 4 springs we used to store the energy from the motor can be seen in the above picture. The springs are attached to the two white upright supports and R4. When the motor was turned on it pulled the 4-bar back using the pulley system connected to the pin between R4 and R3. Our release mechanism is a hook that holds the pulleys to the 4-bar that is also attached to a string. The other end of this string is attached to one of the uprights and as the 4-bar is pulled back the string tightens and causes the pulleys to fall off
the hook. Our ball holder was a plastic mug cut down to fit a squash ball and screwed into the top of R2.

We drew the mechanism in AutoCAD to test out the various dimension of our basic design. We were able to determine the angular limits of bar 4 based on its overall length being 2 ft, the maximum size and adding in a 2-inch safety margin. Drawing below:
Dynamic Designer Prototype:

R1: 5" theta1: 0
R2: 17" theta2: 180
R3: 9" theta3: found from geometry
R4: 21" theta 4: 152

And the spring constant for each spring is
0.667 lbs./in

and each spring is stretched 15" which means each spring has
0.667 * 15 = 10 lbs. force

with 4 springs gives
4 *10 = 40 lbs. force

and then acting at 17 inch from the point of revolution gives
40 sin (46.5)* 17 = 493.6 in*lbs or 41 ft*lbs
Initial position:

![Diagram showing the initial position]

Throwing position:

![Diagram showing the throwing position]
**Throwing position Magnitude of angular velocity**

At the position the projectile is located:

![Angular Velocity Graph]

**Throwing position Magnitude of angular acceleration**

At the position the projectile is located:

![Angular Acceleration Graph]
Angular velocity of theta 2

Angular acceleration of theta 2

Angular velocity of theta 4
Angular acceleration of theta 4
**Simulation based design:**

Some of the methods we used in order to come up with the dimensions of the final mechanism were using MATLAB and Excel. Using MATLAB helped me find the best lengths of the four bar mechanism to create an optimal angular acceleration of the third and fourth link. On MATLAB we used method 3 to illustrate the important variables associated with it. There are set up variables that can be imputed in for the lengths of the links to provide certain angular accelerations. Another method we used was Excel. We simulated all possible lengths or the four links in step sizes of .001 until the number reaches 2 which corresponds to the largest value we can attain with the four bar. There are many variations in fact; a little over 1200 points was calculated for each length using a spreadsheet. In the shade of green, the optimal lengths are recorded with there related angular accelerations. We picked these to be the optimal lengths because it gave us the best result in terms of the angular acceleration of the 4th link. As a result from this data, and theory, we knew what parameters to place on each link to get a desired output.
**Construction of the Four-bar Catapult:**

The base of the four-bar catapult was a 2 x 2-foot piece of ¾ inch plywood. This enabled a strong and stable base to support the mechanism and would tolerate modifications to the mechanism without compromising structural integrity. Thin wood sections were used for the links on the four bar mechanism with pins used to secure the joints. This setup provided a quick and sturdy means to build and modify the mechanism. To decrease the weight of the individual links, holes were drilled in them. These holes also provided locations to support a pin joint for modifying the mechanism.

Two sturdy 2 x 4 columns just under 2 feet in length were screwed to the base of the mechanism using steel brackets and wood screws. These columns supported one spring each that connected to the four bar mechanism. One of the columns also supported a small nylon string with a hook attached at one end. This hook was the release for the four-bar mechanism. As the four-bar was pulled back into a launch position by the motor, the string that attached the column to the release hook gained tension. The tension in the spring would eventually pull the hook out of some connecting strings and resulted in the release of the four-bar mechanism.
**Performance:**

The overall success of our catapult was slightly higher than we thought. During testing we were throwing the ball around 25 feet. During competition we had a longest throw of 31.5 feet. The reason for this increase in distance could have been due to the fact that we used fresh batteries where as the ones for testing had been used previously. We went zero for three in the precision-shooting contest because we did not have time to calibrate it.

If we were able to redesign our catapult we would build a crank rocker. The reason for this is we would be able to connect the springs onto the slider and the pulleys to the throwing arm to give the motor more of a mechanical advantage. This way we could put stronger springs on and have the ball travel further. Things to change would be to have more testing of the mechanism for accuracy. Also we would redesign the mechanisms by moving the input to the 4th link and have the motor pull back on the 2nd link using the mechanism for “gear reduction”. This would be good because it would release links 2 and 3 from link 4 when throwing because the weight would be less.
r1=pick values;  %These are just variables that can be inputed to find the best
result of the shot!
r2=pick values
m2=3;
p=((r2+r1)-(r4*cos(24*pi/180)))^2;
g=(r4*sin(24*pi/180))^2;
r3=sqrt(p+q);
r4=pick values;
T=3;
I2=5;
theata4=2.72*pi/180
C=r4*sin(24*pi/180);
D={(r2+r1)-r4*cos(24*pi/180)};
theata3=atan(C/D);
t3=tan(theata3);
theata2_=T/I2;
E=-t3*r2*(theata2_);
g=-r4*sin(theata4*180/pi);
h=t3*r4*cos(theata4*180/pi);
F=(g+h);
theata4_=E/F       %This represent the angular acceleration at link 4
i=(r4*cos(theata4*180/pi))*(theata4_)-(r2*theata2_);
j=(r3*cos(theata3));
theata3_=i/j      %This represents the angular acceleration at link 3