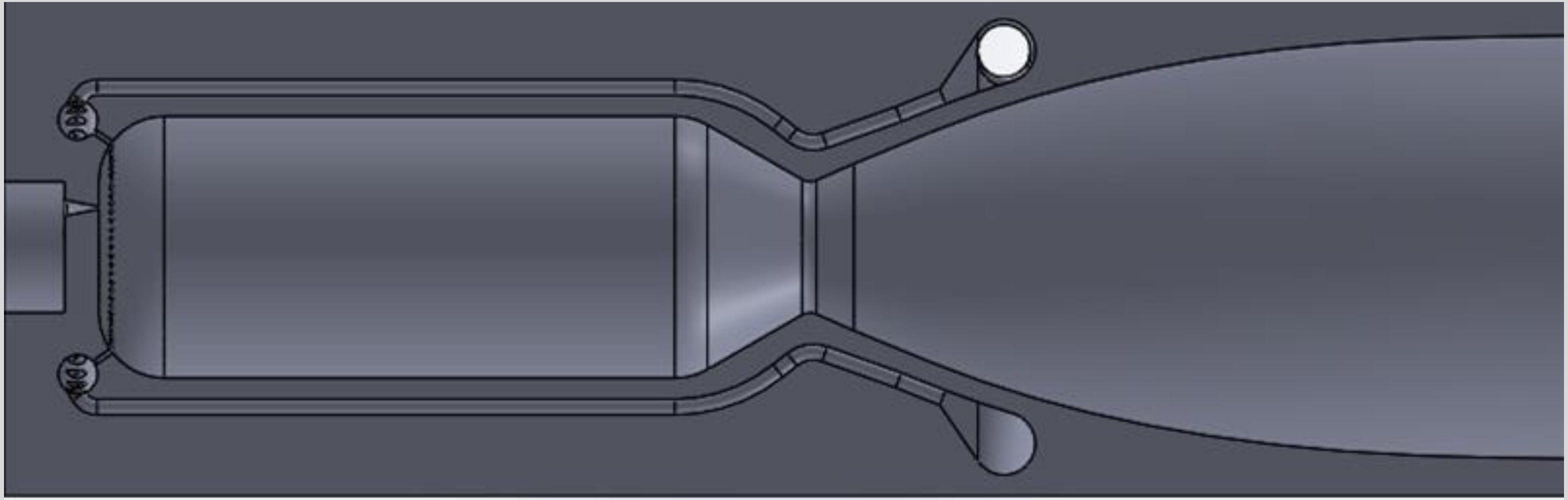


Fluid Engine Design Review

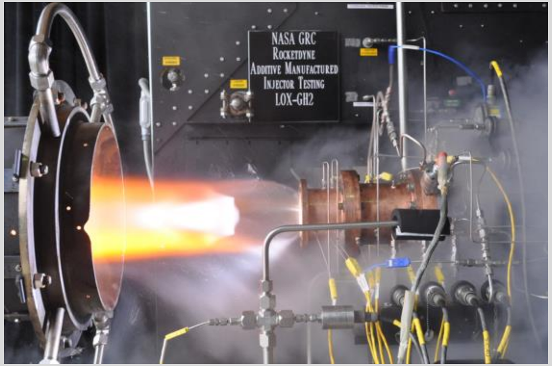
Justin Stanton, Mario Reillo, Lucas Verge, David Estrada-Echegaray,
Connor McBride, Franco Spadoni

Outline

- Objectives
- Calculations/Simulations
- Overview
- Thrust chamber
- Tanks
- Valves
- Bill of Materials
- What is next?

Objectives

- Compete in IREC
  - Deliver 10 lb payload to 10000 ft
  - Fully recover in flyable state
- Be the Safest Team at Competition
- Be the first successful liquid rocket engine at competition
- Be the first 3D printed thrust chamber to fly
- Have fun



Aerojet 3D printed thrust chamber test fire

Similar Systems

- Smart rocket German team from Space Systems at TUD (test engine intended for flight)
- Robert’s rockets (test engine)
- Aerojet-Rocketdyne class (educational rocket)
- University of Florida (compare control system and non engine components)

Space Systems Logo

https://tu-dresden.de/die_tu_dresden/fakultaeten/fakultaet_maschinenwesen/ilr/rfs/forschung/folder.2007-08-

