Mini Motors DRM – Ride My Rocket

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DRM Overview

- Motor Design Requirements
- Major Trades
- Motor Specs - MATLAB Simulation
- Forward Closure
- Head-End Ignition
- Casing
- Nozzle
- Full BOM
- Questions

Mission

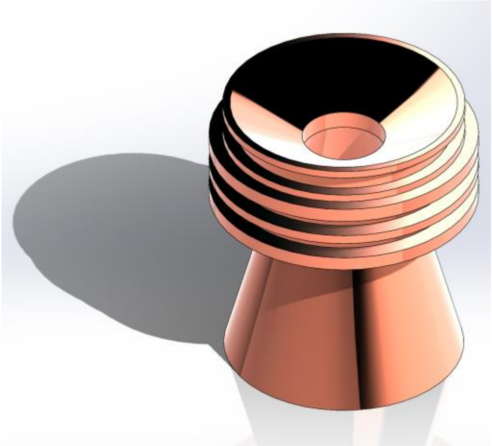
- Create an N-class solid rocket motor design that innovates in terms of retention method, ignition method, and nozzle design to serve as a testbed for future GTXR motor designs.

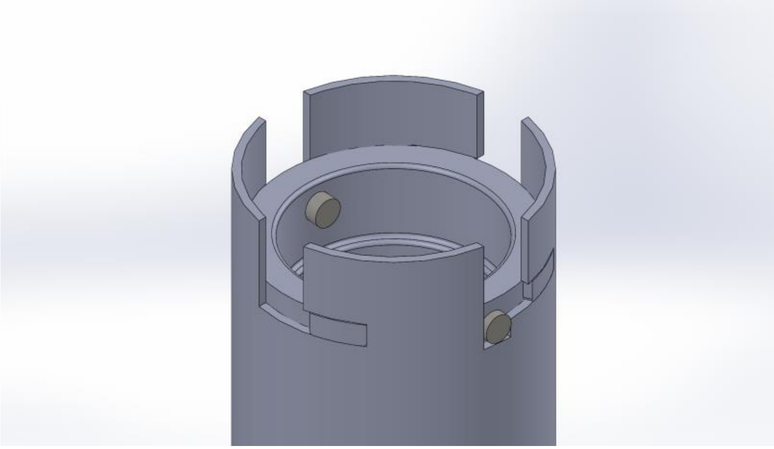
Design Requirements

- N-Class Motor
- Maximum Possible Impulse
- Novel Designs: Graphite Nozzle w/ Aluminum Jacket, Head-End Ignition
- In-Depth Analysis
- Good Documentation
- Maximize Wet Mass : Dry Mass Ratio
- Cost < 2k

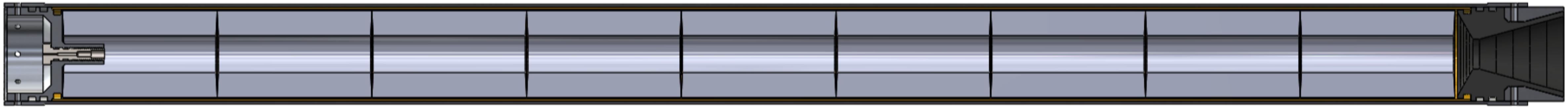
Major Trades

- Nozzle: Considered copper, steel, and **graphite**
  - One-piece nozzle: Chosen for continuity
- Retention Methods: Tried instant pot method, now using **radial bolts**
- Ignition: Considered black powder
  - **Chose flash powder**: larger flame, burns longer





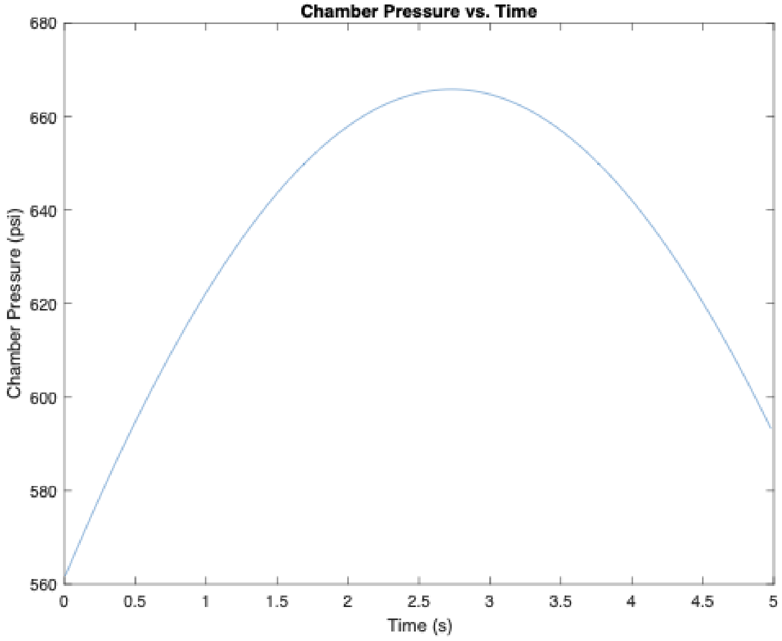
Motor CAD Assembly

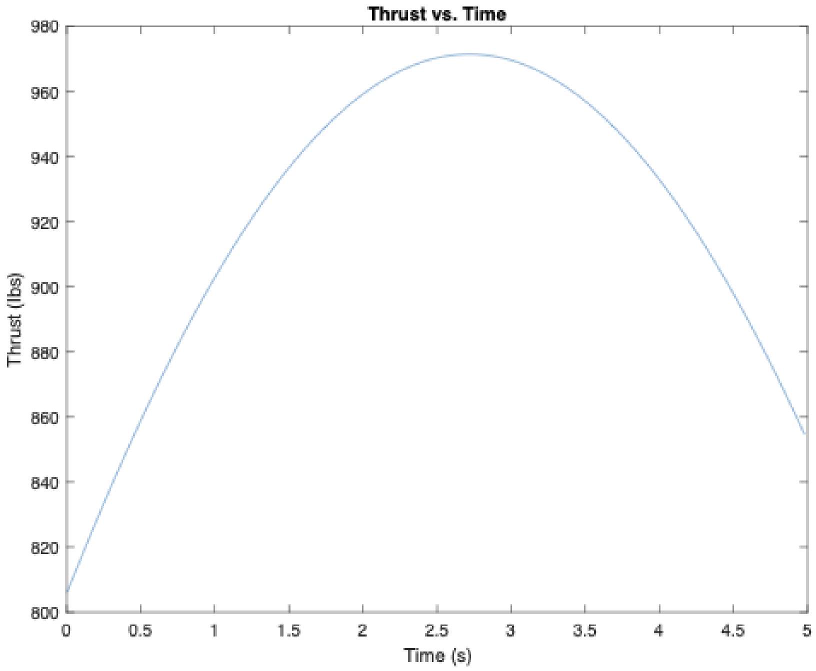


Motor Geometry + Specs

- 9 Grains, OD 3.7in
- Total Impulse: **4603 lbf*s**
- Max Thrust: 971 lbf
- MEOP: 666 psi
- Propellant Mass: 20.4 lbm

