Aerospace Structural Analysis and Design Project

Carbon Fiber Rocket - Extended Report

Noah Miranda & Nicholas Walker

Preliminary Design

- Components
  - fiberglass, carbon fiber, and aluminum
- Dimensions
  - length: 42 inches, diameter: 1.6 inches

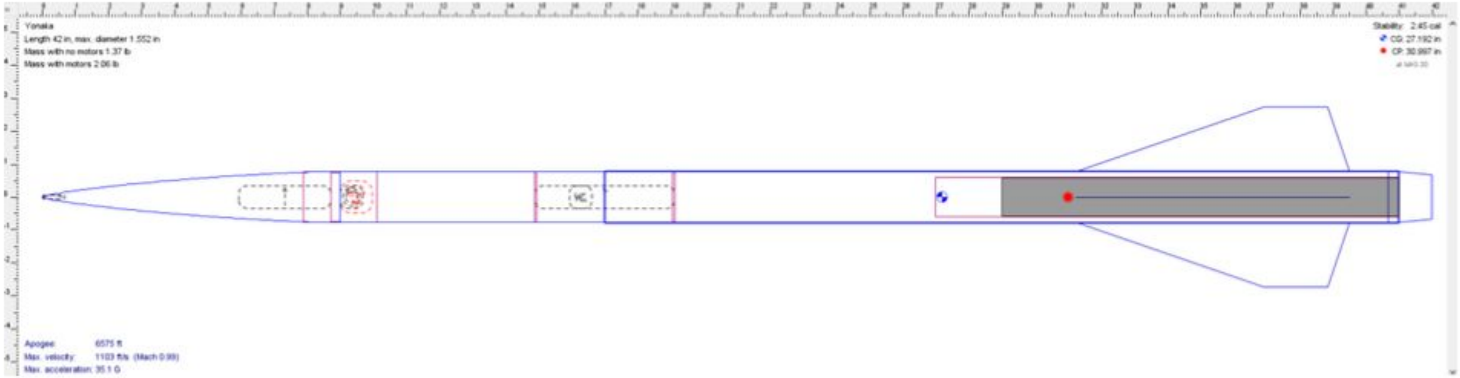


Figure 1. Rocket Outline

Analysis

Methods

- Finite Element Method (FEM)
- Analytical Solution

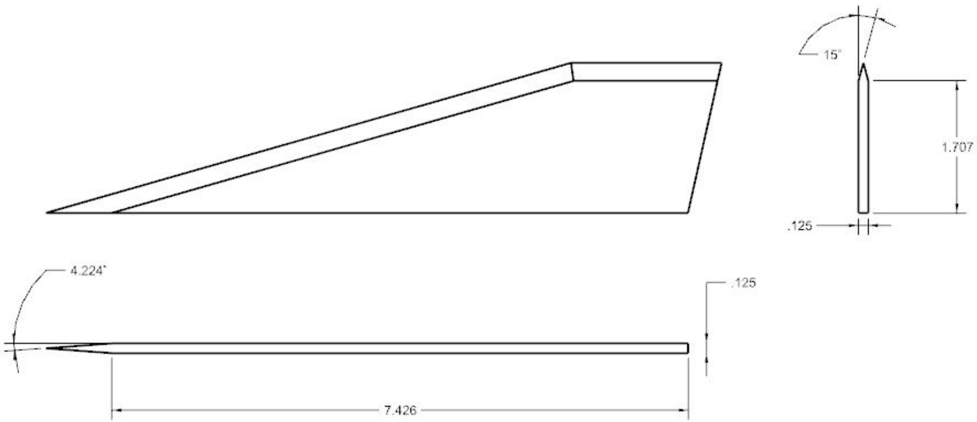
Calculations

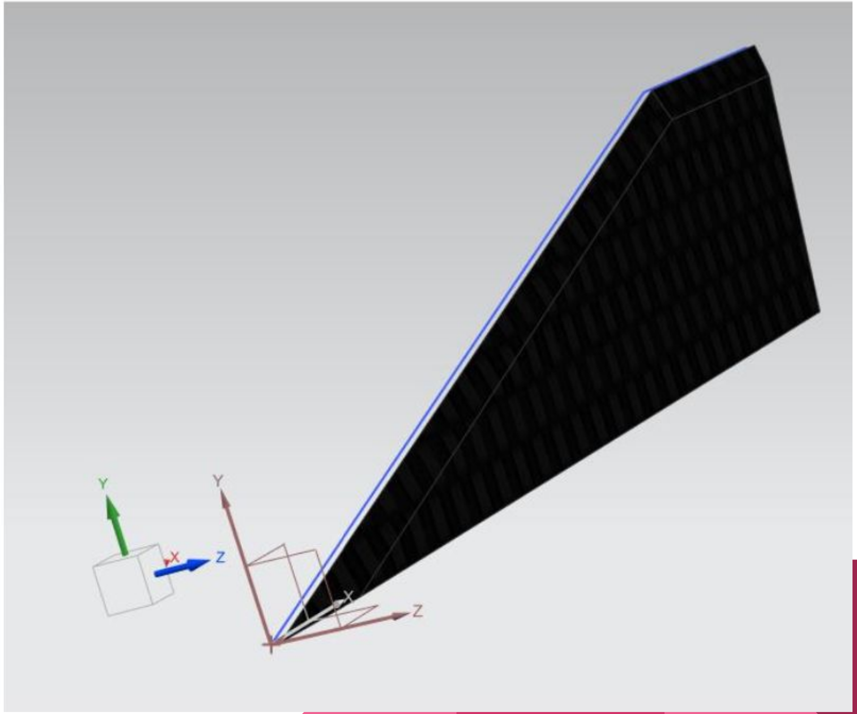
- NX NASTRAN
  - Global stresses and deflections
- Written/Analytical
  - Locations of maximum stress and deflection
  - Homework

Assembly

- Fins
  - 1/8-inch sheet of G12 fiberglass
- Nosecone
  - 1.6 inch diameter filament-wound fiberglass nose cone (5:1 length/diameter)
- Airframe
  - two carbon fiber tubes for “booster” and “payload” section (24 inches, 8 inches, respectively)
  - ID: 1.5 inches
  - OD: 1.6 inches
    - 0.05 wall thickness

Fin Design - CAD, NX





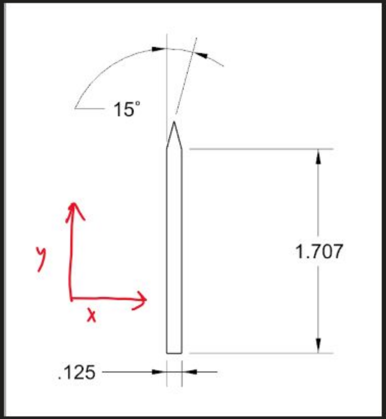
Calculations - based on homework

Project Calculations based on homework topics

1. Sectional Properties → Fins
2. Bending → Fins
3. Shear → Airframe (open section)
4. Torsion → Airframe
5. Combined Sections → Airframe
6. Structural Idealization →
7. Aerospace Materials →

Sectional Properties

1



Assumptions:

Chamfer angle is small, assume chamfered area to be included:

Treat as rectangle.

$b = .125$ in

$x \rightarrow x + 1.707 = h$

$.0625 \cot(15°) = x \quad = .233 \Big) \; h = 1.94$ in

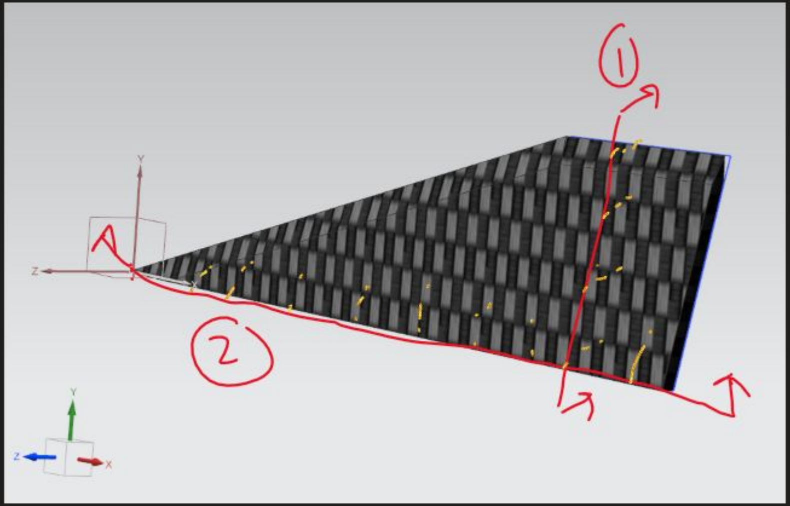
Simple rectangle $\bar{x} = .0625 \quad \bar{y} = \frac{1.94}{2} = .97$ in

$I_{xx} = \frac{(.125)(1.94)^3}{12} = .0761 \text{ in}^4$

$I_{yy} = \frac{(1.94)(.125)^3}{12} = 3.15 \times 10^{-4} \text{ in}^4$

$I_{xy} = 0$ (symmetry)

Project: Sectional properties of fin.



1 will examine "thickest point" of fin

2 will examine adhesion surface to airframe.

2

$\bar{X} = .0625$ in $\quad h = .125$ in

Chamfer approx: $7.426 + .0625 \cot(4.224) = b$

$b = 8.272$ in

mfer approx: $7.426 + .0625 \cot(4.2$

$b = 8.272$ in

$= \dfrac{8.272(.125)^3}{12} = 1.346 \times 10^{-3}$ in^4

$(.125)(8.272)^3$

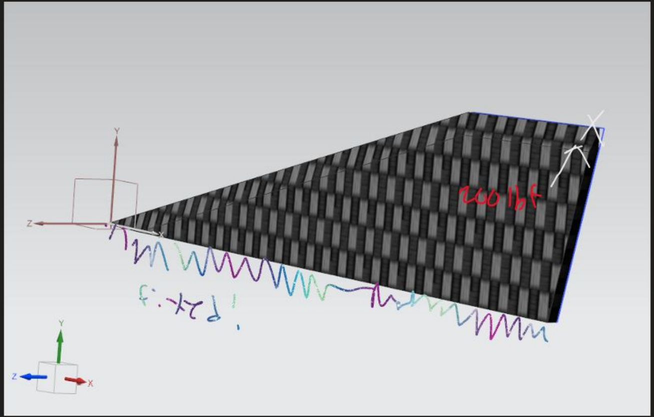
Deflection Calculations

Neumann B/C's: 200 lbf applied to tip of fin (worst-case loading)

Dirichlet B/C's: Zero deflection on root of fin (y = 0)

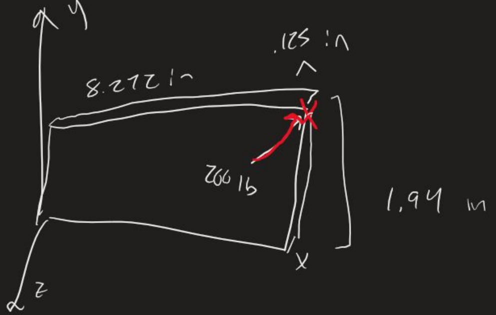
Assume material properties of *aluminum*

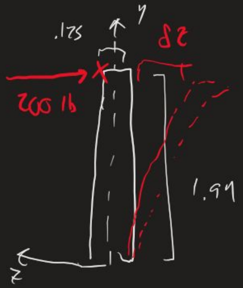
Project Problem:



Apply a force of magnitude 200 lb on the fin section shown.

