Theme Park Transportation
the trebuchet approach

Eric Miller & Nathan Yee

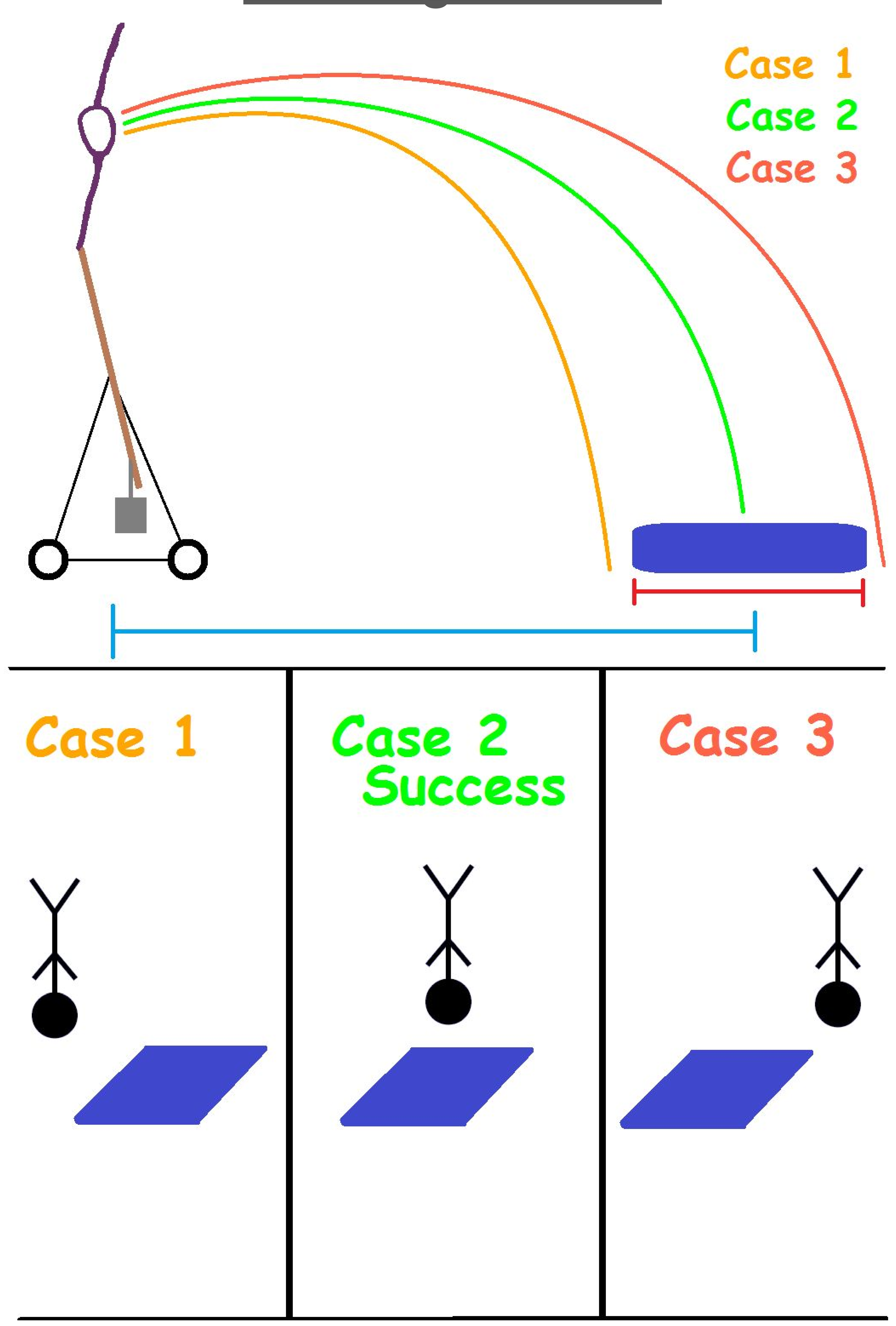
Abstract:
Motivated by Disney's proposed trebuchet trans-park transportation, we investigated the behavior of such a trebuchet using a model based on lagrangian mechanics. We find that for any given rider mass between 15kg and 90kg, there exists at least one pin angle setting that results in a successful landing. This validates the concept of using an adjustable release angle to adapt for varying rider weights, but serious challenges likely remain with safety and regulatory factors.

