Launch

Team Members

Timothy Clifford
Levis Li
Victor Little
Nolan Goldthwaite

Customer

University of Rochester
Department of Mechanical Engineering

Tim

Levis

Victor

Nolan

Floating Arm Trebuchet

Project Overview

This project involved the design and construction of a floating arm trebuchet to compete in the annual University of Rochester Pumpkin Launch Competition. The trebuchet uses a vertical counterweight to accurately launch pumpkins to specified distances between 50 and 300 feet.

Problem Statement

The University of Rochester has not won its home pumpkin launch competition in six years. Traditional designs, such as air cannons, slingshots, and conventional trebuchets, are widely used but typically sacrifice either accuracy or range, creating an opportunity for a more optimized solution.

- The competition scoring emphasizes both distance and accuracy
  - This project will be considered a success if the launcher wins the 2027 Pumpkin Launch Competition
  - As well as hits targets during our Design Day Showcase
- Designing a pumpkin launcher builds and tests knowledge in areas like energy transfer, structural reliability, and dynamic systems.

Air cannon

Slingshot[2]

Traditional Trebuchet [1]

Deliverables, Requirements and Specifications

The deliverables, requirements and specifications define what will be done and how to be objective about what it means to have a "successful" project.

Deliverables:

1. Prototype Device (Pumpkin Launcher)
2. Technical Report
3. Theory of Operation (Instruction manual for launcher)
4. Test Data Analysis
5. Safety Plan

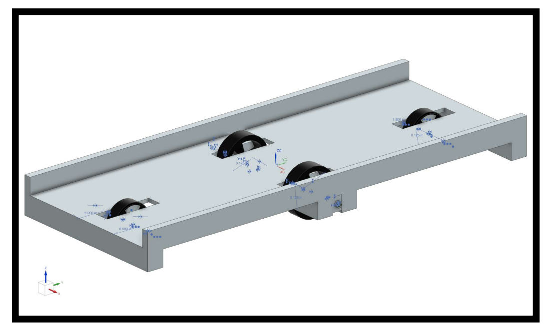
Requirements:

1. Device capable of safely, reliably, and repeatably launching a pumpkin at different target distances.
2. Launcher will be purely mechanical and not use any chemical propellants/electrical power.
3. Human power will not be used to hold the launcher in an energized state before firing.
4. The launcher will be evaluated prior to the competition.
5. Stored mechanical energy used to launch the projectile will be created with the judges who are present.
6. The launcher must be suitable for transport and setup at the launch site.
7. The launcher must maintain its integrity through multiple uses.
8. The device must follow all competition rules and site constraints.
9. The launcher must be easy and quick to assemble.

Specifications:

Specifications	# Value	Units	description	method of evaluation (brief description)
1	5	%	Mean error will be less than 5% over 3 shots	whether pumpkins are landed in this range. Test conditions: clear day, sub 15 mph winds
2	4	ft	The entire launcher's width must not be more than 4 feet	Tape measure
3	120	lbf	The heaviest piece muct not exceed 120 lbf	Scale check
4	2	FS	Minimum factor of safety for yield/rupture of material	Ruler and reference mark, or use FEA for its 3D drawing
5	15	degree	Device must be stable at this minimum incline	Protractor
6	50	ft	Minimum target distance	Set the launcher to 50ft shooting range setting, and measure the pumpkin landing point from the target distance
7	300	ft	Maximum target distance	Set the launcher to 300ft shooting range setting, and measure the pumpkin landing point from the target distance

