COMBUSTION INSTABILITY STUDIES FOR DUAL FUEL APPLICATIONS

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MOTIVATION / OBJECTIVES

- **Motivation:**
  - **Lean-premixed combustors provide reduced pollutant emissions but are susceptible to destructive combustion instability behavior**
  - **Effective use of liquid fuel as an alternative to natural gas requires a systematic study which allows direct comparison between natural gas and liquid fuel operation**
- **Objectives:**
  - **Study of parameters affecting combustion instability**
  - **Comparison of liquid fuel/gaseous fuel operation of an experimental model combustor**
  - **Obtain data base available to industry for model validation efforts**

APPROACH

- Three phase research program involving:
  - Prevaporized liquid fuel studies
  - Uni-element liquid fuel spray studies
  - Multi-point injection studies
- Utilize previously developed optically accessible model gas turbine combustor
- Employ simple swirl injectors
- Apply extensive diagnostic tools available to characterize controlling combustion processes

DIAGNOSTIC CAPABILITIES

- **Monitoring of pressure oscillations using high frequency pressure transducers (~1 MHz)**
- **Monitoring of exhaust emissions using gas analyzers:**

Species	Range
CO (ppm)	0-1000
CO_2 (%)	0-20
NO (ppm)	0-1000
NO_x (ppm)	0-1000
O_2 (%)	0-25
HC (ppm)	0-30,000

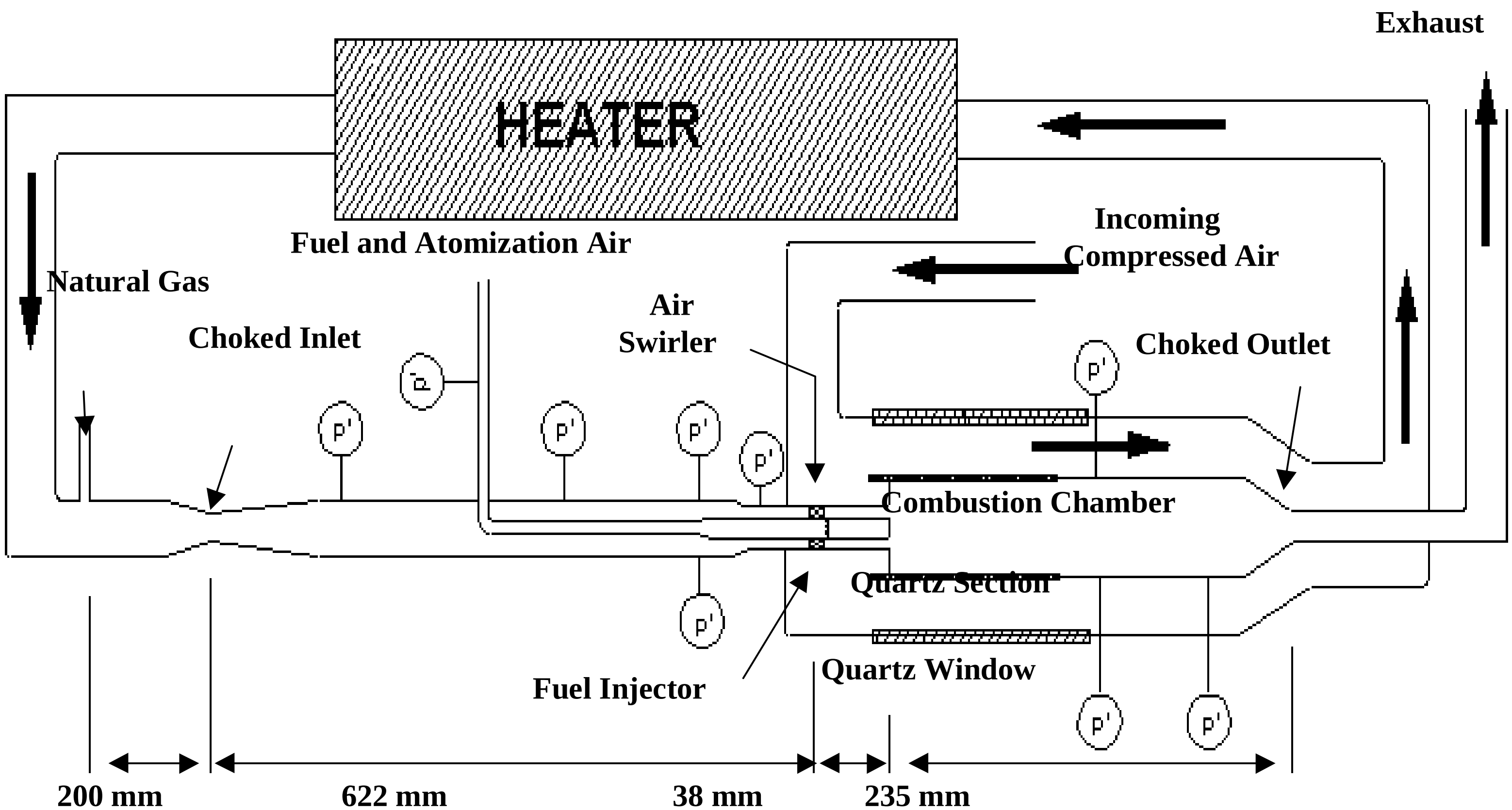
ADVANCED OPTICAL DIAGNOSTICS TECHNIQUES:

- **OH*/CH* Chemiluminescence**
- **OH Planar Laser-Induced Fluorescence (PLIF)**
- **Raman Scattering**
- **Phase Doppler Particle Analyzer (PDPA)**

