Small-Scale Air-Breathing Rotating Detonation Engine

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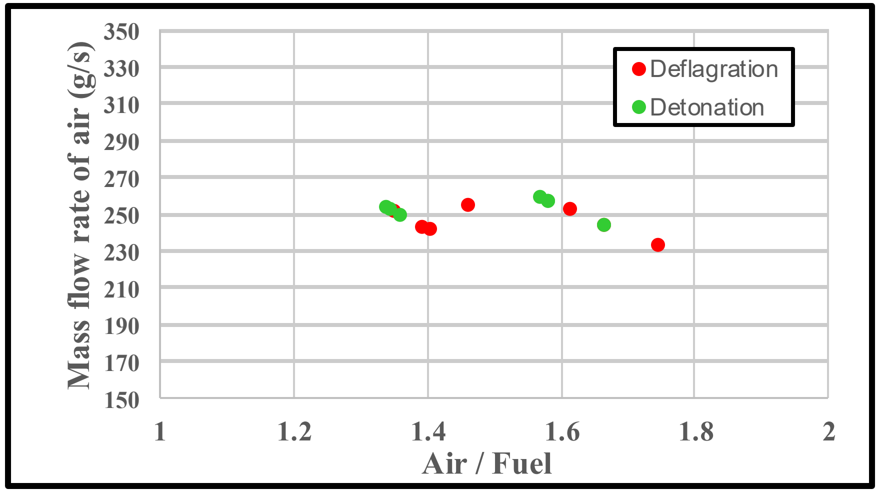
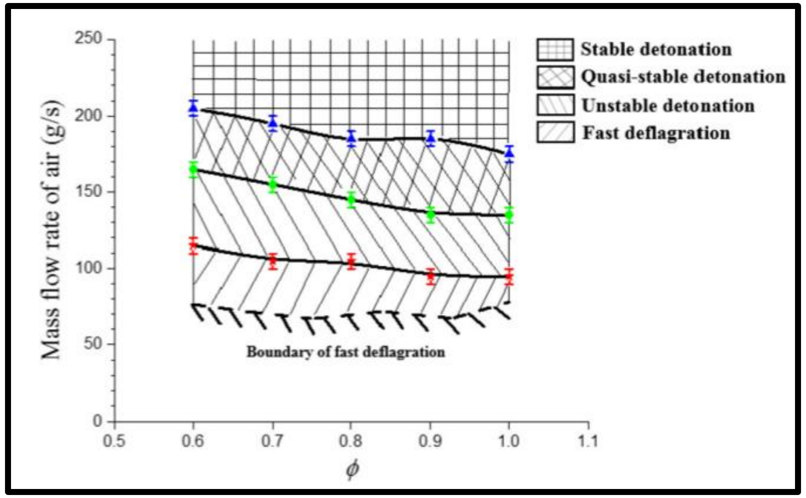
Project Goals