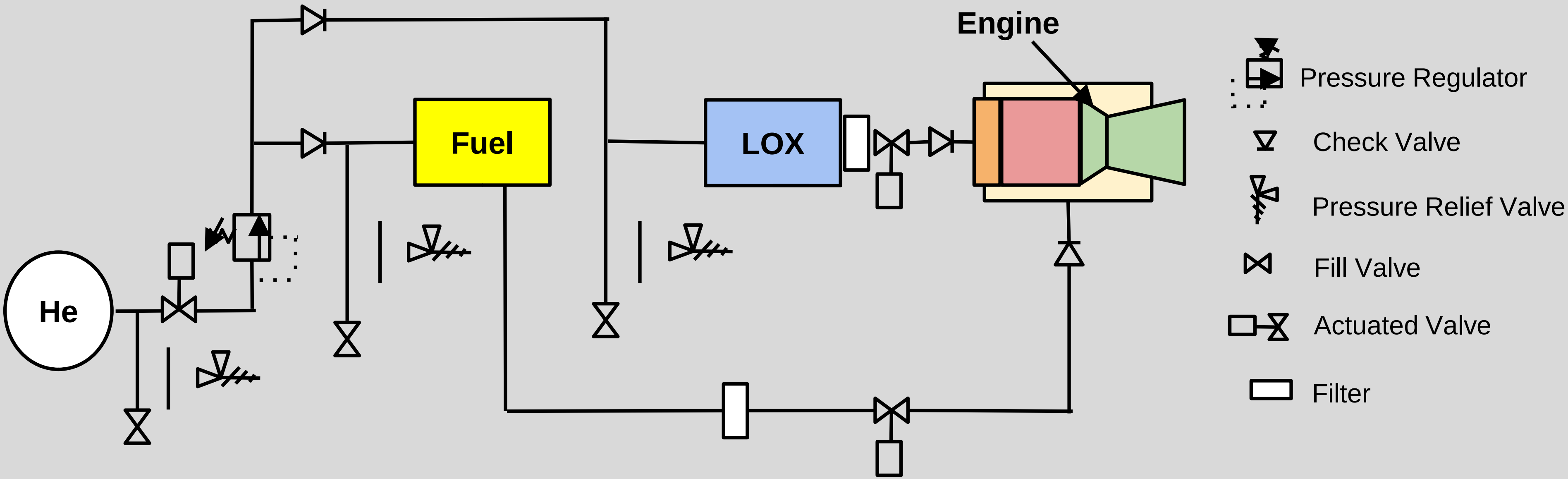
Roberts 250lb Rocket

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

UF Team Logo

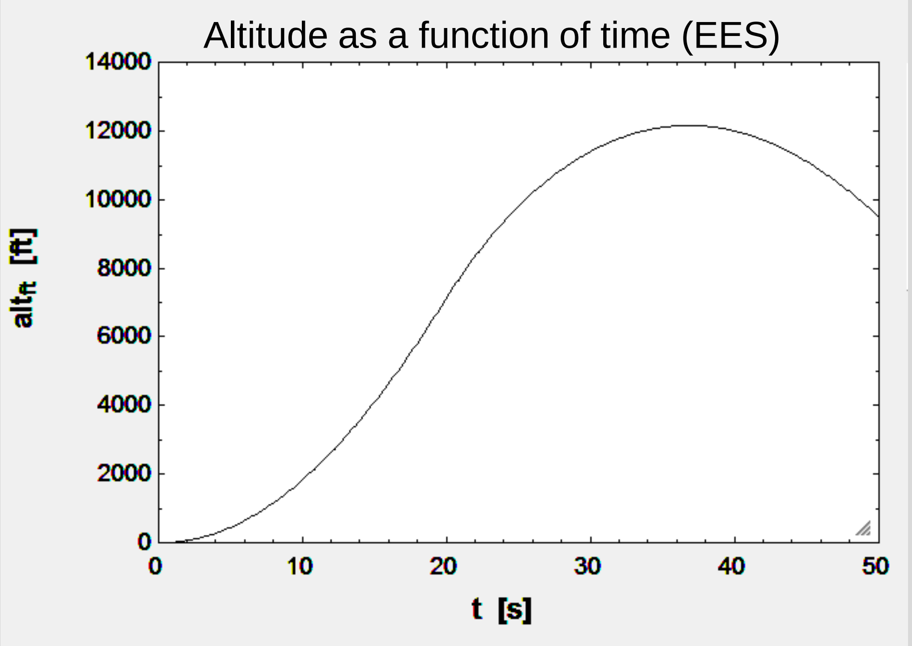
http://www.ufrocketteam.com/

System Diagram



Design Objectives

Requirements
Safe flight at competition
Design for rapid manufacturing
Budget of $3000



Flight Parameters

- Optimized for final mass and altitude of 10000 ft (AGL)
- Standard atmospheric conditions
- Isentropic conditions through throat and nozzle
- Will stay subsonic to simplify design
- Constant mass flow rate
- Mixing ratio of 1
- Choked flow at throat
- Chamber pressure of 1.5 MPa and temperature of 2757 K
- Tank diameter of 15 cm

Unit Settings: SI K Pa J mass deg

Variable±Uncertainty

$\dot{m}$ = 0.3285±0.1642 [kg/s]

$burn_{time}$ = 12±4 [s]

ThroatDiameter = 0.8±0.2 [in]

Thrust = 1426±746.7 [N]

$burn_{time}$ = 12±4 [s]

ThroatDiameter = 0.8±0.2 [in]

$Volume_{Ethanol}$ = 2.444±1.469 [L]

$burn_{time}$ = 12±4 [s]

ThroatDiameter = 0.8±0.2 [in]

$Volume_{Oxygen}$ = 1.726±1.037 [L]

$burn_{time}$ = 12±4 [s]

ThroatDiameter = 0.8±0.2 [in]

No unit problems were detected.

Improvements

- Combustion chamber sizing for calculations
- High pressure tank calcs
- Fuel tank and Ox tank models
- Line pressure models
- Integrating models

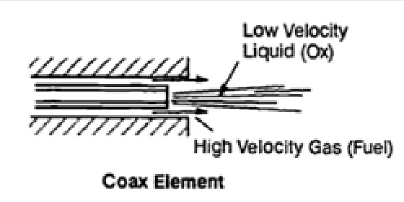
Fluid Thrust Chamber and Gas Feed System

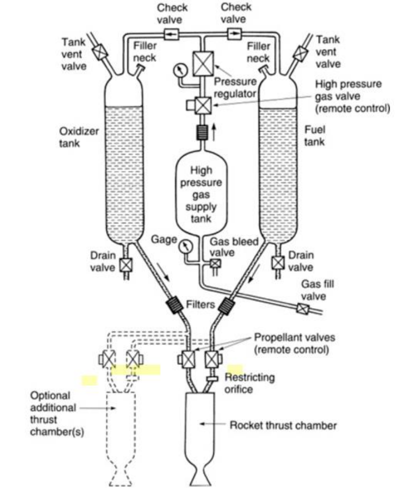
First Choices
- Injector: Coax Element
- Cooling System: Regenerative Cooling
- Thrust Chamber Material: C-103

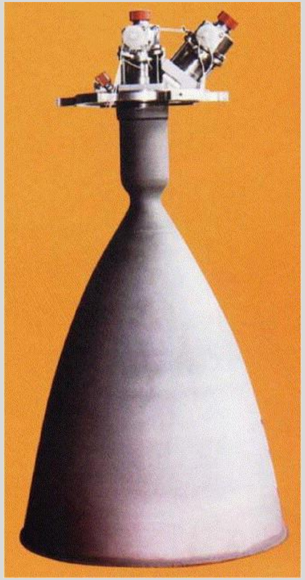
Gas Pressure Regulator
- Mixture ratio constant
- Constant Pressure

Helium
- Inert gas
- Won’t form a liquid-liquid mixture with LOX

Advantages
- Thrust does not decreases throughout burn
- More accurate mixture ratio







Piping, Tanks, and Valves

Copper Tubing

- Easy to work with
- Easy to obtain
- Can be used with O2 and ethanol

LOX Tank

- Medical Oxygen Tank
- O2 Approved
- Custom Tank
- Needs Gas in, O2 out

Piping, Tanks, and Valves

Ethanol Tank

- Custom Aluminum Tank
- Does not need to be O2 Approved

Helium Tank

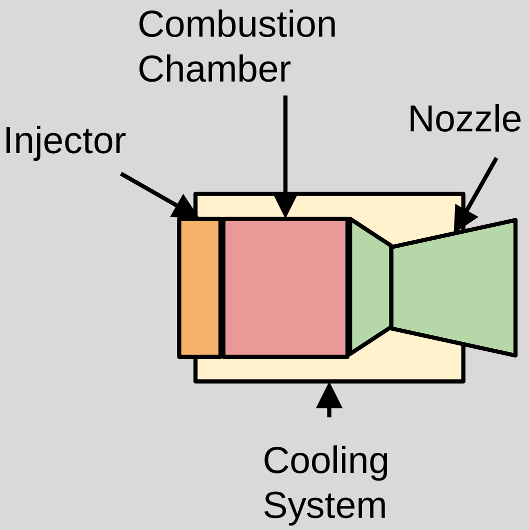
- Highest Pressure (10-30 MPa)
- Composite Materials (light weight)
- Does not need
  to be O2 Approved

Design Considerations for valves

- High Pressure (Ethanol/LOX/Helium)
- Cryogenic (LOX)
- O2 Approved (LOX)

