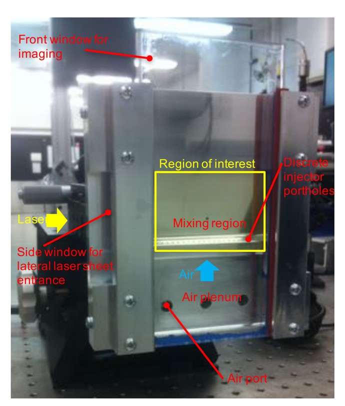
Fuel Injection Dynamics and Composition Effects on RDE Performance

Fabian Chacon, Takuma Sato, James Duvall, Supraj Prakash, Mirko Gamba and Venkat Raman
University of Michigan | Aerospace Engineering
Project sponsored by University Turbine Systems Research/NETL, award no. DE-FE0031228

Project Pbjectives

- **Objective 1:**
  Develop a comprehensive understanding of injector dynamics, coupling with diffuser back-reflections, and their impact on RDE mixing, operation and performance.
- **Objective 2:**
  Develop a comprehensive understanding of multi-component fuels (syngas and hydrocarbon blends) on RDE detonation structure and propagation, operation and performance.
- **Objective 3:**
  Develop advanced diagnostics and predictive computational models for studying detonation propagation in RDEs, with arbitrary fuel composition and flow configuration.

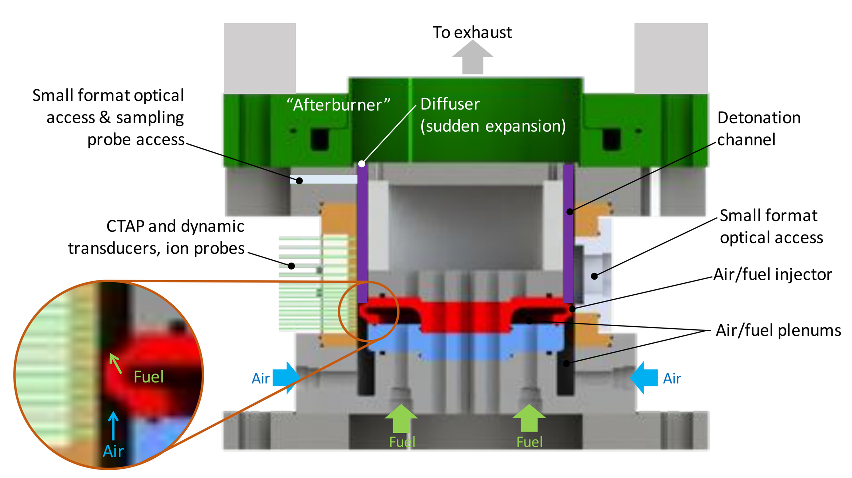
Capabilities

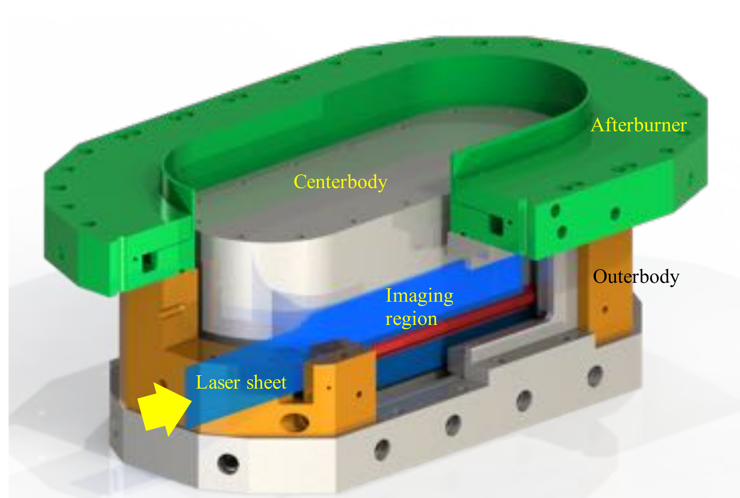


Experimental infrastructure and capabilities:

Sector Test Bed
Small ~4 inch sectors modeling injector designs with optical access for High Speed Schlieren Imaging. Test are conducted with air and helium at equivalent stoichiometry and flow rates.

