FUEL FLEXIBILITY INFLUENCES ON COMBUSTOR OPERABILITY

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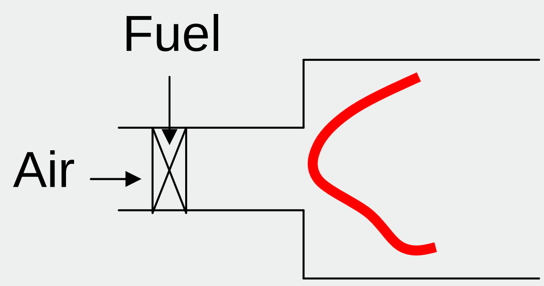
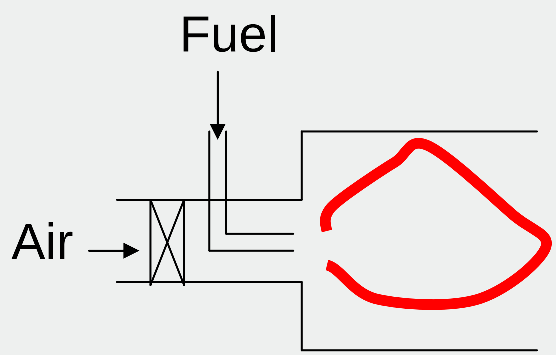
Fuel Flexibility Influences Upon Combustion

- **Combustor has relatively little influence on overall cycle performance, such as efficiency**
- **What are important combustor performance parameters?**
  - Operability: Flame doesn't blow out, vibrate, flash back
  - Low pollutant emissions
  - Good turndown
- **Focus of this talk is on operability**
  - Turndown to a secondary extent (also influenced by emissions)

Premixed vs Non-Premixed Flames

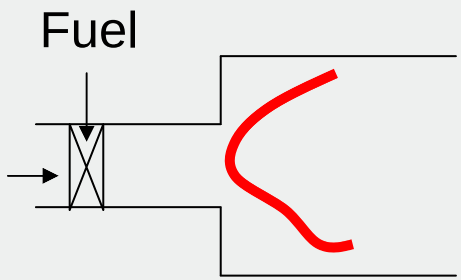
- **Premixed flames**
  - Fuel and air premixed ahead of flame
  - Mixture stoichiometry at flame can be controlled
  - Method used in low NOx gas turbines (DLN systems)
- **Non-premixed flames**
  - Fuel and air separately introduced into combustor
  - Mixture burns at $\phi=1$
    - i.e., stoichiometry cannot be controlled
    - Hot flame, produces lots of NOx and more sooting
    - More robust, higher turndown, simpler





Combustor Operability Issues

- **Blowout ("static stability")**
- **Combustion Instability ("dynamic stability")**



- **Flashback**
- **Autoignition**

Discussion on Fuel Composition

- **Variety of gas/liquid feedstocks**
  - Gas fuels:
    - Coal and bio-derived syngas
    - Petrochemical, blast furnace off gases
    - Natural gas (coal bed methane, imported)
    - Landfill gas
  - Liquid fuels
    - F-T derived fuels
    - Bio derived fuels (e.g., pyrolysis oils)

- **Wobbe index insufficient to capture fuel property influence on operability issues**

Discussion on Fuel Composition, Cont'd

- **Helpful groupings for gaseous fuels:**
  - H_2 content
    - Syngas, refinery off gas
  - Higher hydrocarbon content
    - Vaporized liquid fuels, LNG, associated gas
  - Diluents
    - H_2O, CO_2 – Not chemically inert!
    - N_2

