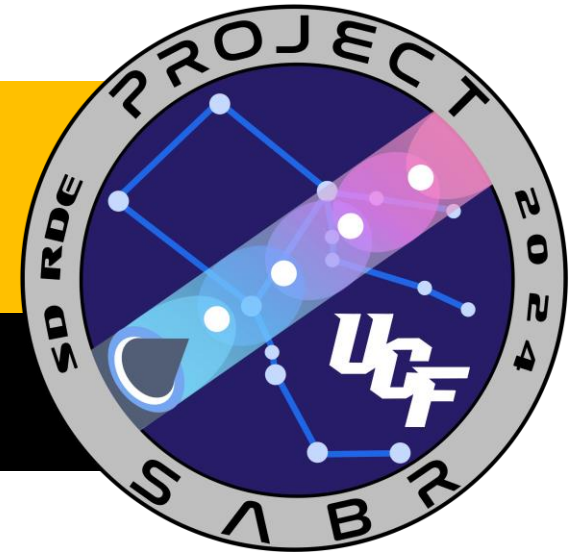




UCF

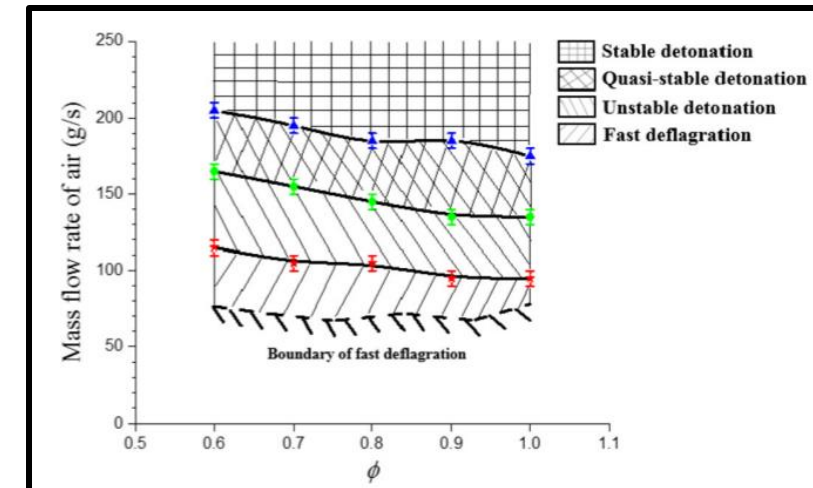
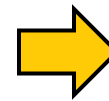
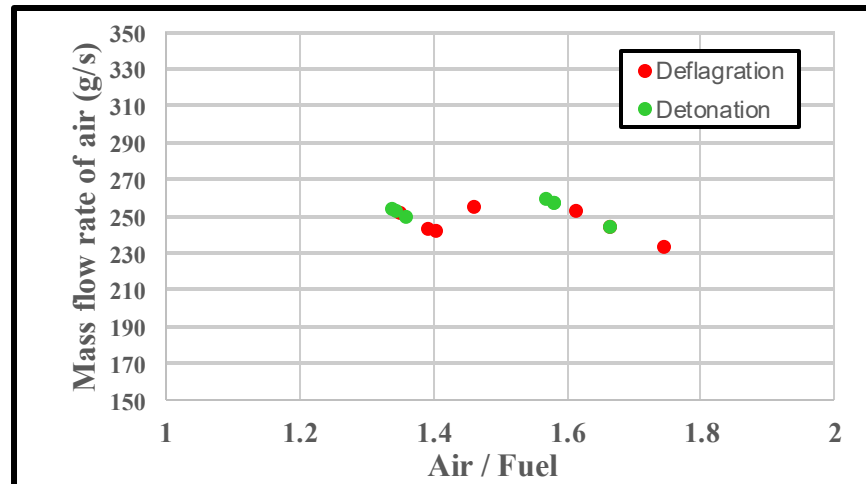
# Small-Scale Air-Breathing Rotating Detonation Engine

*By: Paul DeHart, Joshua Kopp, Nathaniel Michnoff, Arturo Negrette, Hunter Quinlan, Egan Rigney, Subhan Wade, Edward Woodruff*



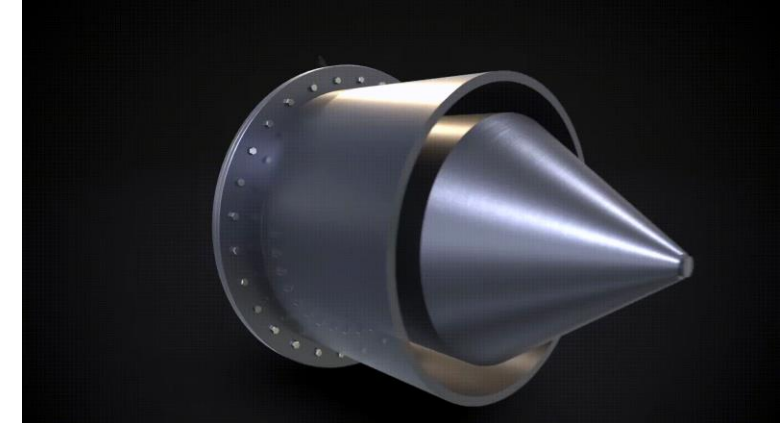
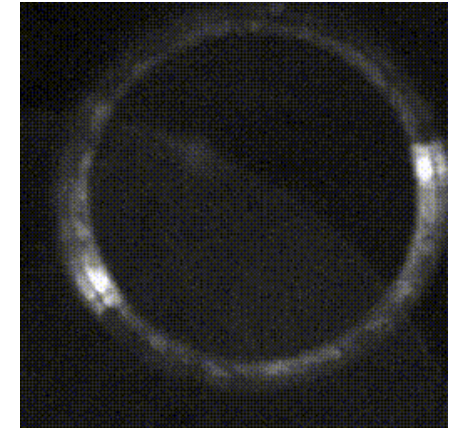
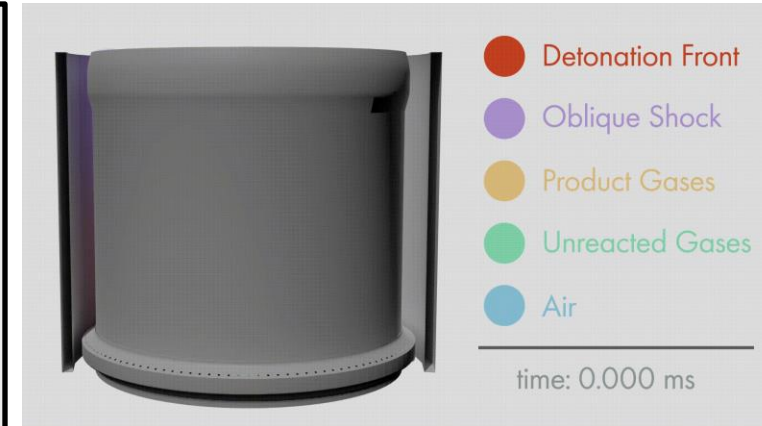
# Project Goals