GAS TURBINE SYSTEM CAPABILITIES

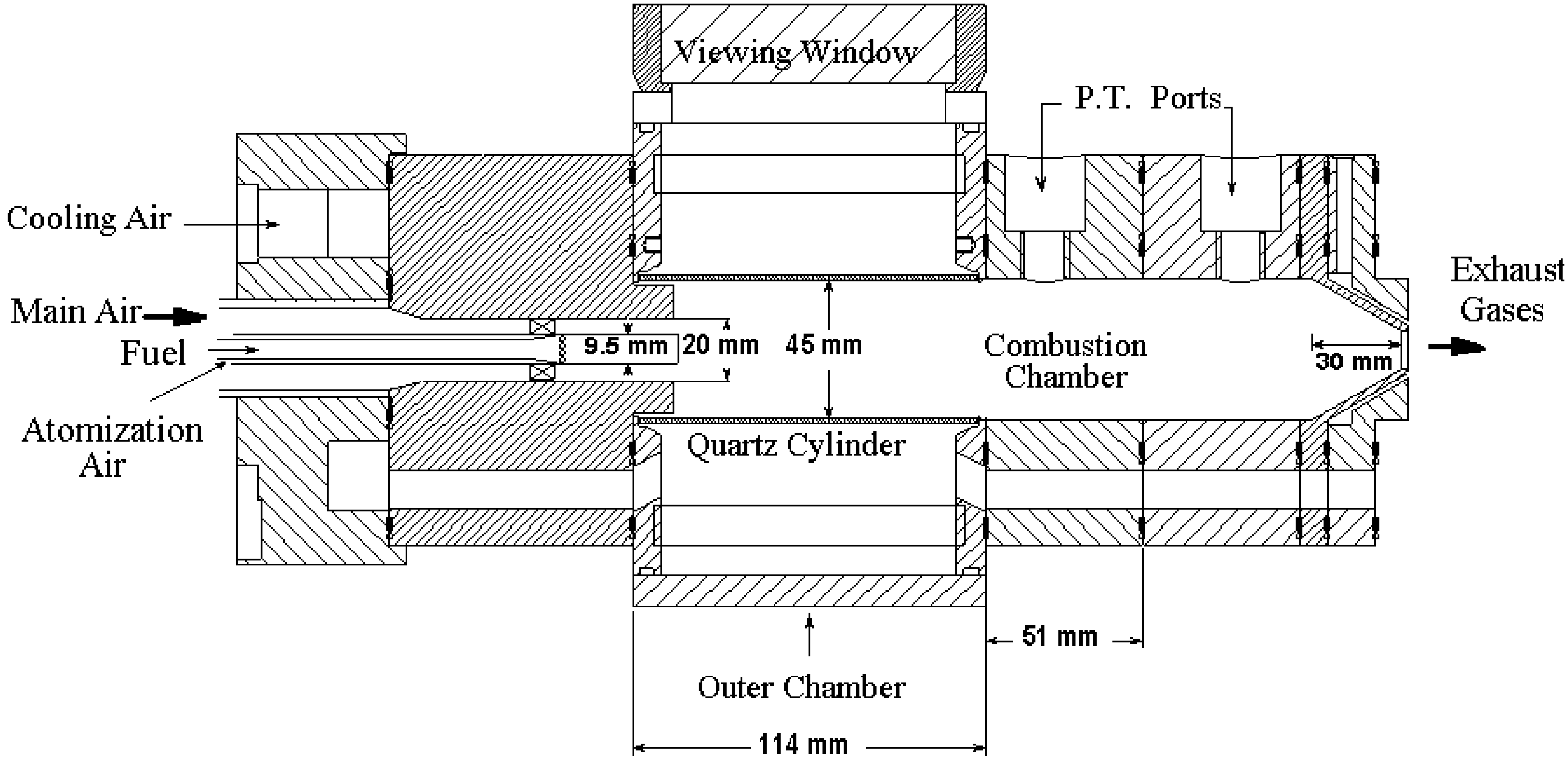
PARAMETER	RANGE
Inlet air flow rate-g/s (lbm/s)	20-200 (0.04-0.44)
Inlet air temperature-K (°F)	300-800 (80-980)
Inlet air velocity-m/s (ft/s)	57-90 (187-295)
Fuel flow rate	
Natural gas-g/s (lbm/s)	1.2-12 (0.003-0.03)
Liquid fuel-ml/s (gal/min)	0.53-9.50 (0.0085-0.15)
Chamber pressure-MPa (psia)	0.2-2 (29.4-294)
Degree of swirl	Variable
Fuel injection location	Variable
Chamber length-mm (in)	235 (9.25), 350 (13.78)

APPARATUS CONFIGURATION



- Single straight-vaned 45° swirler and bluff body
- Choked inlet and outlet boundary conditions
- High pressure/high temperature operation

CUTAWAY VIEW OF COMBUSTION CHAMBER

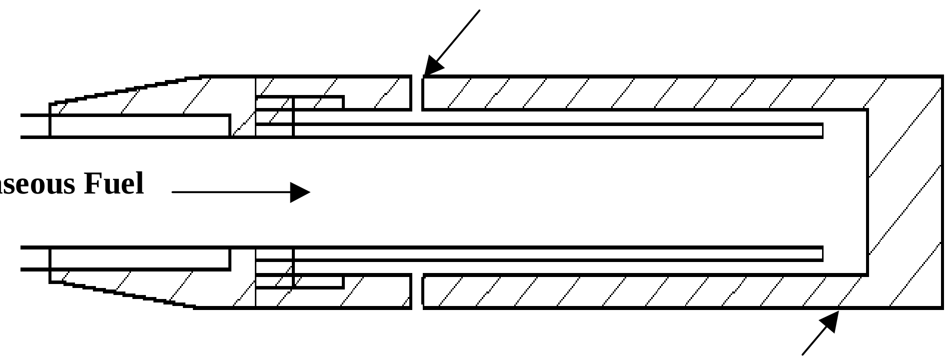


- Sudden-expansion dump combustor
- Optically accessible combustion chamber
- Modular chamber design allows length variation and diagnostic flexibility

FUEL INJECTORS

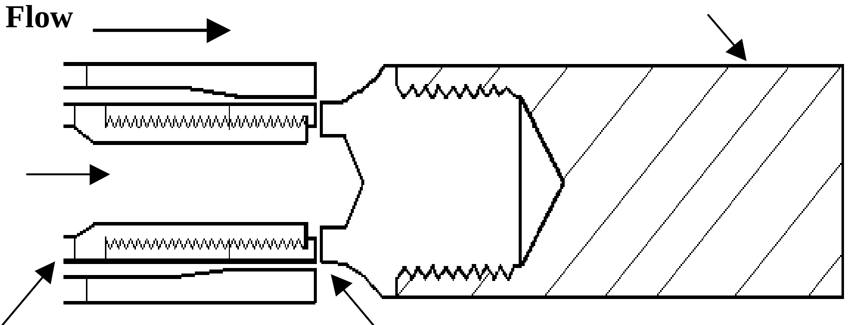
PSU Style Gaseous Injector

Both styles of injectors utilize single swirl configuration and inject fuel 36.8 mm upstream of dump plane.

