Car Jack

MAE 157 Final Project

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Motivation For The Project

The motivation behind this project is that most heavy duty car jacks that are able to lift trucks are large and unwieldy.

They are required to be wheeled around on rollers and not normally able to be casually stored in smaller vehicles.

Project Objectives

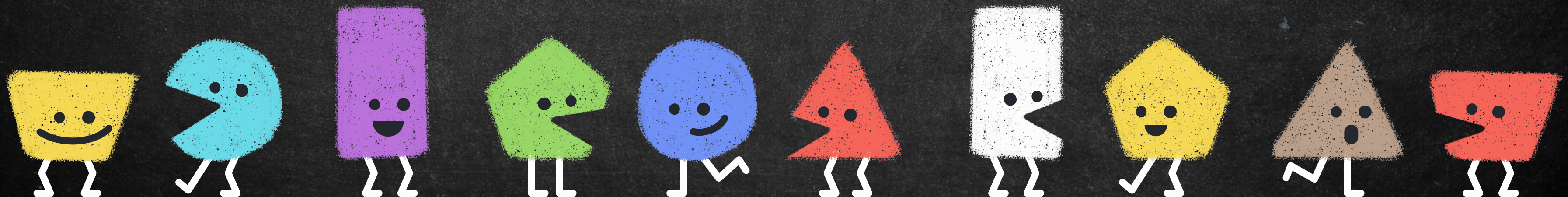
The goal for this project is to design a scissor car jack with:

- Minimum mass
- Ability to lift ¼ the weight of a car (up to a midsize pickup truck)

Description of the car jack

- The jack is made up of 4 equal length beams with a U-shaped cross section arranged in a diamond shape.
- The weight of the car will be applied to the top of the diamond

Approach



For Structural Analysis

The values we need are the stress in the beams, and the displacements of the nodes.

- Stress failure indicates material failure (the jack would break and collapse)
- Displacement failure means that the jack would not be able to lift the car high enough.

Structural analysis: Initial assumptions

- Weight of the car: 18,894.4 N, based on the weight of a Toyota Tacoma
    - Divided by 4
- Car ground clearance: 15 cm, based on the average ground clearance of a sedan
- Desired lift height: 30 cm, based on the average ground clearance of midsize trucks
- Beam length: 18cm

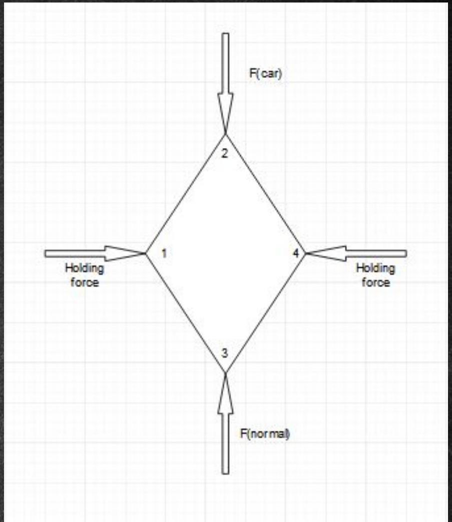
Structural Analysis: stress

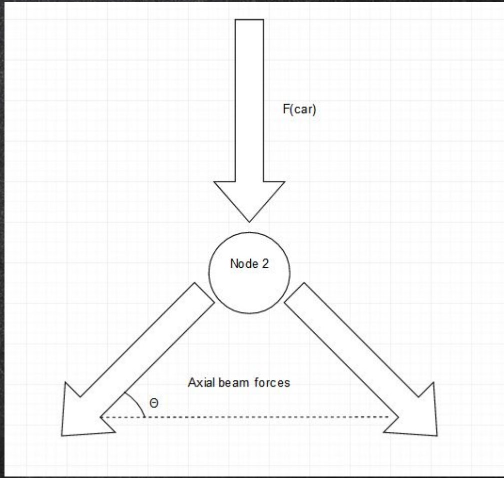
1. Define our boundary conditions for the entire truss

