

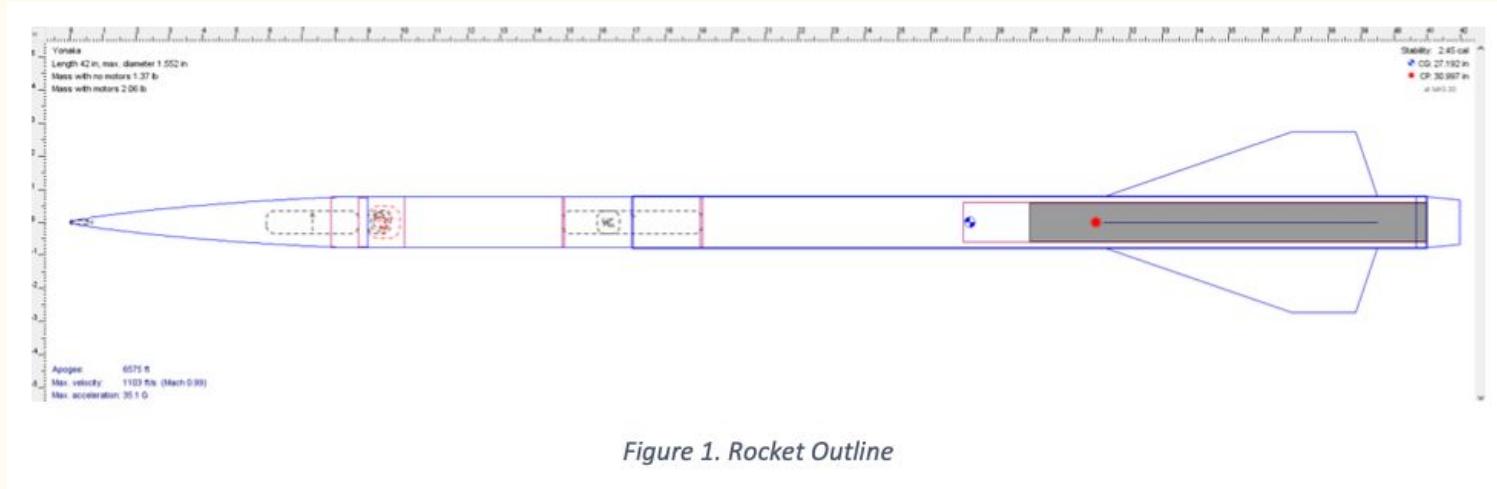
AeroSpace Structural Analysis and Design Project

Carbon Fiber Rocket

Noah Miranda & Nicholas Walker

Preliminary Design

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



Analysis

Methods

- Finite Element Method (FEM)
- Analytical Solution

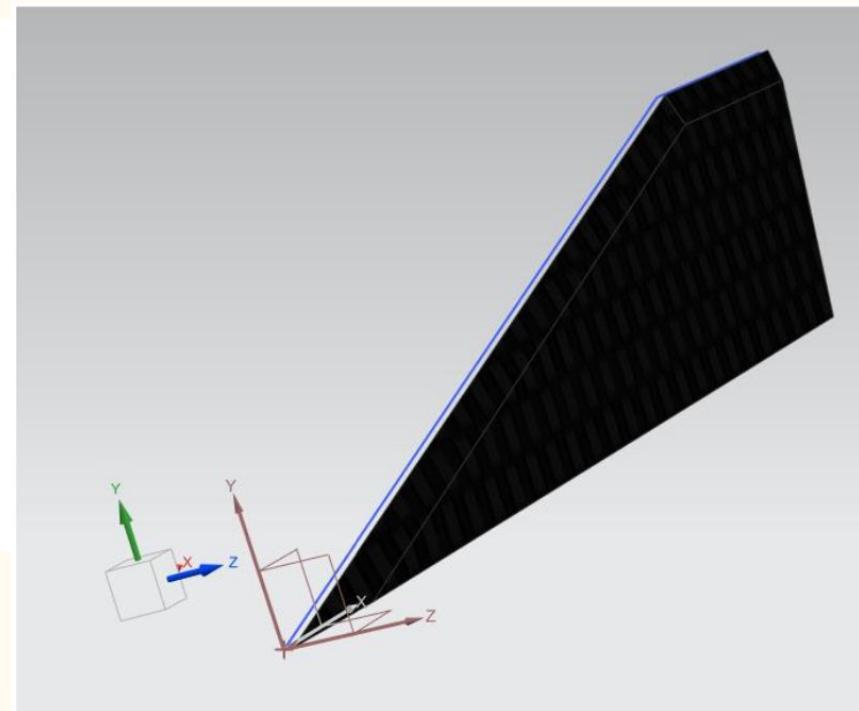
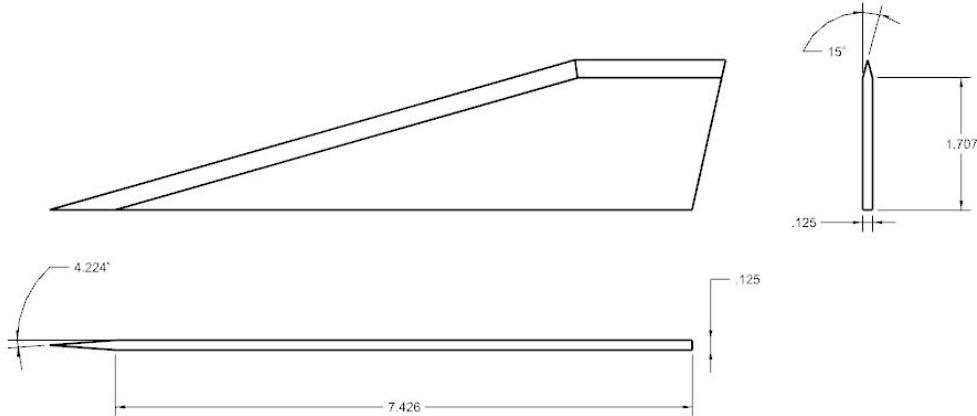
Calculations