Thrust Chamber Components

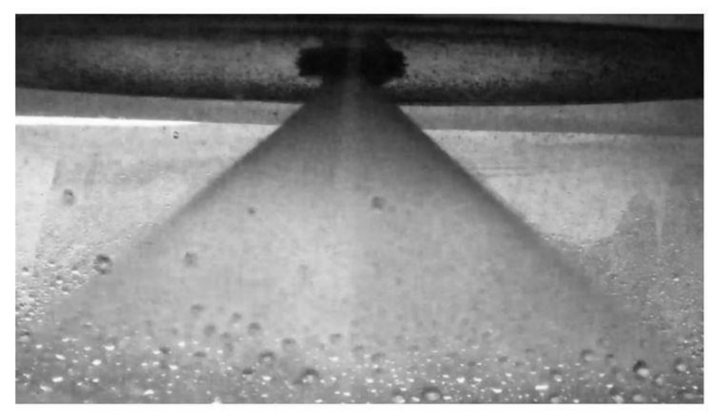
- Injector
  - Mix Fuel and Oxidizer
- Combustion Chamber
  - Fully mix and combust
  - Increase Pressure and Temperature
- Nozzle
  - Convert Chemical Energy to Kinetic Energy
  - Converging Sonic Section
  - Diverging Supersonic Section
- Cooling System
  - Prevent thermal failure
  - Increase life of engine



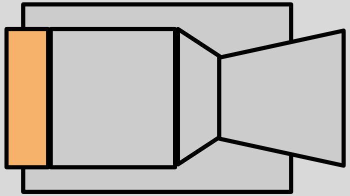
Basic layout of rocket engine

Injector Design

- Commercial injectors
- Testing custom design
  - 3D print various geometries
  - Pressurized water spray test
    - Spray pattern
    - Determine Discharge Coefficient
    - $Q=C_DA(2\Delta P/\rho)^{1/2}$
  - Live Fire Test
    - Determine Flame Temperature
- Current Designs Concepts
  - Coaxial injector
  - Conical injector
  - Double impinging
  - Fan spray

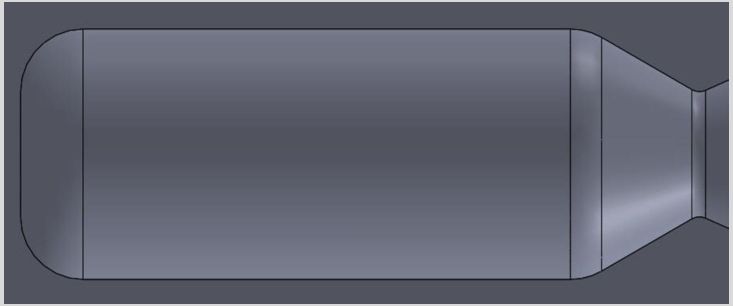


Water test for DLR STERN smart rocket ethanol injector

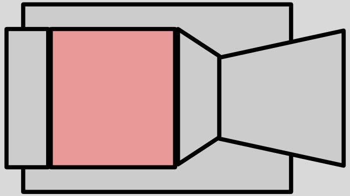


Combustion Chamber Design

- Length based on the characteristic length L* = 0.75m
  - Table 4.1 Design of Liquid Propellant Rocket Engines
  - CFD simulations
- Contraction area ratio $A_c/A_t = 4$
  - Recommended for pressure feed systems

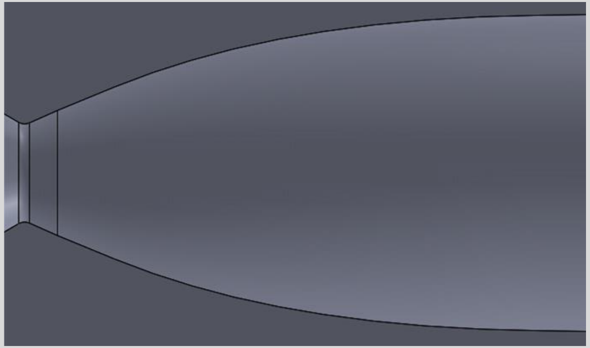


http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19710019929.pdf



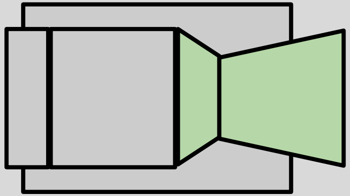
Nozzle Design

- Optimized using 2D MOC matlab code developed at Stanford
  - Assumptions Determined in RPA
    - T combustion = 2400 K
    - P combustion = 1.5 MPa
    - P design = 80 kPa
    - ɣ = 1.22
    - Molecular weight = 20 kg/kmol
    - throat height = 2.5 cm
- Thrust at design pressure ~ 1 kN
  - Assumptions
    - mass flow is 0.44 kg/s



http://www.mathworks.com/matlabcentral/fileexchange/14682-2-d-nozzle-design

http://www.propulsion-analysis.com/



Cooling System Design

- Regenerative cooling with ethanol
  - Tubular cooling jacket
  - Transportation cooling in nozzle region
  - Nucleate boiling
- Wall thickness
  - Thin walled pressure vessel
  - Heat transfer rate

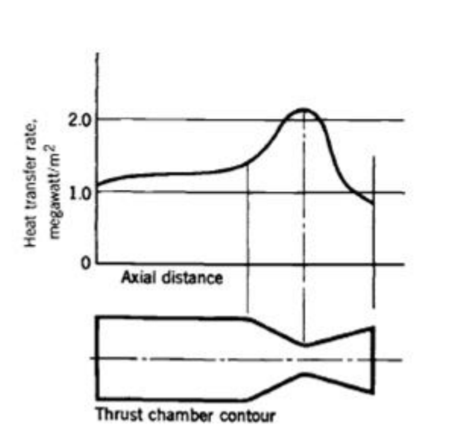
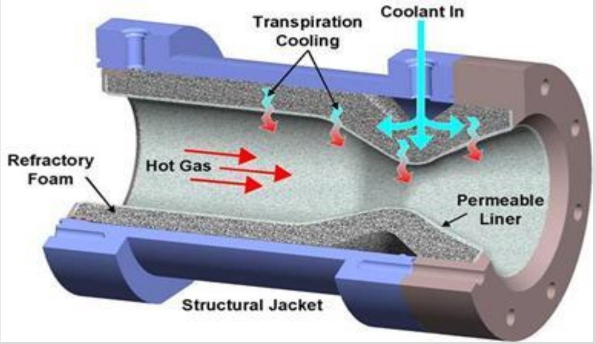


Fig 8-8 Heat transfer vs axial position



Transportation cooling ULTRAMET

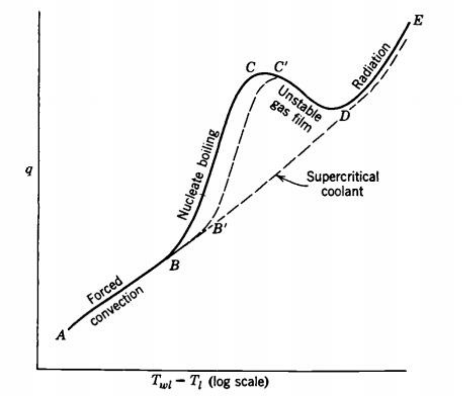
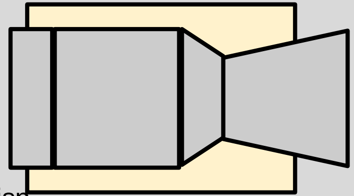