Maximum Impulse specs generated with optimization script. N-Motor max impulse can be 4604 lbf*s

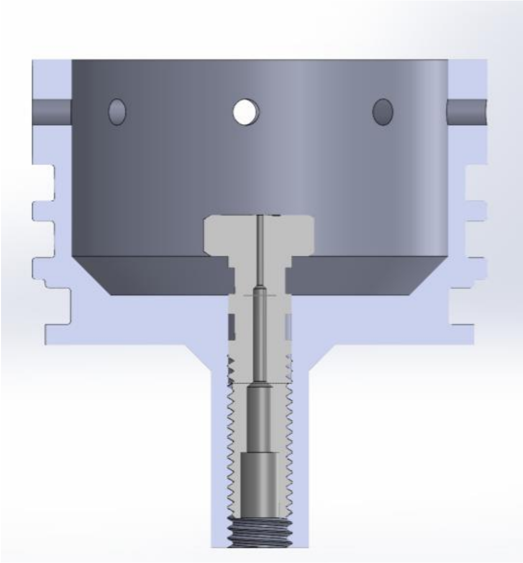


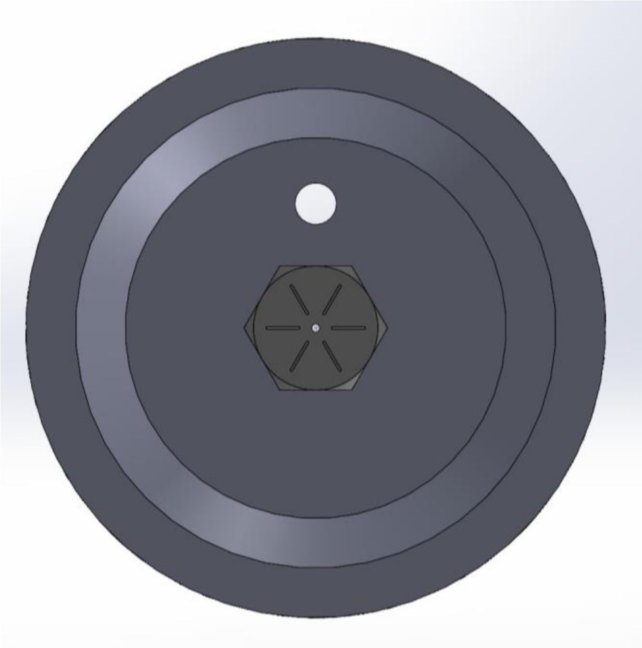


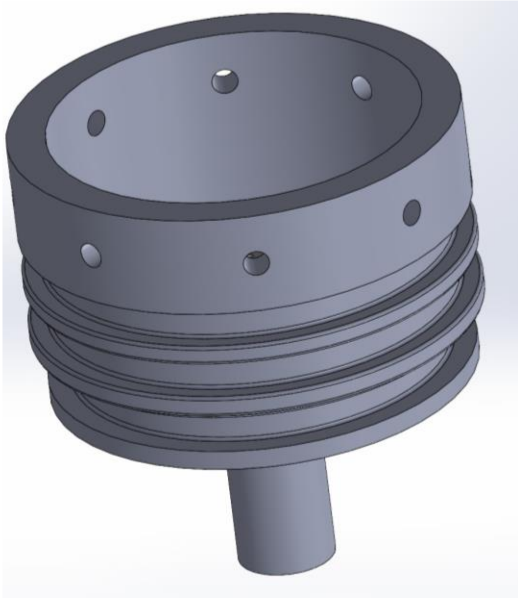
Peak Ride my Rocket Team

Forward Closure – Overview, CAD

- Design requirements create a high-pressure seal to withstand extreme pressure.
- Holes for Pressure Transducer and Igniter







Forward Closure – Analysis/ Risk

- Plate Thickness: 0.375 in
  - FOS = 2.32
- FWD. Closure Plate stress: 16370 psi
  - FOS = 2.3
- 8 Bolt Shear Stress: 727 psi per bolt
  - FOS = 9

