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Propulsion

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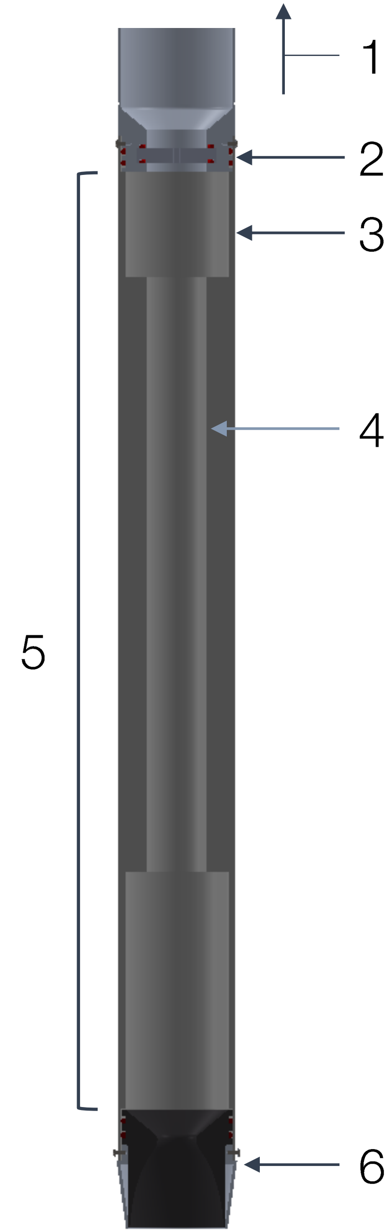
Defiance – Hybrid Rocket

REDEFINING LIMITS

SUBSYSTEM OVERVIEW

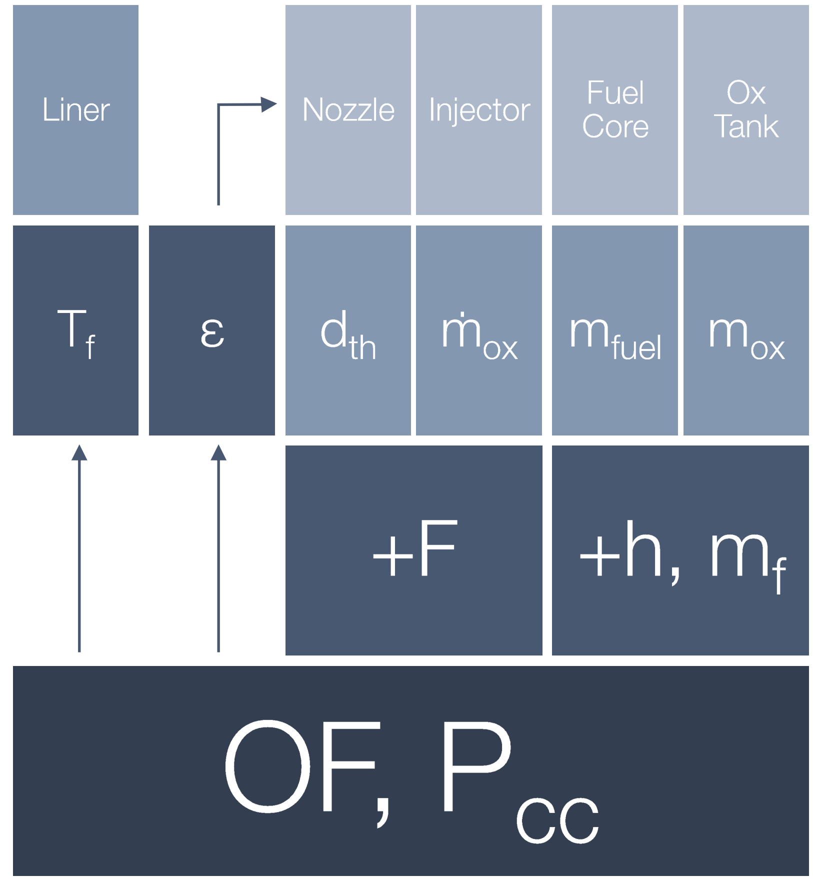
1. Oxidizer tank
2. Injector plate
3. Ignition mechanism
4. Fuel core geometry
5. Combustion chamber & liner
6. Nozzle



REQUIREMENTS AND DESIGN

- N_2O-Paraffin propulsion system
- OF ratio = 4.5
- Thrust = 6.5 kN (1460 lbf)
- Max ox tank pressure = 4,826.33 kPa (900 psi)
- Chamber Pressure = 3,102.64 kPa (450 psi)
- Structural safety factor = 2
- Rocket outer diameter = 139.7 mm (5.5”)
- Rocket dry mass = 40 kg
- Target altitude ≥ 18.6 km

- Preliminary design done on Excel
- Design is iterated upon using in-house MATLAB engine simulation



NOZZLE DESIGN AND ASSEMBLY

REQUIREMENTS:

- Mass ≤ 2 kg
- Length ≤ 15 cm
- Exit diameter ≤ 12 cm
- Structural factor-of-safety ≥ 2

SPECIFICATIONS:

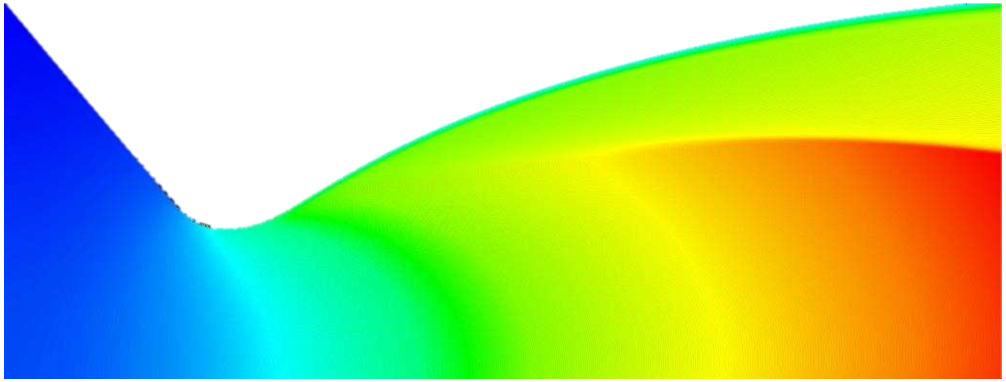
- Length = 14.28 cm
- Throat Radius = 2.33 cm
- Expansion Ratio = 5.87

- Note that picture shows carbon fiber concept, we are opting to use graphite instead

