UCI Samueli School of Engineering

Team 9 - Thrust Chamber Design and Cooling

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Problem Definition

This team is tasked with providing a preliminary design of a thrust chamber to the UCI Rocket Project with a major focus on an efficient cooling system to replace the ablative cooling method used on the current engine. The design of the injector, combustion chamber, nozzle, and cooling system must be well-documented with significant analysis completed to support the design choices.

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.

Injector

- Purpose: mix the fuel and oxidizer to provide a stable combustion
- Many different types: from showerhead to pintle
- Requirements:
  - Compatible to handle LOX and LCH4
  - Propellant flow rate of between 6.75 to 7.25 lbm/s
  - Withstand a temperature of 5913 R and pressure of 500 psi

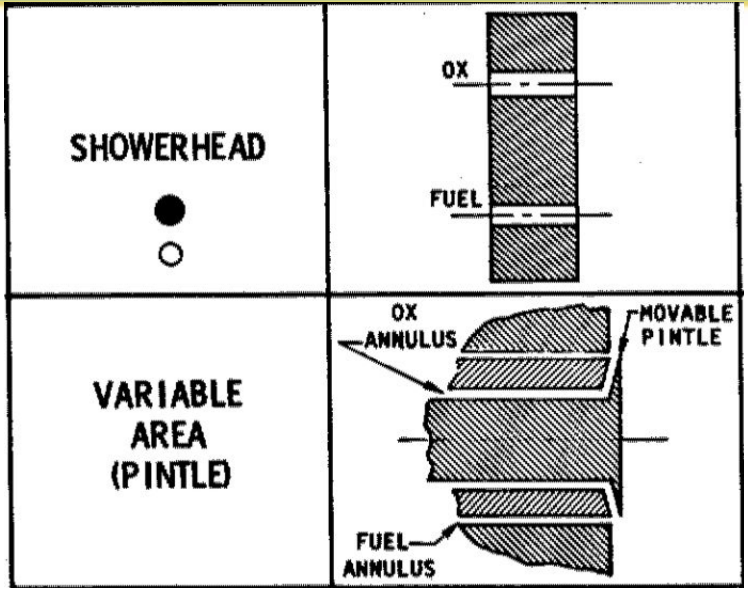


Figure 1: Depictions of a showerhead and pintle injector type

Injector - Design Process

- Watched informational videos that defined what is an injector and its different types
- Read NASA SP 8089 that listed the pros and cons of the injector types
- Went through the UCI Rocket Project Drive
  - They chose a showerhead design for their current rocket
  - Main reason was its low cost and easy to manufacture
- Leaning towards showerhead design

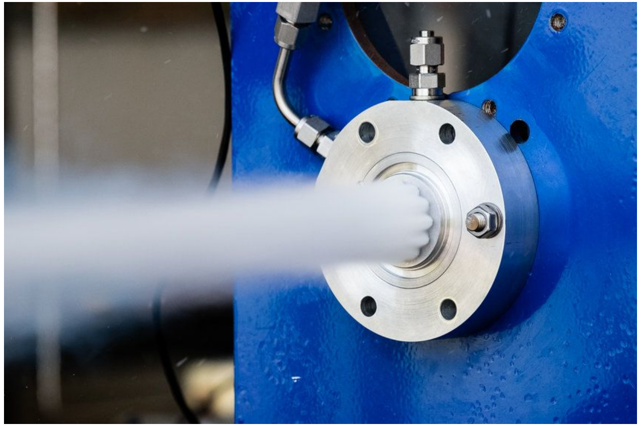


Figure 2: Testing showerhead injector without combustion chamber

Injector - Future Tasks

- Verify showerhead design with team’s requirements
- CAD model with analysis
- Provide a manufacturing process
    - Material choice
    - Machining