2. Find reaction forces using Newtons Second Law: ΣFx = 0 and ΣFy = 0

3. Use Newton's second law again on each node to find the axial forces in each beam

4. Find the axial stress in each beam using σ = F / A

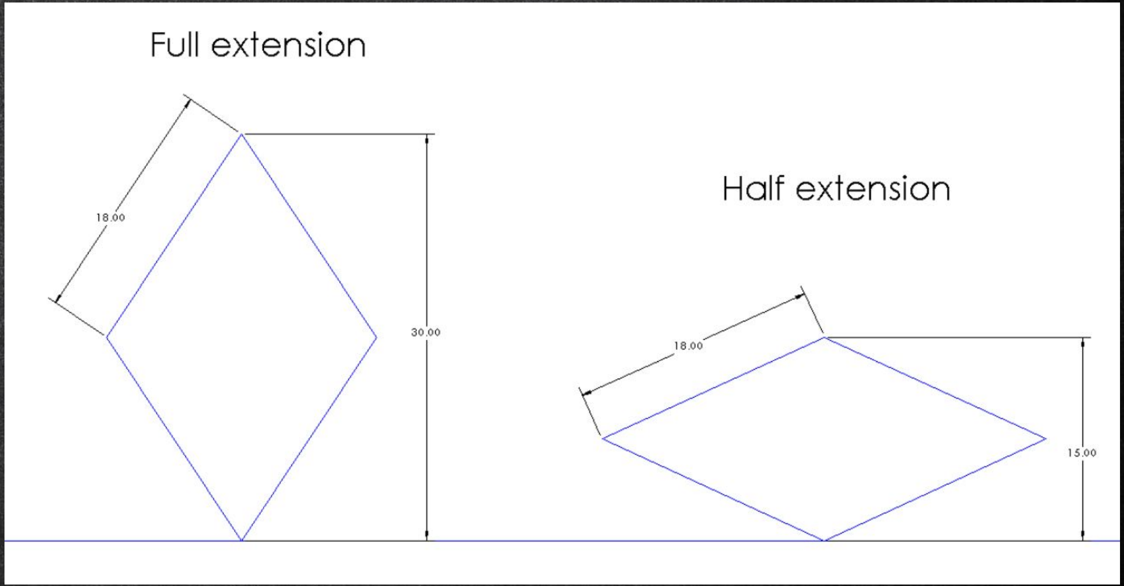




- We found the axial stress in each beam to be:

[σ = -5668 / A] Pa at half extension
[σ = -2833 / A] Pa at full extension

- “A” denotes the cross sectional area of the beam
- The stresses are negative denoting compressive stress
- We can disregard the stress at full extension. Since it is lower than our half extension stress, it will not dictate our minimum mass



Structural Analysis: Displacement

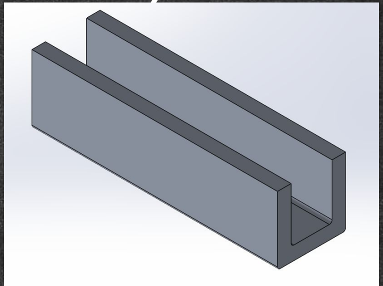
1. Define our boundary conditions
2. Using these boundary conditions define our vectors for node forces (F) and node displacements (U)
3. Find the stiffness matrix of each beam
4. Find the stiffness matrix of the entire truss K
5. Create the system of equations F = K * U
6. Solve the system of equations to find the displacement of each node.

```
%set the matrix equal to boundary conditions and solve
for i = 1:8
    e(i, 1) = K(i) == forces(i);
end
vpa(e, 6)

sol = solve(e, [fx1 fx3 fy3 fx4 uy1 ux2 uy2 uy4]);
```