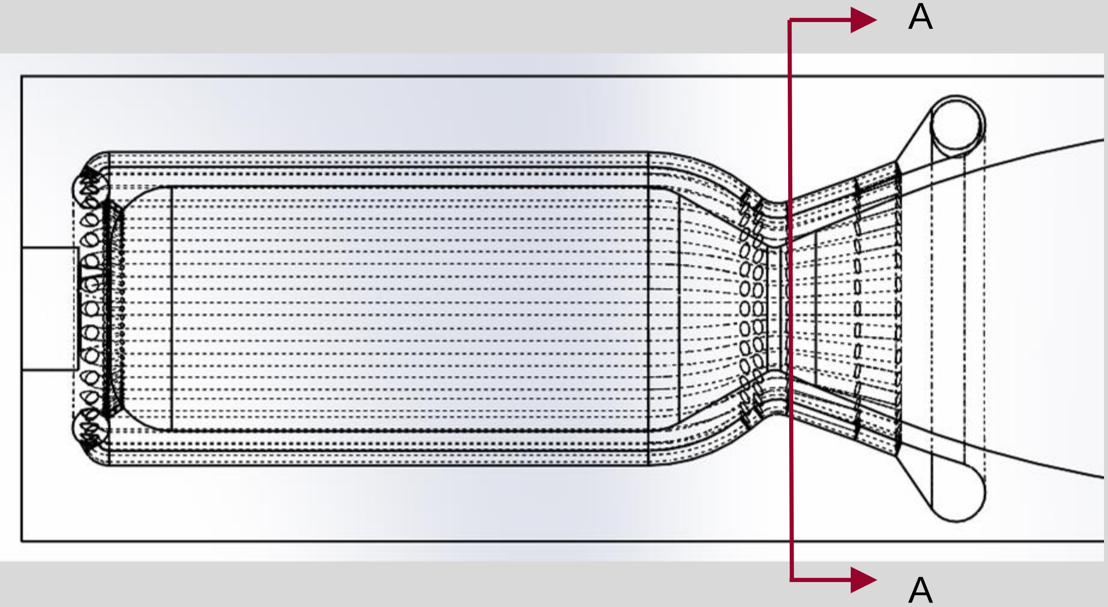
Fig 8-21 Heat transfer vs Twall - Tbulk

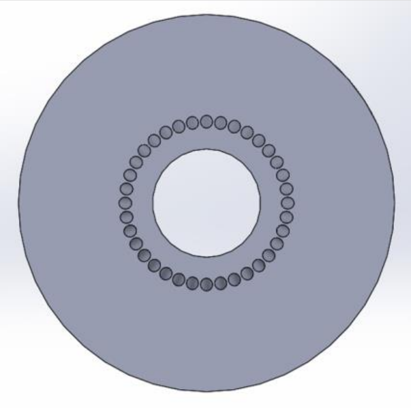


Life Enhancing Design http://ntrs.nasa.gov/search.jsp

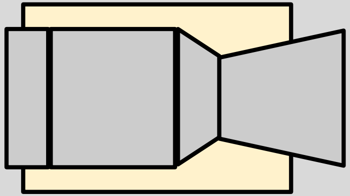
Cooling System Design

- Regenerative cooling with ethanol
  - Axial tubular cooling jacket
  - Circumferential tubular jacket





Section A-A axial cooling jacket



Manufacturing Paths

Additive Manufacturing

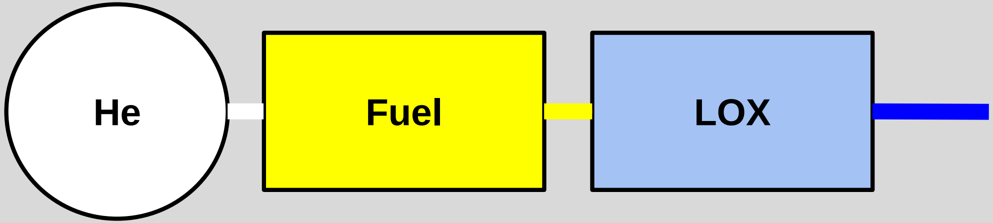
Selective Laser Sintering

Subtractive Manufacturing

HAAS CNC Mill

Parts Selection

- Tanks
  - He
  - LOx
  - Ethanol
- Valving
  - Actuated Valves
  - Check Valves
  - Fill Valves
  - Pressure relief
  - Regulator
- Piping
  - Material
  - Fitting
- Bill of Materials

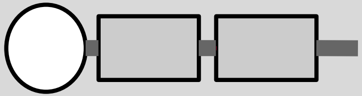


Tanks - Helium

- Helium
  - 1000~3000 psi (7-21 MPa)
- Ninja Carbon Fiber Paintball tank
  - Volume: 1 L (.001 m^3)
  - Max pressure 4500 psi (31 MPa)
  - Empty Weight 2.6 lbs (1.18 kg)
  - Max output pressure 850 psi (5.9 MPa)
  - $165
- Additional Considerations
  - Total mass of He
  - Head loss

Ninja paintball tank

Image from ANS Gear

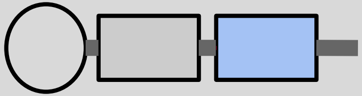


Tanks - LOX

- LOX
  - Mass flow rate = 0.175 kg/s
  - Burn time = 11 s
  - Volume burned = 1.75 L (.00175 m^3)
  - Operating pressure 350-700 psi (2.4-4.8 MPa)
- Al Medical Oxygen Tank Size "C"
  - Volume 3.8 L (.0038 m^3)
  - Max Pressure 2015 psi (13.9 MPa)
  - Dimensions 4.38"x10.9" (111x277 mm)
  - Empty weight 3.7 lbs (1.7 kg)
  - $58
- Insulation
  - Cryogel insulating blanket

Size C medical oxygen tank
Worldwide EMS Equipment Sales

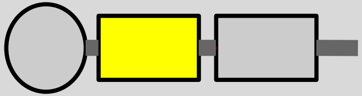
Cryogel (Freeze dried aerogel)



Tanks - Ethanol

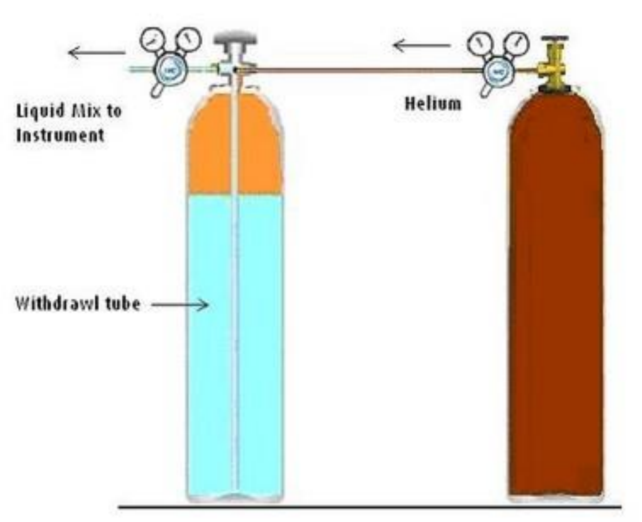
- Ethanol
  - Mass flow rate = 0.175 kg/s
  - Burn time = 11 s
  - Volume burned = 2.4 L (.00241 m^3)
  - Operating pressure 350-700 psi
    (2.4-4.8 MPa)
- Al Medical Oxygen Tank Size “C”
  - Volume 3.8 L (.0038 m^3)
  - Max Pressure 2015 psi (13.9 MPa)
  - Dimensions 4.38”x10.9”
    (111x277 mm)
  - Empty weight 3.7 lbs (1.7 kg)
  - $58