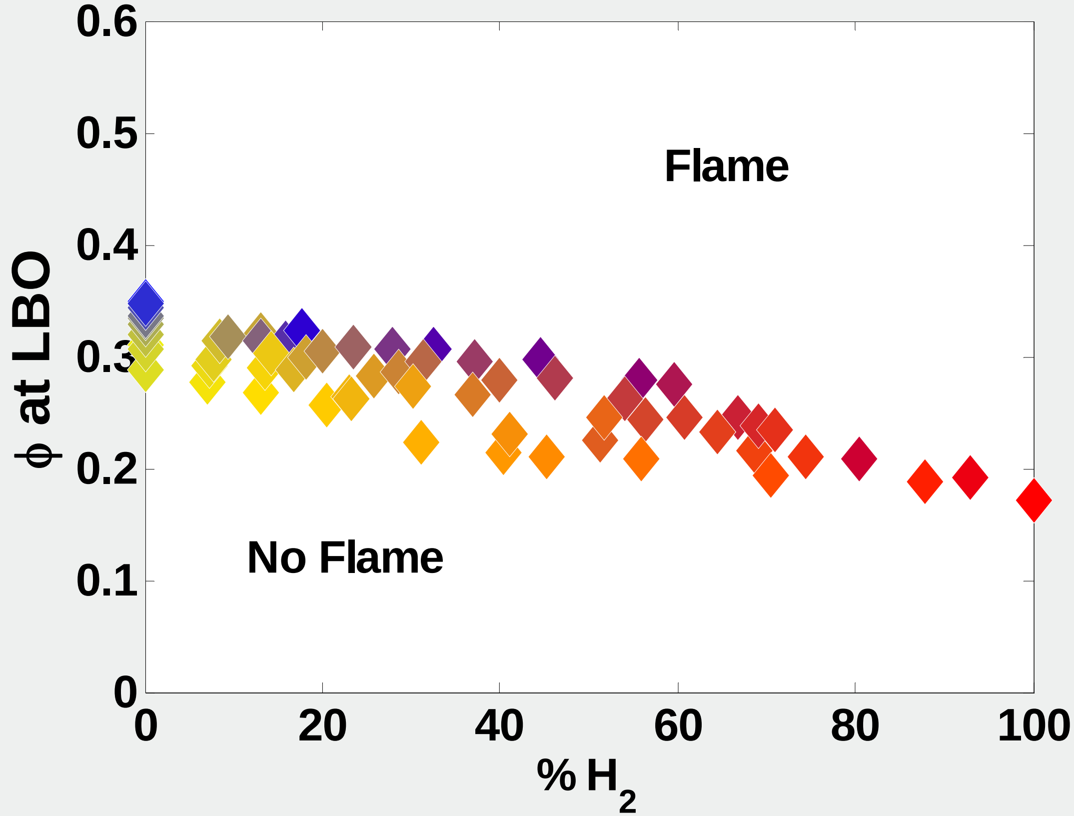
Operability Issues - Blowoff

Operability Issues- Blowoff

- **H_2 addition significantly extends blowoff limits**

- **Diluent addition contracts blowoff limits**

Conditions: U_0=60 m/s, T=460K, P=4.4atm,



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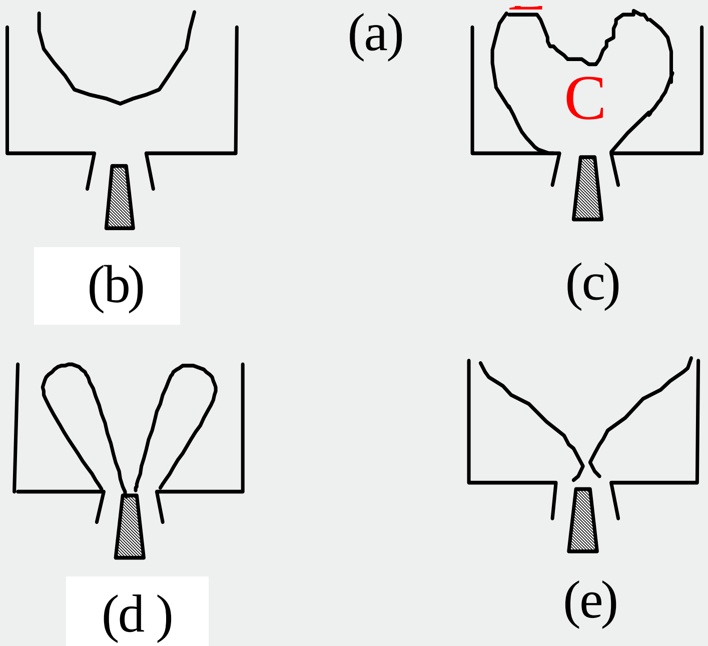
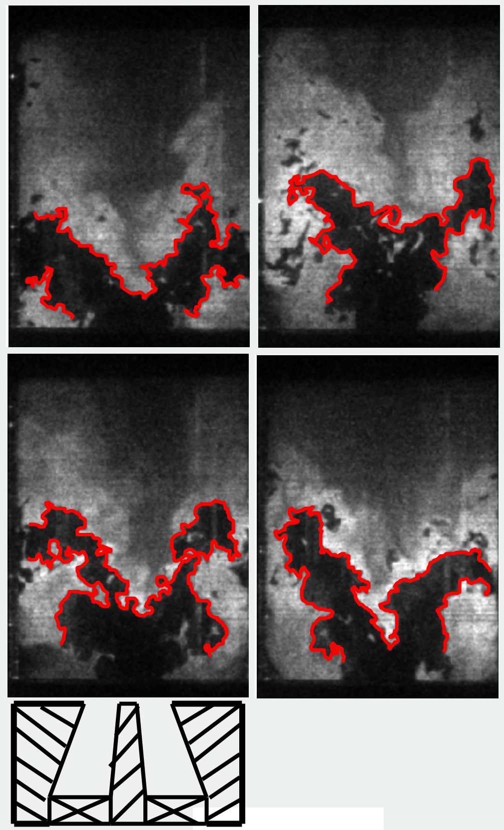
"Local Blowoff" also important in controlling flame shape