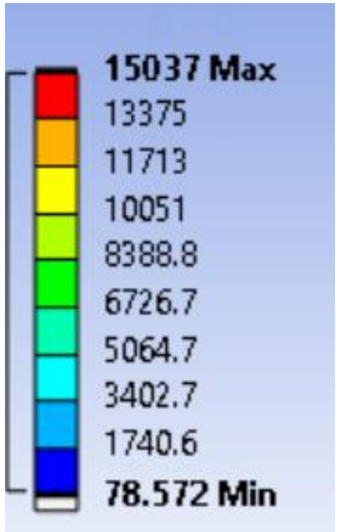
$$\sigma = \frac{3(3+\nu)Pr^2}{8t^2}$$

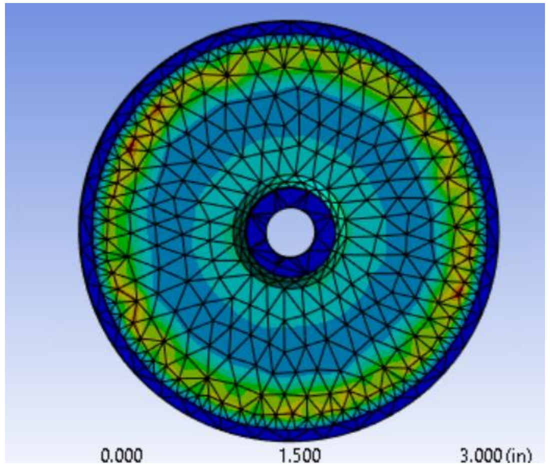
$$\sigma = \frac{4F}{\pi D^2}$$

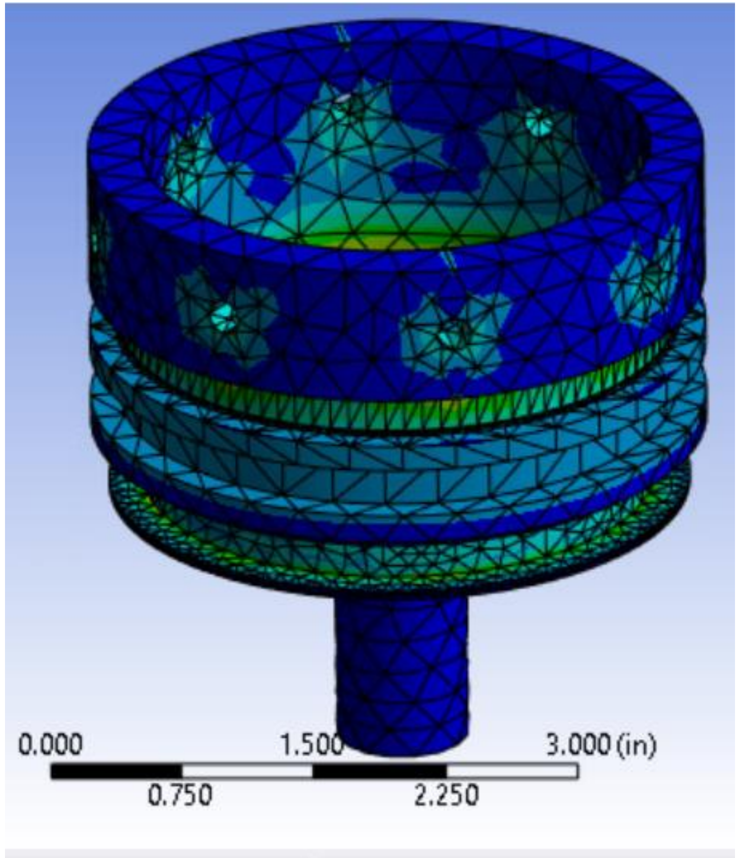
- Risks
  - Overheating leads to the O-rings melting, might lead to leaks

Forward Closure – Ansys

- Ansys Static Structural
- 5791.6 lb force acting upwards on bottom face
- Pin holes as fixed surfaces
- Tensile Strength of Al 6061-T651: 38,000 psi





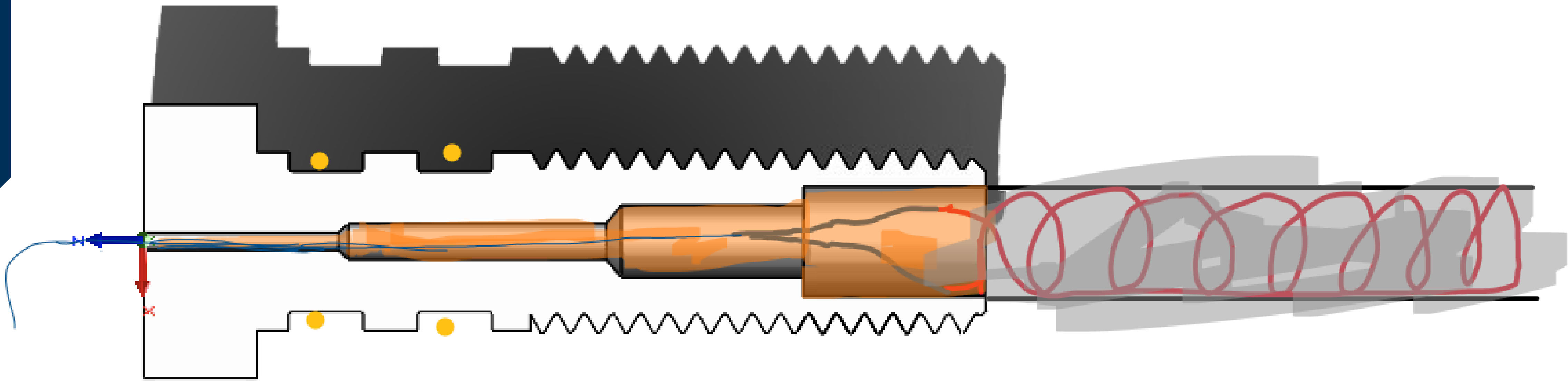


Forward Closure – Manufacturing/Integration

- Manufacturing Plan: Simple lathe operations with milling holes and tapping holes
- Grains & thermal liner can be loaded from the top, bolts are used to fasten closure

Head-End Ignition - Overview

- Design Requirements:
  - Create an igniter that can safely and effectively ignite the motor from the head
  - The igniter must hold back the pressure of the motor and be reusable

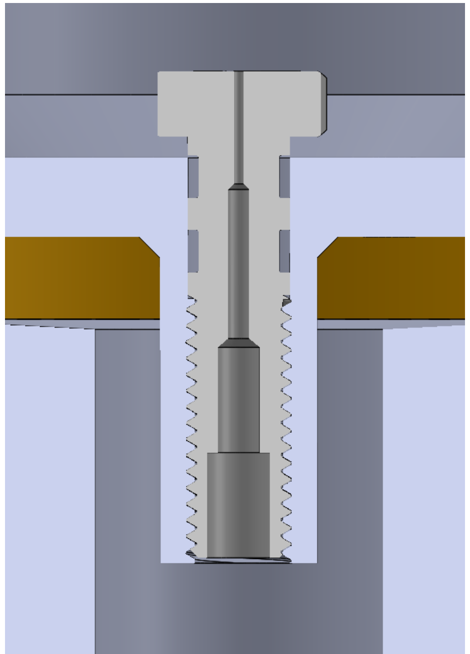


Igniter Testing Plan

1. Mix Flash Powder + Quick Setting Epoxy to create sturdy clump
   - Flash Powder burns hot and fast while epoxy burns slow
   - 60% Potassium Nitrate
   - 30% Aluminum Powder
   - 10% Sulfur Powder
2. Apply mixture to igniter bolt with nichrome wire wrapped around mesh
3. Adjust flash powder amount increase flame length, wrap nichrome wires and run around 3 amps to ignite.
4. We choose the recipe that generates the greatest flame length and quickest ignition time

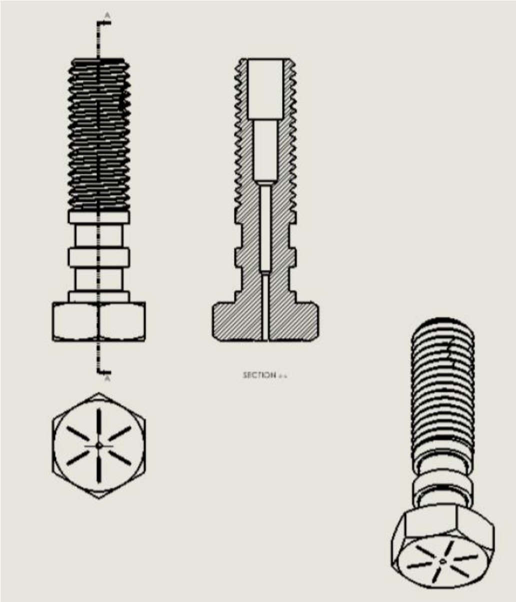
Head-End Ignition – Manufacturing

- Manufacturing, Simple lathe operations on a COTS bolt
- Attach steel mesh to the inside bolt using epoxy
- Wrap Nichrome wire around mesh and attach to another wire that will pass through the tiny hole. Mix the flash powder epoxy and coat onto mesh.



