AeroSpace Structural Analysis and Design Project

Carbon Fiber Rocket

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Preliminary Design

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

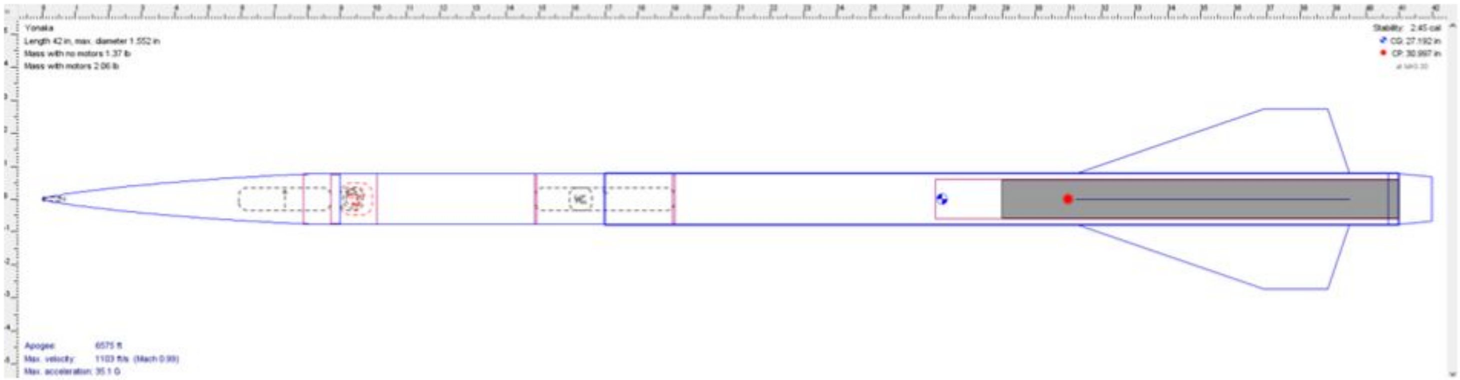


Figure 1. Rocket Outline

Analysis

Methods

- Finite Element Method (FEM)
- Analytical Solution

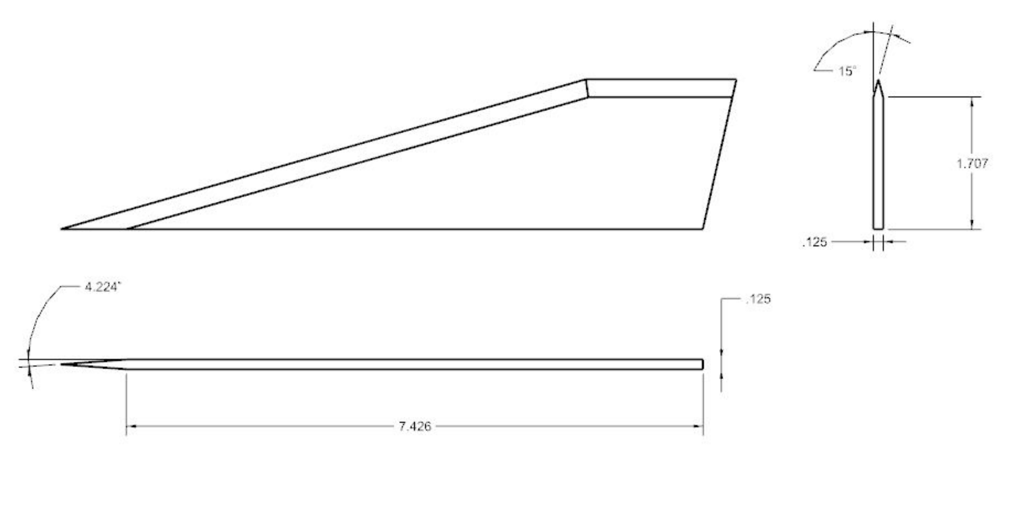
Calculations

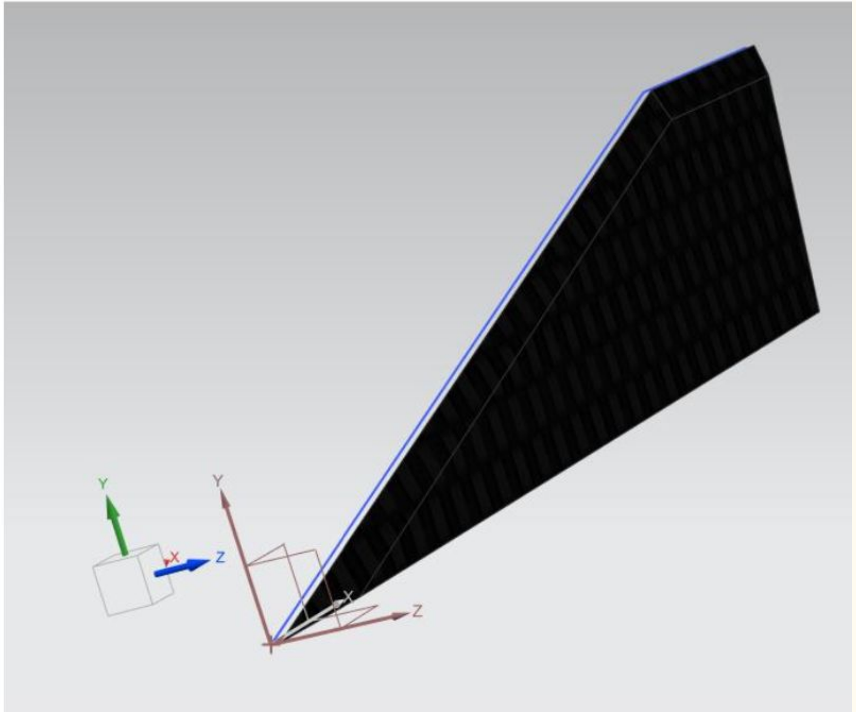
- NX NASTRAN
  - Global stresses and deflections
- Written/Analytical
  - Locations of maximum stress and deflection
  - Homework

Assembly

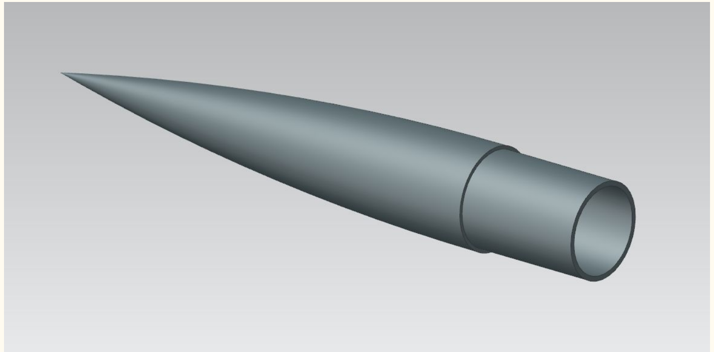
- Fins
  - 1/8-inch sheet of G12 fiberglass
- Nosecone
  - 1.6 inch diameter filament-wound fiberglass nose cone (5:1 length/diameter)
- Airframe
  - two carbon fiber tubes for “booster” and “payload” section (24 inches, 8 inches, respectively)
  - ID: 1.5 inches
  - OD: 1.6 inches
    - 0.05 wall thickness