Assume rectangular geometry. The X-Z bottom surface is fixed!





Find the deflection along the z axis of the top left corner where the force is applied.

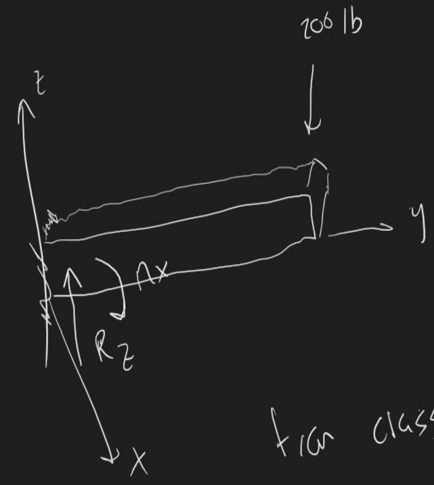
Assume material properties of aluminum

$E = 1 \times 10^7$ psi

Cantilever beam of sectional properties:

bottom surface $\left\{ I_{xx} = 1.346 \times 10^{-3} \text{ in}^4 = \left(\frac{8.272(.125^3)}{12} \right) \right.$

Singularity functions / FBD



$$\Sigma F_z = R_z - 200\,lb = 0$$

$$R_z = 200\,lb$$

$$M_x = -200\,lb\,(1.94\,in)$$

$$= -388\,lb\cdot in$$

from class:

$$\delta_z = \frac{-PL^3}{3EI} = \frac{-200(1.94)^3}{3(1\times10^7)(1.346\times10^{-3})}$$

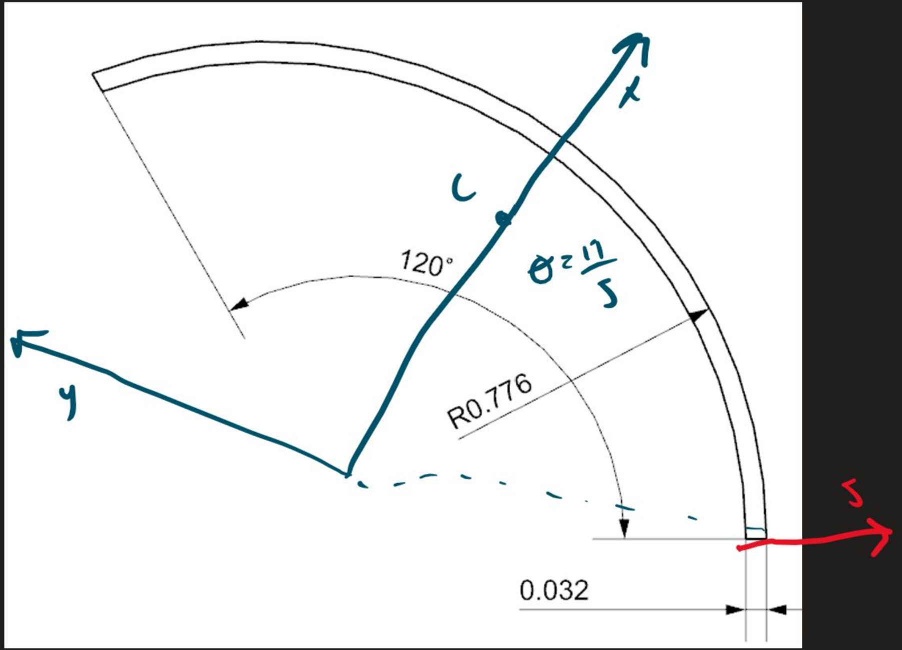
$$\delta_z = -.036\ in$$

Shear - Center of Airframe: open section

This region of the airframe is based on the *fin-canister* section

Assumption: Symmetry across a 120 degree span, analysis of one-thirds of a section would reflect across the rest of the airframe.

A 200 lb load is applied tangential to 1/3 of a cylindrical airframe shown:



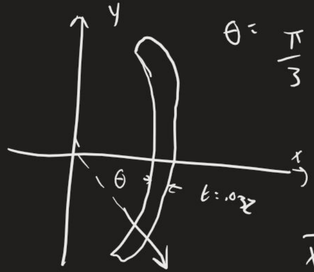
Shear acts along the x-direction.

Find: Sectional Properties.

Shear Flow

location of shear center due to S_x

Based on geometry / assume thin-wall assumption.



$\theta = \frac{\pi}{3}$ °

$\bar{y} = 0$

$x = \frac{r \sin\theta}{\theta}$

$\bar{x} = \frac{.726 \sin(\frac{\pi}{3})}{3(\frac{\pi}{3})} = 0.214$

Sectional Properties:

$I_{xx} = \int y^2 \, dA = \frac{r^4}{8}\left(\frac{\theta}{2} - \sin\left(\frac{\theta}{2}\right)\right)$

$= 1.07 \times 10^{-3} \text{ in}^4$

$I_{yy} = \int x^2 \, dA = \frac{r^4}{8}\left(\frac{\pi}{2} + \sin\left(\frac{\pi}{2}\right)\right)$

$= 4.63 \times 10^{-2} \text{ in}^4$

$I_{xy} = 0$

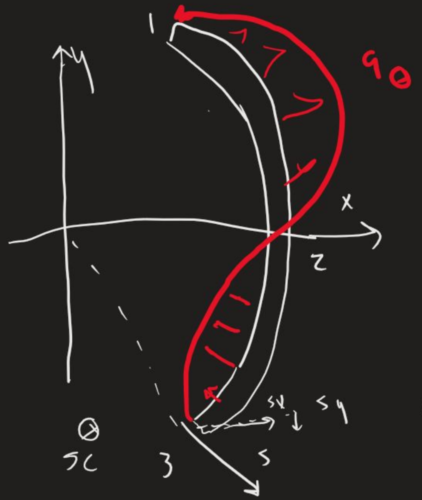
$S_x = 200 \cos\left(\frac{\pi}{3}\right) = 100 \text{ lb} \rightarrow$

$S_y = -200 \sin\left(\frac{\pi}{3}\right) = -173 \text{ lb} \downarrow$

$$q_s = -\left(\frac{s_x I_{xy}}{\underbrace{I_{xx} I_{yy}}_{c_x}}\right)\int_0^s t\,x\,ds - \underbrace{\left(\frac{s_y I_{yy}}{I_{xx} I_{yy}}\right)}_{c_y}\int_0^s t\,y\,ds$$

$$q_\theta = -c_x t r \int_{-30}^{30} \cos\theta \, d\theta + c_y t r \int_{-30}^{30} \sin\theta \, d\theta$$

$$q_\theta = \overbrace{c_x \cdot t r}^{55.6}\left(\sin 30 - \sin(-30)\right) + \overbrace{c_y t r}^{4015}\left(\cos 30 - \cos(-30)\right)$$



$0 \; e$

$-\pi/3, \; 0, \; \frac{\pi}{3}$

Min @ $\frac{\pi}{6}$: 107.77 lb/in

Max @ $\frac{-\pi}{6}$: −107.77 lb/in

Moment about point 1, $y = -.776 \sin 60$

$= -.672$ in

$\xi_s S_x$

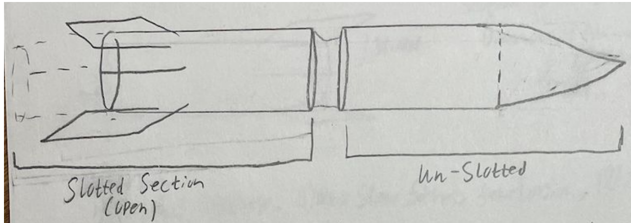
$$q_G = \overbrace{C_x}^{55.6} \cdot tr\left(\sin 30 - \sin(30)\right) + \overbrace{C_y}^{4015} tr\left(\cos 30 - \cos(-30)\right)$$

$q(\pi/3) = 0 \Rightarrow \xi_s = 0!$

Shear center is at $(0, -.672)$ in

Torsion

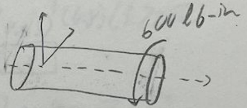
Pre problem notes: lengths: 42”--> 1.0668m, diameter: 1.6”--> 0.04064m



Unslotted Section of Airframe: Undergoes Torsional Load of 600 lb in

Prop. of Aluminum: $G = 3.77E6$

Assumption: One end is fixed



Dimensions:

$OD = 1.6\,in$, $ID = 1.5\,in$, $L = 8\,in$

Find: I) Torsional Rigidity, II) Max Shear Stress, III) Rate & Angle of Twist

i) Torsional Rigidity: $TR = \frac{4A^2}{\oint \frac{ds}{Gt}}$ $\Big]$ $\oint ds \Rightarrow 2\pi R \Rightarrow R = 0.8\,in$

$TR = \frac{4A^2}{\frac{2\pi R}{Gt}}$; $A = \pi(R^2 - r^2)$, $r = 0.75\,in$

$$TR = \frac{4[\pi(0.8^2 - 0.75^2)]}{\frac{2\pi(0.8)}{(3.77E6)(0.05)}} \Rightarrow \boxed{TR = 8.9E3\ lb \cdot in^2}$$

ii) Max Shear

$\tau_{max} = q/t$, $q = \frac{T}{2A}$; $t = \text{Const}$

$q = \frac{600}{\pi(0.8^2 - 0.75^2)} = 1232\ lb\,in^{-1}$, $\tau_{max} = \frac{1232}{0.05} = 2.46E4\,psi$

iii) Rate & Angle of Twist

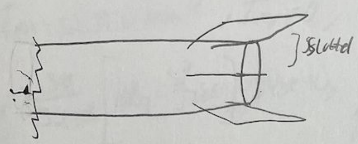
$$\frac{d\theta}{dz} = \frac{1}{4A^2 Gt}\oint ds = \frac{600/2\pi \cdot 0.8}{4\left(\frac{\pi}{0.8^2 - 0.75^2}\right)(3.77E6)(\theta)} \Rightarrow \frac{d\theta}{dz} = 0.067\ rad/in$$

$\theta(8) = 0.54\,rad$

$\hookrightarrow 31°$

Analysis of Combined Sections

Section of Airframe Undergoes 200 lb



Dimensions: Aluminum : : Shear Load

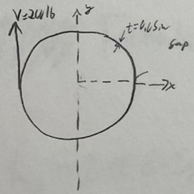
$G = 3.77E6$ psi

$R = 0.8$ in, $t = 0.05$ in

Determine:

I) Torsional Rigidity, II) Max Shear Stress from Torsion, III) Max Shear Stress

IV) Max Shear due to Both



I) Torsional Rigidity: $TR = GS = \frac{2}{3} r t^3 G$

$$T_R = \frac{2\pi}{3}(0.05)^3 (0.8)(3.77E6)$$

$$\boxed{T_R = 790 \text{ lb} \cdot \text{in}^2}$$

II) Max Torsional Shear Stress $\tau_m^t = \frac{T t}{J}$

$$T = 200 \text{ lb}(0.8) \Rightarrow -160 \text{ lb in}$$

$$J = \frac{2\pi}{3}(0.05)^3(0.8) \cdot \tau_m^t \Rightarrow \frac{(-160)(0.05)}{\frac{2\pi}{3}(0.05)^3(0.08)}$$

$$\tau_m^t \Rightarrow \boxed{3.8E4 \text{ PSI}}$$

III) Max Shear Stress-Force

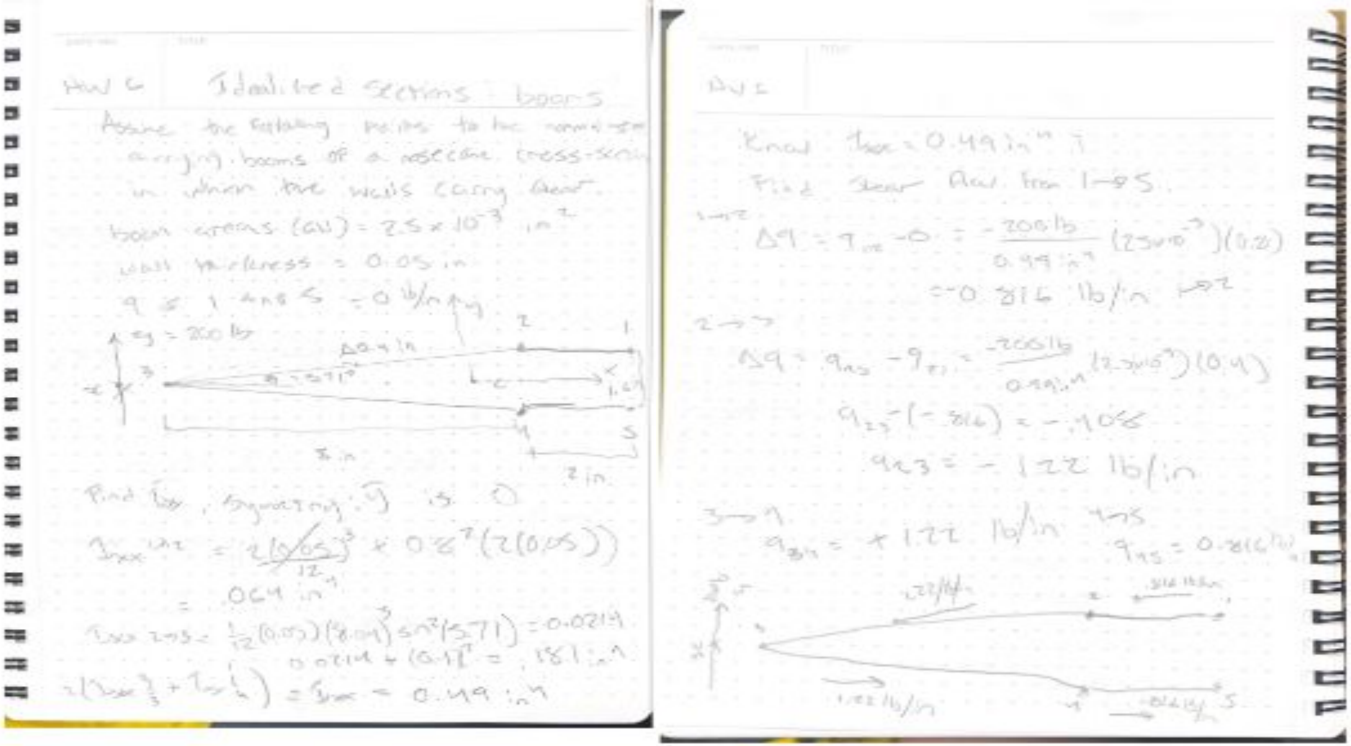
$$q_s \overset{\text{simplified}}{=} -\frac{S_y}{I_{xx}} \int_0^s t y \, ds = \frac{-S_y}{I_{xx}} \int_0^\theta t(-r\sin\theta) r \, d\theta \Rightarrow q_\theta = \frac{S_y}{\pi r} \cdot \left[1 - \cos\theta\right] \Bigg| \; 0 \le \theta \le 2\pi$$

$$q_{\theta,max} \text{ @ } \theta = \pi = \frac{2 \cdot 200}{\pi \cdot 0.8} \Rightarrow q_{\theta,max} = 160 \text{ lb in}^{-1}$$

$$\tau_{max}^{S_y} = \frac{160}{0.05} = \boxed{0.32E4 \text{ psi}}$$

IV) $\tau_m^T + \tau_m^{S_y} = \boxed{4.2E4 \text{ psi}}$ Max Shear stress due to Both

Structural Idealization



Fatigue Analysis

HW 7 — Fatigue - Service life

An aluminum rocket fin is subject to an average of 60 Hz of flutter for 2 seconds each flight.

If the fin is comprised of 6061-T6 aluminum, which has a yield strength of 241 MPa, how many flights are possible before the fins fail?

Calculate at at the following reliabilities → 99.9%, 95%, and 90%.

$\sigma_a = 150$ MPa

$\sigma_m = 0$ MPa

HW 7

Cycles per flight

$60 \text{ Hz} \cdot 2 \text{ sec} = 120$ cycles/flight

6061 S-N curve @ 150 MPa σ_a

$N = 10^{5} = 100{,}000$ cycles

$\frac{100000 \text{ cycles}}{120 \text{ cycles/flight}} = 833$ flights until fail

at 99.9% → $k_r = 0.75$

$\sigma_a = \frac{150}{0.75} = 200 \text{ MPa} \rightarrow N = 10^{4.5}$

$10^{4.5} = 31622 \rightarrow \frac{31622}{120} = 263$ flights

at 95% → $k_r = 0.81$

$\sigma_a = \frac{150}{0.81} = 185 \text{ MPa} \rightarrow N = 10^{4.6}$

$10^{4.6} = 39810 \rightarrow \frac{39810}{120} = 331$ flights

HW 7

at 90% → $k_r = 0.9$

$\sigma_a = \frac{150}{0.9} = 166 \rightarrow N = 10^{4.8}$

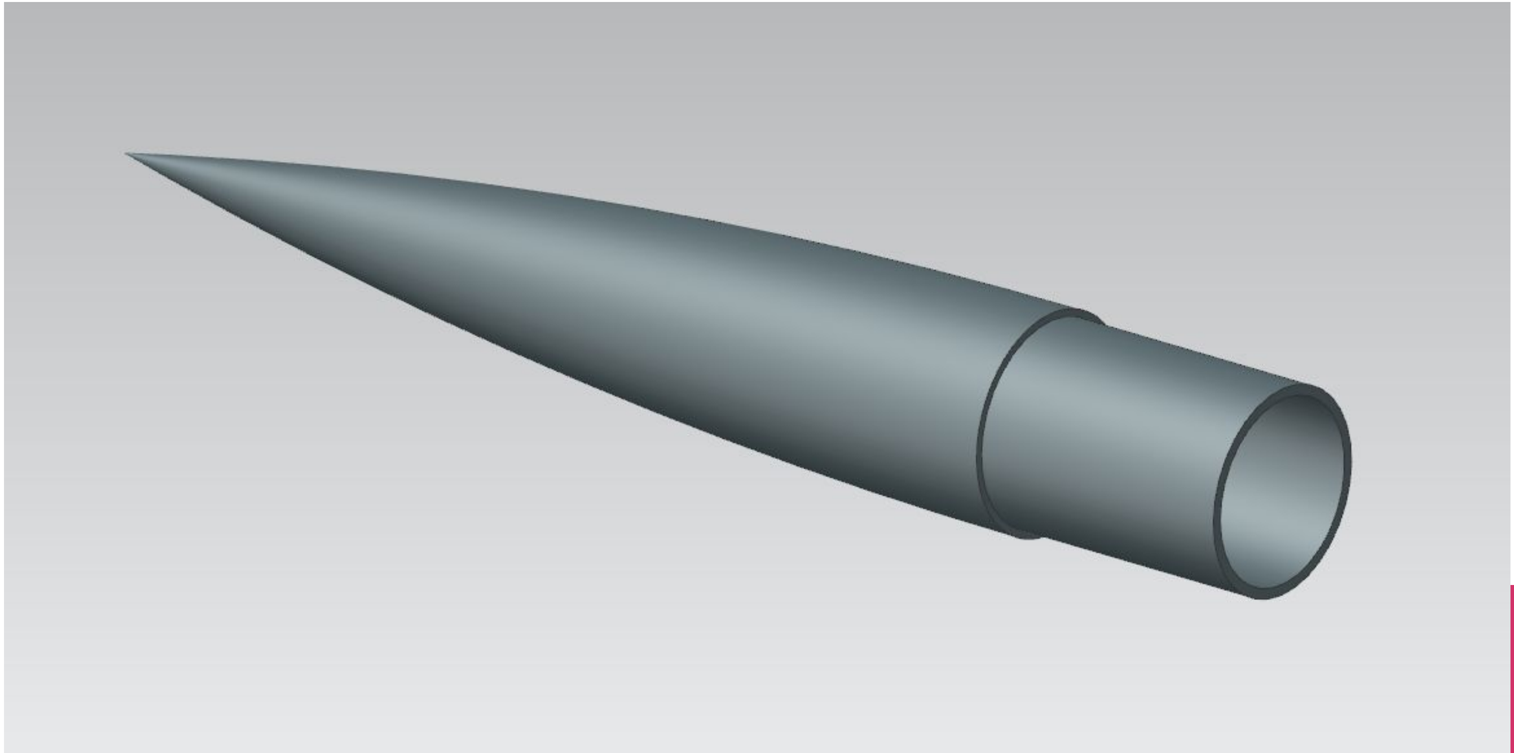
$10^{4.8} = 63095 \rightarrow \frac{63095}{120} = 525$ flights

