Development of a High-Pressure Hydrogen-Ammonia Combustion System for Flame Dynamics Research

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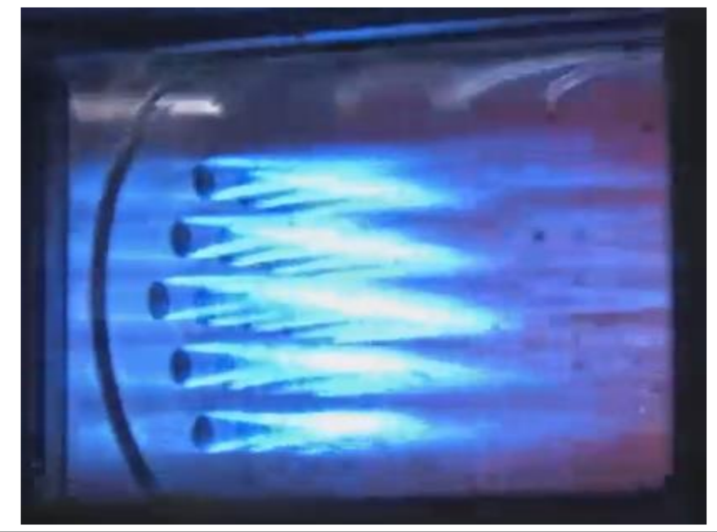
1. Motivation and Significance

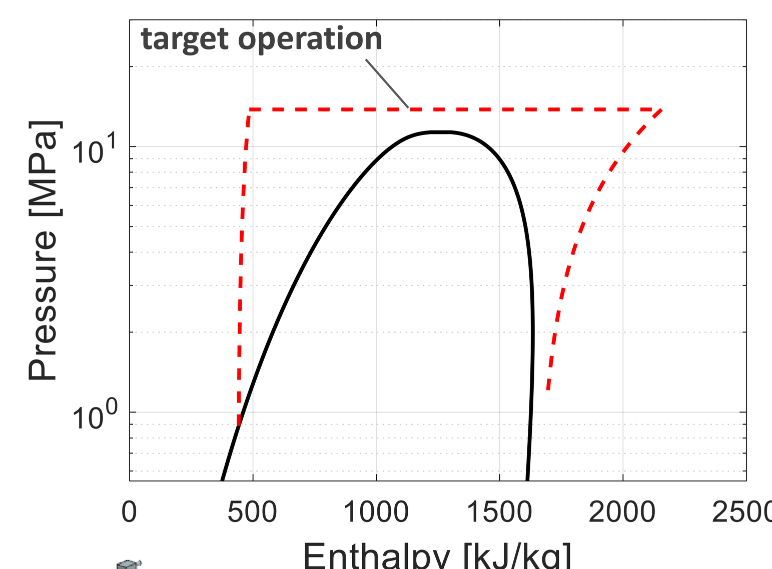
Investigate flame structure and dynamics for gas turbine combustion with hydrogen, ammonia, and mixtures of these fuels with natural gas at engine relevant conditions