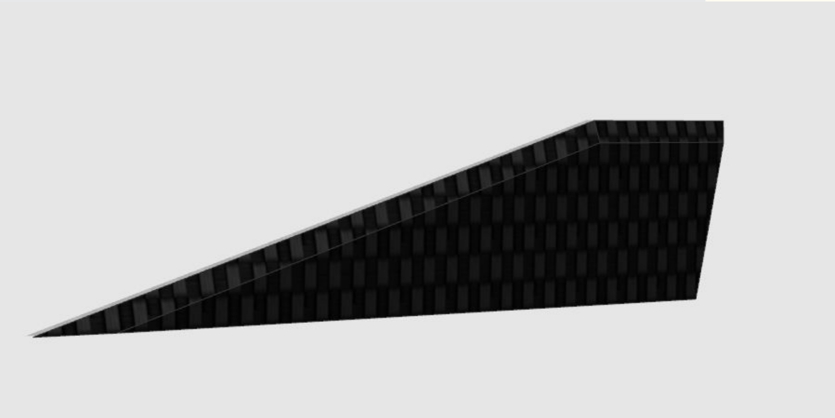
Fin Design - CAD, NX

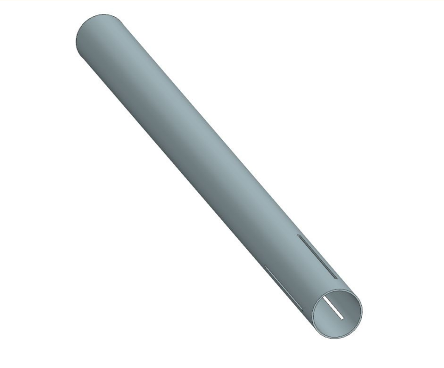


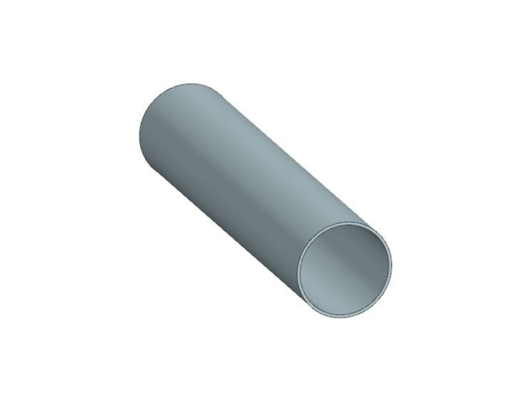


CAD NX, Components - Nosecone, Fins, Slot-tube, Non-slot tube









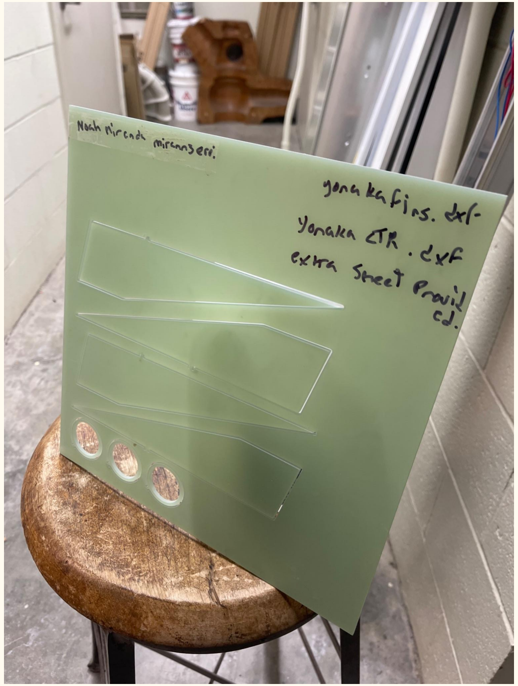
Manufacturing

Fins

- Water-jet cut @JEC

Airframe

- Carbon Fiber Tubes

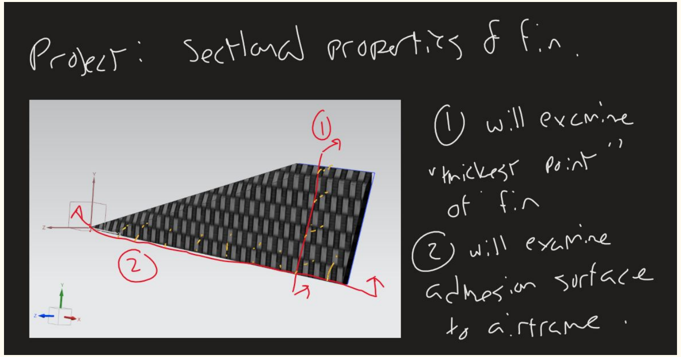


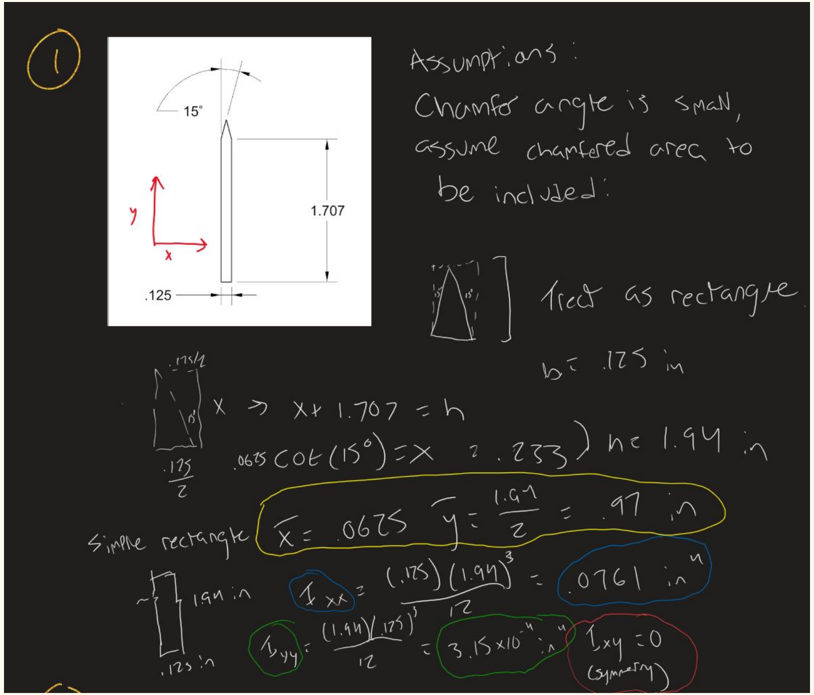
Calculations - based on homework

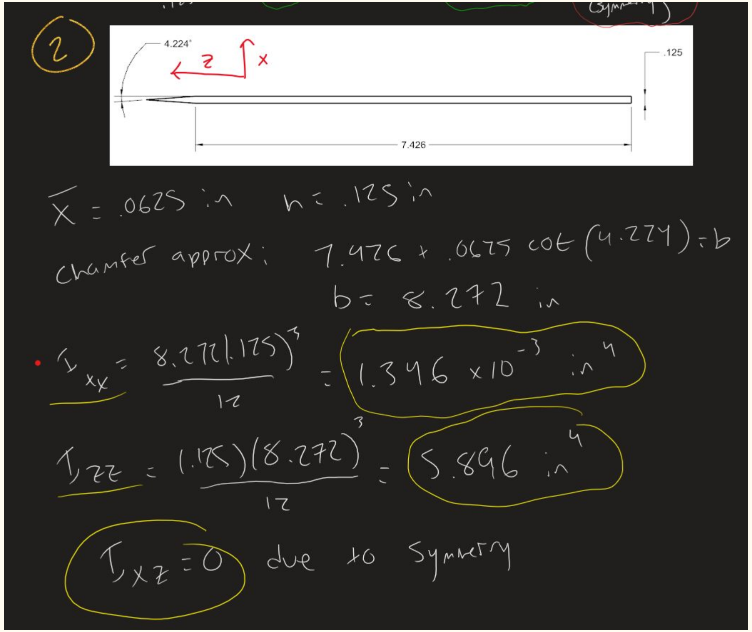
Project Calculations based on homework topics