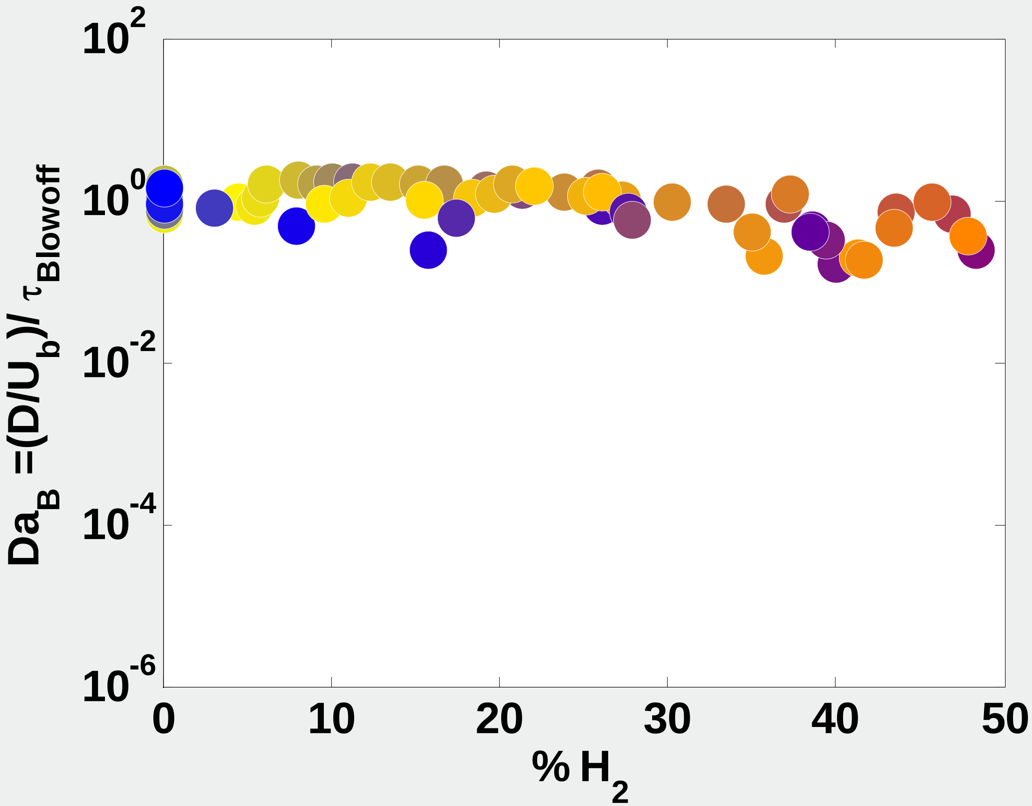
Fuel composition has significant influences upon flame position



