UCI Samueli
School of Engineering

Team 9 - Thrust Chamber Design and Cooling

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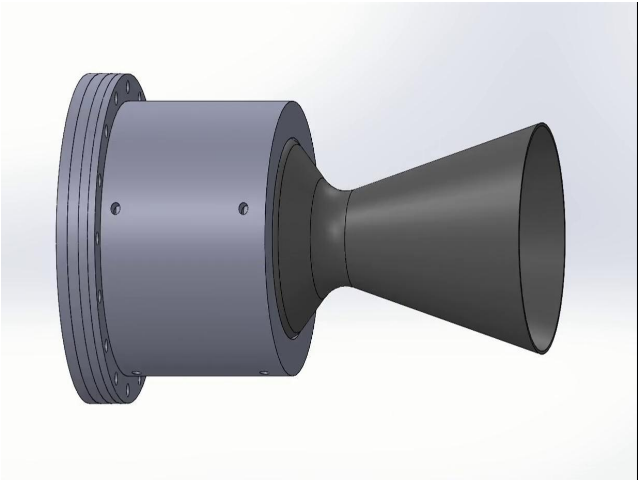
Problem Definition

- Tasked with providing a preliminary design of a thrust chamber capable of producing 2000 pounds of thrust at a specific impulse of 278 seconds and a chamber pressure of 500 psi.
- Must have a cooling system that can replace the ablative cooling used currently
- Design an injector that will replace the current showerhead design.
- Thrust chamber should be able to fit inside current rocket housing.
- Each component must be well-document with justification to the design choices



Rigoberto

Objectives

- Conceptualize and design an injector that can thoroughly mix the fuel and oxidizer to ensure stable combustion while also being relatively simple to manufacture.
- Determine combustion chamber dimensions to achieve given chamber pressure and guarantee complete combustion of the propellants.
- Calculate nozzle geometries to achieve the given thrust and exit pressure.
- Design a cooling system that is capable of keeping the combustion chamber and nozzle within safe operating temperatures.
- Select materials for each component that are capable of handling the high pressures and temperatures while also remaining lightweight and cost-effective.

Rigoberto

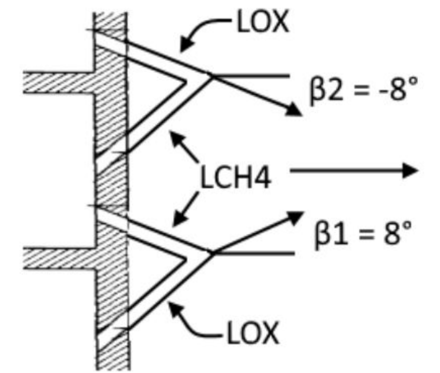
Injector

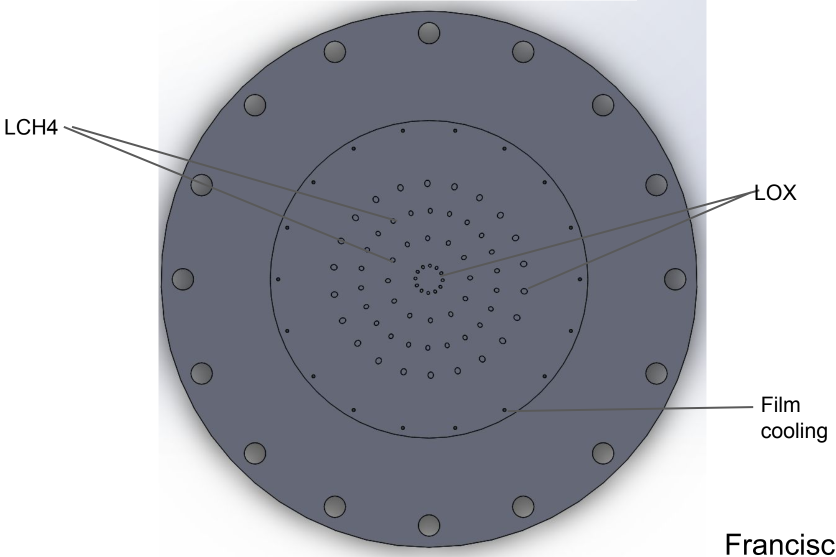
- Purpose: mix the fuel and oxidizer to provide a stable combustion
- Requirements:
    - Compatible to handle LOX and LCH4
    - LOX and LCH4 flow rate of between 5 to 5.3 and 1.85 to 2 lbm/s
    - Incorporate cooling system design
    - Withstand a temperature of 1200 F and pressure of 500 psi
    - Resultant spray in axial direction

Francisco

Injector

- Selection:
    - Impinging element - unlike-doublet
- Parameters:
    - Impingement angle: 60°
    - Immediate spray angle: 9°
    - Orifice diameters:
        - LOX: 0.069 in.
        - LCH4: 0.052 in.
        - Film cooling: 0.039 in.
    - Injector face diameter: 4 in.
- Material:
    - Inconel 718