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

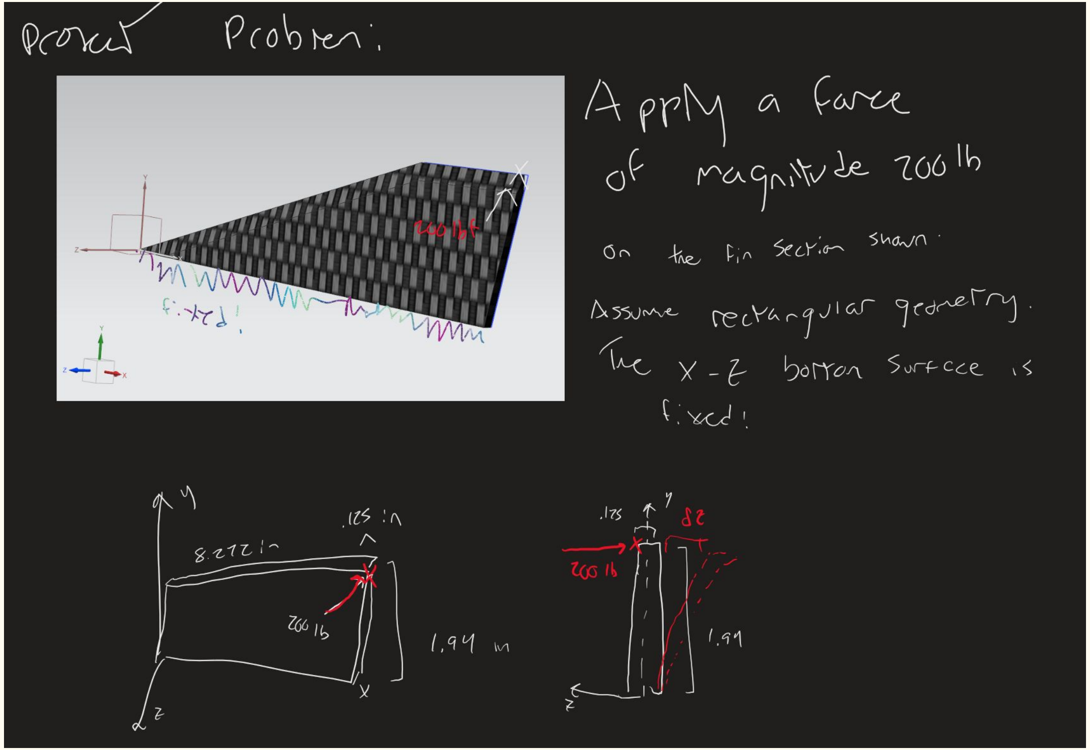
Sectional Properties







Deflection Calculations (p1)



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.

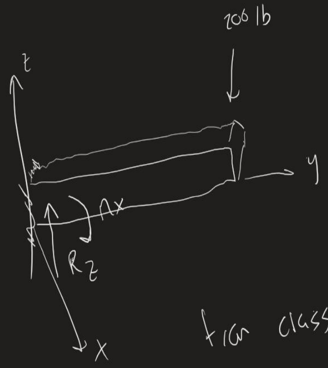
Assume material properties of aluminum

$E = 1 \times 10^7$ 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



$\Sigma F_z = R_z - 200 \text{ lb} = 0$

$R_z = 200 \text{ lb}$

$M_x = -200 \text{ lb} (1.94 \text{ in})$

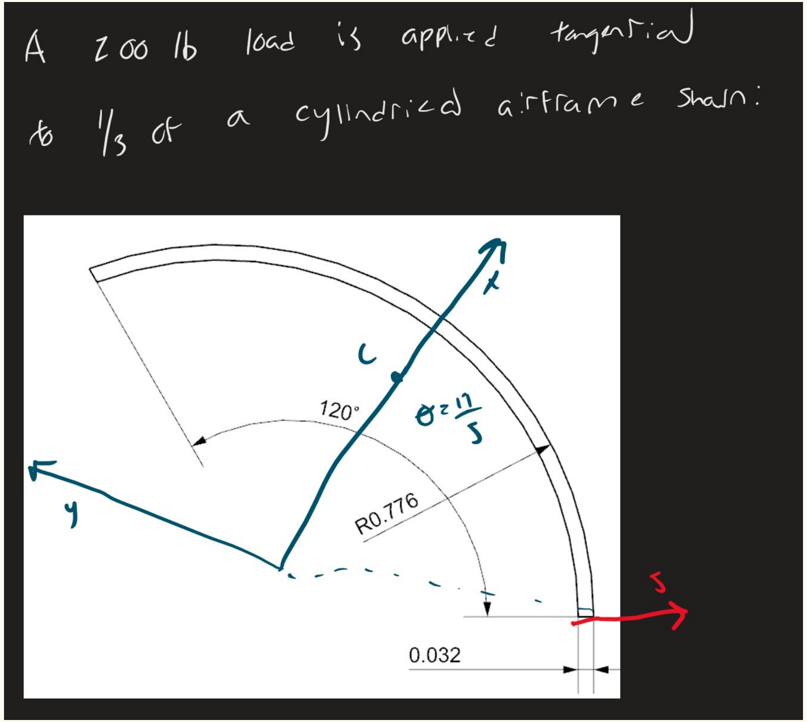
$= -388 \text{ lb} \cdot \text{in}$

from class:

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

$\delta_z = -.036$ 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.

Shear - Center of Airframe: open section (p2)

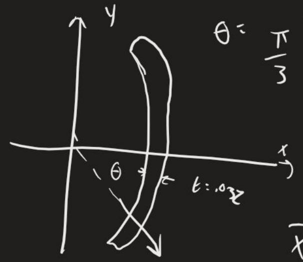
Shear acts along the x-direction.

Find: Sectional Properties.

Shear Flow

location of shear center due to S_x

Based on geometry / assume thin-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:

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

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

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

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

$I_{xy} = 0$

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

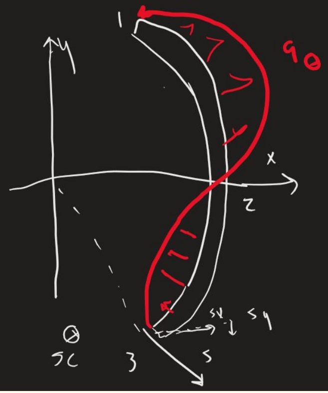
$S_y = -200 \sin\left(\frac{\pi}{3}\right) = -173 \text{ lb} \downarrow$

Shear - Center of Airframe: open section (p3)

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

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

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



θ 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

$\xi_s S_x$

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

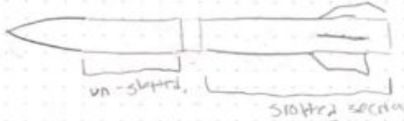
$q(\pi/3) = 0 \Rightarrow \xi_s = 0$!

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

Torsion - Center of Airframe: closed section (p4)

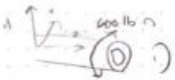
HW 4 — Closed-sec. Torsion

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



Assume material properties of aluminum.
$G = (3770\ ksi = 3.77 \times 10^6\ psi)$

Assume one end fixed.
Use the following dimensions
OD = 1.6 in ID = 1.5 in L = 8 in



Determine:
i) Torsional Rigidity
ii) Max. shear stress
iii) Rate and angle of twist @ 8 in.

i) Torsional Rigidity $TR = \frac{4A^2}{\oint \frac{ds}{Gt}}$

know G and t are const.

$\oint ds = 2\pi R \Rightarrow R = 1.6/2\ in = 0.8\ in$

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

$t = 0.05\ in$ $\Rightarrow r = 1.5/2\ in = 0.75\ in$

$$TR = \frac{4(\pi(0.8^2 - 0.75^2))^2}{\frac{2\pi(0.8)}{(3.77\times10^6)(0.05)}} = 8.9\times10^3\ lb\,in^2$$

ii) Max shear $\tau_{max} = q/t$ $q = \frac{T}{2A}$

t is constant

$q = \frac{600\ lb\,in}{\pi(0.8^2 - 0.75^2)} = 1232\ lb\,in^{-1}$

$\tau = \frac{1232}{0.05} = 2.46\times10^4\ psi$

iii) Rate and angle of twist

$$\frac{d\theta}{dz} = \frac{T}{4A^2Gt}\oint ds = \frac{600(2\pi \cdot 0.8)}{4(\pi(0.8^2 - 0.75^2))^2(3.77\times10^6)(0.05)}$$