Size C medical oxygen tank
Worldwide EMS Equipment Sales

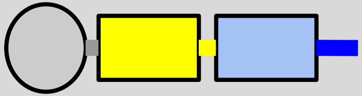


Tanks - Access Ports

- Dual Port Fittings
  - Allows tanks with a single access port
  - O_2 rated
  - Pressure tested
  - Purchase
  - Build

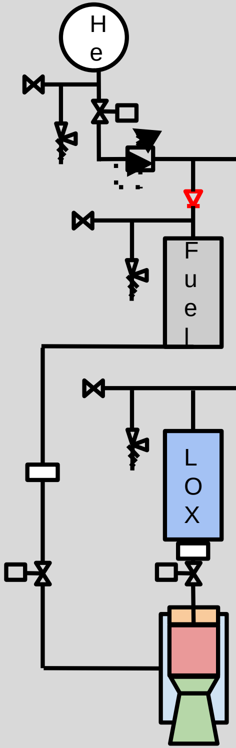


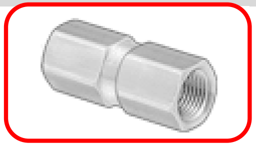
http://muniche.linde.com/



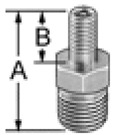
Valve Overview

- Check Valves x 2
  - Only allows one direction of flow
- Fill Valves x 3
  - Feeds fuel into tanks
- Actuated Valves x 3
  - Valves which must be opened to allow flow
- Pressure Relief Valves x 3
  - Limits the pressure supplied to our tanks
- Pressure Regulator x 1
  - Automatically cuts off the flow at a specified pressure





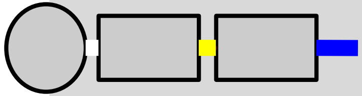
Check Valve
McMaster 8549T32



Fill Valve
McMaster 8063K38

Pressure Relief Valve
McMaster 5027K11

Pressure Regulator
McMaster 3811T11



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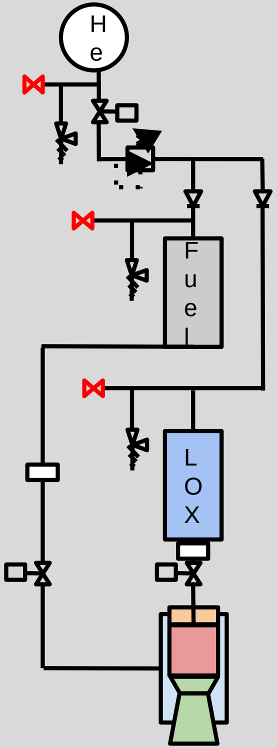

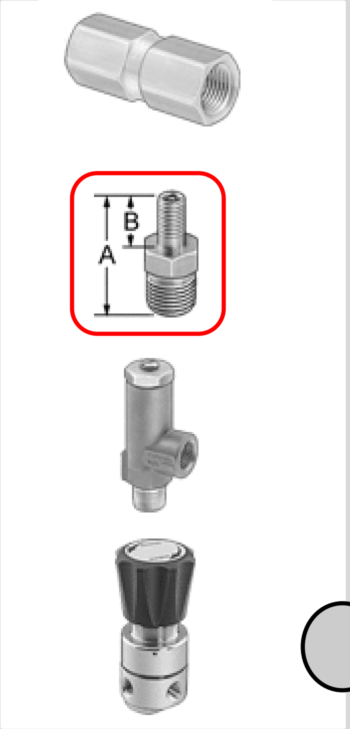

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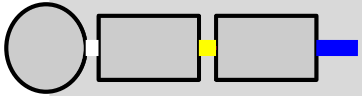

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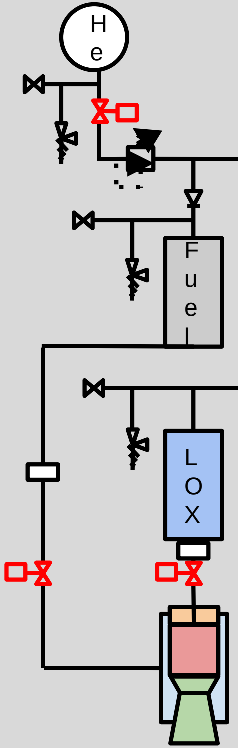
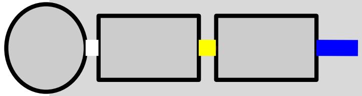


Check Valve
McMaster 8549T32

Actuated Valve
McMaster 47865K53

Pressure Relief Valve
McMaster 5027K11

Pressure Regulator
McMaster 3811T11



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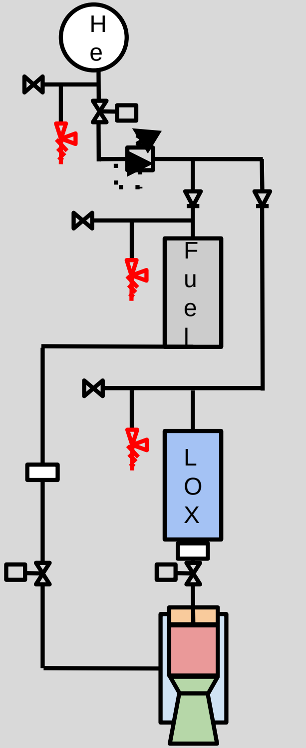

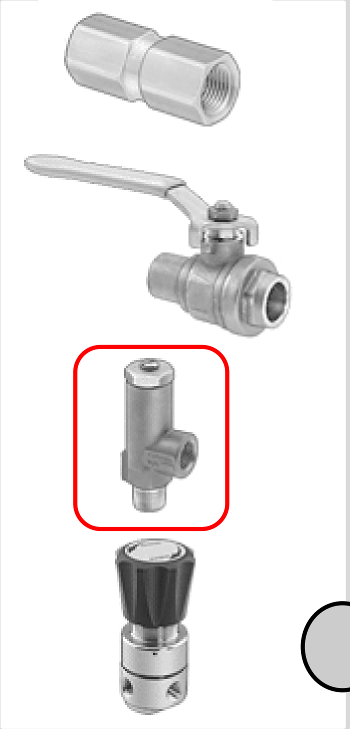

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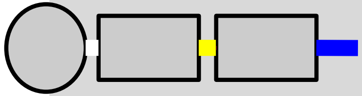