Head-End Ignition – Analysis & Risks

- Threads rated for 150,000 psi; Two O-rings rated for 400C
- Nichrome Wire requires 4.5 amps to raise temp to 500C
- The RTV silicone is rated to handle 350 psi, however, based on our design, the silicone should push up against the walls of the bolt since they converge.



Casing – Overview

- Design requirements: contain all the grains, while containing high pressures
- High temp at thermal liner edges lead to vulnerabilities
- Casing Wall Thickness = 0.1" and 0.15" around holes

Casing – Analysis & Risk

- **Hoop Stress:** 11700 psi
  - FOS = 3

$$\sigma_\theta = \frac{Pr}{t}$$

- **Longitudinal Stress:** 5800 psi
  - FOS = 6

$$\sigma_z = \frac{Pr}{2t}$$

- **Bearing Stress :** 18900 psi
  - FOS = 2

$$\sigma_b = \frac{F}{A_b}$$

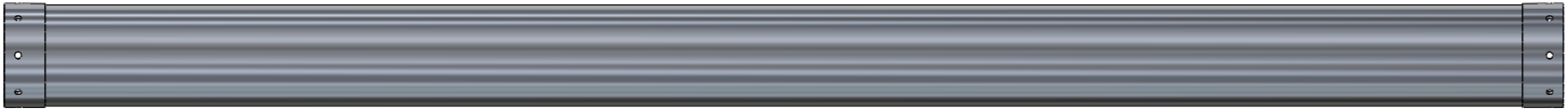
- **Tear-through stress:** 3900 psi
  - FOS = 9

$$\sigma_{\text{tear}} = \frac{F}{A_{c,\text{reduced}}}$$

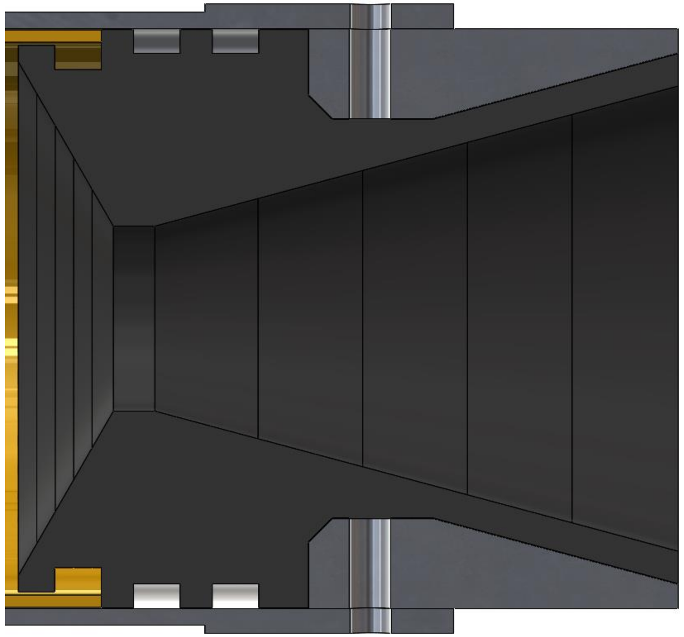
- High temp at thermal liner edges thermal liner lead to vulnerabilities

Casing - Manufacturing

- Manufacturing: Lathe OD down and add radial holes with Mill



Nozzle - Overview/Risks



- Two-Part Nozzle – insert CAD
  - Full Graphite Contour
  - Aluminum Jacket w/ Radial Bolts
  - Jacket is cut in half to insert onto the nozzle
- Liner Interface
- Risks
  - Aluminum Melting
  - Graphite Cracking

Heat Transfer Methodology

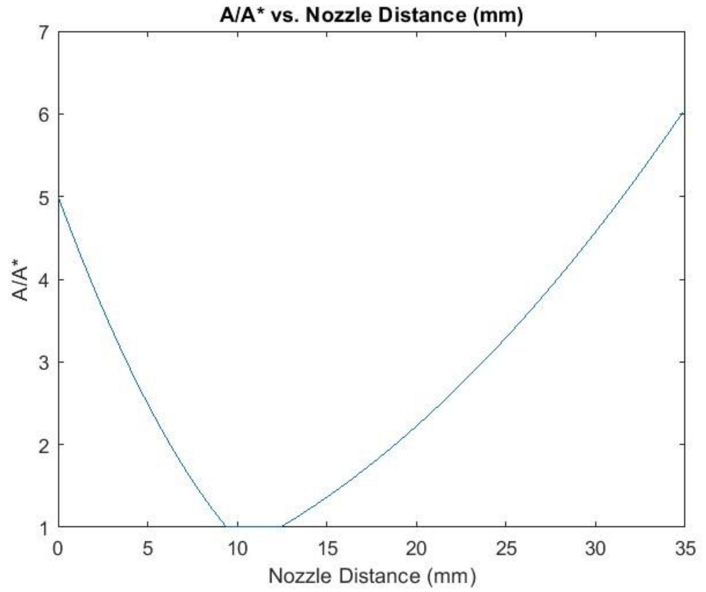
- Bartz Equation [1] gives heat transfer coefficient and is accurate for nozzle heat transfer as per NASA paper + Connor has used it before

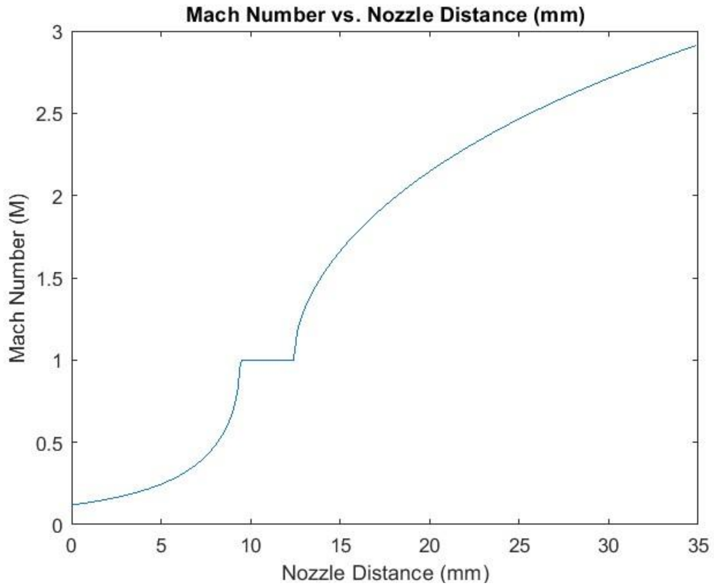
$$h_g = \left[\frac{0.026}{(D^*)^{0.2}}\left(\frac{\mu^{0.2}}{\mathrm{Pr}^{0.6}}C_p\right)_0\left(\frac{P_0}{c^*}\right)^{0.8}\left(\frac{D^*}{r_c}\right)^{0.1}\right]\left(\frac{A^*}{A}\right)^{0.9}\sigma$$

