DEPARTMENT OF MECHANICAL ENGINEERING

TEAM 21

Steel Team Six

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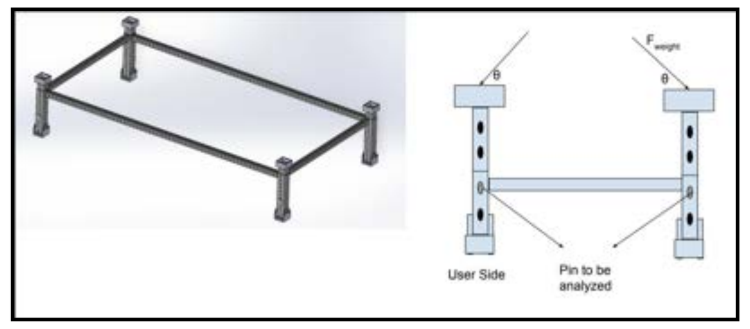
Problem Definition

The current method of reaching higher applications such as baffles and ceiling lights pose significant risk to the janitorial staff at the College Park Academy. The staff currently uses a 12' ladder in attempt to reach these heights, but the ladder falls short, tempting the staff to stand in higher, more dangerous positions. While this is problematic, the tasks are too infrequent for the stakeholder to significantly budget for.

Design Calculations & Analysis

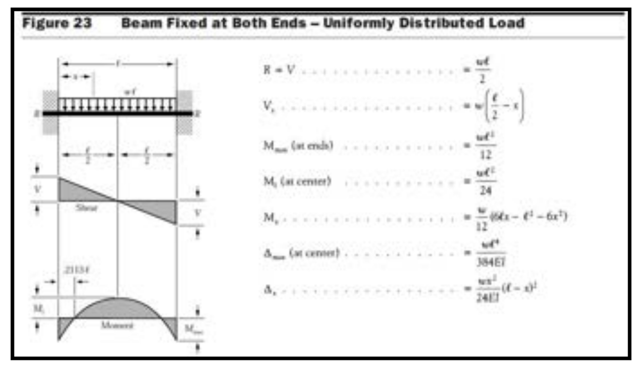
Pin Selection



$F_{weight,y}$ = (248 lb)(sin(78.13°)) = 242.696 lb

Note: This weight will be shared by both legs of the user side so the weight experienced by one leg will be 121.348 lb

Other important parameters that will be needed for this calculation will include the length of the pin, the diameter of the pin, and the area of the pin. The length of the pin was measured to be $\mathbf{L_{pin}}$ **= 2.25"** and the diameter is equal to $\mathbf{d_{pin}}$ **= .375"**. With the diameter of the pin, the area of the pin face can be found using the area of a circle A = $\pi/4*d_{pin}^2$ which will lead to an area for the pin being $\mathbf{A_{pin}}$ **= .11044 in²**.



Using the formula V = w(l/2-x) we can find the approximate shear force. In treating this application like a fixed beam we find the distributed load for this calculation, w, is equal to the force over the length of the pin:

- w = Weight of Applied Force/Length of Pin = 121.348 lb/2.25" = 53.932 lb/in
- l = 2.25"
- X = 0" at the most stressed area along the beam

After calculating the shear force, the max shear stress can be found by applying the formula for a circular cross-section max = 4V 3A where:

- V = 60.674 lb
- A = Apin = 0.11044 in^2

The calculated max shear stress by the pin is 732.512 psi. When looking at the maximum shear stress for steel, the maximum shear stress is 200-300 MPa.The final material choice for the pins used in this project will be made of 304 stainless steel. The material is cost-effective and easy to manufacture as it is a very common material. The maximum shear stress of 304 stainless steel is 55984.6 psi. This gives a safety factor of 76.428 for the pin which is more than safe for use.

Friction Calculations

The coefficient of friction between rubber and wood is roughly 0.95.

Ffriction = Normal Force * coefficient of friction

Normal force is equal to the applied downward force from the assembly, ladder, and user
Normal Force = Wassembly + Wladder + Wuser = 40 lbs + 68 lbs + 180 lbs = 288 lbs

Ffriction = 288 lbs * 0.95= 273.6 lbs

273.6 lbs of force would have to be applied to the bottom of the assembly to cause slipping. The team does not expect forces of this magnitude to be applied.

