Runaway V2 Design Review

The Propulsion Team

Combustion Chamber

Design Requirements:

1. Must withstand a static pressure of 500psi and internal combustion temperature of 700K
    a. Verified data from previous hybrid engine research of comparable size
    b. http://www.braeunig.us/space/propel.htm is a report that shows expected pressure.
    c. https://web.stanford.edu/~cantwell/AA283_Course_Material/Combustion_of_Solid_Propellants.pdf
    d. https://www.eucass.eu/doi/EUCASS2017-613.pdf for temperature estimates. Used solidworks simulation for testing. (steel combustion chamber). Adequate **maximum service temperature**
2. Must seal with the rest of the engine via flanges.
    a. Further investigation of bolting methods will be completed once the Frame subgroup has decided their major criteria.

Material

Material Choices:

1. Aluminum 6061-T6
    a. Lower strength and operating temperature
    b. Cheaper and easier to work with
    c. Lower density
2. Stainless Steel 316
    a. Stronger and much higher operating temperature
    b. Expensive
    c. High Density
3. Carbon Steel
    a. Better heat distribution in material
    b. Lower melting temperature
    c. Malleable and durable

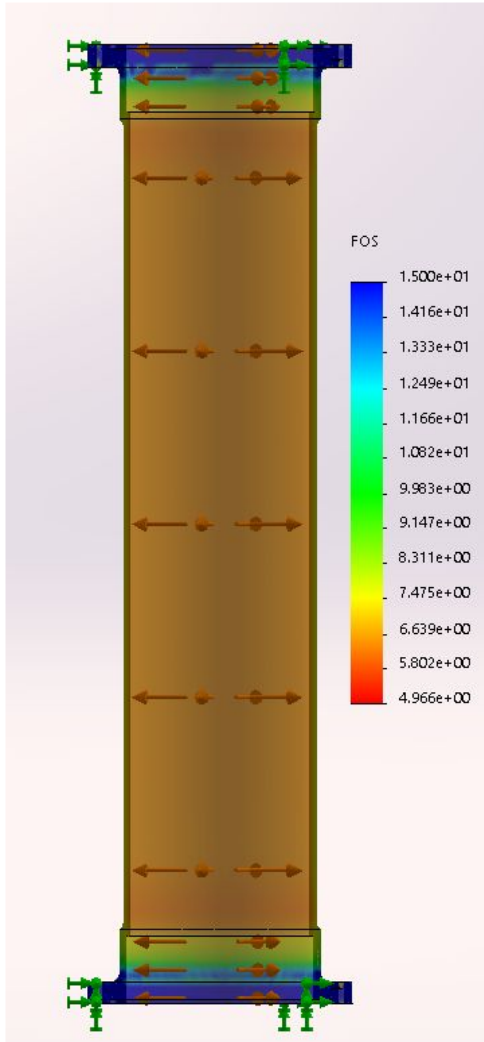
Analysis

Stainless Steel

Component Name	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
OD [in.]	3.1	3.15	3.2	3.25	3.3
Mass [lb]	5.08581	5.830635	6.587378	7.356038	8.136615
Minimum FOS	2.2	3.4	5.2	6.1	7.6

Aluminum 6061-T6

Component Name	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
OD [in.]	3.1	3.2	3.3	3.4	3.5
Mass [lb]	1.7164608	2.22324	2.746107	3.285063	3.763021
Minimum FOS	1.7	3.7	5.1	7.4	9.2