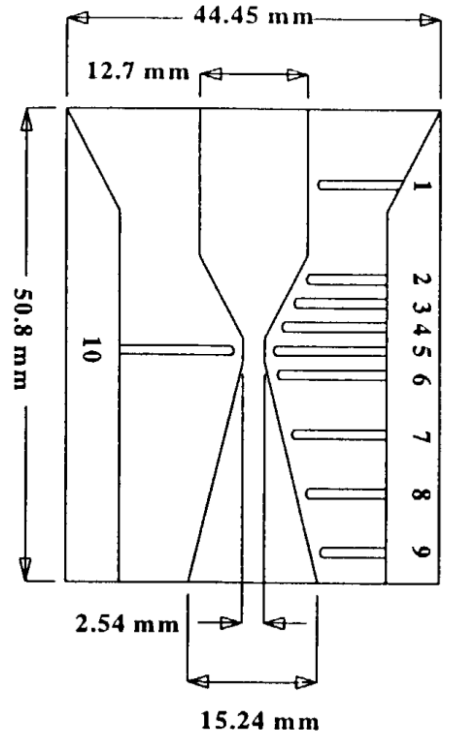
$$\sigma = \frac{1}{\left[\frac{1}{2}\frac{T_{wg}}{T_{0g}}\left(1+\frac{\gamma-1}{2}M^2\right)+\frac{1}{2}\right]^{0.8-.2\omega}\left(1+\frac{\gamma-1}{2}M^2\right)^{0.2\omega}}$$

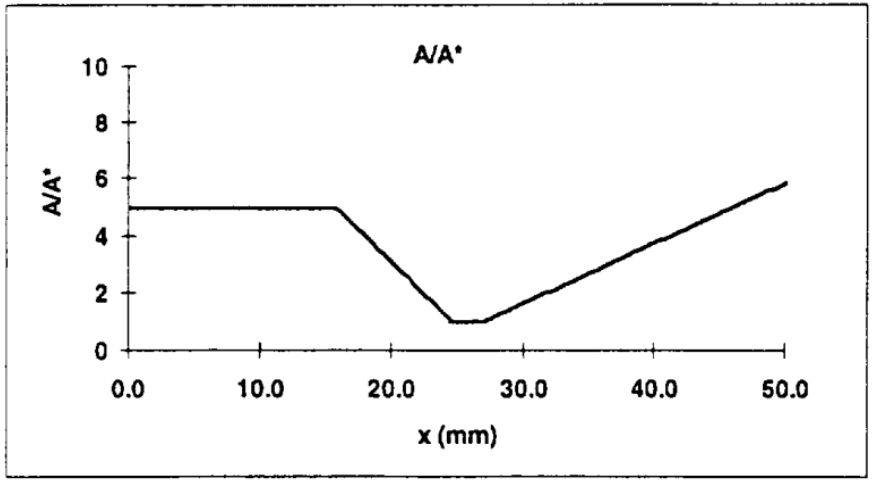
- Wrote code to graph h_g vs. Nozzle Distance + pulled properties from CEA and Nozzle Geometry
- Input heat transfer coefficient into ANSYS

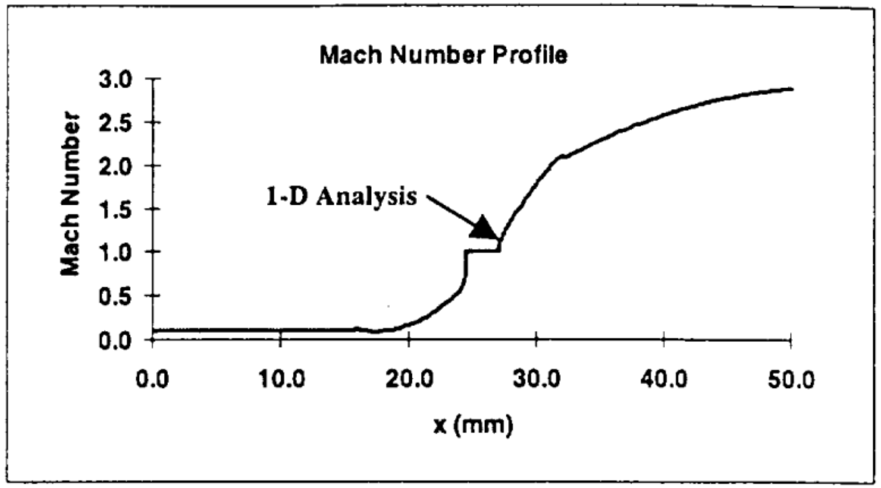
Verifying Heat Transfer Code w/ NASA Paper