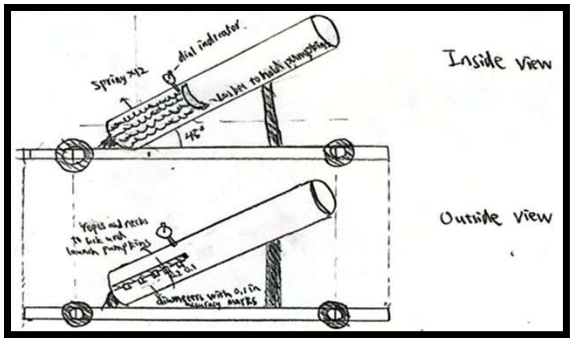
Floating Arm Trebuchet Pumpkin Launcher



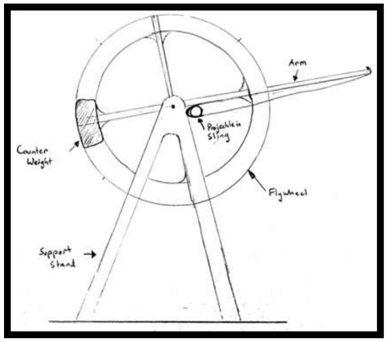
Design for transportation

Current Project Status
Research & Design Ideas

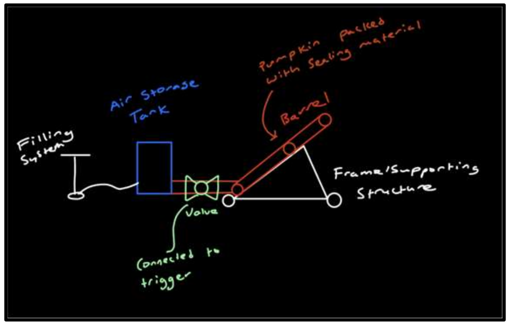
- Each group member researched one of the following four concepts:
  - Air Cannon
  - Spring Launcher
  - Flywheel Trebuchet
  - Floating Arm Trebuchet
- Calculations showed that the air cannon could not meet the accuracy specification
- Spring cannon cannot feasibly launch pumpkins 300 ft
- Flywheel Trebuchet presented major safety concerns
- Simulation results showed that the Floating Arm Trebuchet could meet both the distance and accuracy specifications



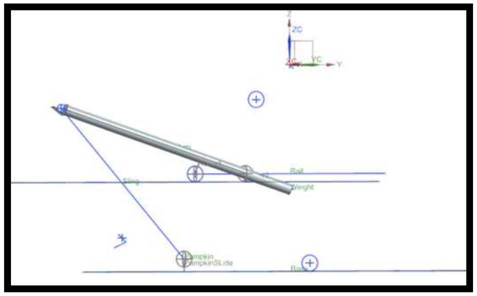
Spring Launcher



Flywheel Trebuchet



Air Cannon


Floating Arm Trebuchet Simulation Setup

Counter Weight (lbm)	Initial Y Velocity (ft/s)	Initial Z Velocity (ft/s)	Resultant Velocity (ft/s)	Launch Angle (degrees)	Pin Angle	Distance (ft)
45	20.01	37.57	42.57	28.04	70	46.06
50	22.92	40.42	46.47	29.56		57.77
55	25.84	42.47	49.71	31.32		68.85
60	28.61	44.43	52.84	32.78		80.36
65	31.19	47.35	56.70	33.37		93
70	33.89	48.68	59.32	34.84		104.8
75	36.29	50.26	61.99	35.83		115.65
80	38.7	52.2	64.98	36.55		128.38
85	41.15	52.87	67.00	37.89		140.3
90	43.73	53.91	69.42	39.05		153.9
95	45.73	57.11	73.16	38.69		165.67
100	47.96	57.38	74.78	39.89		176.61
105	49.97	59.28	77.53	40.13		189.98
110	52.3	60.24	79.78	40.96		202.5
115	54.09	62.73	82.83	40.77		213.63
120	56.34	63.67	85.02	41.50		226.99
125	54.44	67.93	87.05	38.71		239.1
130	58.45	67.69	89.43	40.81		251.6
135	63.17	64.66	90.40	44.33		266.16
140	64.63	65.85	92.27	44.46		277.02
145	66.21	67.9	94.84	44.28		288.5
150	67.75	68.99	96.69	44.48		300.43

Trebuchet Simulation Results

Current Project Status
Performance Metrics

Release Pins

- ¼ scale model was used to test different pin angles and designs.
    - Original square/circular pin designs were too weak
    - Pin design was revised into a fin/hook shape
- 60°, 70°, and 80° release pins were simulated in NX
    - 60° pin is optimal for long-range launches
    - 70° and 80° pins are more relevant for short to mid-distance launches