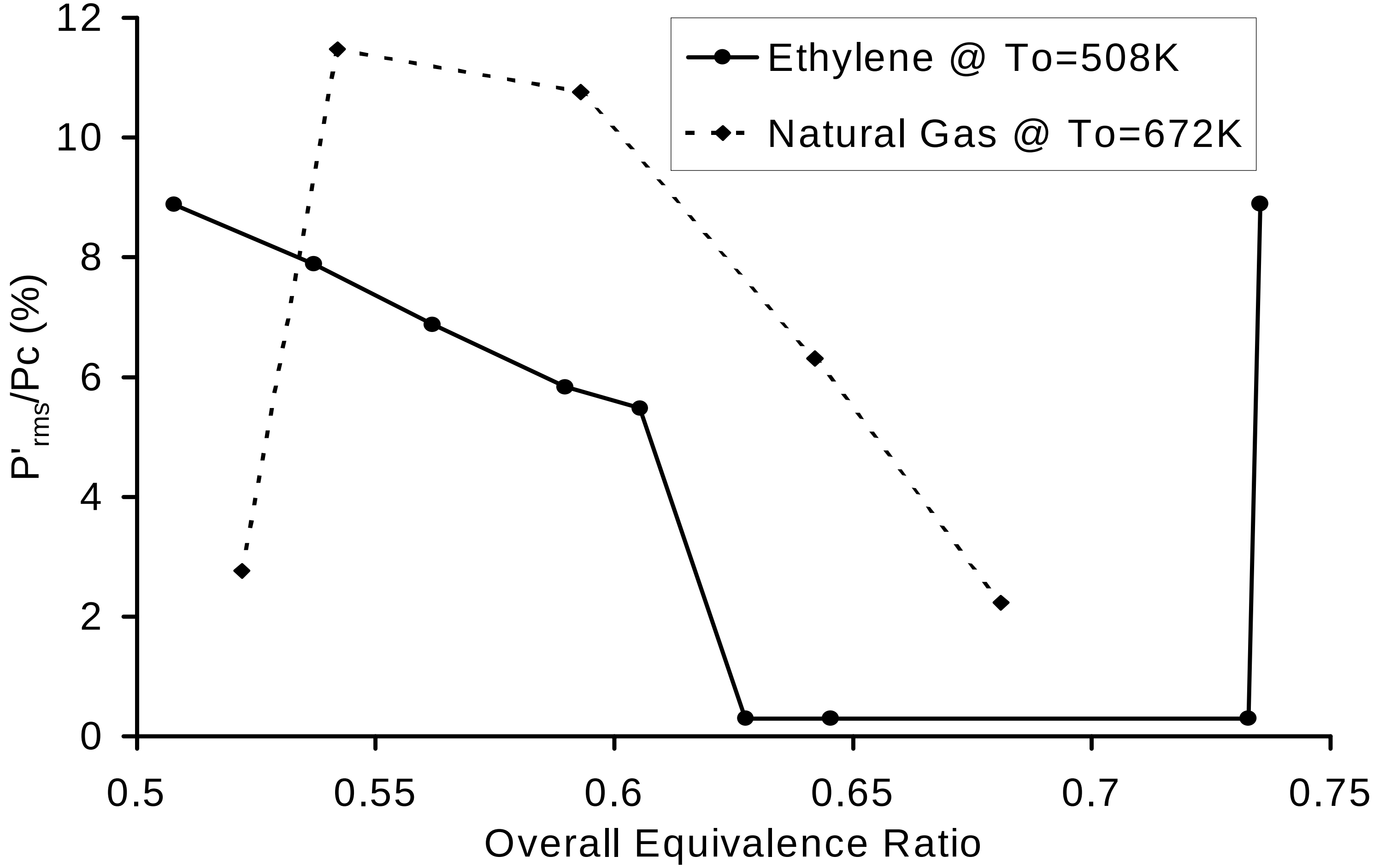


MP Style Liquid and Gaseous Injectors

For liquid fuel injector, 8% of the main air is diverted to provide cooling and atomizing shearing flow



GASEOUS FUEL STABILITY MAP



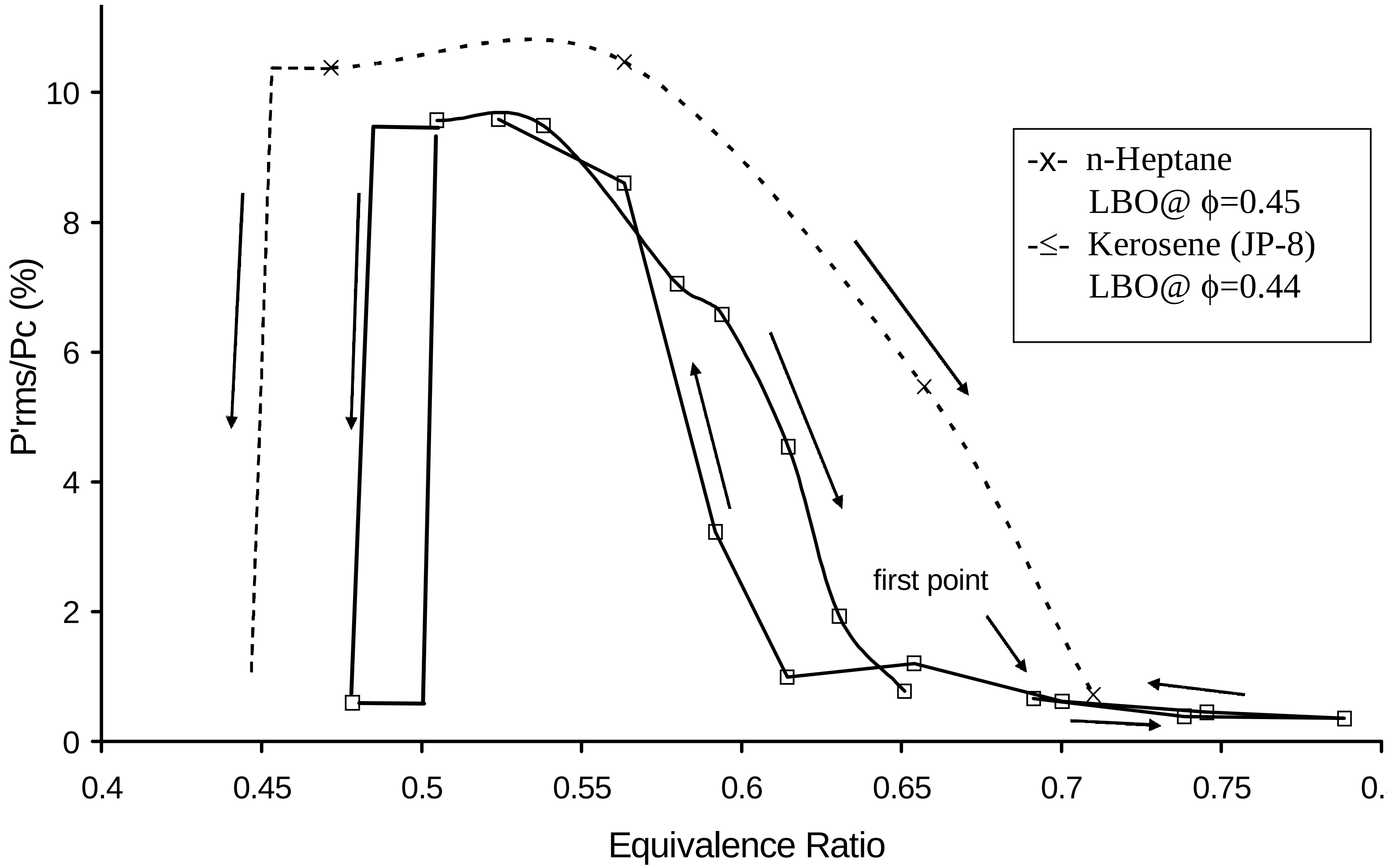
Air Mass Flow Rate ~ 50 g/s (0.11 lbm/s)

Lc = 235 mm (9.25 in)

Pc = 0.43-0.49 MPa (63-71 psia)