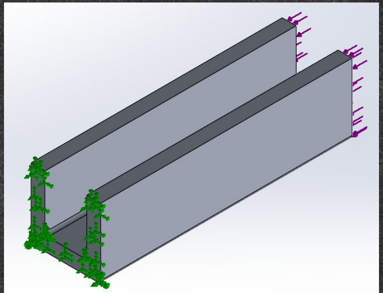
```
%stiffness matrices of each beam
K12 = [c12^2      c12*s12    -(c12^2)        -(c12 * s12) 0 0 0 0;
       c12*s12    s12^2        -(c12 * s12)    -(s12^2) 0 0 0 0;
       -(c12^2)   -(c12 * s12) c12^2           c12*s12 0 0 0 0;
       -(c12*s12) -(s12^2)     c12*s12         s12^2 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;];

K13 = [c13^2      c13 * s13    0 0 -(c13^2)        -(c13 * s13) 0 0;
       c13*s13    s13^2        0 0 -(c13 * s13)     -(s13^2) 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       -(c13^2)   -(c13 * s13) 0 0 c13^2           c13*s13 0 0;
       -(c13*s13) -(s13^2)      0 0 c13*s13         s13^2 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       ];

K24 = [0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 c24^2      (c24 * s24)  0 0   -(c24^2)        -(c24 * s24);
       0 0 c24*s24    s24^2      0 0   -(c24 * s24)    -(s24^2);
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0  -(c24^2)   -(c24 * s24) 0 0  c24^2           c24*s24;
       0 0 -(c24*s24) -(s24^2)     0 0 c24*s24         s24^2;];

K34 = [0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 c34^2      c34 * s34    -(c34^2)        -(c34 * s34);
       0 0 0 0 c34*s34    s34^2        -(c34 * s34)    -(s34^2);
       0 0 0 0 -(c34^2)   -(c34 * s34) c34^2           c34*s34;
       0 0 0 0 -(c24*s34) -(s34^2)     c34*s34         s34^2;];

%combine the stiffness matrices
K = (K12 + K13 + K24 + K34);
vpa(K, 6);
K = (E * A / L) * K * u;
```

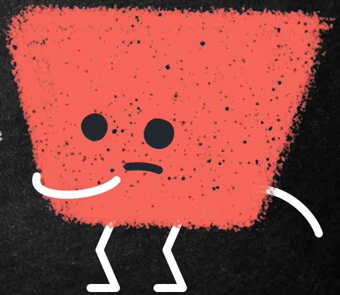
Simulation Setup (Bar Member)

1. Model:
   a. Simple Bar with consistent cross section



2. FEA Setup:
   a. Pink Arrows are a Force Applied
      i. 5668N applied evenly over face
   b. Green Arrows are Fixed Geometry at the Bottom.

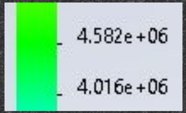




Simulation Validation

Material: 6061 Alloy
t = 0.01M
B and H = 0.05M

Stress

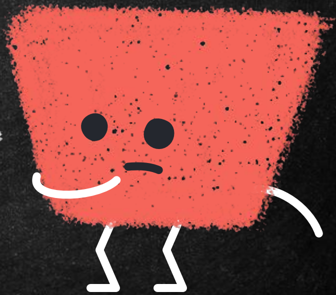


~=

```
sigma =

   4.3604e+06
```

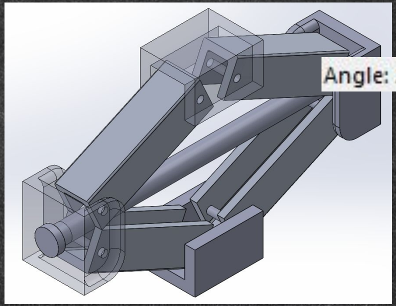
```
%Yield Criterion
syms sigma sigmastar t B F A SF
sigmastar = 5.515e7
SF = 1.5
B = 0.05
F = 5668.53
t = 0.01
A = 3*B*t - 2*t^2
sigma = F/A
```

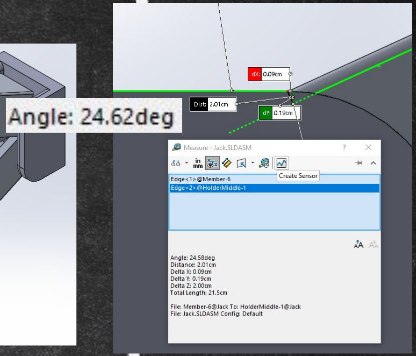
In the right ballpark!