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

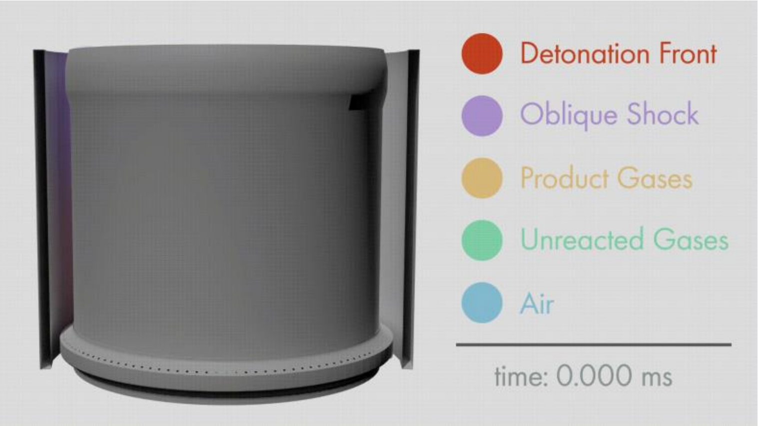


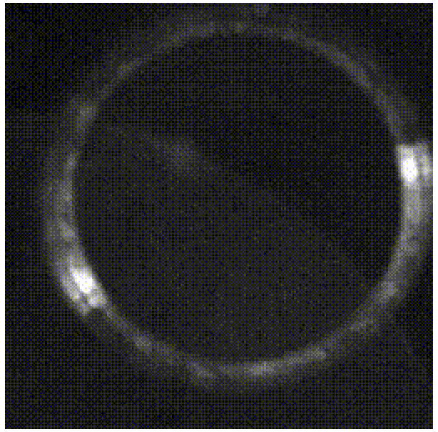


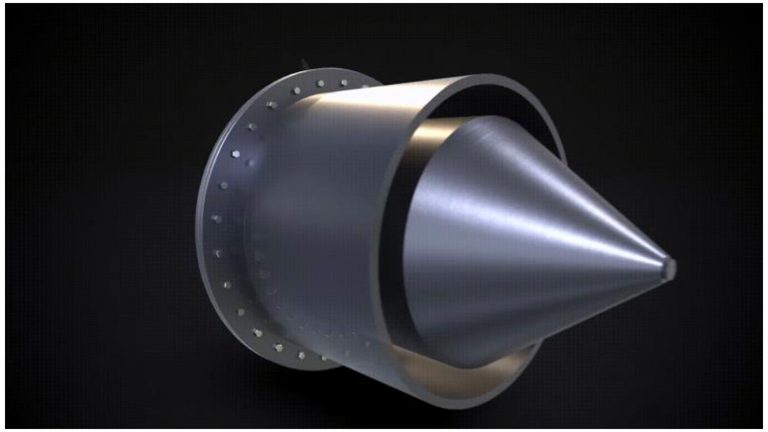
What is an RDE?

- 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

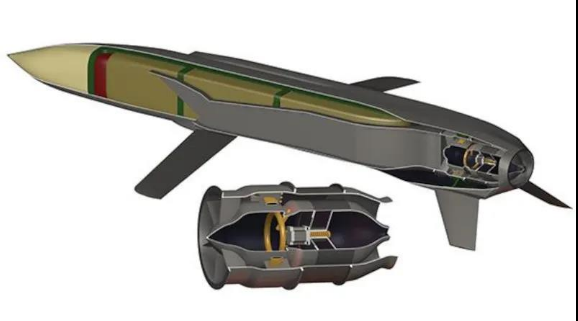






Why is SABR important?

- 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

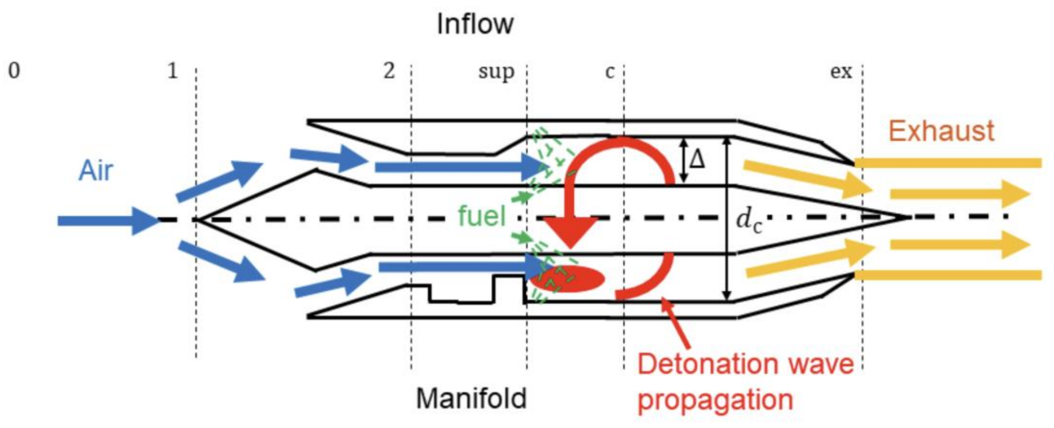
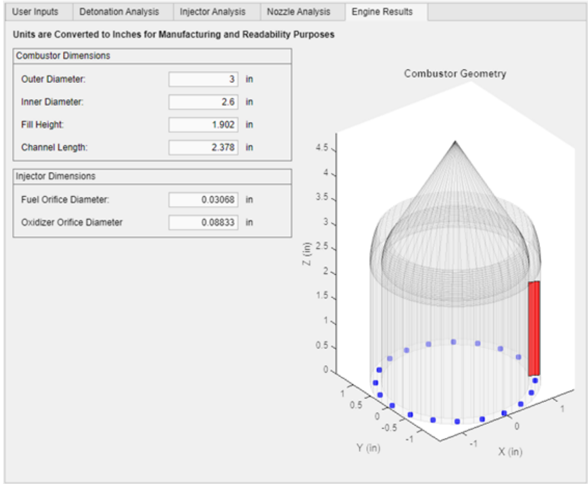
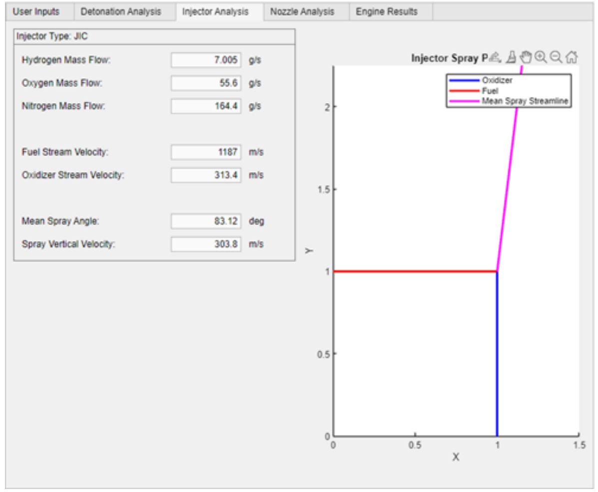


