Liquid Fuel Rocket Engine

Portland State Aerospace Society
Senior Capstone Project

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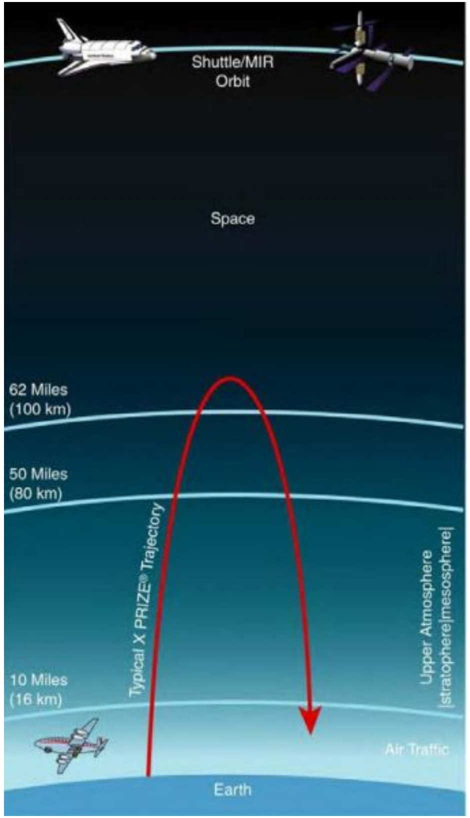
Portland State Aerospace Society (PSAS)

-University Space Race - The Von Karman Line (100km)

-Last Launch Altitude ~5km

-Transition from solid motor to liquid fuel engine to reach 100km

-Open Source - Github



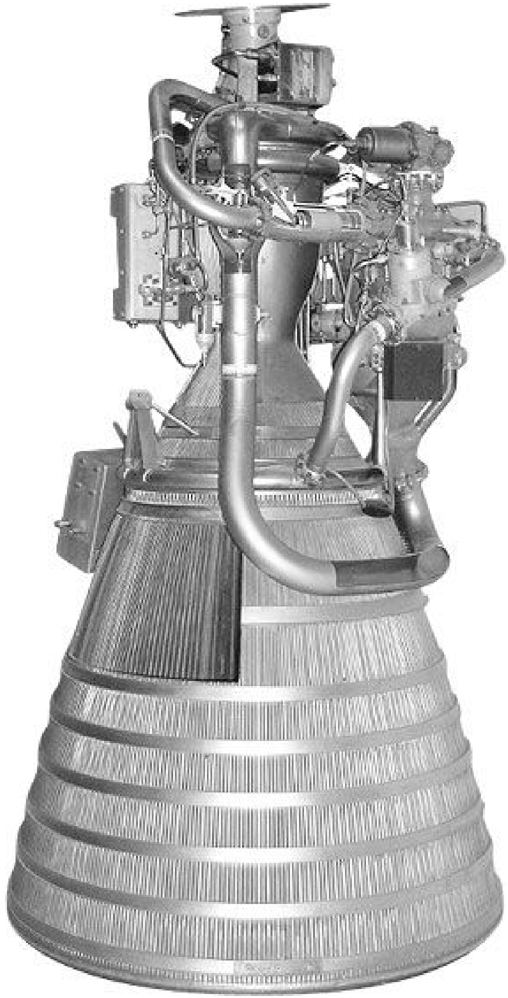
Original Design Criteria

-Design, build and test a prototype static liquid fuel rocket engine with 50 lbf thrust capability

-Use DMLS additive manufacturing technology (3D-Print Direct Metal Laser Sintering)

-Scalable proof of concept design for future engine design iterations

-Develop and document engine design process to provide open source ‘templates’ for future engine designs



External Search and Design Review

-Armor Harris - SpaceX and Boston University Rocket Group

-Robert Watzlavick - Aerospace Engineer

-Peter McCloud - Aerospace Engineer

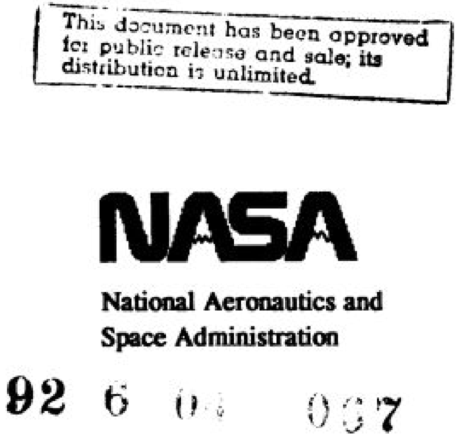
-Oregon Air National Guard - LOX handling