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

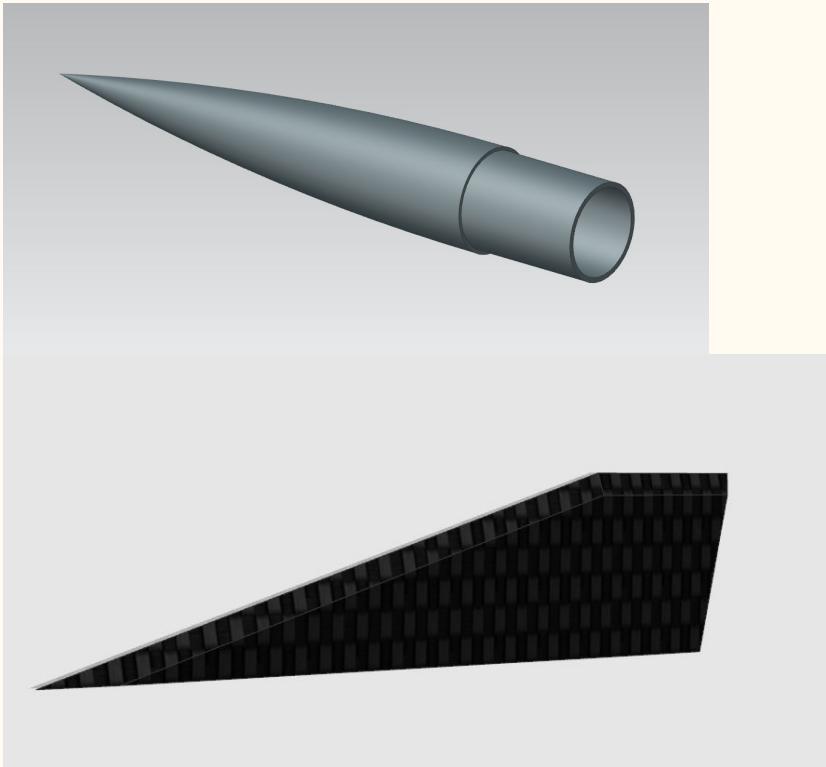
Assembly

- 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



CAD NX, Components - Nosecone, Fins, Slot-tube, Non-slot tube



Manufacturing

Fins

- Water-jet cut @JEC

Airframe

- Carbon Fiber Tubes

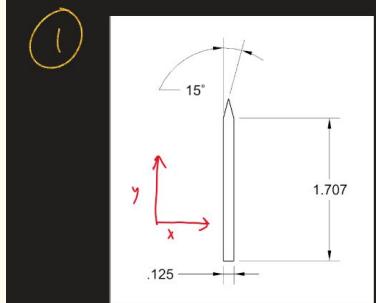


Calculations - based on homework

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 → [Airframe](#)
7. Aerospace Materials → [Airframe](#)

Sectional Properties



Assumptions:

Chamfer angle is small,
assume chamfer area to
be included.

 Treat as rectangle
 $b = .125 \text{ in}$

$$\frac{.125}{2} \times \frac{.125}{2} \times \cot(15^\circ) = x = .233 \text{ in}$$

$$h = 1.94 \text{ in}$$

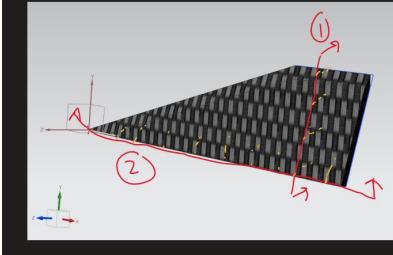
Simple rectangle $\bar{x} = .0625 \text{ in}$ $\bar{y} = \frac{1.94}{2} = .97 \text{ in}$

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

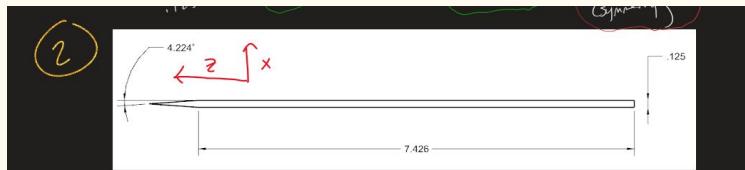
$$I_{xy} = \frac{(.125)(.125)^3}{12} = 3.15 \times 10^{-6} \text{ in}^4$$

(Symmetry)

Project: Sectional properties of fin.



- (1) will examine "thinnest point" of fin
- (2) will examine adhesion surface to a frame.



$$\bar{x} = .0625 \text{ in} \quad n = .125 \text{ in}$$

Chamfer approx: $7.476 + .0625 \cot(4.224) = b$
 $b = 8.272 \text{ in}$

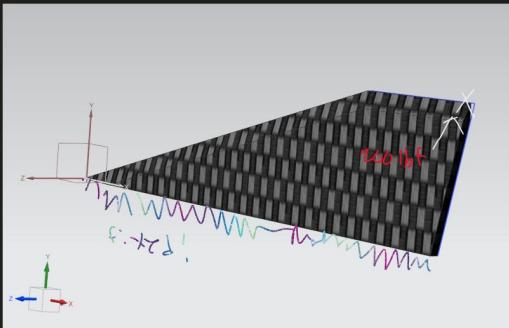
$$I_{xx} = \frac{8.272(.125)^3}{12} = 1.346 \times 10^{-3} \text{ in}^4$$

$$I_{zz} = \frac{(1.18)(8.272)^3}{12} = 5.896 \text{ in}^4$$

$I_{xz} = 0$ due to symmetry

Deflection Calculations (p1)

Project Problem:

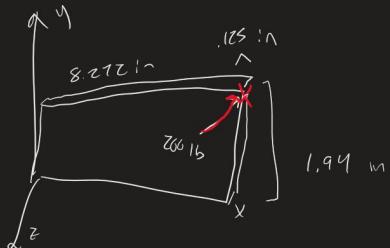


Apply a force
of magnitude 200 lbf

on the fin section shown.

Assume rectangular geometry.

The $x-z$ bottom surface is
fixed!



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

Deflection Calculations (p2)

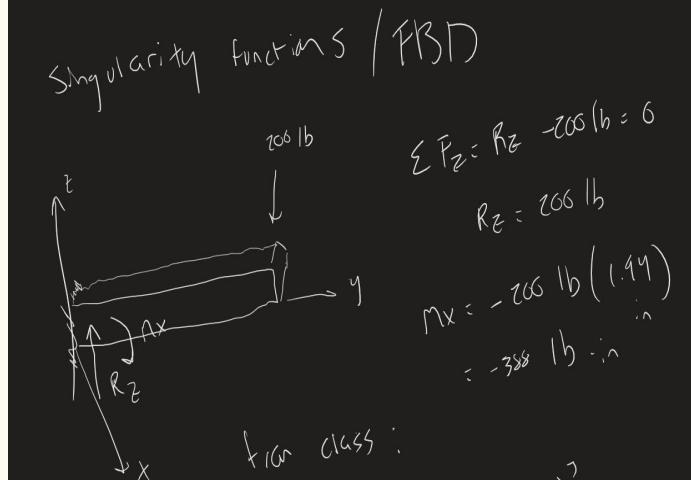
Find the deflection along the z axis of the top left corner where the force is applied.

Assume material properties of aluminum

$$E = 1 \times 10^7 \text{ PSI}$$

Consider beam of sectional properties:

boxcar surface $\{I\}_{xx} : 1.346 \times 10^{-3} \text{ in}^4 = \left(\frac{8272(1.125^3)}{12} \right)$

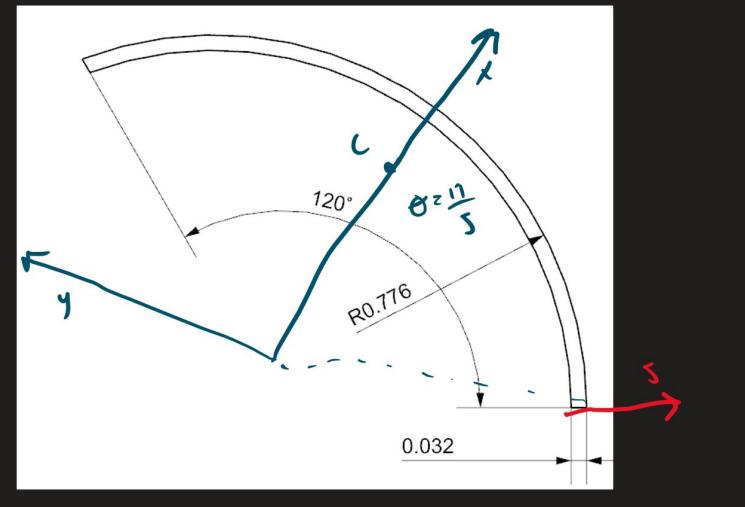


$$\delta_z = \frac{-PL}{3EI} = \frac{200(1.94)}{3(1 \times 10^7)(1.346 \times 10^{-3})}$$

$$\delta_z = -.036 \text{ in}$$

Shear - Center of Airframe: open section

A 200 lb load is applied tangential
to $\frac{1}{3}$ of a cylindrical airframe shaft.