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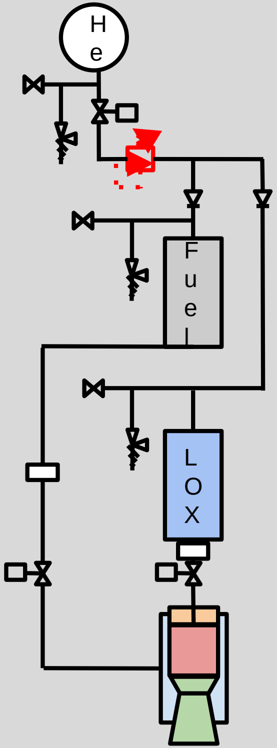

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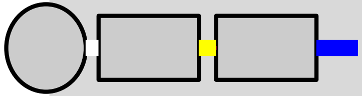
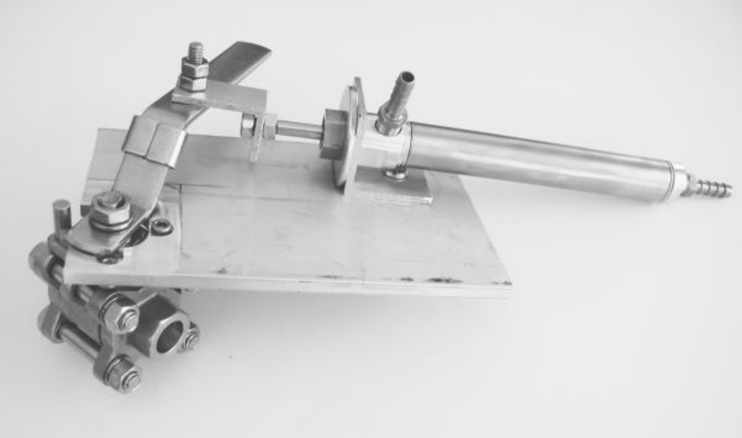
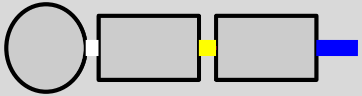


Valve Actuation

- Need a system that can open our actuated valves at launch
- Options
  - Electronic
    - need 24V or 120V to actuate available valves
    - electronic control system within rocket will operate on a 9V battery
    - other option is umbilical system connected to sufficient power source
  - Pneumatic
    - incorporate pneumatic piston system attached to helium supply to actuate flanged valve
  - Cost benefit analysis



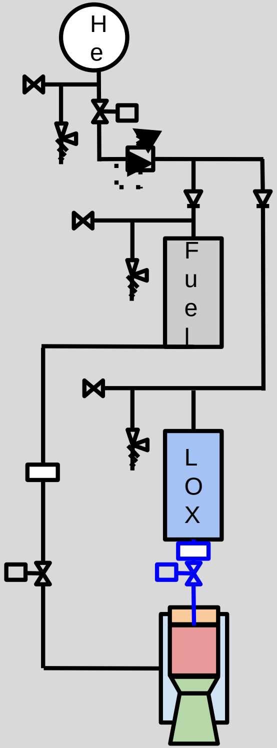
http://watzlavick.com/robert/rocket/testStand/airValvePic.jpg



Cryogenic Valve

- Components in blue need to endure cryogenic temperatures
  - Need cryogenic actuated valve
  - Cryogenic components tend to be far more expensive
- McMaster 68075K83
  - 1/2": 600 psi @ 150° F
  - Temp. Range: -320° to 150° F
  - $72.83
  - Only issue is that it’s a handwheel manual valve
    - Will be difficult to actuate with pneumatic piston

http://www.mcmaster.com/#catalog/121/480/=w6sphp



Bill of Materials

To be finalized by Wednesday (3/11/15) -> Purchasing orders in by Friday (3/13/15)

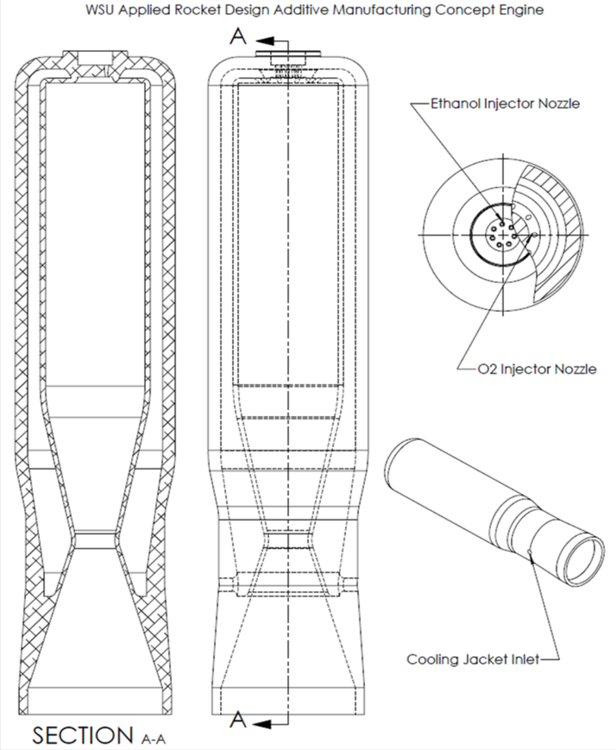
General							
Parts List	Quantity	Material	Total Cost	Supplier	Specs		Link/Part #
Actuated Valve	2	Stainless Steel	$18.00	McMaster	500 psi	1/2" flanged	47865K53
Piping	Length=??	Brass	$207.24	McMaster	male-male	1/2" w/ sealant 1000 psi	50785K211
He Tank	1	Carbon Fiber	$165.00	Ninja Paintball	4500 psi, 2 L	4" diam, 10.5" L	Link
LOx Tank	1	Aluminum	$83.00	Worldwide EMS	2015 psi, 4.6L Vol	4.38x25.4" 7.8 lbs	Link
Eth Tank	1	Aluminum	$83.00	Worldwide EMS	2015 psi, 4.6L Vol	4.38x25.4" 7.8 lbs	Link
Check Valve	2	Brass	$44.22	McMaster	female-female	1/2" 500 psi	7768K54
Pressure Regulator	1	Brass	$270.98	McMaster	500 psi outlet, 3500 psi inlet		3811T11
Fill Valve	3			potentially available through on campus resource?			
Pressure Relief	3	Stainless Steel	$874.74	McMaster	1/2" 40-250 F		5027K11
		Total Cost	$1,819.01	doesn't include shell, parachute, electrical components, fittings,			
Cryogenic				pneumatic pistons/voltage source and wiring for valve actuation			
Parts List	Quantity	Material	Total Cost	Supplier	Specs		Link/Part #
Actuated Valve	1	Brass	$72.83	McMaster	600 psi	1/2" manual wheel	68075K83

What's Next

- Building
  - Nozzle / Combustion chamber
    - 3D- printed
    - Machined
  - Injector
    - Multiple designs
  - Test Stand
    - Collaborative effort

- Testing
  - Specific processes to be determined
  - Test injector designs with water