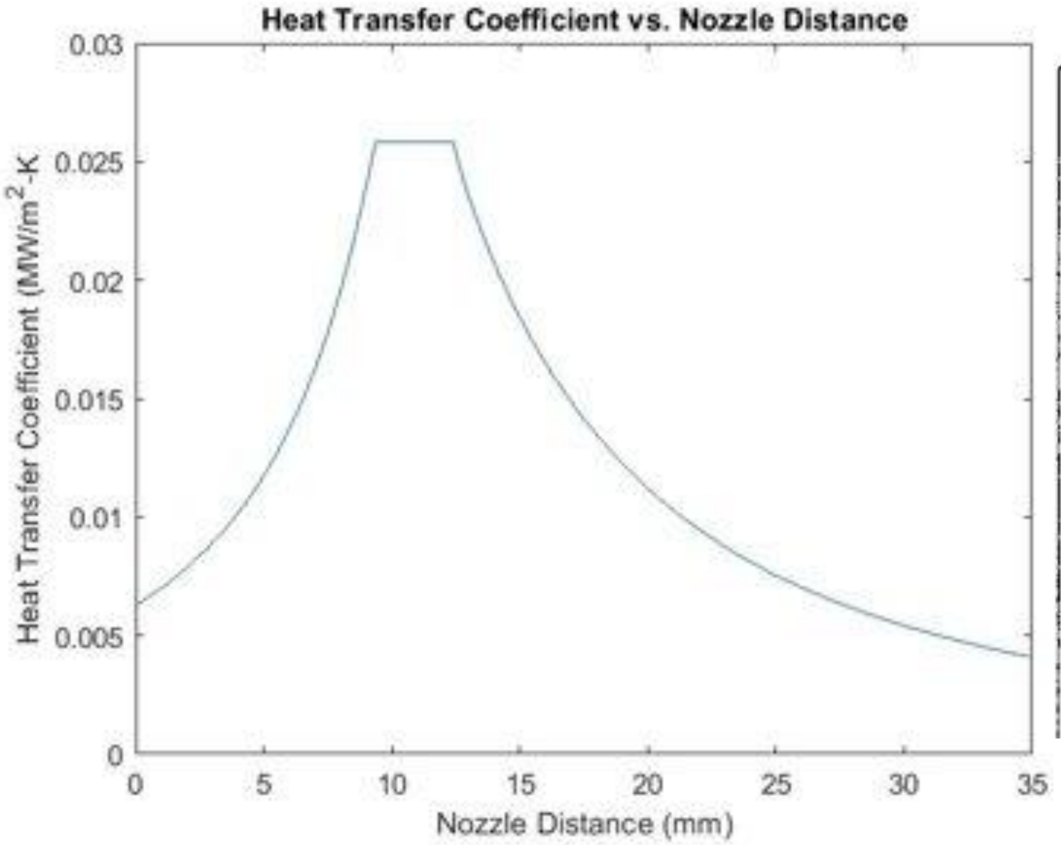


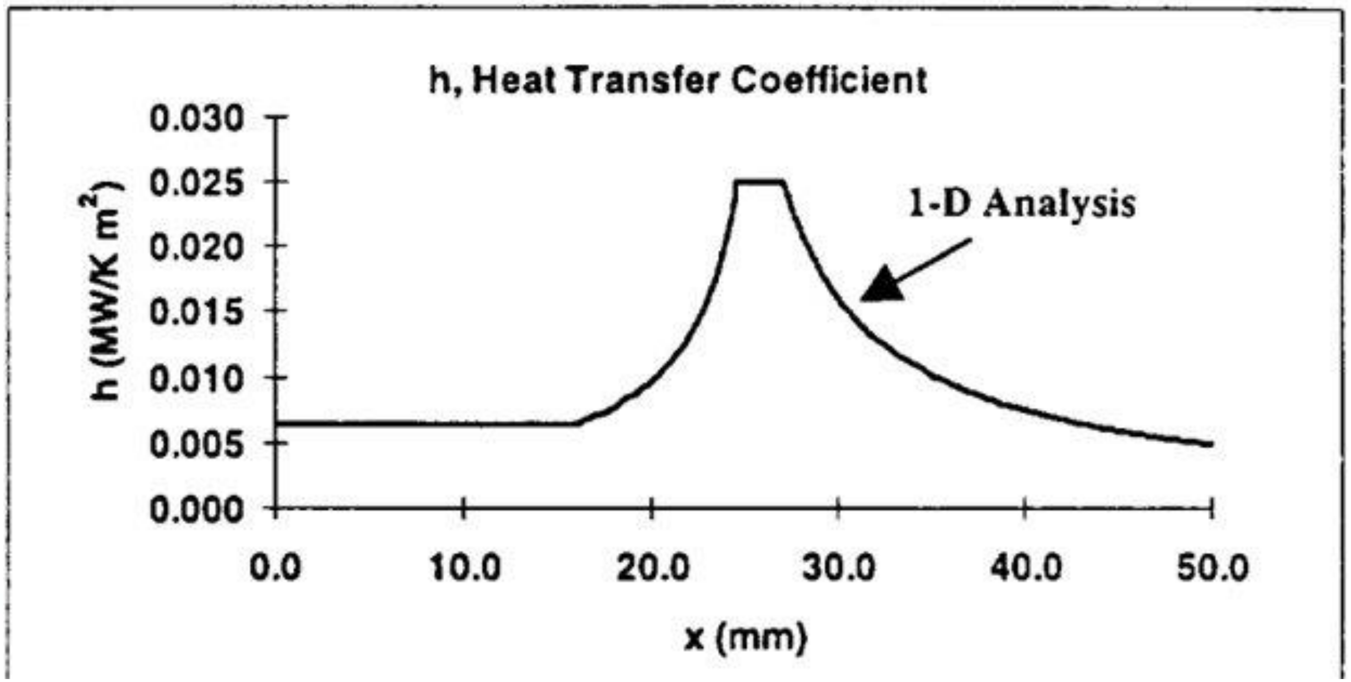




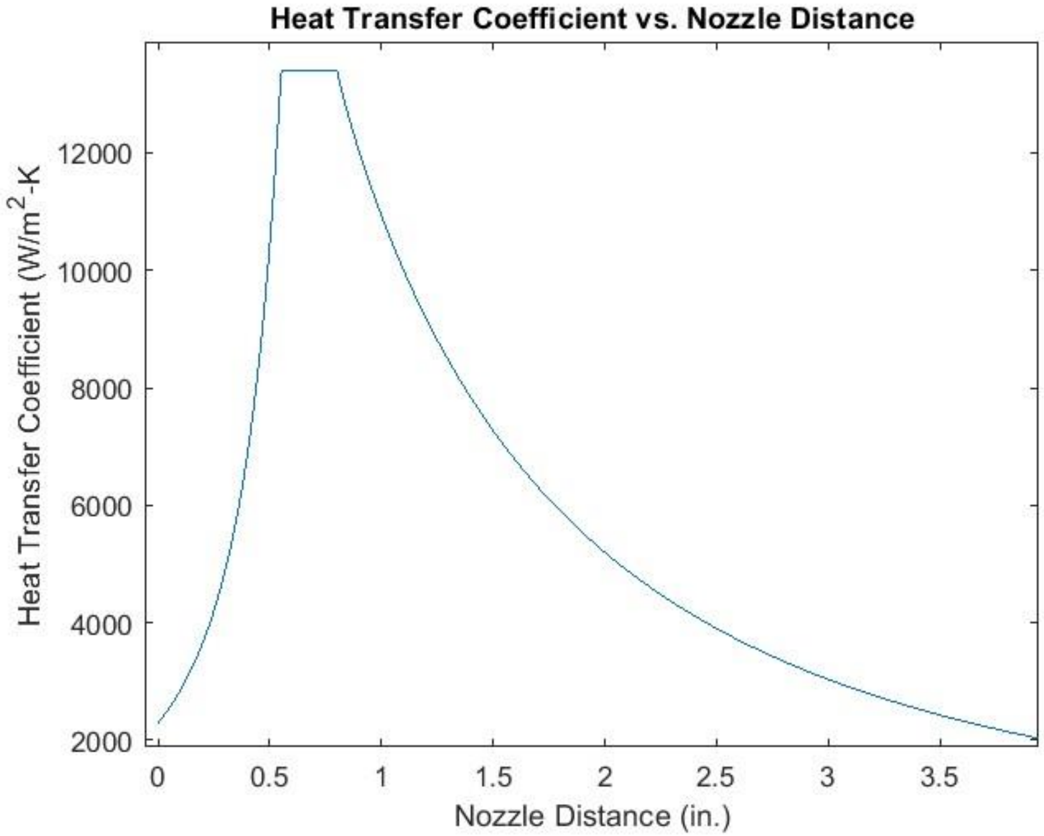
Note: Diameters are actually area, units wrong

Verifying Code (cont.)

