

# **Individual Analytical Analysis**

## **PHS Sustainability Capstone**

### **Structural Analysis**



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**ME 476C**

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**I. Introduction**

The purpose of this analysis is to evaluate the structural stability of the proposed bicycle stand for the PHS Capstone bicycle generator using different materials. The team is primarily using dry wood for the base structure as it is cheap but structurally strong and is a decent insulator for electricity. The team will be using a metal stand to ensure a factor of safety for the construction of the generator. The results from this analysis will aid the team in developing not only a cost-effective solution for what material the team will use but ensures student and faculty safety when operating the generator. A bill of materials for each metal considered will be presented after the validation of stress equations. And lastly, a SolidWorks model of the proposed design will be presented afterwards with a drawing and static analysis of forces.

This analysis focuses on mathematical equations to calculate the potential stresses in the stands main structure for holding the bicycle up. The end goal is to provide sufficient information for the team to select a material that will best support the students. The main components of the analysis are

- Forces in the Stand
- Member Stresses
- Buckling Stresses

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I.

### **Assumptions**

Assumptions and known values of the forces acting on the bicycle stand are seen below with justifications and/or short description.

*Assumption 1:* The rider will weigh a maximum of 90 kg.

*Justification:* The average American weights anywhere from 90-60kg.

*Assumption 2:* The bicycle will weigh a maximum of 10 kg.

*Justification:* Bicycles are typically light and transportable and weigh roughly 10g

*Assumption 3:* The rider will exert a force of 200 N on the pedals.

*Justification:* These are students without fully developed muscles and bicycles can withstand a high number of forces, typically the full weight of a cyclist. We are assuming that this is the peak constant force.

*Assumption 4:* The bicycle chain will have a loss of 3%.

*Justification:* No system is 100% efficient, so some lost is potentially there.

*Known 1:* The pedal crankshaft will have a length of 0.17 m.

*Justification:* Measured value from team's prototype bicycle.

*Known 2:* The Rear Shaft has a diameter of 0.01 m.

*Justification:* Measured value from the team's prototype bicycle.

*Known 3:* The shafts have an outer diameter of 0.0422 m for the larger tubes and 0.0382 m for the smaller tubes, and both have a thickness of 0.00277 m.

*Justification:* Measured value from the team's prototype bicycle.

*Known 4:* Dimensions of the bicycle stand are from the SolidWorks model. (Fig 1.)

*Justification:* Measured value from the team's SolidWorks Model.

### III. Methods

Table I

List of Variables

Variable	Description
$W$	Weight (Force) of Rider and Bicycle
$r_{crank}$	Radius of pedal crank
$\tau_{crank}$	Torque in the pedal crank
$\tau_{sp,front}$	Torque in the front sprocket
$\eta$	Chain loss
$r_{shaft,rear}$	Radius of rear shaft
$\tau_{sp,rear}$	Torque in the rear sprocket
$F_{shaft}$	Force on the rear shaft
$F_{joint}$	Force being applied on to the top joint
$F_{leg}$	Force on the stand legs
$\theta$	Angle of Tube
$F_{hor}$	Force on the horizontal bottom beam
$\sigma_M$	Member stress
$A$	Area
$P_{cr}$	

$E$	Critical buckling Force
$I$	Young's Modulus of Elasticity
$L$	Moment of inertia of a tube
$K$	Length of leg
$\sigma_b$	Column Effective length factor (K=1) Bending Stress

To start this structural analysis, we will need to calculate the dynamical force of being applied to the rear bicycle wheel shaft as it's connected to the top joints. To do this, we need to calculate the torque being applied to rear shaft from the pedal. These torques and forces can be calculated using Eq. (1), Eq. (2), Eq. (3) and Eq. (4).

