Department of
Mechanical Engineering
UNIVERSITY of WEST FLORIDA

Trebuchet Pensacola

Intro:

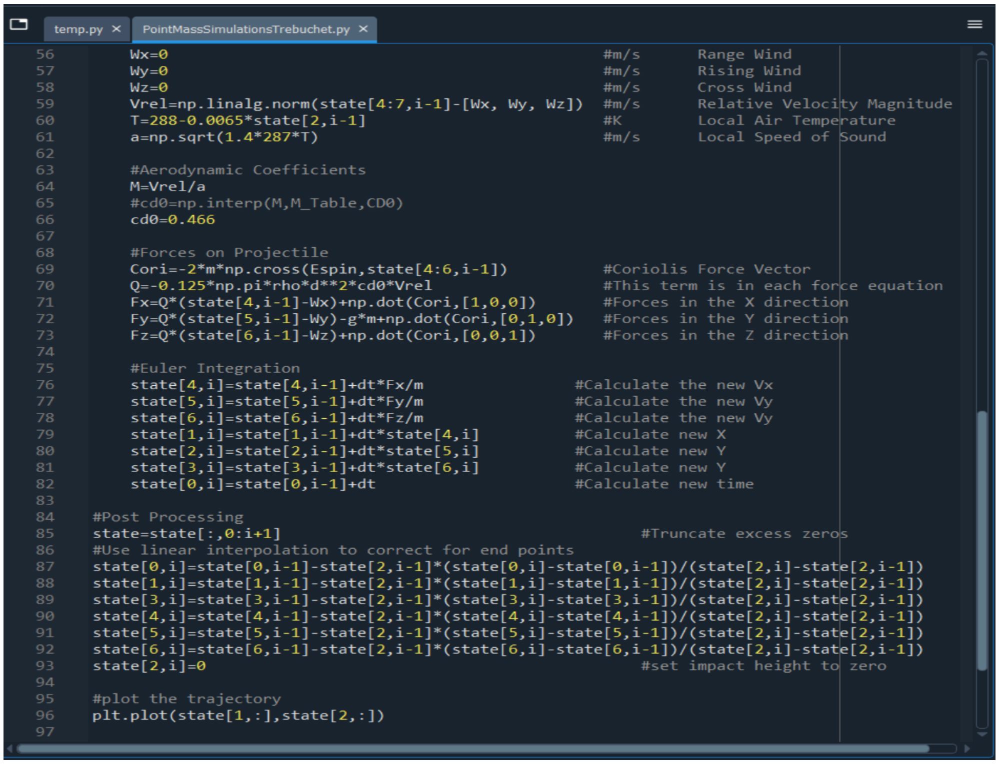
The Pensacola Trebuchet team sought out to build a large-scale medieval-style trebuchet that is capable of launching a 25 lb projectile 150 yards with a reload speed of ~1 minute. In reality, the team would only be capable of firing a 10lb projectile 60 yards due to material availability. In order to accomplish this the team split into four sub-teams each responsible for making a design tool for their respective part of the trebuchet. The teams are the Ballistics team, responsible for all things to do with predicting the flight path of the projectile; the Structure team, responsible for designing a base structure strong enough to support the heavy loads during launch; the Release Mechanism team, responsible for the precise release of the projectile with adjustable launch angles; and the Beam team, similar to the Structure responsible for finding the correct material and size/proportions for a sturdy beam strong enough for the launch. The design tools the individual teams came up with were specific to their needs/capabilities as engineers

Ballistics:

For the ballistics team, the objective of last semester was to create a design tool to calculate the range at any velocity, starting height, or dimensions of the projectile. The ballistics team successfully made an accurate program that calculates the range, height, and flight time of the projectile put into the program. It also produces a graph showing the trajectory of the projectile. Since an easy and convenient way to calculate range was made, this left the team with determining a projectile.

At the beginning of the Spring semester, before building, the trebuchet had to be reduced to nearly half its size due to transportation and legal issues. This meant the starting height and velocity would be reduced significantly. From the program, the team found that it would be impossible to throw the projectile 150 yards with the new launch velocity and height, no matter how small the 25-lb projectile was. This meant one of the objectives had to be changed instead of having a range of 150 yards it was reduced to 60 yards. Everything was adjusted to this new goal, but due to the beam breaking, the team wasn't able to test out the Trebuchet, but if a new, stronger beam were used theoretically it should be within that range.

