PUMPKIN LAUNCHING DEVICE WITH ROTATING TIRES

Alexander Morgenthaler **Henri Pretorius** **Max Friedman** **Nick Pomianek**

ABSTRACT

For years, our local undergraduate ASME chapter has hosted an accuracy based pumpkin launch competition, and the Mechanical Engineering department has not been able to secure the win since its conception. Therefore, in an exercise of over-engineering and deriving precision from an intrinsically variable system, this capstone project was born. Sacrificing testing due to time constraints and shipping issues of proprietary parts, a pitching machine inspired launcher was proudly designed and constructed to exemplify the engineering process to a physical working model.

PROBLEM DEFINITION

Mechanical engineering students at the University of Rochester have never won the annual ASME Pumpkin Launch Competition. Engagement in engineering for young students is lower than desired, and a physical representation of such skills may help boost young students' interest in engineering.

This is important because without clear interest in the math and engineering field from the younger generation, the level of technical advancement their generation can achieve can be diminished. Not only does this impact the current generation of young students, but also future generations of engineers as well.

The team hopes that a solution lies with creating an interesting pumpkin launcher that can spark interest in the field of mechanical engineering with the younger generation. By creating an interesting and successful physical model of engineering in action through a pumpkin launcher, the team hopes to help inspire the next generation of engineers.

REQUIREMENTS, SPECIFICATIONS, DELIVERABLES

Deliverables for the Pumpkin Launcher	
Deliverables #	**Description of Deliverables**
1	Structure of the Pumpkin Launcher
2	Ground Contact system of the Pumpkin Launcher
3	Basllistics analysis of the Pumpkin Launcher of the Pumpkin Launcher
4	Analysis of the Pumpkin Launcher
5	Mechanism Design of the Pumpkin Launcher
6	Testing of the Pumpkin Launcher
7	Analytical model integration of the Pumpkin Launcher
8	User Manual for the Pumpkin Laucnher Device
9	Bill of Materials
10	Drawing Package of the Pumpkin Launcher

Table 1: Deliverables

Requirements for the Pumpkin Launcher	
Requirements #	**Description of Requirements**
1	The device must be able to launch pumpkin.
2	No chemical propellants can be used for the launcher.
3	No electromagnetic launching mechanisms are allowed.
4	All energy used to launch the pumpkin must be generated on site.
5	The launcher's weight must not compromise it's ability to be moved to the launch site.
6	Nothing can be attached to the pumpkin to aid it's flight.
7	Must be unable to launch a pumpkin opposite the intended direction.

Table 2: Requirements

Specifications for the Pumpkin Launcher				
Specifications #	**# Value**	**Units**	**Description of Specifications**	**Method of Evaluation**
1	10	%	The launchers accuracy must be ± 10% of the launch distance.	Repeated launches will have the impact location measured with respect to the intended target.
2	4	ft.	The launcher must be no more than 4 ft. wide.	Measuring tape measuring from the left side to the right side of the launcher.
3	5	min.	The launcher must use less than 5 minutes to "re-arm" between shots.	During accuracy testing the re-arming process will be timed.
4	10	min.	The time it takes to set up and launch the first shot must be 10 minutes or less.	Before accuracy testing the initial setup time will be timed.
5	2	lbf.	The launcher must be able to launch projectiles up to 10 lbf.	A projectile weighing 2 lbf. (± 0.1 lbf.) will be tested for launcher functionality.
6	6	ft.	The launcher must be able to be triggered from at least 6 ft. away from the launcher.	The launch trigger system will be measured using a measuring tape.

Table 3: Specifications

CONCEPTS

There were three designs considered for the future direction of the project. All three designs incorporate a flywheel because of the mechanical benefits it can provide such as energy storage between shots. The first design, named 'Two Wheels,' uses two rotating flywheels to accelerate and maintain speed for each launch of the pumpkin. A sketch of the Two Wheel design can be found in Annex B, Figure 1. The second design considered is named the 'Ramp.' In this design there is a large steel flywheel that will be rotating freely until the desired speed is reached. At this time a trigger will engage a clutch that will engage a belt to transfer the flywheel energy into the pumpkin. A sketch of the Ramp design can be found under Annex B, Figure 2. The final design considered is named 'Big Wheel.' In this design another flywheel is used however this time the flywheel will be much larger and be angled at 45º, with the pumpkin attached on the edge. The speed of the flywheel will increase until the desired angular velocity is achieved. at this point a pin will release the pumpkin and launch it towards the desired location. A sketch of the final design can be found in Annex B, Figure 3.

The team based the decision off eight criteria: how much energy is retained in the system after a shot is fired (to gauge reload time), the difficulty of manufacturing and assembling the mechanism, replaceability of critical parts that are loaded significantly, how well the design can launch a pumpkin out to the farthest target distance, how common the components are, how easy it is to maneuver the design, how dangerous the design is in case of the most likely catastrophic failures, and how efficiently the launcher delivers its energy to the pumpkin. The team didn't include a criterion for novel design because all three of the designs are thought to be novel. Below the Launch Mechanism Selection Pugh Matrix can be found as Table 4.

After the creation of the Pugh Matrix, Table 4, It was deduced that the two-wheel design was the best one to move forward with. The benefits of maintaining the energy between shots and additional safety were important factors that compensated for the shortcomings of how difficult the wheels and tires would be to procure while remaining in budget.