Francisco

Combustion Chamber: Current Progress

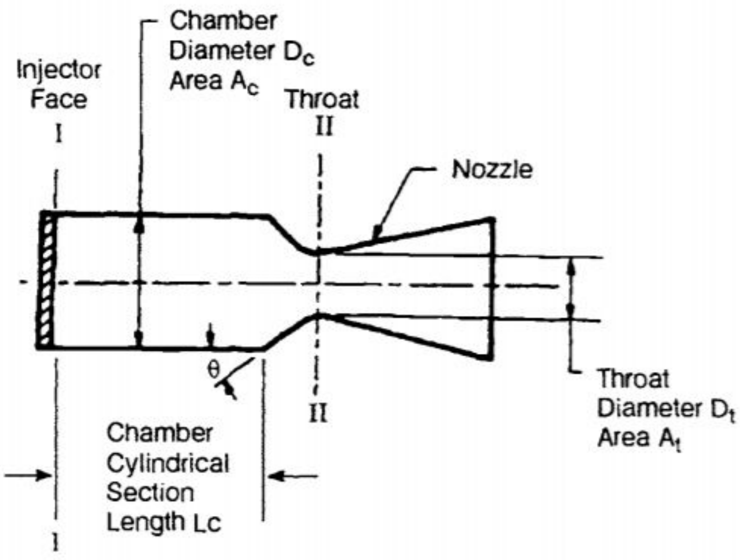
- Ideal values to obtain 2000 pounds of thrust at a chamber pressure of 500 psi have been calculated (assuming isentropic, steady, 1-D flow).
- Decided chamber shape is cylindrical, rather than spherical or near-spherical.
- Rough determination of chamber dimensions have been made.
- Characteristic chamber length (L*) of 22 inches has been chosen based on previous experimental data.
- Current calculated values are supported by analysis software (Rocket Propulsion Analysis).

Nareg

Combustion Chamber Geometry Considerations

- Larger L* values allow for more complete combustion, but result in larger combustion chambers.
- The diameter of the combustion chamber must be large enough to fit a sufficient injector.
- Long chamber lengths allow for a more complete combustion, but can result in non-isentropic pressure losses.
- Design must fit into current Rocket Project housing. May not be possible.

$$L^* = \frac{V_c}{A_t}$$



Nareg

Combustion Chamber: Future Tasks

- Determine optimum contraction ratio, chamber volume, chamber diameter, and chamber length.
- Trade study on materials needs to be conducted. Considerations for materials should be yield strength, melting point, weight, and cost.
- Determine combustion chamber wall thickness to withstand stresses induced by combustion chamber pressure.
- Heat fluxes on combustion chamber walls to be calculated to determine cooling requirements.

Nareg

Nozzle Design

Nozzle Type:

- Conical Nozzle ✔️
  - Small rocket engine with small area ratio nozzle and simple fabrication methods
- Bell-Shaped Nozzle ❎
  - Heavier since the dynamics of hot gases w/ particles up to 30% by weight
    - Consideration on the velocity lag of particles
    - Difficult optimization of flow

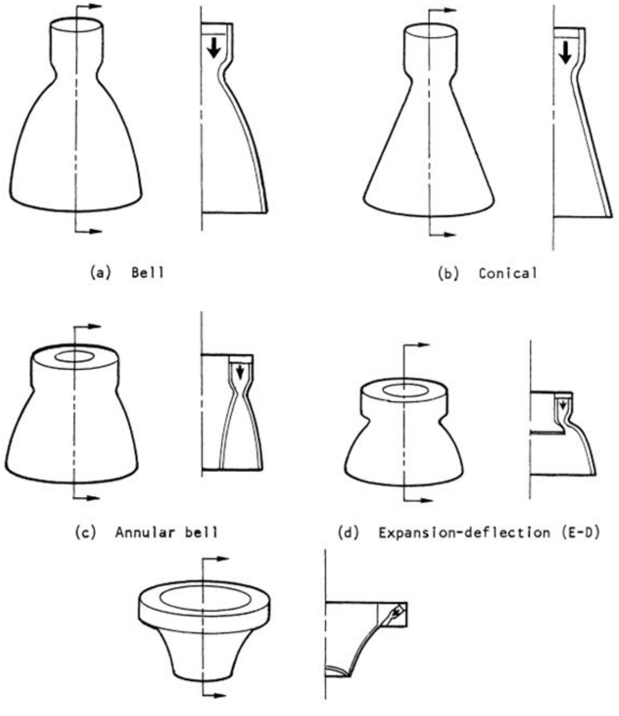


Figure 1. – Basic types of nozzles used in liquid rocket engines.