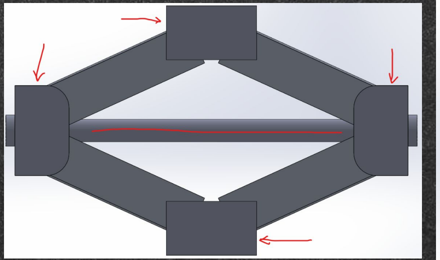
Simulation Setup (Jack Assembly)

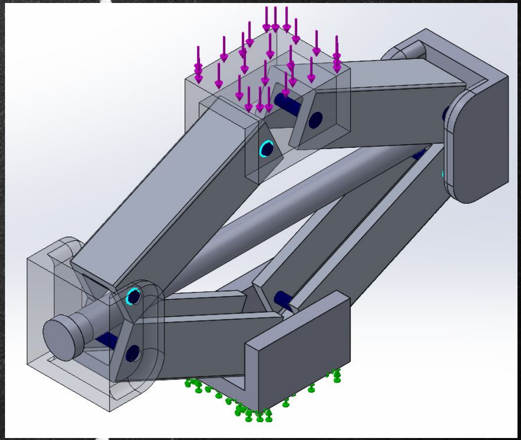
1. **Model:**
   a. Cross sections of bars
   b. Length of bars
   c. Angles match Truss Analysis





2. **FEA Setup:**
   a. Red marked components were made rigid
   b. Blue Cylinders are Pin Connections
   c. Pink Arrows are a Force Applied (4733N)
   d. Green Arrows are Fixed Geometry at the Bottom.

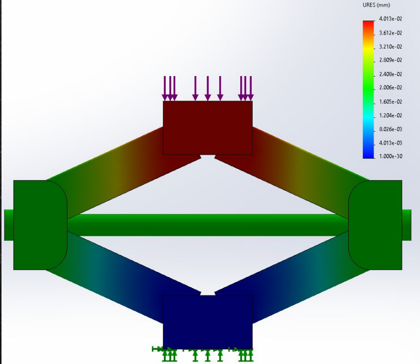




Simulation Validation

Material: 6061 Alloy
t = 0.01M
B and H = 0.05M

Displacement



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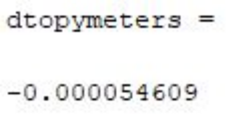
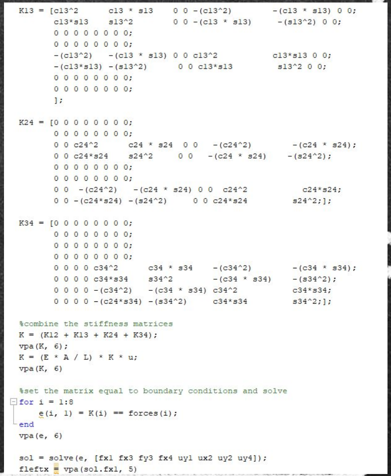
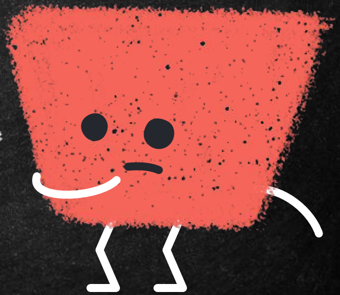


Within 1/100 mm!



```
K13 = [c13^2      c13 * s13    0 0 -(c13^2)        -(c13 * s13) 0 0;
       c13*s13    s13^2        0 0 -(c13 * s13)     -(s13^2) 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       -(c13^2)   -(c13 * s13) 0 0 c13^2            c13*s13 0 0;
       -(c13*s13) -(s13^2)      0 0 c13*s13          s13^2 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       ];

K24 = [0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 c24^2      c24 * s24  0 0   -(c24^2)        -(c24 * s24);
       0 0 c24*s24    s24^2     0 0   -(c24 * s24)    -(s24^2);
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0  -(c24^2)   -(c24 * s24) 0 0  c24^2            c24*s24;
       0 0 -(c24*s24) -(s24^2)     0 0 c24*s24          s24^2;];

K34 = [0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 0 0 0 0;
       0 0 0 0 c34^2      c34 * s34    -(c34^2)        -(c34 * s34);
       0 0 0 0 c34*s34    s34^2        -(c34 * s34)    -(s34^2);
       0 0 0 0 -(c34^2)   -(c34 * s34) c34^2           c34*s34;
       0 0 0 0 -(c24*s34) -(s34^2)     c34*s34         s34^2;];

%combine the stiffness matrices
K = (K12 + K13 + K24 + K34);
vpa(K, 6);
K = (E * A / L) * K * u;
vpa(K, 6)

%set the matrix equal to boundary conditions and solve
for i = 1:8
    e(i, 1) = K(i) == forces(i);
end
vpa(e, 6)

sol = solve(e, [fx1 fx3 fy3 fx4 uy1 ux2 uy2 uy4]);
fleftx = vpa(sol.fx1, 5)
```