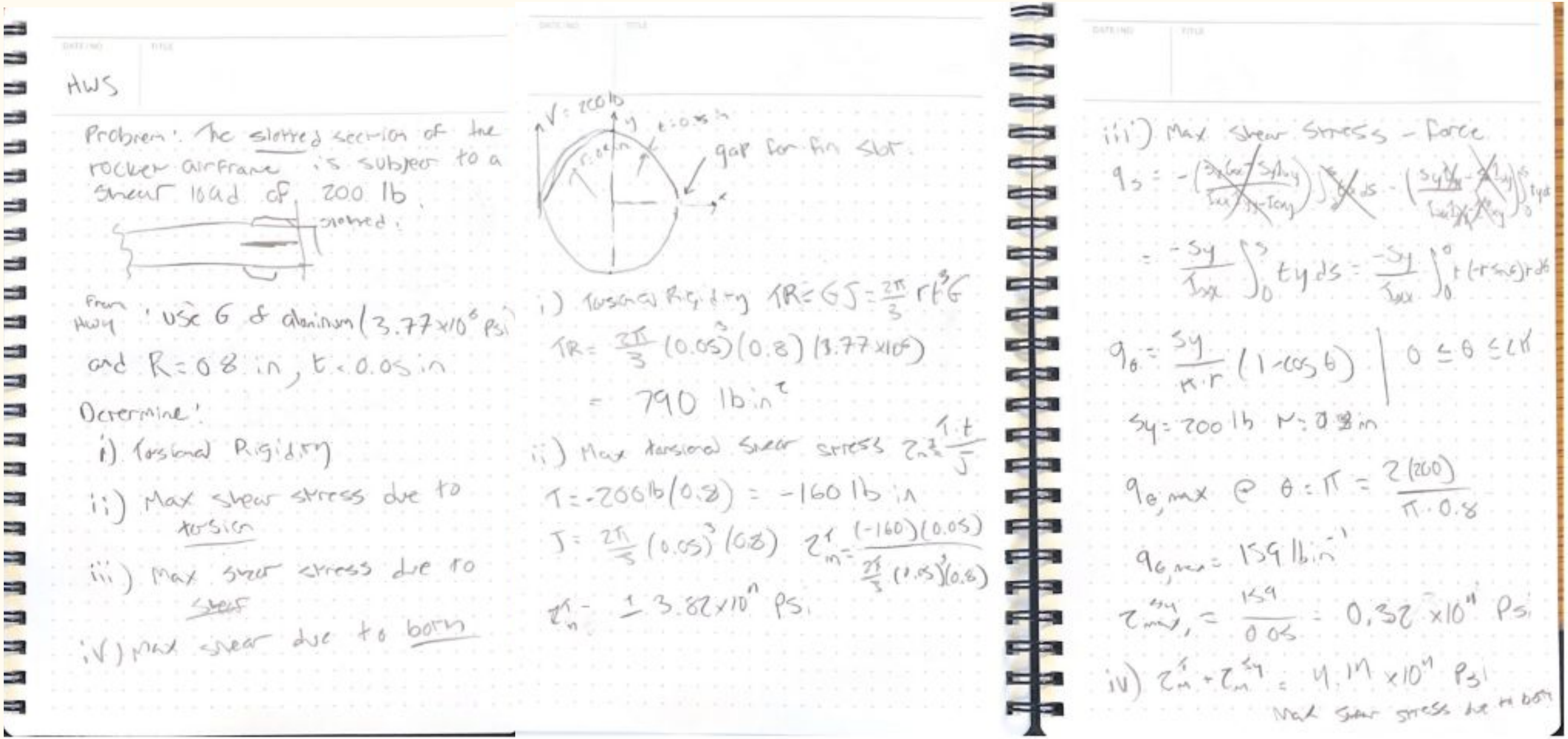
$\frac{d\theta}{dz} = 0.067\ rad/in$

$\theta(z) = 0.067z + \cancel{C}$

$C = 0$ b/c fixed end = 0 twist!

$\theta(8) = 0.54\ rad$ or 31°

Torsion - Center of Airframe: open section (p5)