Swirl = PSU45º

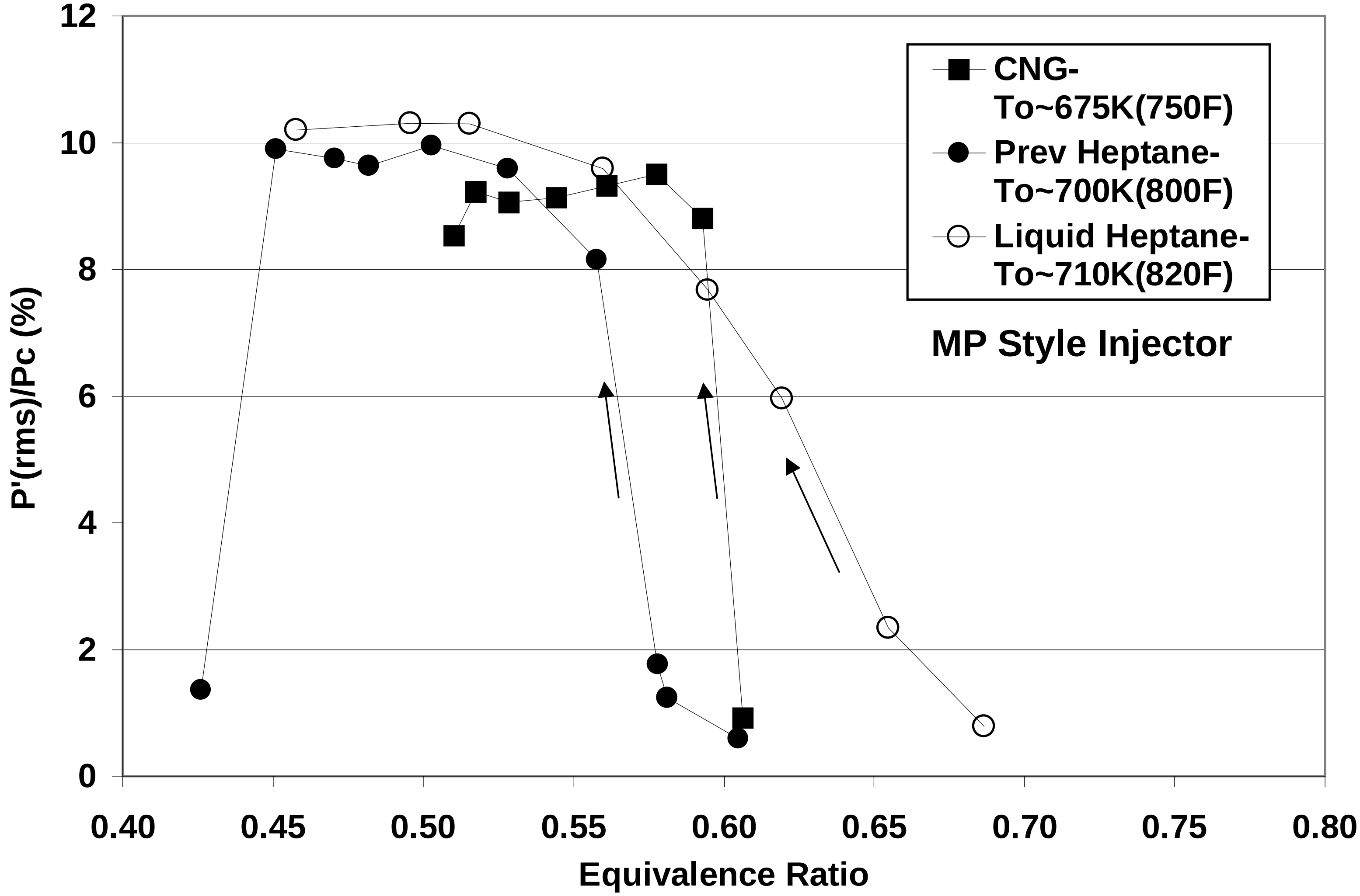
LIQUID FUELS STABILITY MAPS



Air Mass Flow Rate = 49.5-53 g/s (0.109-0.117 lbm/s)
Pc = 0.41-0.49 MPa (60-70 psia)
Lc = 235 mm (9.25 in)