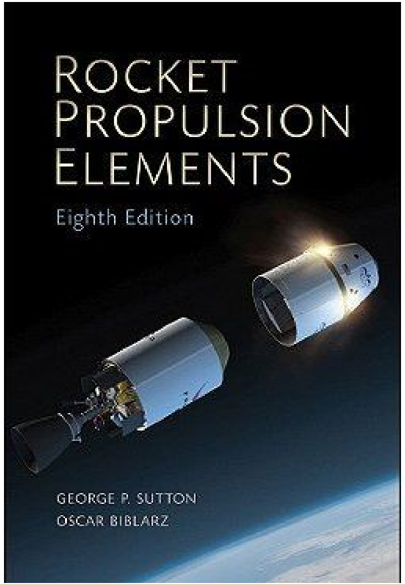
-NASA and AIAA Publications

-aRocket - Amateur rocketry email list

-Reddit - Rocketry Thread

-Erin Schmidt - PSAS





Current Engine Design

-500 lb Thrust

-Static test stand engine

-3D printed in Aluminum (AlSi10Mg)

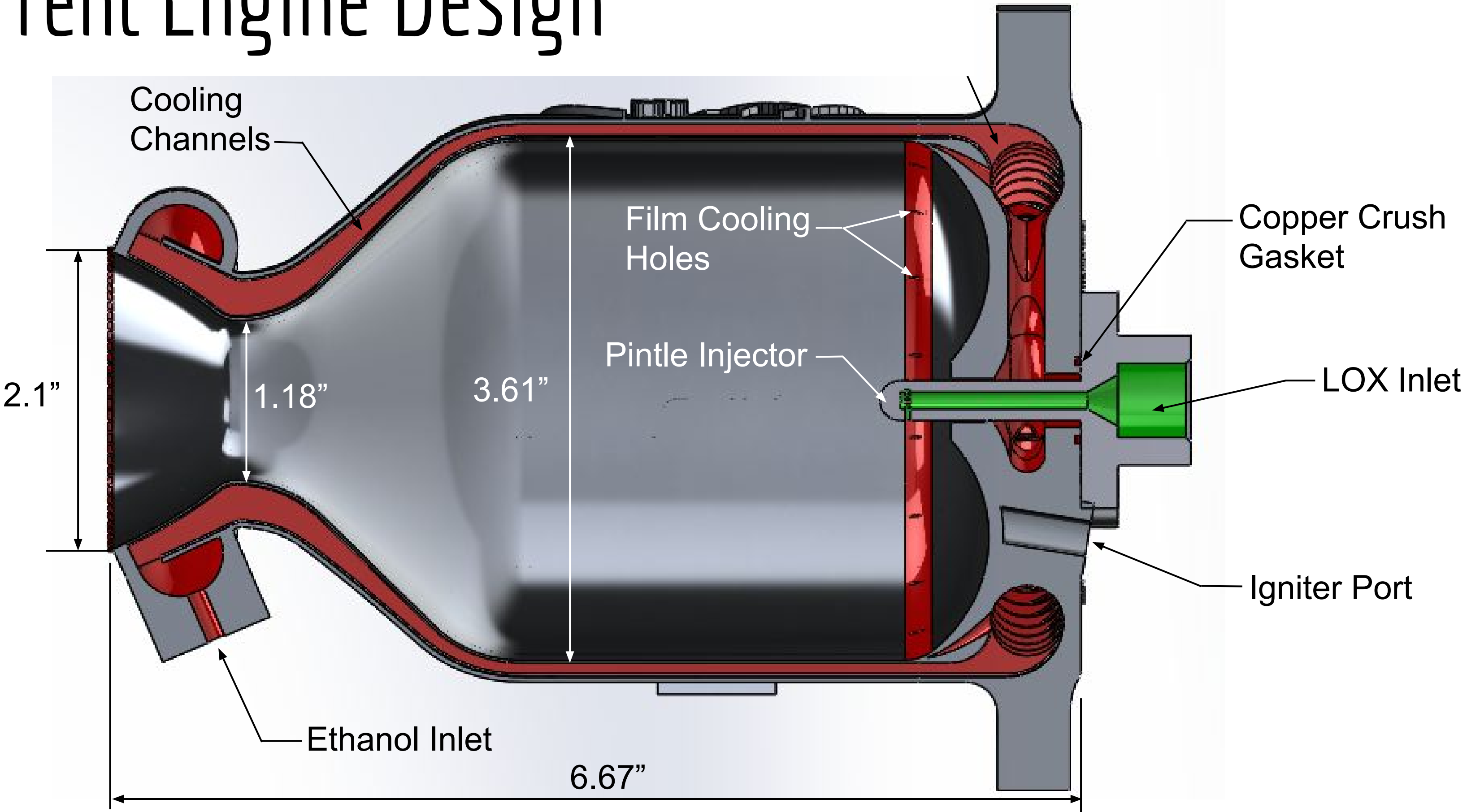
-Ethanol and Liquid Oxygen (LOX) Propellants