- Develop a small-scale RDE testbed using air as the oxidizer
- Build an operational map of the RDE such that a band of successful fuel to air ratios is found
- Design a unique ignition system that would aid in the optimization of applied system designs



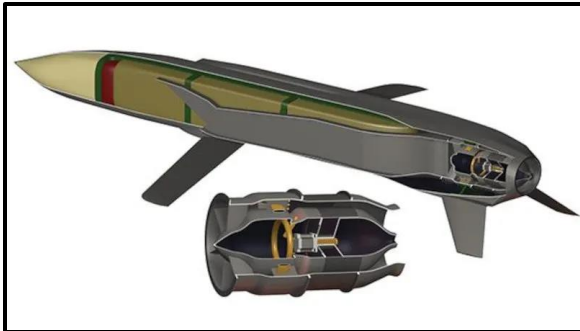
# What is an RDE?

- Fuel and oxidizer injected into an annulus
- Detonation forms from a shockwave that induces autoignition of propellants
- Autoignition causes pressure rise, which provides performance gain compared to traditional rocket and jet engines
  - Roughly 30% performance increase

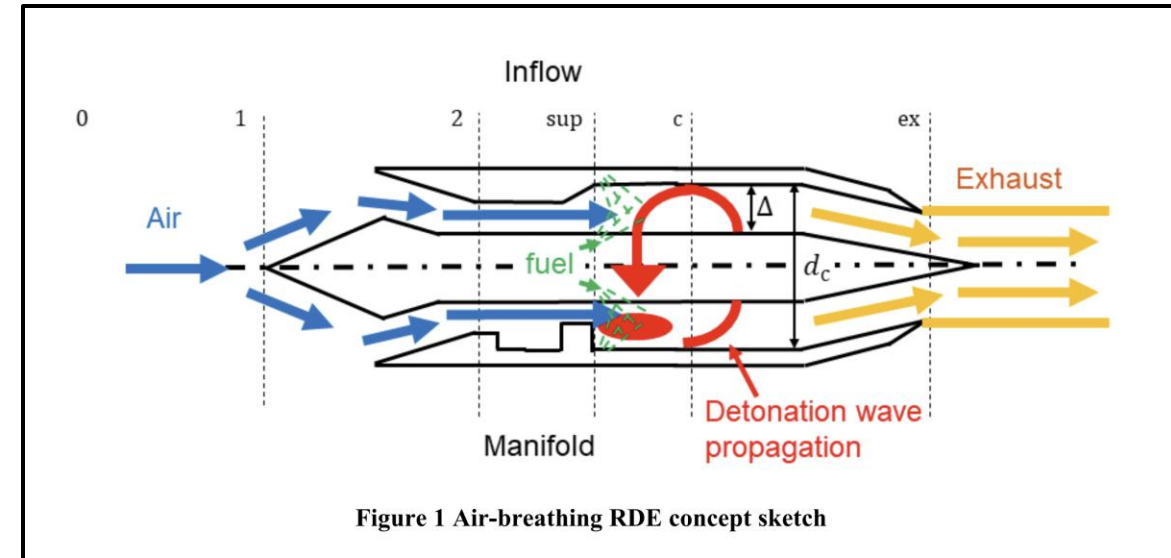


# Why is SABR important?

- Detonation combustion significantly reduced the length scale required in combustors
- Axial air injectors with jet-in-crossflow are representative of ramjet and turbojet engines
- Small-scale RDEs with Air and Hydrogen are seldom studied in the public
  - Hydrogen storage systems are being advanced
  - Hydrogen and air is highly detonable

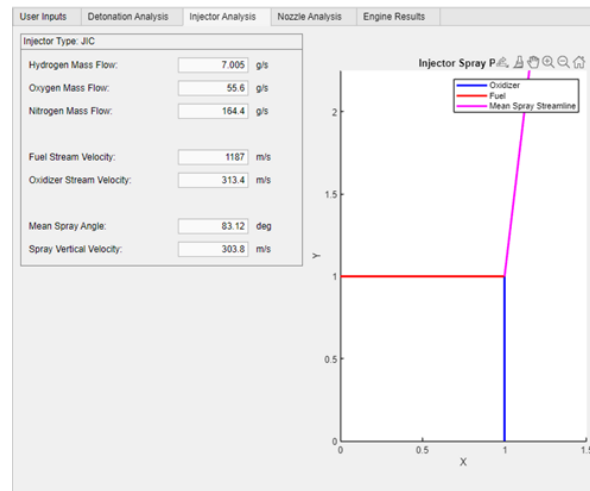
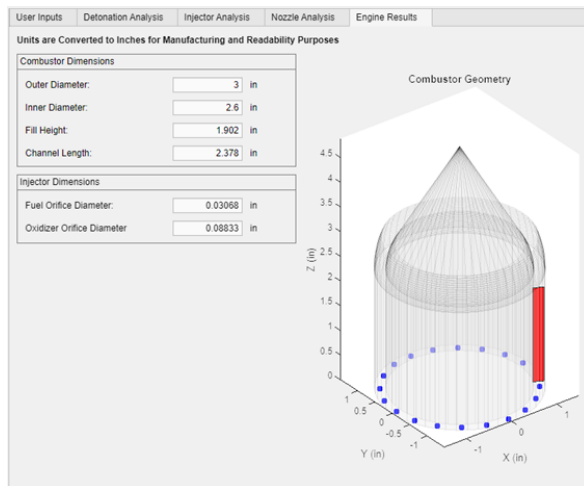