Another objective was to find a suitable projectile material to make into 25-lb spherical balls. To determine the best material three candidates were researched and tested. These were ice, sand, and dirt. From the research it was found that the sand and glue mixture would be ideal. It had a relatively low diameter which meant easy storage and transport, but it was also abundant and environmentally friendly. When testing, smaller samples of the hypothetical projectile were made, but later on it was found that no matter what ratio of glue to sand, the ball would not dry. So after testing, it was concluded that with our budget, it would be nearly impossible to find any material that could meet the criteria. The new criteria for the projectile was a 10-lb spherical projectile, and watermelons were found to be suitable for this project.



```
temp.py   PointMassSimulationsTrebuchet.py
    Wx=0                                              #m/s     Range Wind
    Wy=0                                              #m/s     Rising Wind
    Wz=0                                              #m/s     Cross Wind
    Vrel=np.linalg.norm(state[4:7,i-1]-[Wx, Wy, Wz])  #m/s     Relative Velocity Magnitude
    T=288-0.0065*state[2,i-1]                         #K       Local Air Temperature
    a=np.sqrt(1.4*287*T)                              #m/s     Local Speed of Sound

    #Aerodynamic Coefficients
    M=Vrel/a
    #cd0=np.interp(M,M_Table,CD0)
    cd0=0.466

    #Forces on Projectile
    Cori=-2*m*np.cross(Espin,state[4:6,i-1])          #Coriolis Force Vector
    Q=-0.125*np.pi*rho*d**2*cd0*Vrel                  #This term is in each force equation
    Fx=Q*(state[4,i-1]-Wx)+np.dot(Cori,[1,0,0])       #Forces in the X direction
    Fy=Q*(state[5,i-1]-Wy)-g*m+np.dot(Cori,[0,1,0])   #Forces in the Y direction
    Fz=Q*(state[6,i-1]-Wz)+np.dot(Cori,[0,0,1])       #Forces in the Z direction

    #Euler Integration
    state[4,i]=state[4,i-1]+dt*Fx/m                 #Calculate the new Vx
    state[5,i]=state[5,i-1]+dt*Fy/m                 #Calculate the new Vy
    state[6,i]=state[6,i-1]+dt*Fz/m                 #Calculate the new Vy
    state[1,i]=state[1,i-1]+dt*state[4,i]           #Calculate new X
    state[2,i]=state[2,i-1]+dt*state[5,i]           #Calculate new Y
    state[3,i]=state[3,i-1]+dt*state[6,i]           #Calculate new Y
    state[0,i]=state[0,i-1]+dt                      #Calculate new time

#Post Processing
state=state[:,0:i+1]                                          #Truncate excess zeros
#Use linear interpolation to correct for end points
state[0,i]=state[0,i-1]-state[2,i-1]*(state[0,i]-state[0,i-1])/(state[2,i]-state[2,i-1])
state[1,i]=state[1,i-1]-state[2,i-1]*(state[1,i]-state[1,i-1])/(state[2,i]-state[2,i-1])
state[3,i]=state[3,i-1]-state[2,i-1]*(state[3,i]-state[3,i-1])/(state[2,i]-state[2,i-1])
state[4,i]=state[4,i-1]-state[2,i-1]*(state[4,i]-state[4,i-1])/(state[2,i]-state[2,i-1])
state[5,i]=state[5,i-1]-state[2,i-1]*(state[5,i]-state[5,i-1])/(state[2,i]-state[2,i-1])
state[6,i]=state[6,i-1]-state[2,i-1]*(state[6,i]-state[6,i-1])/(state[2,i]-state[2,i-1])
state[2,i]=0                                                  #set impact height to zero

#plot the trajectory
plt.plot(state[1,:],state[2,:])
```

Figure 1. Design Tool for Range

Figure 2. Watermelon Projectile

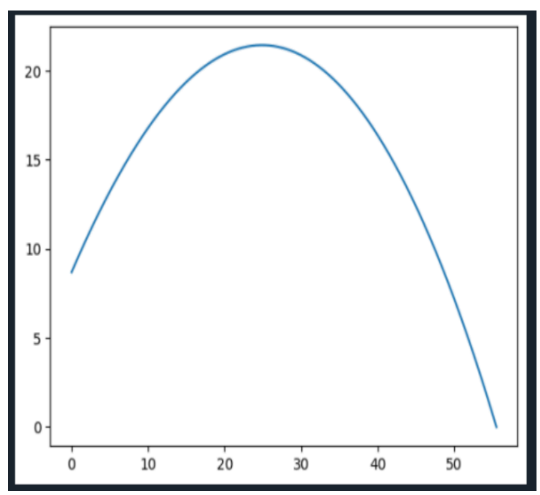


Figure 3. Trajectory Graph

Release Mechanism:

Release Mechanism had one of the more complex jobs as a team because it was important for functionality to create a design that had consistent launches, adjustability and accuracy. The goal was to create a mechanism that could be adjusted in order to alter the release angle but have a predictable trajectory when fired. In order to adjust the angle of release it was decided that the most effective way was to design variable angle fingers on the end of the beam. The final design of the release sling consisted of a rubber mat and lightweight low stretch rope clamped together with a sheet metal bracket pictured in Figures 4 and 5 below.

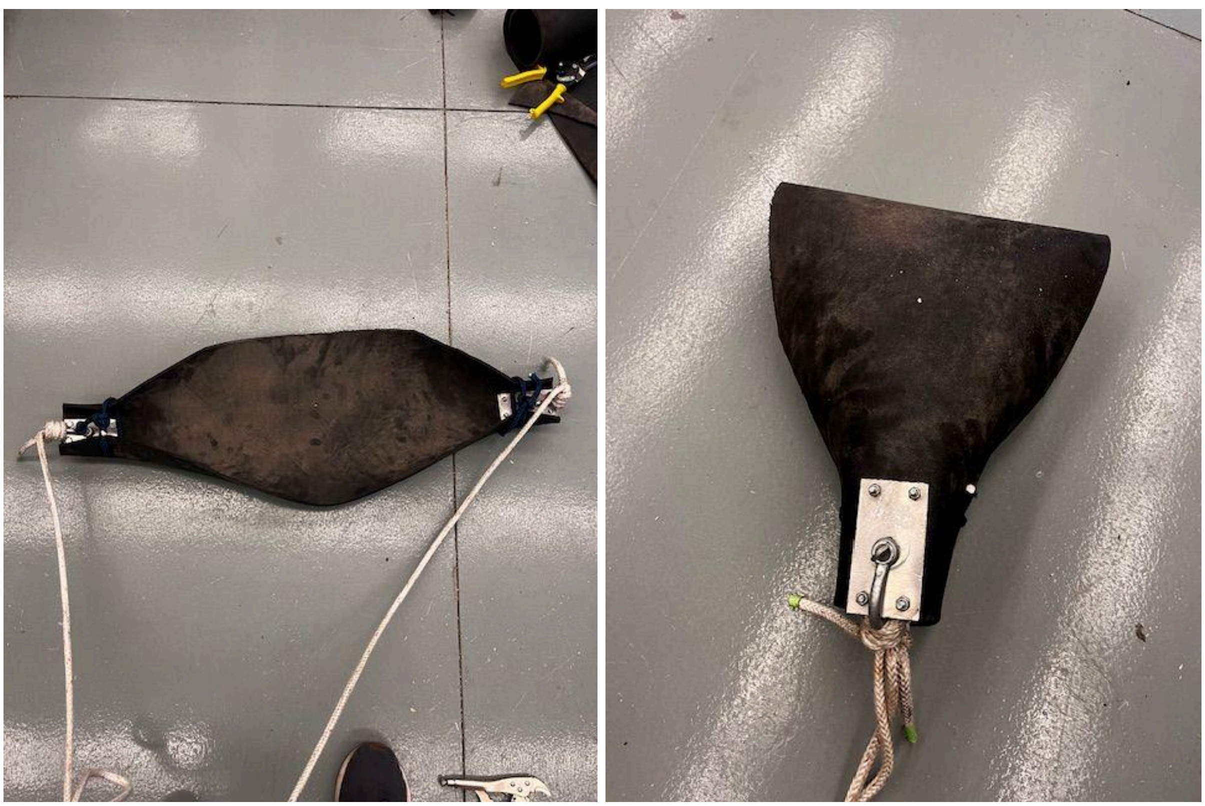


Figure 4/5. Final Release Mechanism Design.

Structure:

The Structure Team was tasked with creating a base structure capable of supporting the weight of our design, both static and dynamic. Along with a CAD model (figure 7), the Structure team did a manual analysis (Figures 4 & 5) of the material to cross-examine with the model so that they were absolutely certain the structure would support the loads with high confidence. The structure team was also tasked with choosing a pivot rod and to make sure the pivot rod can hold up to the forces of the design (figure 9) stress/strain the team could be absolutely certain of their design capabilities. The structure team then took the model from solidworks into the real world and did more testing to be sure the structure will be able to withstand the real world forces. The completed trebuchet structure is shown in figure 9 & 10 this structure was completed using the exact calculations we did in the design tools.