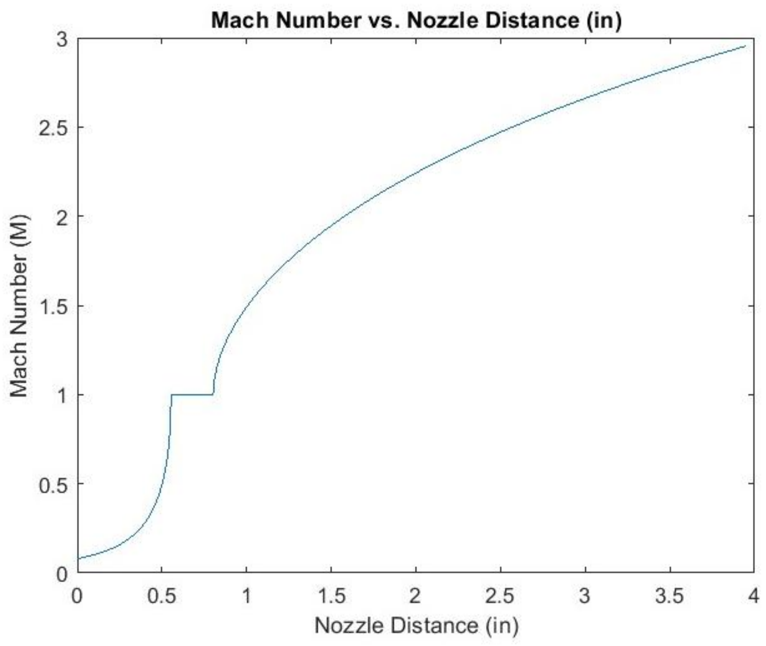




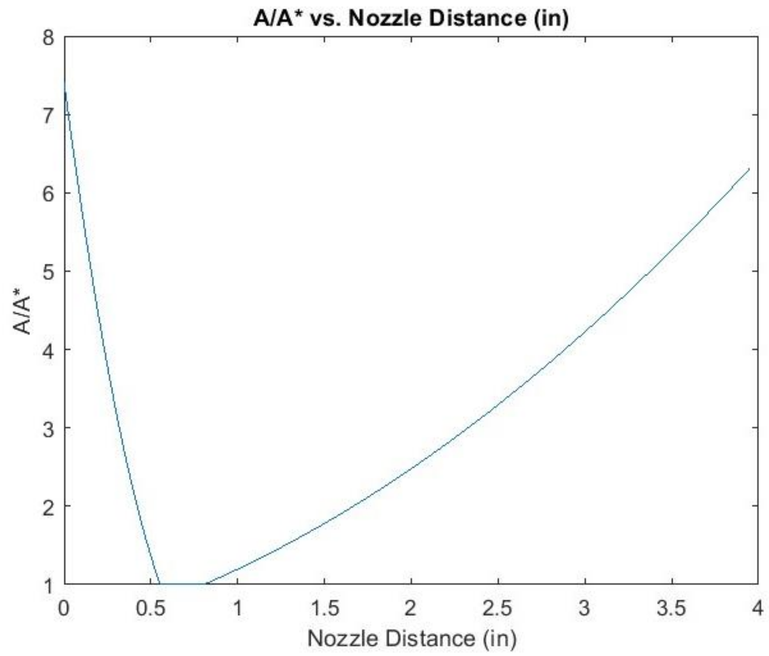
Heat Transfer Graphs



Max h: 13,400 W/m^2*k

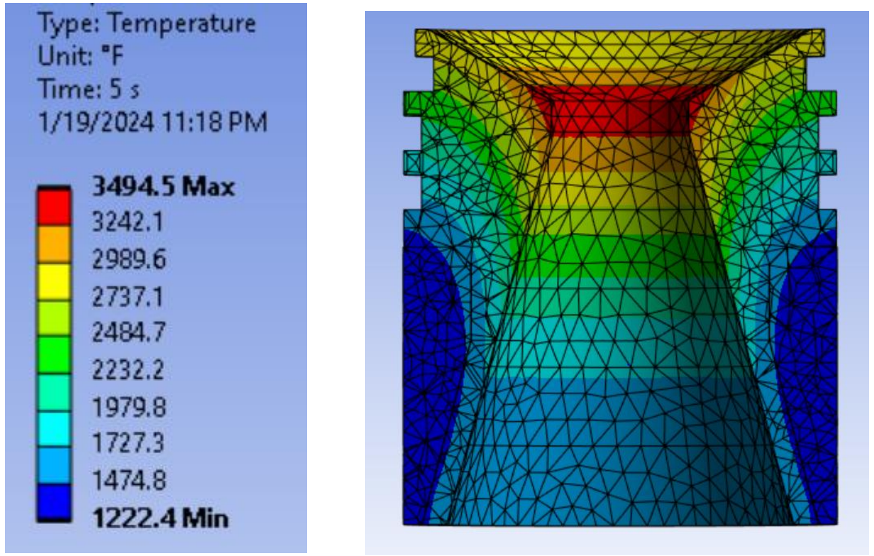


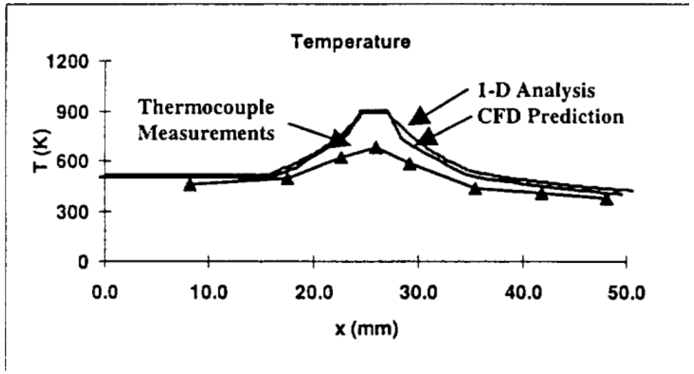
Exit Mach matches up with Motor Simulation



Nozzle – Analysis (Transient Thermal)

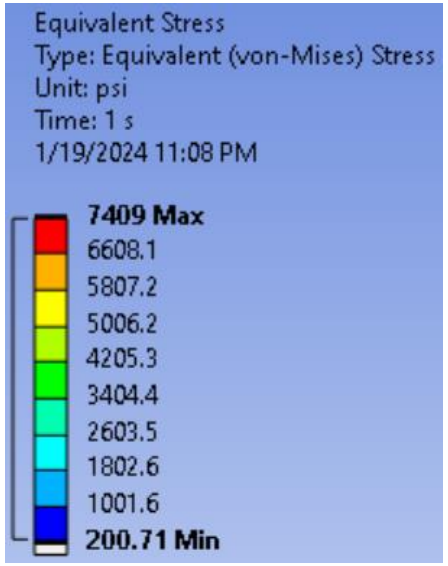
- Heat transfer into nozzle: mainly convection, others ignored
  - ANSYS Transient Thermal Analysis
- Boundary Conditions: Sliced nozzle, took weighted avg's of corresponding sections of Heat Transfer Coeff. Vs. Nozzle Distance and assigned to each slice
- Graphite Melting Temp: 5000 F
- Aluminum Melting Temp: 1221 F