Table 4: Launch Mechanism Selection Pugh Matrix

Launch Mechanism Selection Pugh Matrix

Pumpkin Launcher

Criteria \ Designs	Two Wheels	Ramp	Big Wheel
Energy Maintained between shots	+		-
Ease of manufacture		-	+
Zero redundancy parts		-	+
Effectiveness	+	+	+
Availability of resources	-	-	+
Cumbersomeness	+		-
Safety / Durability		-	-
Efficiency (launcher to pumpkin)	+	+	+
Totals:	3	-2	2

MECHANICAL ANALYSIS

Tolerance Analysis

In order for the launcher to function properly, the tires need to be attached at an appropriate distance from each other to make good contact with the protective PVC housing. If the tires were to be too close together, they would run the risk of crushing the pipe and if they were too far apart they wouldn't make contact with the pipe. To properly tolerance the placement of the tires, the exact diameter of them had to be measured as well as the diameter of the PVC pipe. That spacing determined the size of the gears that drive the system as well as the width of the overall frame. All of these needed to be precisely measured and manufactured to leave an allowable separation of the tires. Based on the PVC pipe's rigidity and the flexibility of the tires, the appropriate spacing was determined to be 10 ½ ± 1 inches. This was largely determined experimentally by applying force to both the tires and the pipe and measuring how much they deflected under stress. The goal was to allow for a tight grip on the pipe via the tires but also allow for minimal resistance as the pipe passed in between them. The tolerance was kept conservative to minimize the possibility of a possible catastrophic failure as the would be the worst-case scenario given the intended launch setting.

FEA Statics Simulation

To determine if the structure would be able to support the weight of the tires and axles at the necessary angle, an FEA statics simulation using *Siemens NX* was performed. CBAR and CROD elements were used with 10 elements per member to represent the frame and axles of the launcher. An 80 lbf force was applied along the negative Z-axis to simulate the weight of the tires on frame. The results of the analysis can be found in the Appendix. From the results, it can be seen that the frame has more than enough strength to support the weight of the tires and axle assembly with an estimated max stress of 46.03 psi. This is well under the yield stress of American eastern white pine of 503 psi [1].

Dynamics Calculations

By nature of the launcher's design, the exit velocity of the pumpkin can be throttled to achieve different travel distances. To determine how fast the pumpkin needed to be going to reach different distances, a Matlab script was written to solve for the various initial conditions required. The dynamic model works off of an ODE solver inside an optimization algorithm. By solving the kinematic ODE for various speeds at the given conditions and determining how far off the impact location is from the target, the speed it takes to exactly hit the target is calculated. The script takes into consideration the tail/ headwind and target distance to calculate how fast the pumpkin needs to be launched. The code for this script as well as the accompanying equations can be found in the Appendix.

Finite element modeling was used to determine the viability and safety of the frame design. Firstly, a line representation of the frame was created by placing points in space at each joint and connecting them with space curve lines. This line model was used to place CBAR elements corresponding to each lumber/shaft type. These included pine wood 4"x4", 2"x4", and 1"x8" boards, and 1.3" diameter round steel bars to represent the axles. The free ends of the axle were loaded with 80 lbf vertical weights to represent the wheels and tires. SOL101 was used to run a linear statics analysis. The results and setup in Annex E show that the design does not experience high amounts of stress and is well below the level that would cause concern.

Tolerance analysis was performed when machining the gear hubs/couplings. The end of the axle was intended to be slip fitted into the coupling and cross pinned. This fit type was chosen to minimize eccentricity in rotation while allowing for ease of assembly. The methods outlined in A04 were used to analyze the nominal dimension and tolerance to aim for to achieve a slip fit. However, in practice these tolerances were not achieved and one hub is too big while the other is too small. Precision machining was not achievable likely due to the team's lack of machining experience or expertise.

MANUFACTURING

For this project, there were three fundamental parts: frame, launch mechanism, and power transmission. Neither the power transmission system nor the launch mechanism loaded the frame significantly, and so a 4x4 based structure assembled with wood screws was more than sufficient. The power transmission system was next most challenging, where a bike's power was transmitted to a belt from of a friction driven trainer. Using the trainer in this fashion takes advantage of both the bike retention property and incredible reduction on a spindle that's easy to attach a pulley to. The belt is tensioned and directed using two bearing assisted pulleys before interfacing with a right-angle gearbox. A belt was used because the low cost of a long belt meant that the biker could be far away from the most dangerous parts of the mechanism. The total reduction from the bike to the gearbox is almost 23:1. The gearbox actuates the first of four interlocking bearing assisted gears, where the first and fourth gears deliver the power to the launch mechanism. The launch mechanism involved machining couplings that connect the respective gears to OEM Silverado rear axles, wheels, and tires. The couplings were machined in house from scrap aluminum and retained to spindles using set screws and cross pins, since machine keys involved a broach that wasn't accessible to the team. The decision to use these pieces were also driven by cost constraints. The team spent a significant amount of time on the pumpkin launcher. The development time spent on the pumpkin launcher can be seen below in table 5, whereas the total manufacturing cost for the pumpkin launch can be see just below in table 6.

The manufacturing of this device was performed using woodworking methods, traditional machining, and CNC machining. The device's frame was constructed using standard sized lumber boards fastened together using deck screws. This method was chosen because constructing a welded steel frame would be prohibitively expensive and early load estimations indicated that wood' strength would suffice. Another factor that led the team to choose lumber as the primary building material was a lack of shared welding experience, which would require extensive outside help during the construction process. Prof. Chris Pratt aided the team by helping to determine a joinery method, namely angled deck screws at each joint in the frame. Additional parts made with lumber were the gearbox and slide track. The gearbox was made by sandwiching the 90-degree gearbox between two boards and fastening it all together using deck screws. The gearbox also includes press fit holes to fit the gear shaft bearings. The slide track was constructed using a single board with two square PVC extrusions covered in slick wax paper and screwed down on either side. The pumpkin protective tube rides on the corners of the square PVC and is lubricated by the wax paper. The pumpkin protective tube was made by cutting a two-foot length of ten-inch diameter PVC tubing and fastening a fishing net to it using a hose clamp. The slide track and pumpkin protection tube were constructed from PVC because of its low coefficient of friction relative to wood and its low cost for large parts. An earlier design used metal tracks and bearings, but it was determined to be significantly more expensive without a justifiable increase in performance.