-Fuel filled regenerative cooling channels

-Film cooling ports

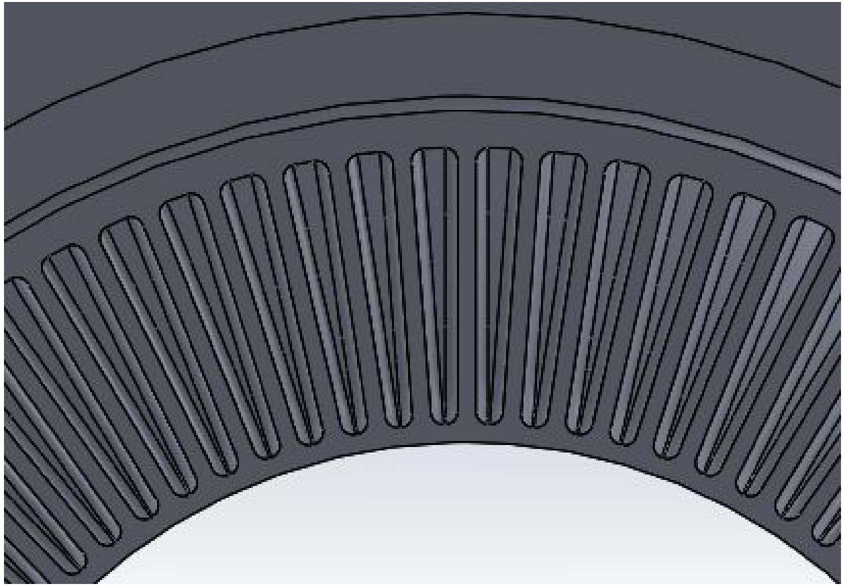
-LOX centered 316 stainless steel pintle injector

Current Engine Design

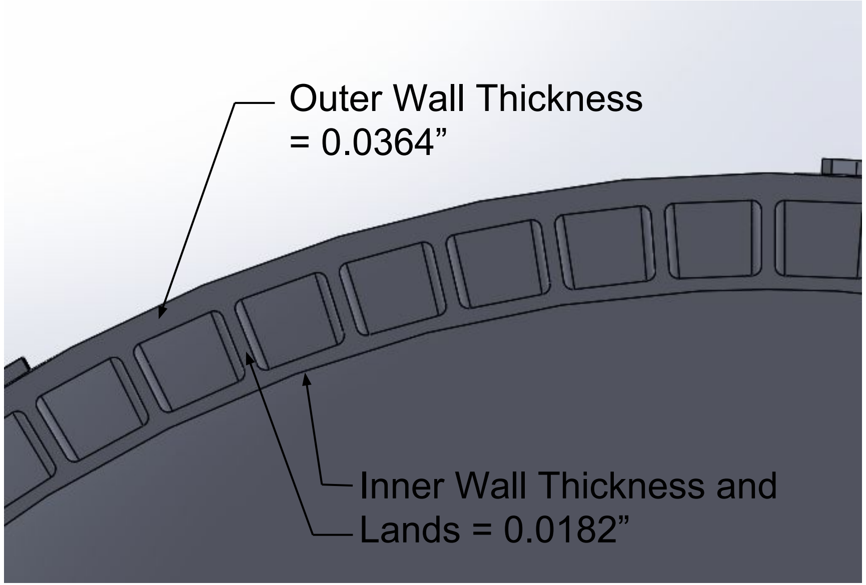


Regenerative Cooling Channels

-Uniform cross sectional area



Cooling Channel Section at Nozzle Throat



Cooling Channel Section at Combustion Chamber

Heat Transfer Analysis and Film Cooling

-Balance between thermal stresses and print resolution

-Flow temperatures approaching 2,782 °C (5,500 °R)