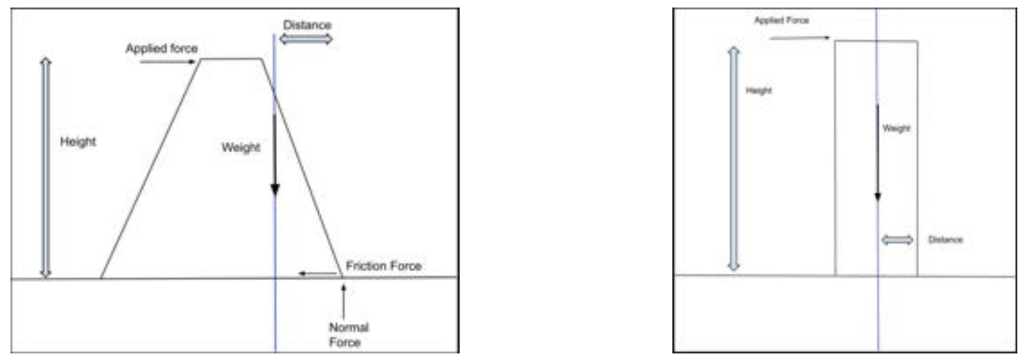
Tipping Calculations

Height =12 ft
Distance= 1.5 ft
Weight =288 lbs
MW = Weight * distance = 288 lbs * 1.5 ft = 432 lbs * ft
MF = Applied Force * Height

If MF > MW , then ladder will tip:

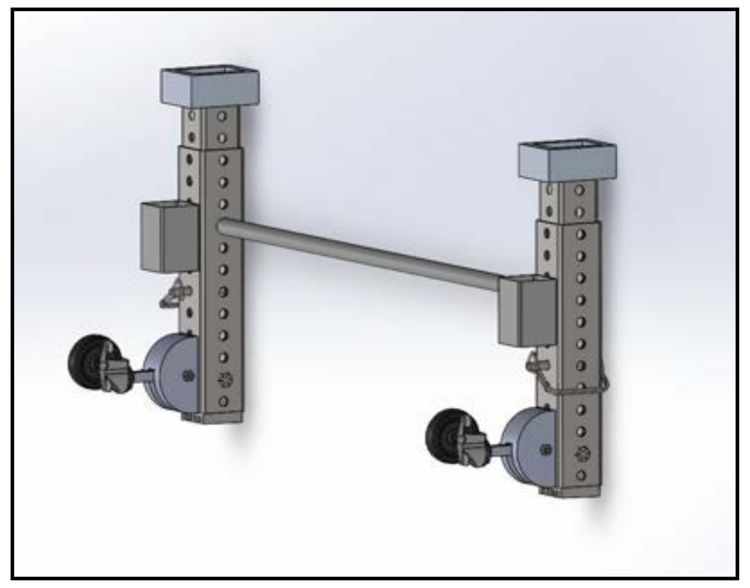
Applied Force * 13 ft = 432 lbs* ft
Applied Force = 33.23 lbs

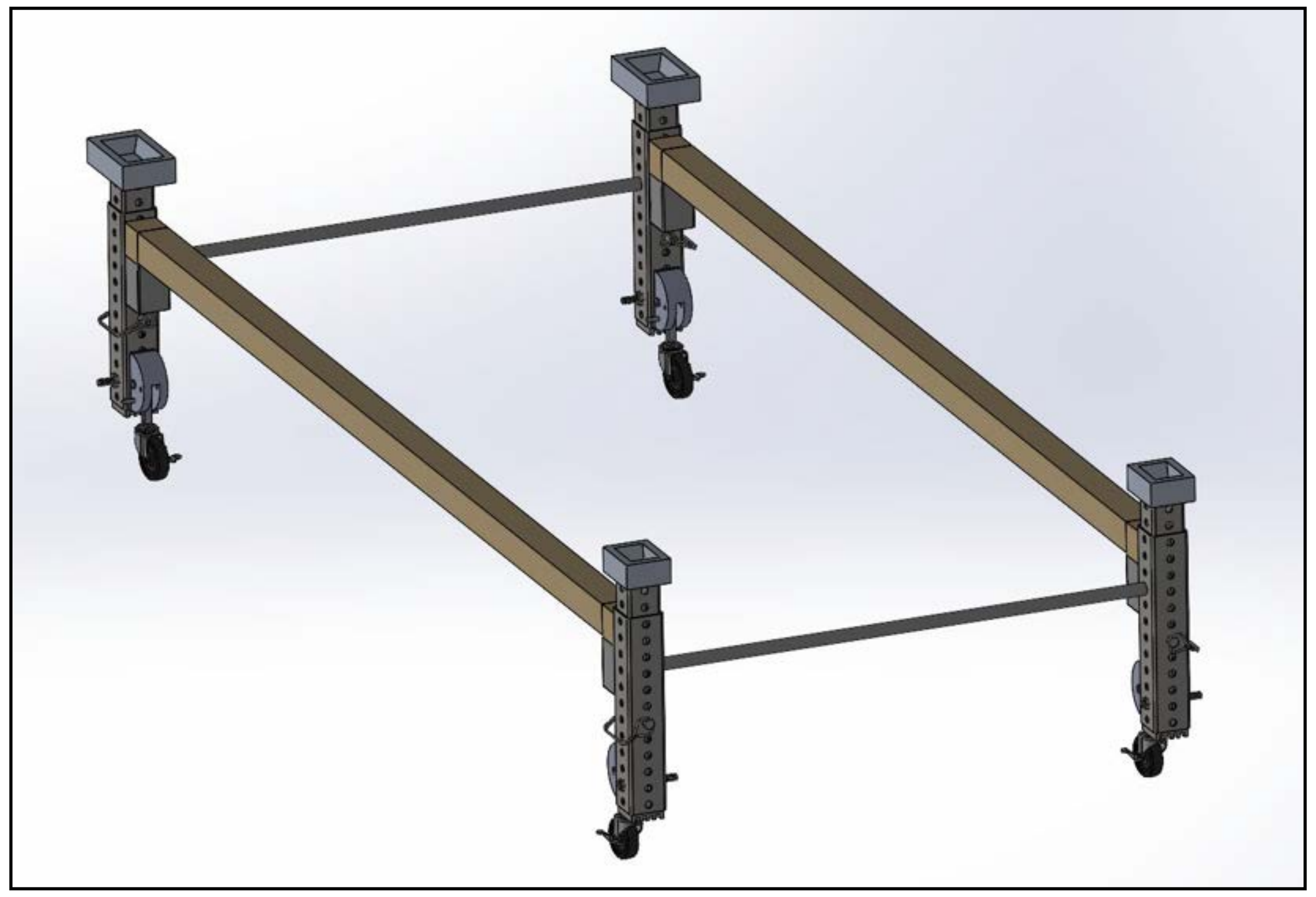
33.23 lbs of applied horizontal force would have to be applied to the top of the ladder to cause tipping.