$$\tau_{crank} = F_{pedal} \times r_{crank} \quad (1)$$

$$\tau_{sp,front} = \tau_{crank} \quad (2)$$

$$\tau_{sp,rear} = \tau_{sp,front} \times (1 - \eta) \quad (3)$$

$$F_{shaft} = \frac{\tau_{sp,rear}}{r_{shaft,rear}} \quad (4)$$

After calculating the dynamical forces in the shaft, we then need to calculate the static forces being applied to the top joint due to weight, which is calculated using Eq. (5)

$$W = (m_{rider} + m_{bicycle}) \times 9.81 \quad (5)$$

Taking the force due to weight we can then combine it with the force in the shaft split it between the two joints. The force is calculated using Eq. (6)

$$F_{joint} = \frac{F_{shaft} + W}{2} \quad (6)$$

Using the force calculated in each joint we can calculate the forces in the leg and subsequently the force in the horizontal beam as extra support. The equations for these forces are calculated using Eq. (7) and Eq. (8).

$$F_{leg} = \frac{F_{joint}}{2 \sin(\theta)} \quad (7)$$

$$F_{hot} = F_{leg} \cos(\theta) \quad (8)$$

Using these forces we can now check the member stresses, specifically the stresses in the legs by calculating the area and dividing the force by the area of the tube to find the member stress, we are going to compare this against the tube's material yield stress. The area and stress are calculated using Eq. (9) and Eq. (10).

$$A = \frac{\pi}{4}(D_o^2 - D_i^2) \quad (9)$$

$$\sigma = \frac{F_{leg}}{A} \quad (10)$$

We then want to compare the critical buckling force of the stand's material, and we can do this using Euler's Buckling equation, assuming the column effective length factor is equal to 1. We need to solve for the moment of inertia in the tube using Eq. (11). After finding moment of inertia we can then calculate the critical buckling using Eq. (12), which is dependent on the material of the stand due to Young's modulus of elasticity.

$$I = \frac{\pi}{64}(D_o^4 - D_i^4) \quad (11)$$

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} \quad (12)$$

Using the critical force, we can compare that with the expected force and determine the factor of safety that the stand will have in comparison to the expected forces applied to the leg.

$$FOS = \frac{P_{cr}}{F_{leg}} \quad (13)$$

Another method our team will use to determine the structural integrity of the stand is by using the SolidWorks' simulation software to apply the expected force in the top joint determined by Eq. (6) and setting it to that the base of the stand will not move as it is expected and assumed it will be bracketed down to the wooden base. The initial figure can be seen below, where the green arrows are the static forces in which the stand while stay still and the purple forces are the downward forces of the shaft acting on the stand.