A Whole New Ride

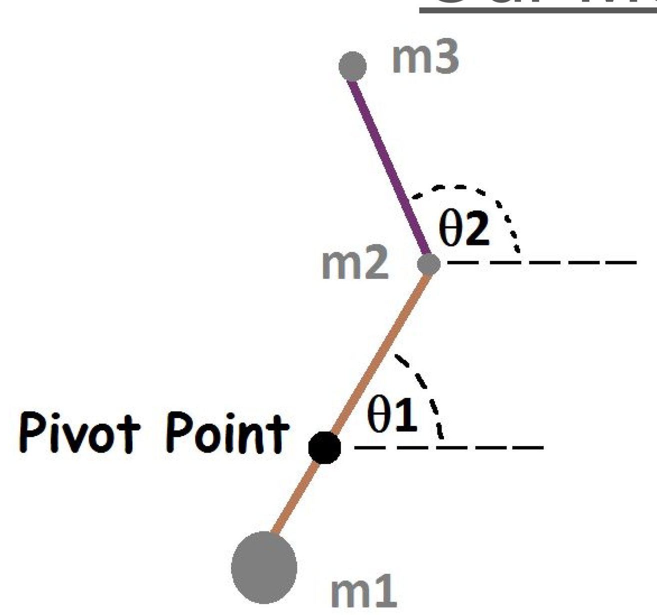
Disney recently proposed a new form of trans-park transportation. First, a person of a particular mass is loaded into a sling. Second, the pin angle is adjusted. Third, the person launched across the park towards a pool of water.

Question: For a particular trebuchet, what values of rider mass and pin angle will result in a successful landing?

The Big Picture



Our Model



Using Lagrangian mechanics, we modelled the trebuchet as a series of three point masses. The counterweight, m_1, is much larger than m_2 or m_3. The point mass, m2, is placed at the end of l_2 and is comparable to m_3. The passenger, m_3, is modelled as a point mass, and is released when (θ_1 - θ_2) (the angle between the arms) reaches some parameterized "pin angle".

System Definition

$$R(\theta) = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix}$$

$$P_1 = -l_1 \times R(\theta_1) \cdot \hat{x}$$

$$P_2 = l_2 \times R(\theta_1) \cdot \hat{x}$$

$$P_3 = P_2 + l_3 \times R(\theta_2) \cdot \hat{x}$$

Lagrangian Mechanics

$$V = g \times (m_1 \times P_1 \cdot \hat{y} + m_2 \times P_2 \cdot \hat{y} + m_3 \times P_3 \cdot \hat{y})$$

$$T = \frac{1}{2}\left(m_1\left(\frac{dP_1}{dt}\right)^2 + m_2\left(\frac{dP_2}{dt}\right)^2 + m_3\left(\frac{dP_3}{dt}\right)^2\right)$$

Equations of Motion

$$\boxed{\frac{\partial}{\partial t}\frac{\partial L}{\partial \theta_2(t)} = \frac{\partial L}{\partial \theta_2(t)}} \qquad \boxed{\frac{\partial}{\partial t}\frac{\partial L}{\partial \theta_1(t)} = \frac{\partial L}{\partial \theta_1(t)}}$$

Lagrangian restrictions

Due to the nature of Lagrangian equations, non-conservative forces are difficult or impossible to include in the model.