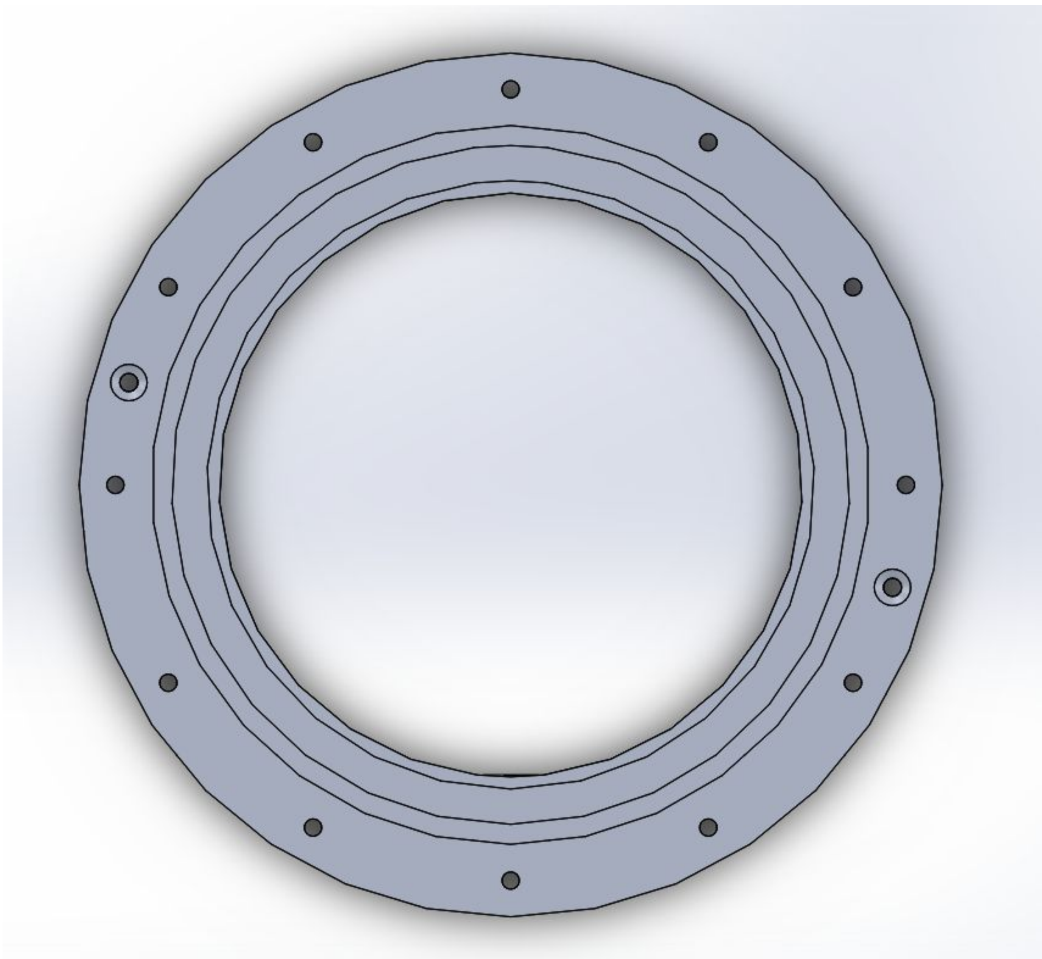
Desired chamber material of aluminum with a ⅛” thickness

An analysis of the simulation results highlight the ability of aluminum to withstand design requirements in terms of load while allowing for reduction of weight. Further analysis must be completed regarding the thermal load and aluminum’s ability to maintain sufficient material properties at the maximum operating temperature. To do this, we will be under the assumption that the surface of the inside of the chamber where the fuel is molded will not reach high temperatures (above 100° C) until the very end of the burn. When it reaches the end of the burn, the pressure will let off, making that not be a potential failure point. The top and bottom recirculation zones will need to have another material to act as a thermal interface between the aluminum chamber and the combustion zone, and will be analyzed later in the report.

Fundamental Chamber Dimensions

A standard 3” ID was chosen for the hybrid combustion chamber to allow a shorter amount of regression needed to expend all of the fuel. An overall thickness of ⅛” was selected as it yielded a FOS of 5 under a static simulation pictured above. Critical locations exist in the chamber and will be detailed in detail later in the report.

Flange



The flange utilizes a bolt circle of 12 18-8 stainless bolt, which enables the chamber to interface with both the injector plate and nozzle. The circle groove will enable the assembly of a silicone o-ring to seal these components, eliminating the chance of leaking. 2 precision holes are also machined into the flange for the insertion of precision pins that will connect with both the injector and nozzle, maintaining a perfect alignment during assembly.

Fuel Production to Decide Length

A mass mixture ratio [O:F] of 4.0 is usually experienced for HTPB and nitrous oxide Given the nitrous on board is 12 lbs 9 oz, we want 3.25 lbs of fuel.