The drivetrain elements of this device were machined using the CNC router, mills, and lathes in the Rettner Fabrication Studio. The four gears used to link wheel rotation were made from Baltic birch plywood on the CNC router. This manufacturing method was chosen because purchasing metal gears would be prohibitively expensive with lead times extending past the end of the semester, and no UR machine shops have the capability to manufacture large gears. The axles are fixed to their axle shafts using wood glue and the axle shafts are simply one-inch diameter pine wood dowels. The central gears are supported by two ball bearings that are press fit into the gearbox. The two outer gears are supported by the axle shafts and a ball bearing press fit into the gearbox (the axle shafts are supported by needle roller bearings press fit into the frame). Delrin washers, that were turned on the lathe, are used to align the gears onto the same plane. The wheels are connected to the drivetrain with single piece rear axle shafts/hubs that were purchased online. The choice to purchase these was made because the cost of raw materials would be similar, but manufacturing time would be significant. The axle shafts are fastened to their respective gears using hubs machined from aluminum using a lathe and a mill. The hubs were constructed by turning a coupling from a round piece of bar stock, then attaching the flange with bolts that thread into the coupling's lower flat surface. This design was chosen to reduce the amount of raw material needed and to work with the available scrap in Rettner. The hub/coupling is fixed to the 90-degree gearbox output shaft with a set screw and is supported by a cross pin. Both hubs are affixed to their respective axles with a cross pin. In order to cross pin the axle, a hole was milled through the splined portion of the axle. This was done because the axles are case hardened at the factory and machining any features more complex than a hole would be beyond our abilities. The wood gears are driven by a 90-degree gearbox that was purchased online for the same reason the choice to make wood gears was made. The input to the 90-degree gearbox is driven by a V-belt pulley system that is connected to the drive shaft of a resistance bike trainer. The pulley system was constructed by fastening V-belt pulleys to the frame using bolts or dowels. The resistance bike trainer was purchased used from Craigslist because it was only $15 and there would be no feasible way to fabricate something at a lower cost. The bike itself was found in Rettner and borrowed for the semester. Manufacturing within the $1000 budget was a challenge, use of salvage and scrap was prioritized and used parts were purchased whenever possible.

Table 5: Development Time for Pumpkin Launcher

Development Time	
Group Member	Time (Hr)
Alexander Morgenthaler	80.5
Nick Pomianek	81
Henri Protorius	72.5
Max Freidman	26.5

Manufacturing Cost			
Group Member	Time (Hr)	Shop Time Cost ($100/Hr)	Purchased Hardware Cost $
Alexander Morgenthaler	49.5	4950	X
Nick Pomianek	43	4300	X
Henri Pretorius	41	4100	X
Max Freidman	25	2500	X
Total Shop Time	158.5	X	X
Total Shop Cost	X	15850	X
Total Hardware Cost	X	X	950.98
Total Cost of Project $	16800.98		

Table 6: Manufacturing Cost for Pumpkin Launcher

Note: For Tables 5 and Tables 6, all the time were collected from the SCRUM daily information as of April 29th, 2021 and may not reflect the most accurate time.

If the pumpkin launcher were scaled to 1000 systems, there are many changes that can be made to improve cost and build time. A large amount of the time was spent trying to figure out how to make the CAD file work in a physical model. This includes measuring the stock of wood and determine the angles to which the materials needed to be cut. The more systems that would be constructed the more comfortable the machinists would be with this measurements and cuts. This would result to the total time to decreasing significantly. As much of the manufacturing needed to be figured out on the fly, with the help of professional manufacturing instructors. With each iteration of the building of the structure, the cuts would be more routine and would speed the process dramatically.

TEST PLAN AND RESULTS

Due to the second axel being shipped the day before the report was due, there was no launch testing performed. Current testing of the launcher involves the fine tuning of the various systems to minimize frictional losses in order to bring the tires to launch velocity more easily. So far, changes in the load path of the axle assembly and the pulley tensioning system have been made to reduce losses throughout the system. Testing on the ability of the launcher to reach the required speed for the farthest target in no-wind conditions was planned. An addendum including the test plan and results will be attached in further editions of the final design report.

INTELLECTUAL PROPERTY

This design may not be patentable as it is using the same principles as a pitching machine. However, from the research found when looking for ideas for this pumpkin launcher, it didn't appear that this idea was applied for a pumpkin launching device that specifically protects the pumpkin from damage. Many of the pumpkin launchers use ideas such as catapults, trebuchet, and even air cannons, but nothing was found for a pitching machine style device. A similar patent for a pitching machine that is similar to the pumpkin launching device the team constructed is US9937400B2 [2]. Which can be seen below in Fig 1.

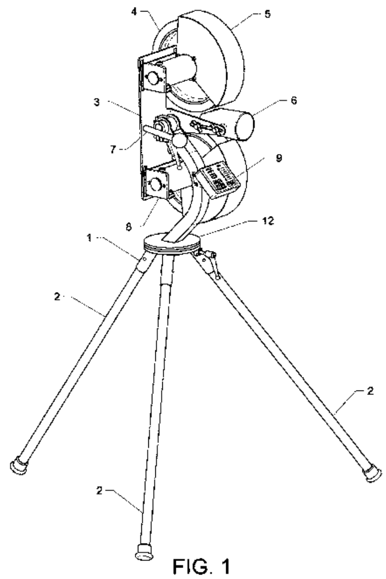


FIG. 1

This patent, seen above is has similar features however its function is quite different. The pitching machine has the two wheels oriented vertically, whereas for the pumpkin launcher, the two wheels are oriented horizontally at a set angle of 40 degrees. This patent and the pumpkin launching constructed do have clear similarities, however. Some companies that are working on such devices are First Pitch Inc, JayPro Sports LLC, and Granada Pitching Machines, to name a few [3].