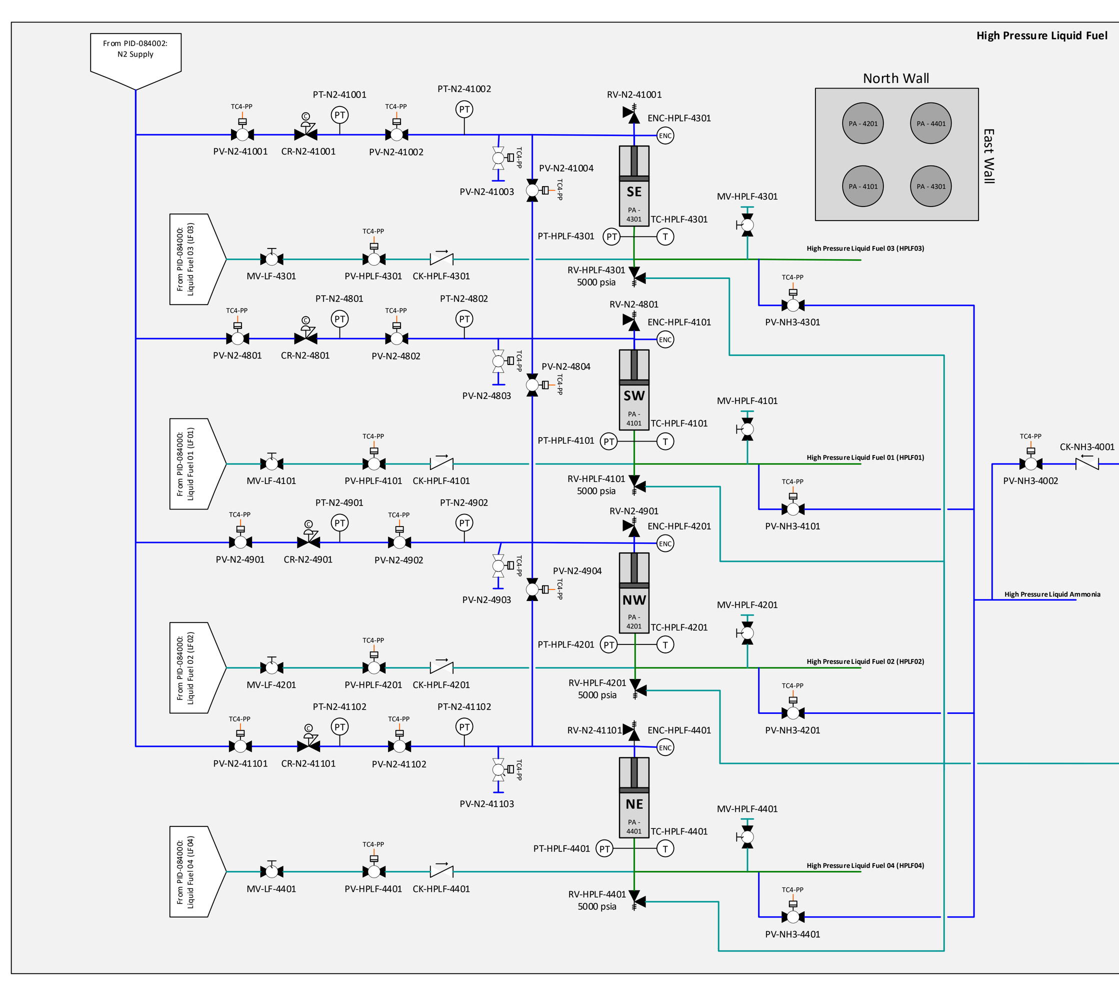


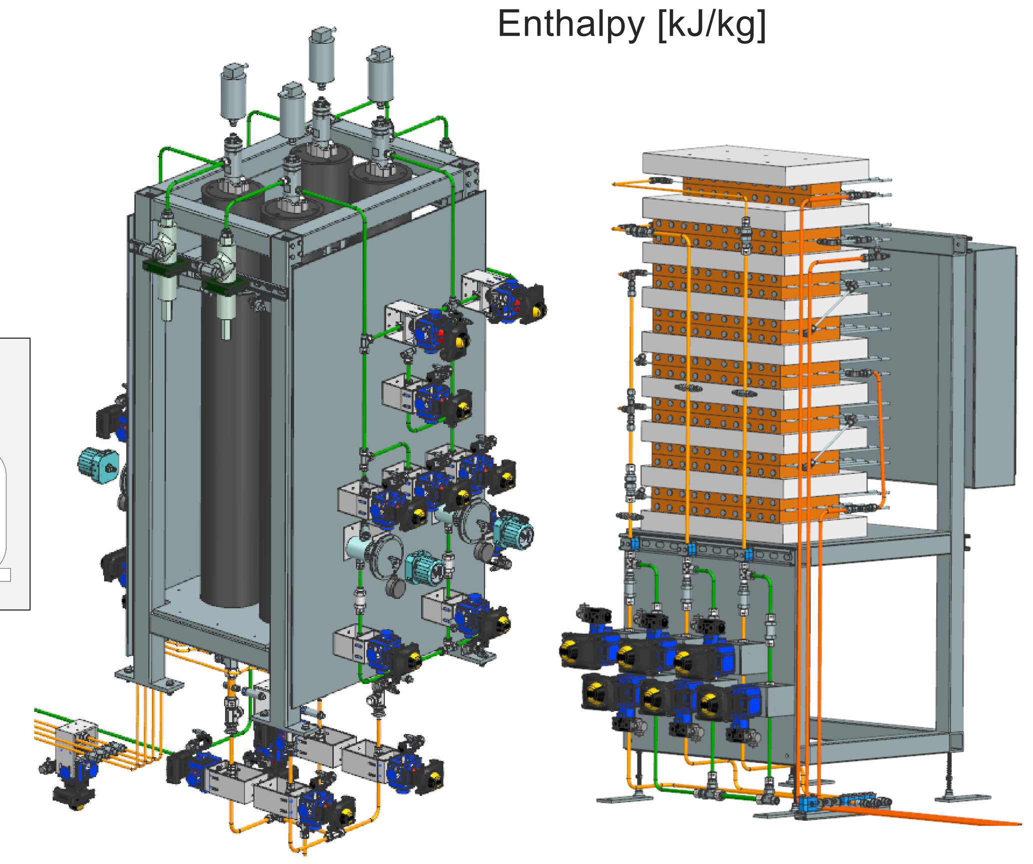
- Research focus on multi-stage, multi-tube, micromix (M3) injectors
- Successful development and demonstration of high-pressure ammonia system for combustion research at engine relevant conditions complete
- Gaseous or liquid phase ammonia injection up to 345 bar
- Influence of ammonia on combustion instabilities demonstrated