Failure Criteria

Yield Failure Criterion

- Stress values from structural analysis
- Found material failure stress though yield stress
- Used 25 as Safety factor

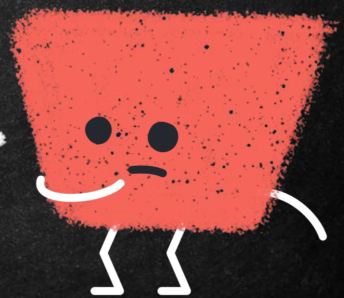
- Plugged into and solved for t

$$\Phi_{\sigma} \sigma \leq \sigma^{*}$$

**We created Matlab code to repeat calculations

Matlab Code

```
clear
clc
%Yield Criterion
syms sigma sigmastar t B F A SF
sigmastar = 5.515e7
SF = 1.5
B = 0.05
F = 5668.53
t = 0.01
A = 3*B*t - 2*t^2
sigma = F/A

eqn = SF*sigma == sigmastar
S = vpa(solve(eqn,t))
```



Failure Criteria

Buckling Failure Criterion

- Stress values from structural analysis
- Used 25 as Safety factor
- Found Critical Stress through:

$$\sigma_{cr} = \pi^2 EI/(KL)^2$$

Inertia

$$I = -2t^4 + 35t^3 - 150t^2 + 250t$$

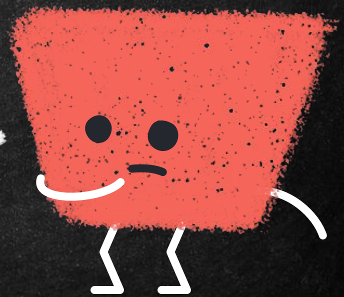
- Plugged into and solved for t

$$\Phi_b \sigma \leq \sigma_{cr}$$

**We created Matlab code to repeat calculations

Matlab Code

```
clear
clc
%Buckling Criterion
syms L t SF B F E I K A Sigma Sigmacr
SF = 25;
B = 0.05;
F = 5668.53;
E = 69e9;
K = 1;
L = .18;
I = (B*(t^3)+2*t*((B-t)^3))/3;
A = 3*B*t - 2*t^2;
Pcrit = ((pi^2)*E*I/((K*L)^2));
Sigma = F/A;
Sigmacr = Pcrit/A

eqn = SF*Sigma == Sigmacr
solutions = vpa(solve(eqn,t))
```



Minimum Mass Design

- Equation used : m =ρ x L x A
- Used minimum thickness found through the failure criteria
- Used three different materials , so found three different densities
- Created a Matlab script to do the calculations for the minimum mass.
- Repeated process for the rest of the minimum thickness

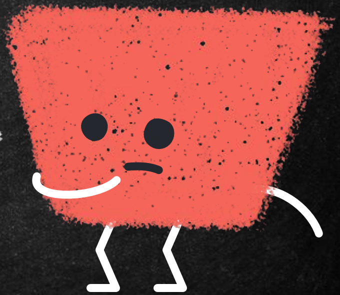
```
clear
clc
% Minimum Mass
syms Density L A B t m_i;
Density = 2810;
L = 0.18;
t = 0.0005198894197323006737573663303929;
B = 0.05;
A = 3*B*t - 2*t^2;
m_i = Density*L*A;

TotalMinimumMass= 4*m_i
```

Results

- ➜ Disregarded the full-extension minimum mass because it will be higher
- ➜ The minimum masses shown resulted by using the minimum thickness from the yielding criterion

Half-Extension: From yielding criterion:

Material	Modulus of Elasticity(Pa)	Density (kg/m^3)	Force(N)	Minimum t (m)	Minimum mass (kg)
6061	69 x 10^9	2700	1558.15	0.000953021844223008596720720973442 93	0.274369891304348
304	190 x 10^9	8000	1558.15	0.000507692350399138061047910370346 44	0.435676893203884
7075	71.7 x 10^9	2810	1558.15	0.000519889419732300673757366330392 9	0.156682359840954