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.

Shear - Center of Airframe: open section (p2)

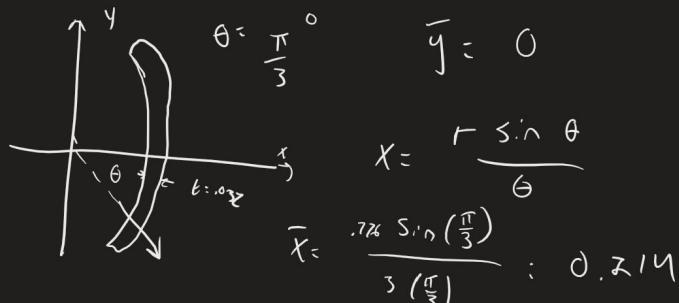
Shear acts along the X -direction.

Find : Sectional Properties.

Shear flow

location of shear center due to S_x

Based on geometry / assume thin-walled assumption.



Sectional Properties:

$$I_{xx} = \int y^2 dA = \frac{r^4}{8} \left(\frac{\theta}{\pi} - \sin\left(\frac{\theta}{2}\right) \right) \\ = 1.07 \times 10^{-3} \text{ in}^4$$

$$I_{yy} = \int x^2 dA = \frac{r^4}{8} \left(\frac{\pi}{\theta} + \sin\left(\frac{\theta}{2}\right) \right) \\ = 4.63 \times 10^{-2} \text{ in}^4$$

$$I_{xy} = 0$$

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

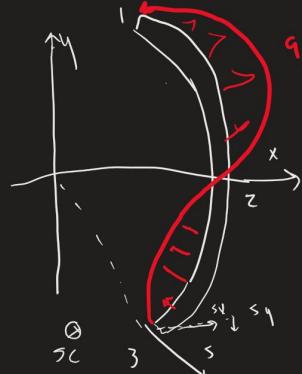
$\overbrace{S_y}^{S_y} \quad S_y = -200 \sin\left(\frac{\pi}{3}\right) = -173 \text{ lb}$

Shear - Center of Airframe: open section (p3)

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

$$q_0 = \left(c_x \text{tr} \right)_{-36}^{36} \cos \theta \, d\theta + c_y \text{tr} \int_{-36}^{36} s_i \sin \theta \, d\theta$$

$$q_G = \underbrace{(x \cdot \text{tr} (\sin 36 - \sin (-36)))}_{ss,6} + \underbrace{(y \text{tr} (\cos 36 - \cos -36))}_{u015}$$



$$\theta \in -\pi/3, 0, \pi/3$$

$$\text{Min } \theta \frac{\pi}{6} : 07.27 \text{ lb/in}$$

$$\text{Max } \theta \frac{-\pi}{6} : -107.27 \text{ lb/in}$$

Moment about point 1: $y = -776 \sin 60^\circ = -672 \text{ in}$

$$\bar{x}_s S_x$$

$$q_G = \underbrace{(x \cdot \text{tr} (\sin 36 - \sin (-36)))}_{ss,6} + \underbrace{(y \text{tr} (\cos 36 - \cos -36))}_{u015}$$

$$q(\pi/3) : 0 \Rightarrow \bar{x}_s = 0$$

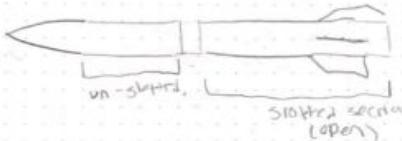
Shear center is at $(0, -672)$ in

Torsion - Center of Airframe: closed section (p4)

Hw 4

Closed-sec. tension

Problem The unstated section of the rocket airframe is subject to a torsional load of 600 lb in.



Assume material properties of aluminum
 $G = 3770 \text{ kpsi} = 3.77 \times 10^9 \text{ psi}$

Assume one end fixed.

Use the following dimensions

$$OD = 1.6 \text{ in} \quad ID = 1.5 \text{ in} \quad L = 8 \text{ in}$$

$\Delta t = 60 \text{ s}$ determine

Determine
Torsional Rigidity

∴ Max. shear stress

(iii) Rate and angle of twist (B6)

$$1) \text{ Tensional rigidity } TR = \frac{IAC}{L}$$

Yard G and + are covered. $\frac{1}{2} \frac{1}{2}$

$$Q ds = 2\pi R \cdot R \cdot 1.67 \text{ in}^3$$

$$\text{so, } TR = \frac{HA^2}{GTR} \quad A = T(R^2 - r^2)$$

$$FR = \frac{4(\pi(0.5^2 - 0.75^2))^2}{2\pi(0.5)(3.77 \times 10^6)(0.05)} = 8.9 \times 10^3 \text{ lb/in}^2$$

$$\text{ii) Max shear } Z_{\max} = q/t \quad q = \frac{1}{ct}$$

t is constant.

$$q = \frac{606 \text{ lb/in}}{\sqrt{0.6 - 0.13}} = 1232 \text{ lb/in}$$

$$Z = \frac{1250}{205} = 2.96 \times 10^3 \text{ PS}$$

(iii) Rate and Angle of twist

$$\frac{ds}{dx} = \frac{1}{y^2 x^2 t} \quad g \, ds = \frac{600(2\pi : 0.4)}{1((0.4 - 0.75)^2)(x^2 + y^2)} \quad (40)$$

$$\frac{d\theta}{dt} = 0.067 \text{ rad/m}$$

$$\theta(z) = 0.067 z + c$$

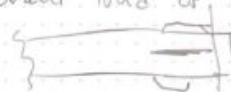
$c = 0$ b/c fixed end $= z_{\text{fix}} = 0$

$$G(6) = 0.54 \text{ rad or } 31^\circ$$

Torsion - Center of Airframe: open section (p5)

AWS

Problem: The slotted section of the rocker airframe is subject to a shear load of 200 lb.