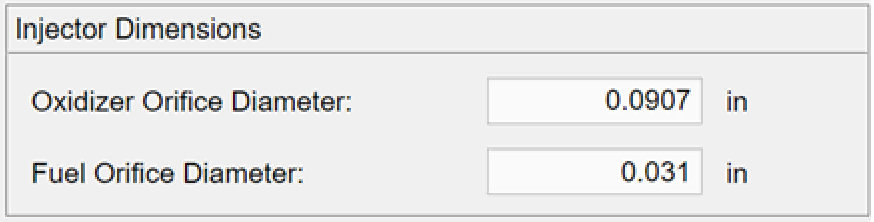
Figure 1 Air-breathing RDE concept sketch

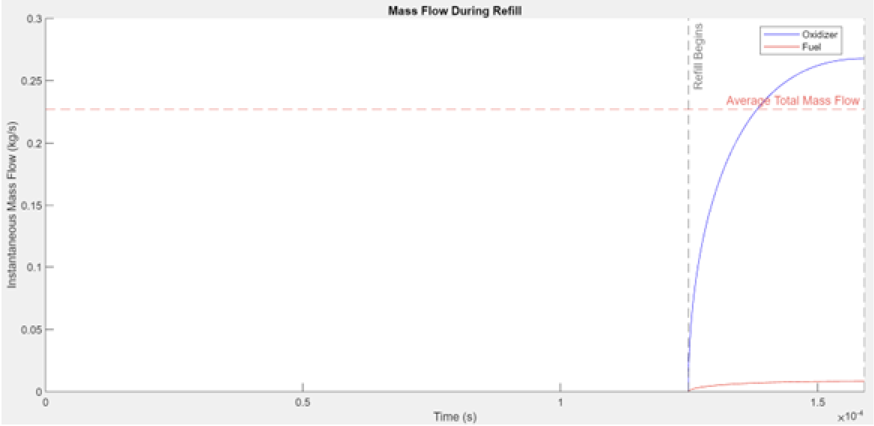
https://arc.aiaa.org/doi/pdf/10.2514/6.2021-0084