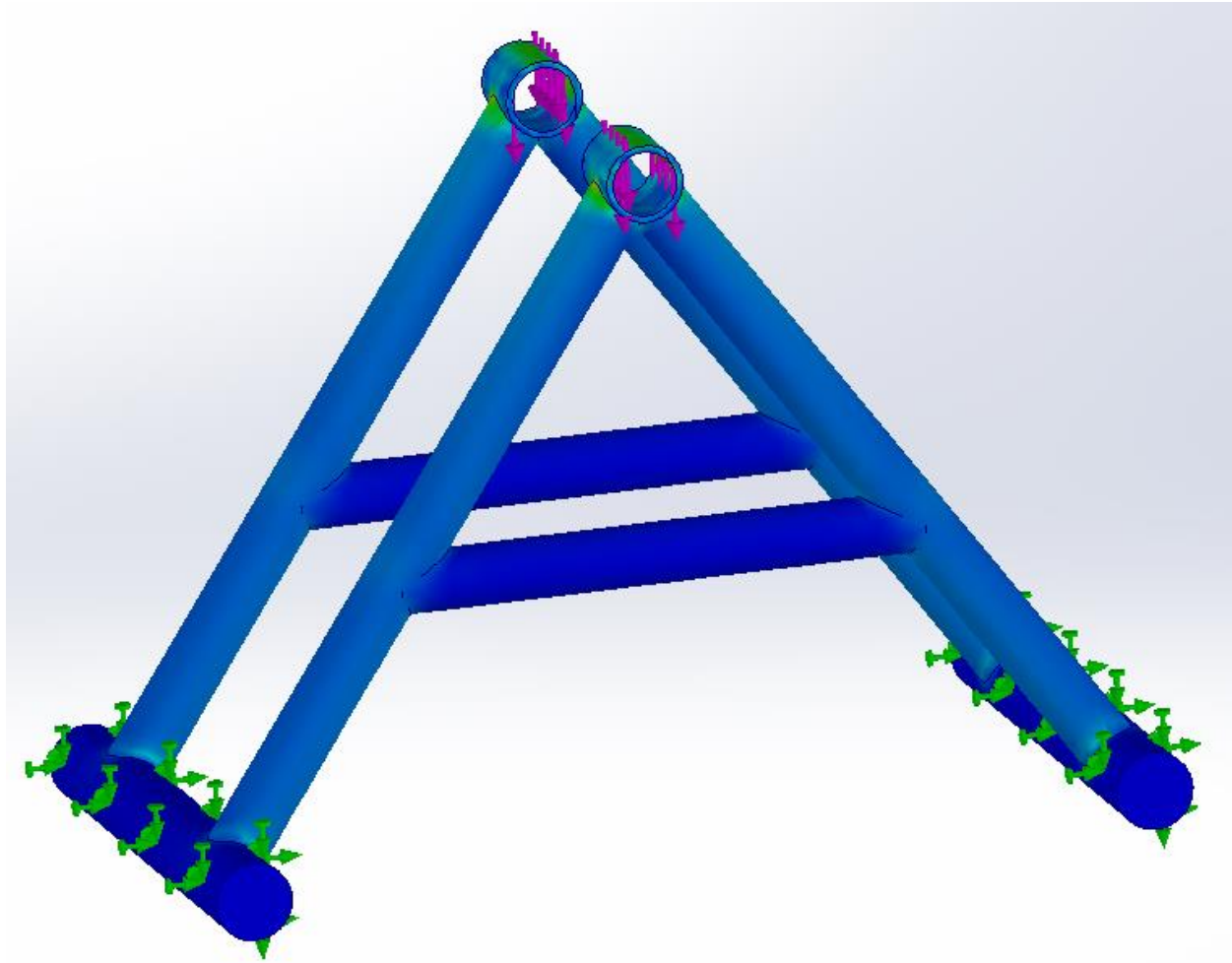


Fig 1. Structural Analysis set-up of Stand

#### IV. Results

Using Eq.(1-11) from the methods section we can calculate the necessary forces and values being applied to the stand. These values will be vital in evaluating the stresses being applied using different materials as the main goal is to determine what material(s) may be idea in the later manufacturing of the stand via the NAU machine shop. Its important to not that this analysis is not evaluating the welding stress as more research will need to be conducted towards calculating these values. The resulting values are displayed in Table II.

Table II

List of Calculated Values

$\tau_{crank}$	34 [N · m ]
$\tau_{sp,front}$	34 [N · m ]

$\tau_{sp,rear}$	32.98 [N · m]
$F_{shaft}$	3298 [N]
$W$	981 [N]
$F_{joint}$	2139.5 [N]
$F_{leg}$	1865.1 [N]
$F_{hot}$	1527.8 [N]
$A$	$3.0832 \cdot 10^{-4}$ [m <sup>2</sup> ]
$\sigma$	6.0491 [MPa]
$I$	$4.8674 \cdot 10^{-8}$ [m <sup>4</sup> ]

Now in order to calculate the critical buckling force and check the ultimate yield strength against the calculated stress. To do this, we will compare 4 different materials those being AISI 1020 steel, wrought stainless steel, 1023 carbon steel, and aluminum 3004-0. The values for their yield strength and Elastic Modulus were found via SolidWorks' directory [1] and can be seen in table 3, as seen below.