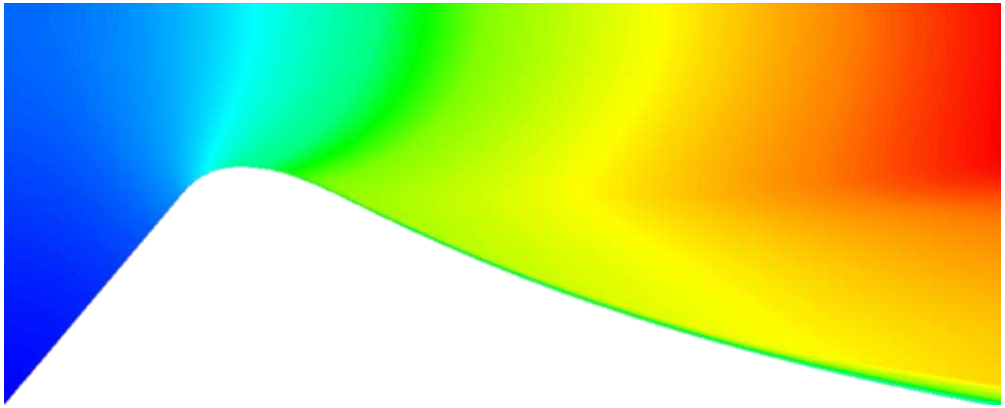
NOZZLE CONTOUR

- Contour based on TICTOP nozzle by German Aerospace Centre (DLR)
  - Truncated ideal contour (TIC) and the thrust-optimized parabola (TOP)

Initial



Optimal



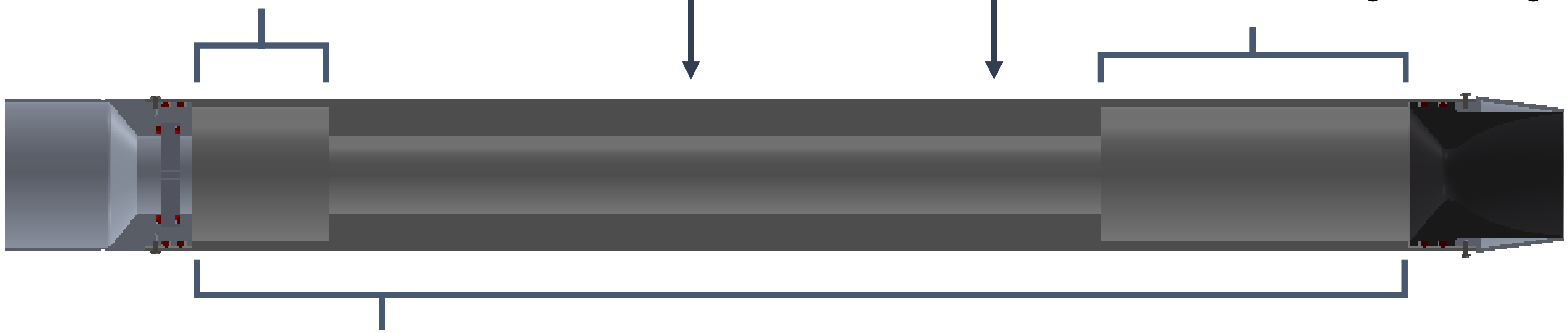
COMBUSTION CHAMBER (CC) DESIGN

CC wall thickness = 3.175 mm
- Complies with safety factor of 2

EPDM liner with custom binder = 5.08 mm
- Internal T = 2,825.98 K.

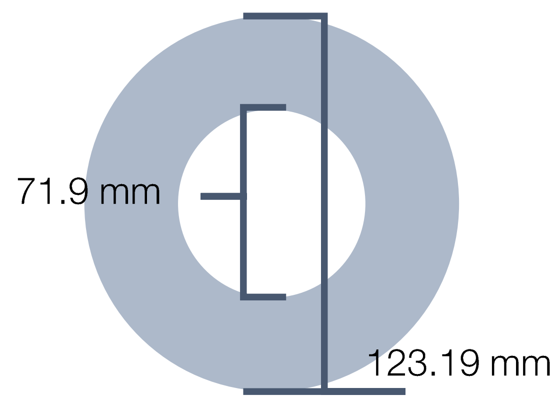
Pre-combustor length = 139.7 mm

Post combustor length determined through testing



Fuel core port length = 757 mm

- Cylindrical port for analytical and manufacturing simplicity.
- Microcrystalline paraffin wax mixed with 10% (by mass) tar as opacifier.



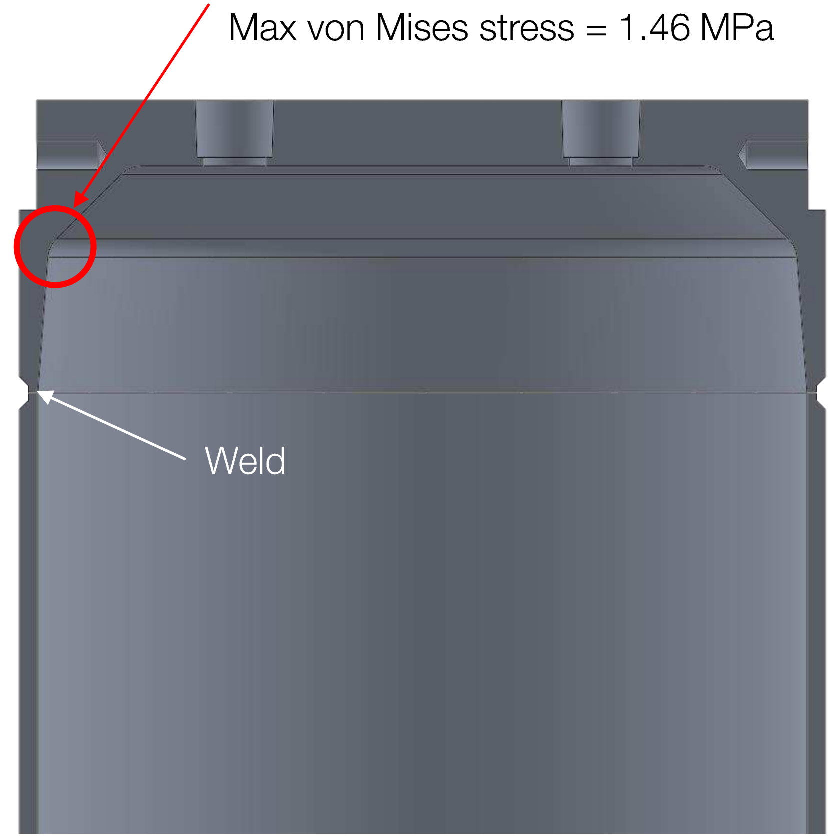
IGNITION & OXIDIZER ACTUATION

- Mylar burst disk ox actuation.
- Nitrocellulose igniter.
  - Some new recipes are being developed and will be tested.
- Igniter burns through some layers of burst disks until ox tank pressure high enough to rupture them.
- Since diameter of retaining ring has increased from previous design, need to redo tests to determine rupture pressure of a single disk.