2. Ammonia System Design

- Ammonia delivered in saturated state pressurized to target conditions in a piston tank
  - 70 kg of ammonia available per test
  - Maximum supply pressure of 345 bar
- Ammonia delivered to steady state vaporizer prior to injection
  - Accommodates liquid NH_3 injection







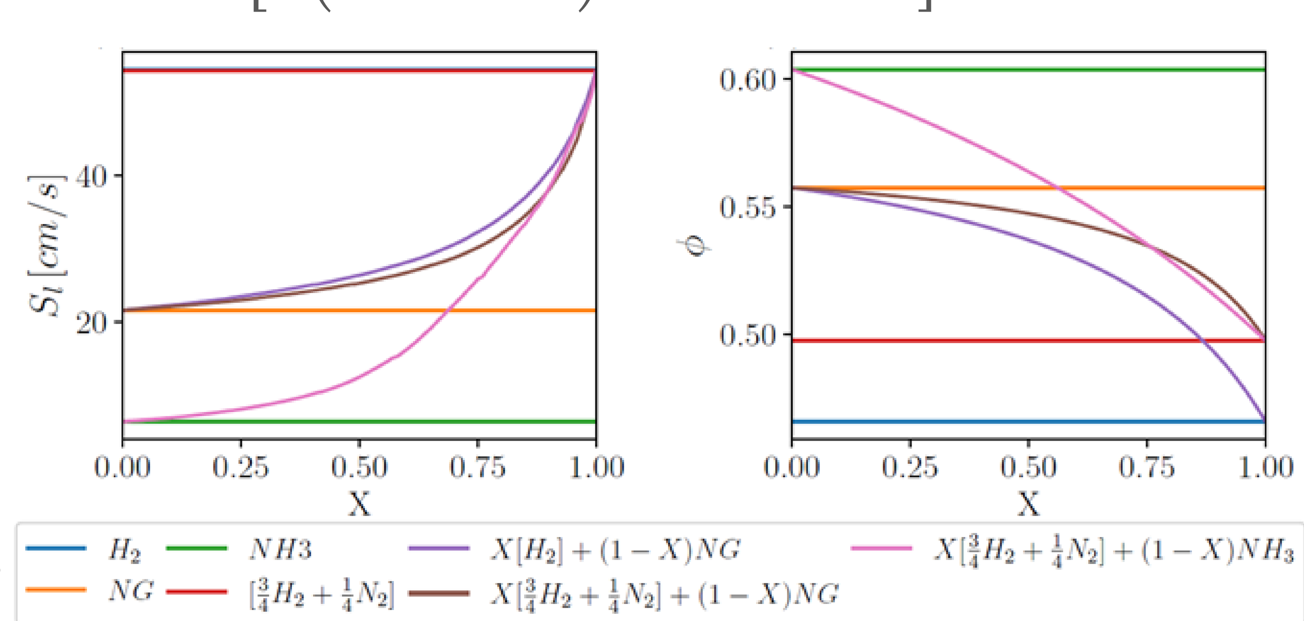
NH_3 Piston Tanks NH_3 Vaporizer

3. Experiment Design

- Experiment designed to study flame structure and dynamics with hydrogen, ammonia, and mixtures of these fuels with natural gas
- Fraction of fuel derived from ammonia: X
  - Varied from 0.5 – 1.0 in experiments
- Ammonia decomposition efficiency: η
  - Varied from 0.4 – 1.0 in experiments
- Fuel-air ratio maintained to attain adiabatic flame temperature of 1980 K (DOE target for 65% combined cycle efficiency)
- Ammonia decomposition efficiency parametrically varied to investigate impact of combustion dynamics (and emissions)

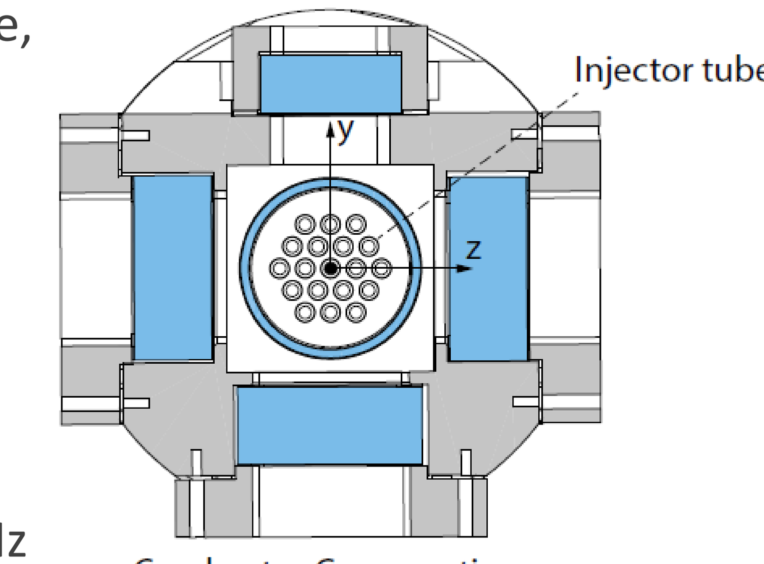
Fuel Composition:

$$X\left[\eta\left(\frac{3}{2}H_2+\frac{1}{2}N_2\right)+(1-\eta)NH_3\right]+(1-X)NG$$