MRDE
The Michigan Rotating Detonation Engine test stand holds a 6 inch RDE capable of flowing up to 0.5 kg/s of air with equivalence ratio of 1. Instrumented with static pressure measurements throughout. The system is capable of CTAP mean profiles as well as high speed pressure measurements.

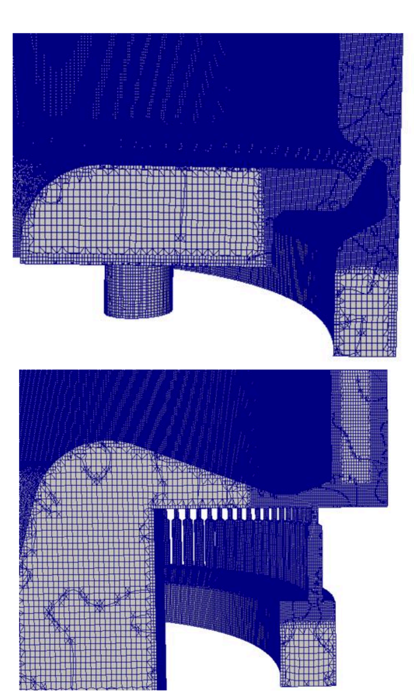




RTRDE
The Race Track Rotating Detonation Engine utilizes the same test stand as the MRDE. It is the equivalent of 12" diameter round RDE. Designed to have optical access for imaging through the main window as well as for laser-based diagnostics, such as planar laser-induced fluorescence, which are enabled by a specially designed laser access window.

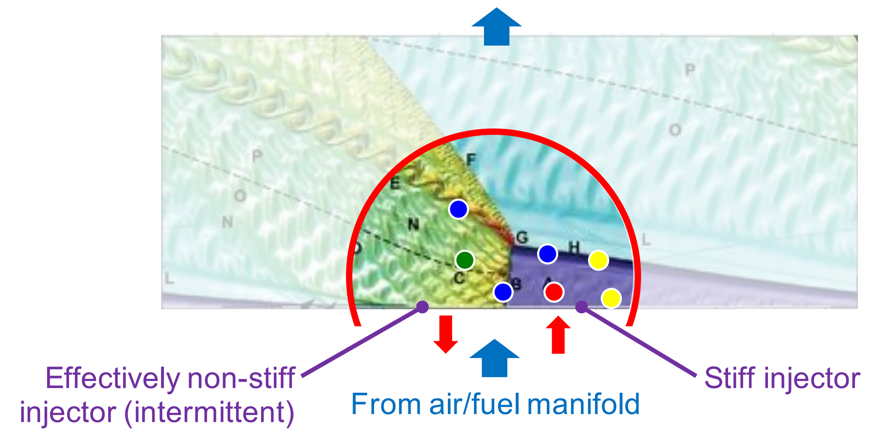
Goals of computational effort:

- **Develop fully-resolved adaptive mesh compressible solvers for capturing detonation processes**
  - Study structure of detonations in non-premixed systems
  - Develop reduced-order models
  - Study fuel composition effects on stability
- **Assist in the development of the experimental RDE configurations**
  - Provide detailed simulation data to complement experimental measurements
  - Conduct simulations outside of experimental parameters to extend datasets
- **Developments and studies leverage**
  - OpenFOAM suites of codes
  - U-M detonation solvers UMDetFOAM