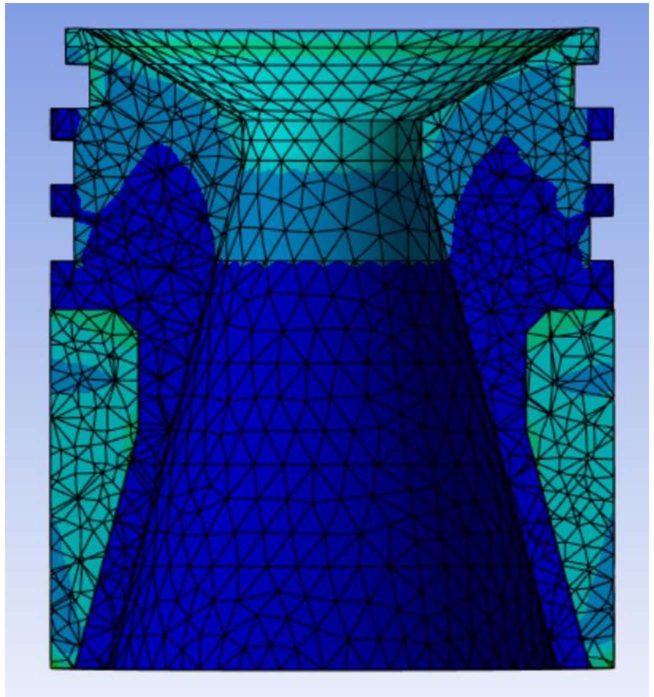




Nozzle – Analysis (Structural Analysis)

- ANSYS Structural Analysis – Nozzle Compressive + Hoop Stresses
- Max stress disregarded (bad mesh around bolt holes)
- Nozzle Ring Bearing Stress
- Bolts Stresses
- Graphite Nozzle FOS = 1.9 ~ 2
  - (Compressive Yield Stress)
- Aluminum Jacket FOS = 11.8
  - (Tensile Yield Stress)





Nozzle – Manufacturing/Integration/Cost

- Graphite Contour can be manufactured with a Lathe
- Aluminum Jacket can be manufactured with the Lathe, Mill, and Wire EDM or Waterjet
- Clamp both pieces of the Aluminum Jacket onto the graphite, slide into motor, attach bolts

Motor BOM

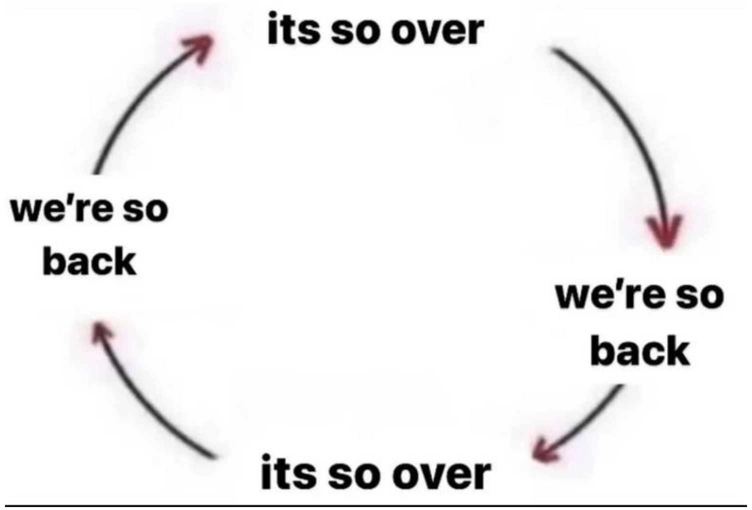
- **Full Cost- $623**
- Fwd. Closure Cost : $80
- Igniter Cost :$170
  - Casing Cost - $260
  - Nozzle Cost - $130

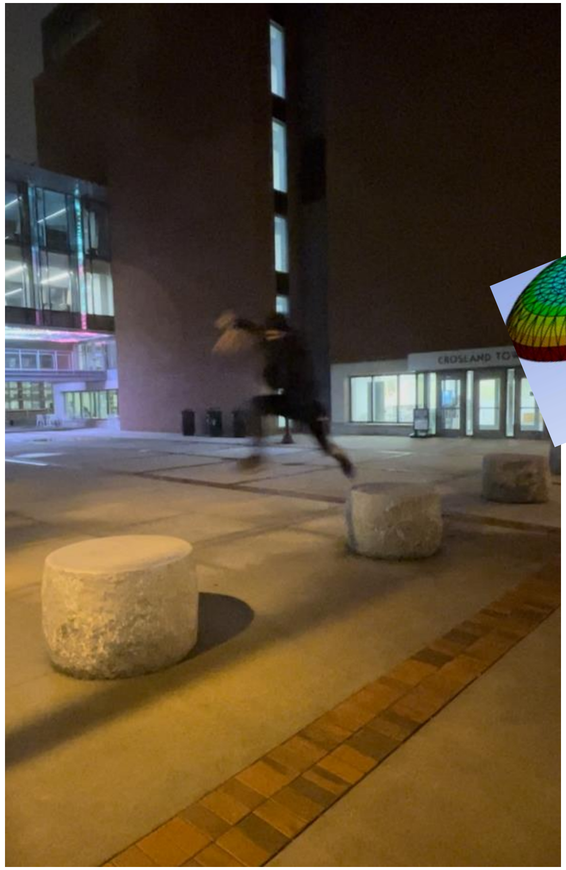
- Link to full BOM

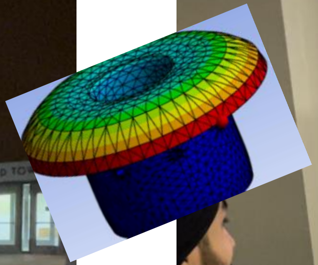
Closing Remarks

- Shoutout Andrew for answering all our questions and Connor for helping with the heat transfer!
- All CAD, calculations, graphs, trade studies found in our SharePoint
- Why should we be picked?
  - **Novel Nozzle, Igniter Desings**
  - **Maximum Impulse for N-Motor**
  - **In-Depth Analysis**
  - **Cheap**

Questions?







References

- Nozzle Heat Transfer NASA Paper - https://ntrs.nasa.gov/api/citations/19990025912/downloads/19990025912.pdf [1]