- Density of HTPB is 0.0335984 lb/in^3
  Source:
  https://pdfs.semanticscholar.org/a15a/a1b29fffeebfcdb70965e4241af07eb5f00f.pdf
- This requires about 96 cubic inches of the HTPB. (3.5lb / 0.0335984 lb/in^3)

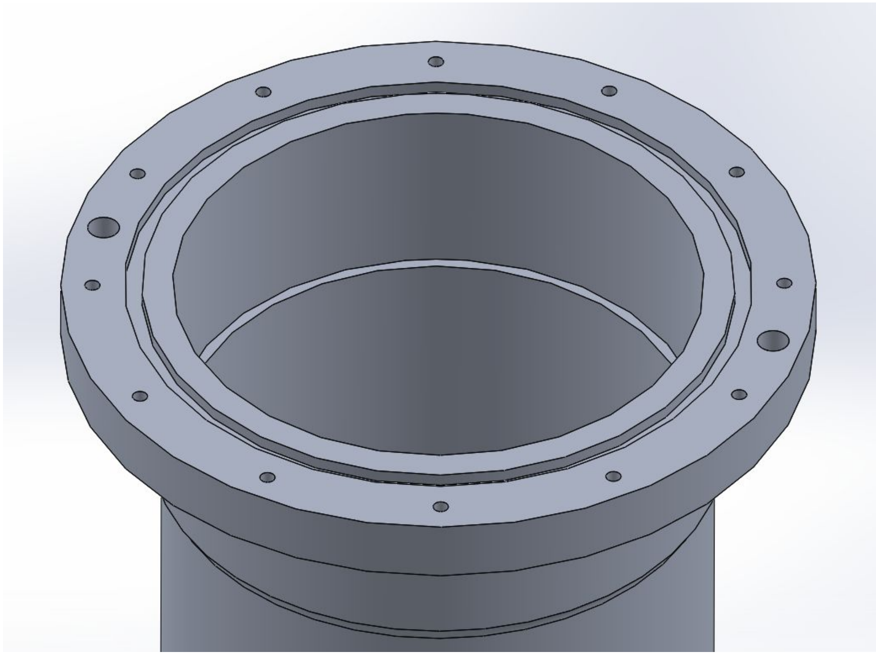
Selecting an ID chamber of 3 in. with a 1 inch gap area at the top and bottom for recirculation zones and a 3/4 in. grain circle.

Chamber length can be calculated using a chamber ID of 3" and a grain circle diameter of 0.75" and accounting for two 1" gaps between the two ends of the chamber and the start of the HTPB mold for recirculation zones.

$(R^2 - r^2)\pi * L = 96$ was used and solved for L, the length of the HTPB section in the combustion chamber. Two inches are then added to account of recirculation zones, making the total length of the chamber 16 inches.

Critical Recirculation Zones

The recirculation zones are the failure points of the chamber if left as is, as it not only has the applied combustion pressure, but is open to the corrosive, high temperature environment of the chamber. As the T6 6061 aluminum does poorly in these environments over the timeframe of the engine burn, an additional, high temperature, low thermal conductive material will be used to interface between this environment, protecting and maintaining the structural integrity of the aluminum.



To find the best insulating material we created a data table of all the different materials we would look into keeping in mind our goal of creating a ring out of the material to seal off the exposed aluminum on the walls of the recirculation zones as seen below.

Material	Temperature rating	Thermal Conductivity
Graphite	3,000+ Celsius	96 W/m-K
Polymer Clay	1,780 Celsius	0.25 W/m-K Depends on moisture content
High Purity Grade Ceramic Fiber	1,260 Celsius	.16-.22 W/m-K
Ceramics	Dependent on Compound	Dependent on Compound