•From Kumar and Lieuwen

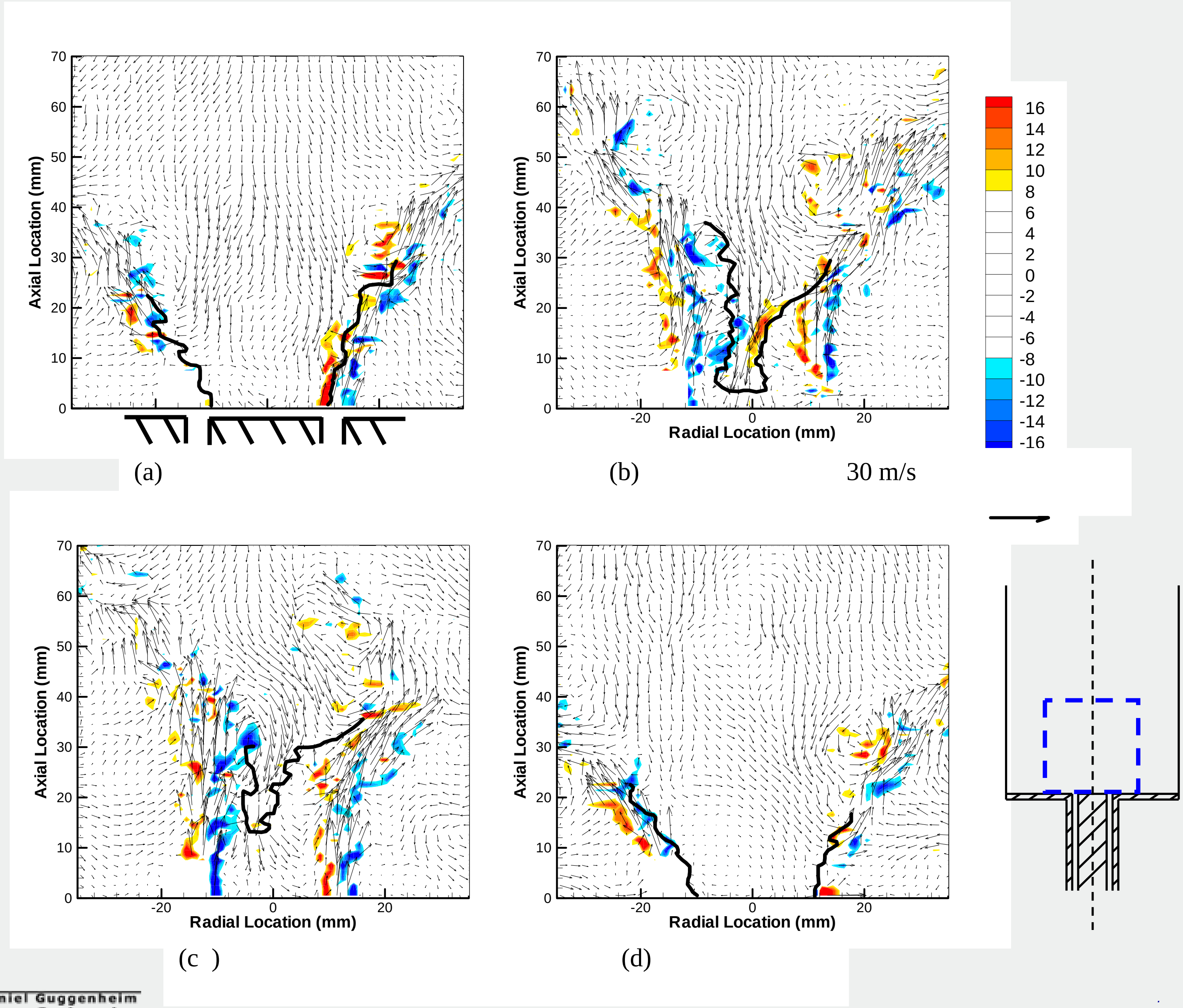
Blowoff Predictions

- **Damkohler # scalings are classic method for correlating blowoff:**
  - Da=residence time/chemical kinetic time
  - Work reasonably well at low H_2 levels – problems at higher H_2 levels



Near Blowoff Dynamics

- **Flame highly unsteady under near blowoff conditions**
  - Local extinction/reignition
  - Flame base bouncing up and down
- **Very complex dynamics, poorly understood**



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Operability Issues - Flashback