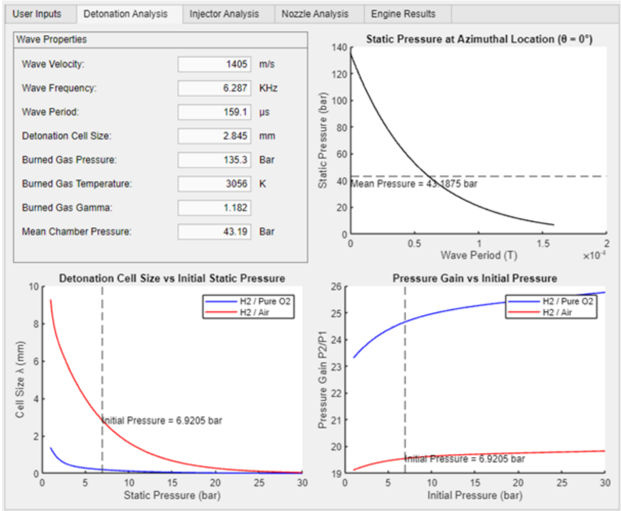
RDE Analysis

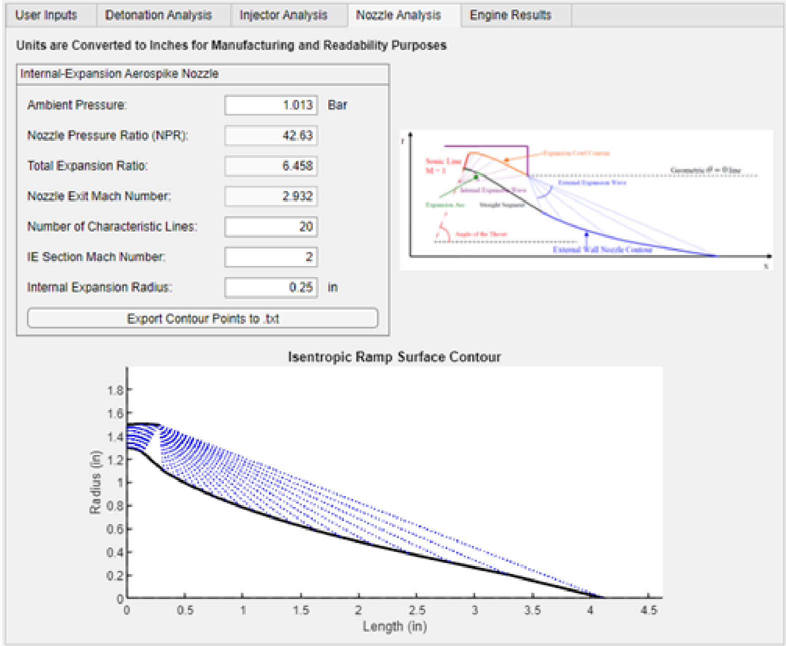


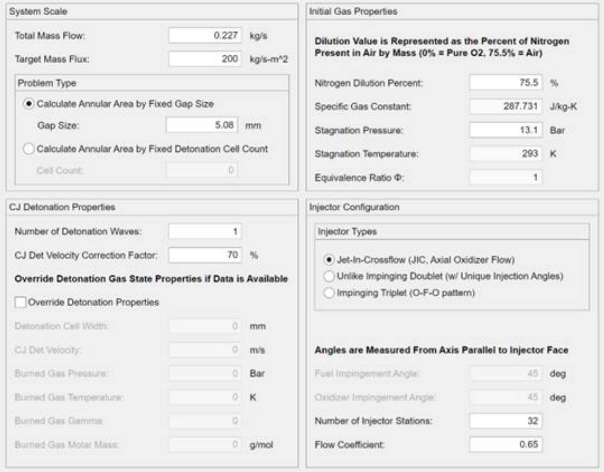






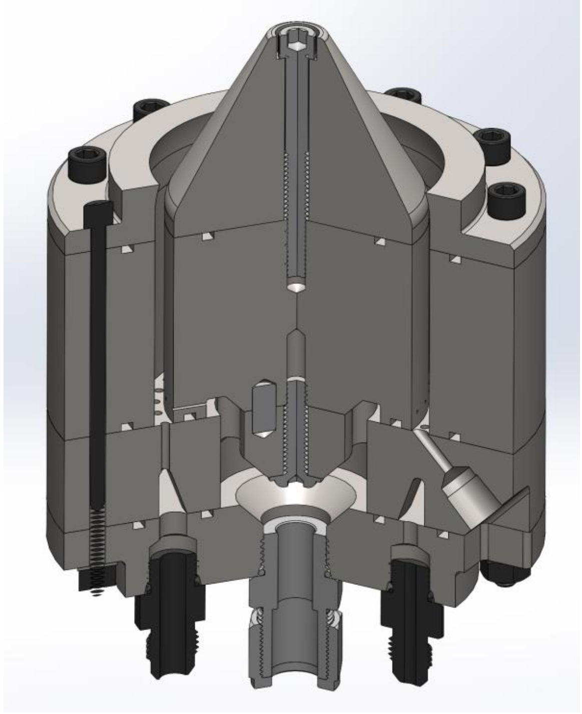






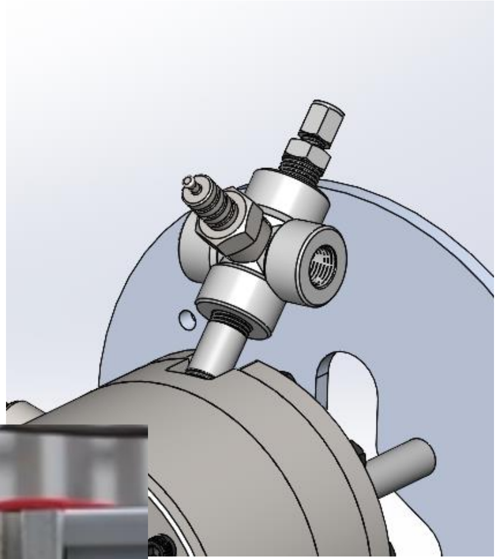
RDE Design

- 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

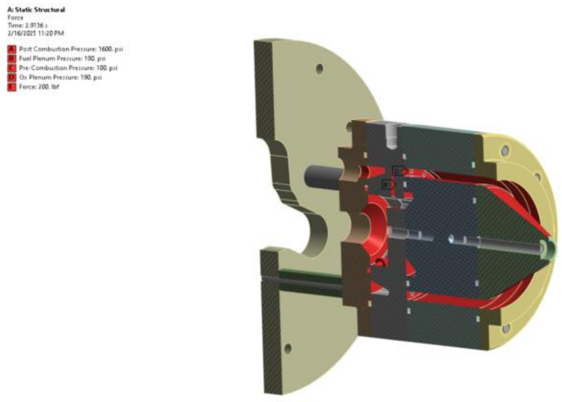


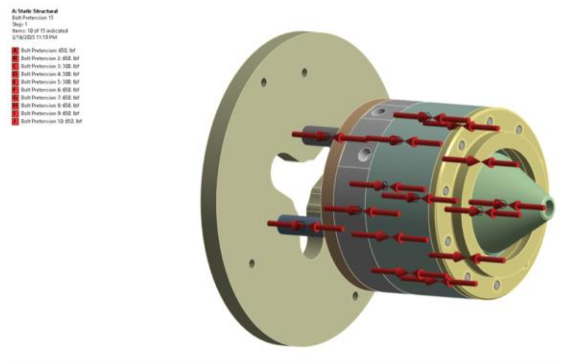