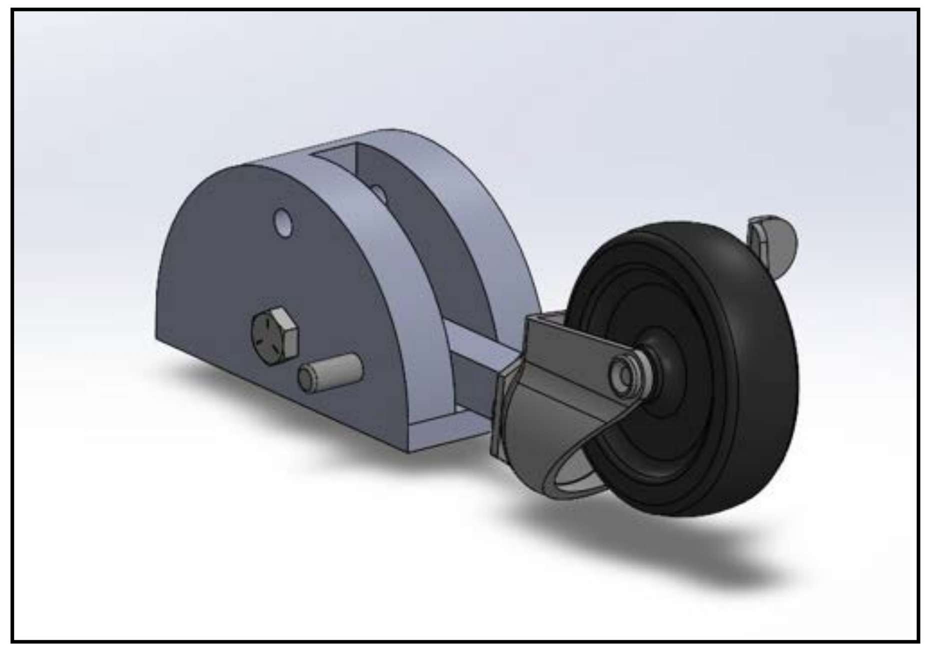


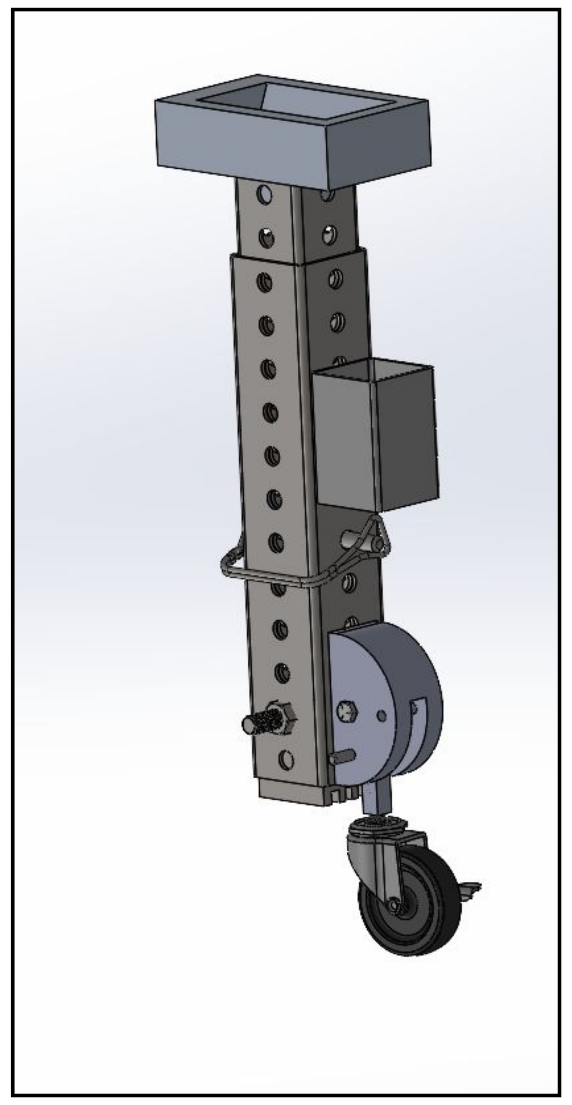
Final Design

Shown below is the main assembly along with the three sub assemblies. The four separate extension legs are unified into one main assembly by the two 3-foot cylindrical support bars and the two 6-foot wooden beams. The support bars are made of steel and will add not only stability but also a bottom step for the user to utilize when climbing onto the ladder. The wooden beams are implemented to support the positioning of the assembly and detach easily for efficient storage. At the base of the extension assemblies, there are rubber ladder shoes as well as foldable wheels. The shoes offer a strong secure base when the device is in operation and the wheels allow for easy transportation to and from storage. Attached on the top of each extension assembly are the fittings that will connect the device to the ladder. The ladder requires two pairs of different sized fittings, one for the front and one for the rear. The final critical design feature is the telescoping rails. The purpose of the rails is to allow the user to adjust the height of the extension device to the desired operation height. The rails range from 1-2 feet which is enough to satisfy the stakeholders main need for a taller ladder.