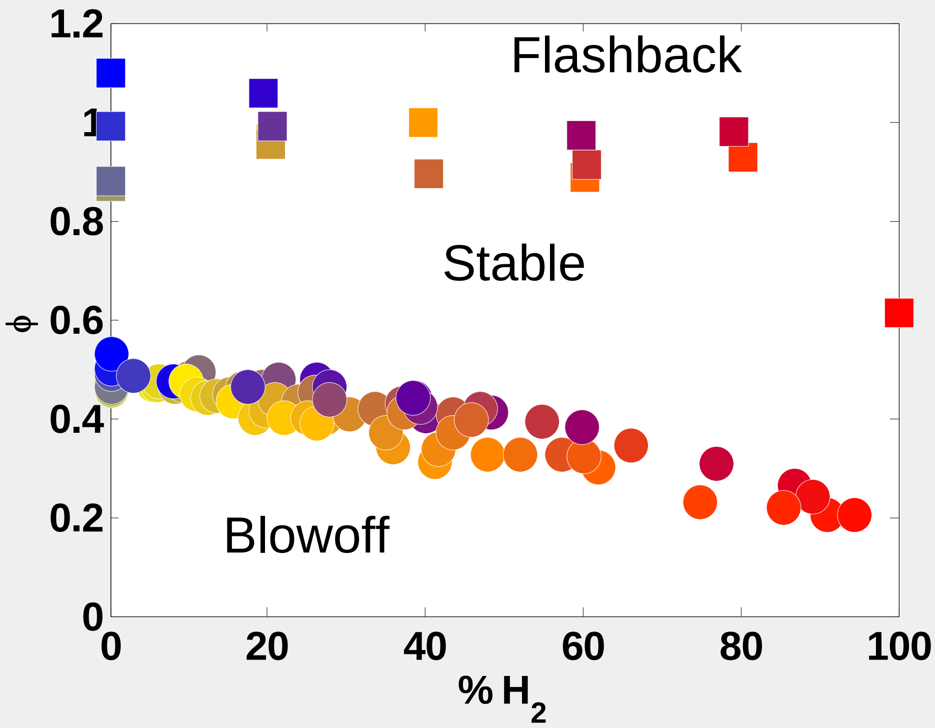
Flashback

- **Multiple flashback mechanisms**
  - In boundary layer
  - In core flow
  - Strong acoustic pulsations lead to nearly reverse flow
  - Combustion induced vortex breakdown

- **Different fuel properties influence these mechanisms differently**

H_2 influences on flashback

- **Boundary layer/core flow flashback more problematic with fast propagating/strain resistant flames**
  - Think hydrogen!
  - Operability window exhibits non-monotonic dependence upon H_2 content



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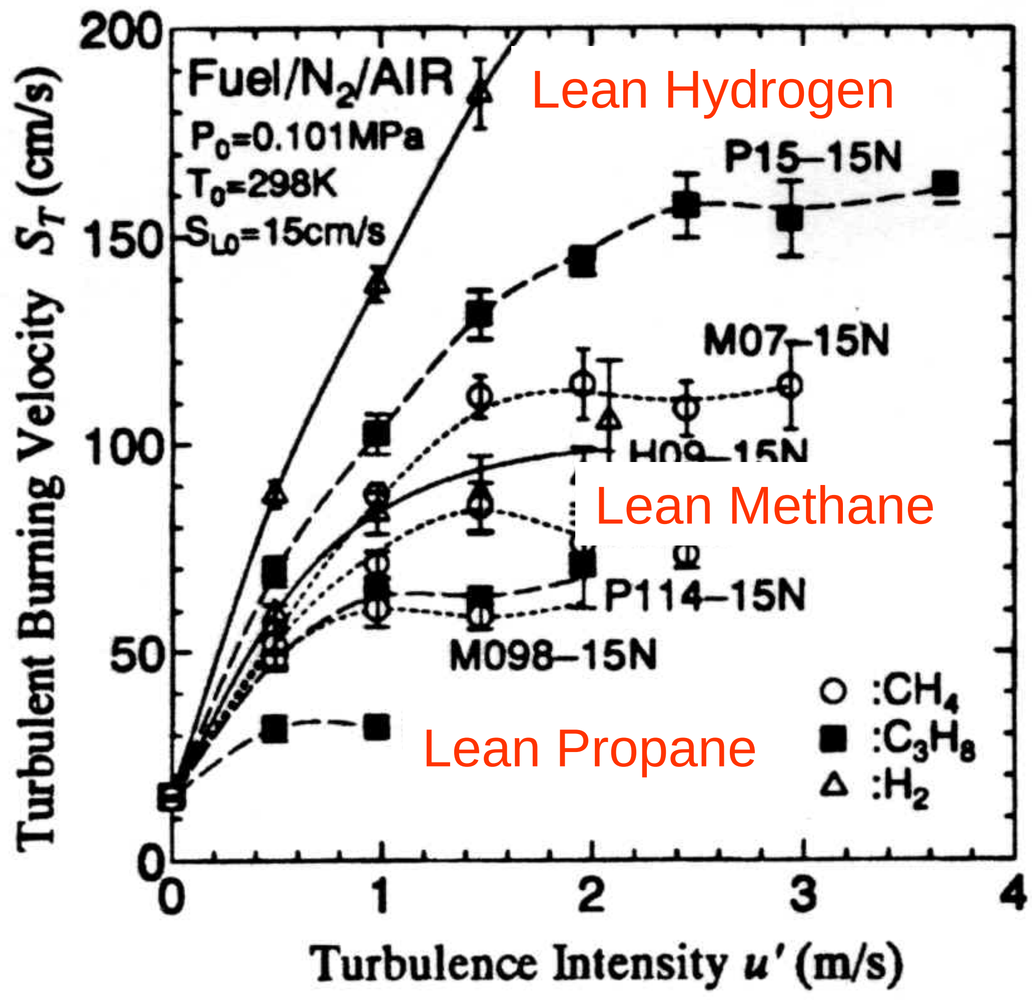
Turbulent Flame Speed and H_2