SOCIETAL AND ENVIRONMENTAL IMPLICATIONS

This project is an interesting one, however the impacts it has on society are limited. Public health, safety, and welfare is one of the regions where the pumpkin launching device may not have an immediate impact on. There potentially be ethical issues in constructing a pumpkin launcher. This could be because of the roots of similar devices, such as catapults, and trebuchet which were constructed for warfare in medieval times. The pumpkin launcher that has been constructed was designed for the sole purpose of competing the ASME Pumpkin Launching Competition and has never been intended to raise any ethical issues. Some benefits that the project presents are to raise interesting in the engineering process for children at a young age. Presenting a physical model of engineering and physics can help raise interesting in the professor and can potentially be one of the reasons why a child grows up to become an engineer. This is important because the 6th Fundamental Canon as an engineer is to enhance the engineering profession, and this can occur by having more children involved in engineering. The main material used is wood, which if harvested unsustainability can be seen as an environmental issue. However, most of the lumber used today is harvested sustainability. Another material that may been seen as an environmental issue is the belt. The belt is made of rubber, which is created in an environmentally ineffective process, as well as the disposal if it breaks. If not recycled properly is can be a detriment to society. Some changes that could be made to decrease the environmental footprint is potentially decreasing the size of the structure, however that would cause more issues mechanically, as it would be more difficult to reach the speeds necessary to launch the pumpkin.

RECCOMENDATIONS FOR FUTURE WORK

If the team had another 6 months to work on the project, there would be a few things that would change that was discovered during the assembly process. One of the most important aspects of this design is the gear box, which spaces the gears properly, and is attached to the two axels. The spacing of the gears is crucial for success, and the gears and spindles in which they ride on are made of wood. Wood works as a gear however the wooden spindles, when attached to the gears is difficult to position properly, even when pressed and glued. When adding the gears through the bearings sometimes the gears would ride off axis and create an angle. This angle would sometimes cause the other gears to bind, and not spin as freely as the design calls for. This could be fixed with, metal gears, and metal rods attaching them as they can be welded together to be true and they would as a result be very difficult to ride off axis, compared to the wood ones. Another priority would be to design the frame based on more FEA analysis to make as efficient as a structure as possible. With the time/money limit with this project, it was difficult to allocate time for an optimized design when, sound engineering principles can be applied easily without the help of Finite Element Analysis to determine the shape of the frame.

ACKNOWLEDGMENTS

No project gets done without support, and this one is no different. A special thank you to Christopher Muir for being not only the primary advisor, but also the sponsor, for this project. Executing this design would not have been possible without his direction and experience. Secondly, Jim Alkins more than deserves a note of appreciation for his patience and advisement on all things fabrication. Lastly, the thoughts and watchful eyes from Chris Pratt, Mike Pomerantz, and Peter (the shop TA) also made this project possible.

REFERENCES

[1] American Eastern White Pine Wood, www.matweb.com/search/datasheet_print.aspx?matguid=1bec7114d2524b63826044c3cc6c344c.

[2] "US9937400B2 - Automatic ball pitching machine." (n.d.). *Google Patents,* Google, <https://patents.google.com/patent/US9937400B2/en> (Apr. 29, 2021).

[3] (n.d.). *Pitching Machines*, <https://www.thomasnet.com/products/pitching-machines-3304748-1.html> (Apr. 29, 2021).

ANNEX A

TREJECTORY AND ENERGY EQUATIONS

Trajectory differential equations and BCs:

$$(x, y)|_{t=0} = (0, h) \tag{1}$$

$$(x, y)|_{t=tContact} = (d, 0) \tag{2}$$

$$v_{rel} = \sqrt{\left(\dot{x} + v_{ref}\left(\frac{y}{y_{ref}}\right)^{\alpha} \cos(\varphi)\right)^{2} + \dot{y}^{2}} \tag{3}$$

$$\vec{a} = -\frac{C_D \rho A}{2m} v_{rel}\dot{x}\hat{\imath} - \left(\frac{C_D \rho A}{2m} v_{rel}\dot{y} + g\right)\hat{\jmath} \tag{4}$$

Where v_{ref} is the tailwind speed measured at y_{ref} at an angle φ from the launch direction in the xz plane, α is the Hellman constant, v_{rel} is the velocity of the wind past the projectile, h is the launch height, d is the target distance, m is the projectile's mass, C_D is the projectile's drag coefficient, A is the area of the projectile normal to v_{rel}, ρ is the density of air, g is gravitational acceleration, t is time, and $tContact$ is the time the projectile hits the ground. The y-axis measures altitude, and the x-axis is the launch direction.

Energy equations:

$$\omega = \frac{v_0}{r_{wheel}} \tag{5}$$

$$J_{gear} = \frac{m_{gear} * t * {r_{gear}}^{2}}{2} \tag{6}$$

$$E_{launcher} = \frac{1}{2} * \omega^2 * \left(2 * J_{wheel} + 4 * J_{gear}\right) \tag{7}$$

$$E_{pumpkin} = \left(m_{pumpkin} + m_{sled}\right)\left(\frac{1}{2} * {v_0}^2 + g * l * \sin(\theta)\right) \tag{8}$$

Where v_0 is the launch velocity, ω is the angular velocity of the wheels and gears, r_{wheel} is the radius of the wheel, r_{gear} is the radius of the gear, t is the thickness of the gear, m_{gear} is the mass of the gear, $m_{pumpkin}$ is the mass of the pumpkin, m_{sled} is the mass of the sled, J_{wheel} is the mass moment of inertia for a wheel, J_{gear} is the mass moment of inertia for a gear, g is gravitational acceleration, l is the length of the ramp, and θ is the launch angle.

For the calculation, wooden gears (which were approximated as solid discs), a launch angle of 45º, ramp of 2ft, the launch speed for the 300ft target without considering drag, and a sled in the shape of a 19" x 19" x 12.5" (l, w, h) box made from 0.5" plywood with the top and front faces removed were used for this calculation.

Furthermore, the impact of a flywheel spinning at an angular velocity of ω was investigated. The table below indicates the energy retention as a function of flywheel's mass MOI.