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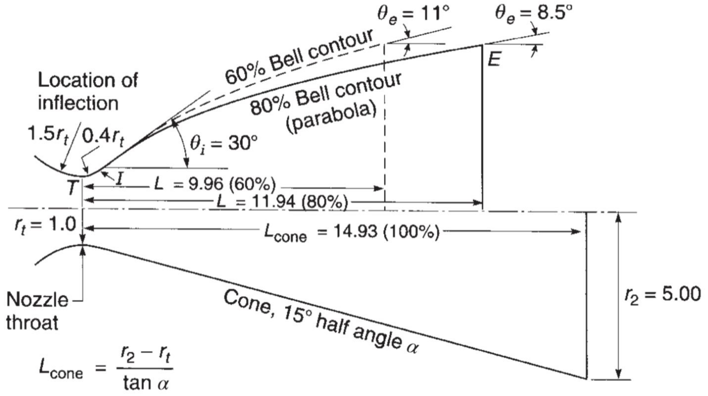
General design:

- Radius of the contour of the nozzle throat:
  - R: 0.25-0.75x throat diameter
- Half-angle of the nozzle convergent cone:
  - Θ: 20-45 degrees
- Divergent cone half-angle:
  - α: 12-18 degrees
- Correction factor:
  - λ = (1+cosα)/2



Sutton's Rocket Propulsion Elements 7th Edition

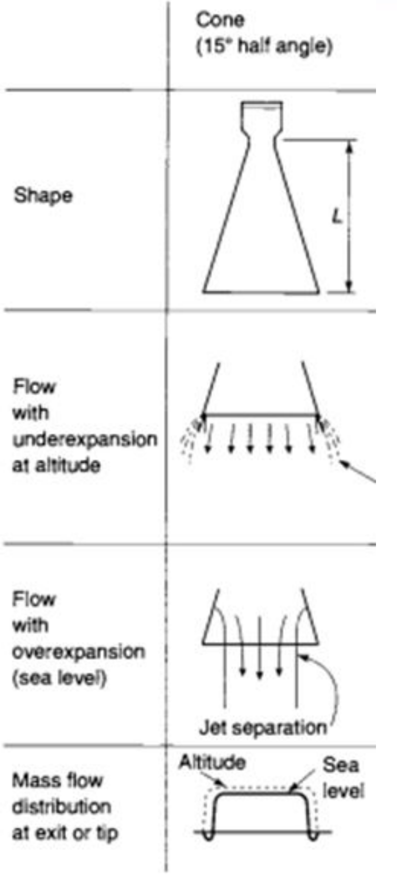
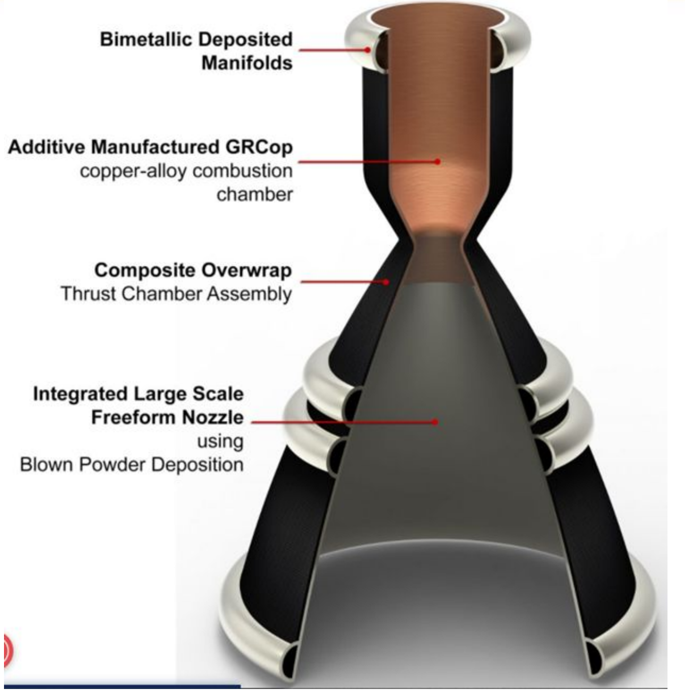