6061-T6 Al - confidence level / # of flights

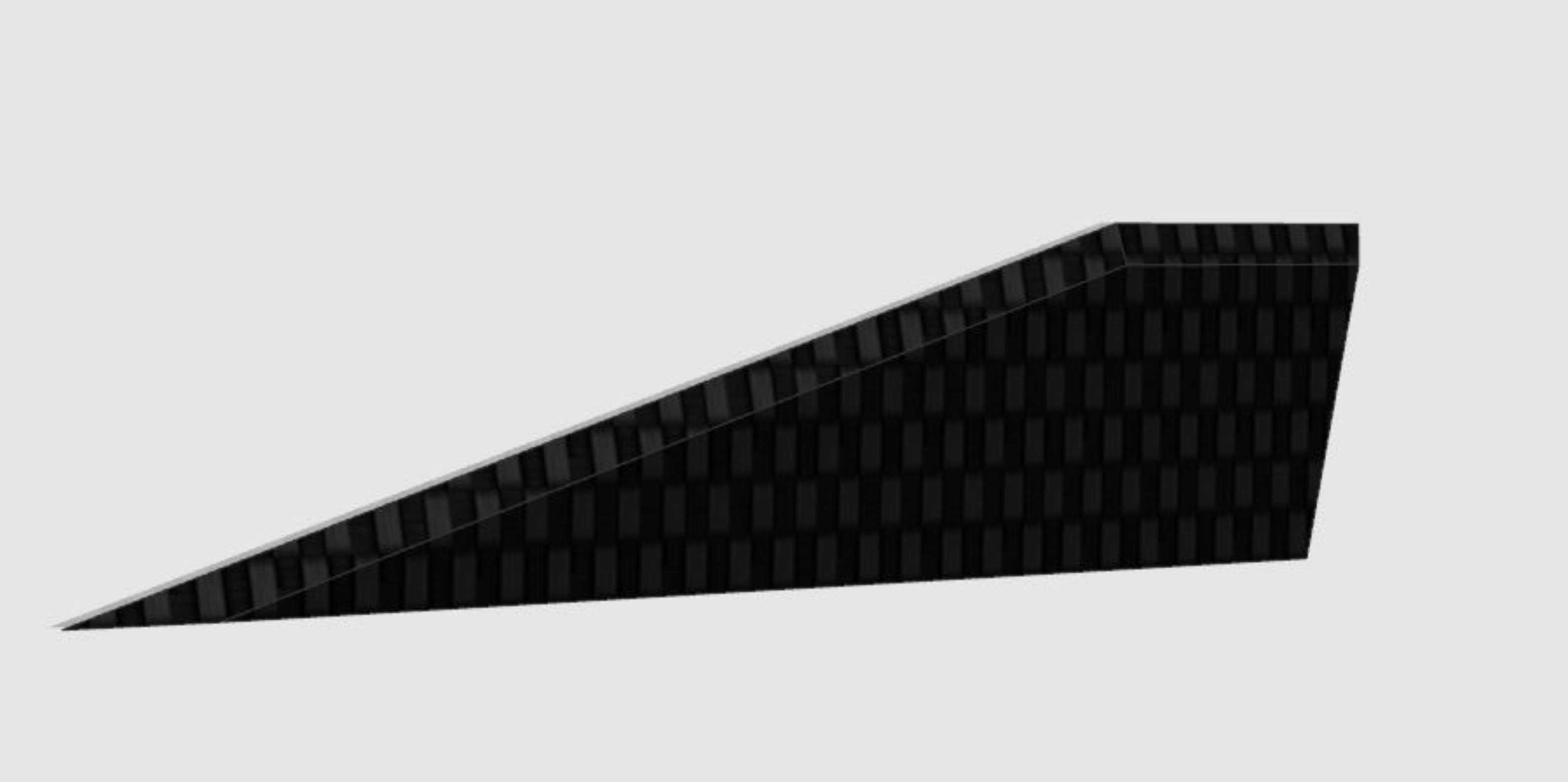
R(%)	# of cycles	# of flights
50	100000	833
90	63095	525
95	39810	331
99.9	31672	263

Comparing the extremes, we are 99.9% confident that the fins will not fail after 263 flights, but are 50% confident the fins will not fail after 833 flights!

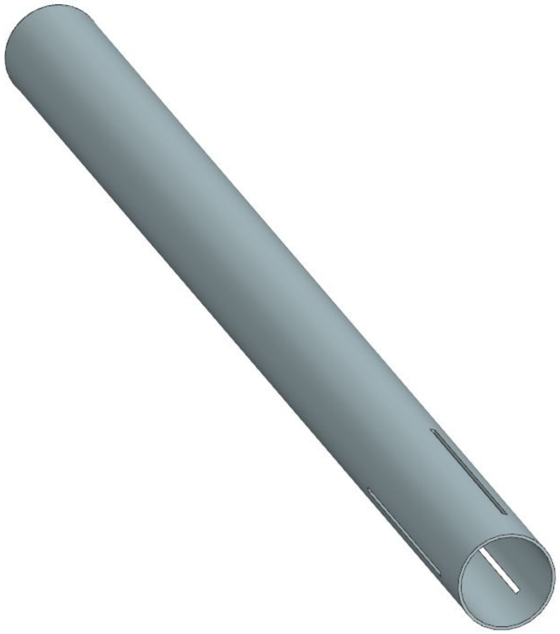
CAD NX, Components - Nosecone

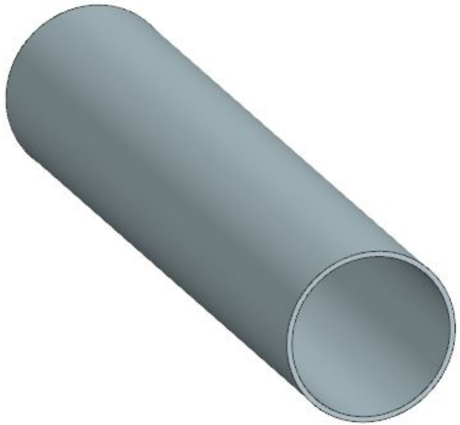


CAD NX, Components - Fins



CAD NX, Components - Slotted & Non-slot Tube





Finite Element Analysis

FEA and Simulations of components:

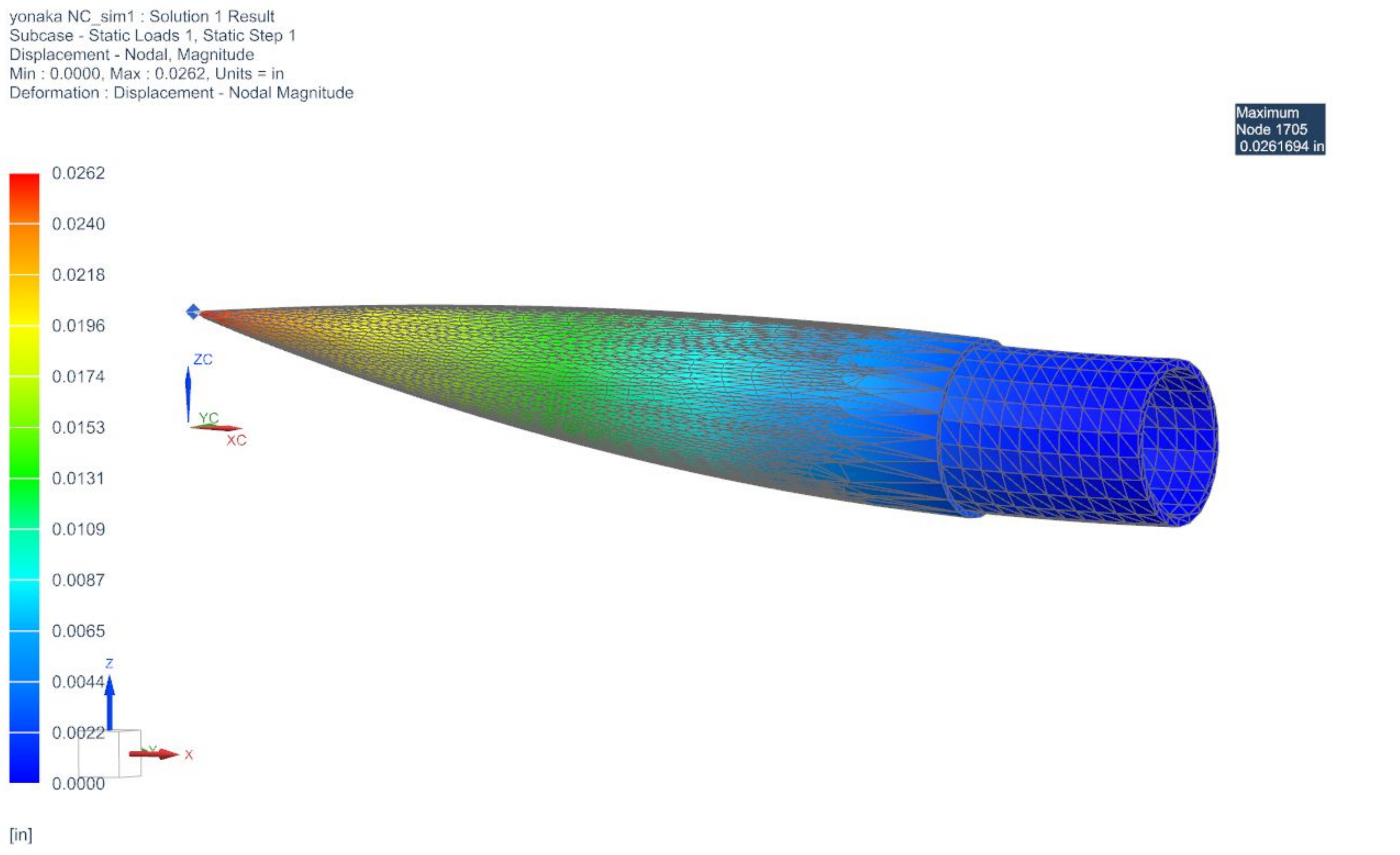
- Nosecone
- Fins
- Slot-tube
- Non-slot tube