Flywheel MOI (slug * ft^2)	0	1.63	3.27	8.16	12.25
Energy retained (%)	61.59	79.59	86.1	92.9	94.95

ANNEX B

SKETCHES OF THE THREE DESIGNS

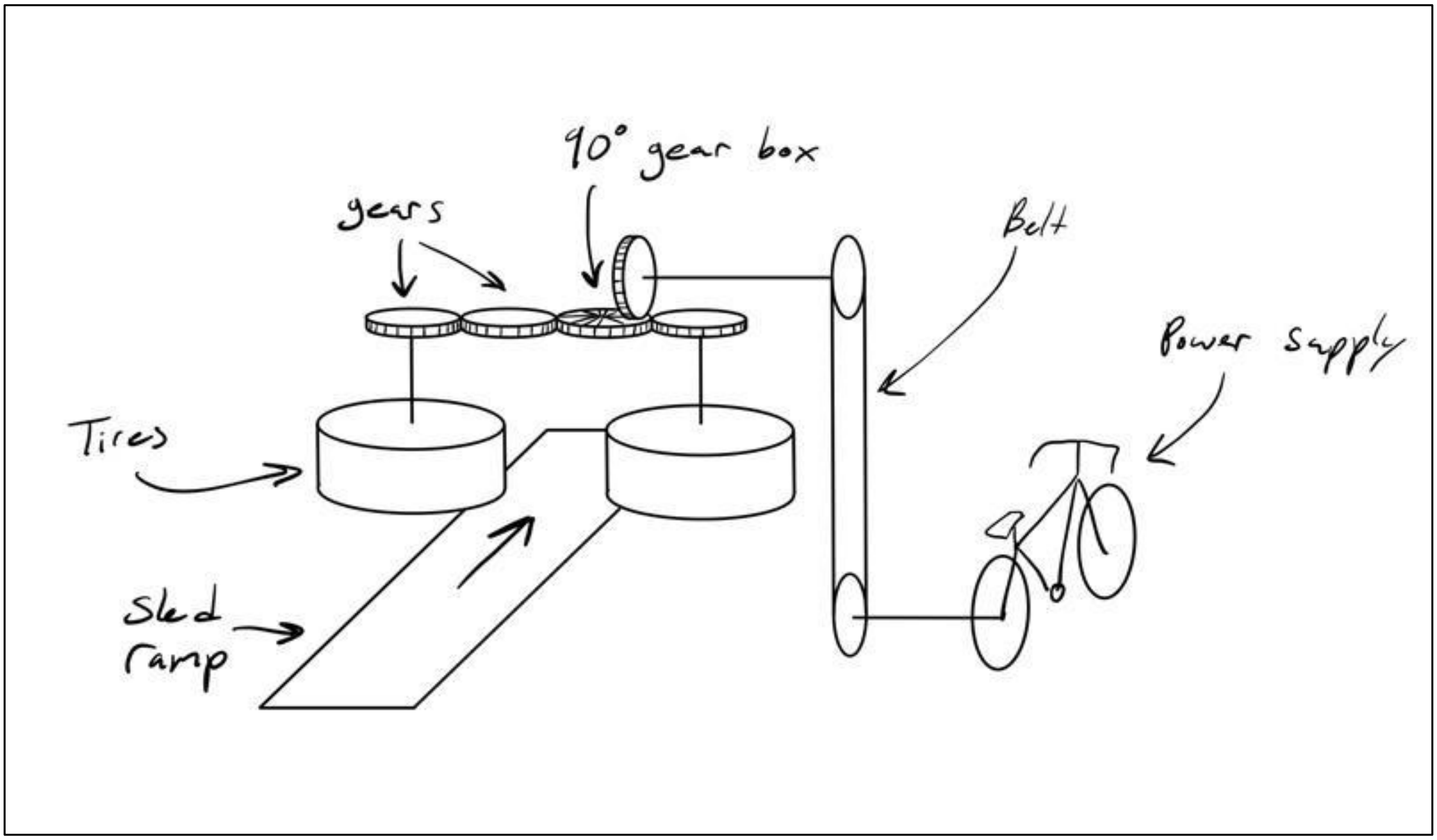


Figure 1: Sketch of the Two-Wheel launcher.