RDE Structural Analysis

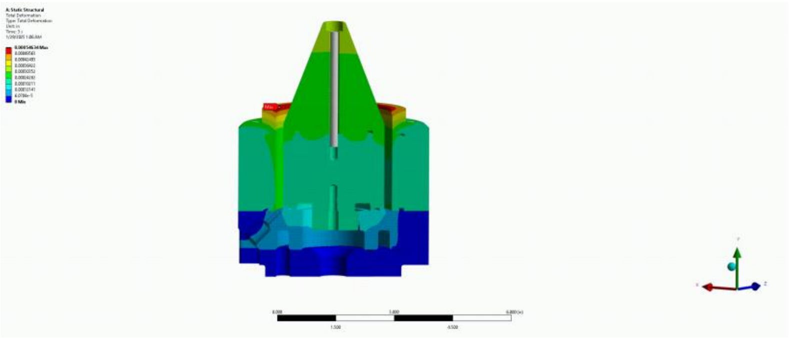
- **Boundary Conditions**
  - Induced Temperature
  - Induced Pressure
  - Load Path Fixation

- **Model Considerations**
  - Beam Modeling
  - Component Fixation
  - Load Path Fixation

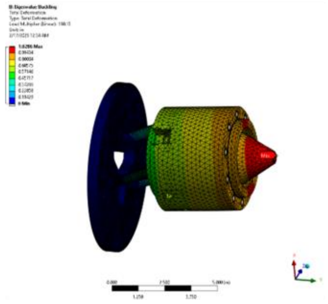
- **Results**
  - No modal or buckling failures
  - No Von-Mises failures
  - Safety Factor: >1.5