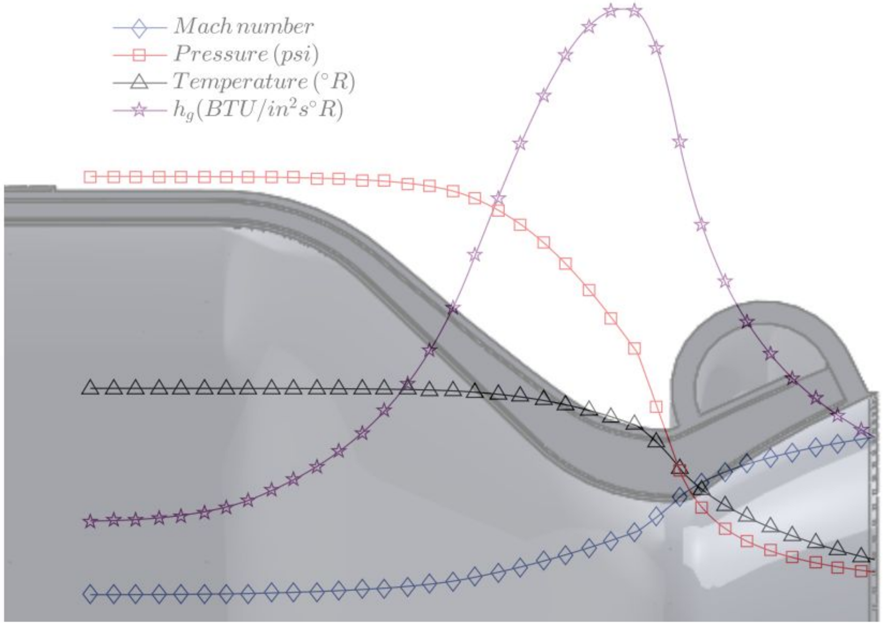


Figure 1: Scaled profiles of the mach number, pressure, temperature and heat transfer coefficient at the wall as a function of x along the length of the nozzle.

Open Source Jupyter (ipython) Design Notebooks

nbviewer.jupyter.org/github/psas/liquid-engine-capstone-2015/blob/master/Nozzle_Construction/LFRE.ipynb

jupyter nbviewer

JUPYTER FAQ

Because the inlet velocity is very small, it is assumed to be zero, this gives the following:

$$V_e = \sqrt{\frac{2g\gamma}{\gamma - 1} R(T_c)_{ns} \left[1 - \left(\frac{P_e}{(P_c)_{ns}}\right)\right]^{\frac{\gamma-1}{\gamma}}}$$

which is dependent on the propellants, chamber pressure which should be chosen for the design, P_i, and the mach number at the nozzle inlet, Mi, which must be calculated iteratively.

Pressure at the exit, Pe, of a test nozzle should be expanded to the pressure of testing conditions (assumed to be sea-level atmospheric pressure).

Flame temperature and gamma can be obtained for a given propellant combination by using NASA's CEArun tool. link to portion in document which describes how to use cearun

The propellent mixture ratio, can be used to manipulate flame temperature as well as cooling capacity. Increasing fuel; and thereby decreasing rw, will result in lower temperatures and more coolant mass flow-rate. CEArun should be used to determine the effect of a given mixture ratio.

Things to add to this section: choosing OF ratios, (maximize theoretical specific impulse, balance with temperature limits, increases in oxidizer tend to lead to higher temperatures. selecting chamber pressures should be dependent on material limits, impulse tends to increase with increases in pressure, more enthalpy is available to convert to exhaust velocity, higher pressures generally result in higher temperatures.

define constants to be used in mathmatics. discuss gas constants and their calculations.

discuss each parameter as well as nomenclature, what does inj, inlet, throat, or exit mean, show locations in diagrams.