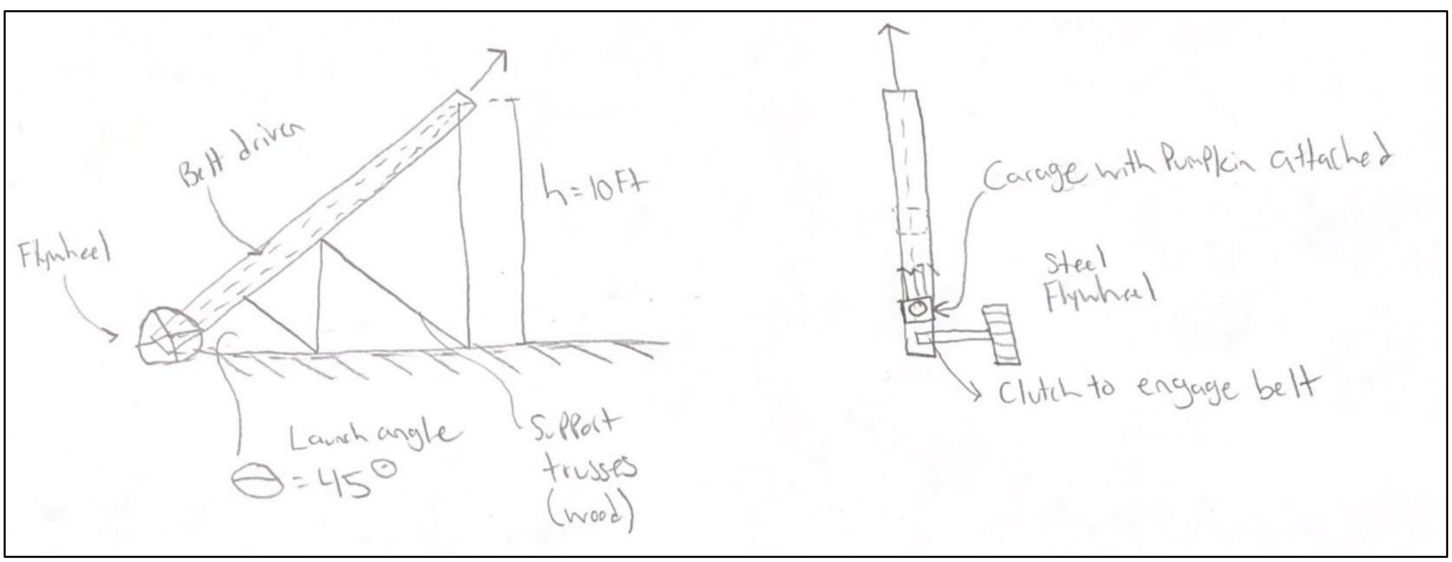


Figure 2: Sketch of the Ramp pumpkin launcher.

ANNEX B

SKETCHES OF THE THREE DESIGNS

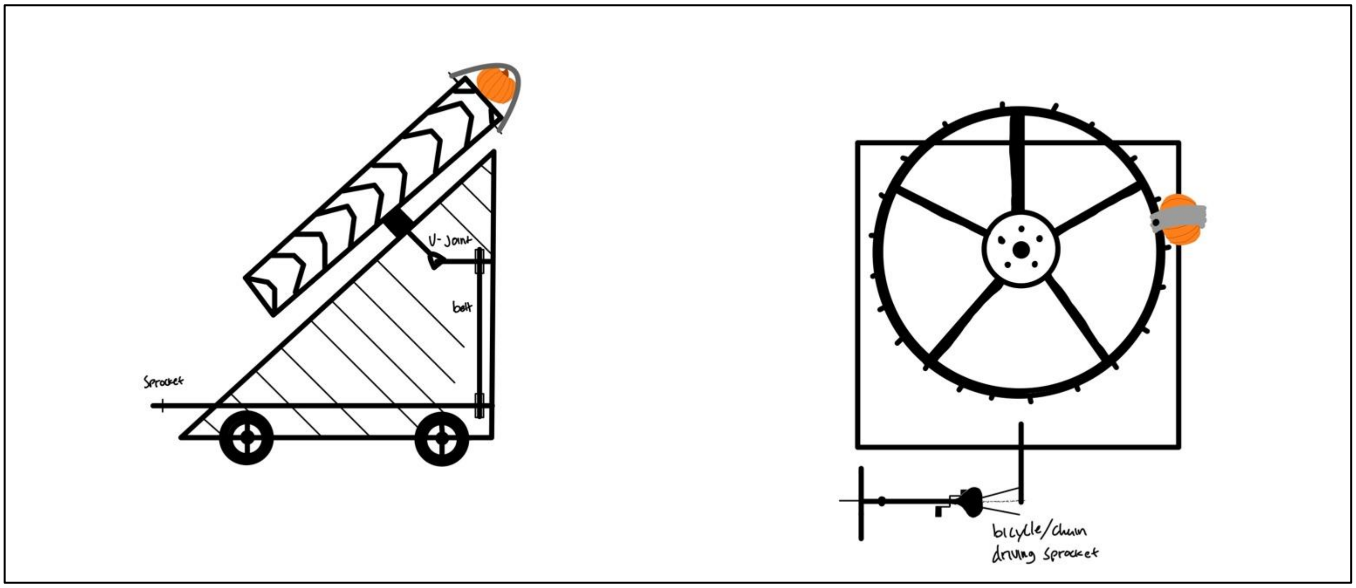


Figure 3: Sketch of the Big Wheel pumpkin launcher.

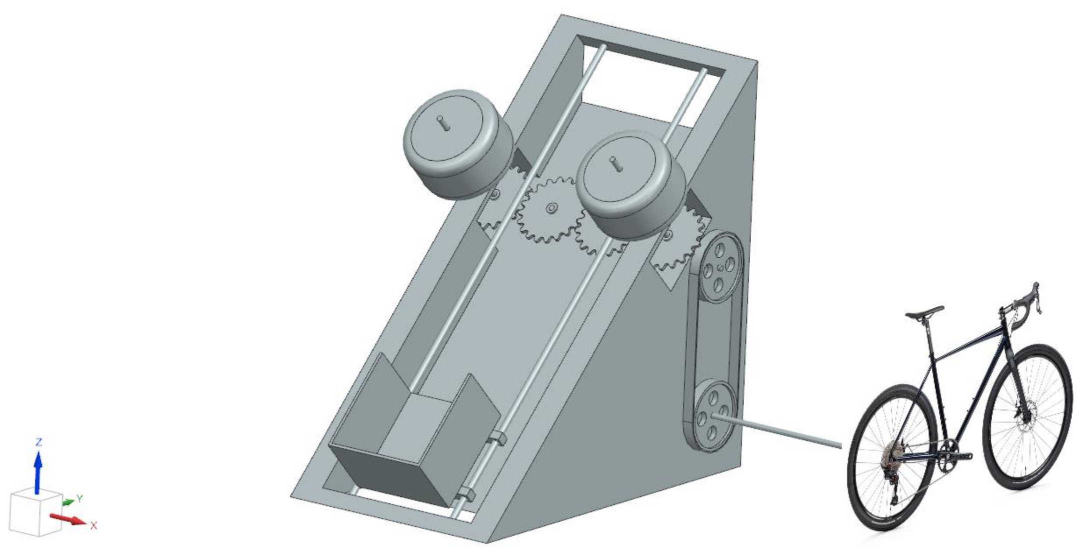


Figure 4: Mockup of Two-Wheel launcher in Siemens NX.