Atomization Air= 8%
To = 675 K (750 ºF)
Swirl = PSU45º

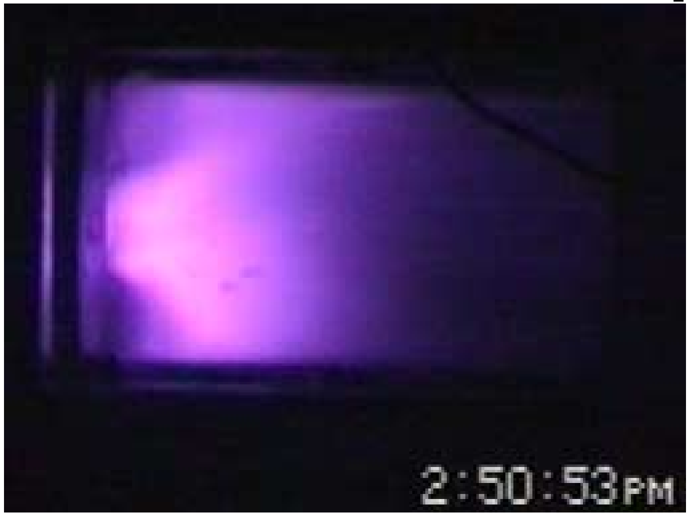
CNG, PREVAPORIZED, AND LIQUID HEPTANE

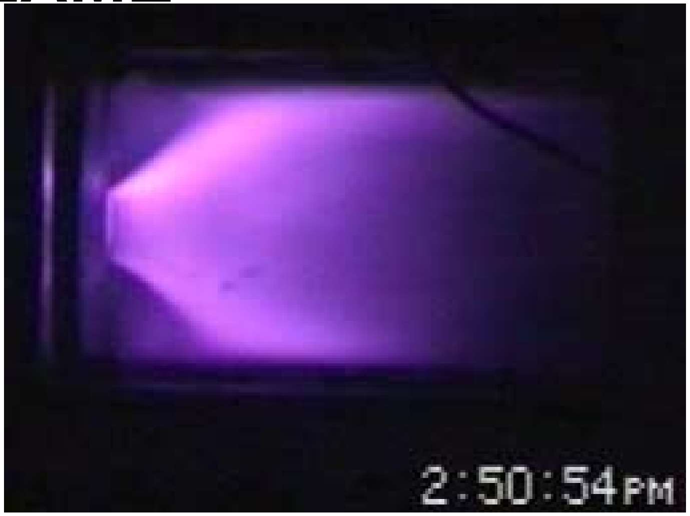


Air Mass Flow Rate ~ 50 g/s (0.11 lbm/s) **Lc = 235 mm (9.25 in)**

Atomization Air~8% **Swirl = PSU45º** **Pc = 0.43-0.49 MPa (63-71 psia)**

KEROSENE (JP8) UNSTABLE AND STABLE FLAME





Unstable Flame
Equivalence Ratio: 0.48

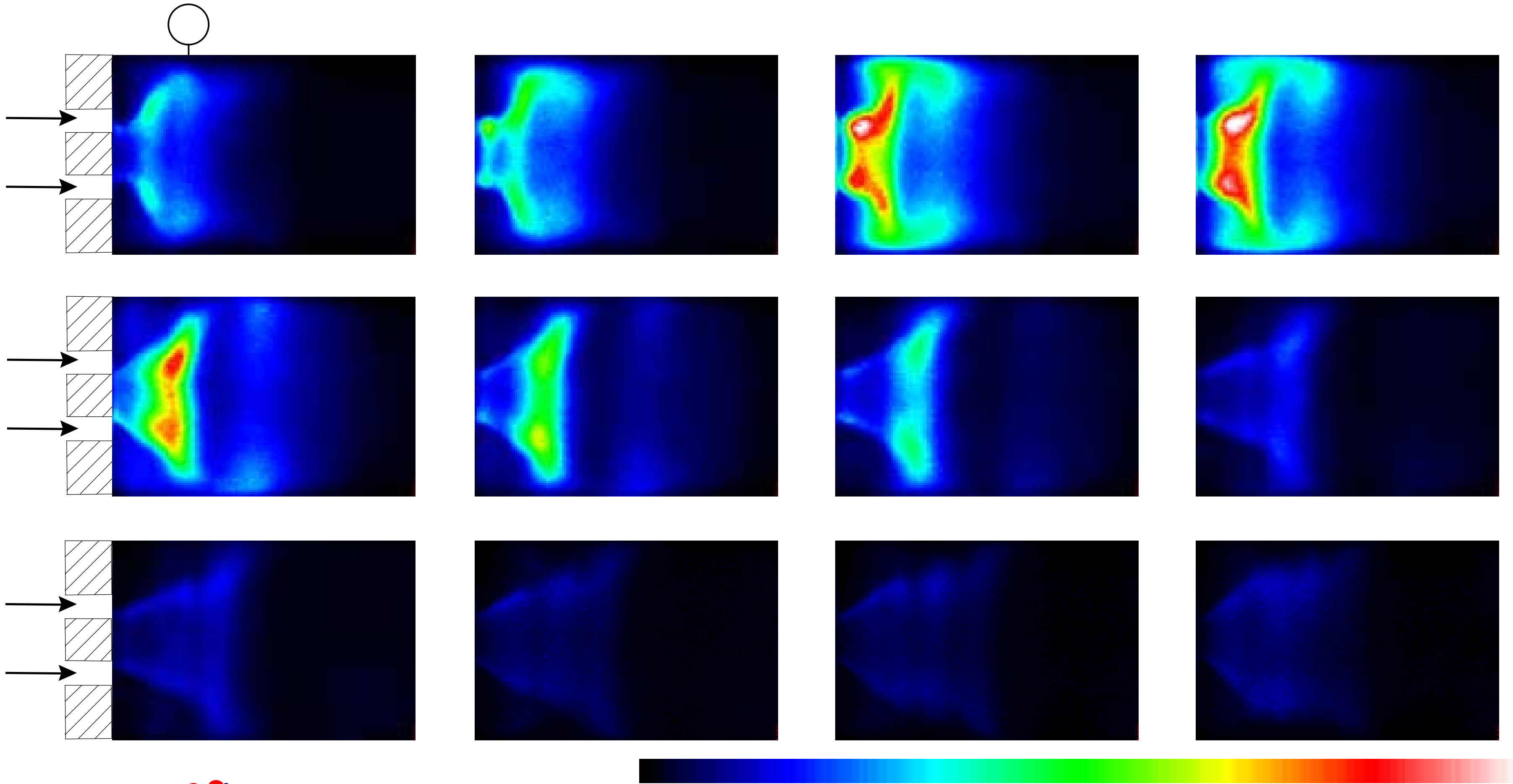
Stable Flame
Equivalence Ratio: 0.48 - ε

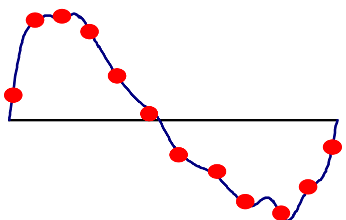
Inlet Temperature : 675 K (750 ºF)
Air Mass Flowrate: 53.6 g/s (0.118 lbm/s)
(Atomization Air : 8%)
Chamber Pressure: 0.445 MPa (65 psia)

Video images obtained using interference filter @ 430 ± 5 nm (CH* chemiluminescence)

- ⇒ **Abrupt initiation of combustion instability by minute decrease in equivalence ratio**
- ⇒ **Significant changes in flame structure**

PHASE-LOCKED CNG HEAT RELEASE (CH*)

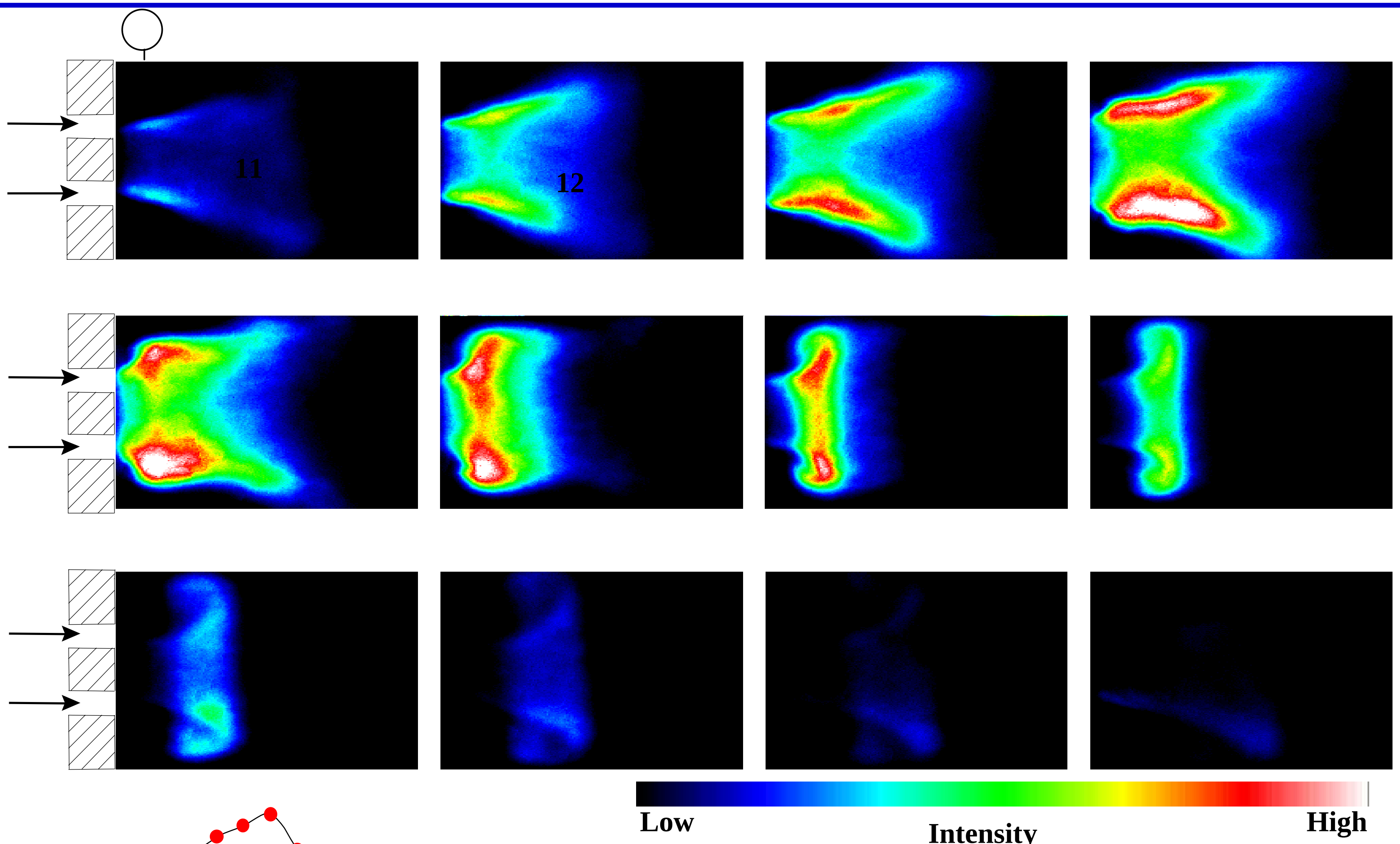


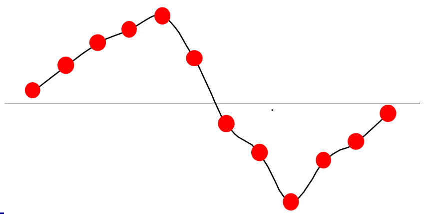


Swirl= 45°, X_{inj}=36.8 mm, P_c=0.448 MPa (65.2 psia)