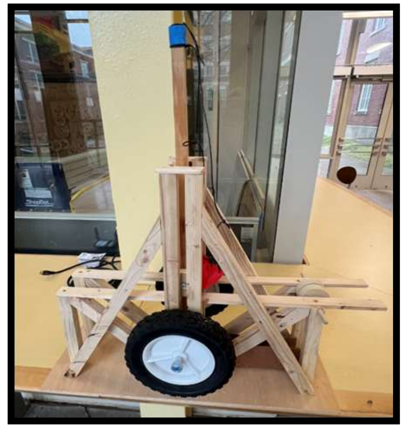
Counterweight Values

- Simulation results show that desired distances can be achieved by varying counterweight from 45lbf – 150lbf.
    - Actual counterweight values will likely be marginally larger

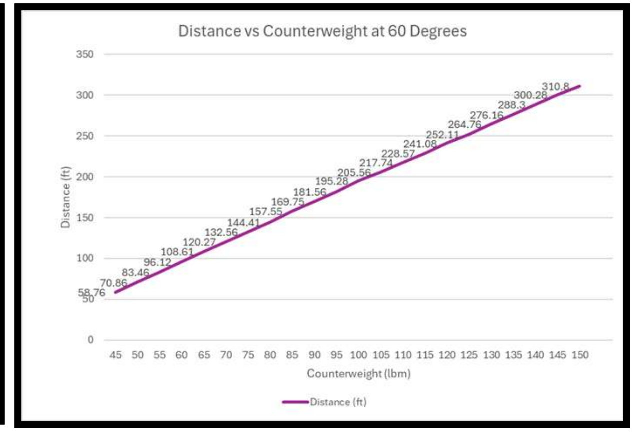
Stress Analysis

- FEA was used to analyze stresses in the launcher arm and release pins. Optimized arm geometry & identified high-stress regions
- Motion simulation was also utilized to collect force data along the rollers and import them into FEM and SIM files to ideally simulate experienced loads during launching.

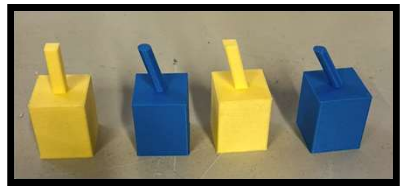
Mechanical Engineering
University of Rochester



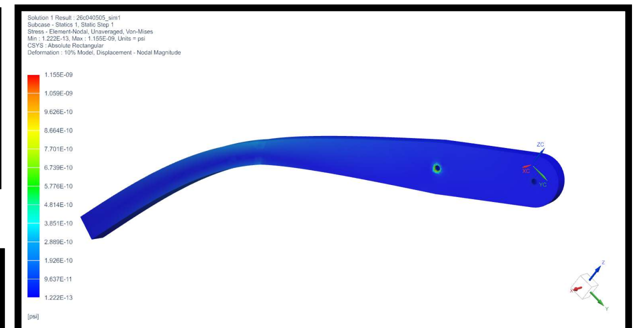
¼ Model

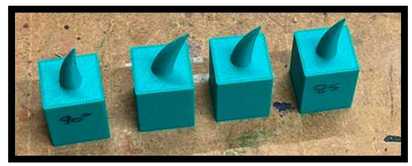


Counterweight metrics for 60° pin



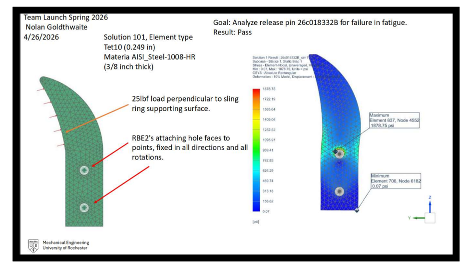
Original pin design (1/4 scale)





Revised 3D-printed release pins (1/4 scale)