- **Strong dependence of S_T on fuel composition – even at fixed S_L**
- **Research needs:**
  - Turbulent flame speeds, strain sensitivities at GT realistic conditions

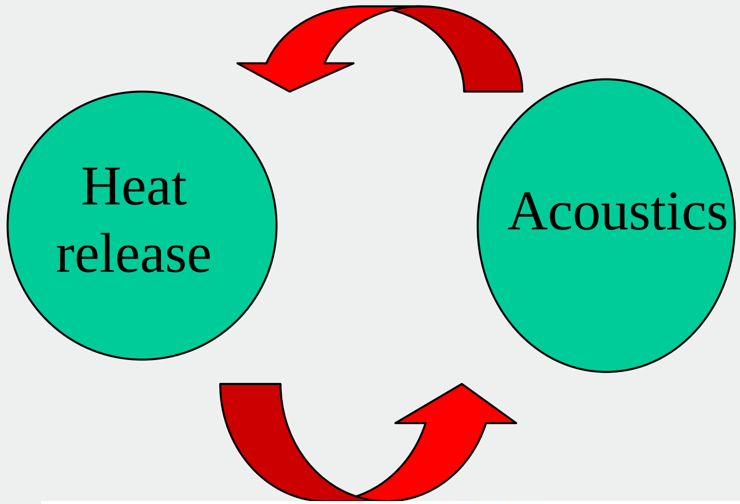
Kido et al. *Proc. Comb. Inst.*, Vol. 29, 2002

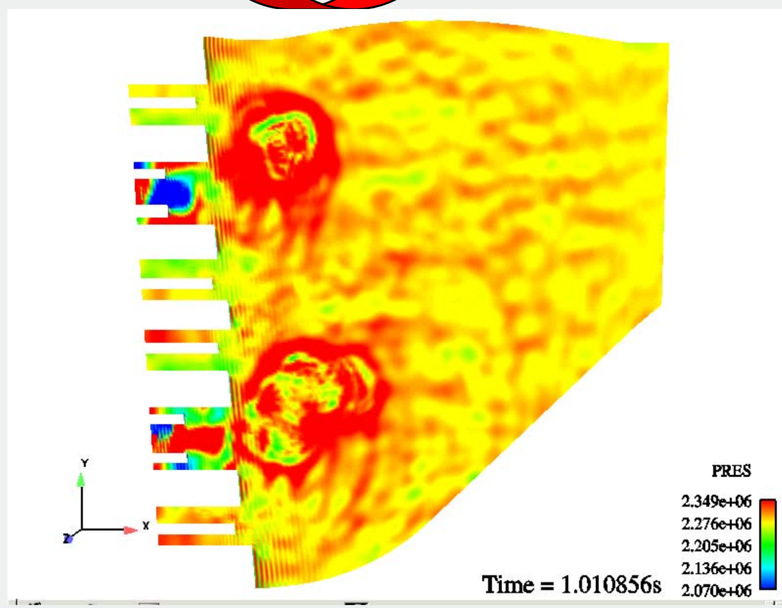


Operability Issues – Combustion Instabilities

Basic Feedback Cycle

- Large amplitude acoustic oscillations driven by heat release oscillations
- Oscillations occur at specific frequencies, associated with resonant modes of combustor