From AWS USE G & aluminum (3.77×10^6 psi)

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

Determine:

i) Torsional Rigidity

ii) Max shear stress due to torsion

iii) Max shear stress due to shear

iv) Net shear due to both



$$i) \text{ Torsional Rigidity } IR = GJ = \frac{2\pi}{3} R t^3$$

$$IR = \frac{2\pi}{3} (0.05)(0.8) (3.77 \times 10^6) \\ = 790 \text{ lb.in}^2$$

$$ii) \text{ Max Torsional Shear Stress } \frac{Tr}{J}$$

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

$$J = \frac{2\pi}{3} (0.05)^3 (0.8) \quad Z_m = \frac{-160}{\frac{2\pi}{3} (0.05)^3 (0.8)}$$

$$Z_m = -3.82 \times 10^6 \text{ psi}$$

iii) Max shear stress - Force

$$q_s = -\frac{(3\pi)(Sy)}{\pi r^3} ds = -\left(\frac{3\pi}{\pi r^3}\right) Sy ds \\ = -\frac{3y}{\pi r^3} \int_0^{t/2} ty ds = -\frac{3y}{\pi r^3} \int_0^{t/2} (rsy) dy$$

$$q_s = \frac{3y}{\pi r^3} (1 - \cos b) \quad | \quad 0 \leq b \leq \pi$$

$$Sy = 200 \text{ lb} \quad r = 0.8 \text{ in}$$

$$q_{s,\max} @ \theta = \pi = \frac{2(200)}{\pi \cdot 0.8}$$

$$q_{s,\max} = 159 \text{ lb/in}^2$$

$$Z_m^{sy} = \frac{159}{0.05} = 0.32 \times 10^6 \text{ psi}$$

$$iv) Z_m + Z_m^{sy} = 4.17 \times 10^6 \text{ psi}$$

Net shear stress is 4.17 psi

Code - C++, Torsion (HW4)

```
public:
    static double cyclicIntegral(double a);
    static double torsionalRigidity(double A, double ds, double Gt);
    static double maxShear(double T, double ZA, double t);
    static double rateOfTwist(double A, double t, double ds);

};

double RocketMath::torsionalRigidity(double A, double ds, double Gt) {
    double cyclicIntegralResult = cyclicIntegral(1);
    return A * (4 * A * A) / (cyclicIntegralResult * (ds / Gt));
}

double RocketMath::maxShear(double T, double ZA, double t) {
    double q = T / (ZA);
    double Zmax = q / t;
    return Zmax;
}

double RocketMath::rateOfTwist(double A, double t, double ds) {
    double cyclicIntegralResult = cyclicIntegral(1);
    double dt_dz = (1 / (4 * (A * A) * 6 * t)) * cyclicIntegralResult * ds;
    return dt_dz;
}
```

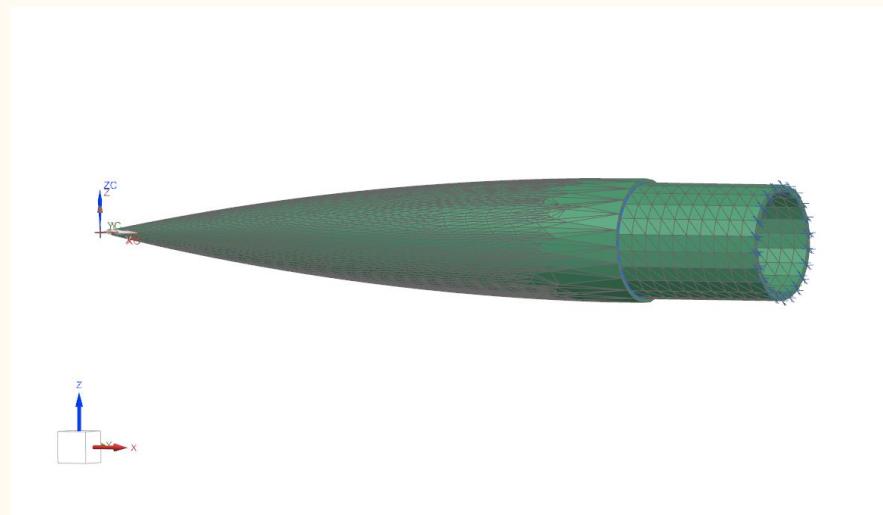
Finite Element Analysis - Overview

FEA and Simulations of components:

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

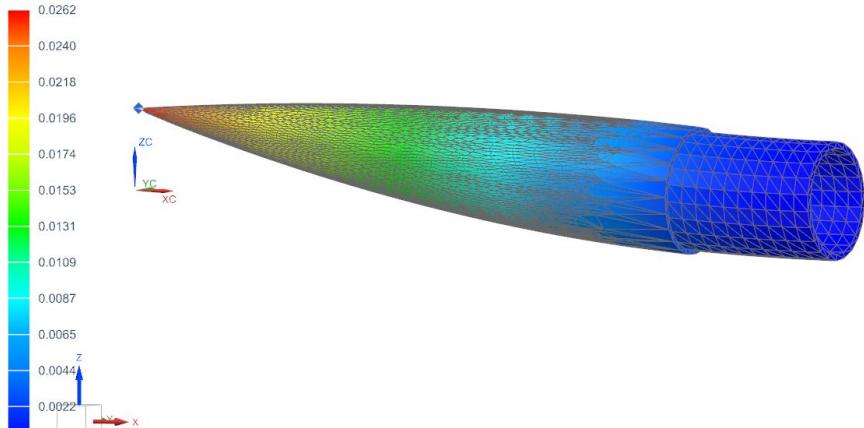
FEA - Nosecone

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

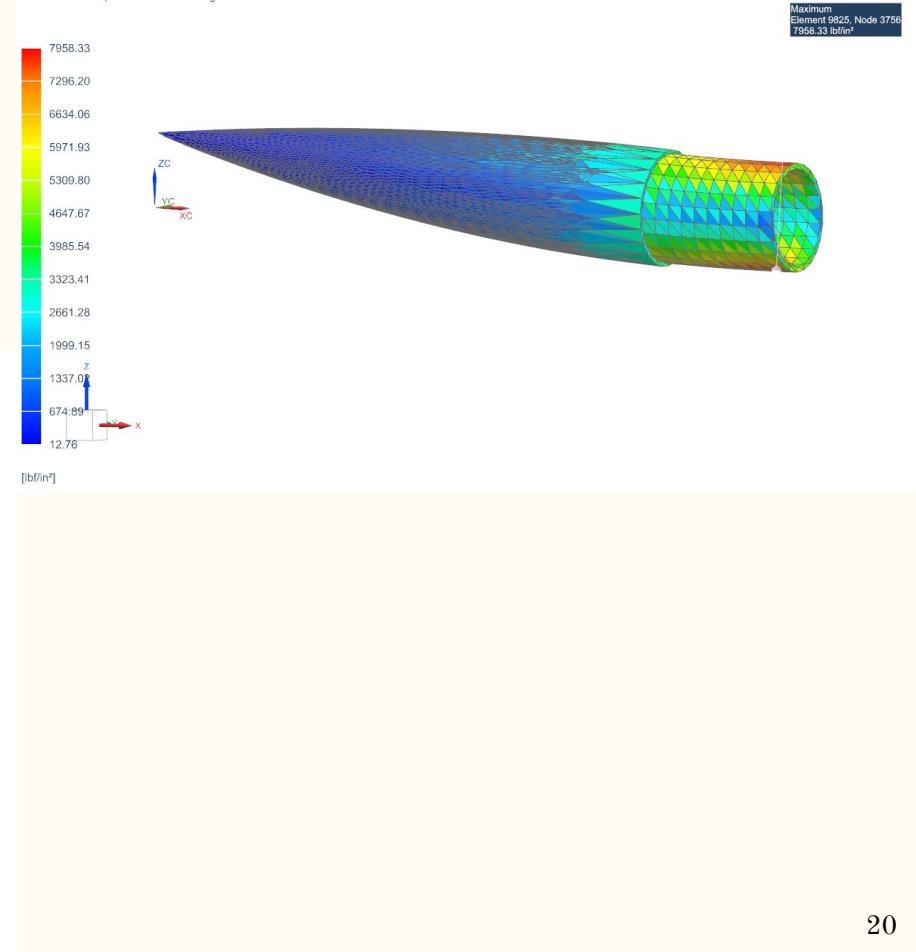


Displacement and Stress

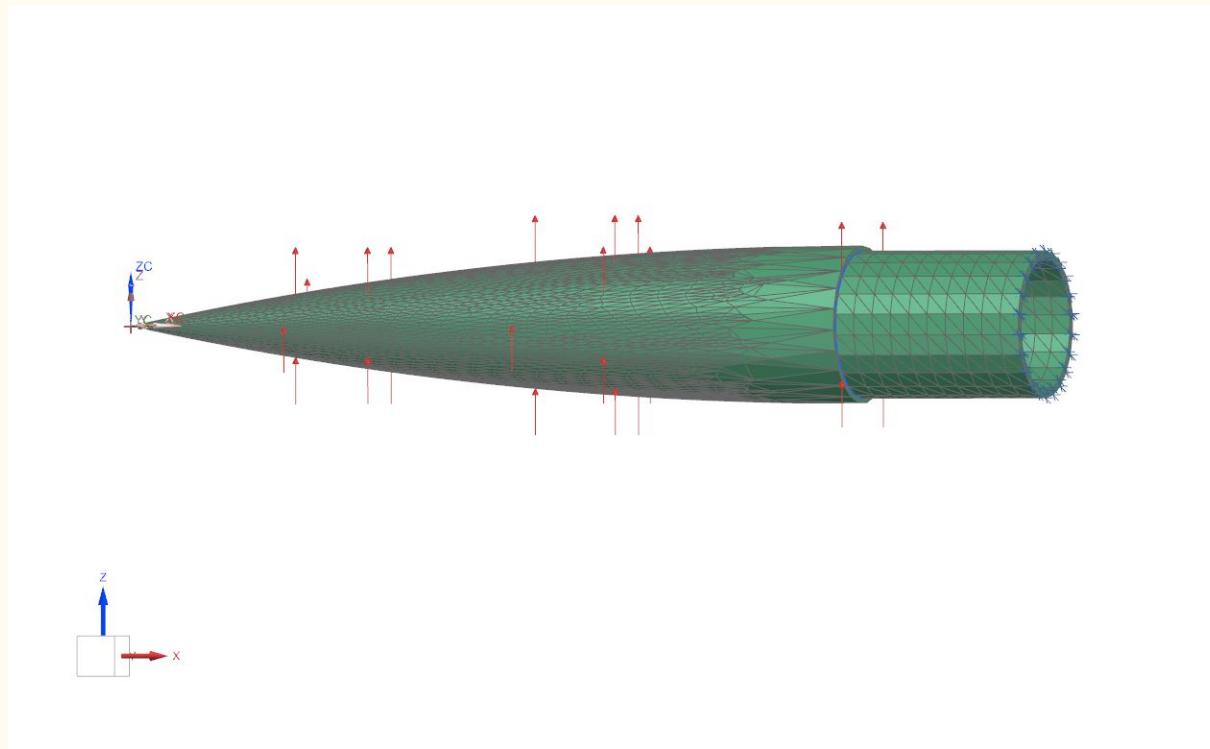
yonaka NC_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Displacement - Nodal Magnitude
Min : 0.0000, Max : 0.0262, Units = in
Deformation : Displacement - Nodal Magnitude



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

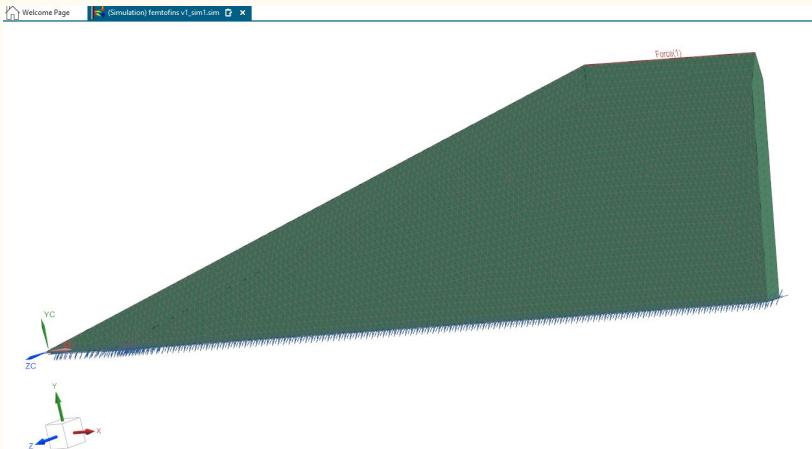
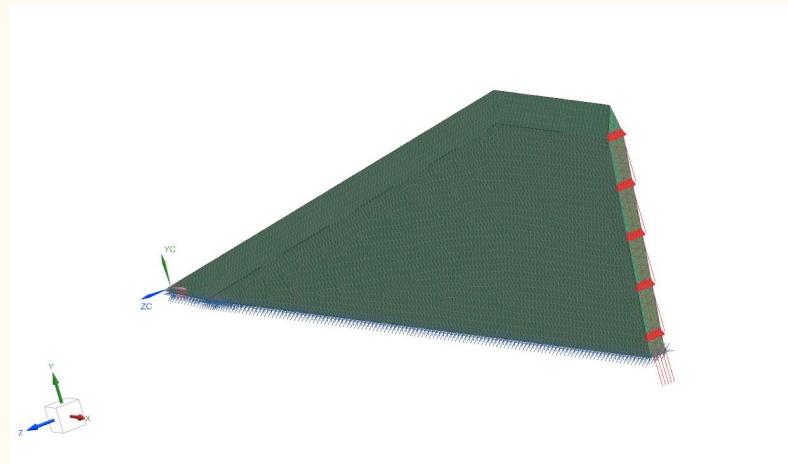