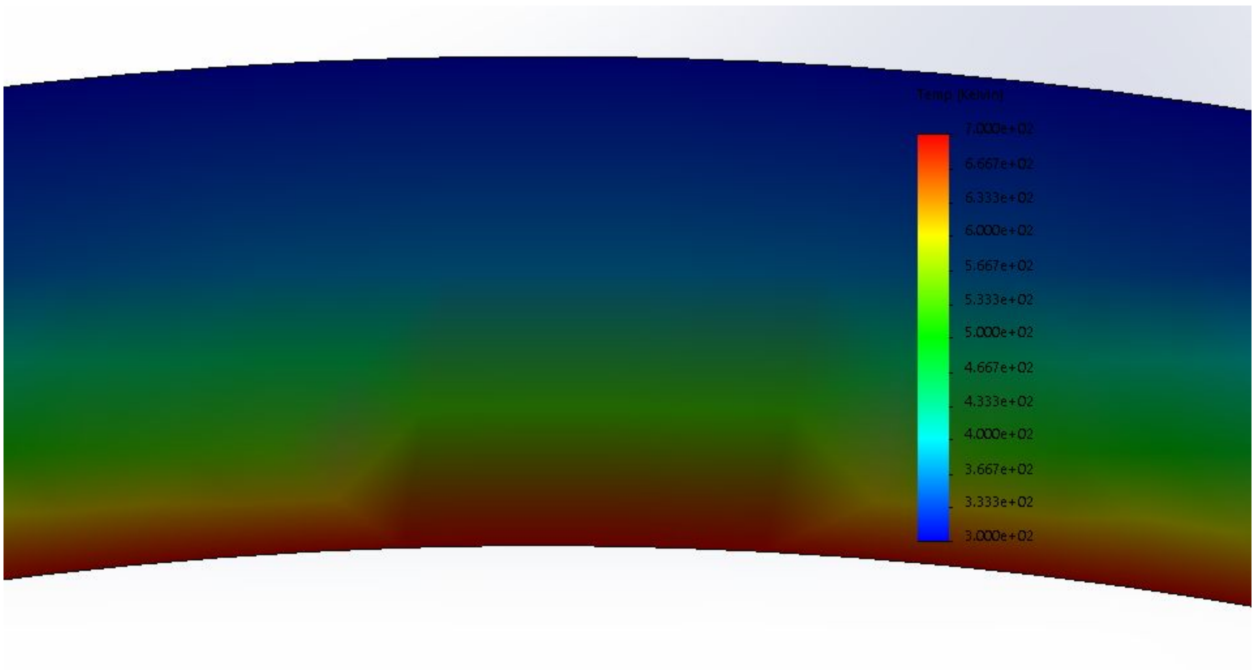
- **Ceramic Fiber**
  - High temperature rating and low thermal conductivity, low cost, flexible
  - May not create a tight seal with walls of aluminum and may not stay in place due to being a fiber mesh
- **Polymer Clay**
  - Very high temperature rating and low thermal conductivity
  - May be hard to form or produce in shape needed without structural flaws

- **Graphite**
    - Very high melting point and thermal shock resistance
    - Transfers heat relatively easy and much faster than other options
- **Ceramic Compounds**
    - Silicon Dioxide (SiO_2) 1.38 w/m-k - 1100 Celsius
    - Silicon Carbide (SiC) 120 w/m-k - 1650 celsius
    - Boron Carbide (B_4C) 17 w/m-k - 2000 Celsius
    - Silicon Nitride (Si_3N_4) 29 w/m-k - 1000 Celsius
    - Aluminum Oxide (Al_2O_3) 18 w/m-k - 1700 Celsius
    https://accuratus.com/fused.html used to research thermal properties for each ceramic compound

Examining the thermal properties of several insulative materials, ceramic materials had the lowest heat transfer rates, as well as being chemically inert, and having high temperature shock resistance, low thermal expansion, and high operating and melting temperatures. Of the many Ceramic compounds, the compound we settled on was silicon dioxide (SiO_2) otherwise known as Fused Quartz. The properties of this material include a heat transfer rate of 1.38 W/m-K, a melting point of 1,100 Degrees Celsius, and a thermal expansion coefficient of $5.5 \cdot 10^{-7}$/K. An important factor in this decision is the availability of the material, which happens to be sold premanufacture into hollow tubes available in the dimensions we need, having a 3” inner diameter.