Dimensions:	**Forces:**	**Angles:**	**Weights:**
length of base (x) (ft)	weight of beam (w) (lb)	angle A(θ) degrees	weight of beam (lb)
13.00	1000.00	60.00	150.00
length of A (y) (ft)	weight of beam w/ safety factor of 4 (lb)	Angle B(θ) degrees	weight of counter-weight (lb)
13.00	4000.00	60.00	1000.00
length of B (y) (ft)	weight for one side (w/2) (lb)	Angle C(θ) degrees	weight of projectile (lb)
13.00	2000.00	60.00	25.00
height (h) (ft)		Angle (ϕ) degrees	weight of sling (lb)
11.26		30.00	25.00

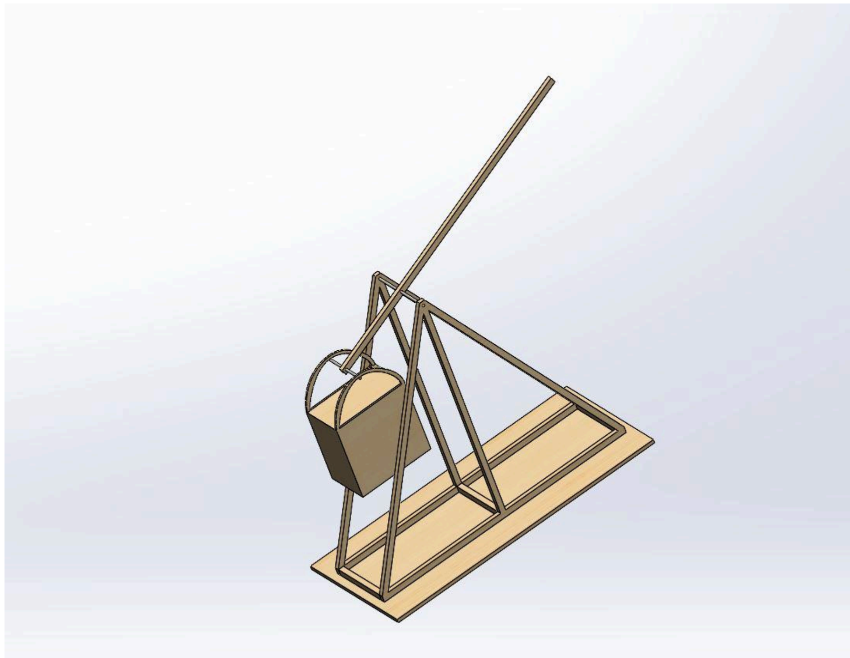
Figure 6. design tool for structural analysis

Buckling Calculations for Wood Beams	
section of beam (in)	modulus of elasticity (lbf/in^2) (white oak)
3.50	1800000.00
moment of solid sqaure wood beam (in^4)	
12.51	
critical buckling load of solid beam (lbs)	
9128.79	

Figure 7. buckling calculation of wood

Rod Strength:		
rod diameter (in)	Modulus of elasticity (psi)	K
1.50	27000000.00	1.00
length (in)	the area moment (I)	
48.00	0.25	
force (lbs)		
28725.67		