Table III

List of Materials from SolidWorks

Material	AISI 1020 Steel	Wrought Stainless Steel	1023 Carbon Steel	Aluminum 3004-0, Rod(SS)
Yield Strength	351.571 [MPa]	206.807 [MPa]	282.685 [MPa]	69 [MPa]
Young's Modulus	200000 [MPa]	200000 [MPa]	205000 [MPa]	69000 [MPa]

Calculating the critical buckling force using Eq. (12) we can compare that against the force being applied in the leg as that's where most of the force will be applied. The results can be seen in Table IV below

Table IV

Calculated Critical Buckling Force of each Material

Material	AISI 1020 Steel	Wrought Stainless Steel	1023 Carbon Steel	Aluminum 3004-0, Rod(SS)
Critical Force	561599 [N]	561599 [N]	575639 [N]	193752 [N]

According to the tables and calculated values, all the materials should be able to withstand the force applied as they all exceed the necessary yield strength requirement and critical buckling force. The team is in communication with NAU Baja team as they may have some spare tubing

they used for the roll cage the team may use. For now the team will most likely use any of the listed steels instead of aluminum as the team plans on welding the beams together.

Continuing the structural analysis, the team wanted to compare these materials in SolidWorks incase the calculation were incorrect or had a human calculation error. The Figures below show each material in order from AISI 1020 Steel to Aluminum 3004-0.