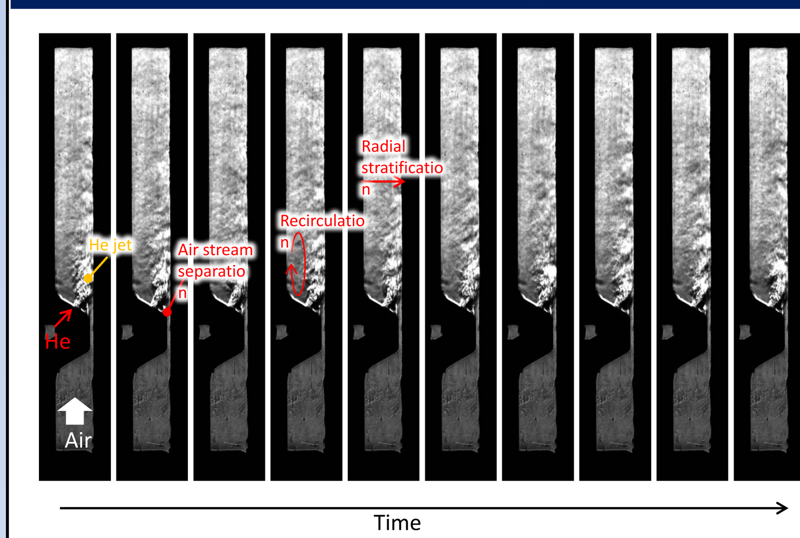
Top: Pintle Mesh
Bottom: AFRL Mesh

Problem Statement

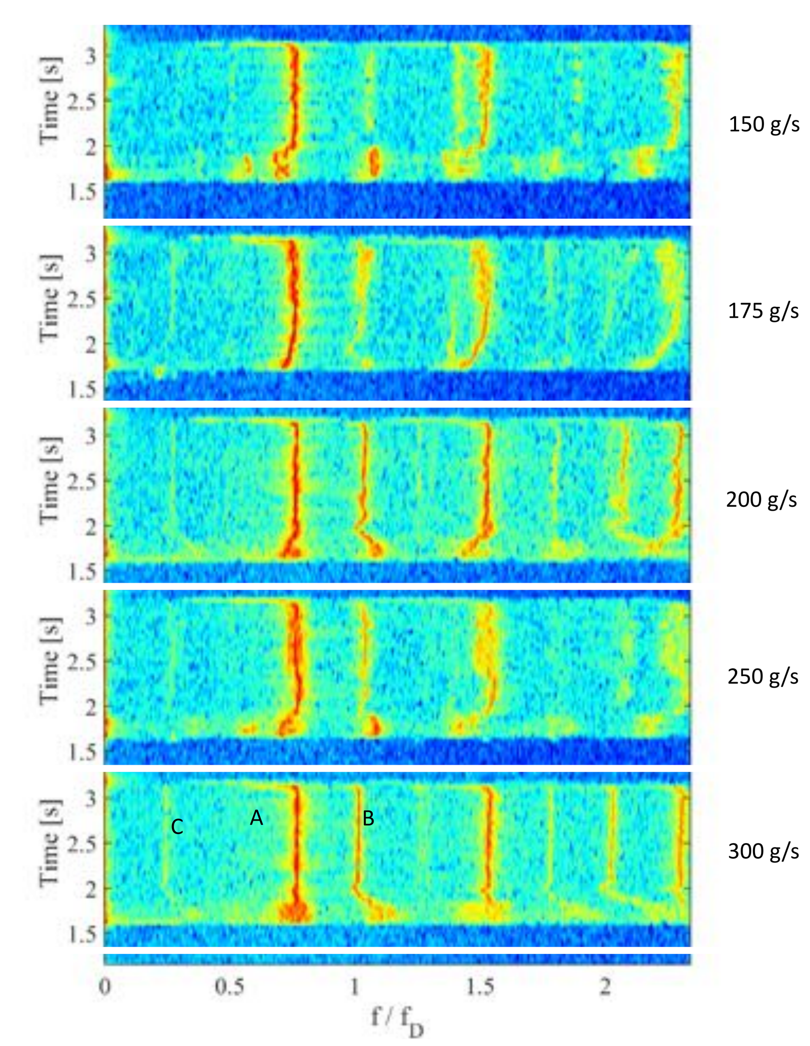


- **Unsteady operation of injection system due to detonation wave:**
  - Injector transitions from stiff to non-stiff operation mode
  - Post-detonation products backflow into plenums
  - Excited plenums dynamics
- **Strongly coupled system: the response of the injection system to detonation wave propagation (pressure forcing) induces:**
  - Pressure oscillations in plenums (non-stiff injector)
  - Back-reflections from diffuser (impedance mismatch and wave reflections)
  - Mixing dynamics and effectiveness are altered, and result in:
    - Incomplete fuel/air mixing
    - Fuel/air charge stratification