FIGURE 3–12. Simpl

Yuchen

Material Narrow down:

- Withstand relatively high temperature, high gas velocity, chemical erosion, and high stress
- Wall material w/ capacity of high heat transfer rates
- Adequate strength to withstand the chamber combustion pressure
- Copper would be a good choice for the combustion chamber and nozzle



3D printed copper thrust chamber from NASA
https://www.3dprintingmedia.network/nasa-tests-3d-printed-copper-rocket-thruster-composite-overwrap/

Yuchen

Nozzle: Future Tasks

- Research on the possible copper material of the nozzle
- Determine the potential cost of the nozzle
- Prepare for the SolidWorks modeling

Yuchen

Cooling System- Heat Transfer Methods

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 are created in thrust chamber
- A liquid is meant to absorb the heat being created before being expelled from the rocket

$$q = h(T_g - T_l) = Q/A = \frac{T_g - T_l}{1/h_g + t_w/\kappa + 1/h_l} = h_g(T_0 - T_{wg}) = (\kappa/t_w)(T_{wg} - T_{wl}) = h_l(T_{wl} - T_l)$$

$$\frac{Q}{A} = -\kappa\frac{dT}{dL} = -\kappa\frac{\Delta T}{L}$$

T_g = abs chamber gas temperature
T_l = abs coolant liquid temperature
T_{wl} = abs wall temperature on liquid side
T_{wg} = abs wall temperature on gas side
h = overall film coefficient
h_g = gas film coefficient
h_l = coolant liquid film coefficient
t_w = thickness of the chamber wall
K = conductivity of wall material

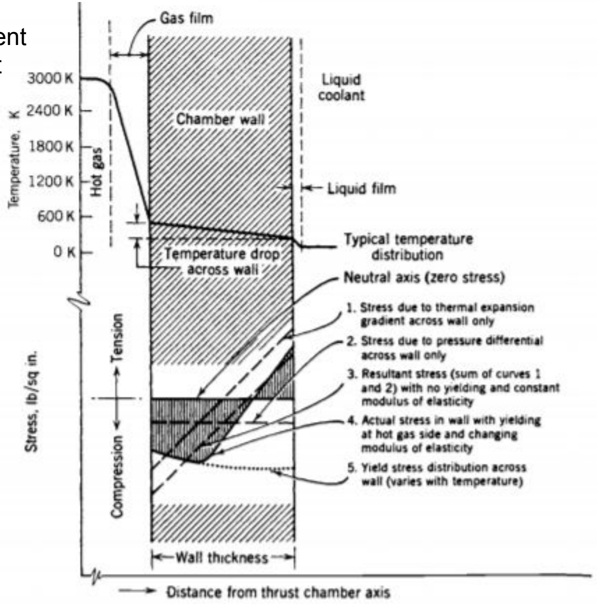


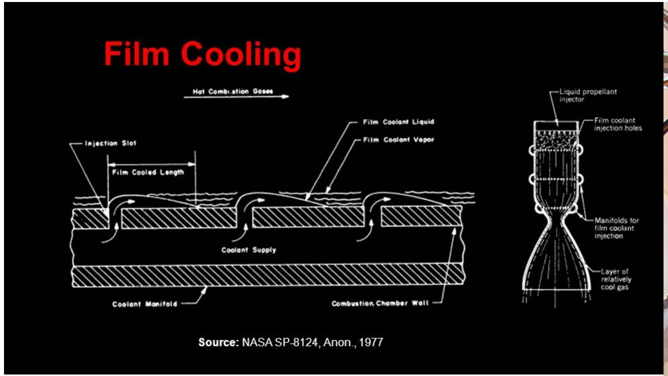
FIGURE 8–12. Typical stresses in a thrust chamber inner wall.