Francisco

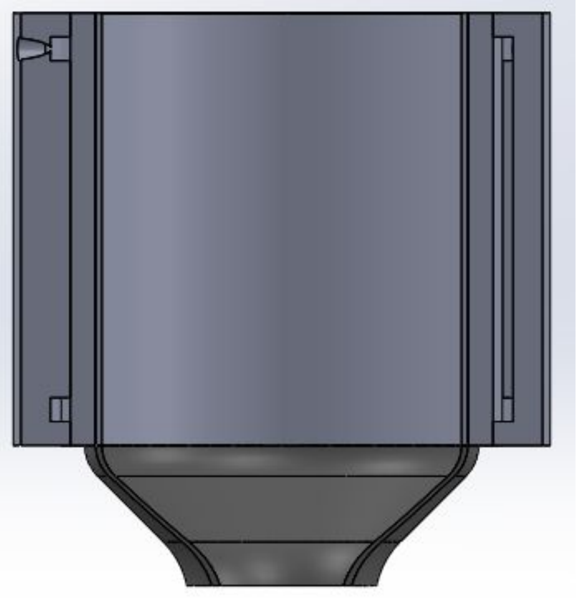
Combustion Chamber

- Purpose: Provide adequate volume for complete combustion and direct flow to the nozzle with minimal pressure losses.
- Requirements:
  - Maintain a chamber pressure of 500 psi during combustion.
  - Maintain structural integrity for temperatures up to 1200 Rankine (5460 Fahrenheit) with cooling.
  - Remain as lightweight as possible to minimize engine mass.
  - Material should be resistant to thermal shock and corrosion.

Nareg

Combustion Chamber

- Material Selection
  - Inconel 718, a nickel based super alloy, was selected.
  - Yield stress at 1200 Fahrenheit: 142-152 ksi
  - Good corrosion and thermal shock resistance
  - Relatively lightweight: .296 pound per cubic inch
  - Good thermal conductivity
- Relevant dimensions
  - Wall thickness: .063 inches
  - Chamber volume: 70 cubic inches
  - Chamber diameter: 4 inches
  - Chamber cylindrical length: 4.53 inches (down from ~13 inches of current Rocket Project engine due to improved injector design)



Front cross section view of combustion chamber and converging nozzle with cooling jacket

Nareg

Nozzle

Needs	**Requirements**
Small Size	Hold Temperature up to ~5600 R
Low Cost & Great Performance on Material	Weight under 0.5 lb
Feasible Design with other parts	Wall Thickness around 0.06 in
Easy Machinability and Fabrication	Withstand 500 Psi of Pressure

Concerns:

Nozzle type: Conical Nozzle

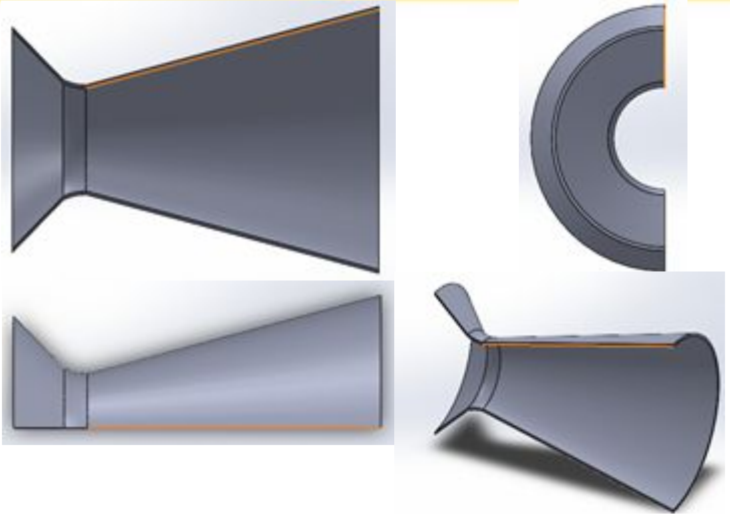
- Fit with the small rocket engine but moderate efficiency

Nozzle material: Pyrolytic Graphite

- Great overall properties but one nozzle per launch (may alter the flow geometry)
- Relatively poor erosion resistance

Yuchen

Nozzle



Four section views of the nozzle (front, left, top, and trimetric)

Properties of Pyrolytic Graphite:

- Withstand temperature over 5000 F
- Low density of 0.079±0.001 lb/in^3
- Good durability, wear resistance, and strength
- Good thermal conductivity and thermal expansion

Parameters:

- Wall thickness: 0.063 in
- Nozzle length: 6.52 in
- Contour Angle: 15 degree
- Throat diameter: 1.82 in
- Exit diameter: 4.61 in