<https://www.twz.com/ges-breakthrough-in-detonating-hypersonic-propulsion-is-a-big-deal>



<https://arc.aiaa.org/doi/pdf/10.2514/6.2021-0084>

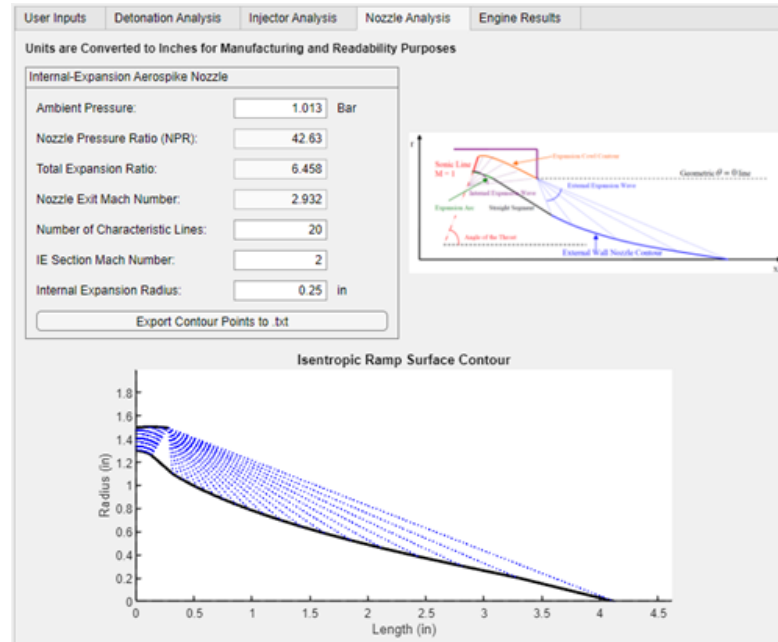
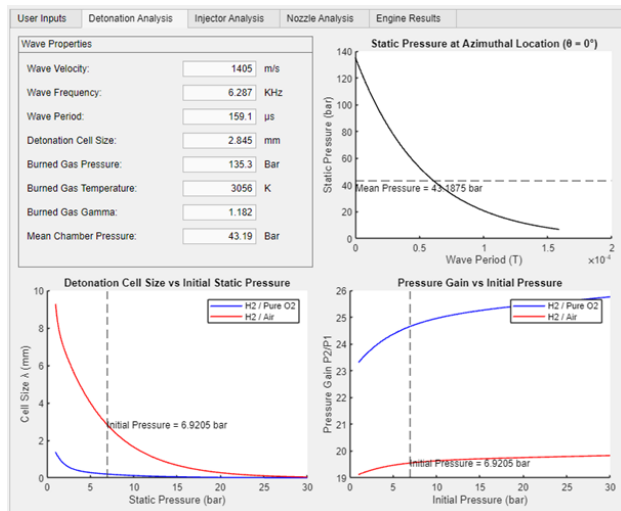
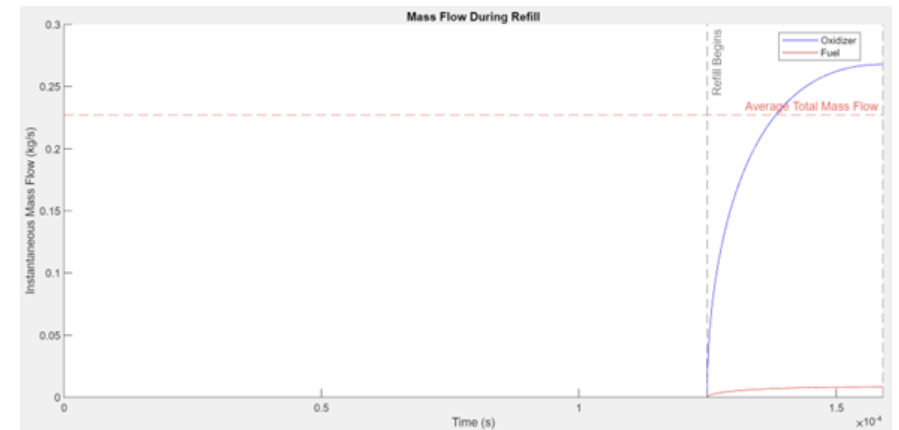
# RDE Analysis



## Injector Dimensions

Oxidizer Orifice Diameter: 0.0907 in

Fuel Orifice Diameter: 0.031 in



**System Scale**

Total Mass Flow: 0.227 kg/s  
 Target Mass Flux: 200 kg/s-m<sup>2</sup>

**Problem Type**

☒ Calculate Annular Area by Fixed Gap Size  
 Gap Size: 5.08 mm  
☐ Calculate Annular Area by Fixed Detonation Cell Count  
 Cell Count: 0

**CJ Detonation Properties**

Number of Detonation Waves: 1  
 CJ Det Velocity Correction Factor: 70 %  
☐ Override Detonation Properties