Boundary Conditions

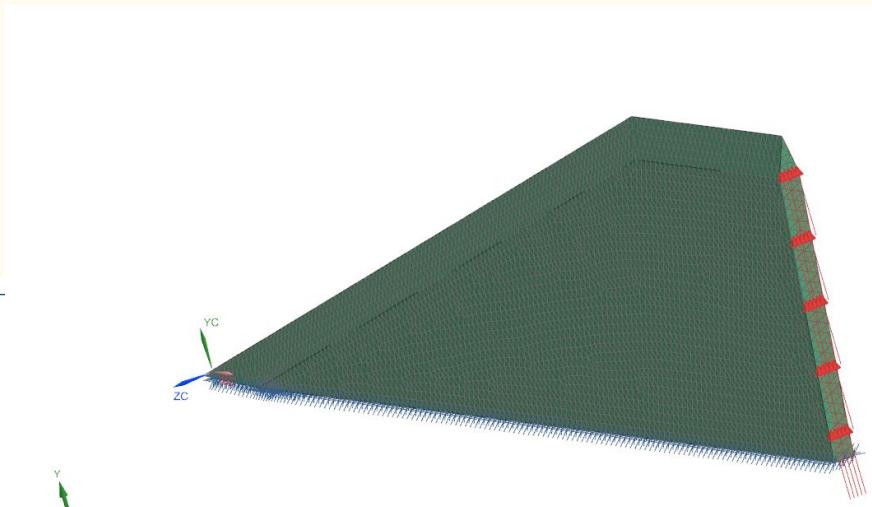
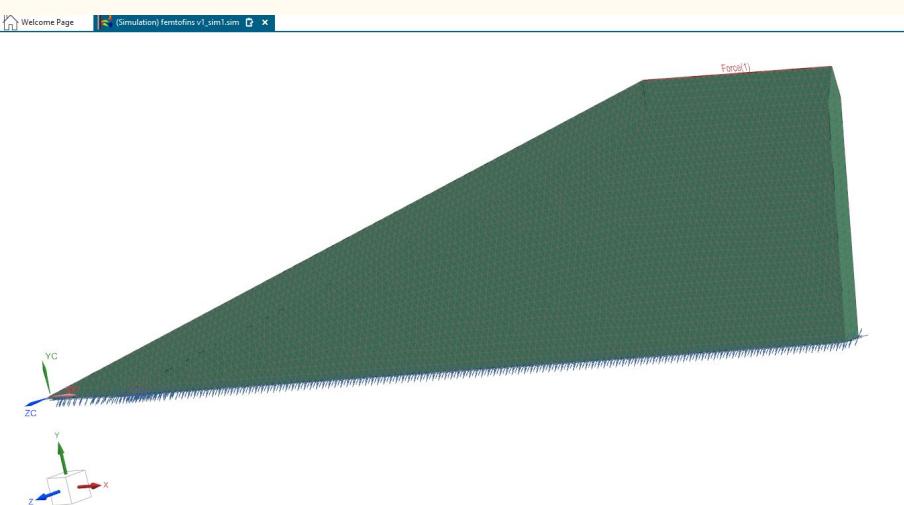


FEA - Fins

- 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)

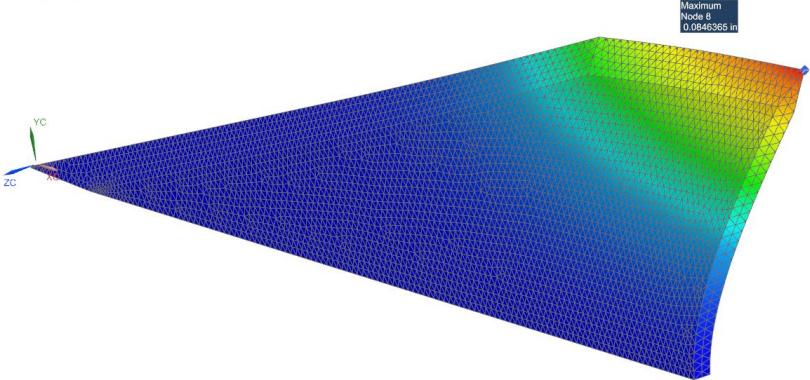


Solution 1 & 2

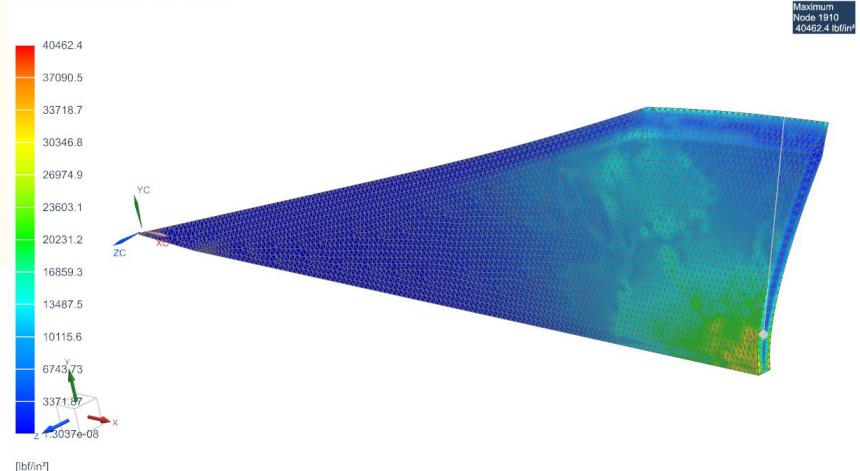


Displacement and Stress for Simulation 1

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

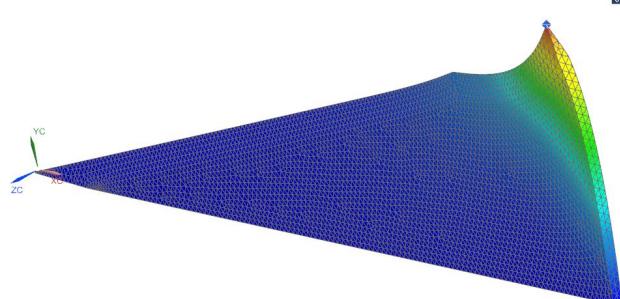


femtofins v1_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Stress - Element-Nodal, Averaged, Von-Mises
Min : 1.3037e-08, Max : 40462.4, Units = lb/in²
Deformation : Displacement - Nodal Magnitude

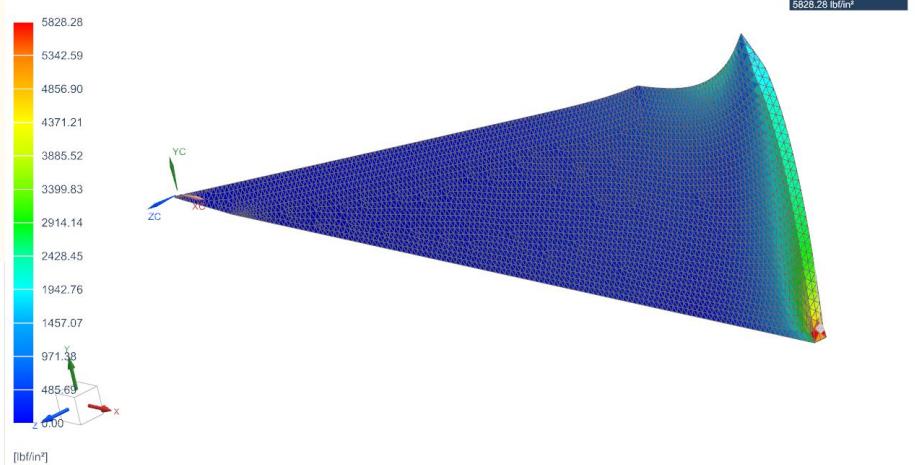


Displacement and Stress for Simulation 2

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



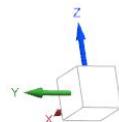
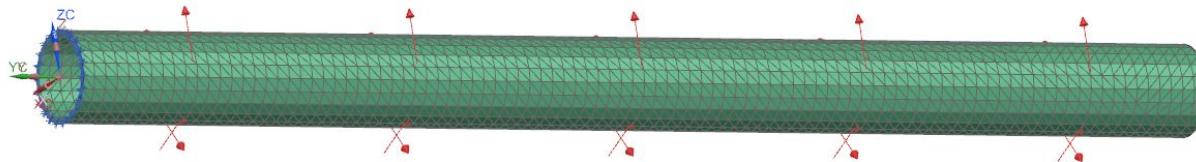
femtofins v1_sim1 : Solution 2 Result
Subcase - Static Loads 1, Static Step 1
Stress - Element-Nodal, Unaveraged, Von-Mises
Min : 0.00, Max : 5828.28, Units = lbf/in²
Deformation : Displacement - Nodal Magnitude