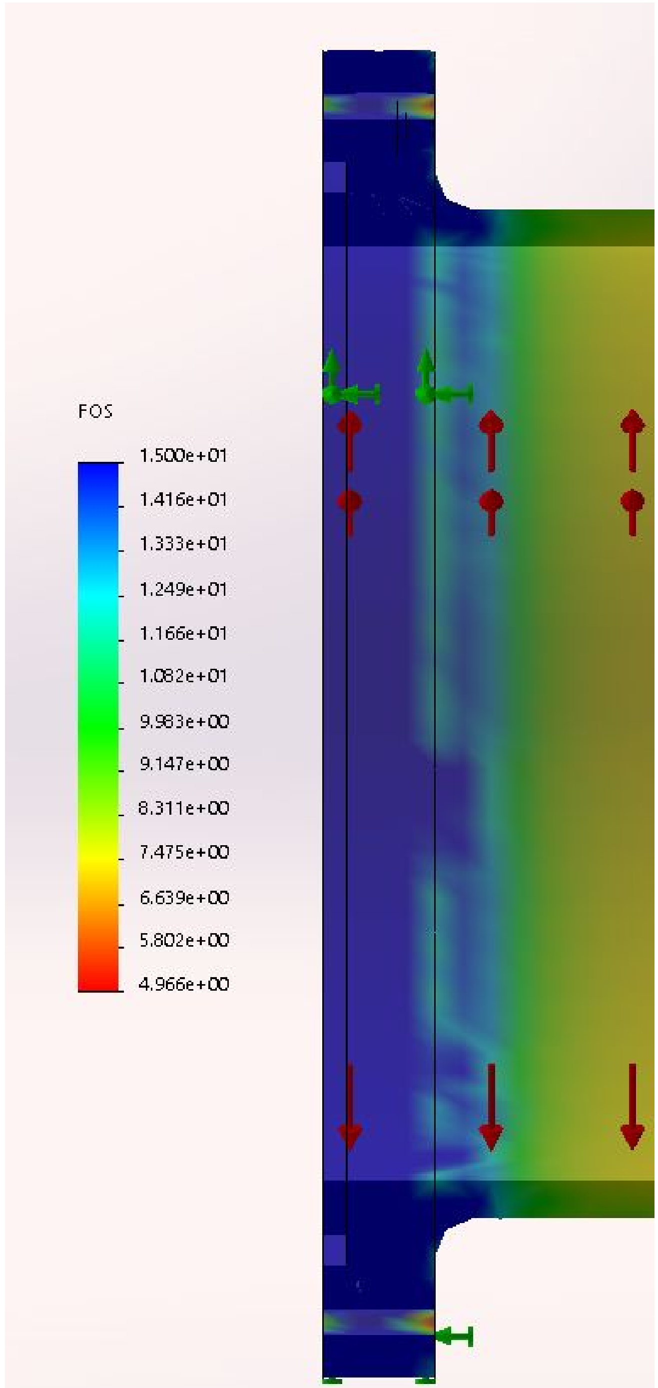
Silicon Dioxide (SiO_2) Properties	
Heat Transfer Rate	1.38 W/m-K
Coefficient of Thermal Expansion	$5.5 \cdot 10^{-7}$/K
Specific Heat capacity	740 J/(kg-K)
Melting Point	1,100 Celsius

According to TheFabricator.com, a website about manufacturing, and materials, Aluminum 6061-T6 has a strength of around 25 KSI at room temperature and at 315 ℃ or half its melting point of 660 ℃, aluminum’s strength is reduced to about half its strength at room temperature or 12 KSI, and aluminum starts to lose its structural integrity and soften or deform as early as 175 ℃. So our goal is to find a thickness for our insulating ring to prevent the aluminum from reaching temperatures above 150 ℃ in order to have a small layer of thermal safety while keeping our insulating ring as thin as possible. Our method for testing our insulating ring was inputting the material data into solid works onto a ring with our 3” inner diameter and gave it a wall thickness greater than necessary. We then applied a temperature of 700 Kelvin to the inside of the ring, our assumed combustion temperature inside our rocket engine, for 5 second or the amount of time our engine will burn for, to see how much heat is dissipated to the outside of our ring. After the model was generated we could easily view how far the heat made its way through the insulating ring, and find the outer diameter of the ring such that it was no more than 150 ℃. The outer diameter that was calculated is 79.5mm or 3.13in. The insulating ring diameters will have to be machined from the ordered size of 75mm inner diameter and 80mm outer diameter to 76.2mm inner diameter and 79.5mm outer diameter.