Detonation Cell Width: 0 mm  
 CJ Det Velocity: 0 m/s  
 Burned Gas Pressure: 0 Bar  
 Burned Gas Temperature: 0 K  
 Burned Gas Gamma: 0  
 Burned Gas Molar Mass: 0 g/mol

**Initial Gas Properties**

Dilution Value is Represented as the Percent of Nitrogen Present in Air by Mass (0% = Pure O<sub>2</sub>, 75.5% = Air)

Nitrogen Dilution Percent: 75.5 %  
 Specific Gas Constant: 287.731 J/kg-K  
 Stagnation Pressure: 13.1 Bar  
 Stagnation Temperature: 293 K  
 Equivalence Ratio Φ: 1

**Injector Configuration**

**Injector Types**

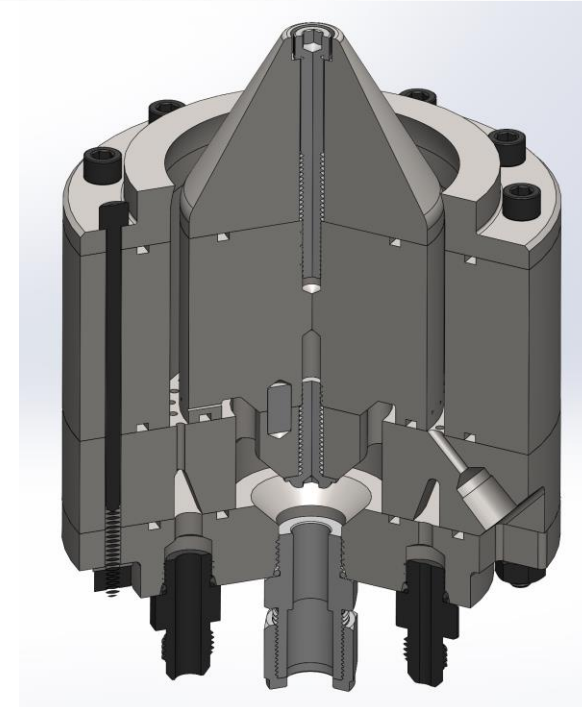
☒ Jet-In-Crossflow (JIC, Axial Oxidizer Flow)  
☐ Unlike Impinging Doublet (w/ Unique Injection Angles)  
☐ Impinging Triplet (O-F-O pattern)

**Angles are Measured From Axis Parallel to Injector Face**

Fuel Impingement Angle: 45 deg  
 Oxidizer Impingement Angle: 45 deg  
 Number of Injector Stations: 32  
 Flow Coefficient: 0.65

# RDE Design

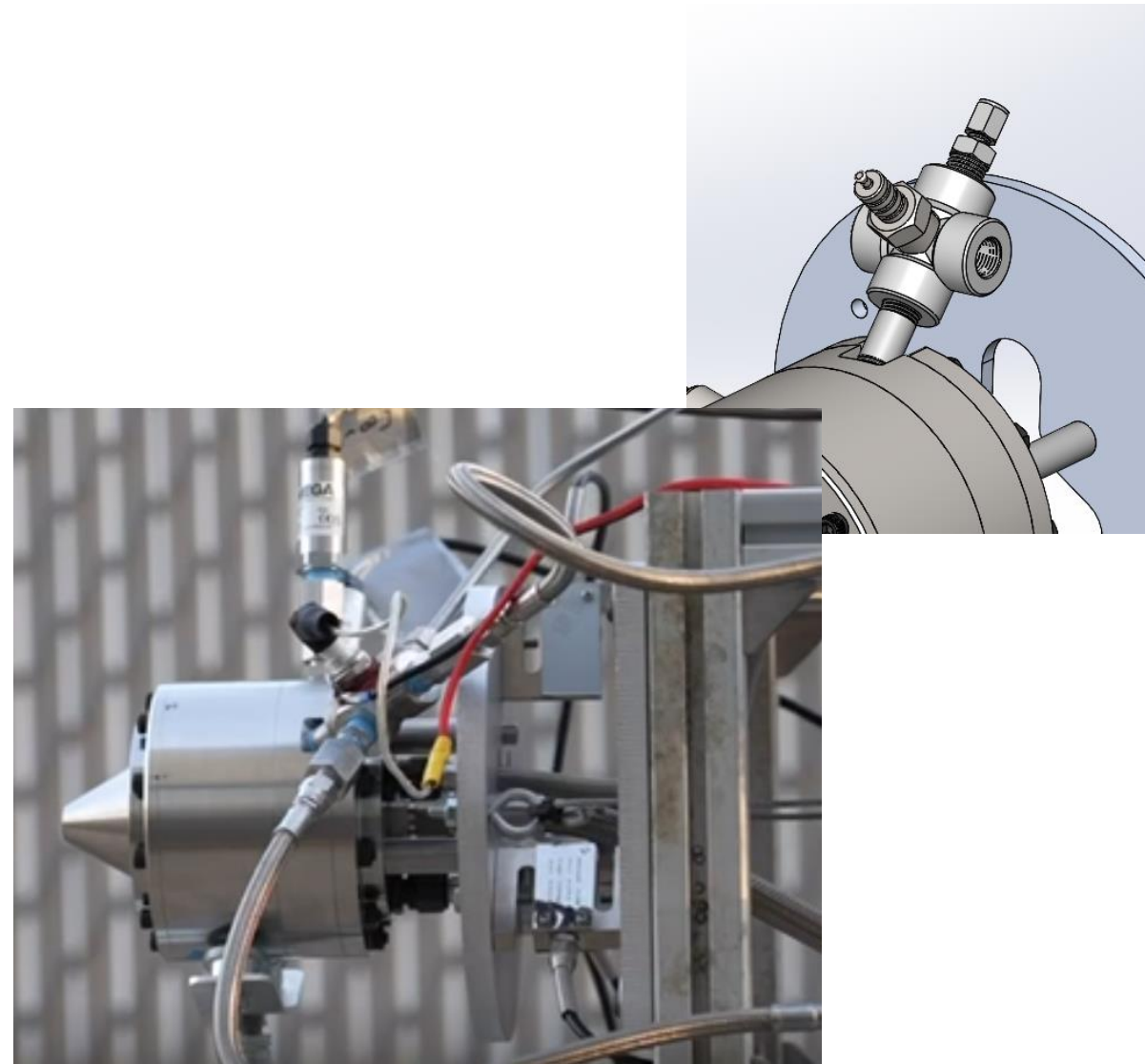
- Hydrogen/Air propellants, initial reactant pressure of 100 psi, peak detonation pressure of ~2000 psi
- Internal expanding aerospike nozzle design ensures operation at design condition throughout the detonation cycle
- Modular plate style design based upon AFRL Topology, pressure taps integrated into injector body
- Igniter flow path routed through injector face, minimal erosion/damage from detonation wave
- 32 Injector elements per side, relatively high L/D for improved diodicity