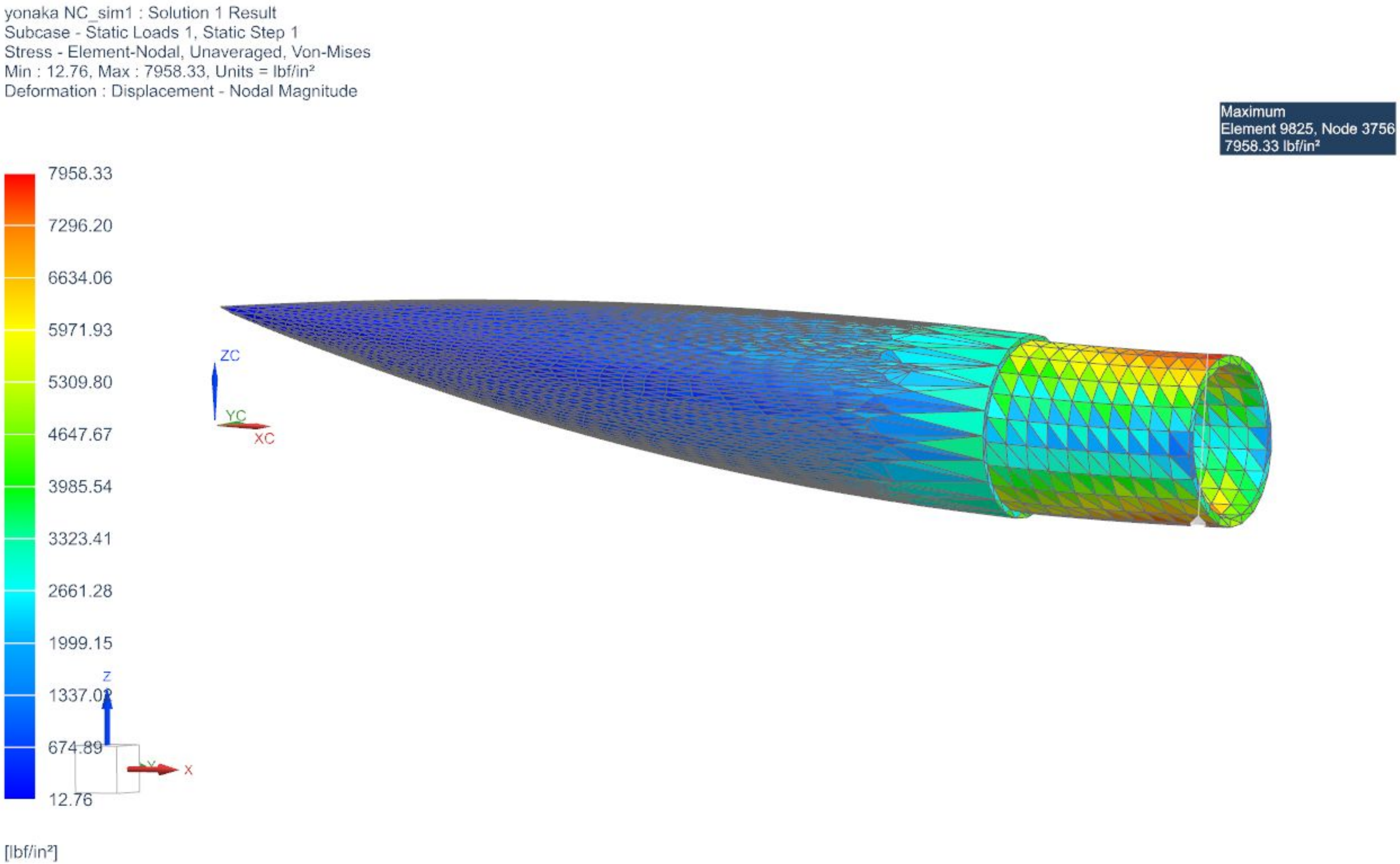
FEA - Nosecone (Overview)

- FIXED constraint on circular edge
- 0.25 inch mesh
- material properties: aluminum 6061
- 200lbf magnitude force on the "nose", +z axis

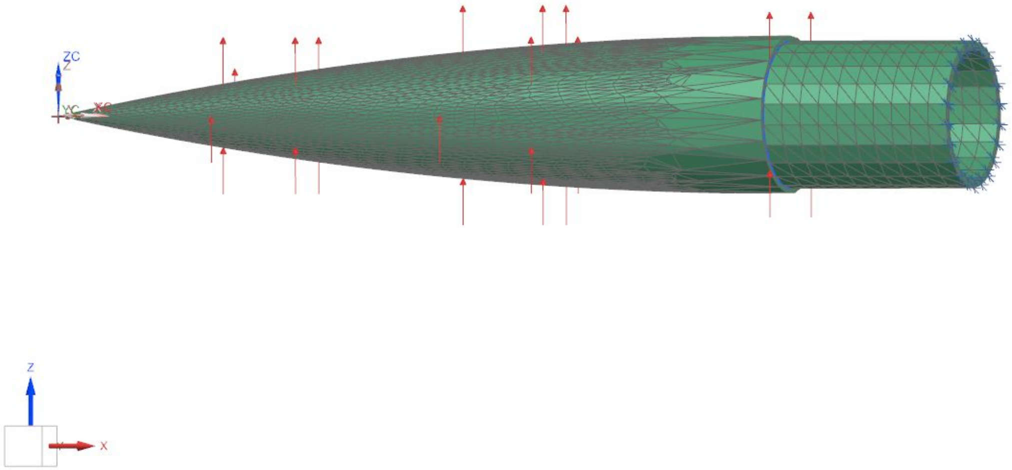
ZC
Z
YC
XC
Z
X

Displacement and Stress


yonaka NC_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Displacement - Nodal, Magnitude
Min : 0.0000, Max : 0.0262, Units = in
Deformation : Displacement - Nodal Magnitude
Maximum
Node 1705
0.0261694 in
0.0262
0.0240
0.0218
0.0196
0.0174
0.0153
0.0131
0.0109
0.0087
0.0065
0.0044
0.0022
0.0000
[in]
ZC
YC
XC
Z
X


yonaka NC_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Stress - Element-Nodal, Unaveraged, Von-Mises
Min : 12.76, Max : 7958.33, Units = lbf/in²
Deformation : Displacement - Nodal Magnitude
Maximum
Element 9825, Node 3756
7958.33 lbf/in²
7958.33
7296.20
6634.06
5971.93
5309.80
4647.67
3985.54
3323.41
2661.28
1999.15
1337.02
674.89
12.76
[lbf/in²]
ZC
YC
XC
Z
X

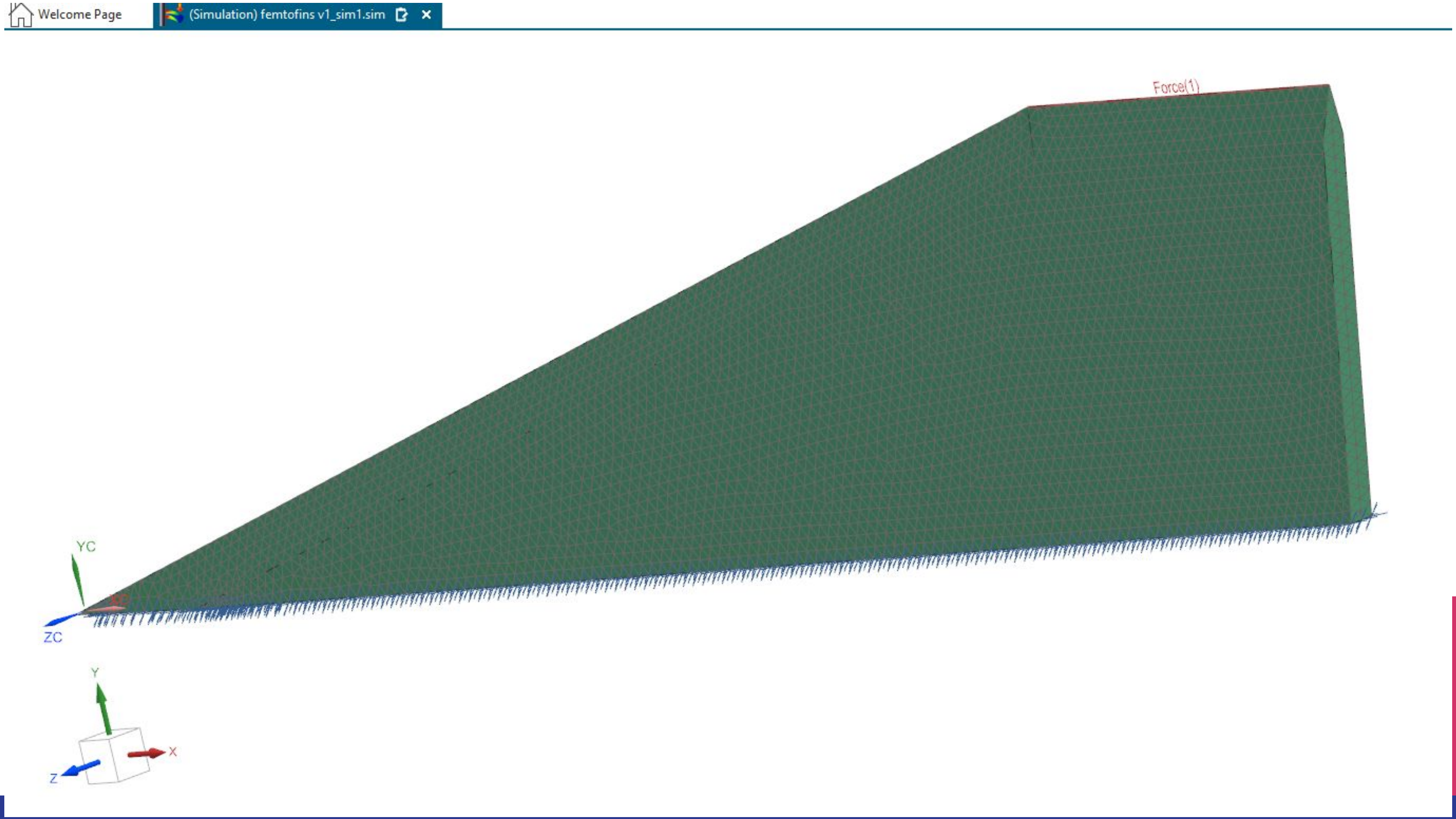
Boundary Conditions



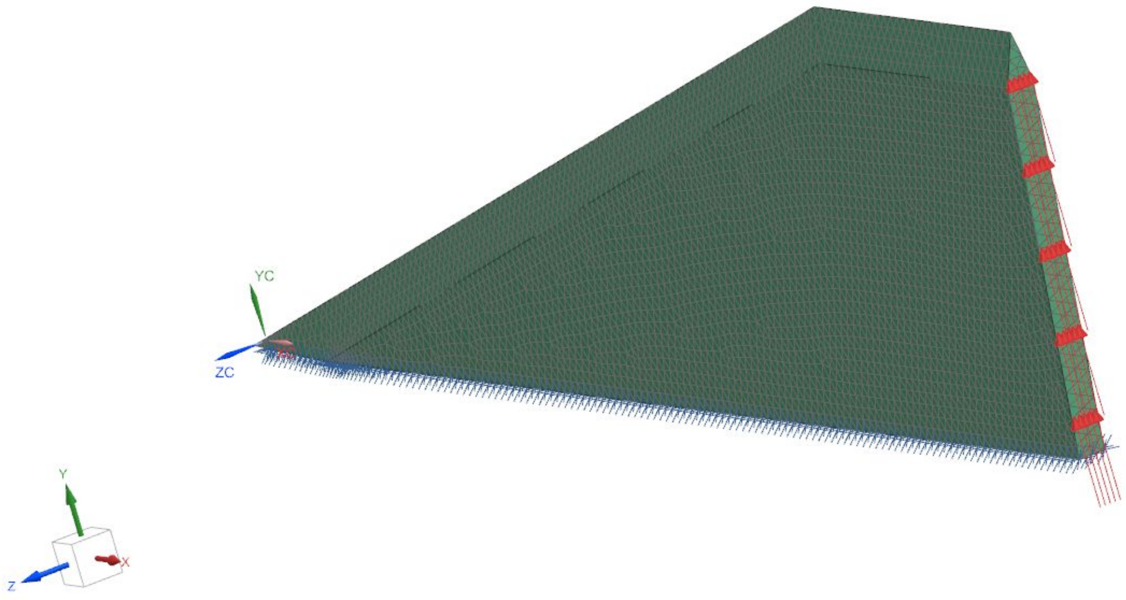
FEA - Fins

- Fixed constraint on bottom edge
- 1/16 inch mesh
- material properties: aluminum 6061
- 200lbf magnitude force applied along top edge, -z axis (solution 1)
- 200lbf magnitude force applied along hind edge, +y axis (solution 2