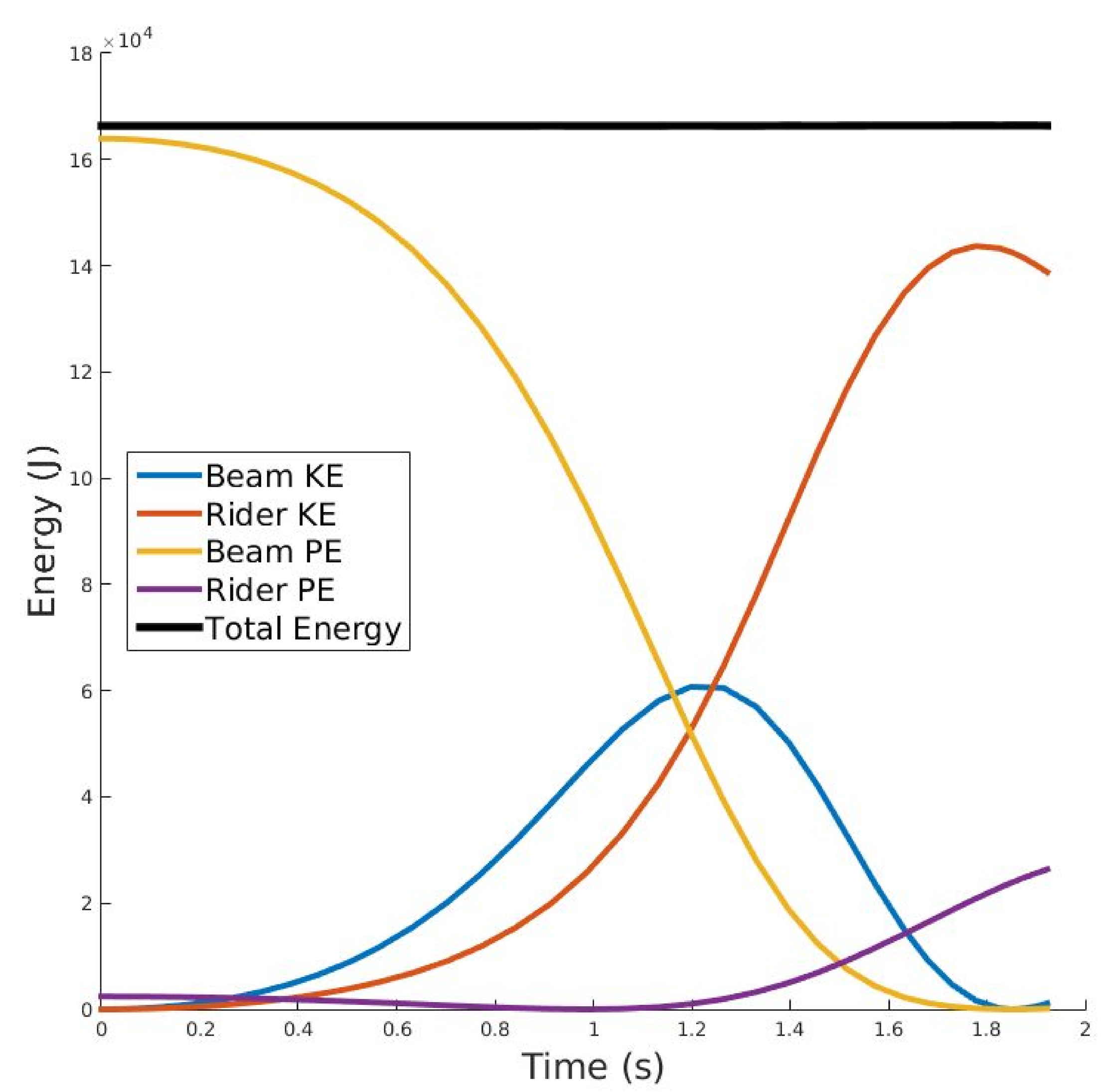
- Joints are frictionless
- Pre-release drag is negli

Modeling Choices

These assumptions are designed to make the model easier to understand and faster to compute, while having minimal impact on simulation accuracy.

- In-flight drag is proportional to v2
- Counterweight is rigidly mounted to main arm