# Torch Ignitor

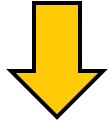
- Tapped off the Main propellant lines to maximize flight vehicle integration
- Jet in Crossflow injection, 360 psi target internal pressure
- Modified COTS NPT cross fitting for ease of manufacture
- Equivalence ratio tuned to produce heated oxidizer and induce deflagration-to-detonation transition in the engine annulus
- Resonant coil spark driver circuit for robustness and ease of integration w/ DAQ electronics



# RDE Structural Analysis

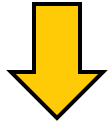
## Boundary Conditions

- Induced Temperature
- Induced Pressure
- Load Path Fixation



## Model Considerations

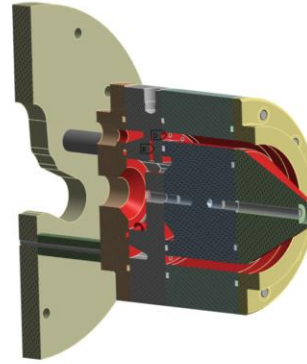
- Beam Modeling
- Component Fixation
- Load Path Fixation



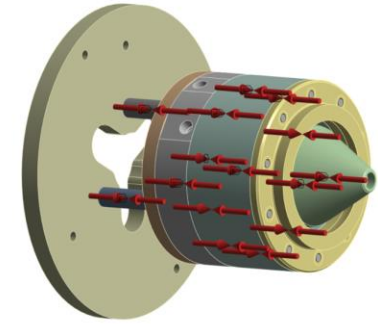
## Results

- No modal or buckling failures
- No Von-Mises failures
- Safety Factor: **>1.5**

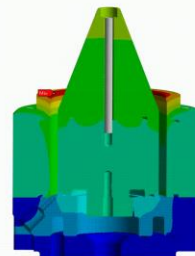
A: Study Structural  
 Force  
 Time: 2.8716 s  
 2/16/2025 11:52 PM  
 Post-Combustion Pressure: 1600 psi  
 Fuel Pressure: 100 psi  
 Pre-Combustion Pressure: 100 psi  
 Ox Pressure: 100 psi  
 Force: 200 lbf



A: Study Structural  
 Bolt Pressure: 15  
 Step 1  
 Press: 12 of 15 analyzed  
 2/16/2025 11:52 PM  
 Bolt Pressure: 652.5 lbf  
 Bolt Pressure: 2.458 kPa  
 Bolt Pressure: 3.138 kPa  
 Bolt Pressure: 4.108 kPa  
 Bolt Pressure: 5.138 kPa  
 Bolt Pressure: 6.458 kPa  
 Bolt Pressure: 7.458 kPa  
 Bolt Pressure: 8.458 kPa  
 Bolt Pressure: 9.458 kPa  
 Bolt Pressure: 10.458 kPa



A: Study Structural  
 Von Mises Stress  
 Step 1  
 Press: 12 of 15 analyzed  
 2/16/2025 11:52 PM  
 Von Mises Stress: 1.00E+008  
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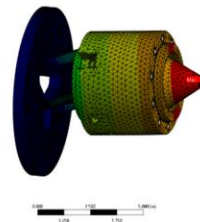


A: Study Structural  
 Von Mises Stress  
 Step 1  
 Press: 12 of 15 analyzed  
 2/16/2025 11:52 PM  
 Von Mises Stress: 1.00E+008  
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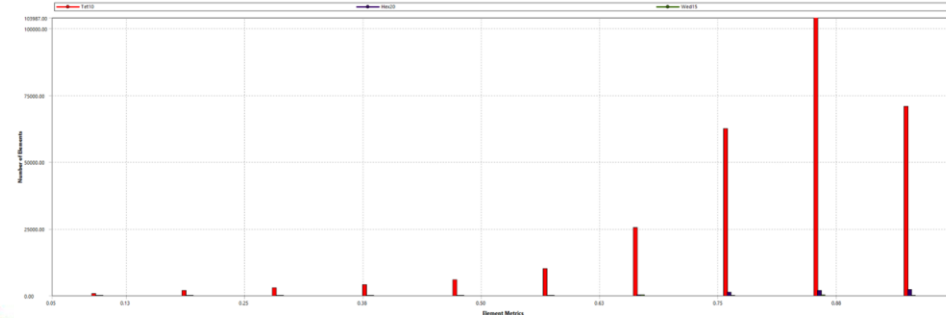
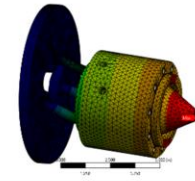


| Mode | Load Multiplier |
|------|-----------------|
| 1.   | 110.13          |
| 2.   | 110.5           |