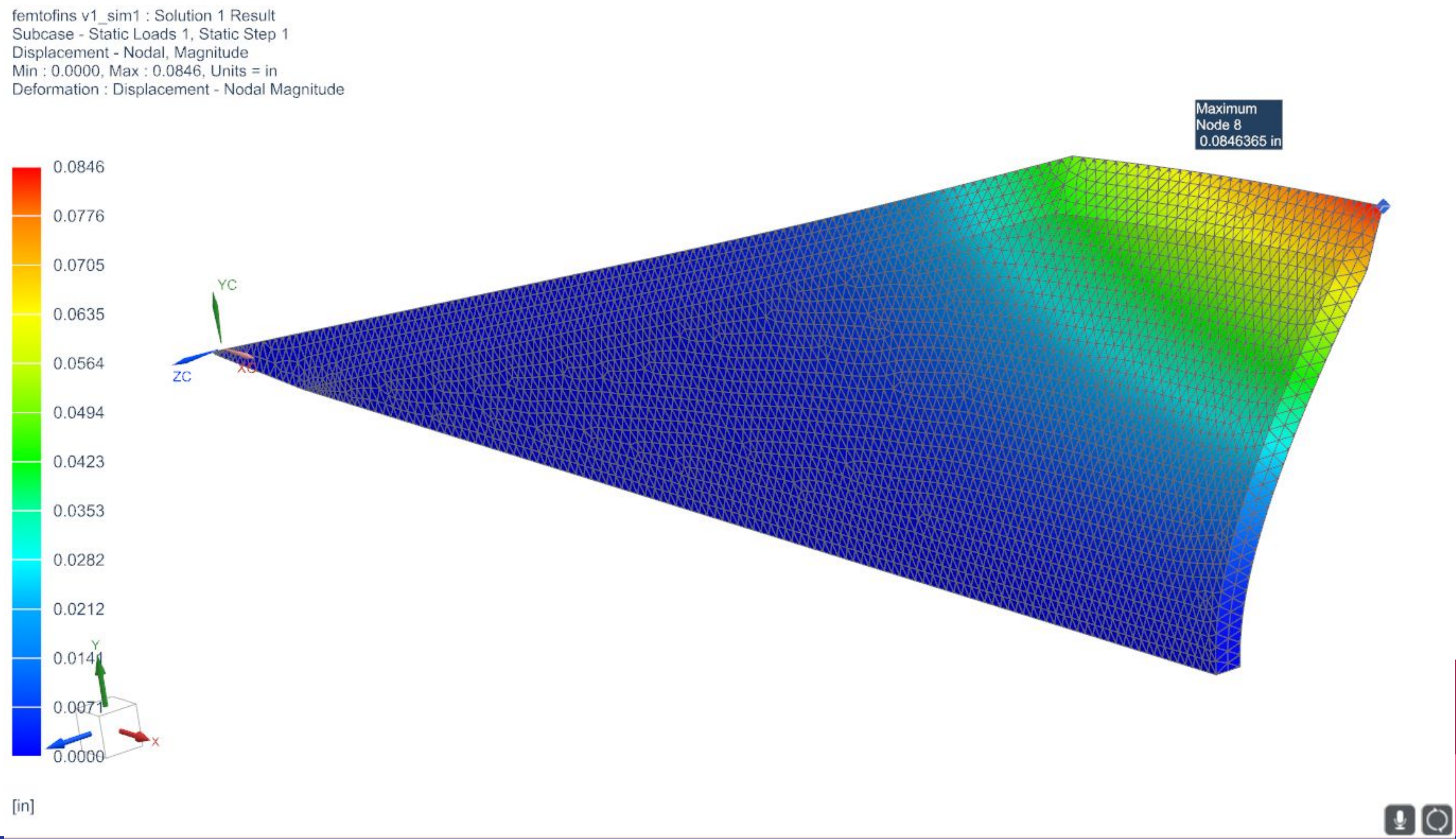
Solution 1

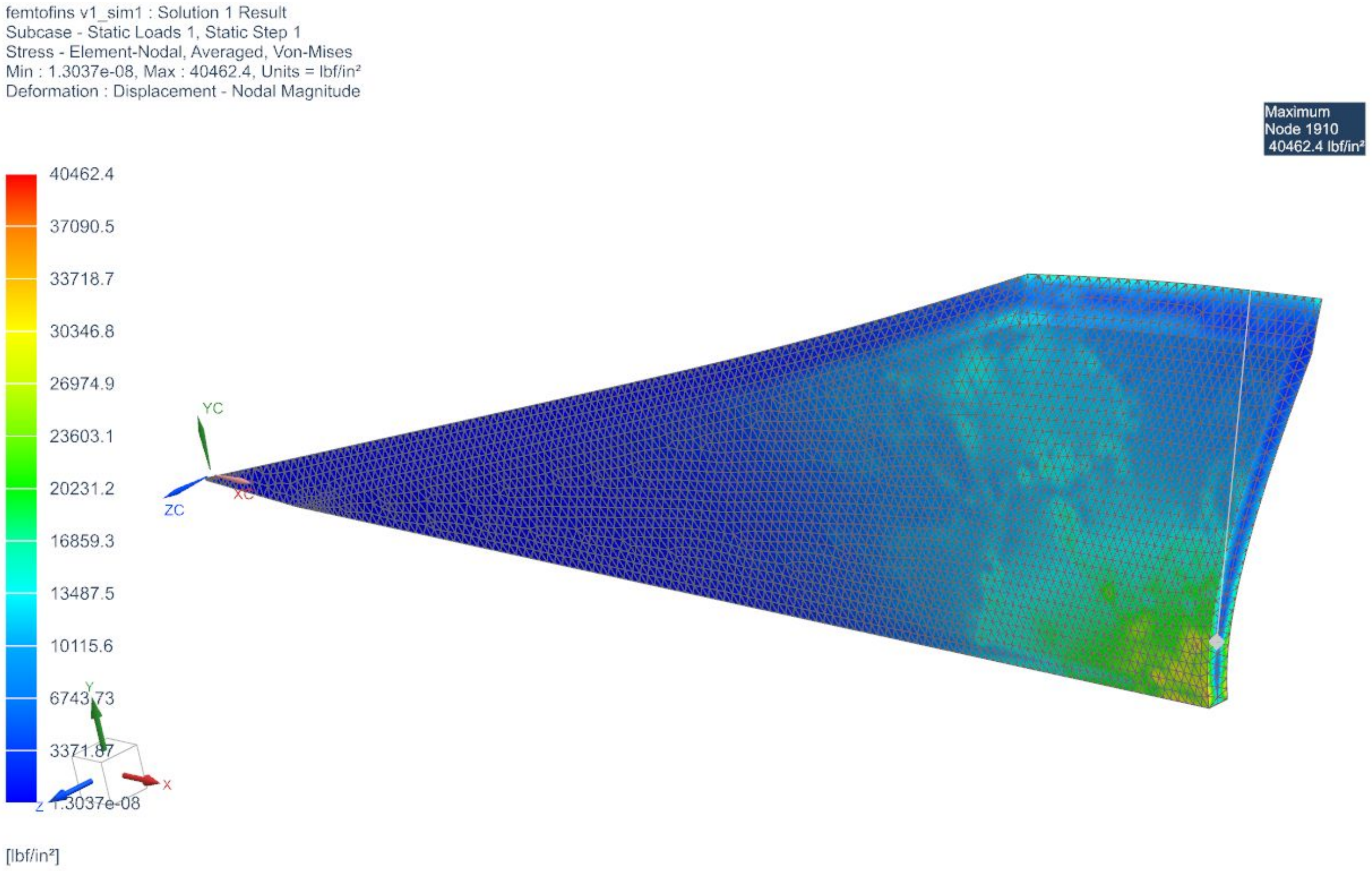

Welcome Page
(Simulation) femtofins v1_sim1.sim
Force(1)
YC
ZC
Y
X
Z

Solution 2

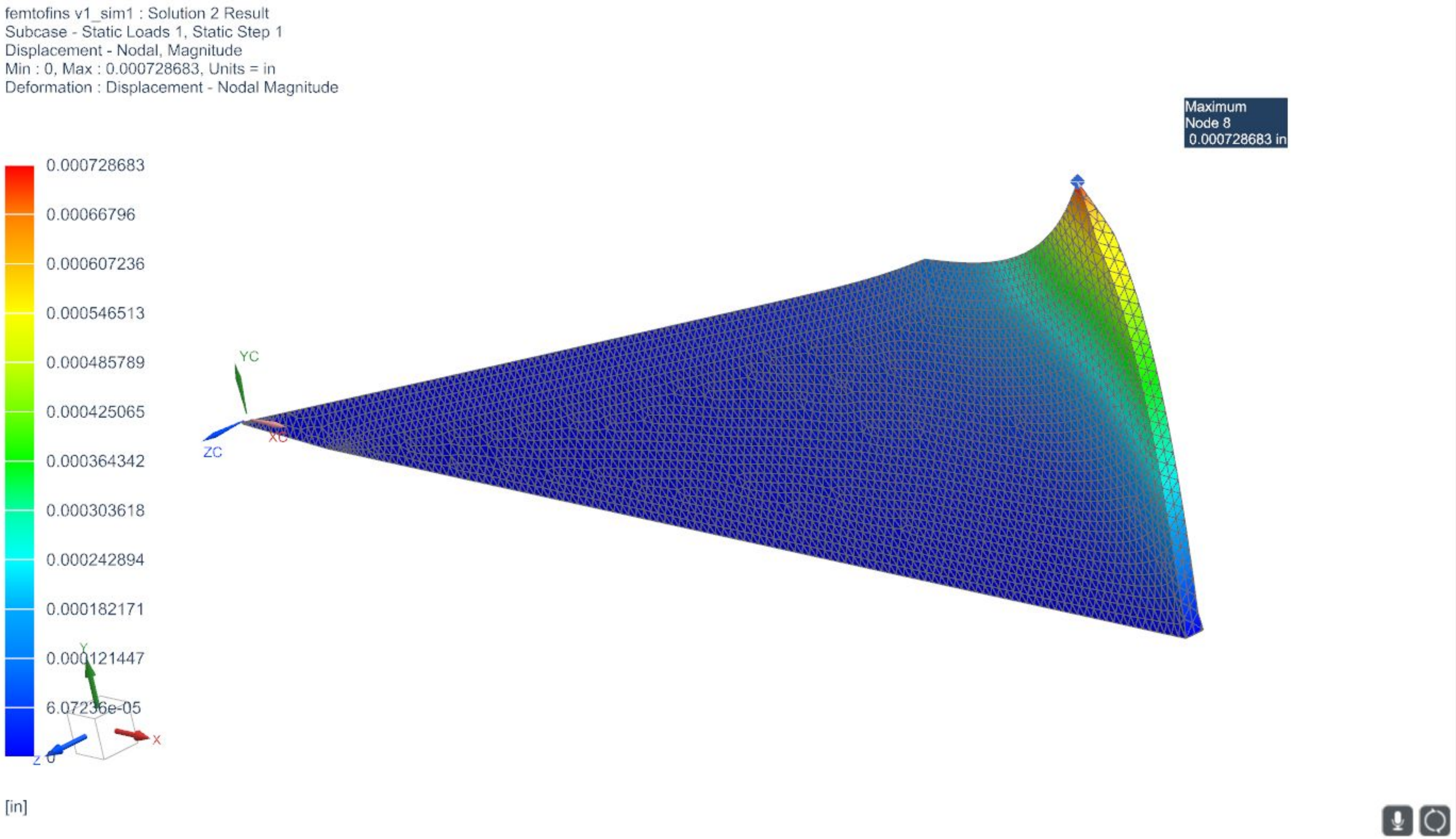


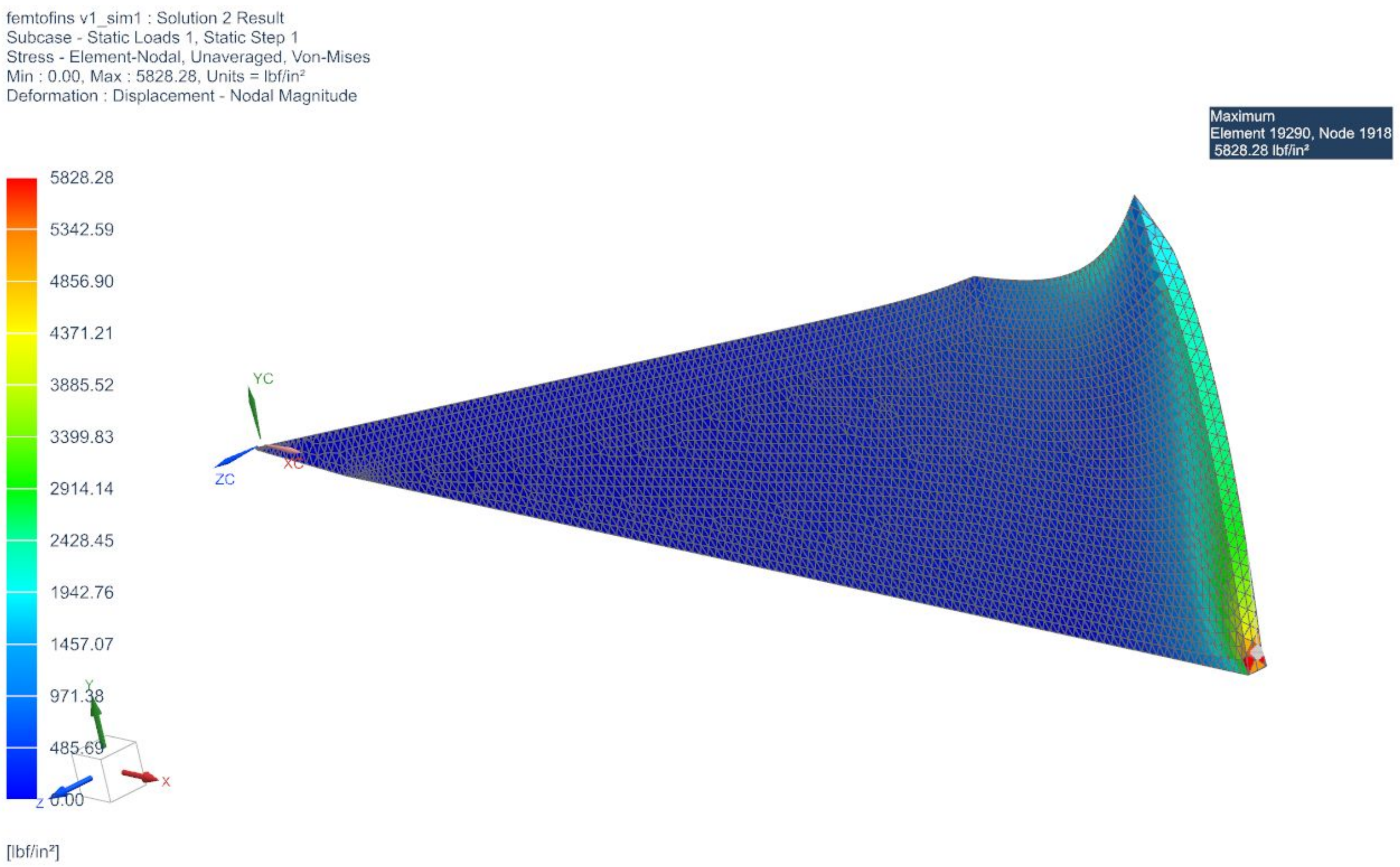
Displacement and Stress for Simulation 1


femtofins v1_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Displacement - Nodal, Magnitude
Min : 0.0000, Max : 0.0846, Units = in
Deformation : Displacement - Nodal Magnitude
Maximum
Node 8
0.0846365 in
0.0846
0.0776
0.0705
0.0635
0.0564
0.0494
0.0423
0.0353
0.0282
0.0212
0.0141
0.0071
0.0000
[in]
YC
ZC
XC
Y
X


femtofins v1_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Stress - Element-Nodal, Averaged, Von-Mises
Min : 1.3037e-08, Max : 40462.4, Units = lbf/in²
Deformation : Displacement - Nodal Magnitude
Maximum
Node 1910
40462.4 lbf/in²
40462.4
37090.5
33718.7
30346.8
26974.9
23603.1
20231.2
16859.3
13487.5
10115.6
6743.73
3371.87
1.3037e-08
[lbf/in²]
YC
ZC
XC
Y
X
Z

Displacement and Stress for Simulation 2