T_o = 665 K (740 °F) and ϕ=0.58 (1L mode)

PHASE-LOCKED ETHYLENE HEAT RELEASE (CH*)

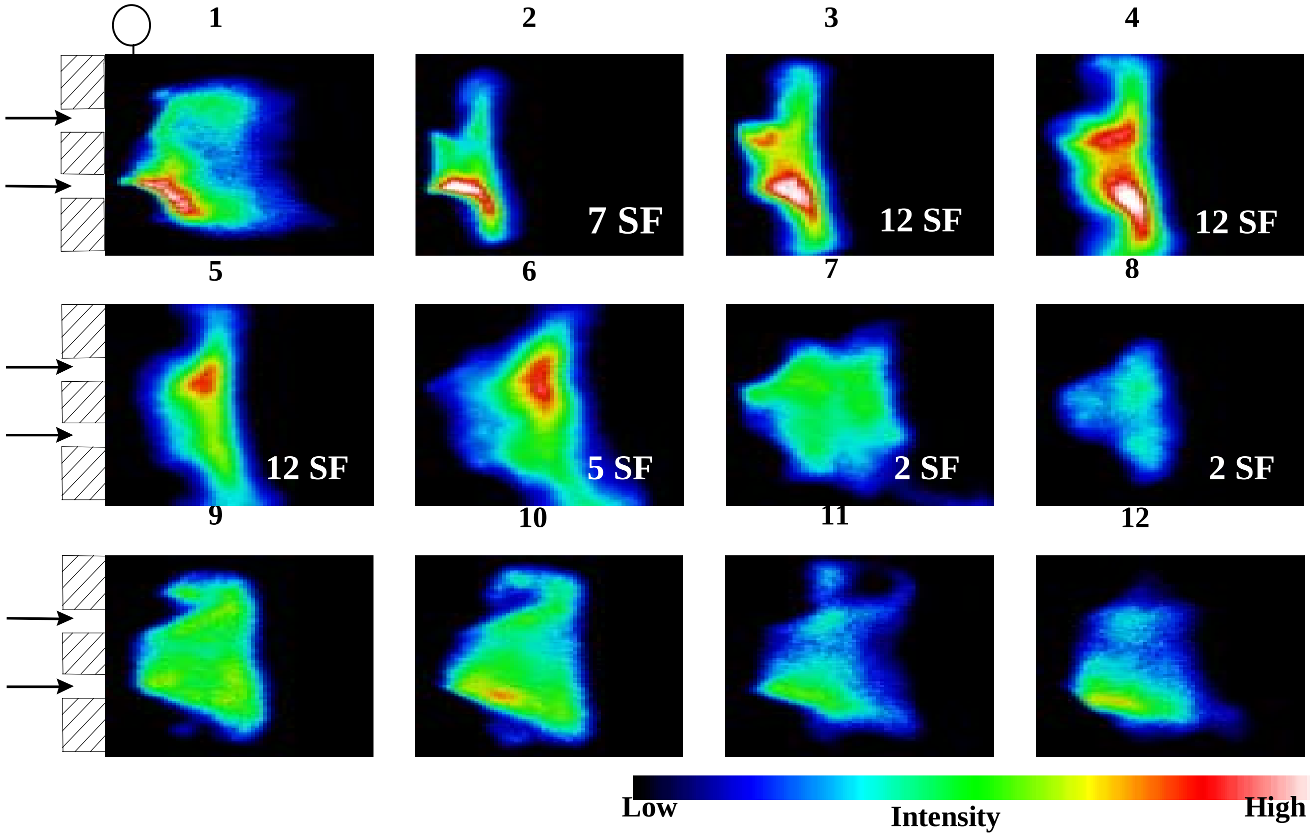


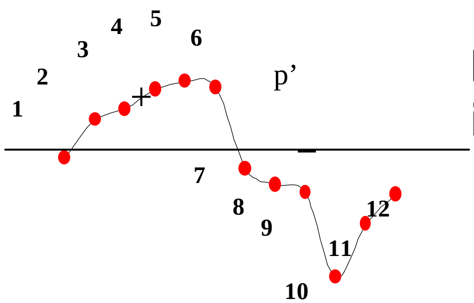


Swirl= 45°, X_{inj}=36.8 mm, P_c=0.452 MPa (66.0 psia)

T_o = 508 K (455 °F) and ϕ=0.56 (1L mode)

PHASE-LOCKED n-HEPTANE HEAT RELEASE (CH*)





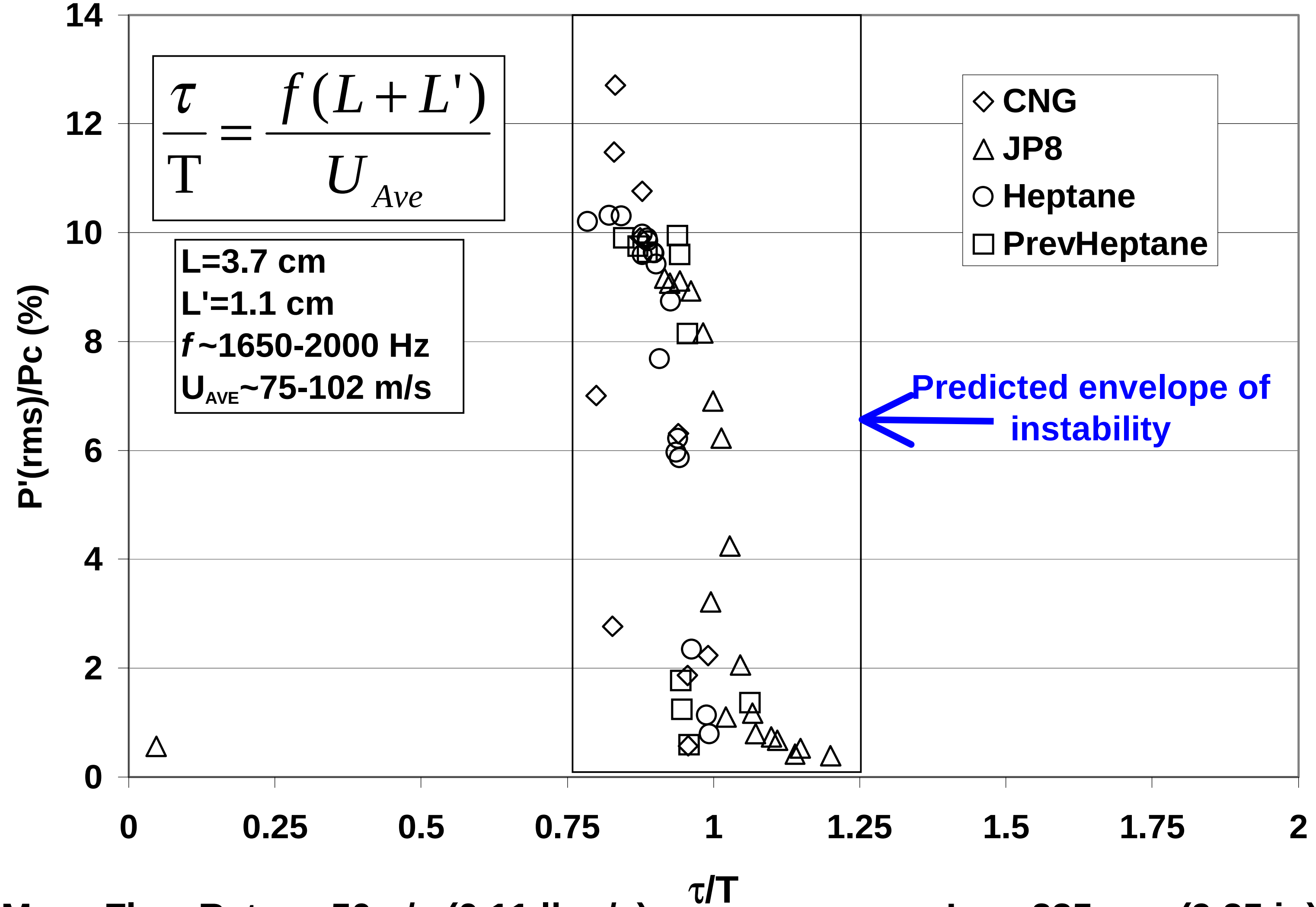
False color intensity of images 2 through 8 are reduced by indicated scale factor (SF) for comparison with images 1 & 9-12