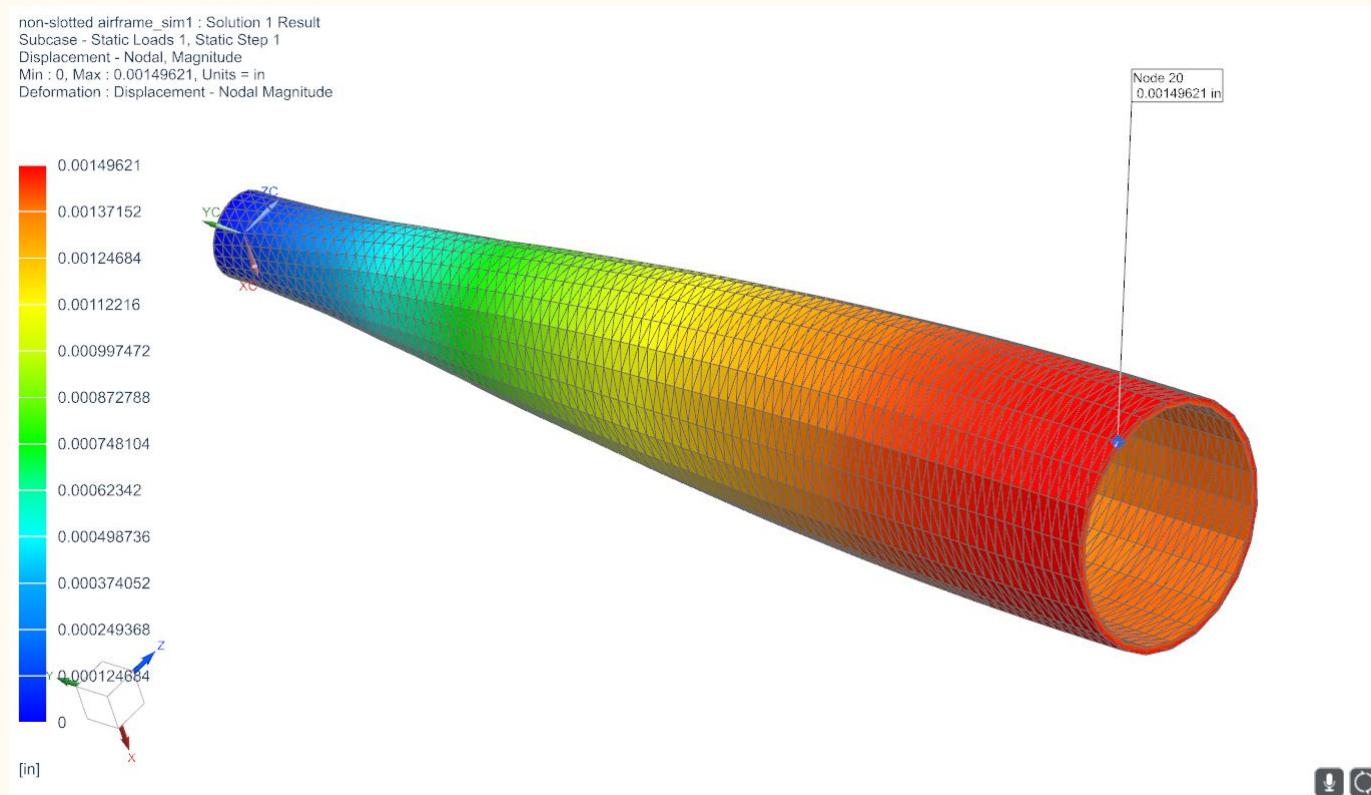
FEA non-slot tube (Closed Section)

- 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



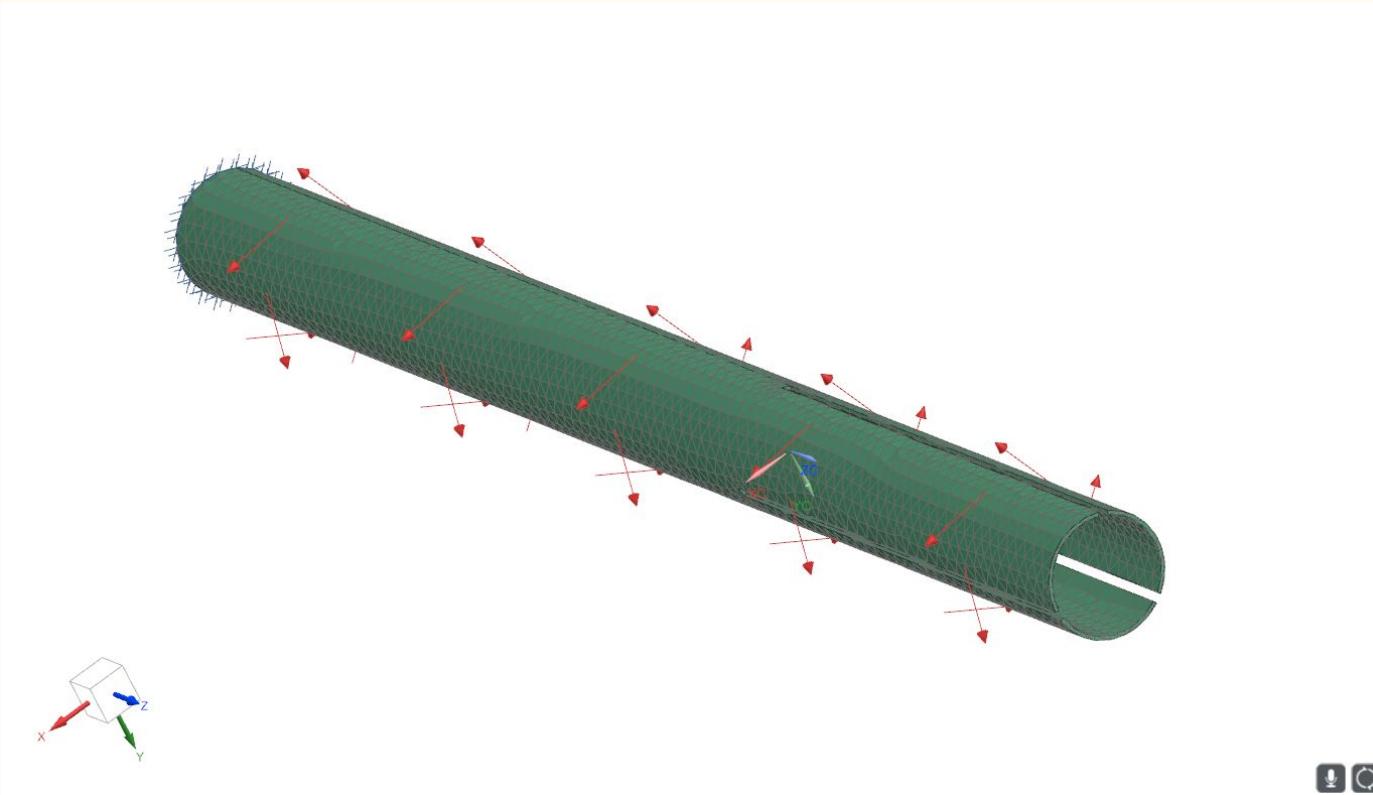
Non-Slotted Tube Results



FEA - Slotted-tube (Open Section)