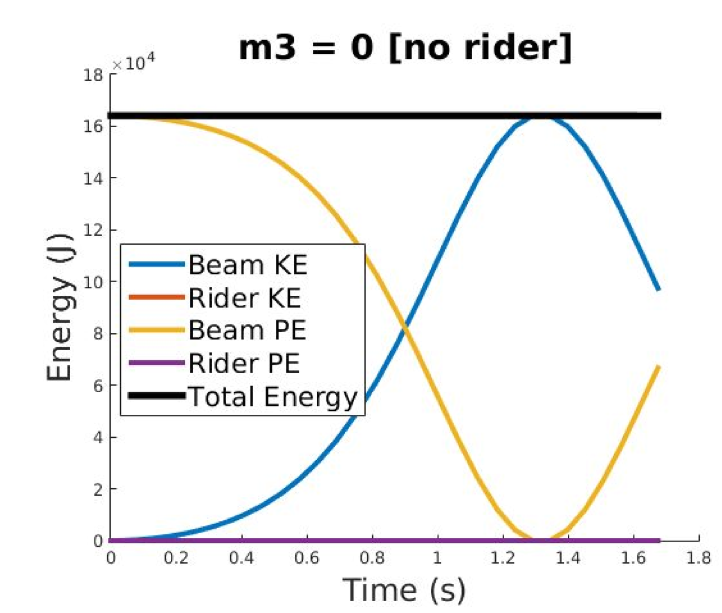
Energy Validation



Limiting Cases

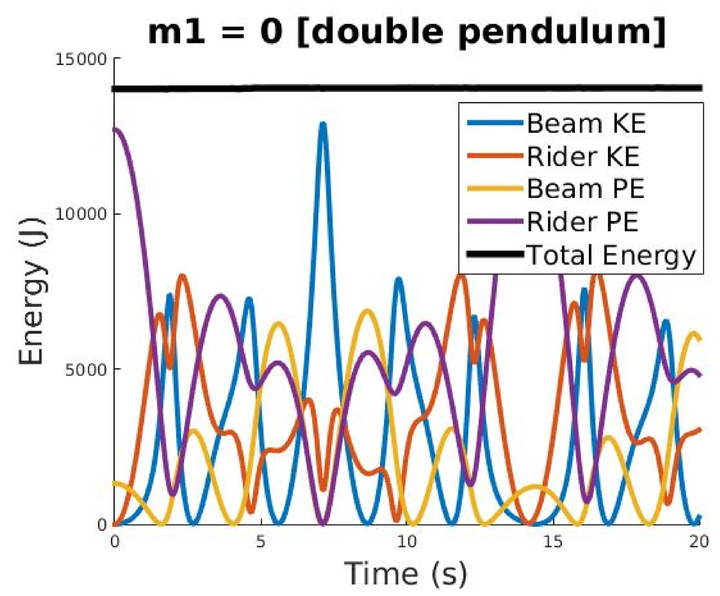
Limiting case 1: m_3=0

Although it falls outside the normal domain of the model, we can simulate a case where the trebuchet is unloaded. As can be seen to the right, our model correctly concludes that the potential and kinetic energies of the rider remain at 0, and the energy of the boom forms the entire energy of the system, behaving as a simple oscillating pendulum.