Yuchen

Cooling System

Heat transfer is important in rocket design:

- The thrust chamber must be cooled in order to withstand imposed loads and stresses
- Requires a lot progress from other design components

General idea of steady-state cooling methods

- Extreme temperatures of 5900 Rankine in thrust chamber
- A liquid is meant to absorb the heat being created before being expelled from the rocket

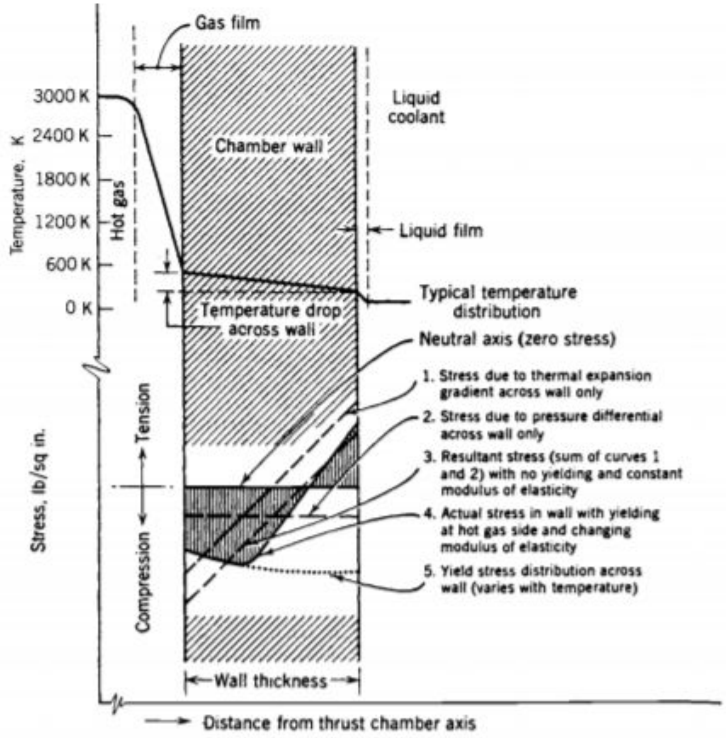
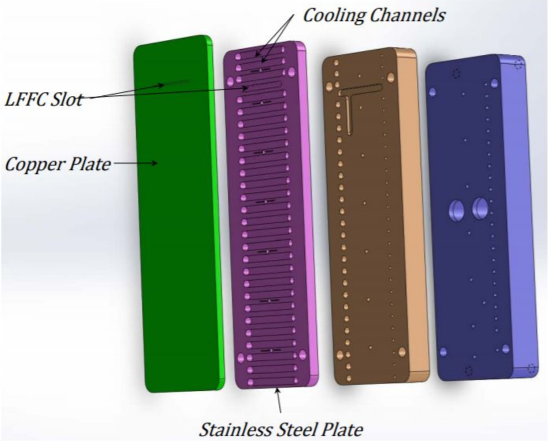


FIGURE 8–12. Typical stresses in a thrust chamber inner wall.

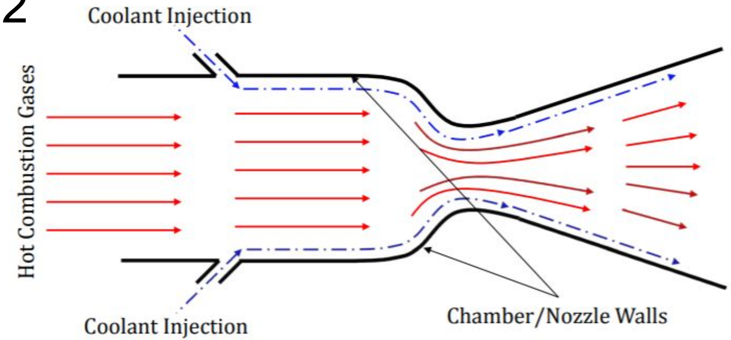
Anika

Cooling System Design: LFFC + Regenerative

- thin film of fuel in combustion chamber wall: thermal barrier between combustion gases and the combustion chamber
- Hot gas wall cooling by flowing coolant through copper liners



- Previous designs: Thor, Jupiter, Atlas, H-1, J-2
- Pros:lightweight, efficient, good for long durations, good for larger engine
- Cons: degrades engine performance