Figure 8. design tool for pivot rod



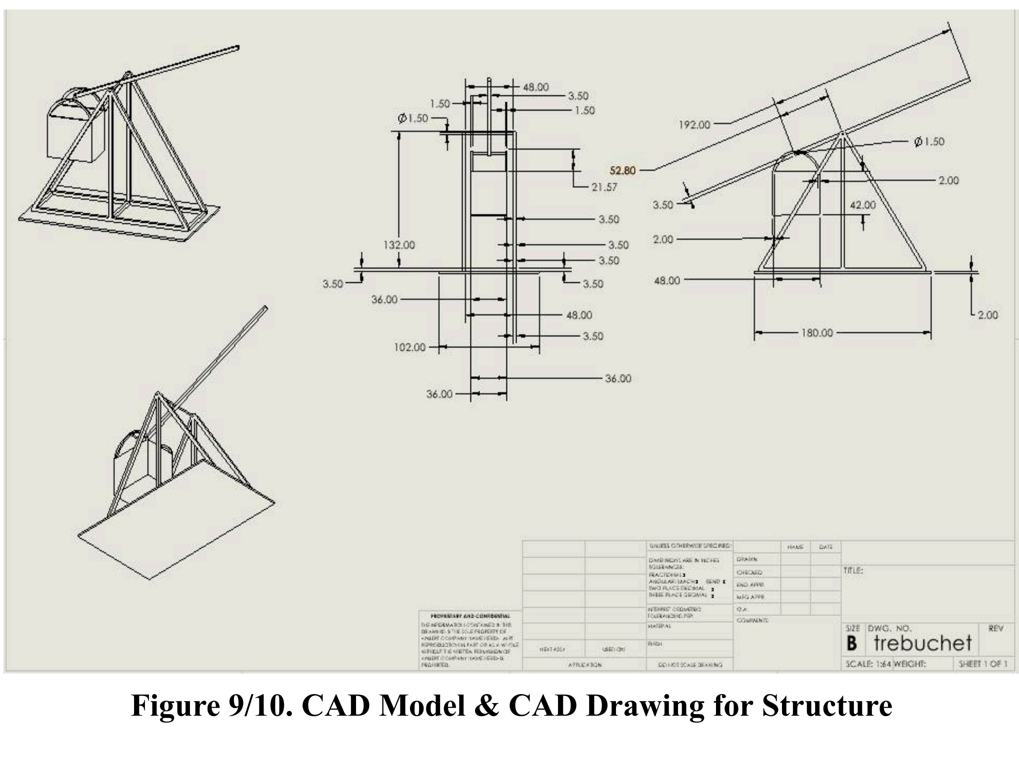


Figure 9/10. CAD Model & CAD Drawing for Structure

Figure 11. Fabricated Structure

Beam:

Buckling Calculations for Metal Beams:		**Rod Strength:**		
section of beam (in)	modulus of elasticity(lbf/in^2)	rod diameter (in)	Modulus of elasticity (psi)	K
2.00	29000000.00	1.50	27000000.00	1.00
moment of solid square metal beam (in^4)	moment of hollow beam (in^4)	length (in)	the area moment (I)	
1.33	5.42	48.00	0.25	
cirtical buckling load of solid beam (lbs)	cirtical buckling load of hollow beam (lbs)	force (lbs)		
15681.46	63705.94	28725.67		
Buckling Calculations for Wood Beams				
section of beam (in)	modulus of elasticity (lbf/in^2) (white oak)			
3.50	1780000.00			
moment of solid sqaure wood beam (in^4)				
12.51				
critical buckling load of solid beam (lbs)				
9027.36				

Figure 12. Buckling Calculations

Budget:

In figure 13 below all of the purchases and donations have been well documented. Most of the income came from generous donors from GoFundMe along with a $1000 grant from the university. One of the biggest purchases that could potentially be used in future projects is the $1400 trailer that was used to build the trebuchet on top of. The team went over budget by a lot due to the miscommunication about precisely what to buy and a lack of understanding what tools would work best for our use case.

Date:	Deposit:	Withdrawal:	Comments:			
8/19	$1,000.00		*ME Department Contribution*		**Total Earned:**	$3,582.22
10/11	$10.00		*Liberty Moench Donation*		**Total Spent:**	$3,177.12
10/18	$500.00		*Vision Construction Donation*		**Available:**	$405.10
10/19	$500.00		*Jose Santiesteban Donation*			
10/21	$100.00		*Elly Fisher Donation*			
10/21	$200.00		*Jason Rebol Donation*			
10/21	$200.00		*Daniel Grundhoefer Donation*			
10/21	$100.00		*Drew Lenn Donation*			
10/21	$200.00		*Richard Russel Donation*			
10/22	$250.00		*Jason Courtney*			
10/22	$200.00		*Victor Wallace*			
10/30	$100.00		*Jones Flooring Center*			
11/2	$50.00		*Lynn McQuaig*			
11/2	$100.00		*Lynn McQuaig*			
11/4		$76.69	*Transaction Fees*			
11/11		$16.64	*Walmart: Bearings*			
11/11		$74.58	*Lowes: Wood, nails, screws, square, spikes, and dowel*			
11/15		$12.60	*Home Depot 2x4*			
11/15		$38.69	*Poster*			
		$122.90	*TSC: Rubber Mat, Nuts, Bolts, Washers, Nylon*			
		$21.67	*Lowes: Sand and Glue*			
		$471.42	*Home Depot 4x16*			
		$367.41	*Carbon Steel Rod, Winch, Pivot Bearings*			
		$1,400.00	*Trailer*			
		$98.82	*TSC: Nuts, Bolts, Lag Screws.*			
4/3	$48.25		*GoFundMe*			
4/3		$4.03	*TSC Washers*			
		$42.00	*Renaissance Faire Poster*			
4/3	$23.97		*GoFundMe*			
4/10		$36.85	Home depot: Screws 1.5' hole saw			
4/12		$36.65	Home Depot: Carabiner, 0.5" I-Bolts, 0.5" Washer			
4/13		$46.00	Harbor Freight: Winch			
4/11		$43.45	Lowe's: CW Bag			
4/14		$42.00	OUR Poster			
4/15		$60.19	West Marine: Snap Shackle			
4/17		$115.24	Home Depot: Sand			
4/13		$44.68	West Marine: 3/8 Shackle, 5/16/ft Line			
4/13		$4.61	Harbor Freight: Grommet			