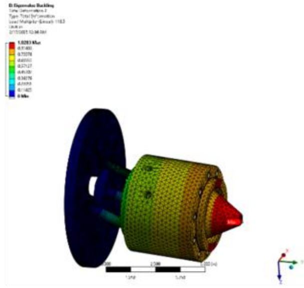


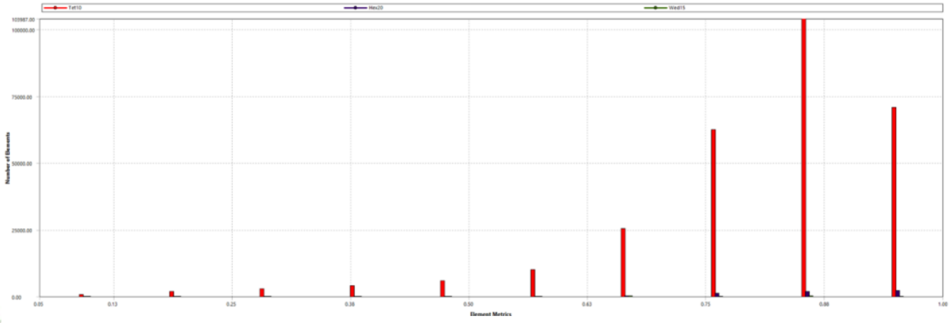




	Mode	Load Multiplier
1	1.	110.13
2	2.	110.5

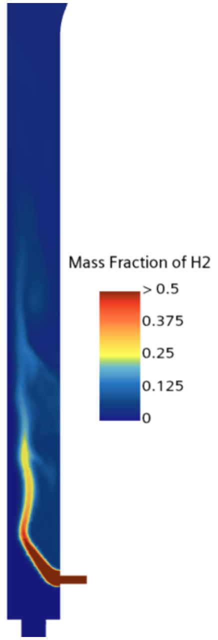


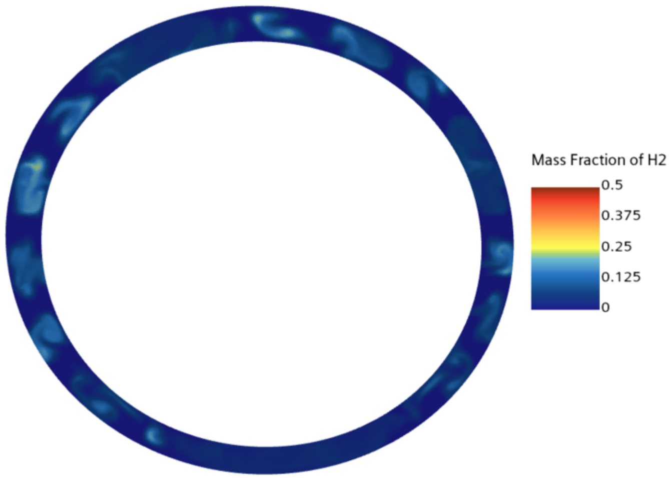


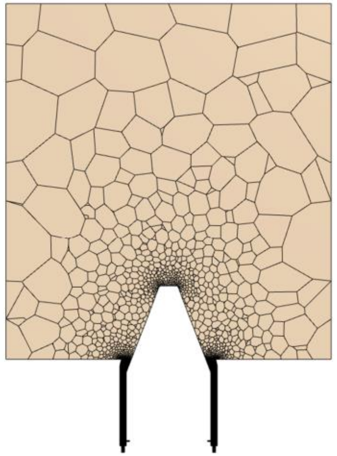


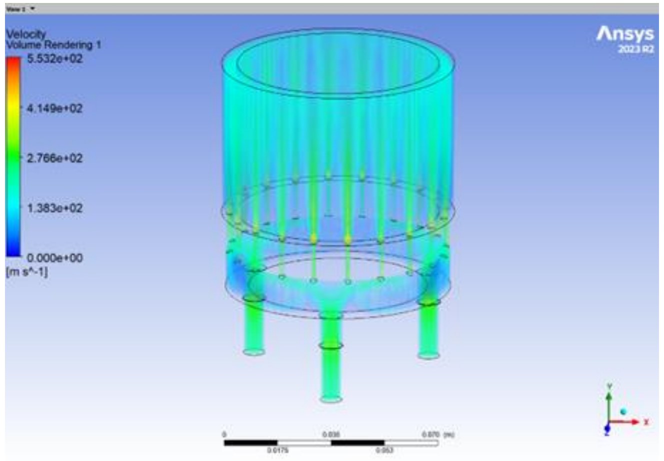
RDE Cold Flow CFD

- 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.