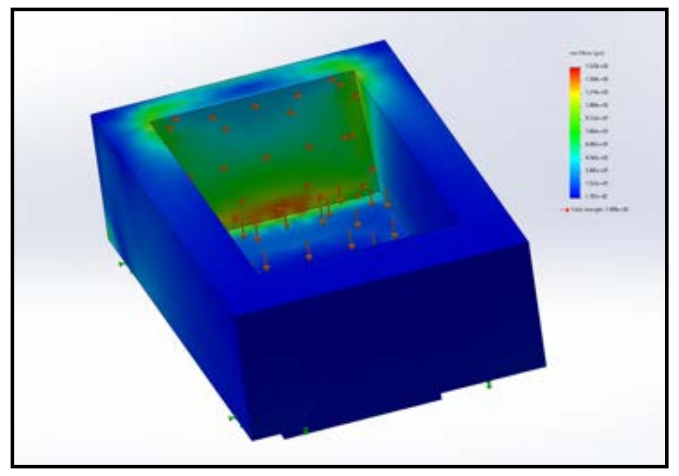




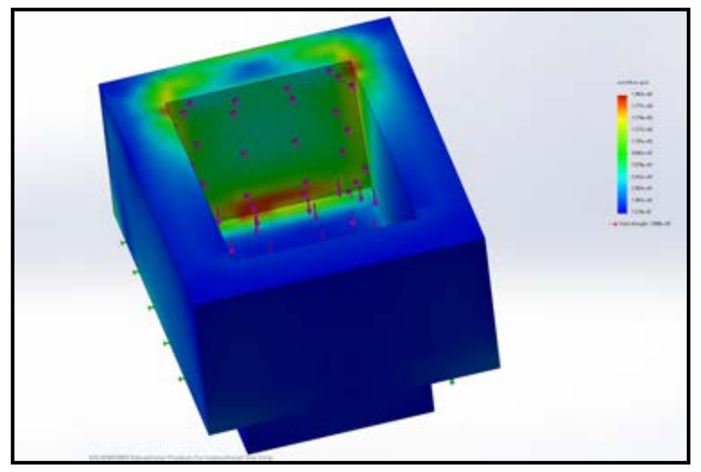




Prototype & Test Results



Von Mises Stress Under Load for Front Fitting



Von Mises Stress Under Load Rear Fitting

To the left shows the results from our FEA tests on the ladder fittings. As the other major support system's safety were easily calculated statically, the fittings required FEA stress tests to decide the final material. After various Von Mises and displacement tests on multiple different materials, the team decided to choose 6061 Aluminum for the fittings for its strength and machinability.

Shown on the left are a couple of images from our prototyping and testing at the academy. The images of the leg extension assemblies show the different stages of the prototyping process. Additionally, the sample ladder fittings are shown being tested with the stakeholders ladder. A few sample fittings were 3D printed to quickly test and refine our fitting design to ensure it operates as expected.