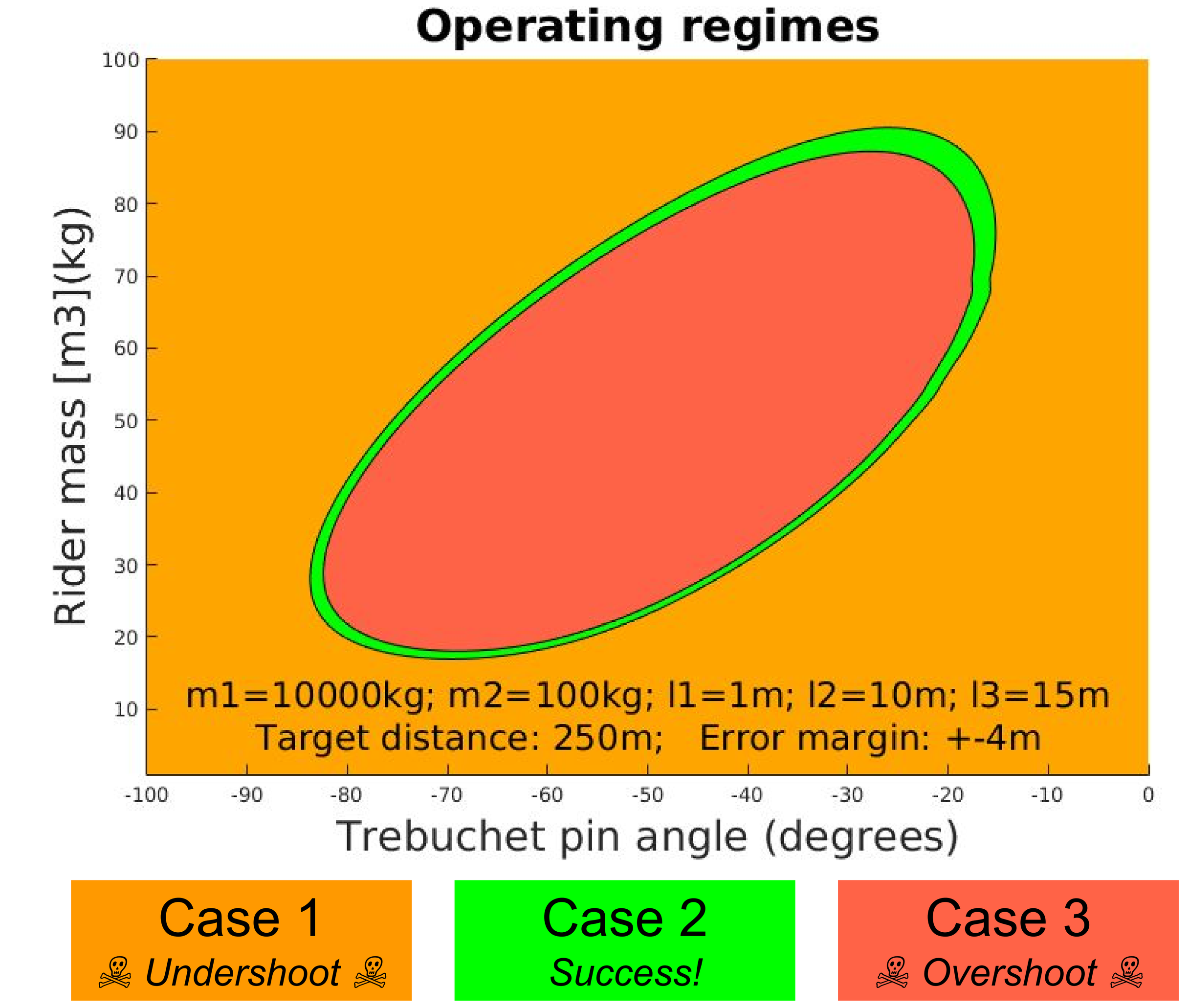


Limiting case 2: m_1=0

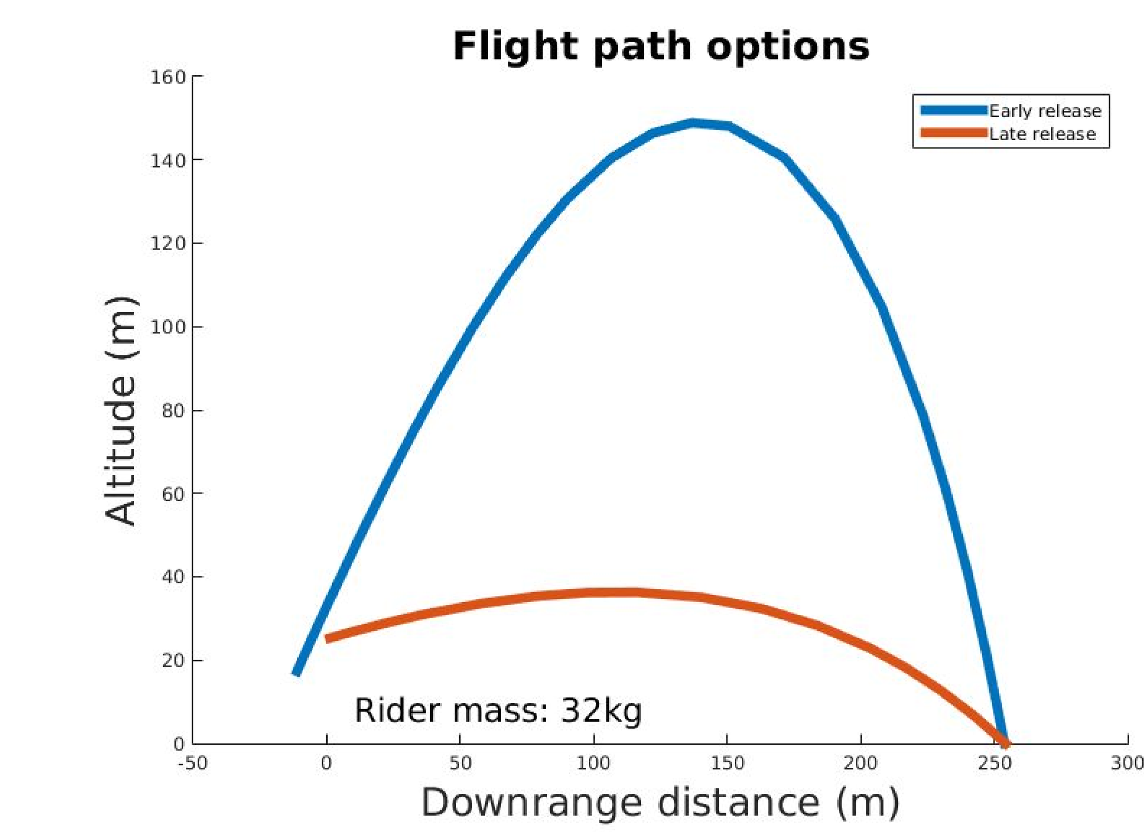
If we remove the counterweight, the system trivially reduces to a gravity-driven double pendulum. Our model correctly simulates this known chaotic behavior.



A Narrow Window for Success



Ride Conditions: "Thrilling"



Conclusions

- Adaptively adjusting the pin angle is capable of effectively compensating for rider mass differences.
- Due to a narrow band of angles, riding the trebuchet is probably a bad idea
- You must weigh between 15 to 90 kg to ride the trebuchet

Future Work

Trebuchet

- Wheels or slider base
- Pivoting counterweight

Model

- In flight realistic drag
- 3D
- Statistical predictions