OXIDIZER TANK DESIGN

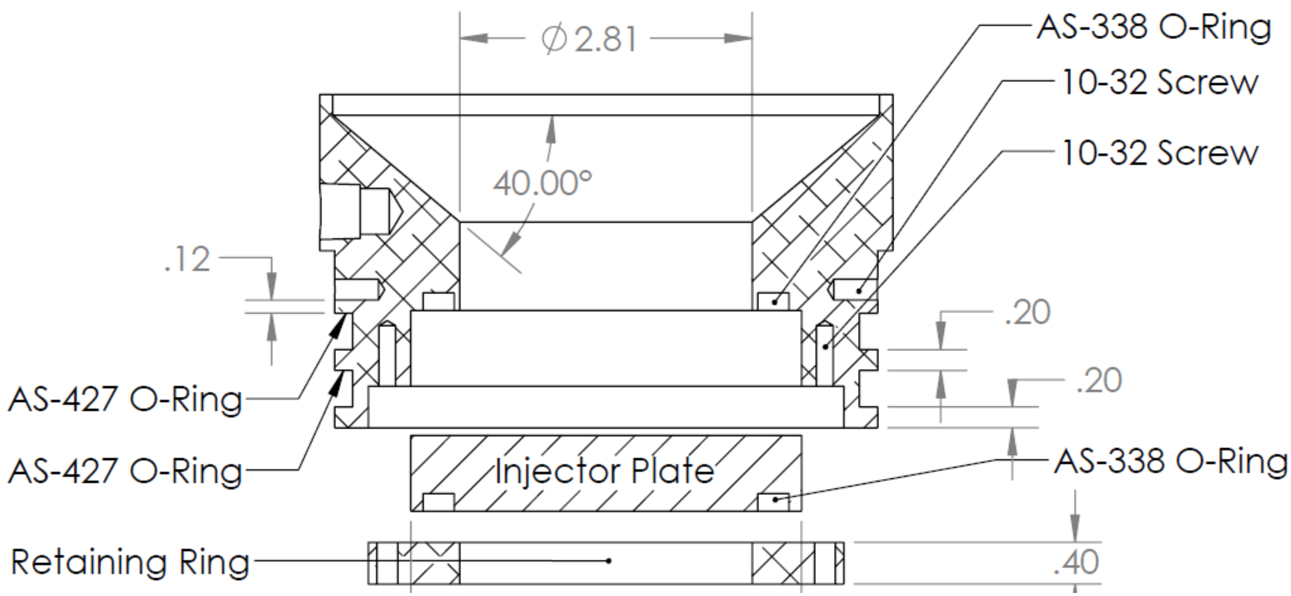
- Thin-walled pressure vessel theory:
  - Al 6061-T6 yield strength = 274 MPa.
  - Min. wall thickness = 3.141 mm.
  - Actual thickness = 3.175 mm (1/8”).
- ANSYS FEA simulation to identify problem areas.
  - Fixture at weld.
  - Applied pressure = 4,826.33 kPa (900 psi).
- Safety factor = 1.9.
  - At 700 psi, safety factor = 2.43.

Stress Concentration:
Max von Mises stress = 1.46 MPa

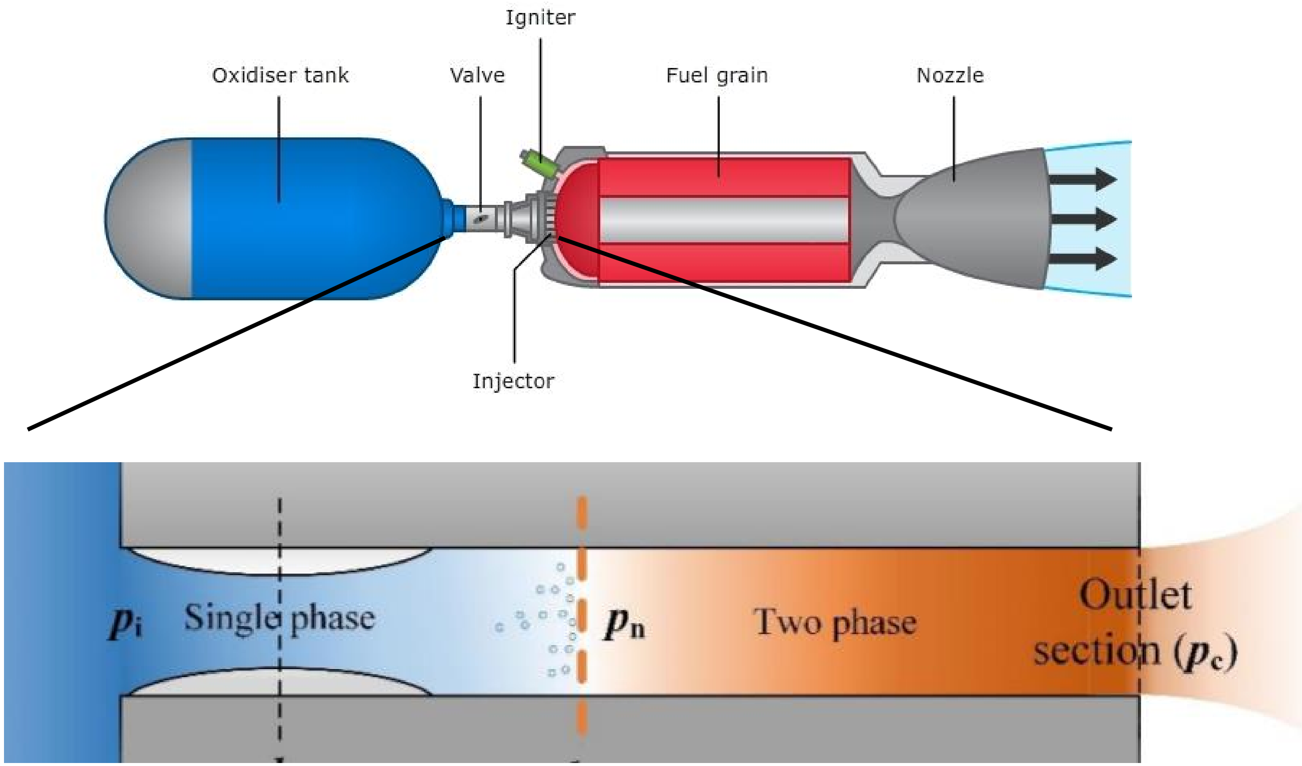


INJECTOR AND INJECTOR ASSEMBLY

- Purpose is to deliver oxidizer to the combustion chamber at the design pressure and mass flow rate
- Injector determines homogeneity and atomization of propellant, ultimately determining combustion stability and efficiency
- Used ANSYS FEA for verifying structural integrity
  - Safety factor of 3.5 at 900 psi (6,205 kPa)