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;
}
```

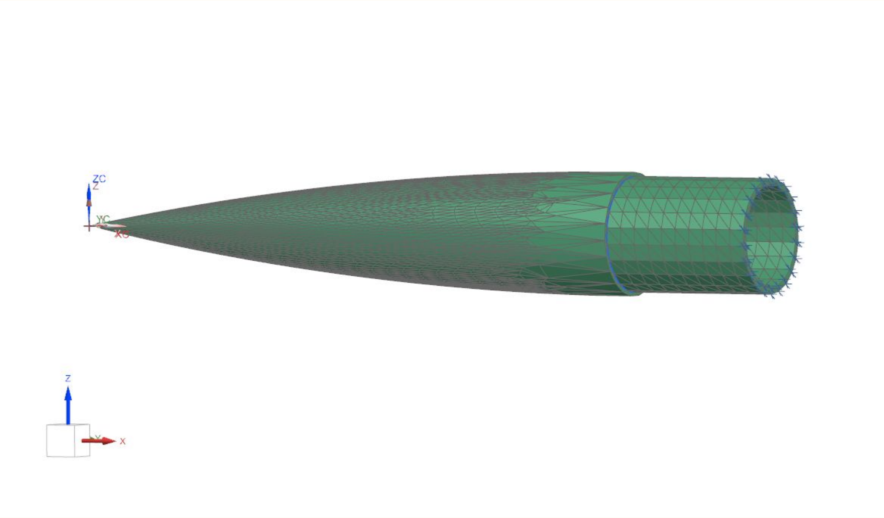
Finite Element Analysis - Overview

FEA and Simulations of components:

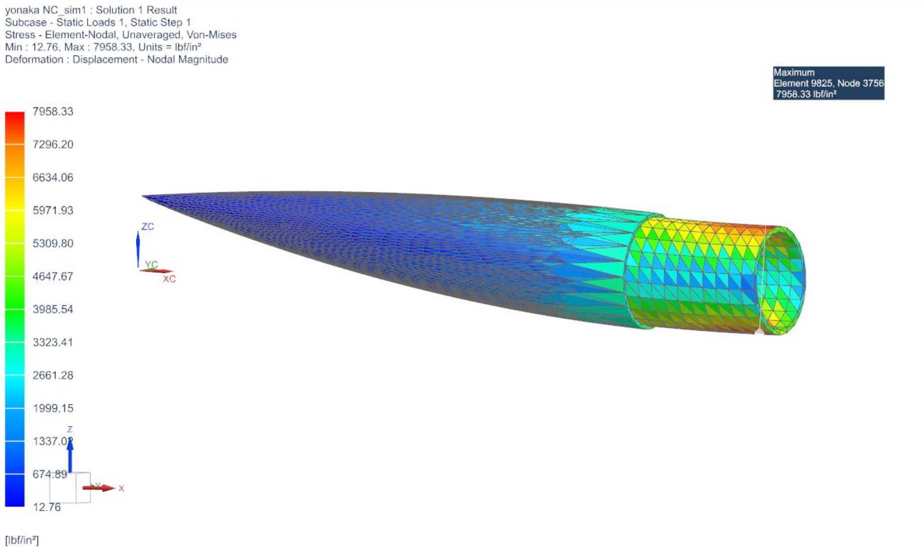
- Nosecone
- Fins
- Slot-tube
- Non-slot tube

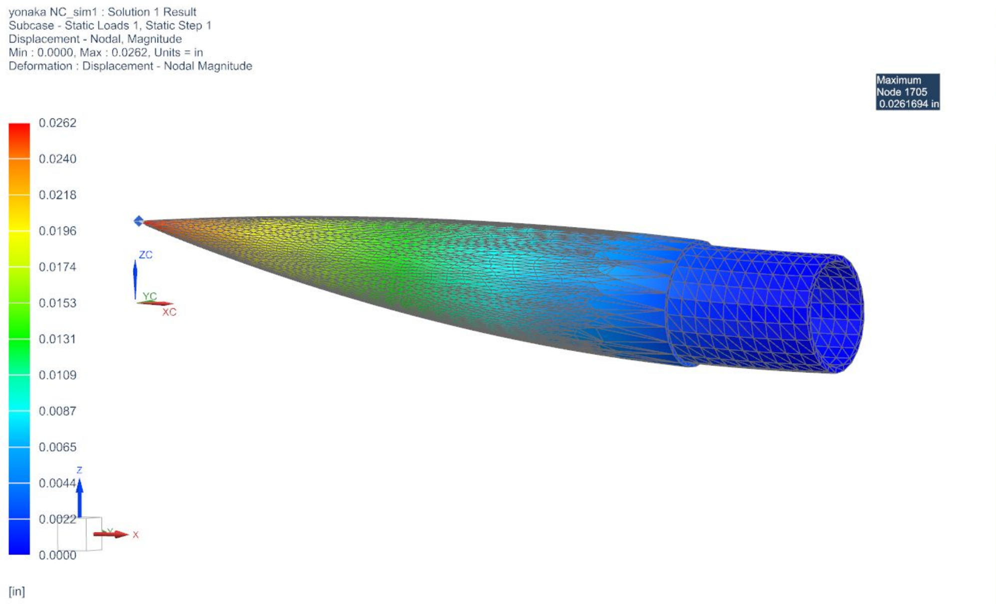
FEA - Nosecone

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