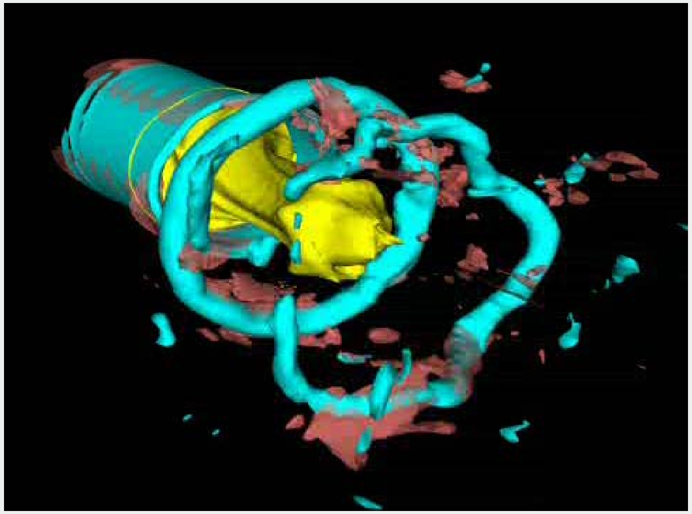
Video courtesy of S. Menon

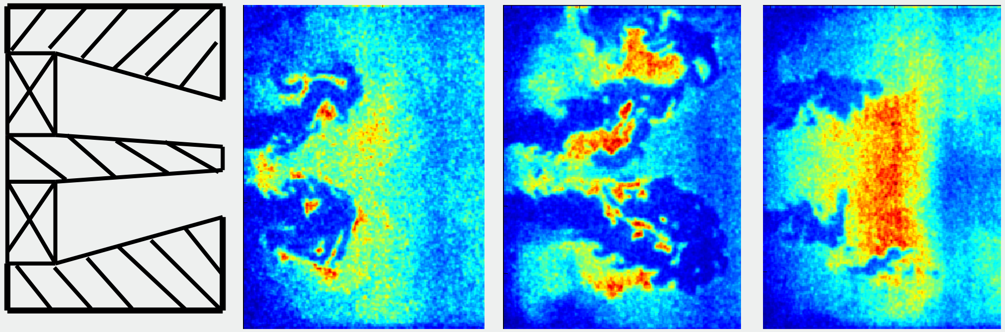
Combustion Dynamics Nomenclature

- Many common terms for combustion dynamics
  - Dynamics, Humming, Rumble, Oscillations, Pulsations, Instability, Screech
- Low Frequency Dynamics (LFD)
  - Rumble, Cold Tone, Helmholtz Mode
- Mid Frequency Dynamics (MFD or IFD)
  - Hum, Hot Tone, Longitudinal Mode
- High Frequency Dynamics (HFD)
  - Screech, Transverse instability
  - Very destructive

Why do Instabilities Occur?

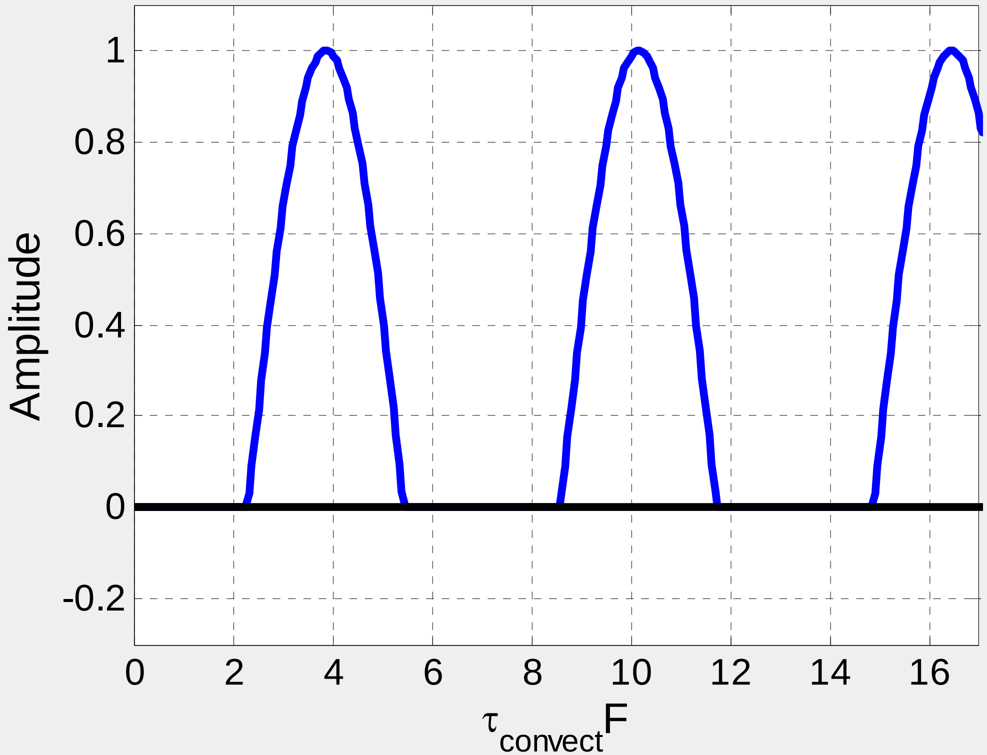
- **2 important mechanisms in DLN combustors**
  - Equivalence ratio of reactive mixture oscillates and disturbs flame
  - Vortices in combustor distort flame