INJECTOR ANALYSIS

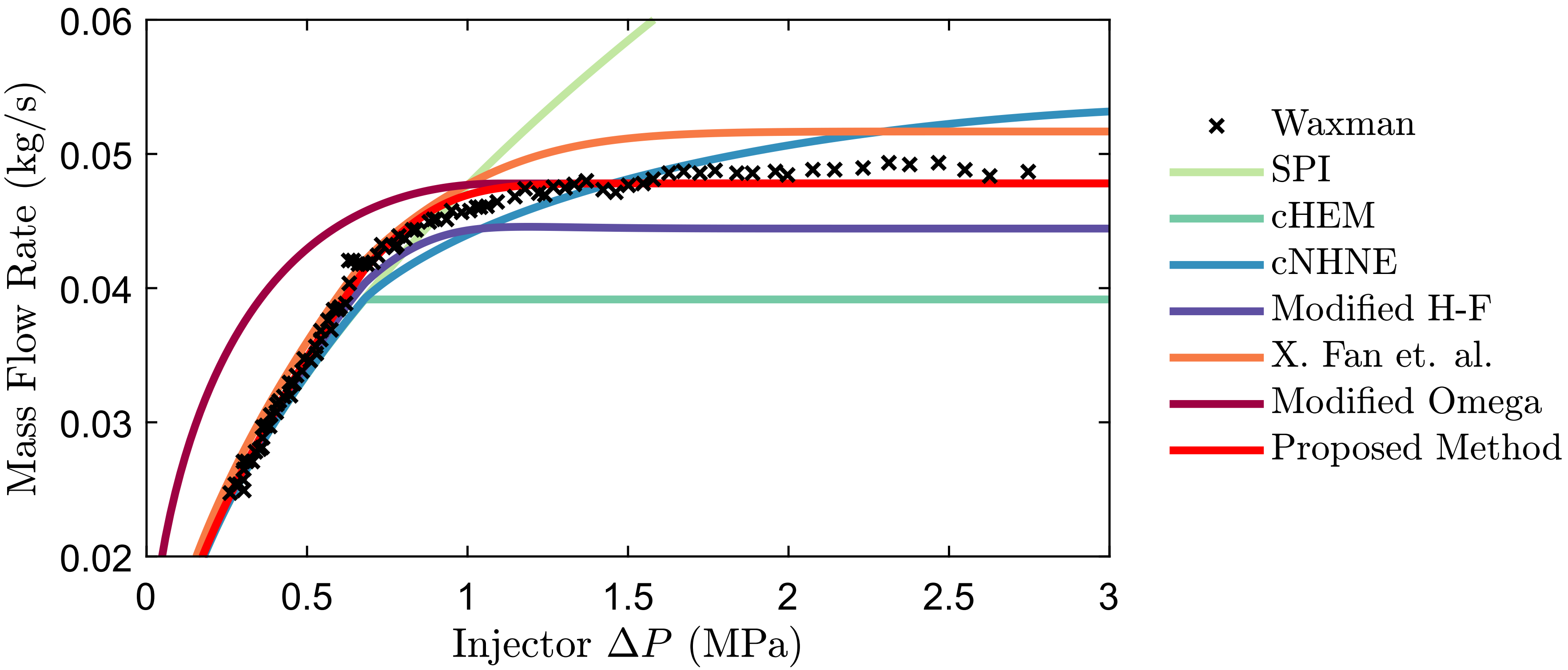


Inlet
High Pressure,
At or above saturation pressure.

Outlet
Low Pressure,
Below saturation pressure.

- Thermodynamic fluid path is unknown

MASS FLOW RATE MODELS – RESULTS



MASS FLOW RATE MODELS – RESULTS

Injector Diameter (mm)	Fluid	SPI (%)	cHEM (%)	cNHNE (%)	Modified Henry-Fauske (%)	X. Fan (%)	Modified Omega (%)	Proposed Model (%)
0.79	N_2O	7.22	6.79	6.50	3.20	26.10	2.01	6.71
0.79	CO_2	5.92	5.88	5.23	3.55	21.77	3.31	5.06
1.50	N_2O	4.44	3.68	2.73	5.82	14.46	4.24	2.69
1.50	CO_2	4.54	4.62	3.47	6.41	27.39	6.32	2.82
1.93	N_2O	3.25	1.22	1.64	4.80	26.81	10.01	1.97
MAPE		**5.07**	**4.44**	**3.91**	**4.76**	**23.30**	**5.18**	**3.85**

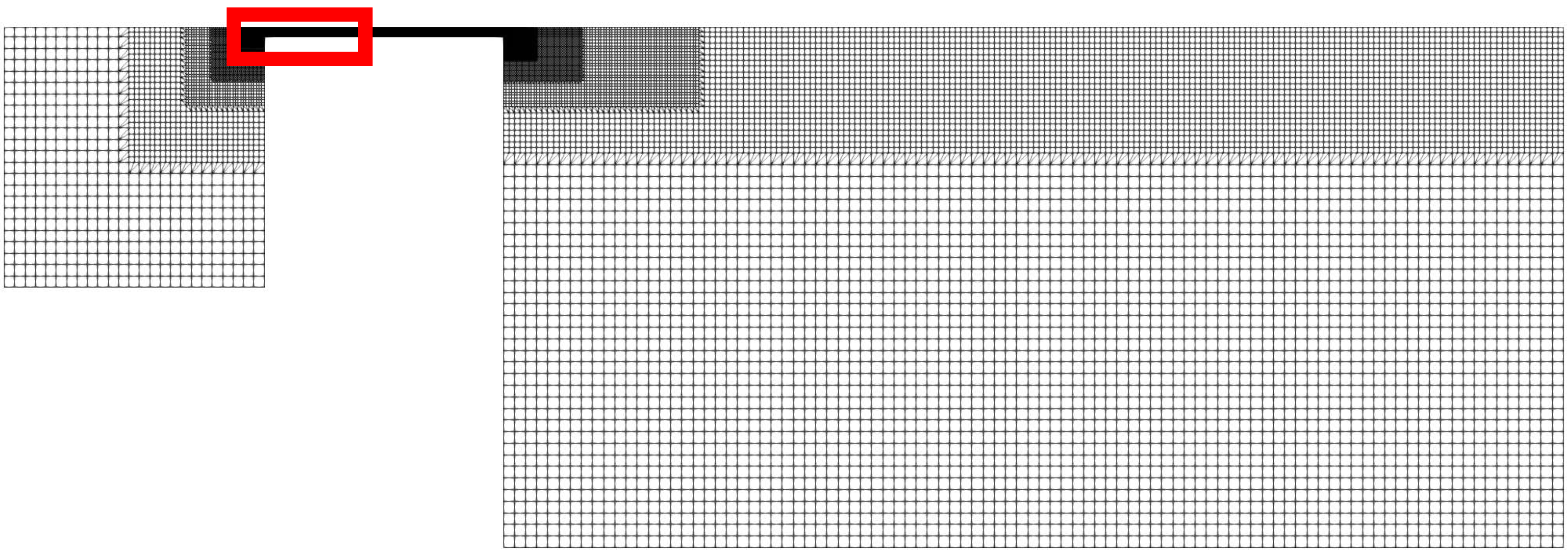
- Error calculated across 2500 test points in 26 test cases.
- Utilized Mean Absolute Percentage Error (MAPE).