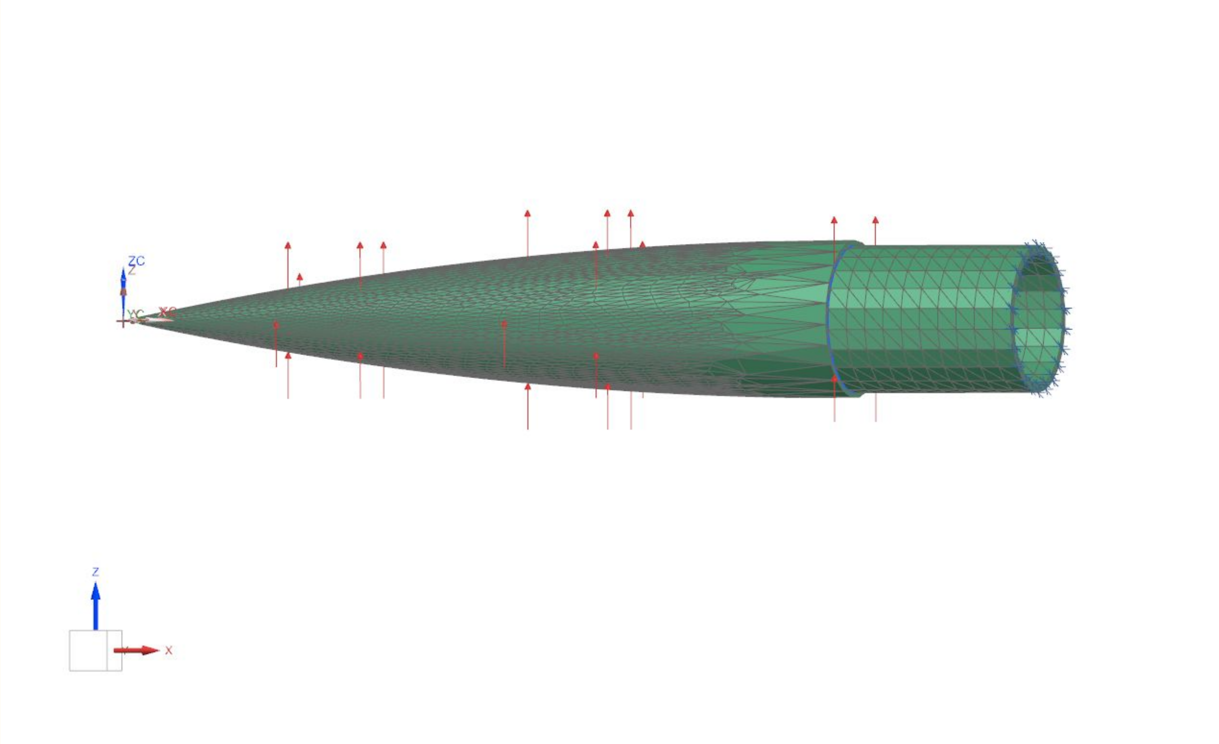


Displacement and Stress

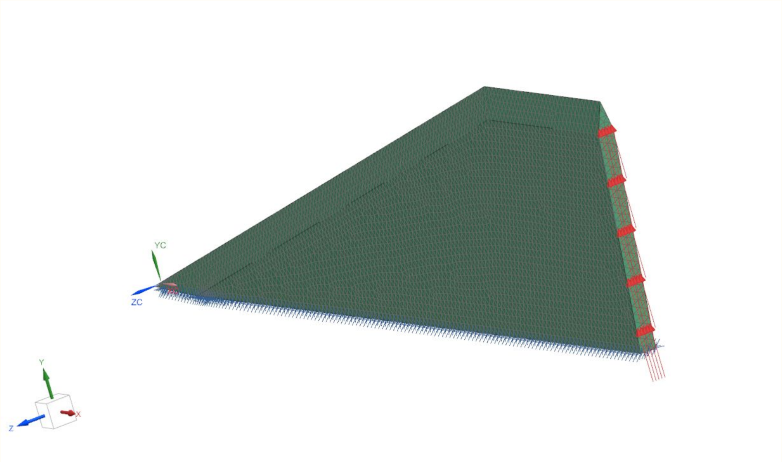




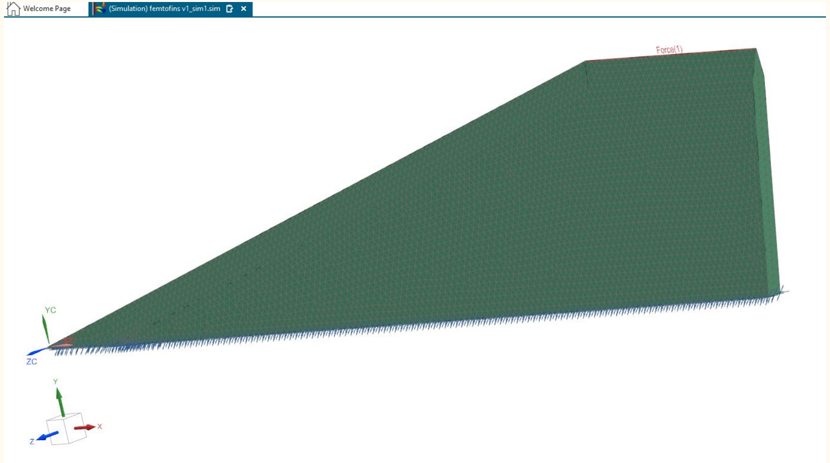
Boundary Conditions



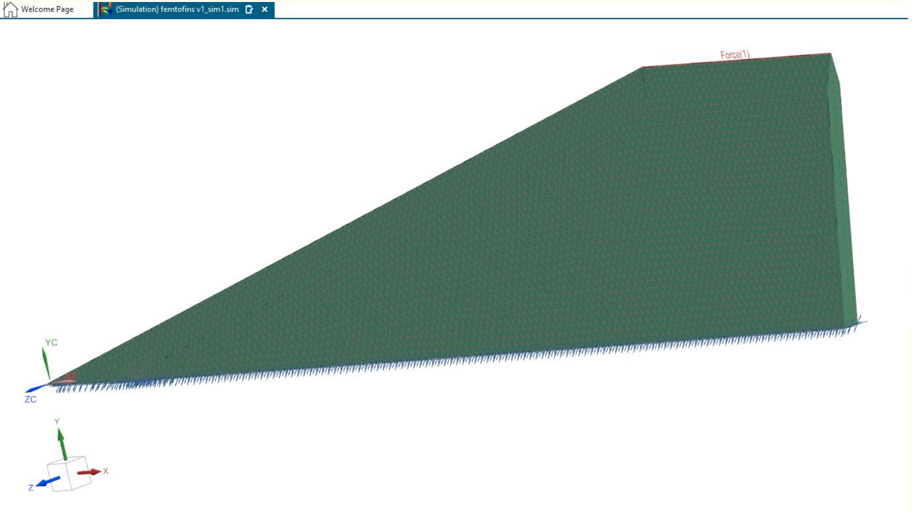
FEA - Fins



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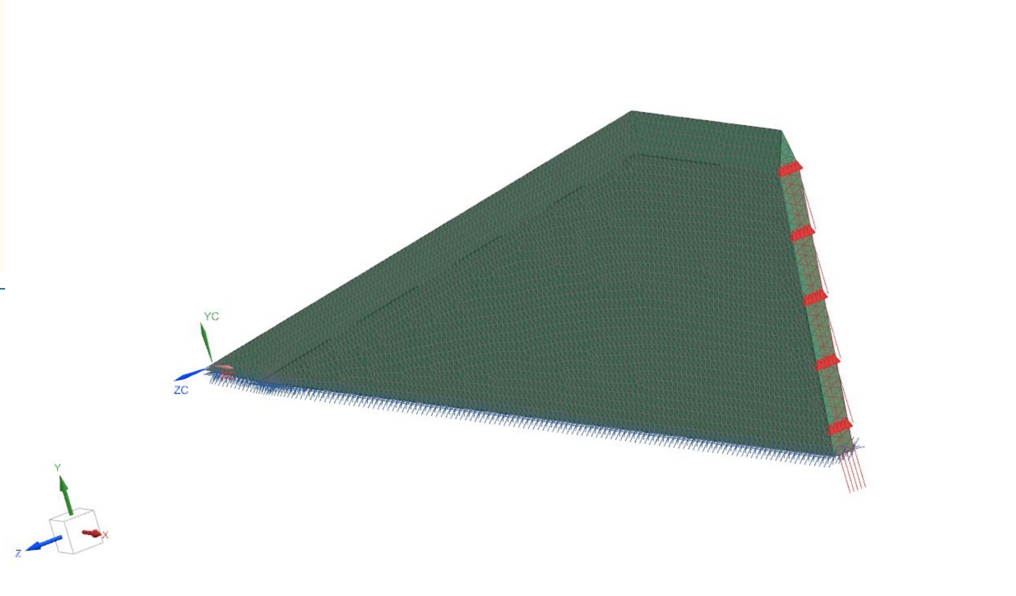
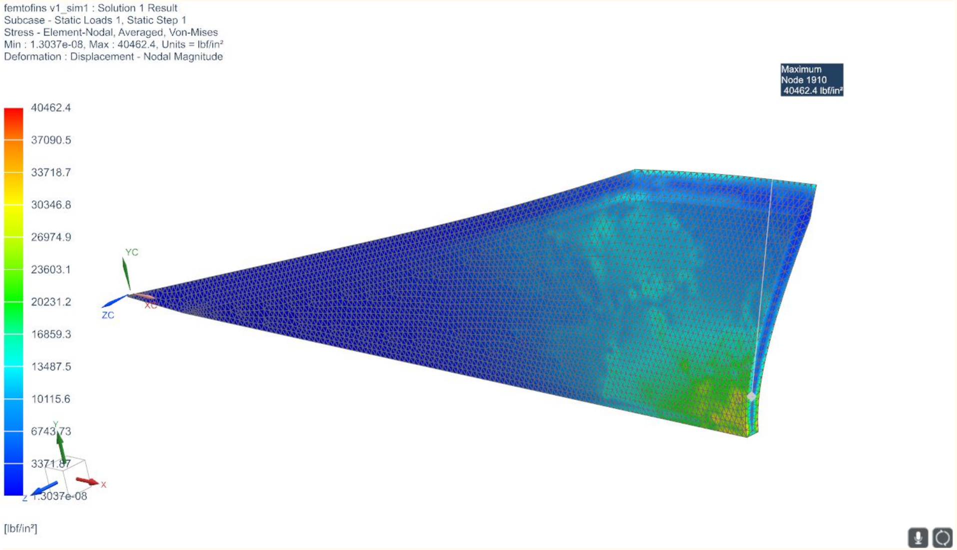
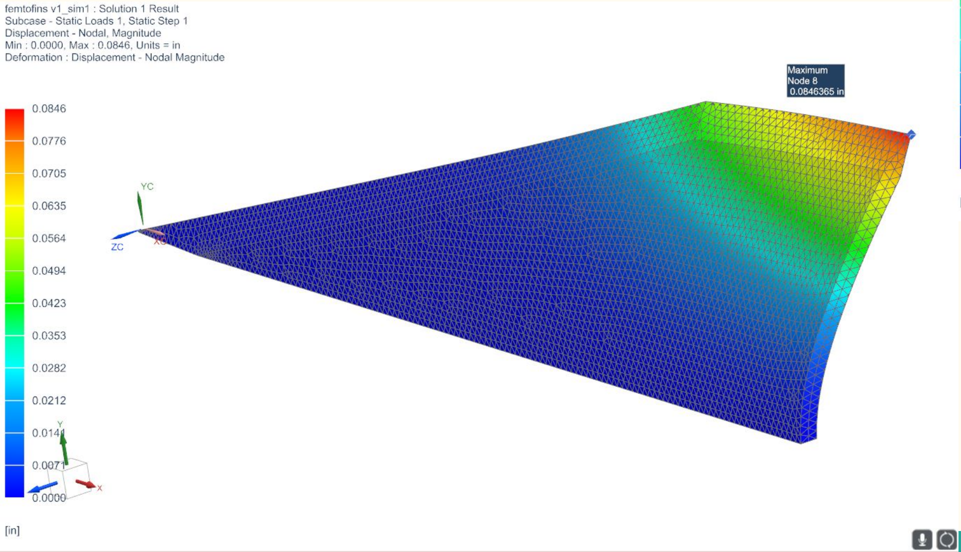