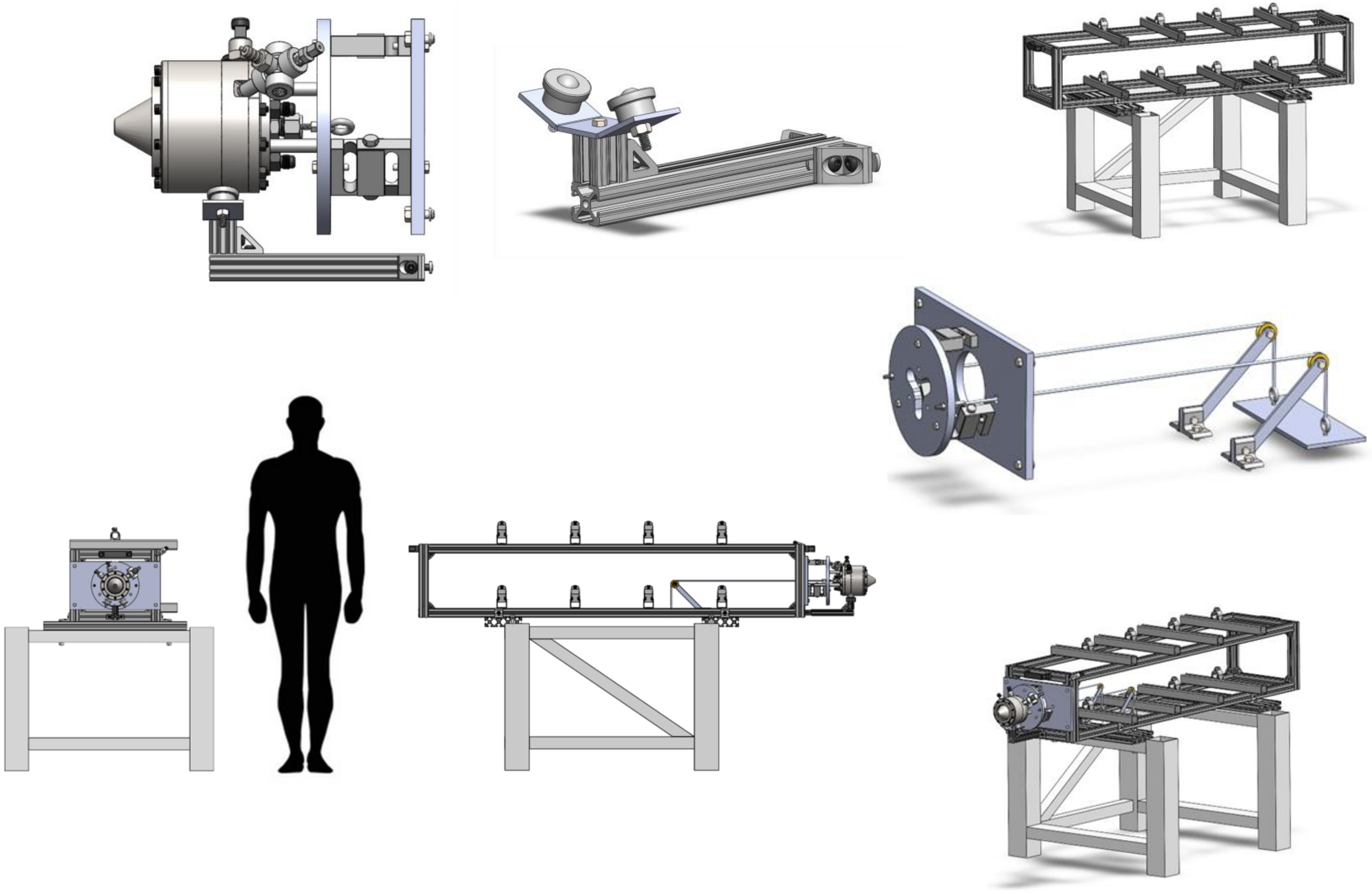






Test Stand Design

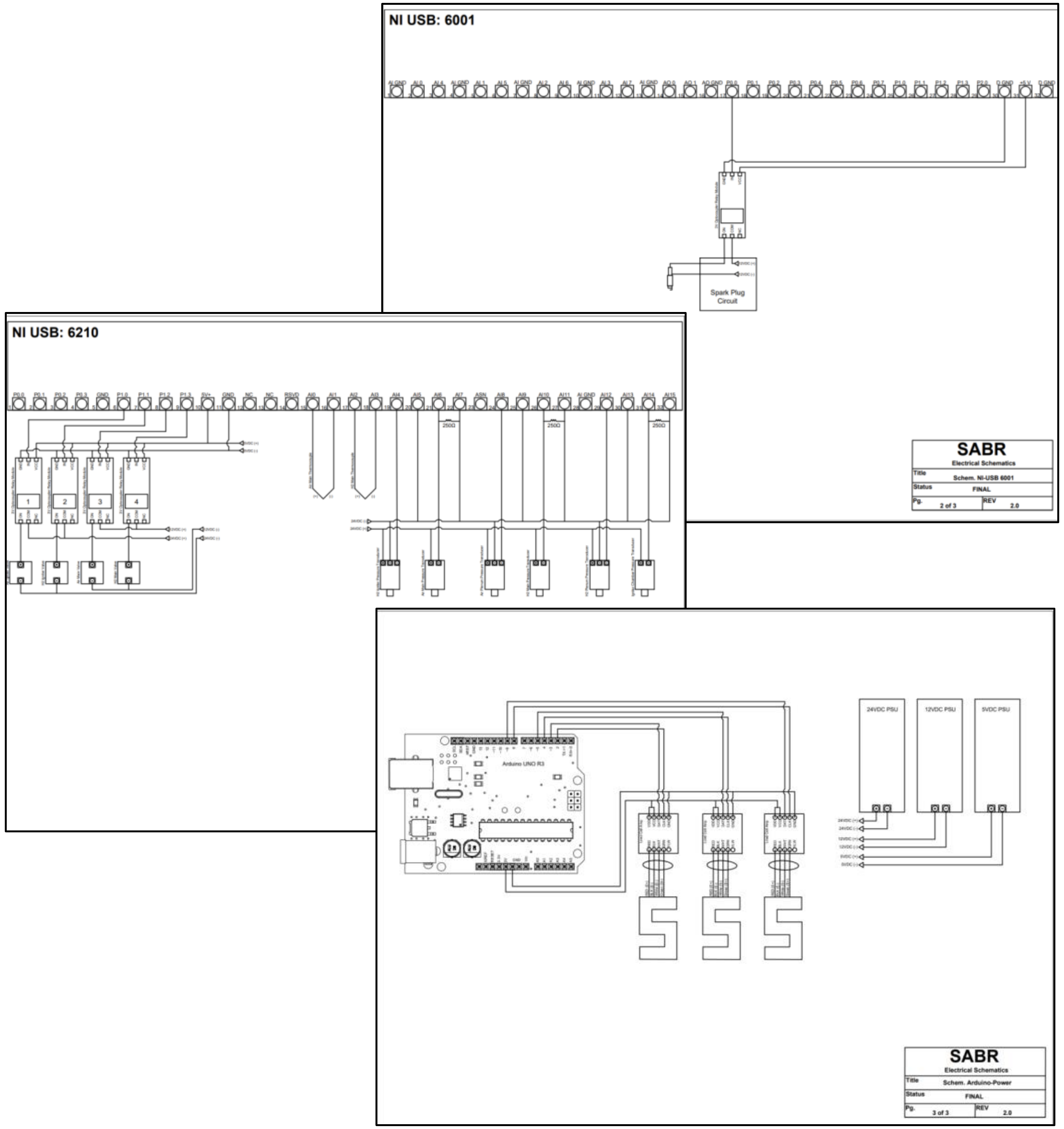
- Simple, modular, cost-effective, but extremely strong
- 8020 aluminum extrusion frame on steel optical table
- Static/floating thrust plate config
- Mass and pulley system for load cell calibration
- Addl. ball transfer mount to support engine from below