In [1142]:

```
import math
from mpmath import *
from IPython.display import display
from ipywidgets import widgets

#Define Constants
g     = 32.2  # gravitational constant in ft/s^2
J     = 778   # Energy conversion factor (ft-lb/Btu)
Regas = 1544  # Gas constant (ft/degR)
```

Pintle Injectors

-Less combustion instability

-Simpler manufacturing

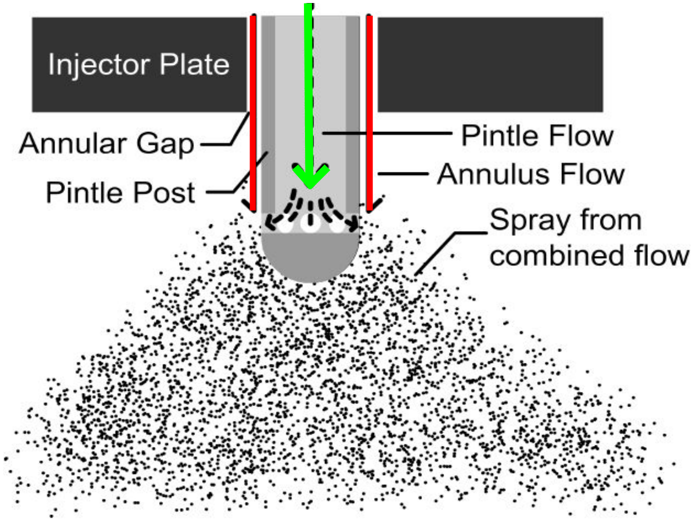
-Easier to replace and redesign

-Throttleable

-Spray angle is a function of the Total Momentum Ratio (TMR)

$$TMR = \frac{\dot{m}U_{inner}}{\dot{m}U_{outer}}$$

Pintle Injector



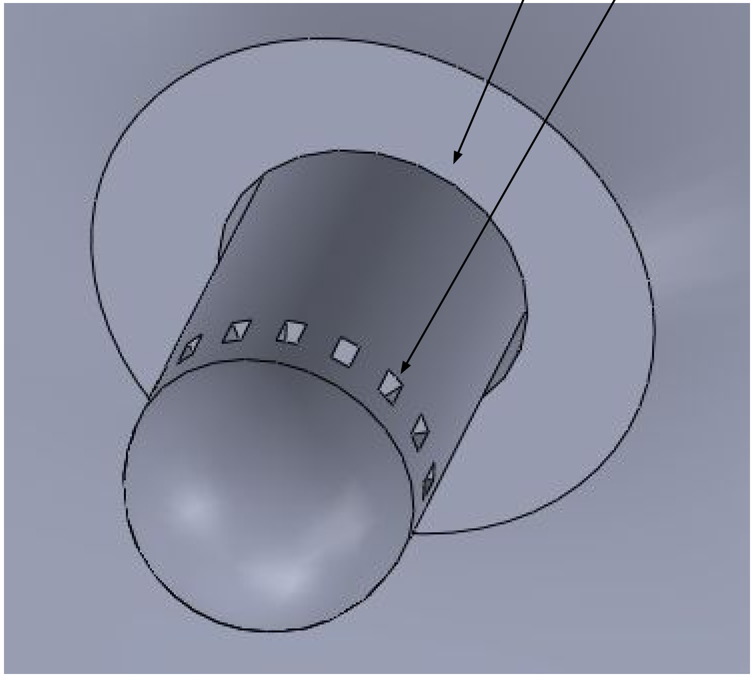
https://www.reddit.com/r/space/comments/1jtt1m/100_percent_throttle_test_of_the_common/