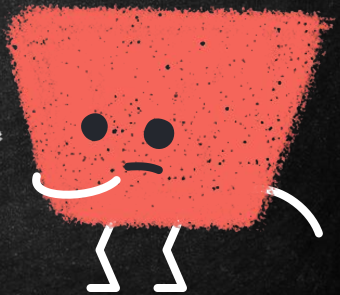


Results

Half-Extension: From Buckling Failure Criterion

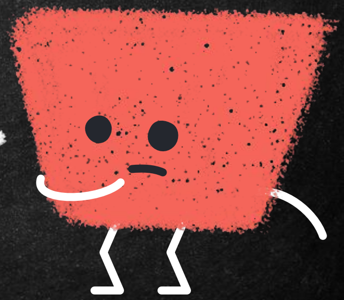
Material	Modulus of Elasticity(Pa)	Density (kg/m^3)	Force(N)	Minimum t (m)	Minimum mass (kg)
6061	69 x 10^9	2700	1558.15	0.000022269325626605371937165562377606	0.006491807204623
304	190 x 10^9	8000	1558.15	0.0000080803979590718381263633147880078	0.006980711663223
7075	71.7 x 10^9	2810	1558.15	0.000021429651797855527177339795901136	0.006501612499438

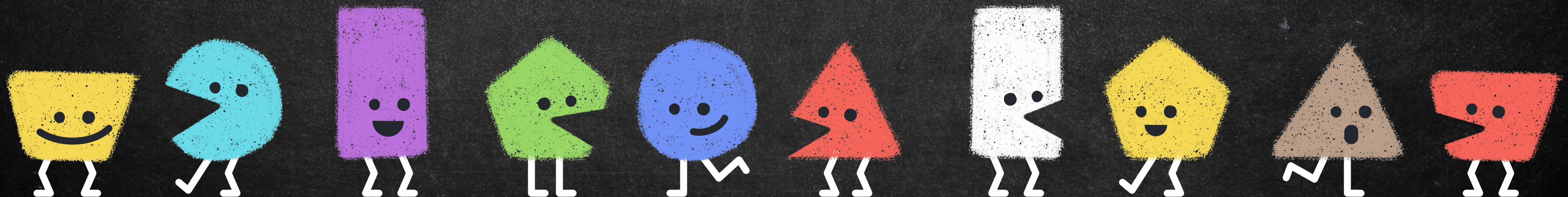
- ➜ The above minimum mass resulted from using the minimum thickness from the buckling failure criterion
- ➜ We found that the material 6061 Aluminum gives us our overall minimum mass of 6.491×10^{-3} kg.



FEA

- Waiting on minimum thicknesses from Failure Criteria, but models and simulations have been validated.

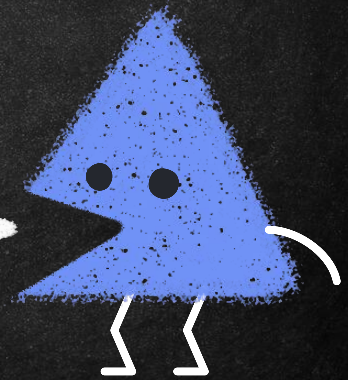




Issues Solved

1. Everyone redid the truss analysis and stress calculations independently
    a. Still getting nonsense answers for t
2. Stress calculations were validated by hand and FEA.
3. Eventually realized that all our work was correct
    a. Issues arose after applying Failure Criteria
        i. Thus our Safety Factor was too Low

Increased Safety Factor from 1.5 to 25
(to keep the humans safe)



Issues Encountered

1. Initially, Safety Factor was set to 1.5

```
%Yield Criterion
syms sigma sigmastar t B F A SF
sigmastar = 5.515e7
SF = 1.5
B = 0.05
F = 5668.53
A = 3*B*t - 2*t^2
sigma = F/A

eqn = SF*sigma == sigmastar
S = vpa(solve(eqn,t))
```

```
S =

0.0010423244932635925448599003 1994
0.073957675506736407455140099 68006
```

2. Caused a lot of issues: Numbers produced were not analyzable on FEA or simply impossible.
3. The truss analysis was confirmed with the simulation

So why aren’t we getting realistic values for thickness???