- Redesign
  - Corrected parameters



What’s Next: Nozzle

- Nozzle Prototype
  - Practice machining
  - Half sized
  - Heat sink

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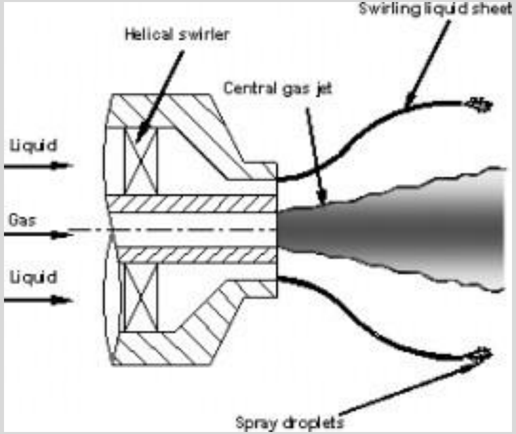
What's Next: Injectors

- Injectors
  - Like Impinging Doublet
  - Shower head
  - Coax element



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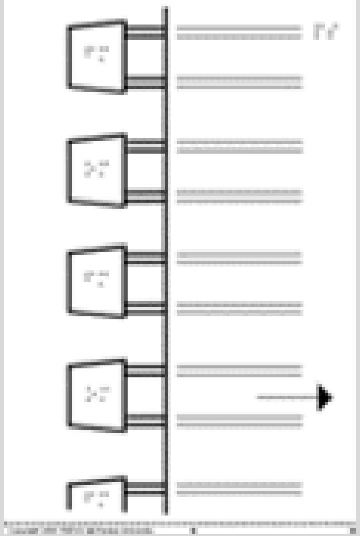

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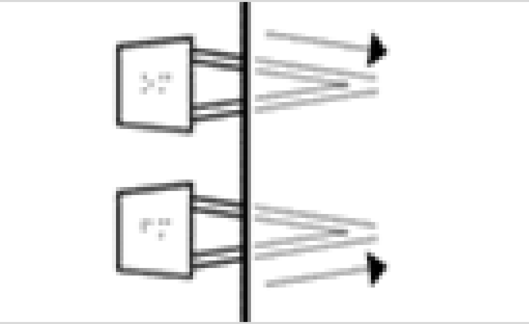

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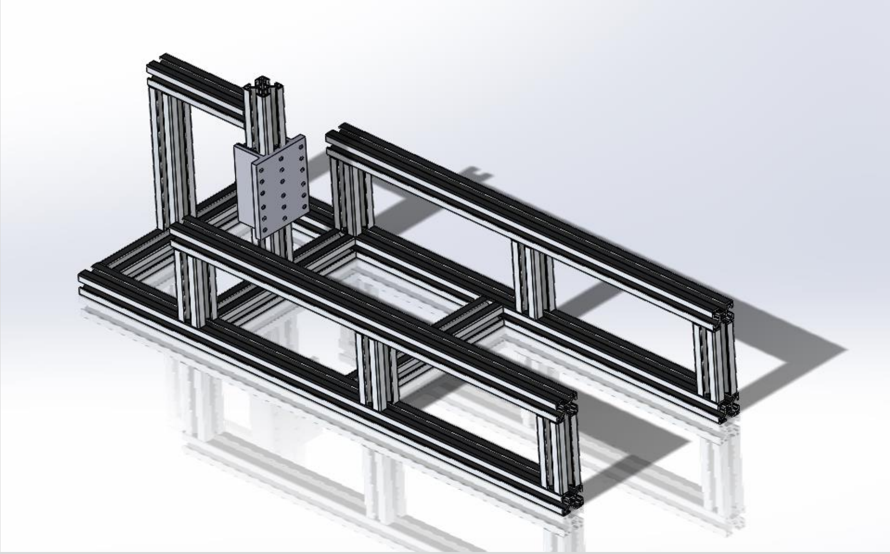
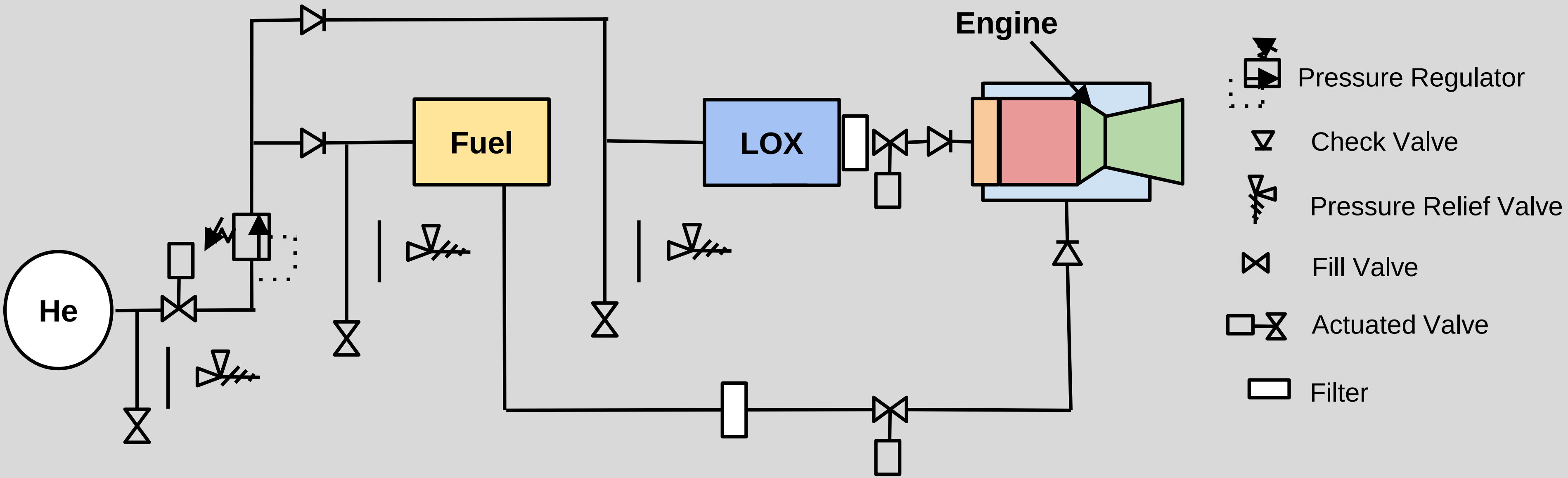
What's Next: Test Stand

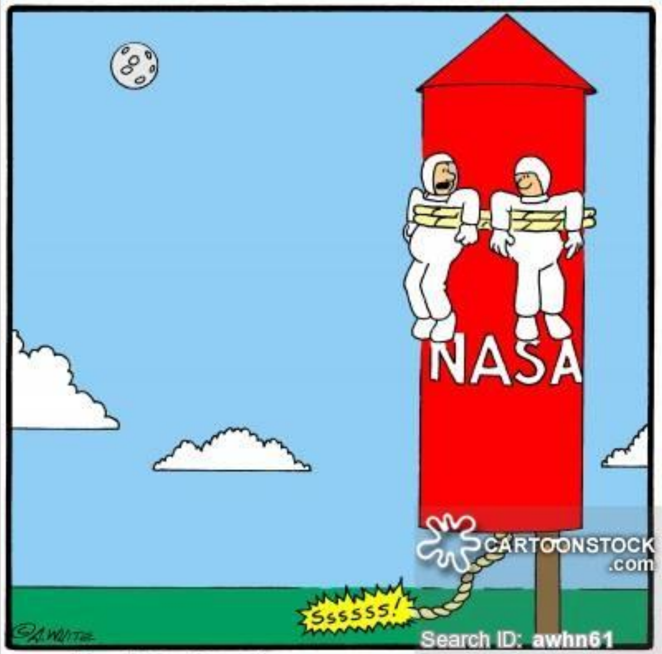
- Current 3D model of test frame
- Sensors DAQ and analysis
  - Excel macro to auto populate from DAQ
- Ignition control system
- Fluid propellant control system