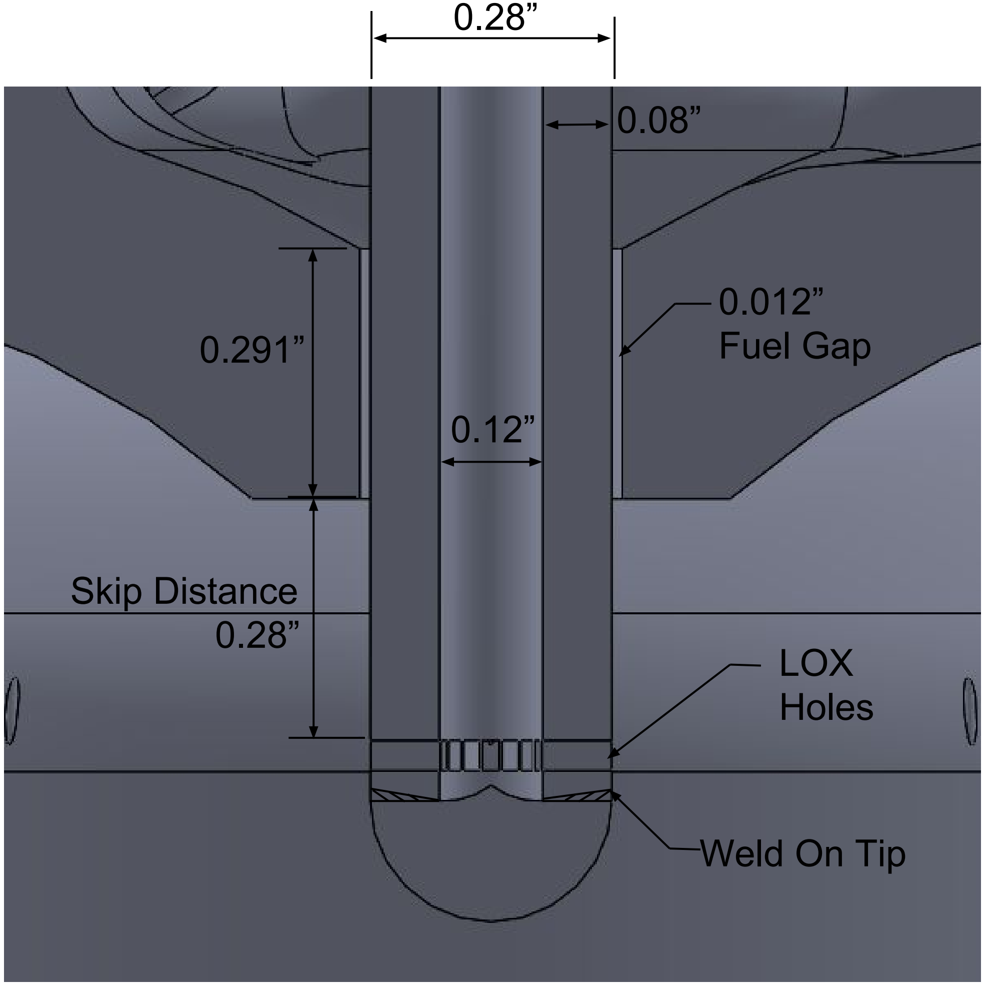
Impinging Plate Injector

http://www.thefintels.com/aer/biprop1.htm

Pintle Injector Design

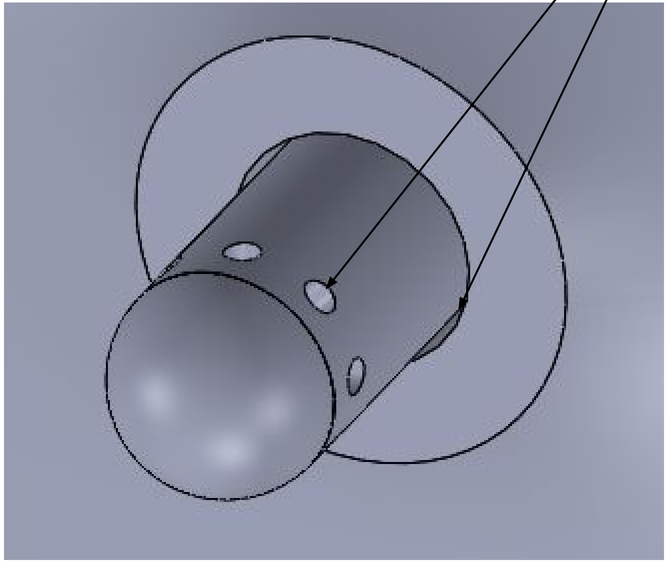
LOX Holes (16 total) = 0.02” x 0.035”
Ethanol annulus gap = 0.012”