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{G_{\text{exp}_i} - G_{\text{model}_i}}{G_{\text{exp}_i}}\right|$$

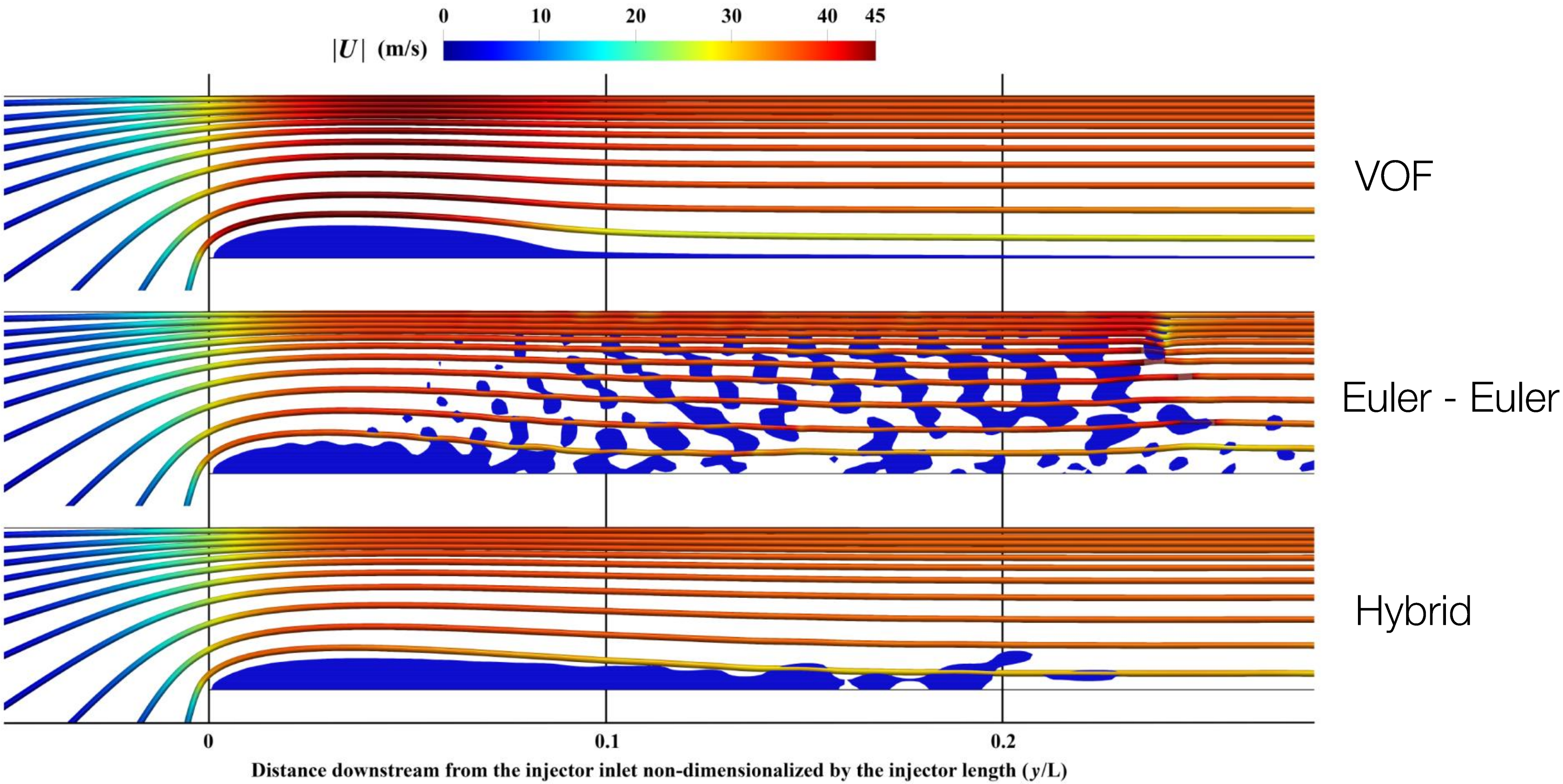
CFD SIMULATION

	VOF	Euler-Euler	Hybrid
Interface sharpening	X		X
Surface tension	X		X
Interfacial momentum transfer		X	X

Cavitation Model	Kunz
Turbulence Model	$k-\omega$ SST
y+ Values	$30-150$
Courant #	0.2
# of Mesh Elements	43,065