System Diagram

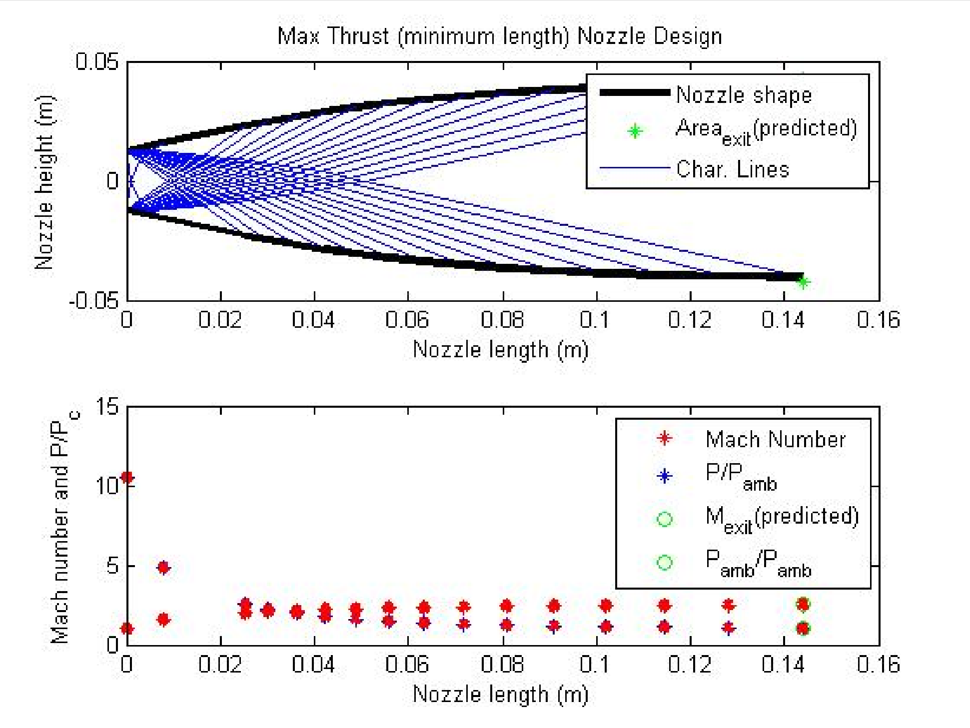


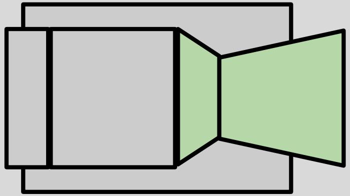
Thank You



"I wish that just once the contract would go to someone besides the lowest bidder."

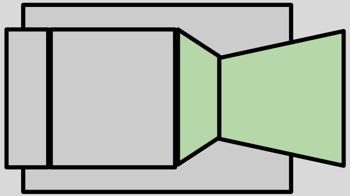
Nozzle Design



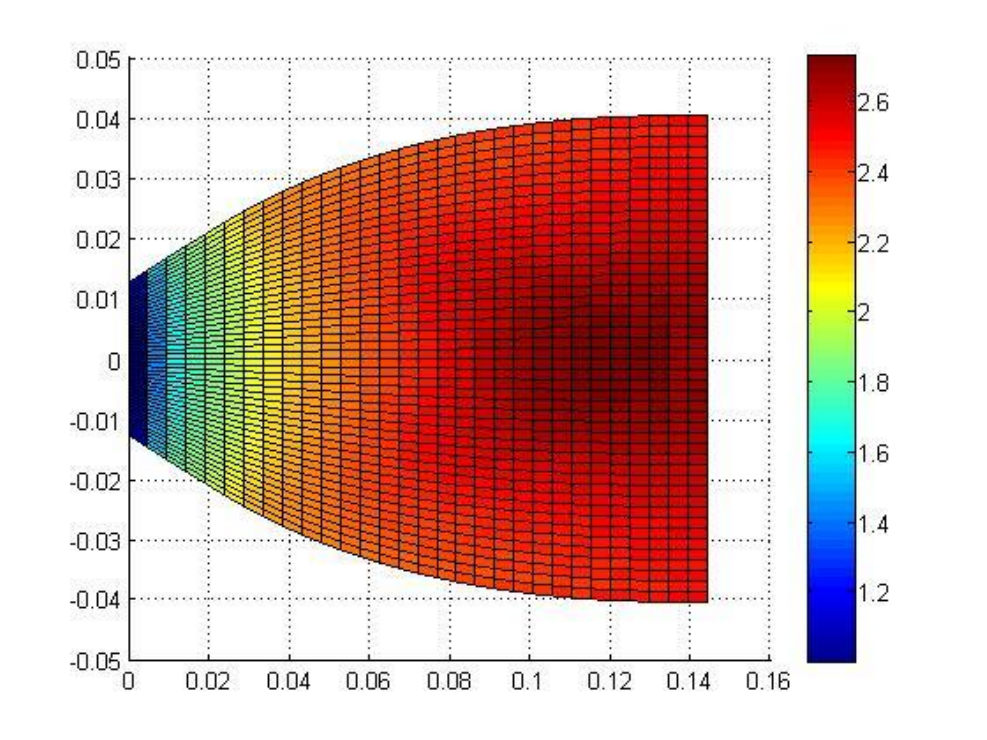


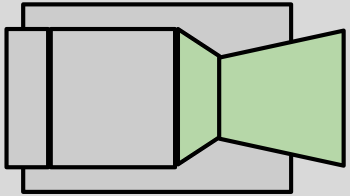
Nozzle Design

Length m	y	P/Pamb	M
0	0.0125	10.511501	1
0.007753	0.015938	4.855501	1.583672
0.02533	0.023103	2.505917	1.994347
0.030158	0.024905	2.220312	2.065362
0.036163	0.026945	1.961029	2.137331
0.042281	0.028822	1.766607	2.197224
0.048776	0.030606	1.611634	2.249478
0.055773	0.032305	1.48514	2.295709
0.063383	0.033914	1.380721	2.336734
0.07171	0.035417	1.294392	2.372917
0.080859	0.03679	1.223617	2.404323
0.090944	0.037996	1.166847	2.430785
0.102087	0.038994	1.123328	2.451913
0.114425	0.03973	1.09306	2.467074
0.128106	0.040137	1.076907	2.47533
0.14384	0.040372	1.067811	2.480031



Nozzle Design





Nozzle Design