B: Eigenvalue Buckling  
 Von Mises Stress  
 Step 1  
 Press: 12 of 15 analyzed  
 2/16/2025 11:52 PM  
 Von Mises Stress: 1.00E+008  
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 Von Mises Stress: 1.00E+008  
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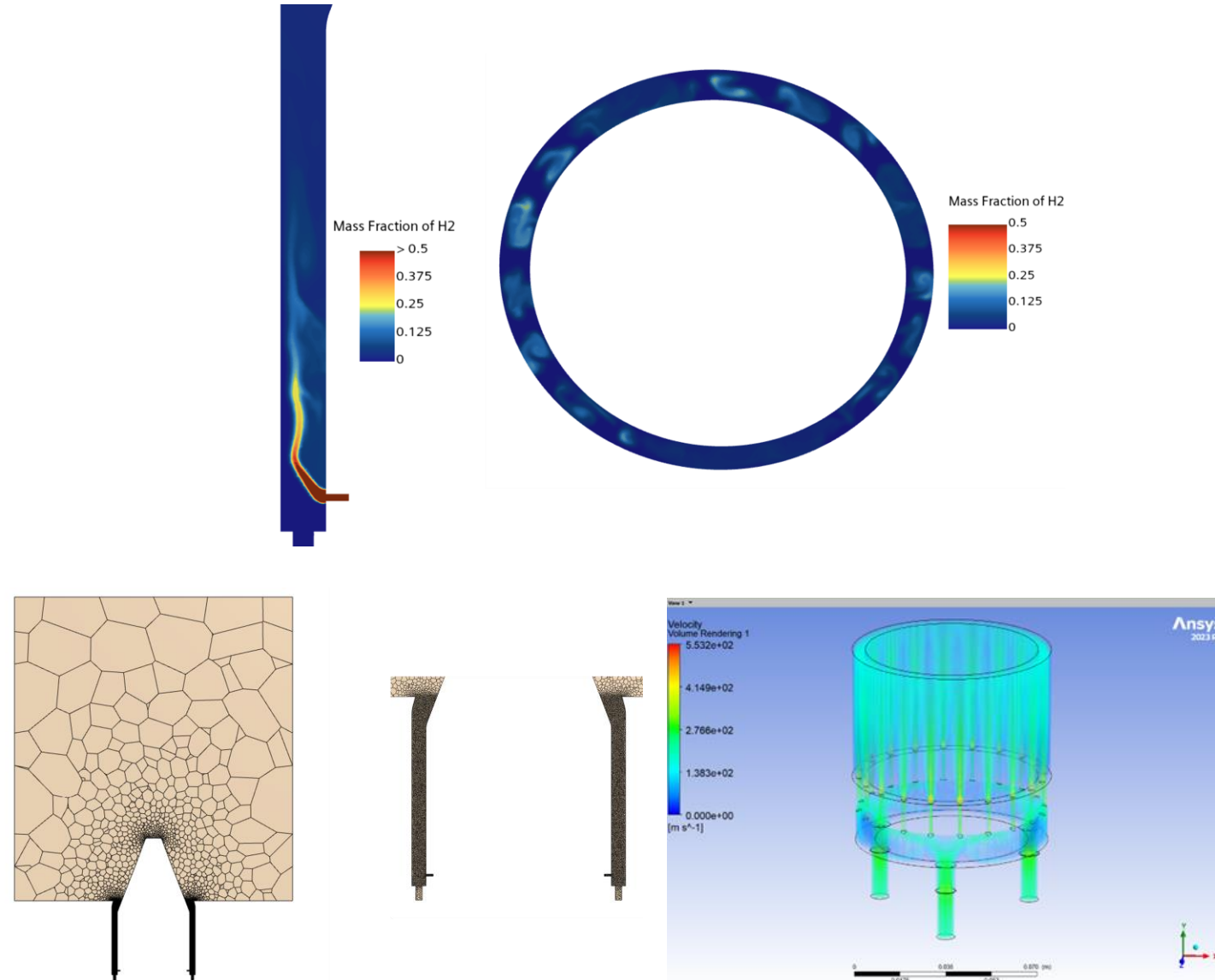
B: Eigenvalue Buckling  
 Von Mises Stress  
 Step 1  
 Press: 12 of 15 analyzed  
 2/16/2025 11:52 PM  
 Von Mises Stress: 1.00E+008  
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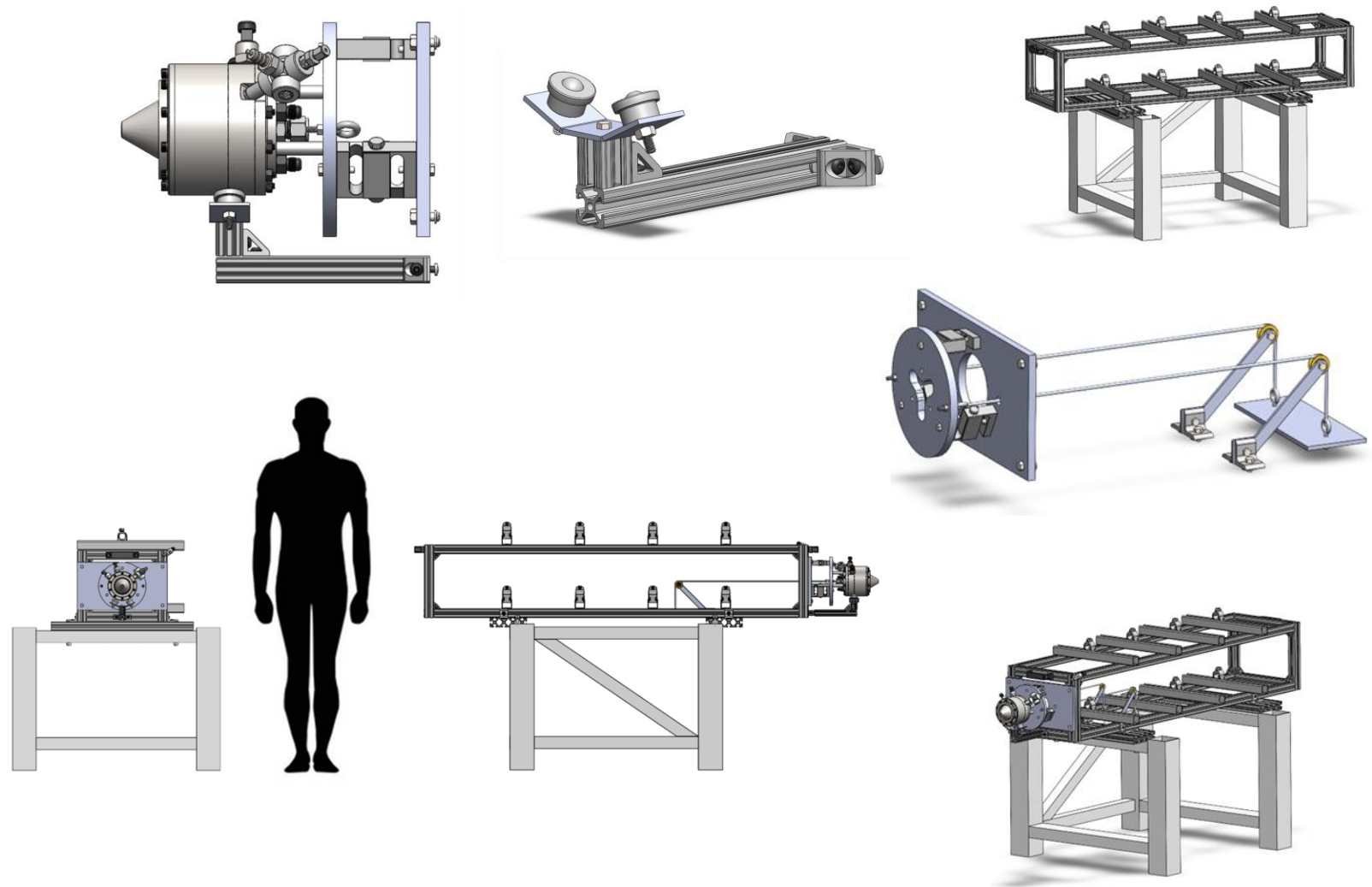
# RDE Cold Flow CFD