Von Mises nodal stresses for arm ^ Stress on pin \/



Current Project Status

Final Product

Frame/Base

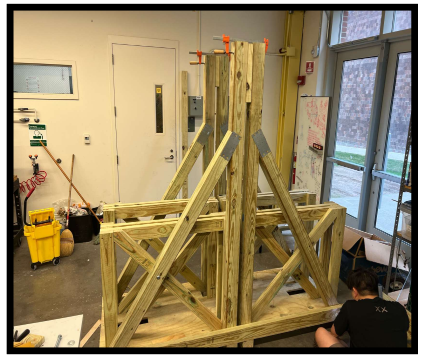
- Consists mainly of 2 x 4 and 4 x 4 lumber
- Base uses removable wheels for transportation and a lifted design to protect underside from moisture
- Cross-braces added in to ensure stability

Arm

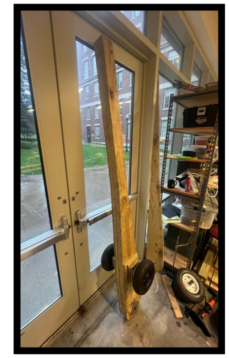
- Designed to evenly distribute stress
- Created by laminating ¾” thick plywood sheets together
- Utilized ideal cantilever beam geometry to support pivot point
- Alignment plate was manufactured to ensure plum and square properties of the counterweight arm when falling

Release

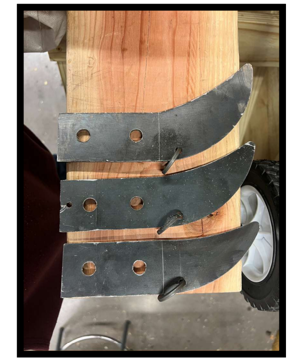
- Multiple pin angles for different launch distances (60, 70, 80)
- Release mechanism uses rotational motion
    - Both pins and release mechanism were plasma cut from 1018 steel
- 3D-printed pully clamps attach to barbell for easy rotation
- Sling was created by sewing fabric together for the housing and attached to pin with carbineer and a slotted plate to ensure smooth release



Wooden trebuchet frame

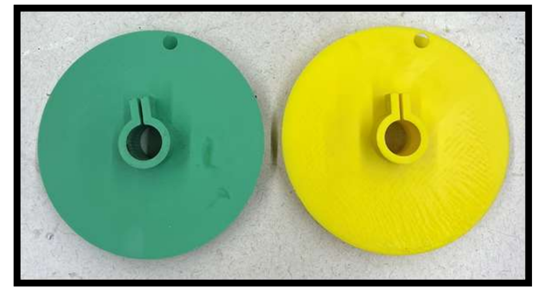


Launcher arm



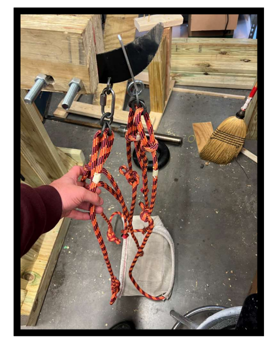
60, 70, 80-degree pins

Trebuchet Base

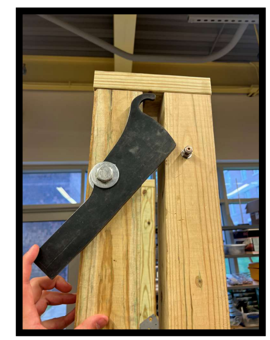


3D-printed clamps

Fully built Trebuchet



Sling



Release mechanism

Current Project Status

Testing Plan & Performance Modeling

Objective

- Develop a predictive model using MATLAB to accurately determine launch settings for a target distance

Test Variables

- Pin Angle (release angle tuning)
- Counterweight Mass (energy input)
- Projectile Mass (pumpkin weight variation)