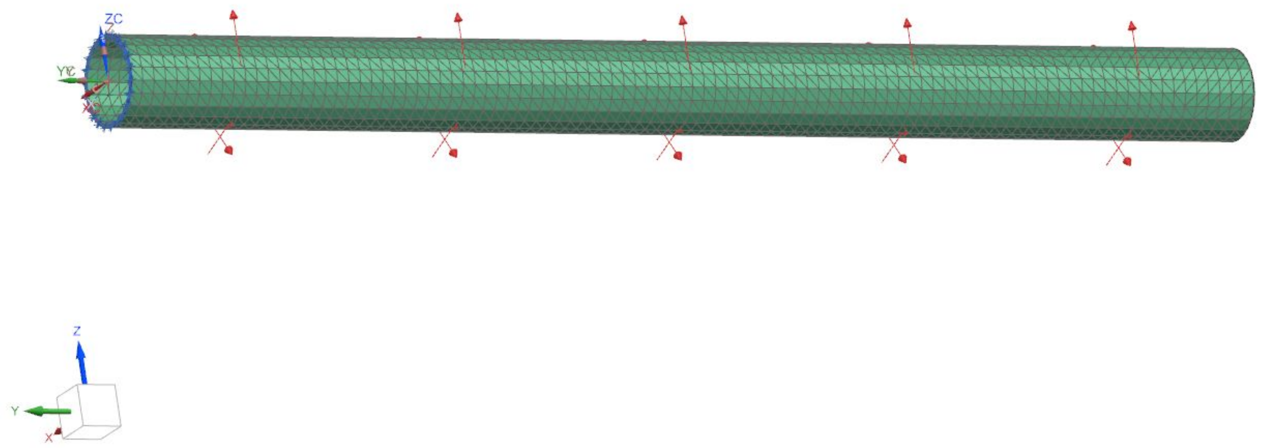

femtofins v1_sim1 : Solution 2 Result
Subcase - Static Loads 1, Static Step 1
Displacement - Nodal, Magnitude
Min : 0, Max : 0.000728683, Units = in
Deformation : Displacement - Nodal Magnitude
Maximum
Node 8
0.000728683 in
0.000728683
0.00066796
0.000607236
0.000546513
0.000485789
0.000425065
0.000364342
0.000303618
0.000242894
0.000182171
0.000121447
6.07236e-05
0
[in]
YC
ZC
XC
Y
X
Z


femtofins v1_sim1 : Solution 2 Result
Subcase - Static Loads 1, Static Step 1
Stress - Element-Nodal, Unaveraged, Von-Mises
Min : 0.00, Max : 5828.28, Units = lbf/in²
Deformation : Displacement - Nodal Magnitude
Maximum
Element 19290, Node 1918
5828.28 lbf/in²
5828.28
5342.59
4856.90
4371.21
3885.52
3399.83
2914.14
2428.45
1942.76
1457.07
971.38
485.69
0.00
[lbf/in²]
YC
ZC
XC
Y
X
Z

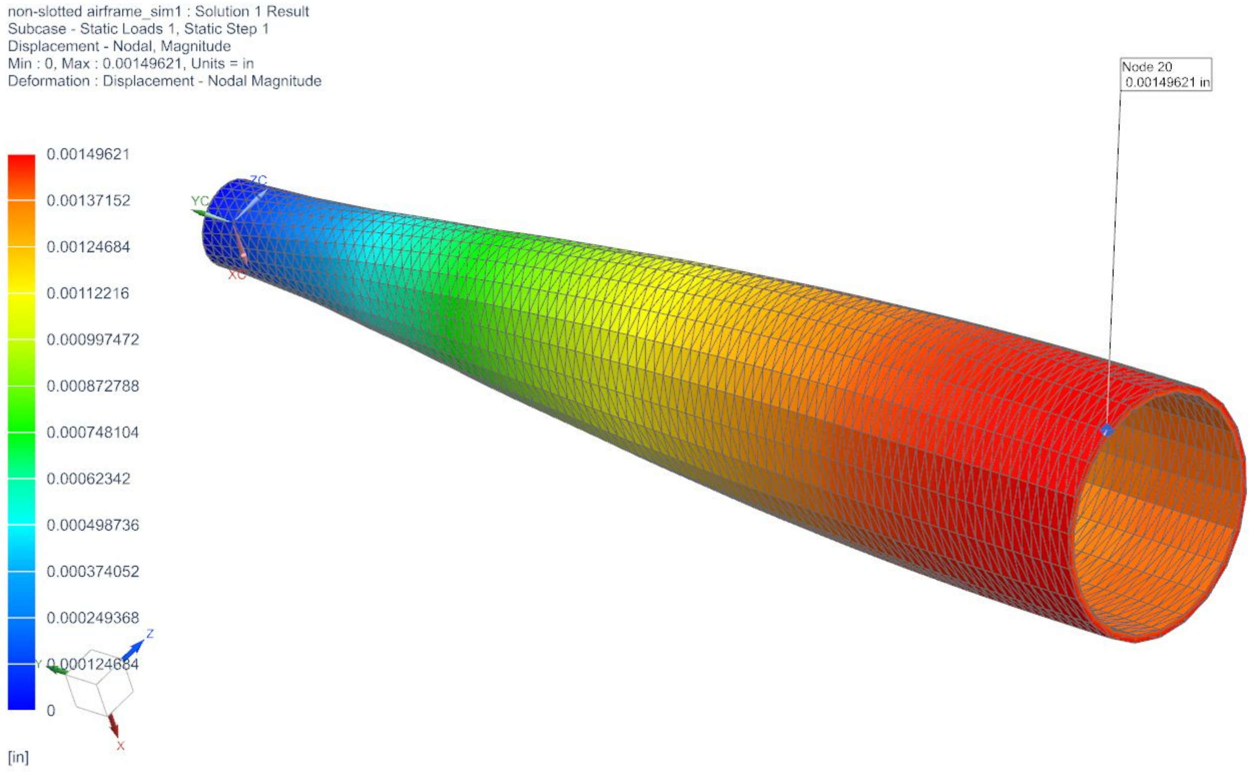
FEA non-slot tube (Closed Section)

- Fixed constraint on face
- 1/4 inch mesh
- material properties: aluminum 6061
- 100 lb-in torque about the y-axis
- 28 inches long, no slots.