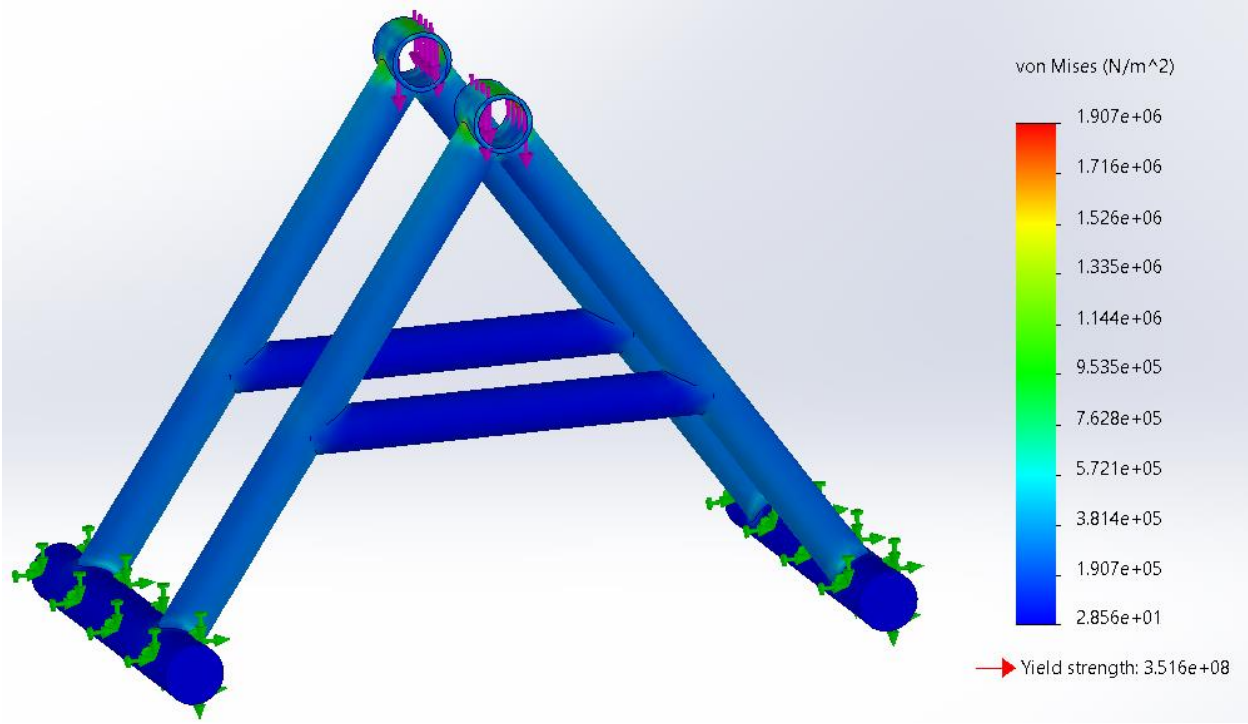


Fig 2. Structural Analysis in SolidWorks for AISI 1020 Steel

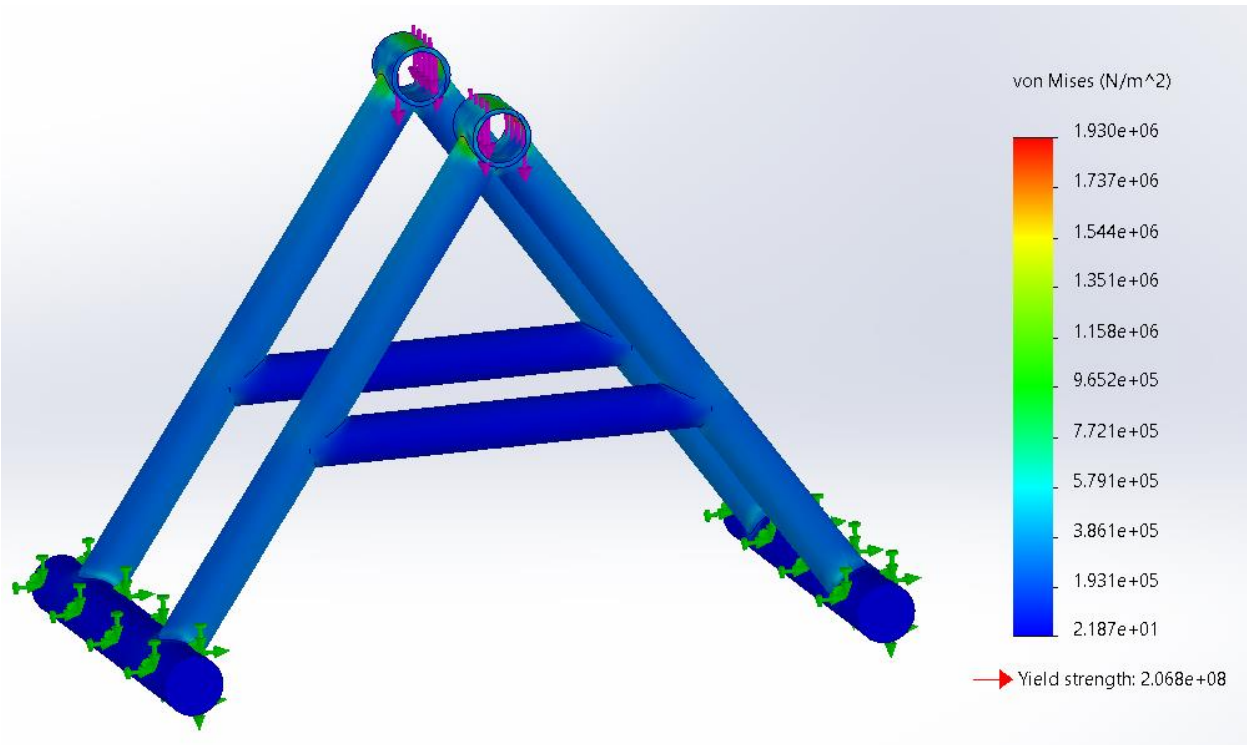


Fig 3. Structural Analysis in SolidWorks for Wrought Stainless Steel

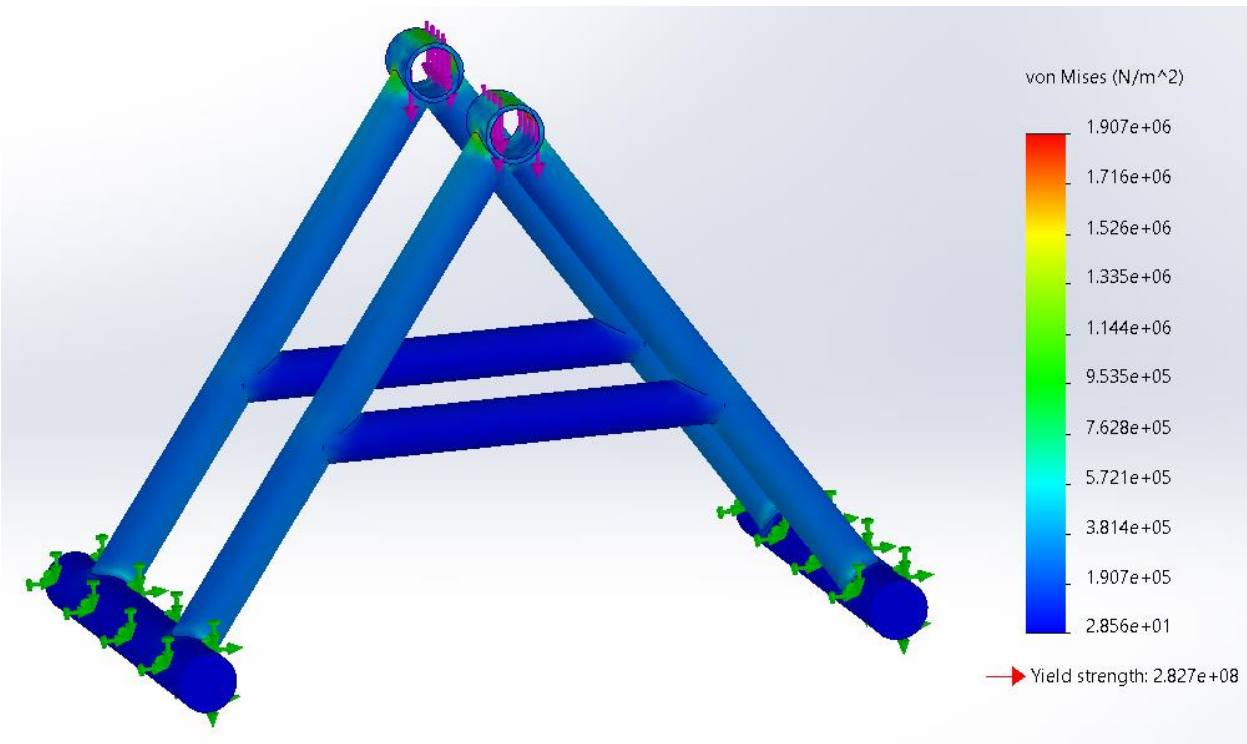


Fig 4. Structural Analysis in SolidWorks for 1023 Carbon Steel

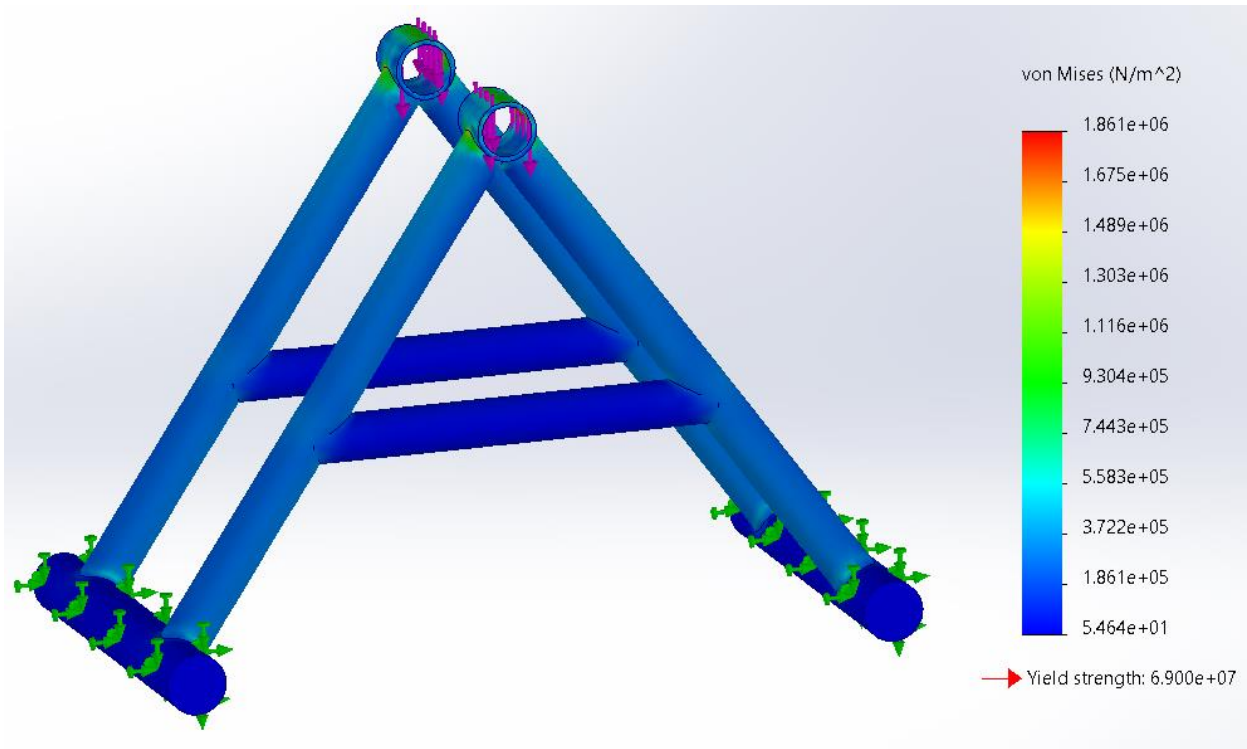


Fig 5. Structural Analysis in SolidWorks for Aluminum 3004-0, Rod(SS)

From these figures, it shows are calculations accurate to the calculated values as the stand does not appear to be in bending or yielding at any point. The areas that could be a major concern are at the top joint when the downward force is being applied to the stand.