Testing Approach

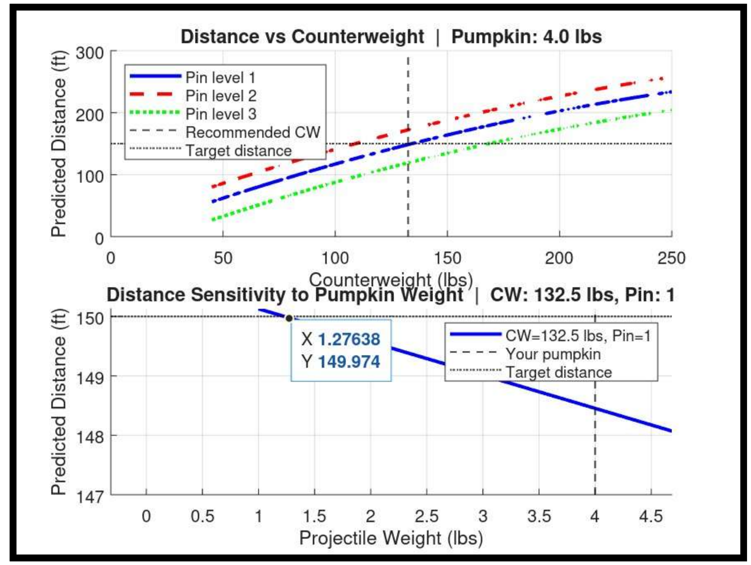
- Conduct systematic launch tests varying one parameter at a time
- Record launch distance with given parameters
- Validate trends against simulation results from Siemens NX

Data Processing & Model Development

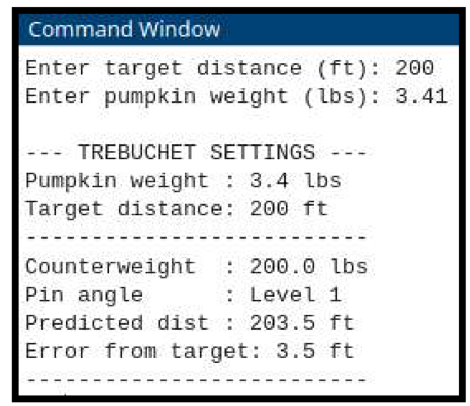
- Compile experimental data into a robust distance predictor
- Establish relationships between:
  - Counterweight and Distance
  - Pin Angle and Trajectory
  - Projectile Mass and System response

Final Output Tool

- Input: Desired distance + pumpkin mass
- Output:
  - Required counterweight mass
  - Recommended pin angle



Example of generated graphs



Example of generated Command Window

Conclusions/Future Work

Current Primary Issues

- Wheels on the arms bounce when the arm contacts the guide rails.
- Barbell tilt during its descent along the track.
- Barbell is at risk of bending under load.
- Sling not releasing at proper timing.

Reasons of Issues

- Loss of continuous surface contact from the rear pivot wheels to the guide rail wheels.
- Small area supporting the counterweight with weights over 2 ft from supported area.
- Sling either is not taught when beginning of firing or sling is too long.

Future Works

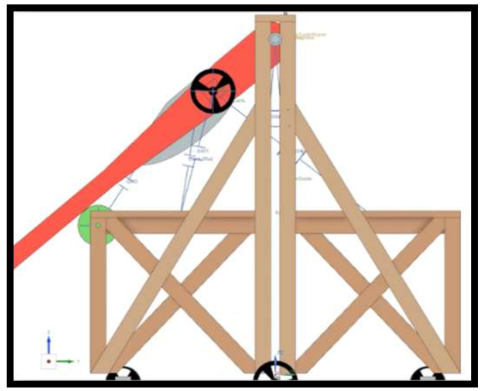
- Apply cam mechanism to engage a roller as the arm rotates, ensuring continuous contact and eliminating bounce.
- Apply four-bar mechanism or rail system.
- Narrower design, wider counterweight support, or narrower counterweight bar.
- Ensure the sling stays taught through the arms entire motion to allow the sling to reach its release point before the arm surpasses 90 degrees.

Acknowledgements

We would like to thank Christopher Muir, Jim Alkins, Bill Mildenberger, Christine Pratt, Paul Funkenbusch, and Angel Bermudez for all their assistance, help and guidance during this project.