  - Detonation wave dynamics and structure may induce:
    - Mixture leakage (incomplete heat release)
    - Parasitic combustion

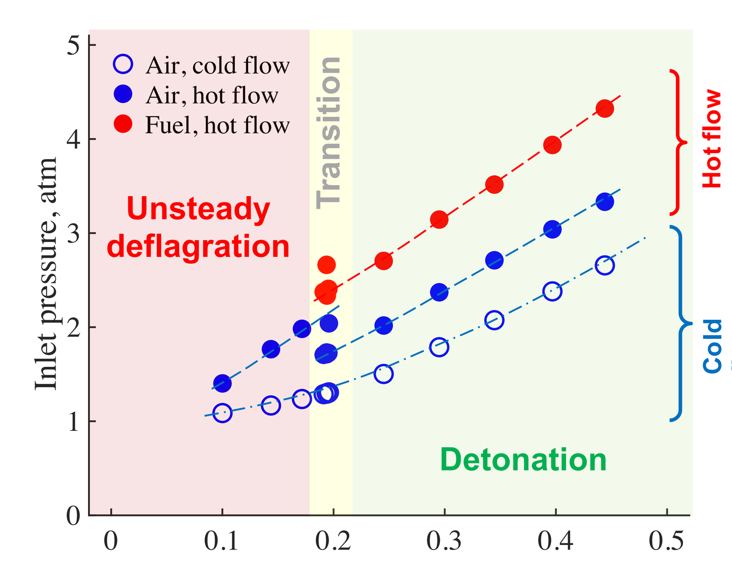
Experimental Results



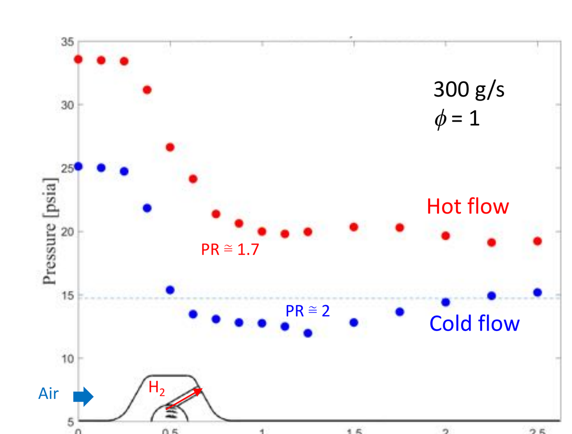
High speed schlieren of pintle sector. From model testing in the above experiment it is possible to see a strong recirculation region following the air throat behind the helium jet, as well as flow separation at the expansion following the air throat.



Waterfall spectra of detonating cases at equivalence ratio of 0.8 computed from high speed pressure measurements. Spectral signatures of main detonation can be seen in feature A. The nature of B and C are under investigation.