ANNEX C

BILL OF MATERIALS

Item	Quantity	Price (USD)
4x4-8 Pressure Treated Lumber	6	15.37
4x4-10 Pressure Treated Lumber	1	23.98
2x4-8 Pine Lumber	5	6.98
2x6-12 Pine Lumber	1	19.28
2x8-8 Pine Lumber	1	0
PVC track	2	6.75
1” Diameter Wooden Dowel	3	4.37
10-24 Screws and Nuts	12	0
265/75R17 Tire + Wheels	4	25
2008 Chevrolet Silverado Rear Axle Shaft	2	89.99
2” Deck Screws (box of 50)	2	9.78
90° Gear Box	1	148
2” OD Ball Bearings	5	11.19
1 5/8” OD Needle Roller Bearings	2	12.59
2.5” Pulley	1	9.59
4.5” Pulley	1	18.84
138” V-Belt	1	30.70
3/16” Keys (10 Pack)	1	7.93
Bicycle Trainer	1	15
Bluetooth Bicycle Speedometer	1	8.98
10” PVC Pipe	1	197.65
5”-7” Hose Clamps	2	3.99
Runner’s Parachute	1	7.46

ANNEX D

MATLAB CODE

```
% calculator to determine the launch velocity to hit a designated target
% using a set angle or optimized angle for a constant mass projectile
% accounting for drag and tailwind with GUI

% Max Friedman and Chris Muir

function out = launchConditionsV3

format compact

% pumpkin dependant vars
m = 4.53592;                    % pumpkin mass,          kg
r = 0.2032/2;                   % pumpkin radius,        m
Cds = .47;                      % Drag Coefficient,      unitless

% wind dependant vars
vref = 0;                       % reference velocity,    m/s
href = 1;                       % reference height,      m
phi = 0;                        % wind angle,            deg

% target dependent vars
targetE = 100;                  % target distance,       ft

% acceptable errors
aError = .1;                    % angle error,           deg
vError = .1;                    % velocity error,        m/s

% launcher dependent vars
thetaMin = 10;                  % min launch angle,      deg
thetaMax = 50;                  % max launch angle,      deg
thetaSet = 40;                  % set launch angle,      deg
height = 1;                     % launch height,         m
maxV = 1000;                    % max launch speed,      m/s

% constants
te = 15;                        % sim end time,          s
g = 9.81;                       % gravity,               m/s^2
rho = 1.298;                    % air density,           kg/m^3
alpha = 1/7;                    % Hellman exponent,      unitless

% set up GUI
answer = 'not empty';
prompt = {'Pumpkin Mass (kg)', 'Pumpkin Radius (m)', 'Tailwind speed (m/s)', ...
    'Wind Angle (deg)', 'Target Distance (ft)', 'Commands (comma space deliminated)'};
default = { num2str(m), num2str(r), num2str(vref), num2str(phi), num2str(targetE), ''};
now = default;
out.input = default;
out.theta = "";
out.v = "";
out.empty = 1;
```

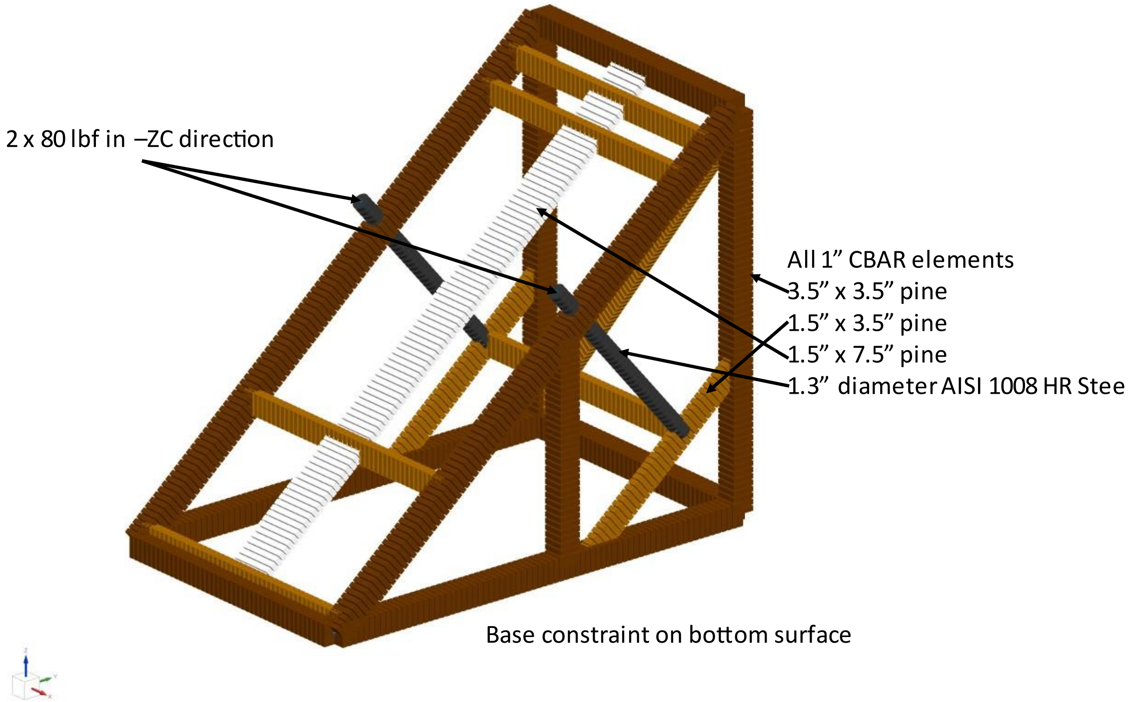
```
disp("Commands: Default, Angle Variable, Hold, End, Dragless");

% GUI loop
while ~isempty(answer)

    % GUI prompt, default, and responce
    answer = inputdlg(prompt,'Launch Parameters', 1, now);

    % considering "cancel" button on GUI
    if ~isempty(answer)

        % parse commands
        commands = upper(strsplit(char(answer(6)), ', '));

        % Command: Default
            % restore default values
        if ismember("DEFAULT", commands)
            answer = default;
        end

        % update paramaters
        m = str2double(answer(1));
        r = str2double(answer(2));
        vref = str2double(answer(3));
        phi = str2double(answer(4));
        targetE = str2double(answer(5));

        % parameter calculations
        target = targetE * .3048;       % target distance,      m
        A = pi * r^2;                   % pumpkin Area,         m^2

        % Command: Dragless
            % eliminate drag
        if ismember("DRAGLESS", commands)
            C = 0;
        else
            C = Cds * rho * A / 2 / m;      % Drag constant,        kg/m
        end

        % Command: Angle Variable
            % optimize the angle
        if ismember("ANGLE VARIABLE", commands)
            theta = bisectionMin(@(theta) bisectionMin(@(v) error(v,theta), 0, maxV,
vError), thetaMin, thetaMax, aError);
        else
            theta = thetaSet;
        end

        % speed and angle calculation
        V = bisectionMin(@(v) error(v,theta), 0, maxV, vError);

        % output
        n = length(out.theta) - out.empty + 1;
        out.input(n, :) = answer;
        if ismember("ANGLE VARIABLE", commands)
            out.theta(n) = sprintf("%4.2f±%3.2f °  ", theta, aError / 2);
        else
```