P_c=0.42 MPa (64.0 psia)

T_o = 683 K (770 ºF) and ϕ=0.55

PENNSTATE

TIME LAG (RICHARDS, ET AL)



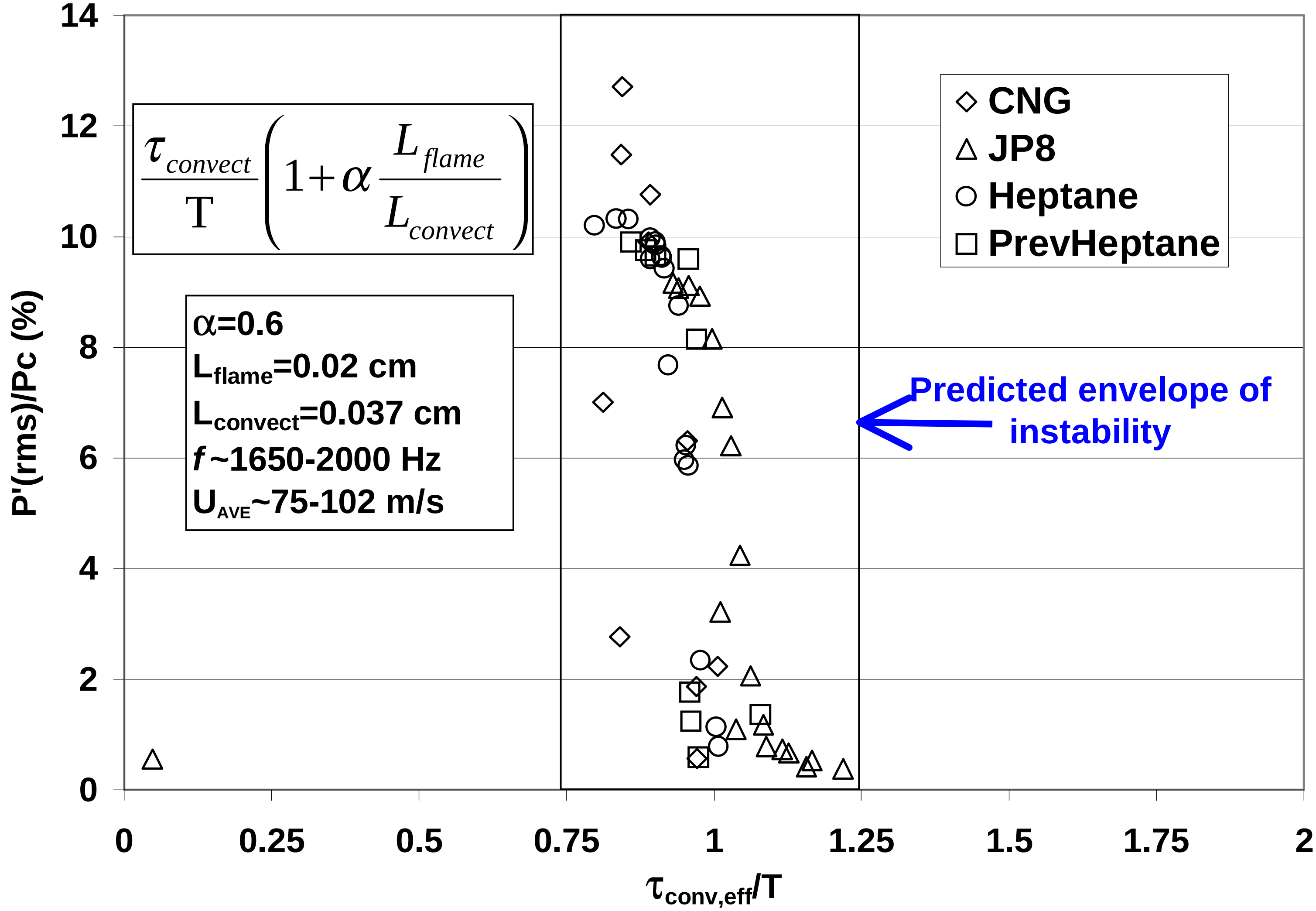
Air Mass Flow Rate ~ 50 g/s (0.11 lbm/s)

Atomization Air~8% **Swirl = PSU45º**

Lc = 235 mm (9.25 in)

Pc = 0.43-0.49 MPa (63-71 psia)