- Simulated in StarCCM+ to assess efficiency of injector mixing.
- 3-Dimensional, Viscous, Steady-State, multi-species model.
- Modeled from injectors to atmosphere to avoid computational intensity of subsonic plenum pressurization.



# Test Stand Design

- Simple, modular, cost-effective, but extremely strong
- 8020 aluminum extrusion frame on steel optical table
- Static/floating thrust plate config
- Mass and pulley system for load cell calibration
- Addl. ball transfer mount to support engine from below



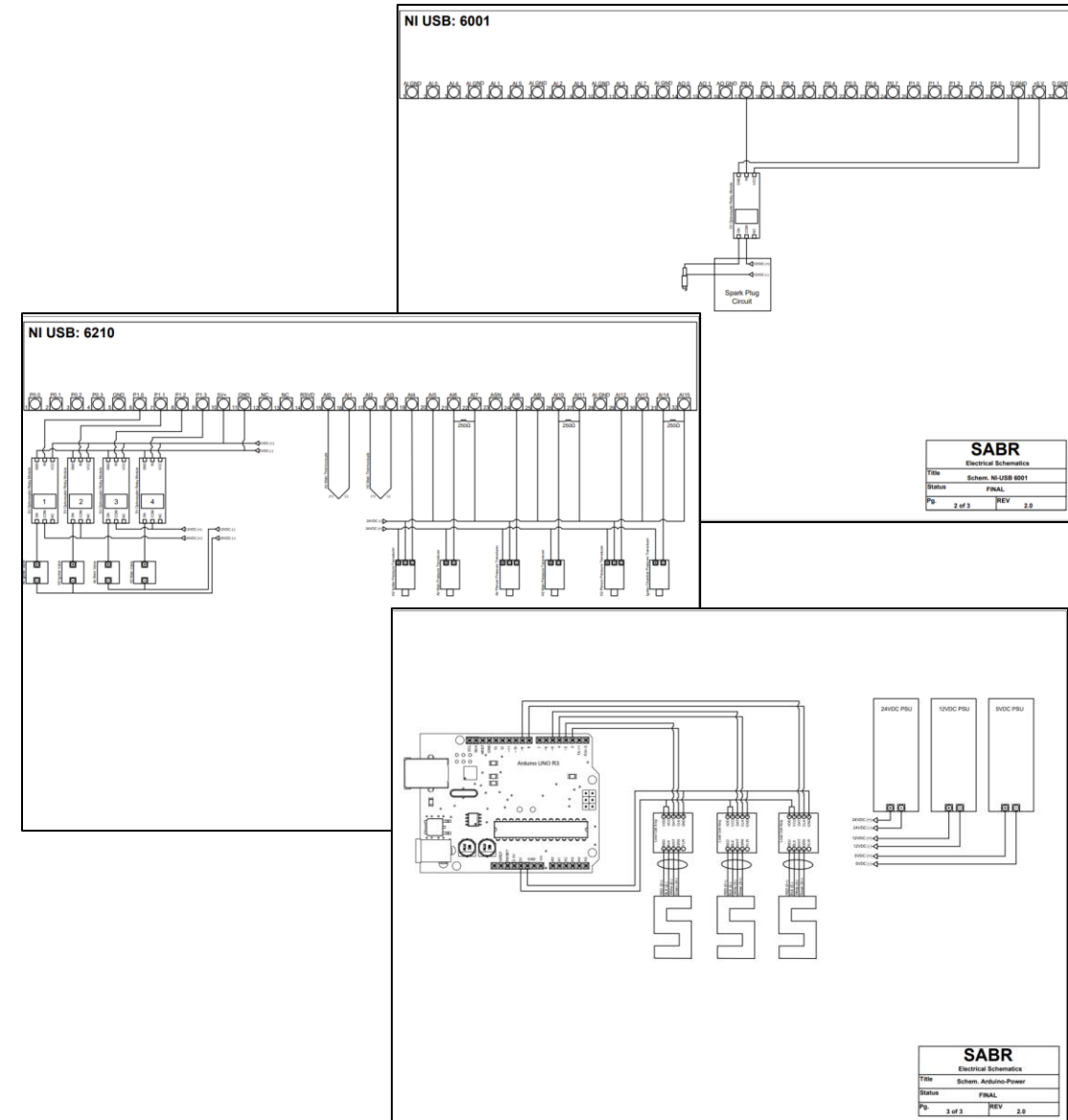
# Data Acquisition and Controls Design

## • 3 Data Acquisition (DAQ) Devices

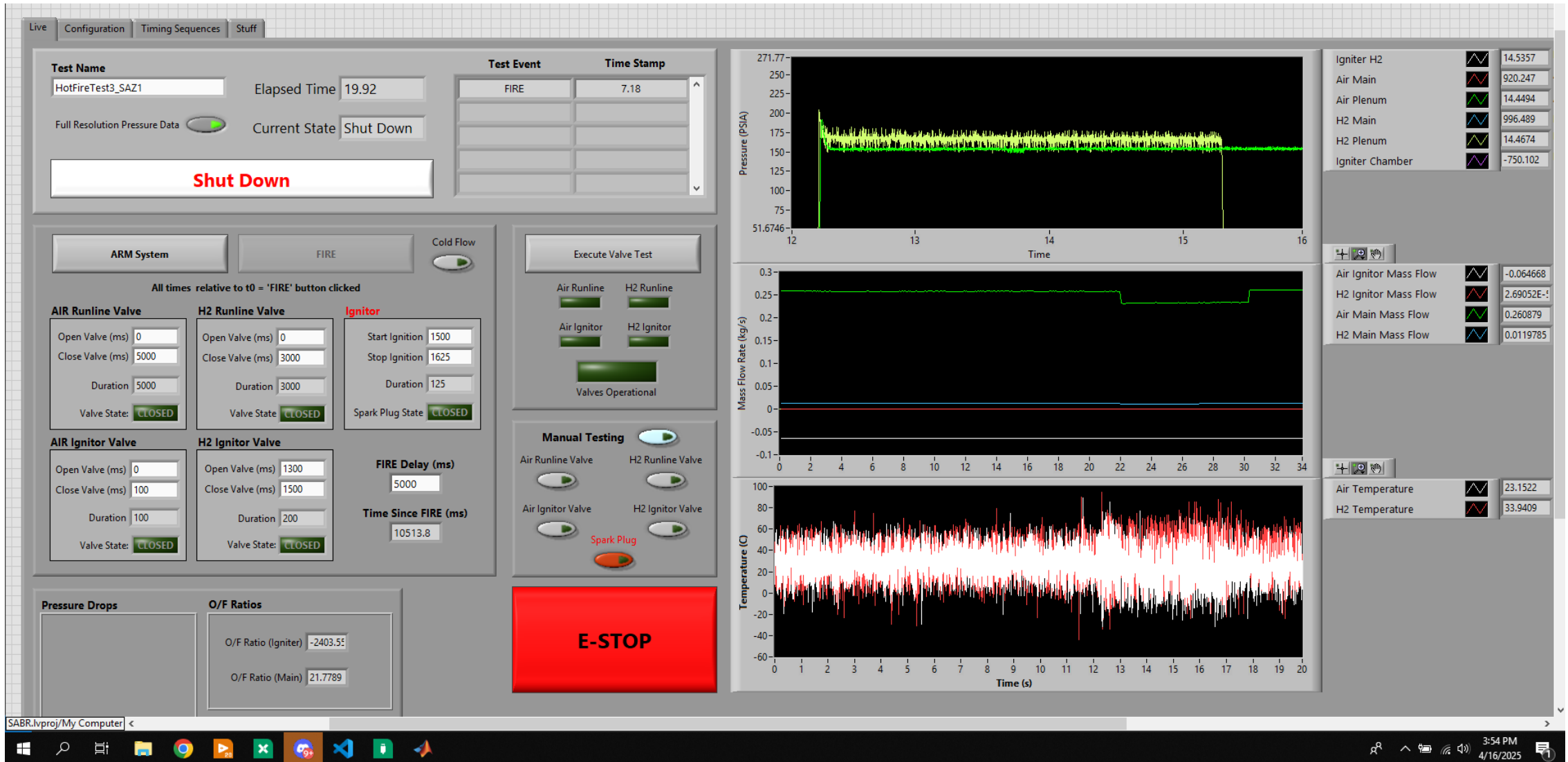
- NI USB-6210
  - 250kS/s Sample Acquisition Rate
  - 16 Single Ended Analog Inputs (8 Differential)
  - 4 Digital Input
  - 4 Digital Output
- NI USB-6001
  - 20kS/s Sample Acquisition Rate
  - 8 Single Ended Analog Inputs (4 Differential)
  - 13 Multifunctional Digital I/O
- Arduino Uno R3

## • Sensor List

- [6x] Pressure Transducers (0 - 500 PSI, 0 - 3000 PSI)
- [2x] K-Type Thermocouples (0 - 900C)
- [3x] S-Type Load Cells (0 - 200kg)
- [5x] 3v Optocoupler Relays



# Data Acquisition and Controls Design



# Fluid System Design

- Developed 1D Matlab energy loss model for calculating flow conditions throughout system
- Created Plumbing and Instrumentation Diagrams (P&ID) for visualizing system/component layout and integration
- Sized and selected components for flow measurement and control requirements