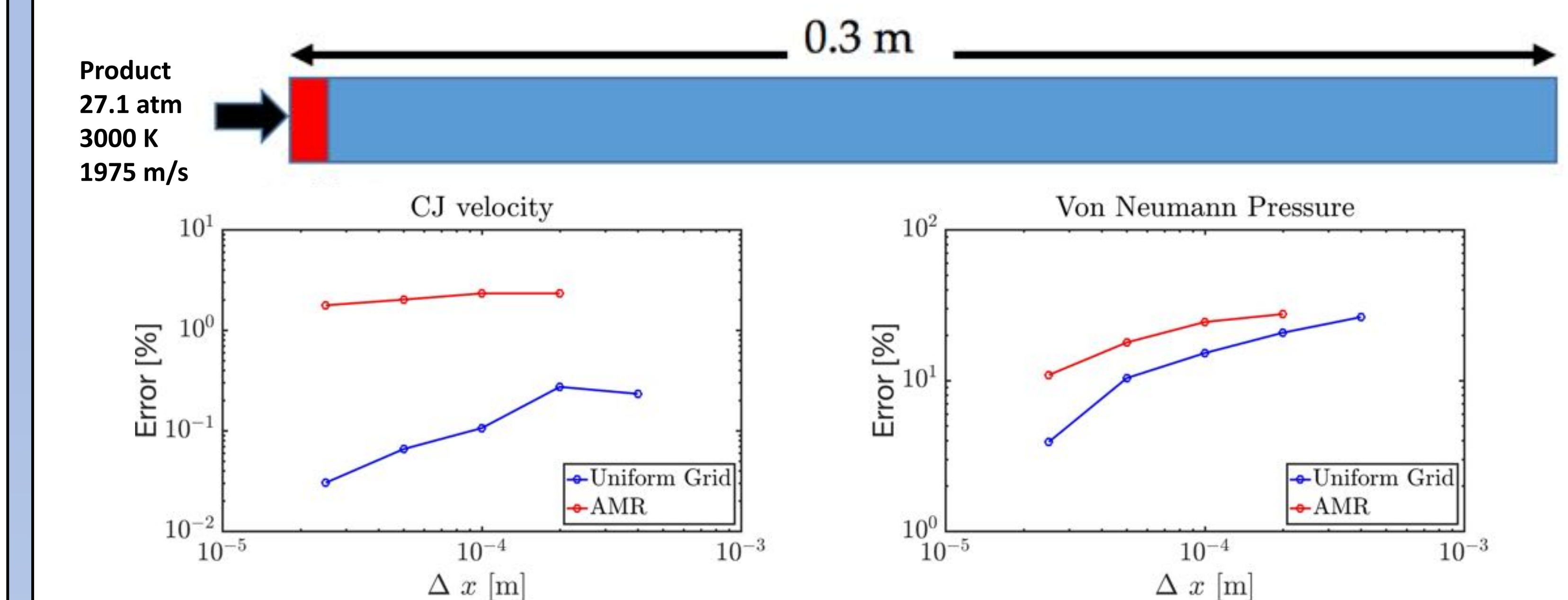


Plenum pressures taken during experimental runs at varying mass flow rates. As mass flow rate increases, plenum pressure rises as well. During combustion, an additional pressure rise is seen as the RDE enters steady state operation. However for cases where the RDE transitions between detonative and deflagrative modes, the plenum pressures are lower when the device is in the detonative mode compared to the deflagrative mode.