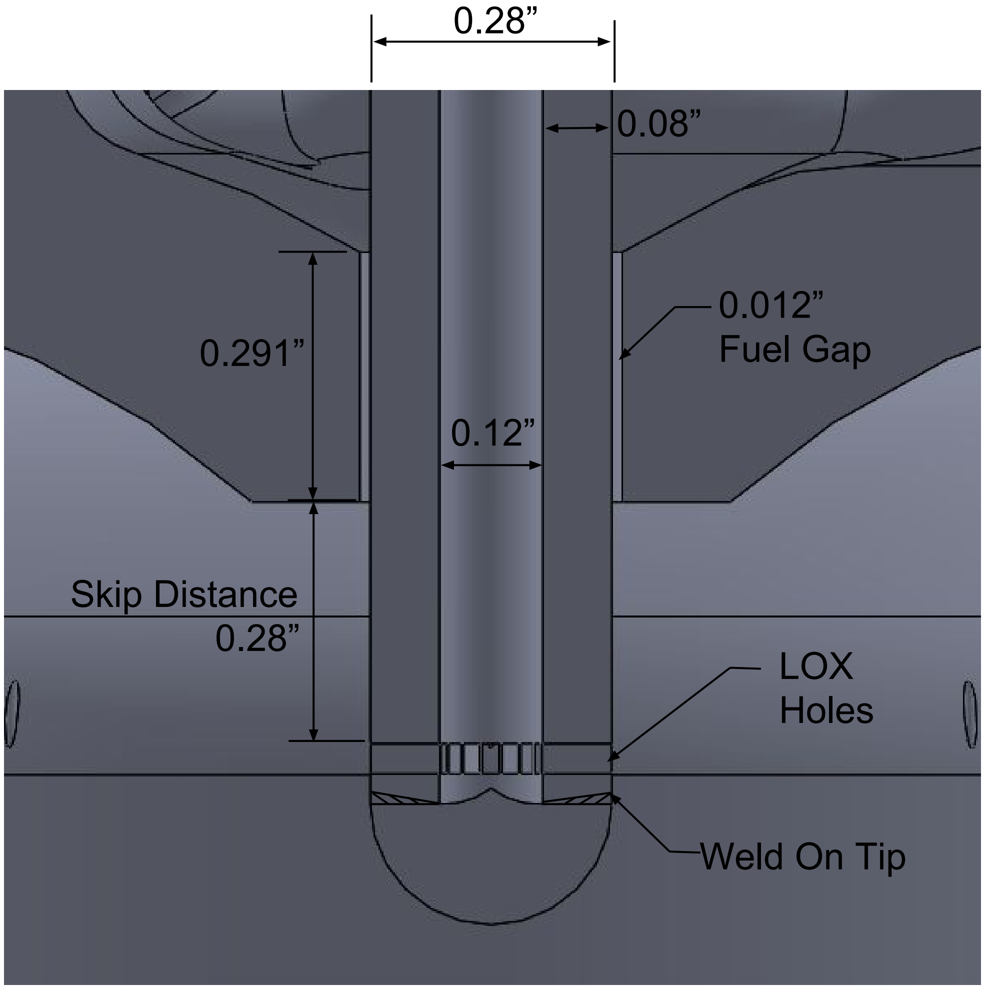




Pintle Injector Design

Fuel Annulus Gap = 0.012”
LOX Holes (8 total) = 0.045” dia.