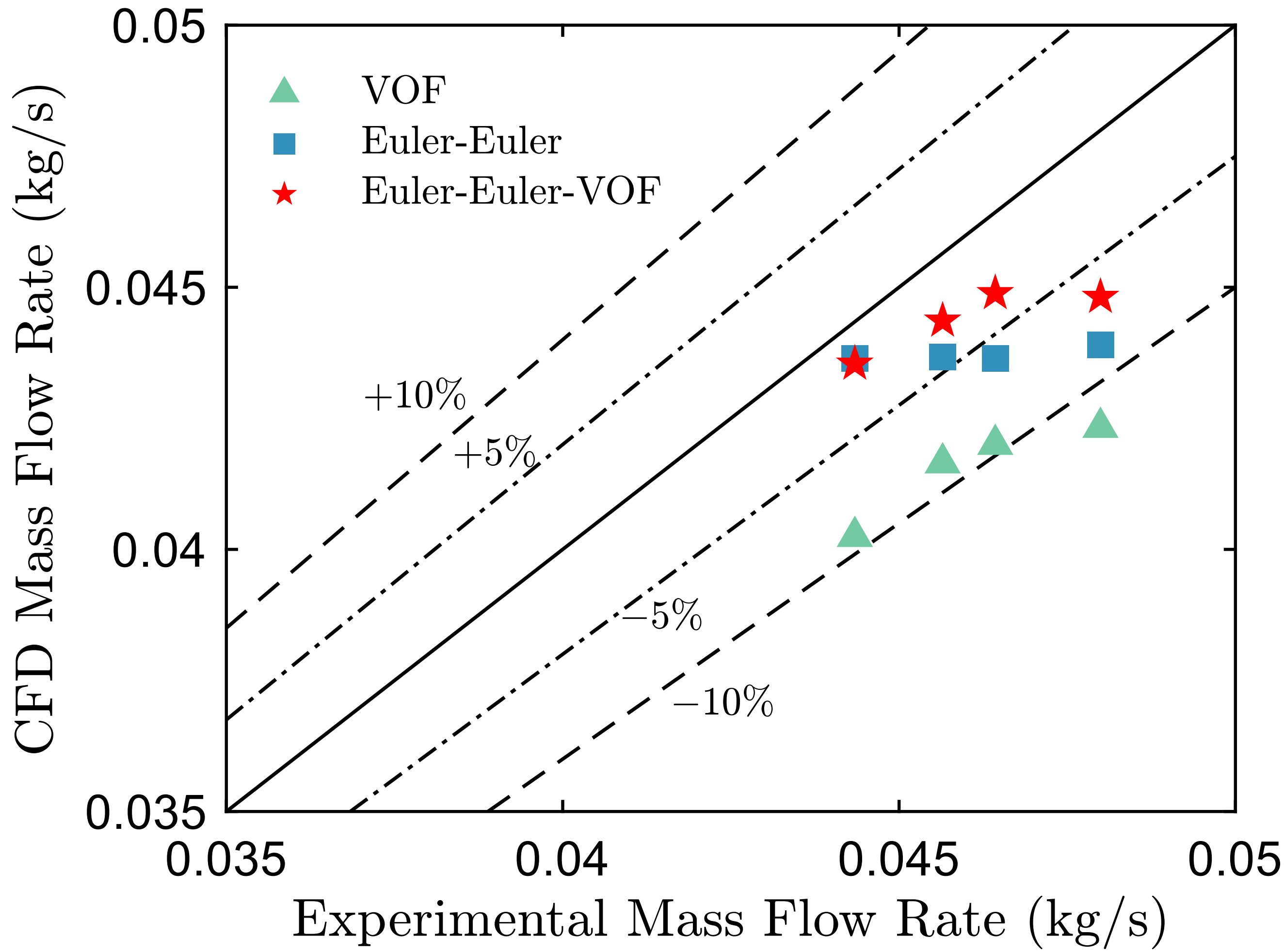


CFD RESULTS

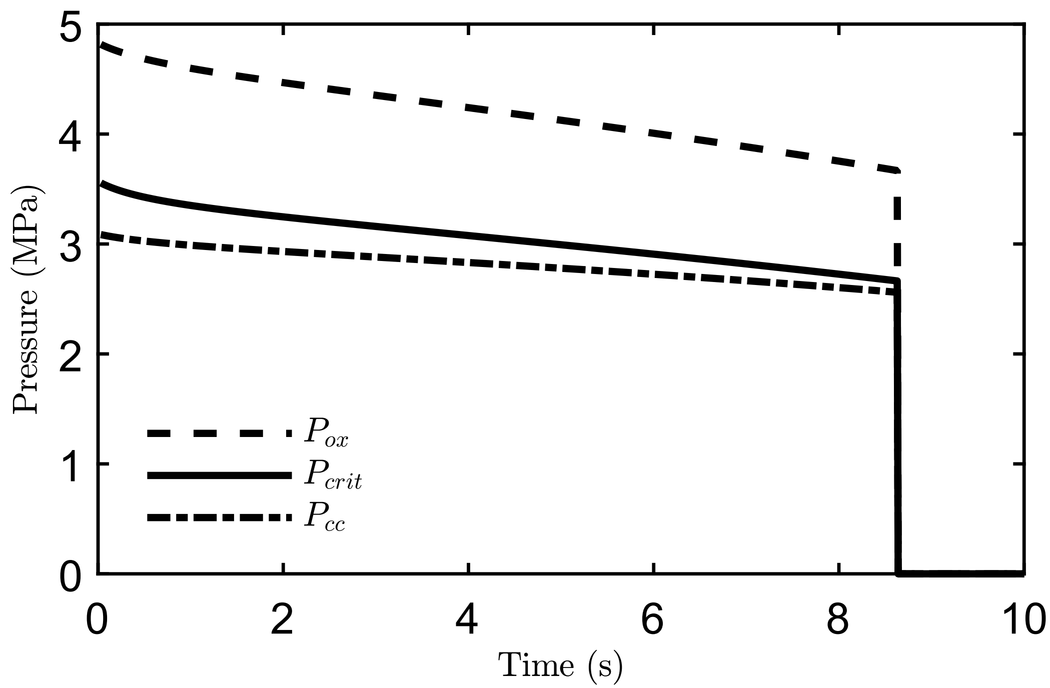


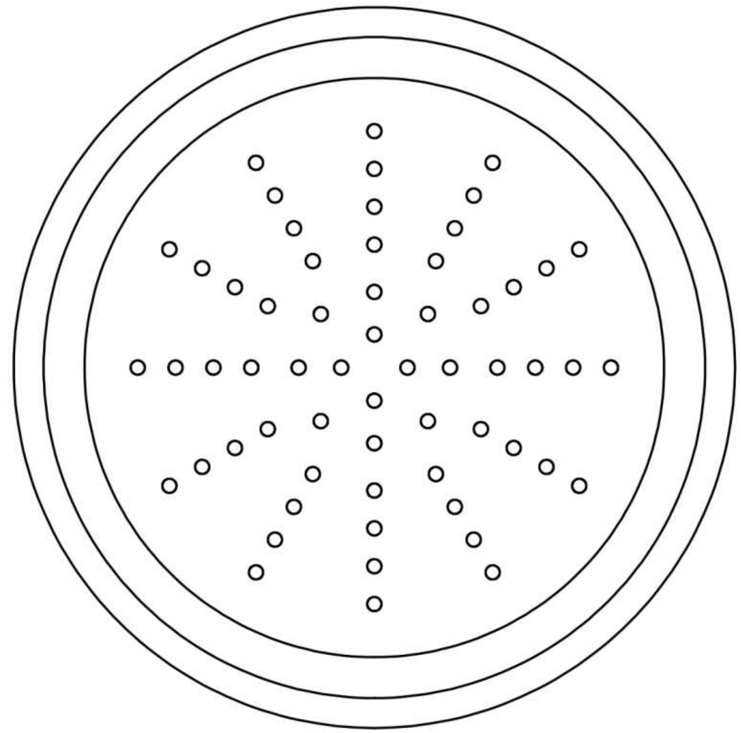
0
10
20
30
40
45
|U| (m/s)
VOF
Euler - Euler
Hybrid
0
0.1
0.2
Distance downstream from the injector inlet non-dimensionalized by the injector length (y/L)