## V. Conclusion/Recommendations

This structural analysis evaluated the stresses and forces acting on a bicycle stand under both static and dynamic loads. Using both analytical calculations and SolidWorks simulations, the forces transmitted through the weight of the rider and bicycle, and the torque due to pedaling was used to determine the resulting bending and member stresses on the stand. These were then compared against the forces and stresses of chosen materials the team is considering using in their final assembly.

The results of each material indicated, through both analytical and simulations, that all the materials are capable of safely supporting the expected load with high factor of safety. Even though all materials meet the requirements the team deliberated and determined that one of the three steel material as they have a higher strength and durability and are high suitable for welding. For future analysis next semester, the team will conduct a fatigue analysis of their choose steel as debates for what material to use are still underway.



## References

- [1] “Welcome to the SOLIDWORKS Web Help,” Solidworks.com, 2026.  
[https://help.solidworks.com/2025/english/SolidWorks/Sldworks/c\\_sw\\_materials\\_web\\_portal.htm](https://help.solidworks.com/2025/english/SolidWorks/Sldworks/c_sw_materials_web_portal.htm)  
(accessed Apr. 27, 2026).
- [2] J. L. Meriam and L. G. Kraige, Engineering Mechanics. Vol. 2, Dynamics. Hoboken, N.J, Chichester: Wiley ; John Wiley distributor, 2012.
- [3] R. G. Budynas and J. K. Nisbett, Shigley’s Mechanical Engineering Design. New York, NY: McGraw-Hill Education, 2014.