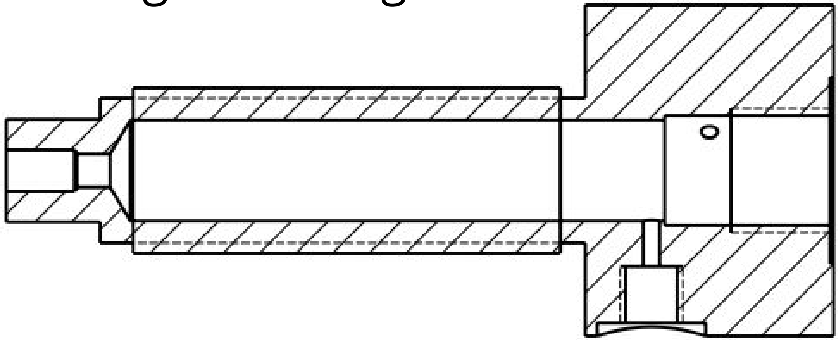


Torch Spark Igniter

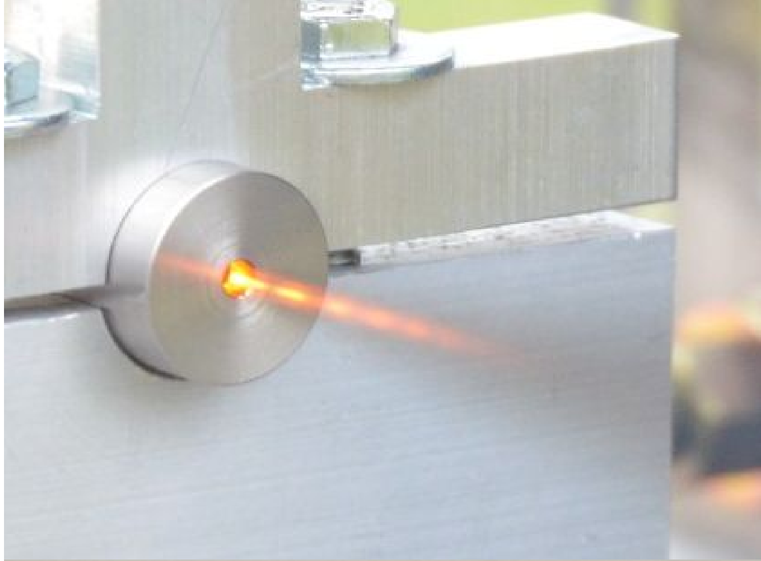
-Based on Robert Watzlavick's Design

-Uses existing fuel (ethanol) and gaseous oxygen (GOX) tapped off the LOX line

-Allows for increased safety and automated repeated firing of the engine



http://www.watzlavick.com/robert/rocket

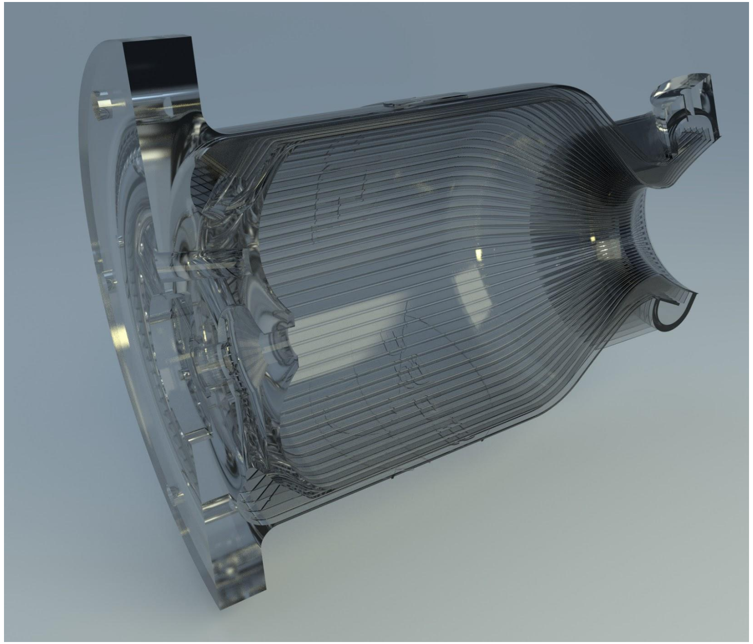


Liquid Oxygen (LOX) Handling

Boils at -283 °C at 101 kPa

Cool Images!

https://sketchfab.com/models/ce8a3ff7d1e2417f9e614df5d085f7b0



https://www.flickr.com/photos/pdxaerospace/27452770590/

Ongoing Projects

-Manufacture injector

-Cold flow test injector

-Test pressure loss in cooling channels

-Manufacture and test igniter

-FEA and CFD model validation

-Fire the Engine!

Questions?

Thank you to all our supporters!

-i3D Manufacturing
-Portland State Aerospace Society
-Derek Tretheway
-Andrew Greenberg
-Armor Harris
-Robert Watzlavick
-Peter McCloud
-Erin Schmidt

Image References

http://psas.pdx.edu/
http://www.mrziegler.com/images/XPrizeTrajectory.jpg
https://www.asme.org/about-asme/who-we-are/engineering-history/landmarks/36-rl-10-rocket-engine
http://i.imgur.com/DfAMi2F.png
http://www.thefintels.com/aer/biprop1.htm
http://www.watzlavick.com/robert/rocket
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