CFD Simulation - RESULTS



FINAL INJECTOR DESIGN

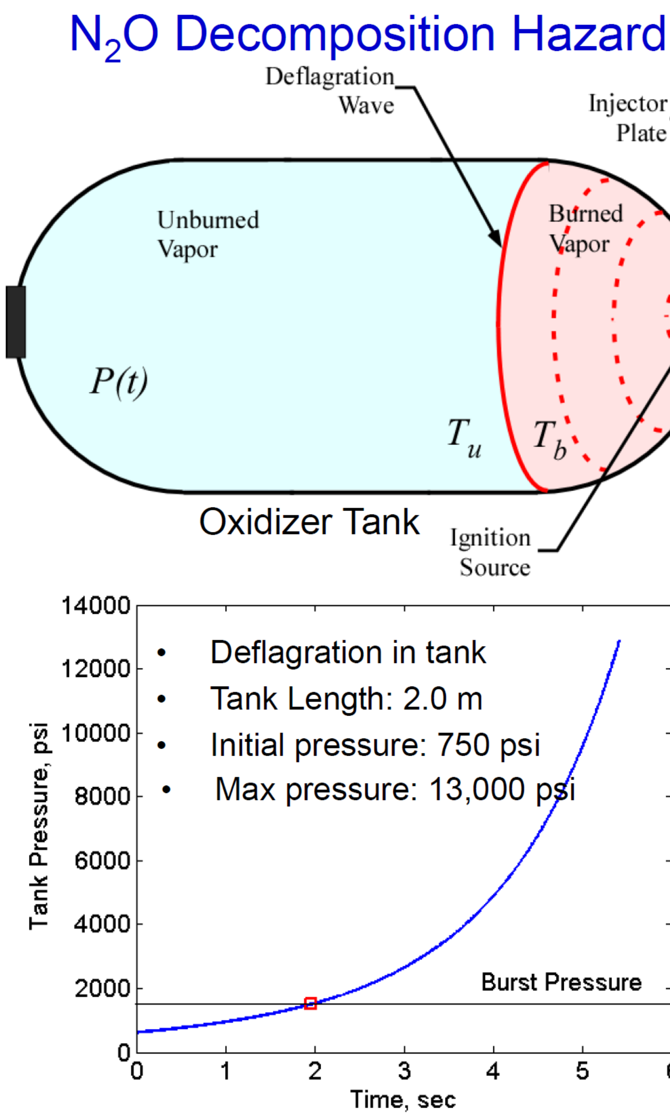




- 60 injector orifices
- Nominal mass flow rate: 2.83 kg/s
- Upstream pressure: 900 psi
- Downstream pressure: 450 psi

Nitrous vapor safety

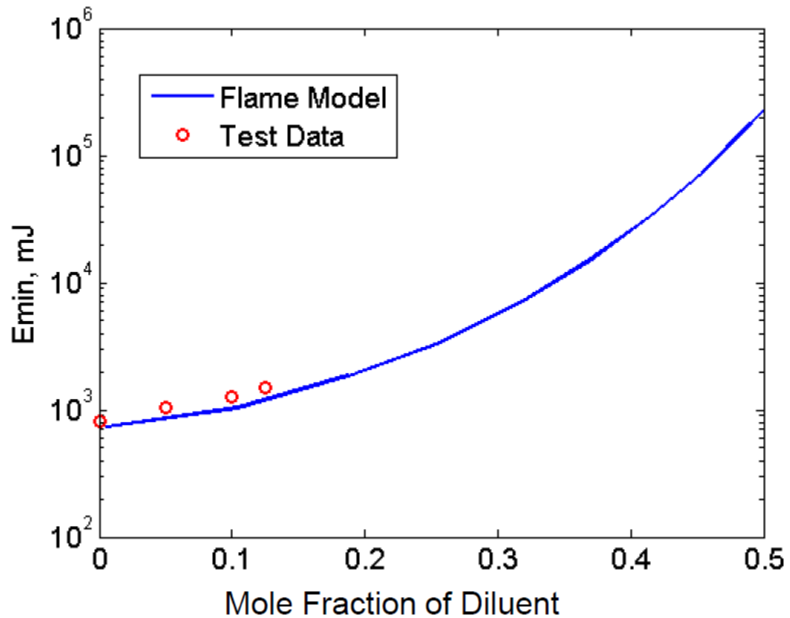
- Pressurized nitrous vapor presents a hazard once the engine burn is completed
- An ignition source (hot injector plate) could start a combustion wave which would result in significant pressure increase
- Would result in a sudden pressure increase which would rupture the oxidizer tank!



Nitrous vapor safety – Mitigation

- Supercharging:
  - Adding additional nitrogen to the oxidizer tank once the nitrous fill is completed
  - Acts as a diluent once the burn is complete

- Tank Purging:
  - Adding additional nitrogen tank to the top of the oxidizer tank
  - Dilutes and blows the nitrous vapor out of the ox tank after the burn



Nitrous vapor safety – Design implications

- Supercharging:
  - Requires additional volume (and mass) to the ox tank or an additional nitrogen bottle to accommodate the extra diluent volume
  - Increased initial ox tank pressure (to 800 psi)
  - Modification to the tank fill procedure

- Tank Purging:
  - Extra mass and complexity of adding a nitrogen bottle and control valve
  - Increased fill system bay length
  - Increased complexity of internal fill system routing

Nitrous vapor safety – Design

- Supercharging:
  - Additional nitrogen bottle with built in regulator to accommodate the extra diluent volume
  - Increased initial ox tank pressure (to 800 psi)
  - Modification to the tank fill procedure
  - Control valve to open bottle once nitrous fill is complete

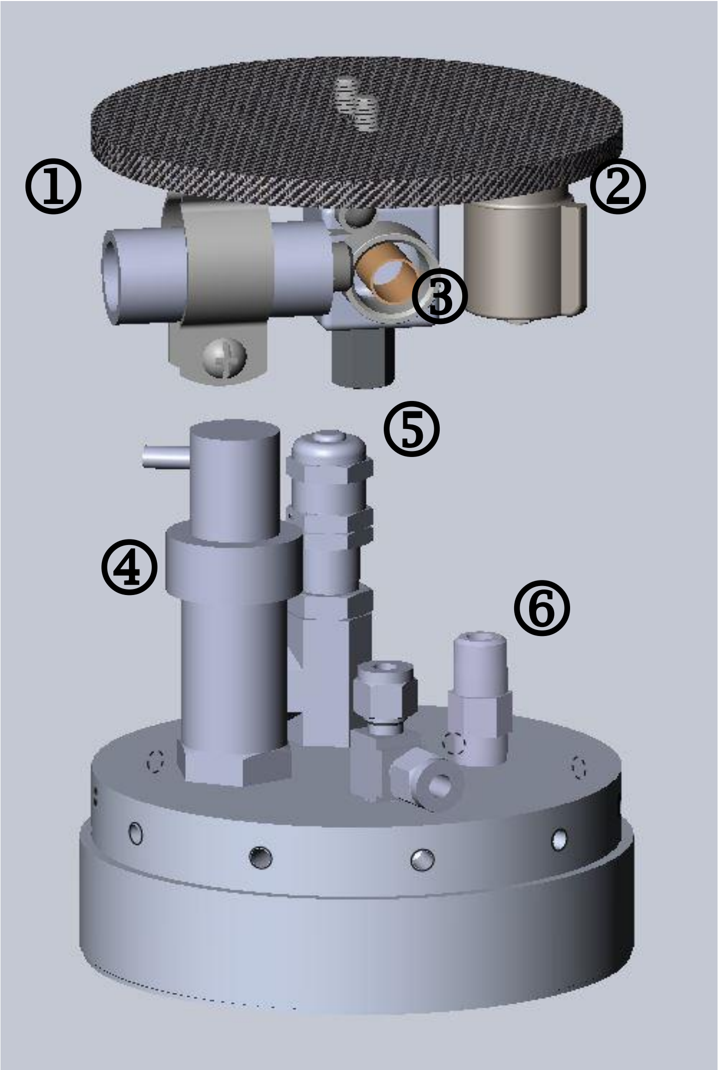
Internal Fill System

- Components of the fill system above the ox tank, contained within the airframe of the rocket.
- Controls the fill to the ox tank, ensures the quick disconnect separates, and
- Limited space to work with.
- Vital for pre-fill and while filling the ox tank.