Material Purchase and Machining

As the engine will be made primarily of aluminum 6061-T6, it is beneficial to be able to buy one 4.5” diameter, 2’ in length barstock to make the injector, chamber and nozzle. This means that the chamber length and injector length must be less than 23” to produce both components from the same piece of raw stock. External machining, outside of the UNH Tool Room, is required due to large outer diameter exceeding most lathe capabilities.

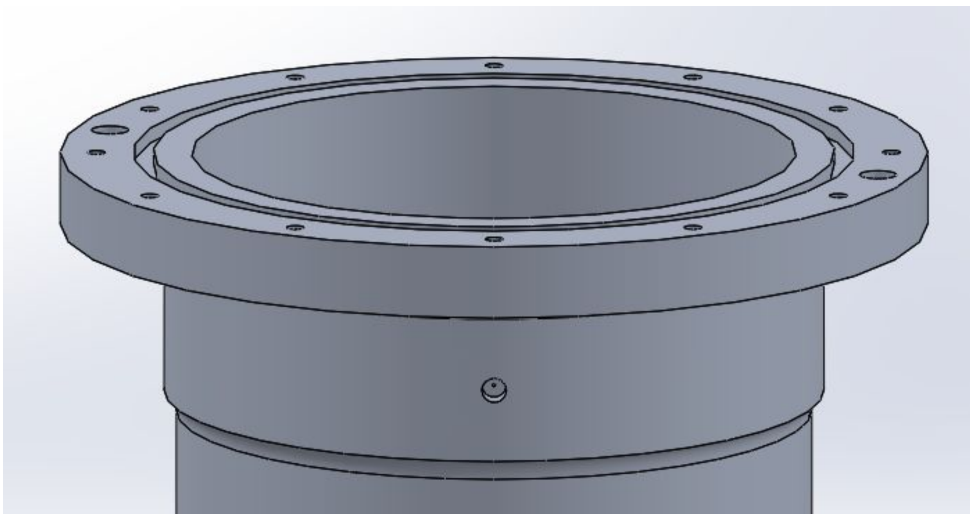


A simulation was run with the addition of the recirculation features without the insert for resistance to temperature. With these features, it proves that the critical zone still maintains a FOS of 5 as an additional thickness was added to compensate for the loss of aluminum material with the integration of the temperature resistance insert.

Sensor Incorporation Features

It is desirable to obtain the thrust output of the engine, which is relatively simple and does not involve any features on the combustion chamber. The other desirable sensor data that is wanted are temperature and pressure.

For the p7075lude two pressure tap insert features which involve the attachment of high pressure aluminum tubing via welding with a small pilot hole to allow the pressure to travel through the tubing and into the pressure sensors we will use.



Temperature will be gathered from utilizing the thermal sensors manufactured by Conax. The sensor selected can withstand temperatures in excess of 1000 C and is inserted via screwing into an NPT female thread, a feature manufactured into the combustion chamber.

It is important to note that the drawing does not contain these features as they will be made after the part is made from the machine shop that makes it. The overall way to integrate these sensors still needs more time to be worked out.

Injector

Design Requirements:

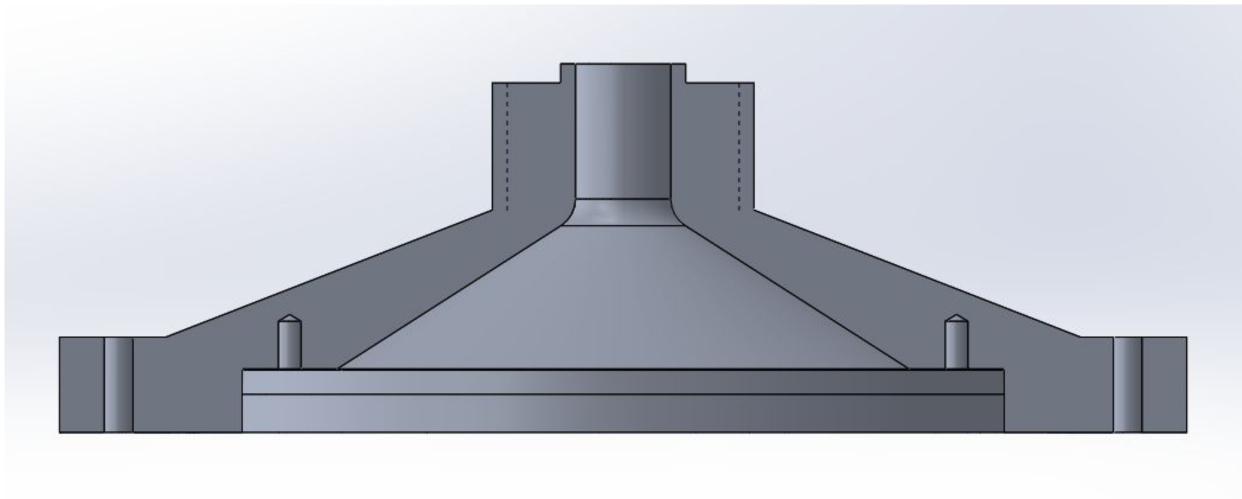
The injector is responsible for the impingement and injection of nitrous oxide into the combustion chamber. It is a pair to the impingement plate which gets fastened to the outlet area of the injector plate in order to direct the flow in the chamber for maximum circulation and gasification of the nitrous oxide. The injector plate, which this report will be focused on, must withstand a pressure of 750 psi and must have the ability to take in and force out nitrous oxide.

Material:

As the chamber has been selected as aluminum as the primary material, the injector was also chosen to be made from base aluminum. This will allow both materials to have the same properties, and we can pull from the same bar stock material to make both components. The impinging plate, when analyzed, might be made of a different material based on if there are problems with temperature resistance as the plate is exposed to the chamber temperature during the full burn.