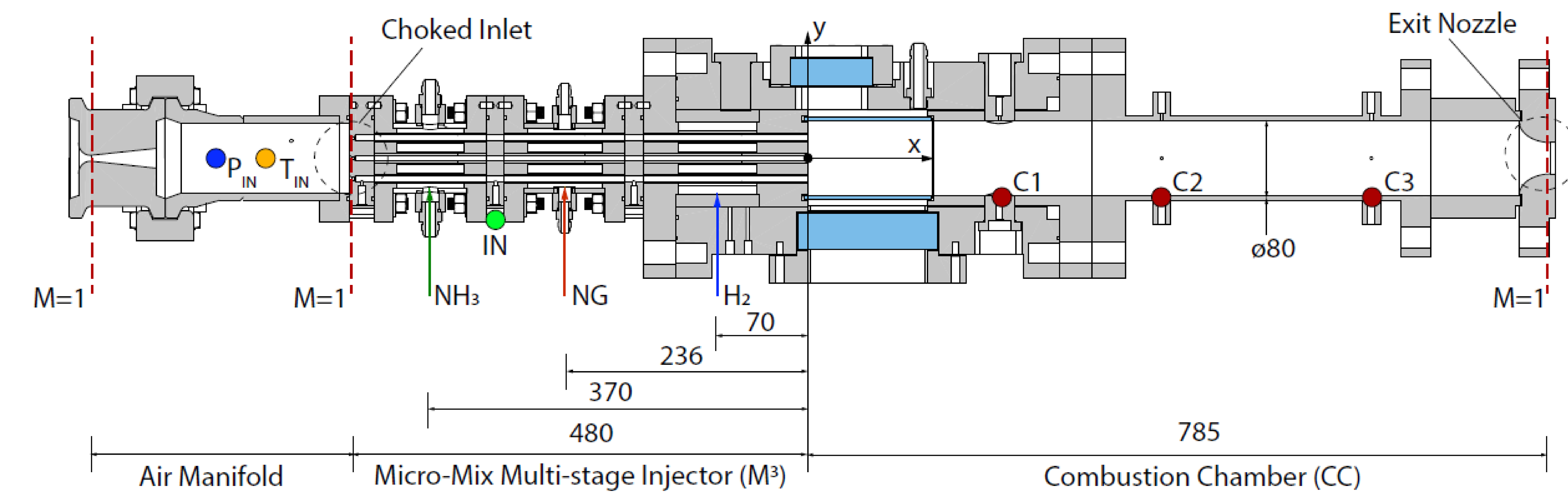


4. Combustor Design

- Optically accessible combustor with premixed multi-stage, multi-tube, micromix (M3) injector (10-20 bar operation)
  - 19 injection elements distributed with uniform inter-element separation in cylindrical combustion chamber
  - Injector Mach number between 0.15 - 0.25
  - Staged NH_3, NG, and H_2 injection (JICF injectors in each tube)
- Combustor designed to investigate fuel composition effects on self-excited combustion instabilities at ~600 Hz
- Array of high-frequency pressure instrumentation (1 MHz) and 50 kHz OH*-chemiluminescence measurements performed



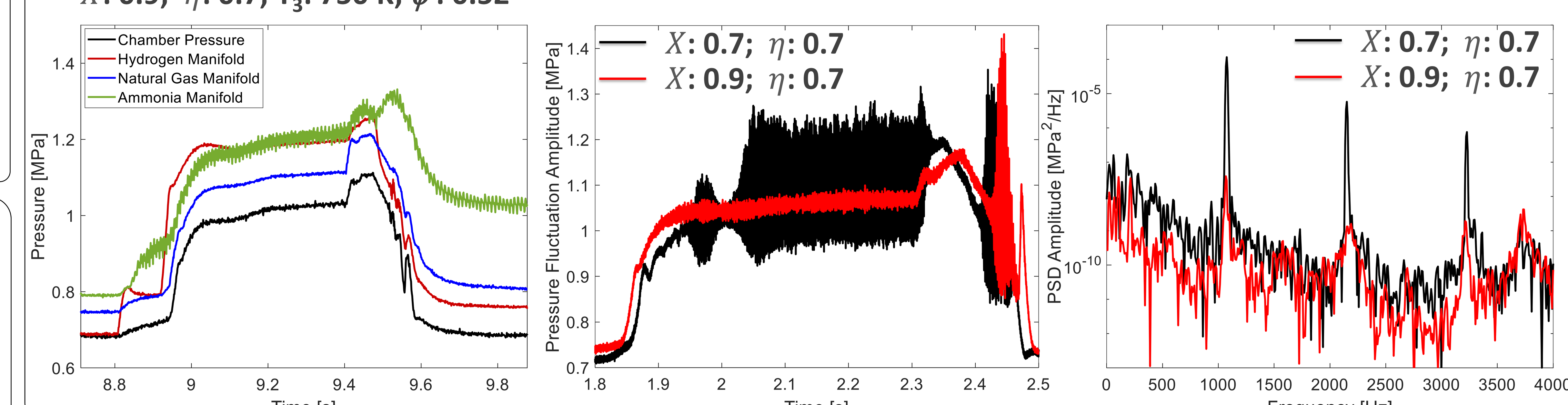
Combustor Cross-section



5. Combustor and Ammonia System Operation

- Successfully delivered high-pressure NH_3 vapor to combustor at varying pressure and mass-flow rates
- Characterized influence of ammonia and hydrogen addition of self-excited combustion instabilities
  - Stability improves with higher hydrogen content but flame flashback remains a concern
  - Ammonia addition adversely affects combustion dynamics in current configuration

X: 0.9; η: 0.7; T_3: 750 K; ϕ: 0.52



6. Summary and Next Steps

- Successfully developed and demonstrated operation of high-pressure ammonia system for combustion research with high hydrogen content fuels
- Characterized influence of ammonia and hydrogen addition on self-excited combustion instabilities at elevated pressure with a premixed multi-element micromix injector

Next Steps:

- Detailed characterization of combustion dynamics with application of chemiluminescence, PLIF, PIV, and CARS measurements
- Global emissions characterization using FTIR based extractive product gas sampling

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