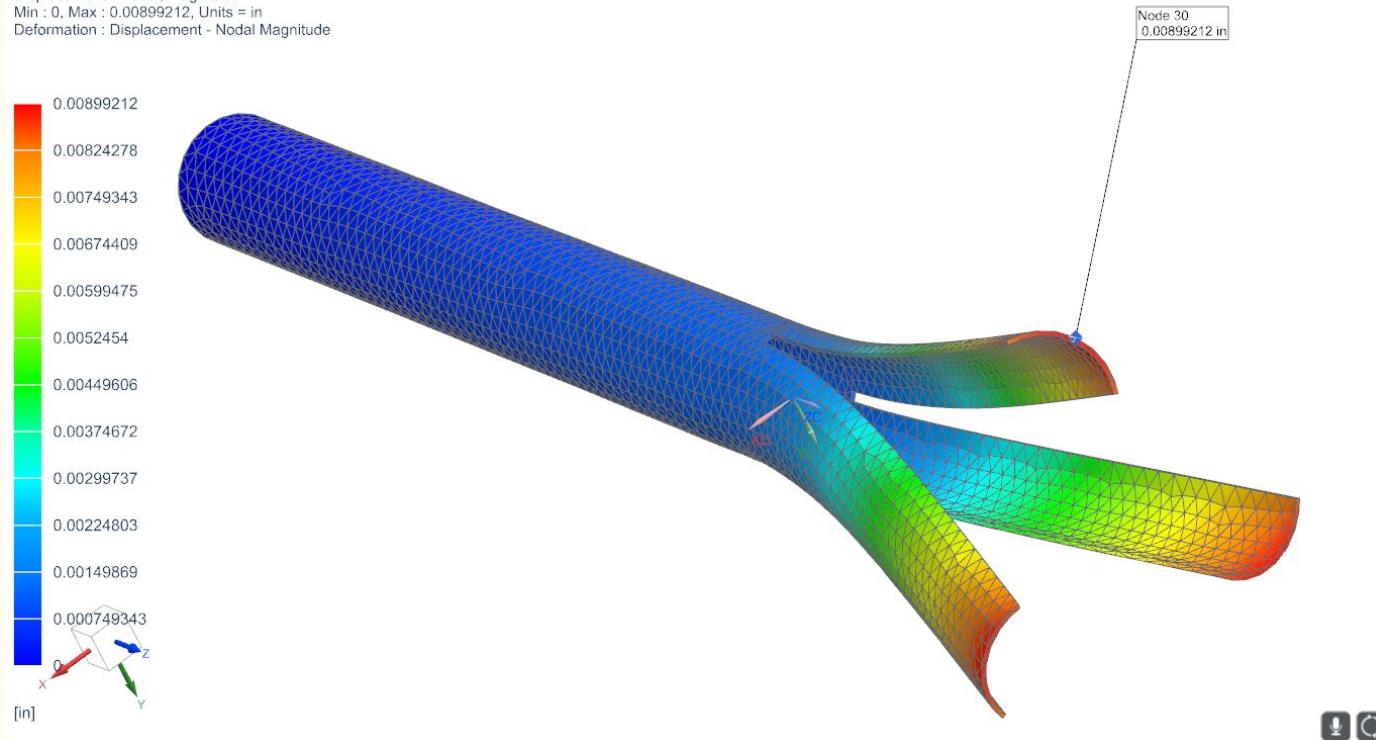
- Fixed constraint on non-slotted face
- 1/4 inch mesh
- material properties: aluminum 6061
- 100 lb-in torque about the y-axis
- 28 in long, slots (3) are 8 inches long and $\frac{1}{8}$ inch thick.

Slotted Tube Boundary Conditions



Slotted Tube Results

slotted airframe_sim2 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Displacement - Nodal, Magnitude
Min : 0, Max : 0.00899212, Units = in
Deformation : Displacement - Nodal Magnitude



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

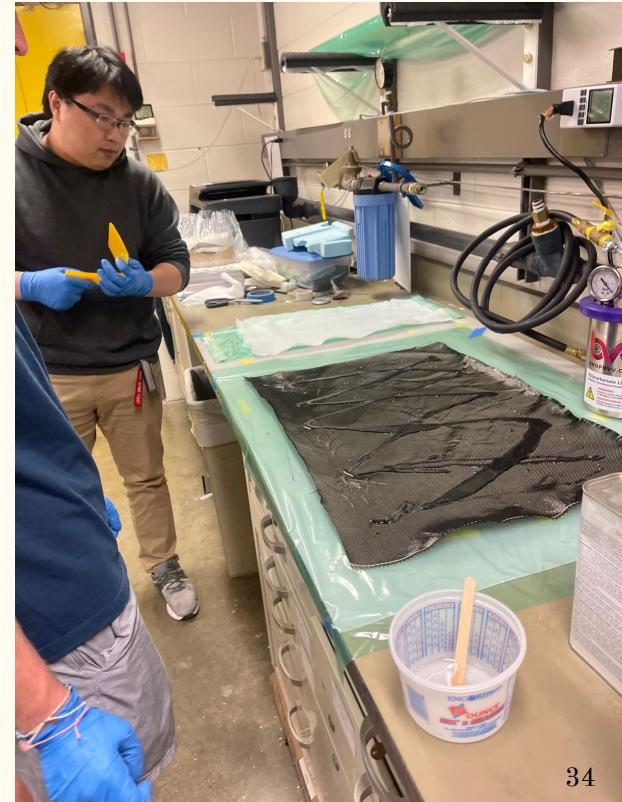
Tubes:

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

Fins:

- 1) Water jet cut from MILL

Manufacturing Process



Manufacturing Process



Manufacturing Process



Reports and Written Analysis

Every process throughout the process has a correspondent written report and summary of the steps taken for preparation and actions required.

Reports (with links):

- [FEA - Outline](#)
- [Manufacturing Process Proposal](#)
- [Process Statements](#)
- [Extended Report](#)
- [Certificate Overview](#)

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](#)

Manufacturing Process Proposal

Prior to the manufacturing of the project, the proposal shows an outline of the process including the idea, preliminary designs, and the manufacturing plan.

link: [Manufacturing Process Proposal](#)

Process Statement - Carbon Fiber Tubes

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

link: [Process Statements](#)

Extended Report

The overall presentation containing all work throughout the project duration.

link: [Extended Report](#)

Certificate Analysis

- Aerospace Structural Analysis and Design Project Master (4)
- Aerospace Project Specialist (1)
- Aerospace Structures Manufacturing Master (2)
- Aerospace Structural Design Master (1)

Other Certificates:

- Thematic Certificates (7)

Total: 15 (A)

In-depth overview of each certificate with correspondence to syllabus.

link: [Certificate Overview](#)