Internal Fill System - Overview

PREVIOUS CONFIGURATION

- Components
  1. Quick Disconnect
  2. Dump Solenoid/Valve
  3. Vent Solenoid/Valve
  4. Pressure Transducer
  5. Relief Valve
  6. Check Valve
- Additional hardware for nitrogen diluent tank.

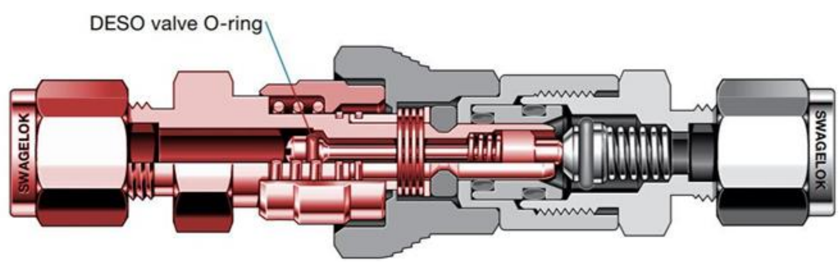


Quick Disconnect

- A connection between the external fill line and the oxidizer tank.
- Reduces the complexity over the Deliverance II explosive cutter design.
- Eliminates the need to dissemble the rocket to reconnect the fill line in the event of a misfire.
- Female end fixed to the internal fill system frame structure. Activated by an external actuator

Double-End Shutoff (DESO)—Red Stem Sleeve

This end to External Disconnect



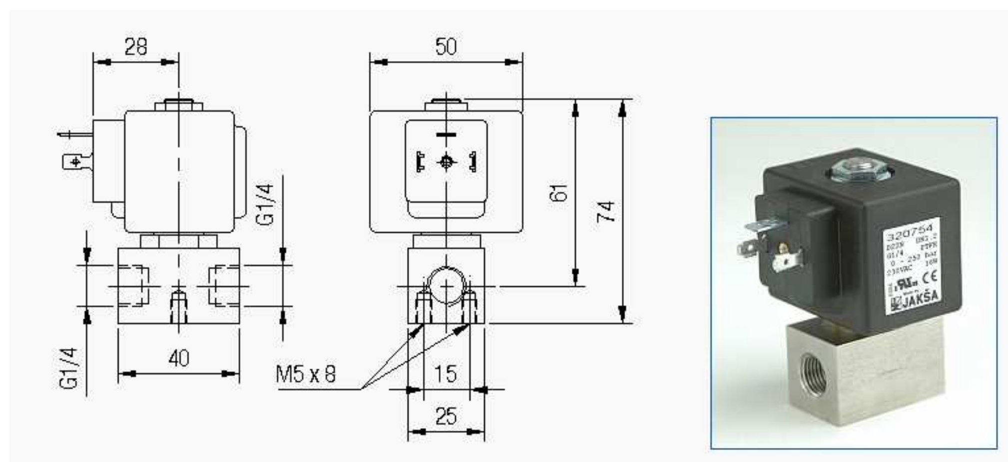
This end in Rocket

Male end

Female end

Vent and dump solenoid/valve

- Vent valve allows for tank to be prefilled with nitrogen which then vents out as nitrous is added to the tank. Closed after filling to prevent loss of nitrous.
- Dump valve allows for a faster emptying of the tank in the event of an aborted launch. Separate control system from the vent valve for redundancy.
- Options include latching solenoid valves, low power solenoids, actuated ball valves.
- Driving requirements
  - Mass
  - Volume
  - Nitrous compatibility (materials and operating temperature)

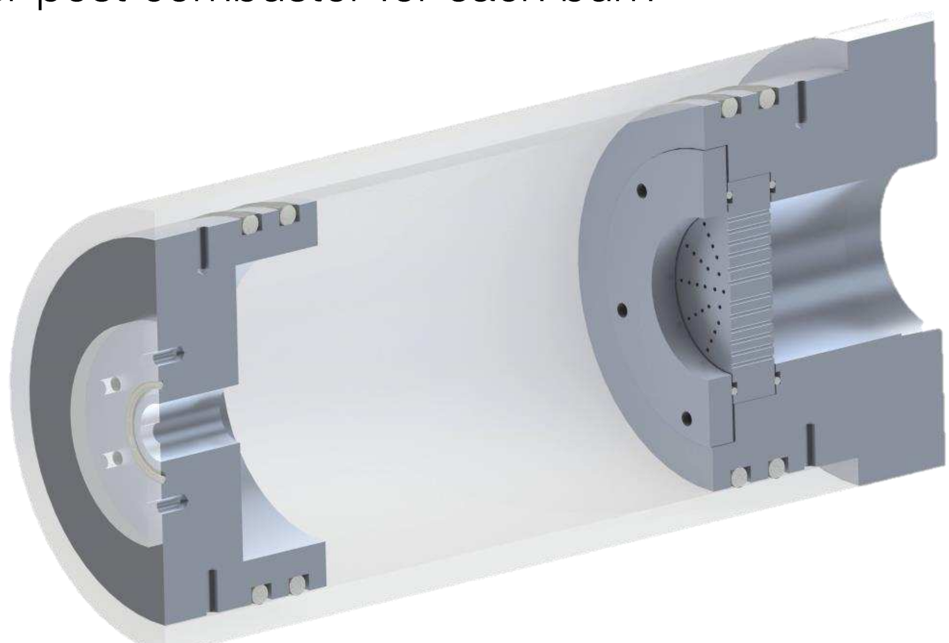


Internal Fill System – Integration and Testing

- Once the components have been choses, they will need to be fit into the space above the ox tank. Considerations for rocket assembly need to be taken into account.
- Airframe will require holes to accommodate the quick disconnect and various vent lines. Bulkheads may act as attachment points for some components.
- Low power solenoids would need to be tested to ensure they don't pose a risk of nitrous detonation.
- Quick disconnect flow and separation mechanism need to be tested to ensure they work as envisioned.

Test plan

- Cold flow testing to evaluate injector performance against predicted values
- 5 scaled engine burns (~3 seconds) to determine post combustor length
  - Use 3, 2.5, 2, 1.5, 1 caliber post combustor for each burn
- One full scale burn will the calculated post combustor length
- Compare test data against engine simulation



Thank you for listening.

Questions?