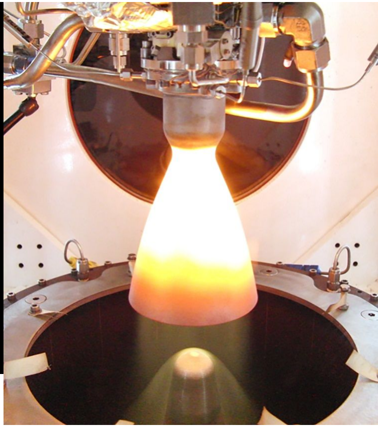
Cooling System Design-Fuel Film Cooling + Radiation

Fuel film cooling works by introducing a thin film of fuel into the combustion chamber wall through orifices found on the periphery of the injector plate. This film is a thermal barrier between the combustion gases and the combustion chamber

Pros: simple

Cons: degrades engine performance





Anika

Cooling System Design - Double Wall Chamber

Hot gas wall cooling by flowing coolant through copper liners

Previous designs: Thor, Jupiter, Atlas, H-1, J-2

Regenerative+film cooling:

Pros:lightweight, efficient, good for long durations, good for larger engine

Cons: in most designs, the combustion-gas-flow cross section is not circular. Therefore, heat flux variation of the gas-side heat-transfer coefficient across each coolant channel may be expected.

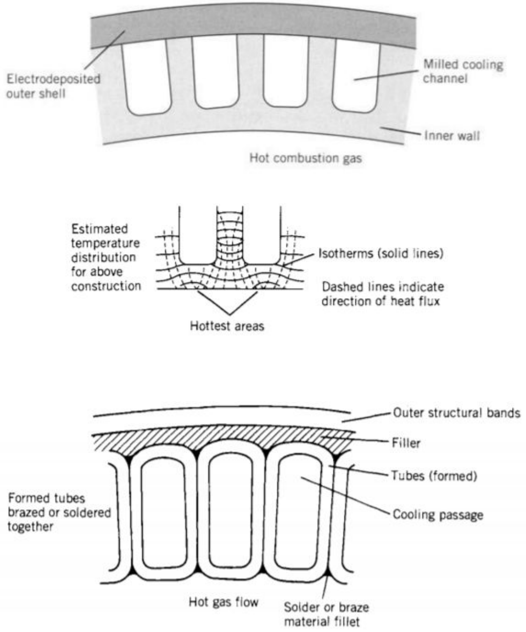


FIGURE 8–17. Enlarged cross section of thrust chamber's regenerative cooling passages for two types of design.

Anika

Future Decisions/Tasks

- Create CAD model of desired cooling system
  - Integrate all parts into one assembly
- Using COMSOL/Solidworks for finite element analysis,obtaining steady-state wall-temperature and heat-flux patterns in the cross section of a rocket thrust-chamber coolant channel
  - With varying elements like thickness and thermal conductivity of channel walls

Concerns and Uncertainties

- Cooling: uncertainty of combustion efficiency and possible errors in thermodynamic and transport properties of the propellant or coolant.
- Cooling: innovation vs. cost-efficiency and manufacturability.
- Combustion Chamber: ensuring the new chamber fits inside current rocket will require several iterations and possible changes to chamber pressure.
- Nozzle: compatibility between the nozzle and the combustion chamber

Rigoberto

Detailed Schedule

Week 6

- Combustion Chamber dimensions should be fully defined.
- Finish nozzle configurations
- Verify injector design with requirements
- Decide on which cooling system will be use

Week 7

- Have a trade study completed for Combustion Chamber material selection
- Research on the possible material for nozzle
- Begin CAD of cooling system

Week 8

- Ensure chosen material for Combustion Chamber can withstand pressures and temperatures.
- Determine the cost of the materials used
- CAD model of injector with analysis

Week 9

- Work with team members to integrate all the components.
- Have a manufacturing process for injector
- Have all analysis completed

Rigoberto