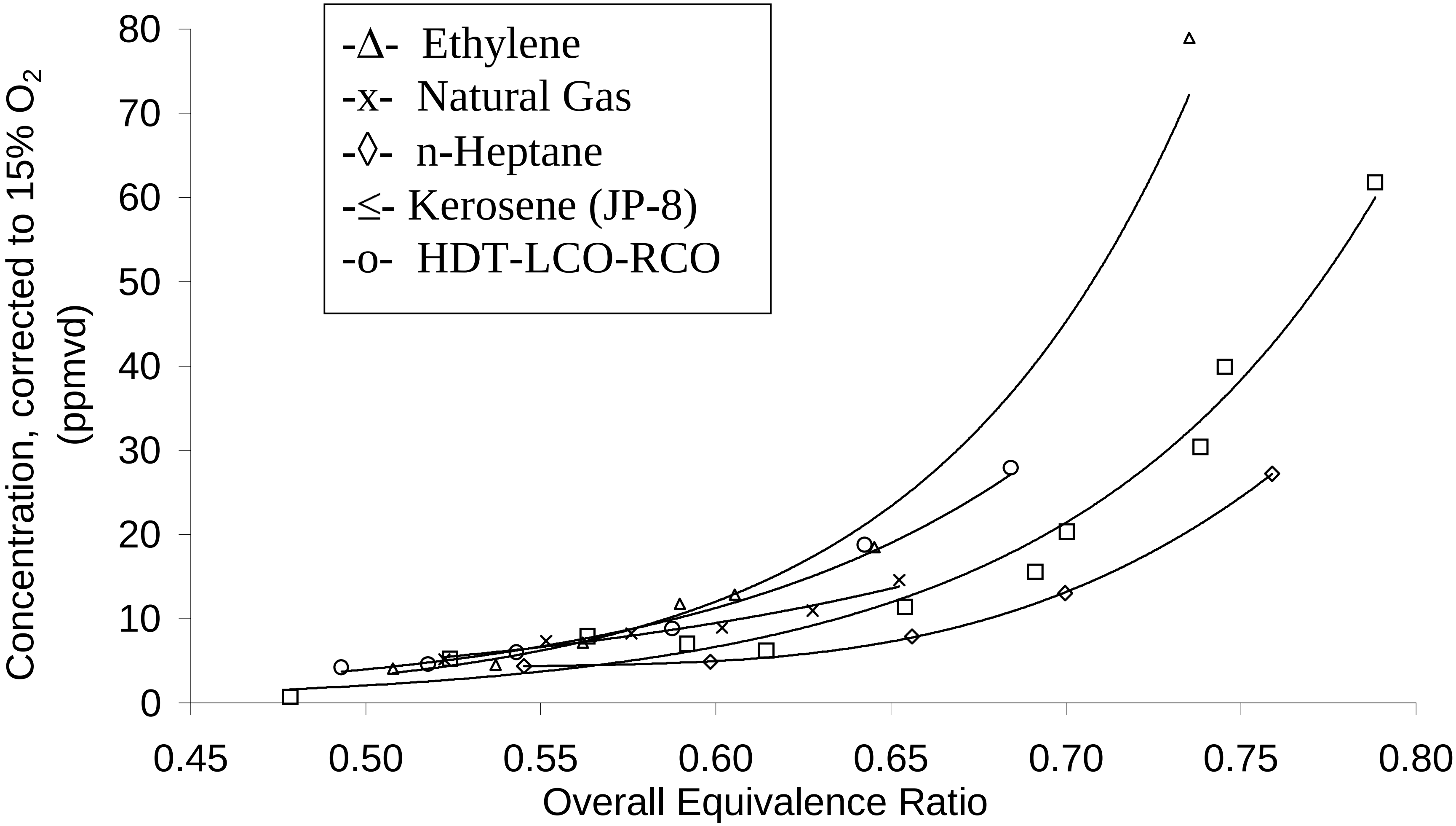
TIME LAG (LIEUWEN, ET AL)



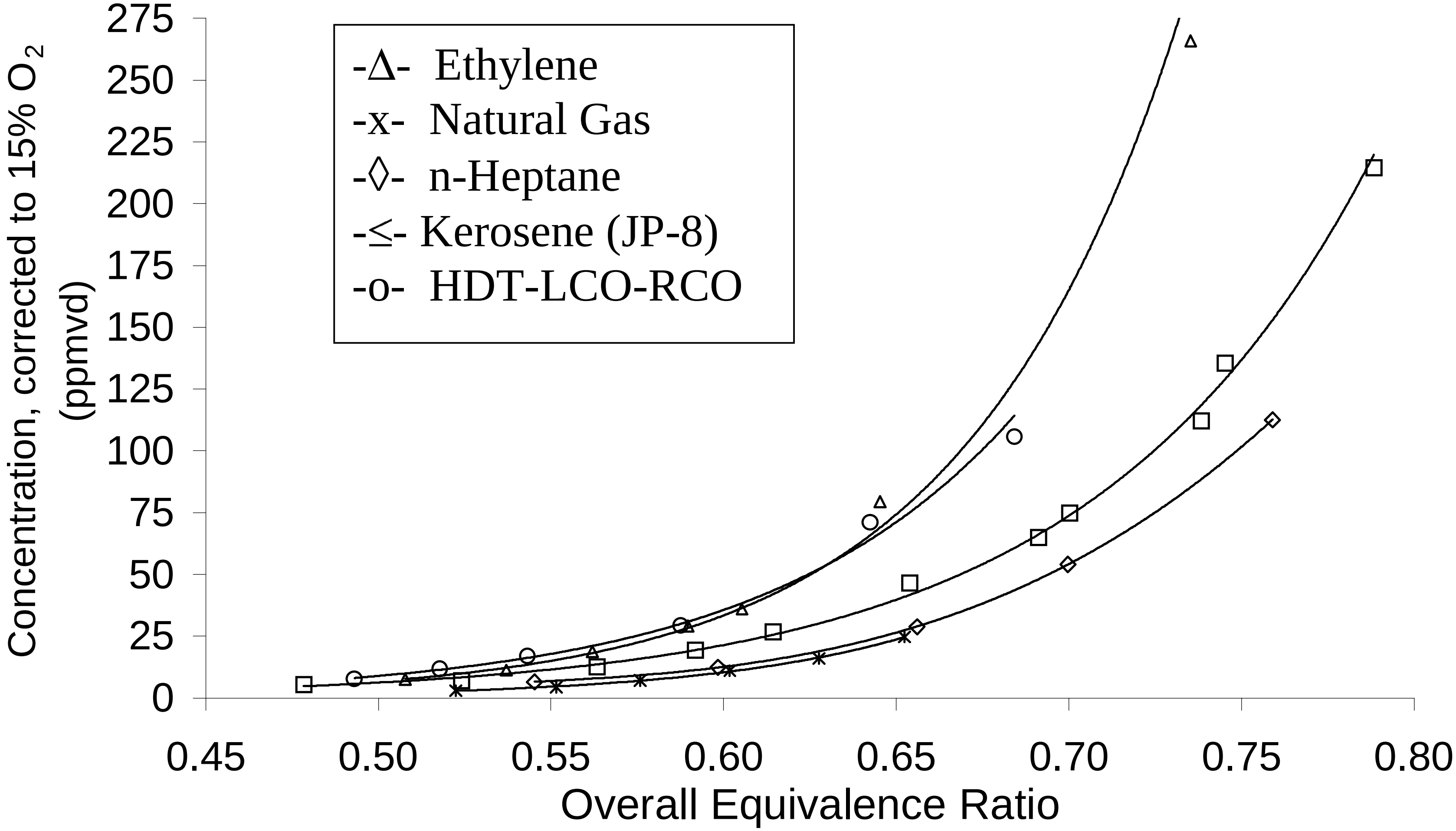
Air Mass Flow Rate ~ 50 g/s (0.11 lbm/s) Lc = 235 mm (9.25 in)

Atomization Air~8% Swirl = PSU45º Pc = 0.43-0.49 MPa (63-71 psia)

COMPARISON OF NOx EMISSIONS



COMPARISON OF CO EMISSIONS



CONCLUSIONS

- ❑ Gaseous fuels: natural gas and ethylene
  - Same level of maximum instability amplitude
  - Significantly different instability domain with respect to inlet air temperature and equivalence ratio
    - ⇒ Strong fuel dependence for gaseous fuels
- ❑ Liquid fuels: n-heptane and kerosene (JP8)
  - Similar stability behavior and levels of maximum amplitude
  - Stability trends similar to natural gas
    - ⇒ Relative insensitivity to liquid fuel composition
    - ⇒ Geometry effects appear to dominate observed stability behavior
- ❑ Benefits to industry
  - Extensive data base available to industry for model validation (e.g. current work at GEAE)
  - Application of advanced laser-based techniques developed at Penn State (NETL)