(Simulation) femtofins v1_sim1.sim
Force(1)
YC
ZC
Y
X
Z

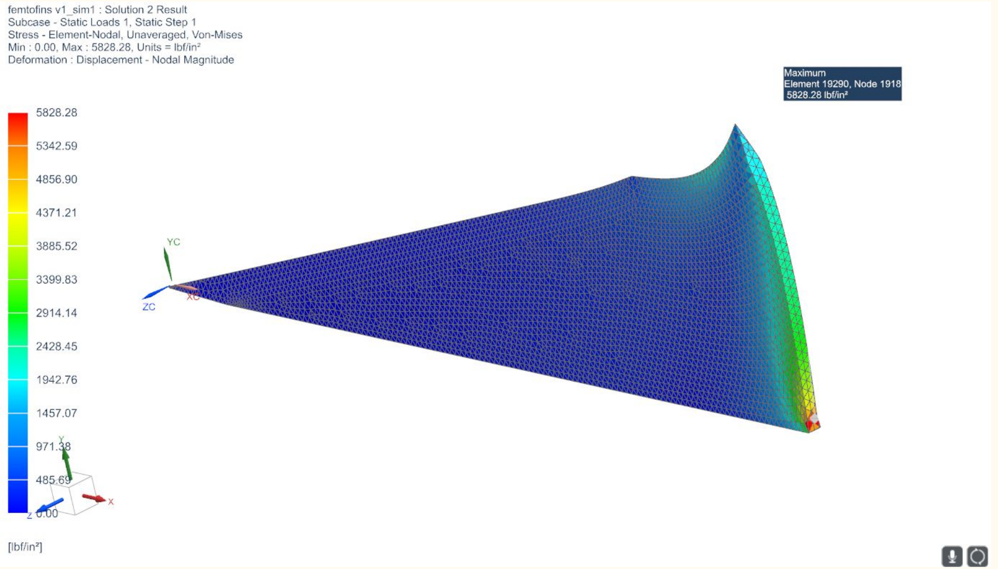

YC
ZC
Y
X
Z

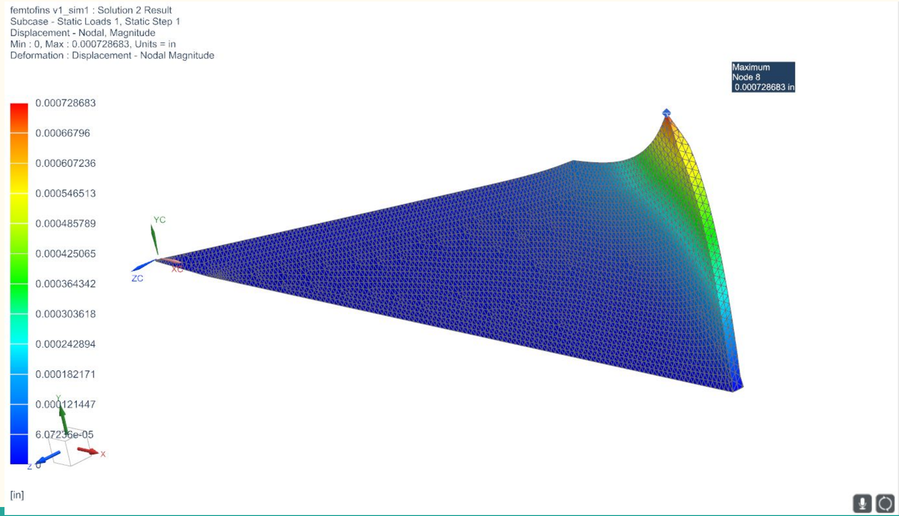
Displacement and Stress for Simulation 1





Displacement and Stress for Simulation 2

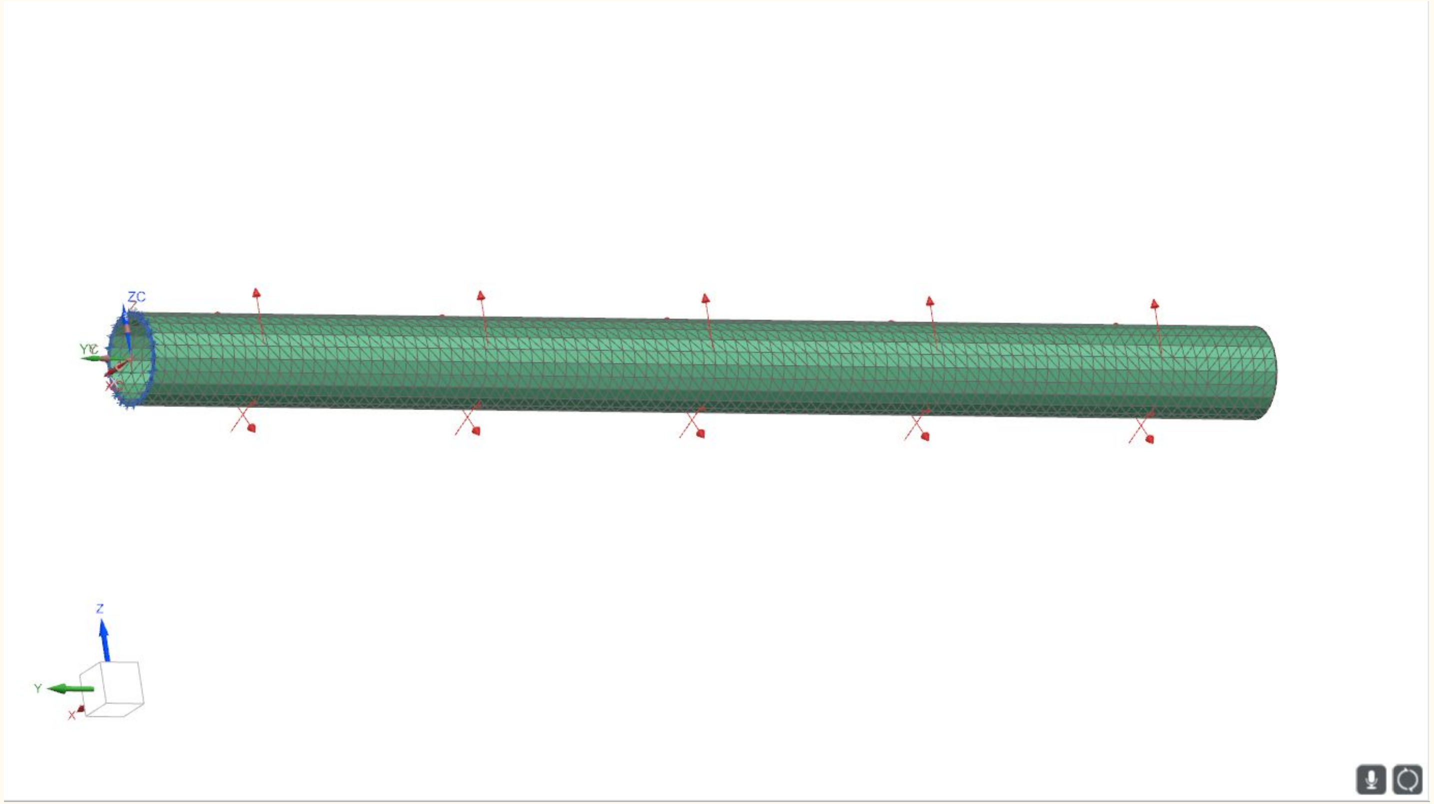




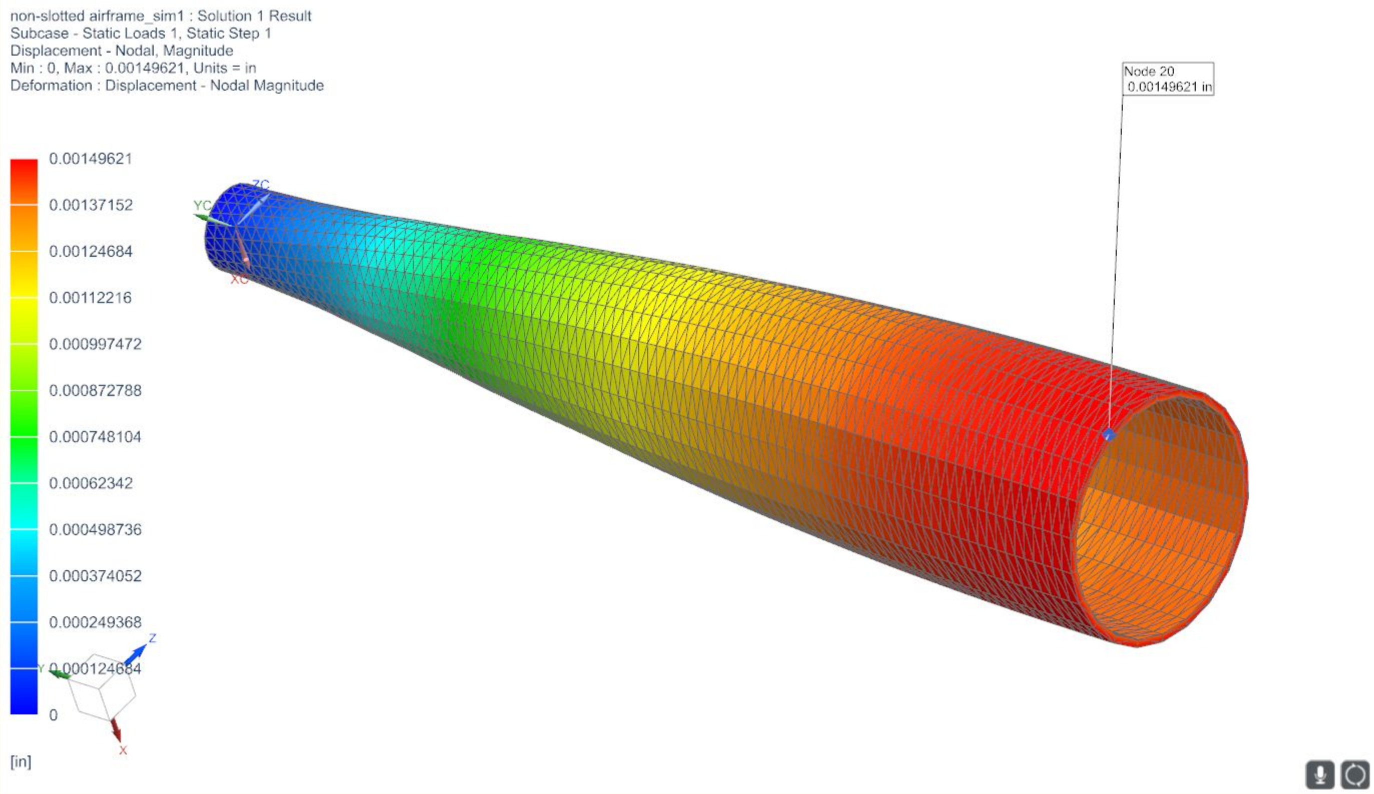
FEA non-slot tube (Closed Section)