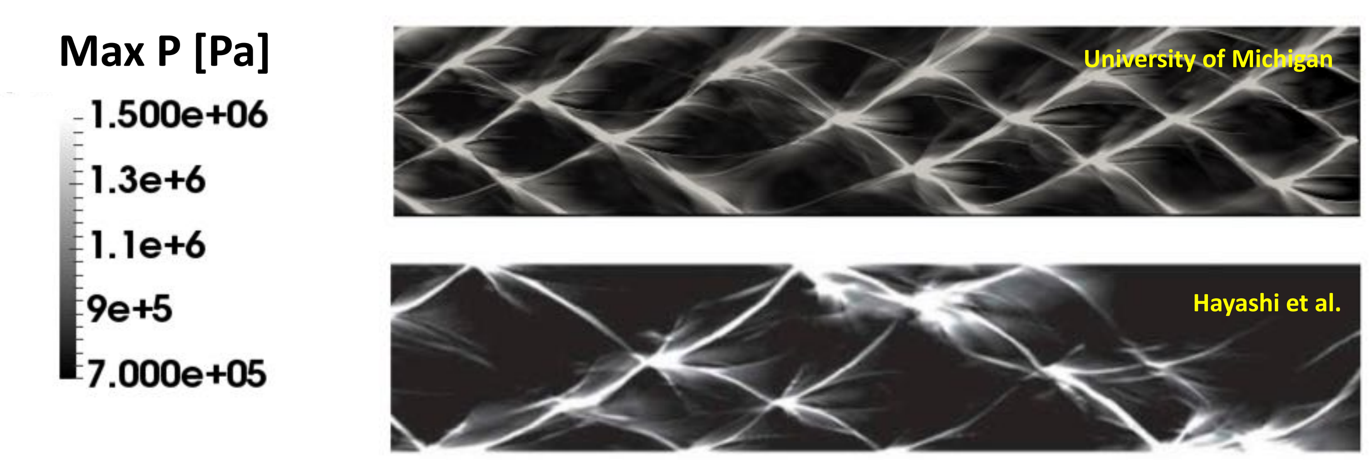


Mean pressure profile taken with CTAP measurements during an experimental run. Comparison between cold (unfueled) and hot (fueled, detonating) flow.