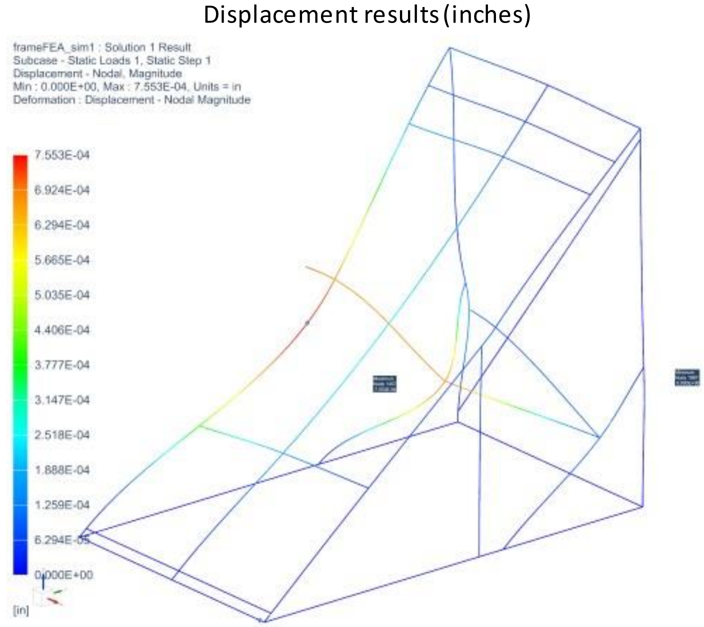
```
            out.theta(n) = sprintf("%4.2f °        ", theta);
        end
        out.v(n) = sprintf("%4.2f±%3.2f m/s", V, vError / 2);
        out.empty = 0;

        % Command: Hold
            % don't update the default settings to the settings of the last
            % launch
        if ~ismember("HOLD", commands)
            now = answer;
        end

        % Command: End
            % break out of the loop
        if ismember("END", commands)
            answer = {};
        end

        % dialogue box to provide angle and speed without closing GUI
        message = sprintf("Launch #%u: %s, %s, to hit %4.1f ft target", ...
            n, out.theta(n), out.v(n), targetE);
        uiwait(msgbox(message),1);
    end
end

    % custom functions

    function c = bisectionMin(f,a,e,error)

    % determines x coord  c of the minimum of a function f where a<b<c<d<e and
    % are all x values

        c = (a + e) / 2;
        while e - a > error
            b = (a + c) / 2;
            d = (c + e) / 2;

            %fprintf("%f, %f, %f, %f, %f \n", a, b, c, d, e);

            fb = f(b);
            fc = f(c);
            fd = f(d);

            if fc < fb && fc < fd
                a = b;
                e = d;
            elseif fb < fd
                e = c;
                c = b;
            else
                a = c;
                c = d;
            end
        end
    %fprintf("return: %f \n", c);

    end
```

```
    function b = bisection0(f,a,c,error)

    % determines the root (b) of function (f) where a < b < c

        b=(a+c)/2;
        while abs( f(b) ) > error
            if f(b) * f(a) < 0
                c=b;
            else
                a=b;
            end
            b=(a+c)/2;
        end
    end
    function distError = error(vi, theta)
        vx = vi*cosd(theta);
        vy = vi*sind(theta);

        loopControl = true;
        t = te;

        while loopControl == true

            % calculate trejectory
            [tm,y] = ode45(@odefun,[0 t],[0 vx height vy]);
                                            % set origional pos and v

            % prevent bug where simulation ends before projectile hits
            if y(end,3) <= 0
                loopControl = false;
            else
                t = t + 10;
            end
        end
        fx = @ (t) interp1(tm,y(:,1),t);
            % define x(t)
        fy = @ (t) interp1(tm,y(:,3),t);
            % define y(t)
        tContact = bisection0(fy,0,t,0.01);
            % determine time of contact via bisection 0
        distError = abs(fx(tContact)-target);
            % error defined as distance between contact point of sim and
            % desired contact point
        %fprintf("%f m/s @ %f° hits %f @ %f s", vi, theta, fx(tContact), tContact);
    end
    function dy = odefun(~,y)
        dy = zeros(4,1);
        vx = y(2)- vref * cosd(phi) * (y(3)/href) .^ alpha;
            % velocity in the x considering wind
        v = sqrt(vx.^2+y(4).^2);
        dy(1) = y(2);
        dy(2) = -vx .* C .* v;
        dy(3) = y(4);
        dy(4) = -y(4) .* C .* v - g;
    end
en
```

ANNEX E
FINITE ELEMENT ANALYSIS



Displacement results (inches)



Element nodal stress results (Von Mises)