Wheel Bounce

Bent bar after test



CAM mechanism

Individual Contributions: Tim Clifford

Design & Analysis

- Evaluated the air cannon concept feasibility
- Created the preliminary trebuchet frame and base designs
- Designed ¼ scale and full-scale release pins

Modeling

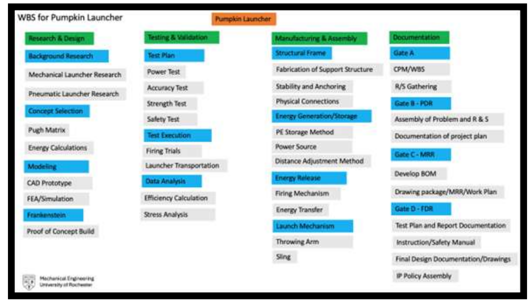
- Created CAD models of preliminary frame/base
- Modeled release pins in NX and prepared tool paths
- Created final assembly using Victor's main assembly

Manufacturing

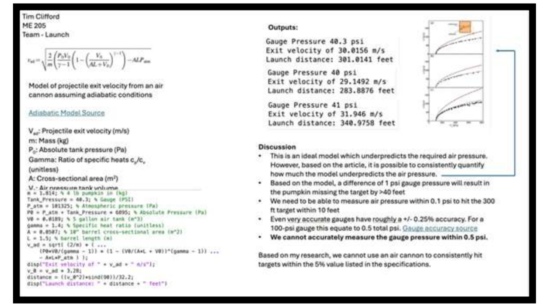
- Contributed to the wood preparation for the base/frame, base assembly, pin attachment
- 3D printed multiple iterations of ¼ scale release pins
- Plasma cut, filed, and cross drilled full-scale pins
- Modified the launcher arm for pin attachment with Levis and Professor Muir's help

Documentation & Testing

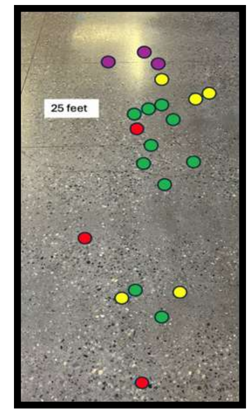
- Worked on WBS and air cannon documentation
- Prepared final drawing package
- Tested ¼ release pins and analyzed data



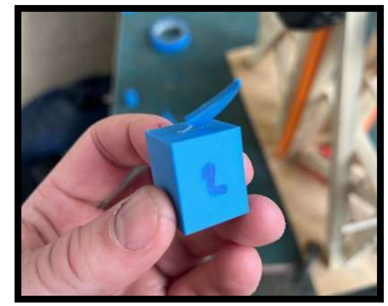
WBS


Air Cannon Calculations


Release pins



¼ pin testing


3D printed pin that failed


Final Assembly

Individual Contributions: Bingchen Li

Design and Analysis

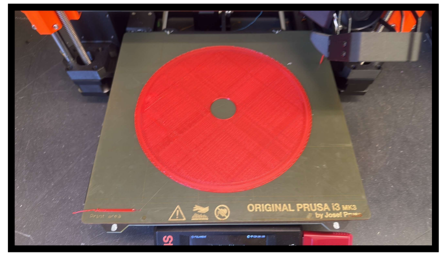
- Created a spring cannon concept and used MATLAB to determine required spring compression for target distances.
- Completed specifications for design
- Did most of the purchase list

Modeling

- Created the CAD drawing of the base mover based on Tim's base.
- Optimized the base mover for better turning and mobility
- Developed the ¼ scale launch pin from fin-shape to horn-shape, and 3D printed it to test for launching
- Designed and printed different versions of clamp or clamp-pulley for testing on the bar.

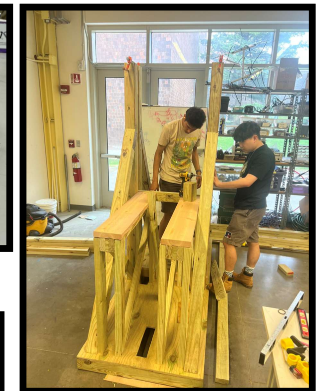
Manufacturing

- Helped to assemble the frame of the trebuchet
- Helped to assemble the moving parts of the base mover
- Helped to make cut on the arm and tap the launch pin to finish the trigger system
- Made the operational manual and