Computational Results

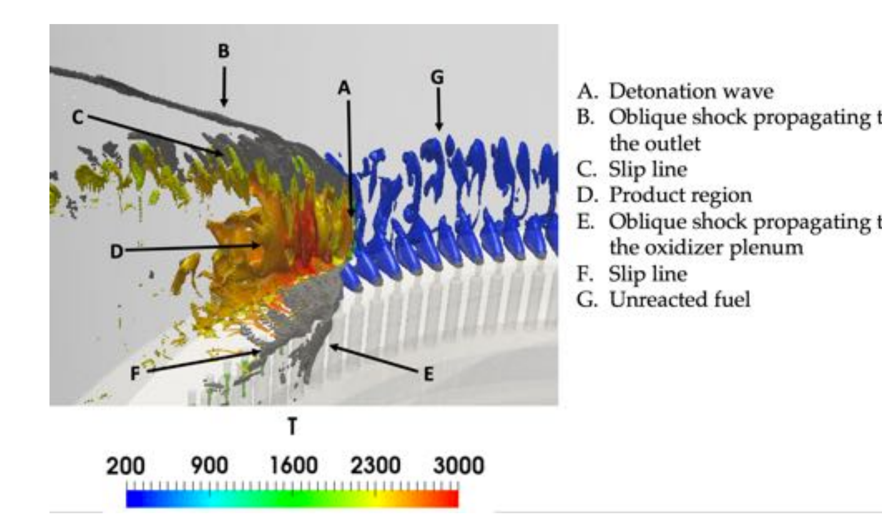


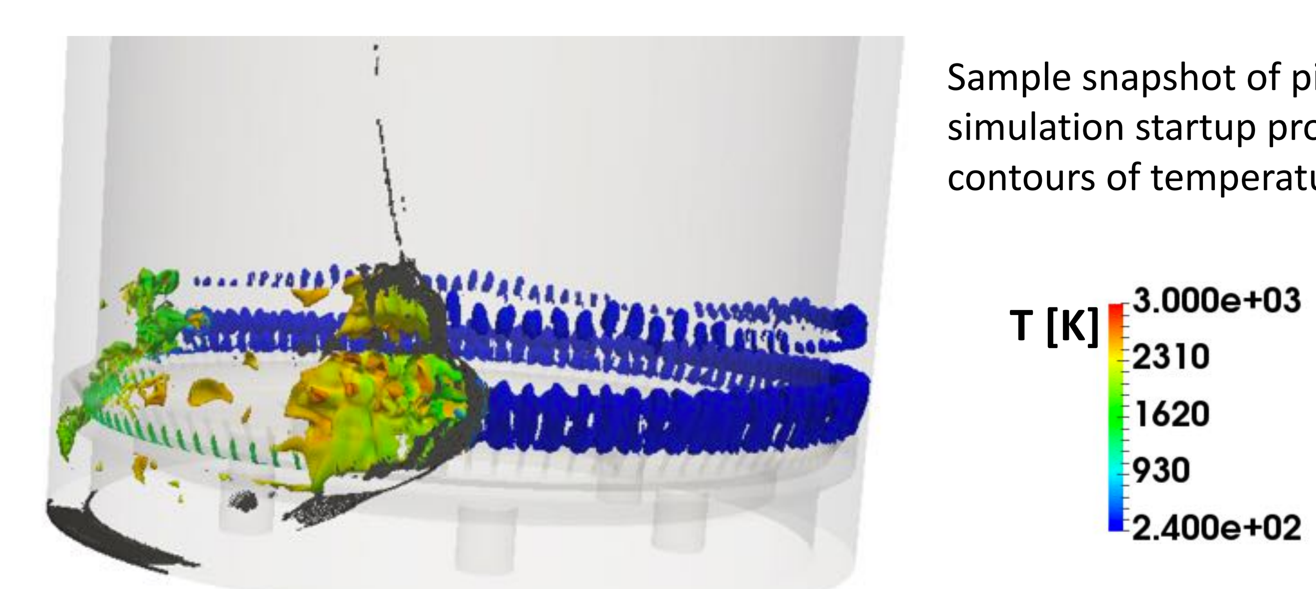
Convergence analysis of H_2/air mechanism in 1D simulation of detonation comparing uniform grid spacing with Adaptive Mesh Refinement.



UMDetFOAM detonation cell size validation with previous literature. 2D computation done on ethylene and oxygen reaction, initial conditions of 300 K and 0.1 atm.

Iso-contour plot of AFRL injector geometry showing the capabilities of the current codes to capture important flow characteristics such as the detonation, oblique shock wave and the resulting slip line between the two.

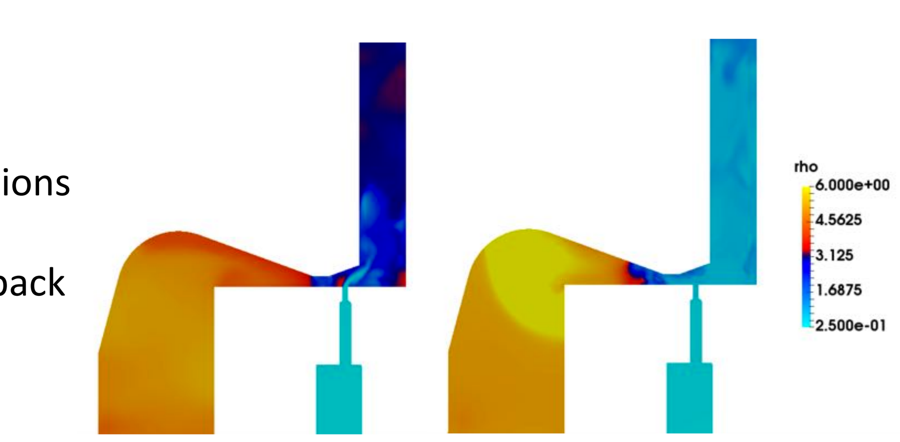




Sample snapshot of pintle geometry simulation startup process. Iso-contours of temperature is shown.

Planar slice of AFRL geometry. Simulations done on this geometry show:

- Post-combustion gases propagate back into both plenums.
- Choking is terminated
- Blast waves move into plenum



Left: Before Detonation
Right After Detonation