Figure 13. Budget Spreadsheet

Accomplishments/Conclusion:

This semester when all was set and ready to fire, catastrophe struck. The counterweight began lifting as it was being hoisted up by the winch and suddenly, the main beam snapped. All the calculations, re calculations, multiple design iterations all leading up to this very moment, all for not. The calculations were reevaluated and it seems some drastic oversights lead to critical failure. What ultimately led to the beam failing under load was when doing the stress and buckling calculations of the main beam, the 1.5 inch pivot hole necessary for the pivot rod was not considered. Rerunning the tests with a weaker beam proved this is what ultimately led to failure. It is important to recognize that the team learned a lot about what it takes to be a good engineer, with good engineering practices, decision making, and work ethic. Unfortunately, without the critical element of the design testing the other elements of our design was impossible, at least for a most accurate test. An accurate CAD Force analysis was done on the main beam with the pivot hole and is shown below (Figure 14). With the existence of a pivot hole in the 4x4x16 pressure treated pine is incapable of sustaining the load. In the future a 6x6 or 8x8 beam would likely be more suited for a trebuchet of this scale. This would increase budget and safety concerns especially when trying to maneuver it 12 ft in the air.

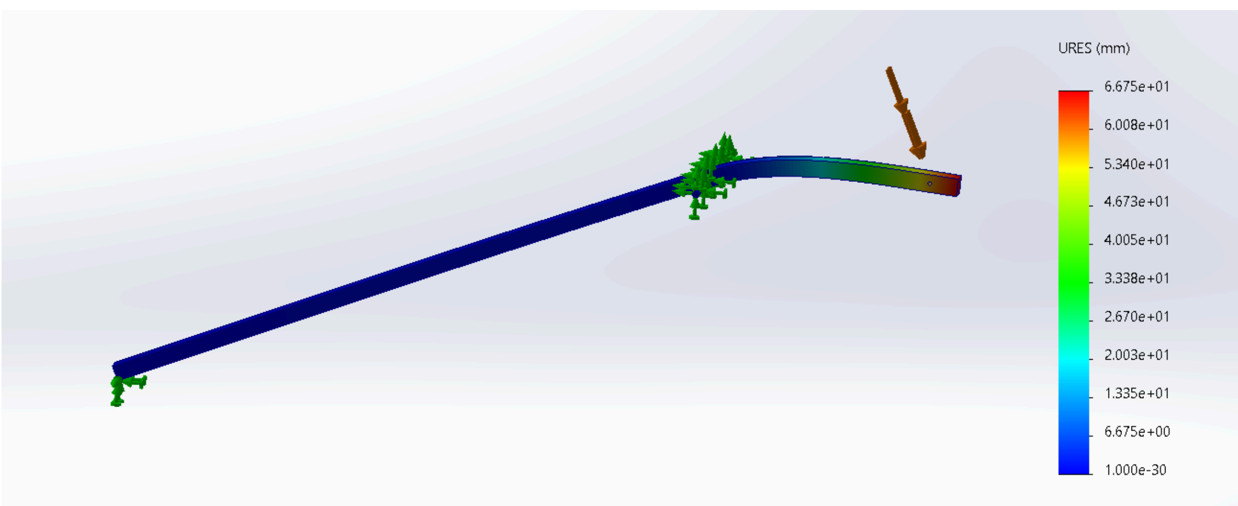


Figure 14. Stress Analysis with Pivot hole