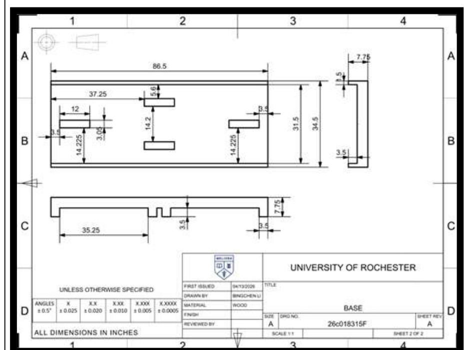


Clamp-pulley in printing

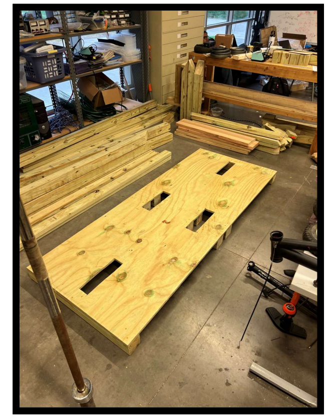
Printed clamp-pulley



Assembly of launcher

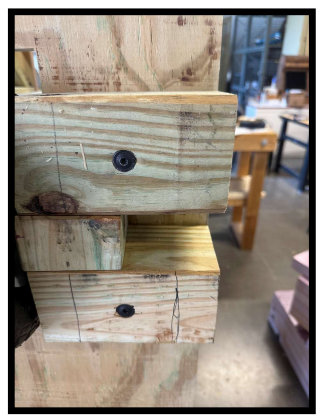


Draft of mover

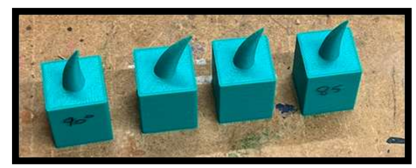


Mover Structure

First iteration of clamp



Draft of mover



Revised 3D-printed release pins (1/4 scale)

Individual Contributions: Victor Little

Design & Engineering Analysis

- Evaluated Floating Arm Trebuchet to meet 300 ft performance target
- Optimized arm geometry & identified high-stress regions
- Performed Load transfer, tolerance, and bolt torque analysis

Modeling and Simulation

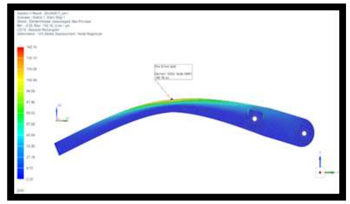
- Built motion simulations in Siemens NX to relate distance to counterweight & pin angle
- Calculated projectile exit velocity and release angle
- Developed 1:1 scale contact model to visualize real-world behavior

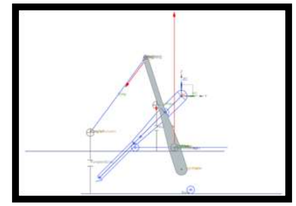
Manufacturing & Fabrication

- Created cut sheets, BOM
- Programmed & operated ShopBot CNC Router for precision parts
- Laminated and manufactured trebuchet arm, as well as helped assemble and fabricate frame assembly

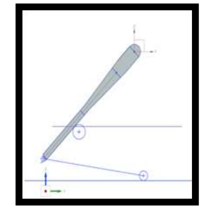
Testing, Iteration & Team Support

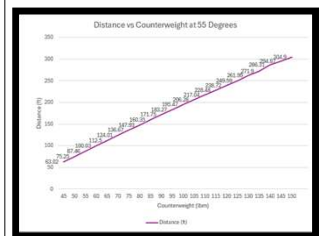
- Tuned design parameters and resolved prototype issues
- Iterated based of performance results
- Guided team in machining and fabrication processes