Non-Slotted Tube Boundary Conditions



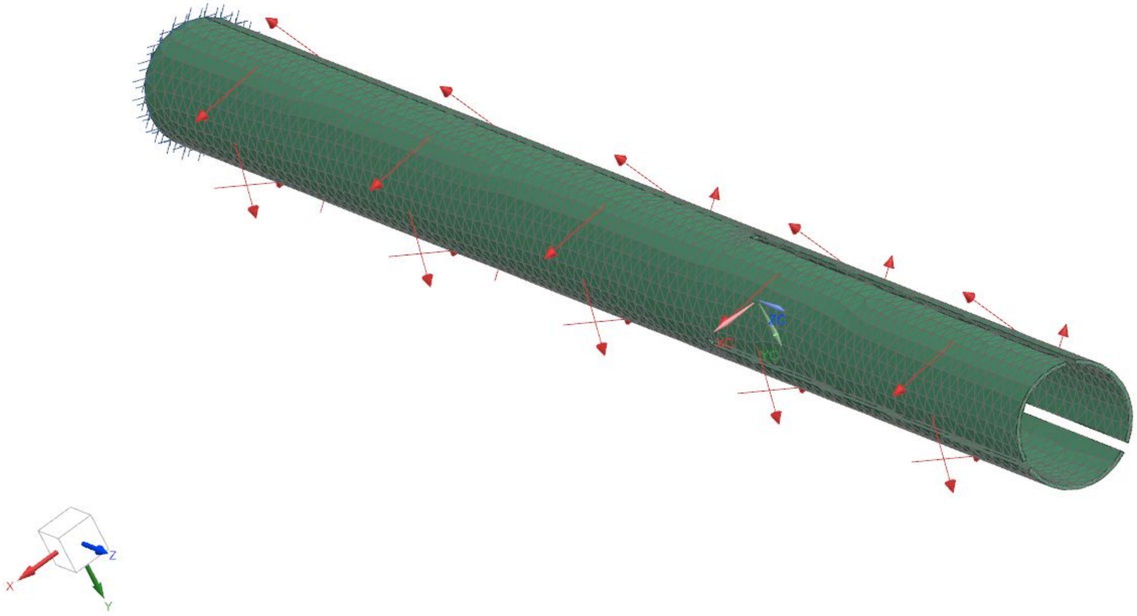
Non-Slotted Tube Results



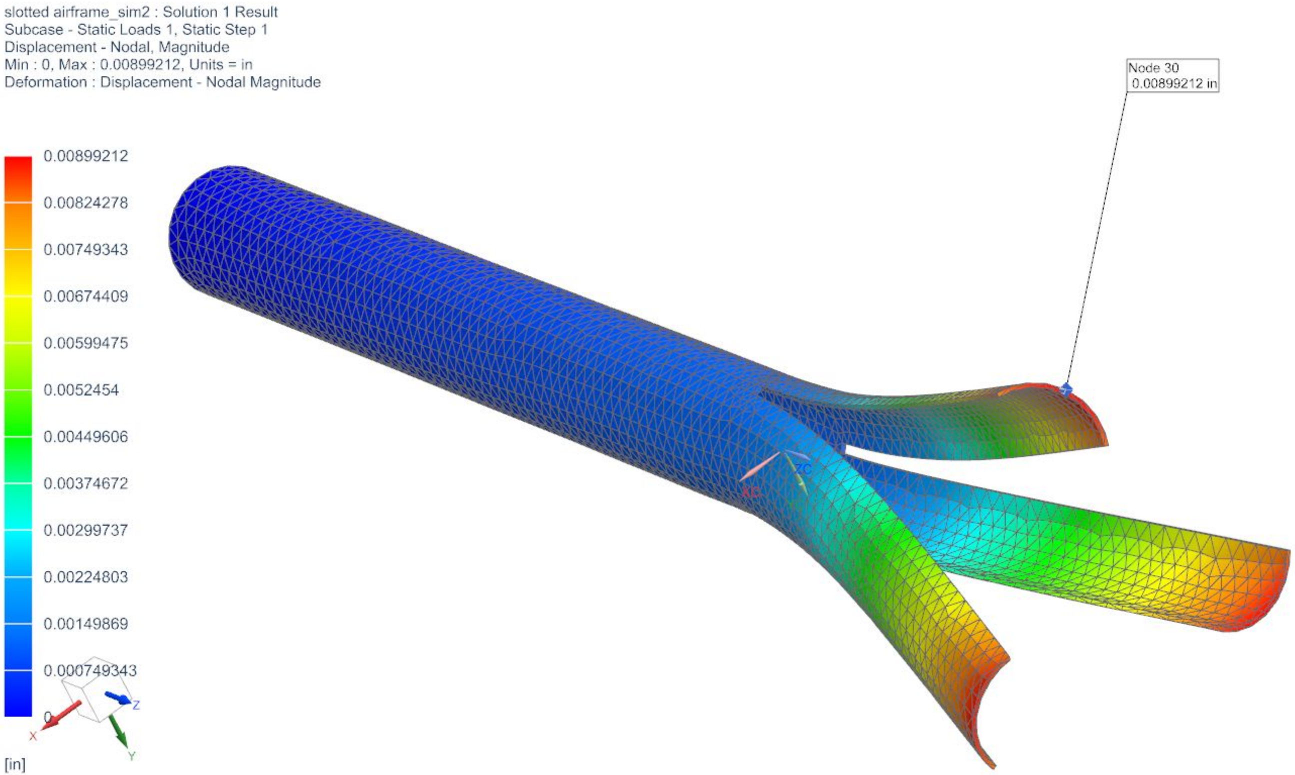
FEA - Slotted-tube (Open Section)

- Fixed constraint on non-slotted face
- 1/4 inch mesh
- material properties: aluminum 6061
- 100 lb-in torque about the y-axis
- 28 in long, slots (3) are 8 inches long and ⅛ inch thick.

Slotted Tube Boundary Conditions



Slotted Tube Results



Airframe Remarks

- Slotted Airframes had a *higher* overall displacement due to a lower torsional rigidity (see HW4 and 5)
- This was used as a design trade on whether or not to make cuts on the tube as fin-slots.

Manufacturing Process - Overview

Tubes:

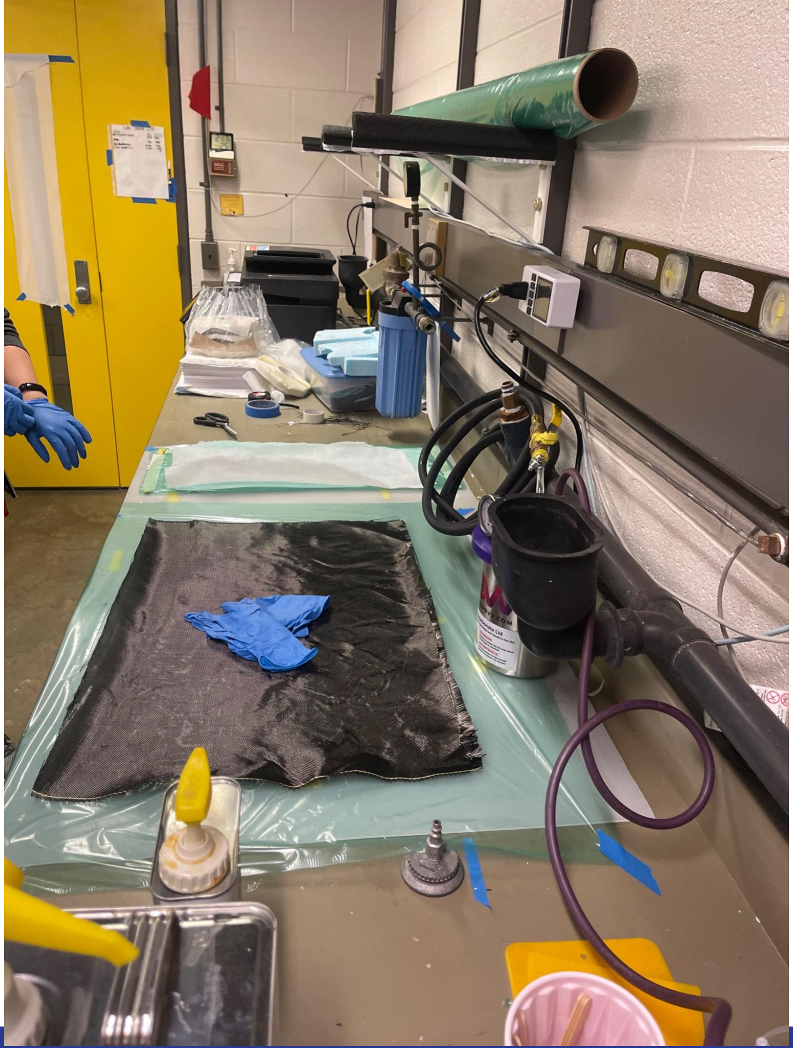
1) Application of mold release: base tube
2) Application of epoxy and resin: carbon fiber
3) Roll wrap
4) Curing - via vacuum

Fins:

1) Water jet cut from JCC

Manufacturing Process - Application of Epoxy and Resin


WEST SYSTEM
105
EPOXY RESIN




16 OUNCE

Manufacturing Process - Roll wrapping


TouchNTuff
92-575
NBR
PARTALL
PASTE #2

Manufacturing Process - Curing

Certificate Analysis

- Aerospace Structural Analysis and Design Project Master (4)
- Aerospace Project Specialist (2)
- Aerospace Structures Manufacturing Master (2)

Finite Element Analysis Outline

Description of all needed work in regards to Finite Element Analysis of the carbon fiber rocket, including and outline of specific calculations needed with descriptions listed.

Link: FEA - Outline

Process Statement - Carbon Fiber Tubes

Overview of all necessary steps for the completion of the carbon fiber rocket design.

link: Carbon Fiber Tubes