- 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



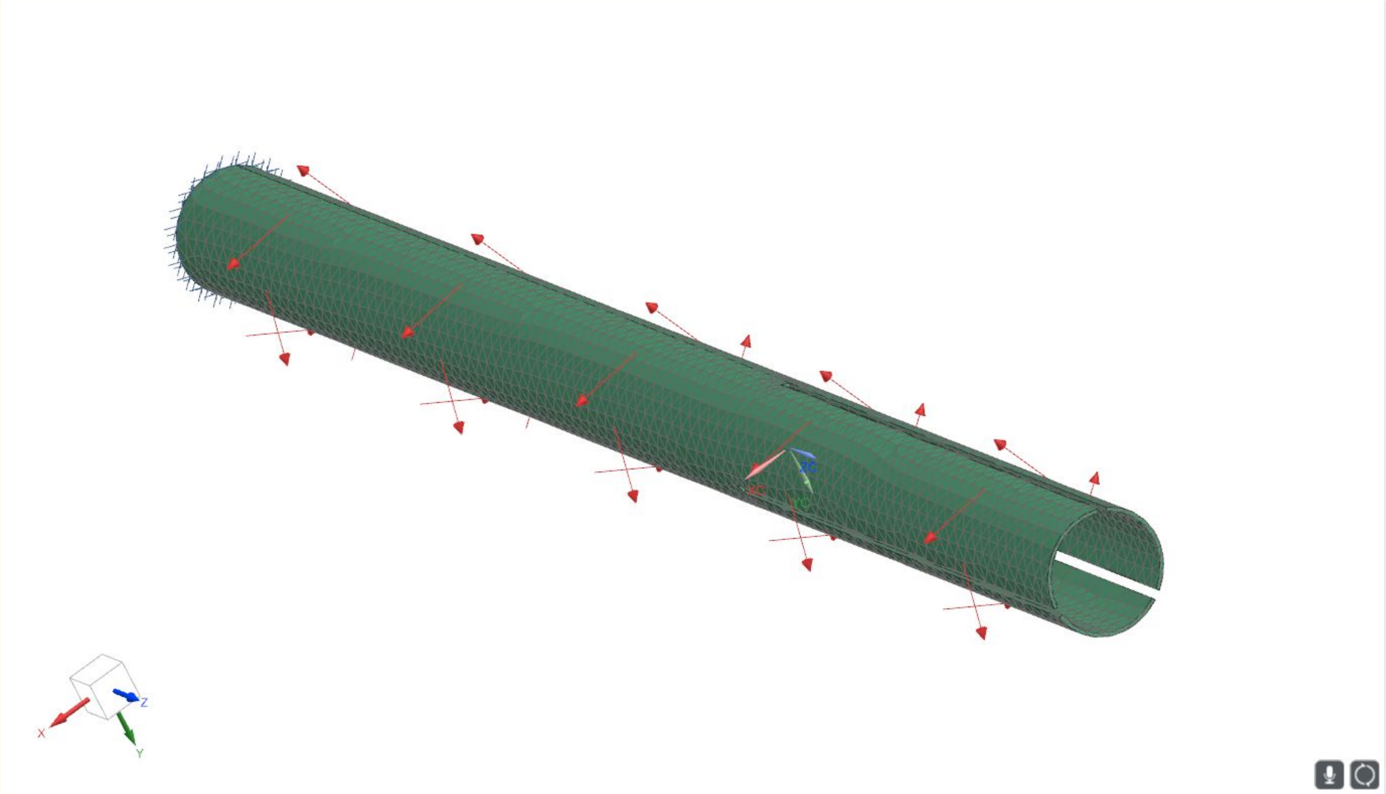
Non-Slotted Tube Results



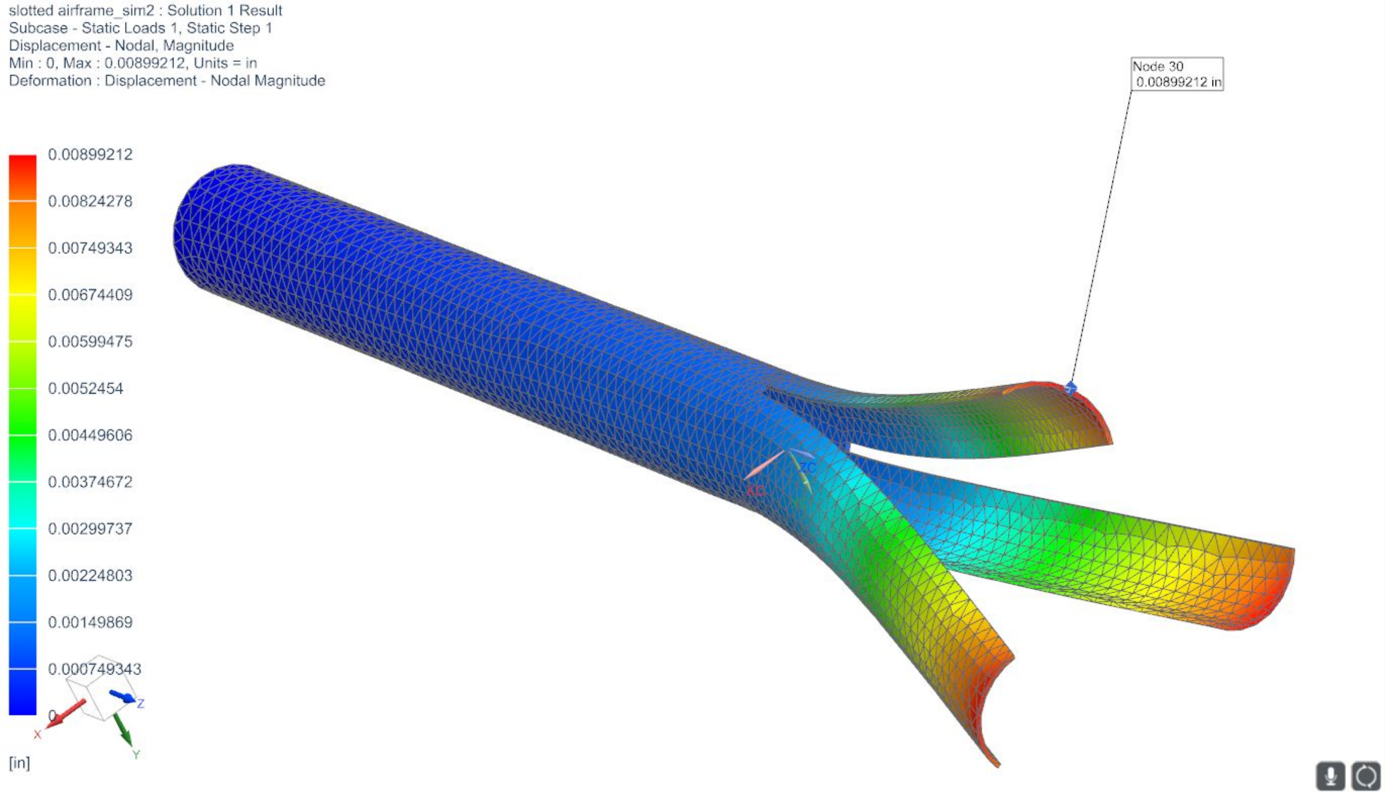
FEA - Slotted-tube (Open Section)

- 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

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

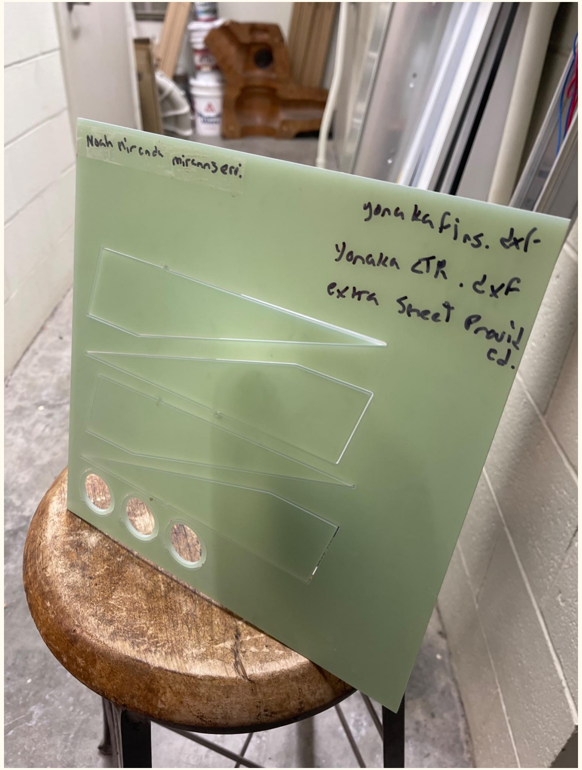
Fins:

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