Stress analysis on arm

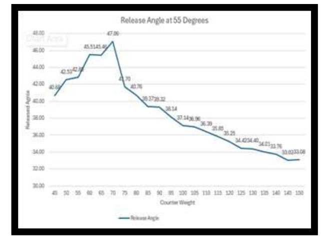

Simulated impact load


3D Contact Assembly


Skeleton Model

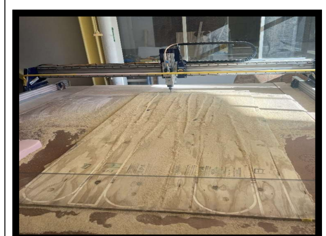


Launch distance data

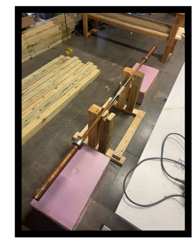


Release angle data


Laminated Arm


Arm Geometry on ShopBot

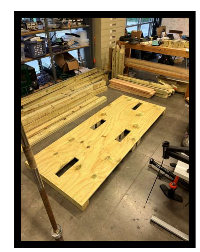

Fabricated wood

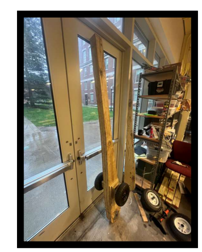

Release test assembly


Serviced weight bar


Building Chute


Assembled Frame


Assembled Base


Assembled Arm

Individual Contributions: Nolan Goldthwaite

Design and Engineering Analysis

- Found and analyzed the concept and fly wheel trebuchet
- Designed automatically resetting release mechanism, allowing synchronized firing.
- Designed and 3D printed rail for testing on ¼ scale model

Manufacturing

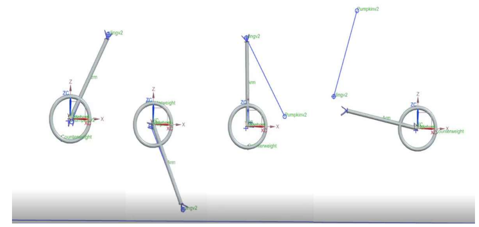
- Built ¼ scale model frame
- Helped assemble frame, base, rail, pins, mover
- Printed release mechanism and rail system for ¼ scale testing
- Plasma cut prepared and installed release mechanism
- Improved sling release and assembled sling

Experimentation and Results Analysis

- Designed experiment and wrote mock prediction equation with help from Professor Funkenbusch
- Wrote MATLAB code for analyzing the launch data including pumpkin mass, pin, distance, and counterweight. Code instructs user of suggested counterweight to hit target distance while factoring in projectile weight.

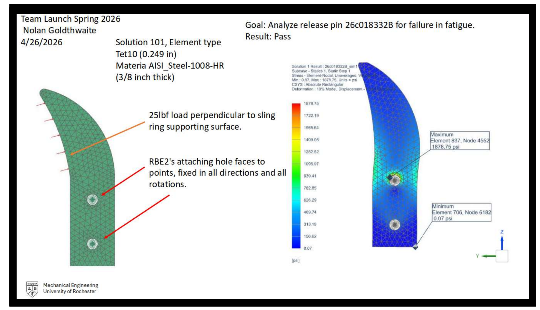
Modeling and Simulation

- Modeled and simulated fly wheel trebuchet concept to check for feasibility.
- Conducted Fatigue analysis on launch pin
- Simulated Cam and Rail design additions in NX
- Conducted FEA of initial release mechanism
- Contributed to designing the frame.



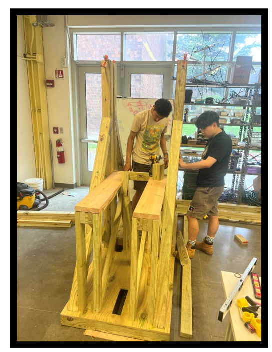
Launch stages of flywheel trebuchet

Release Mechanism

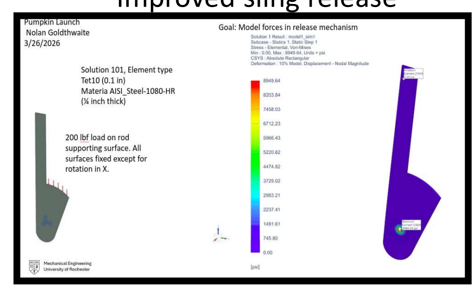


Fatigue analysis using MATLAB code NX simulation

Improved sling release



Assembling the trebuchet



FEA of early release design

References

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