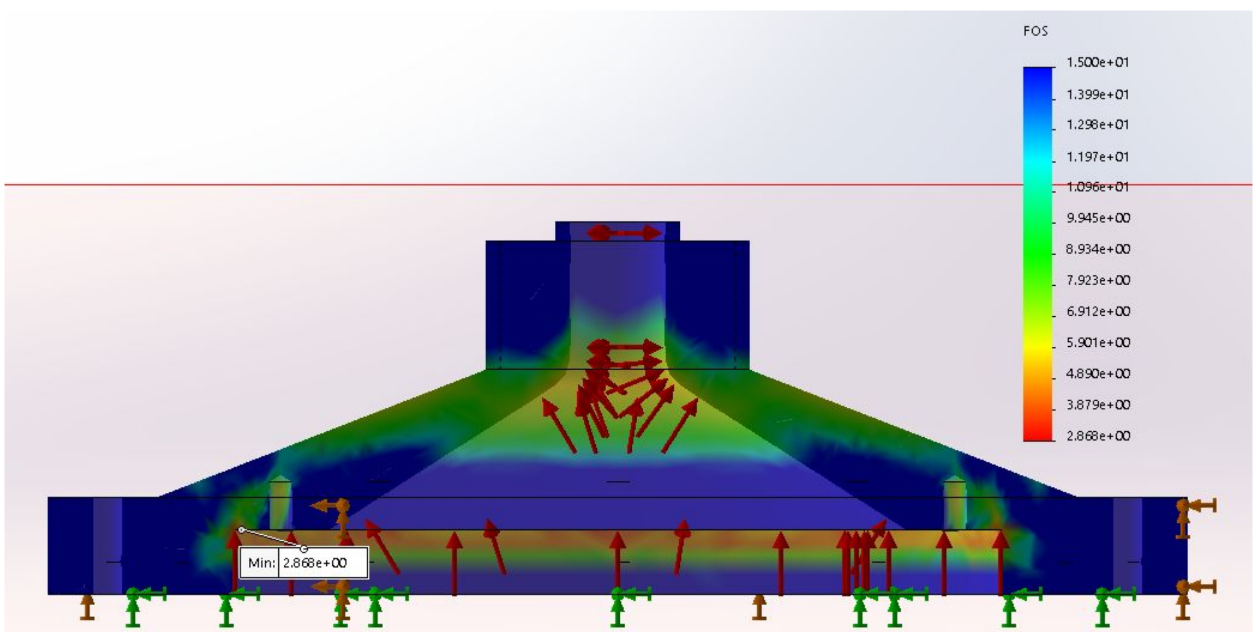
Fundamental Injector Dimensions

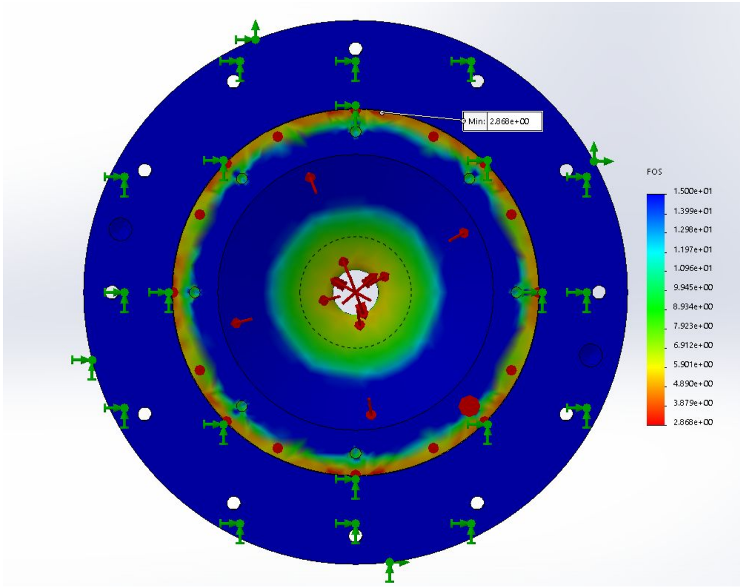
The injector is a relatively simple part as the overall diameter and injector plate sizing is dependent on the chamber. There is a bolt circle with through holes to fasten to the chamber, a tapped bolt circle inside to fasten the impinging plate to the injector taper hole, and a flow inlet path from the top to flow into the impingement plate. A CGA standard thread is machined at the top to interface with the tubing used from the flow regulation system.



Analysis

As the injector is subject to the highest pressure of 750 psi, it must be the strongest component of the engine. With the requirement from above and applying the estimated stresses it will encounter, a minimum factor of safety of 2.8 is reached, allowing us to feel safe with our design decisions.





Assembly and Bill of Materials

Below is the current drawings of Runaway V2 excluding the nozzle. A bill of material list follows. The total cost of all the material needed for these parts is around $1355.22. Enough material is purchased to have at least two Runaways.

Bill of Materials

Combustion Chamber

1. High Strength 7075 Aluminum Rod, 4.5 Inch - $738.89
    a. https://www.mcmaster.com/90465k74-90465K743
2. High-Temperature Silicone O-Ring, 3.5” ID - $8.67
    a. https://www.mcmaster.com/1283n74
3. Precision 3/16 Pins - $4.94
    a. https://www.mcmaster.com/90145a503
4. 18-8 Stainless Steel Flange Bolts, 4-40 - $4.03
    a. https://www.mcmaster.com/92949a113
5. Corrosion Resistant 3003 Aluminum Pressure Tap Tube, ⅛” OD - $2.21
    a. https://www.mcmaster.com/7237k14
6. Pressure Sensor, SPT25-20-1000A - $123.00
    a. https://www.automationdirect.com/adc/shopping/catalog/process_control_-a-_measurement/pressure_sensors/pressure_transmitters/stainless_steel_sensing_element_-_integral_cable/spt25-20-1000a
7. Adapter for Pressure Sensor Connection, 7075 Aluminum Rod - $7.54
    a. https://www.mcmaster.com/90465k67-90465K672
8. Temperature Sensor ~$300.00
    a. K-SS06-G-T3-MK062A-.5
    b. https://www.conaxtechnologies.com/wp-content/uploads/2016/03/5005B-30-31.pdf
9. Fuzed Quartz tubing- Insulating Ring, custom length - $80.00
    a. https://www.technicalglass.com/product_pages/fused_quartz_tubing/fused_quartz_tubing.html

Injector

1. Impinging Plate 7075 Material - $82.02
    a. https://www.mcmaster.com/90465k38-90465K382
2. Bolts for Impinging Plate - $3.92
    a. https://www.mcmaster.com/92196a106