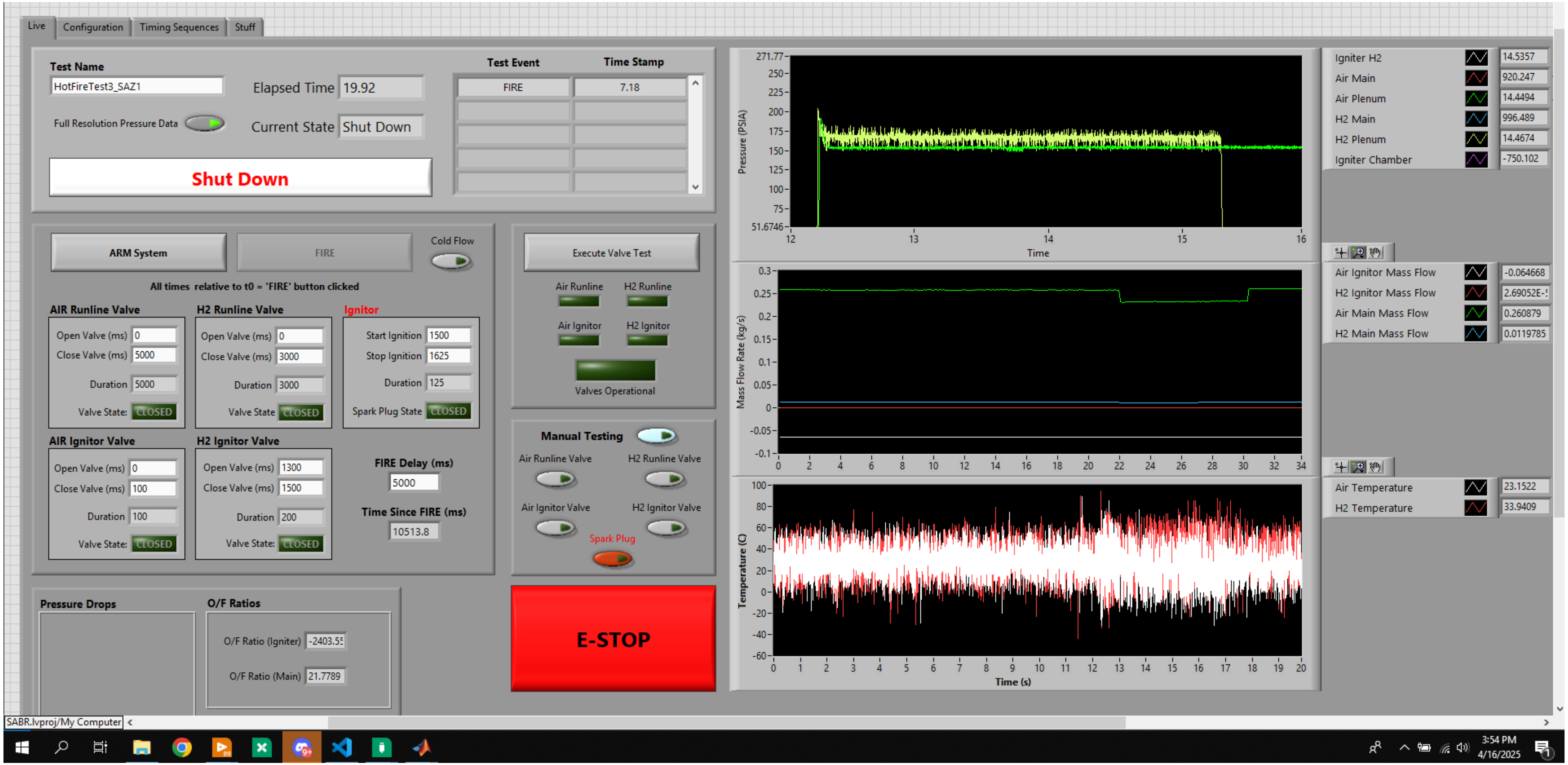
Data Acquisition and Controls Design

- 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