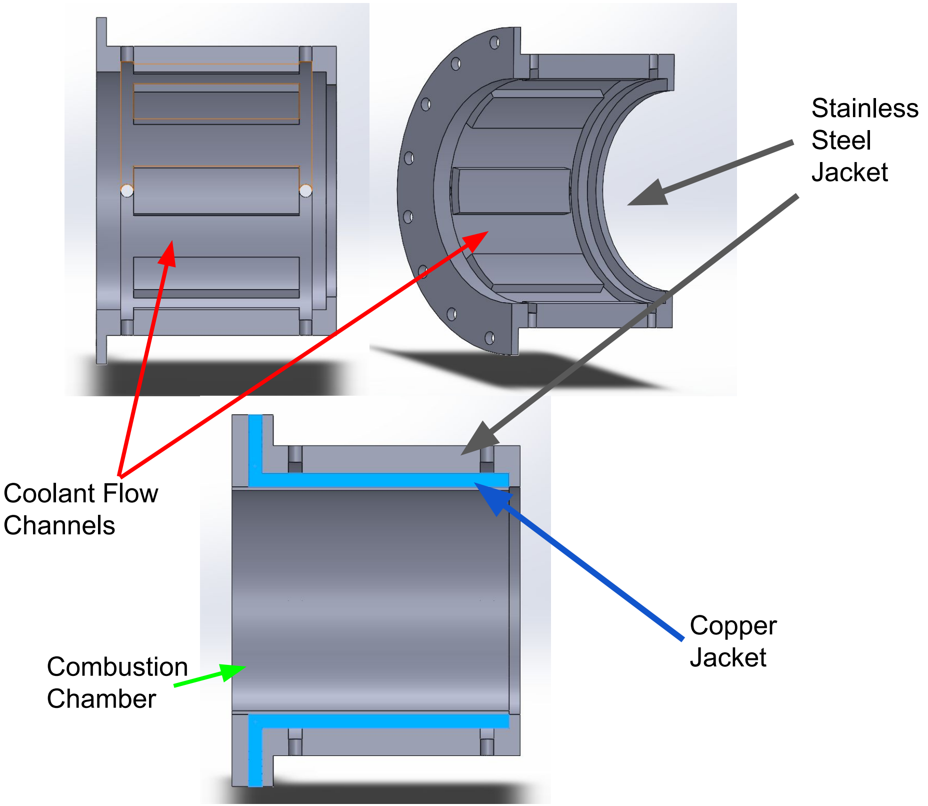


Anika

Combustion Chamber Cooling Jacket

Cooling Jacket made of 2 parts

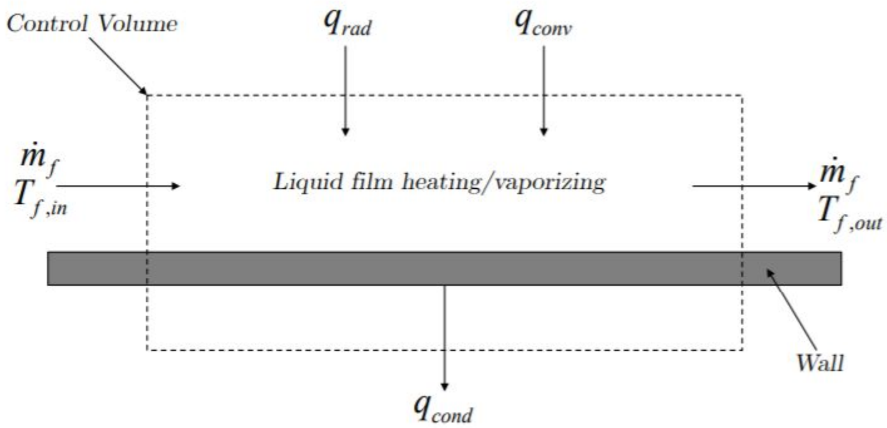
- Stainless Steel 501
  - Thermal Cond. 32.45 W/m*K
  - 8 coolant channels
  - 8 holes to allow coolant flow in/out
  - 0.5” thick
- Copper Alloy C18150
  - Thermal Cond. 323.64 W/m*K
  - Solid with no channels
  - Meant for Heat Transfer
  - 0.25” thick



Rigoberto

Liquid Fuel Film Cooling: a CFD Analysis

- In the realm of film cooling, the majority of research efforts are directed towards gas turbine engines.



Goal: remove ~3500 Rankine of heat

$$(k\frac{\partial T}{\partial y})fluid + q''rad = (k\frac{\partial T}{\partial y})solid$$

- A conjugate heat transfer problem occurs: heat flux from the film (fluid) to the wall (solid) is of main interest.
- At this fluid/solid interface the heat flux conducted by the fluid must balance out with the heat flux conducted by the solid and any radiation (if not neglected) as shown:

Anika

Remaining Questions and Recommendations

Questions:

- Is additive manufacturing possible for some of these components? (i.e. combustion chamber, nozzle, injector and/or solid steel cooling jacket)

Recommendations:

- Figuring out what type of tubing, flexible or rigid, will be used to transport coolant from tanks to cooling jacket and from cooling jacket to injector.
- Determine flange attachment points to connect the combustion chamber to the nozzle.
- Continued study on heat distributions for cooling jacket

Rigoberto