Conditions of Occurrence

- **Instabilities can occur when:**
  - Cos ($\tau_{convect}$F)>0
    - $\tau_{convect}$ = time required for mixture to convect from fuel injection point to flame
    - F= natural combustor frequency

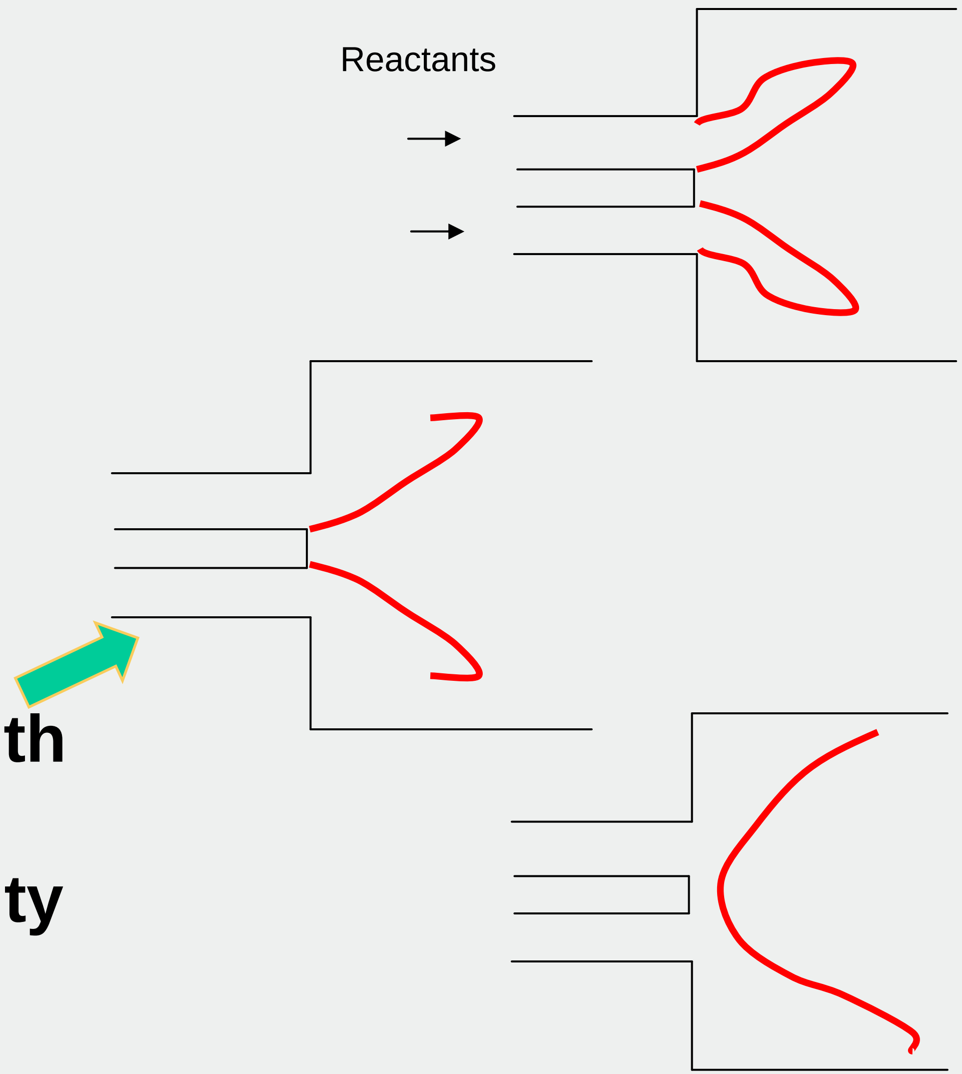


Overarching Idea for Understanding Dynamics Sensitivity to Fuel

Fuel → **Flame shape** → **Dynamics**

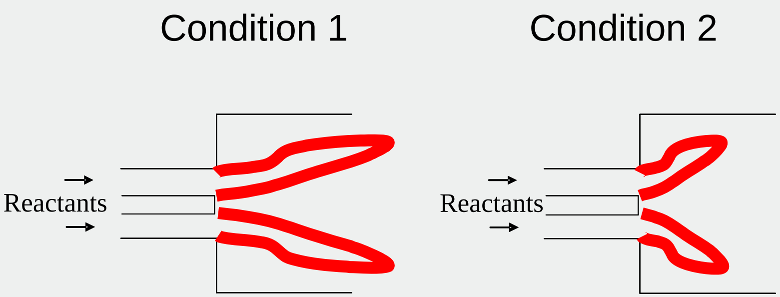
Operability Issues: Combustion Instability

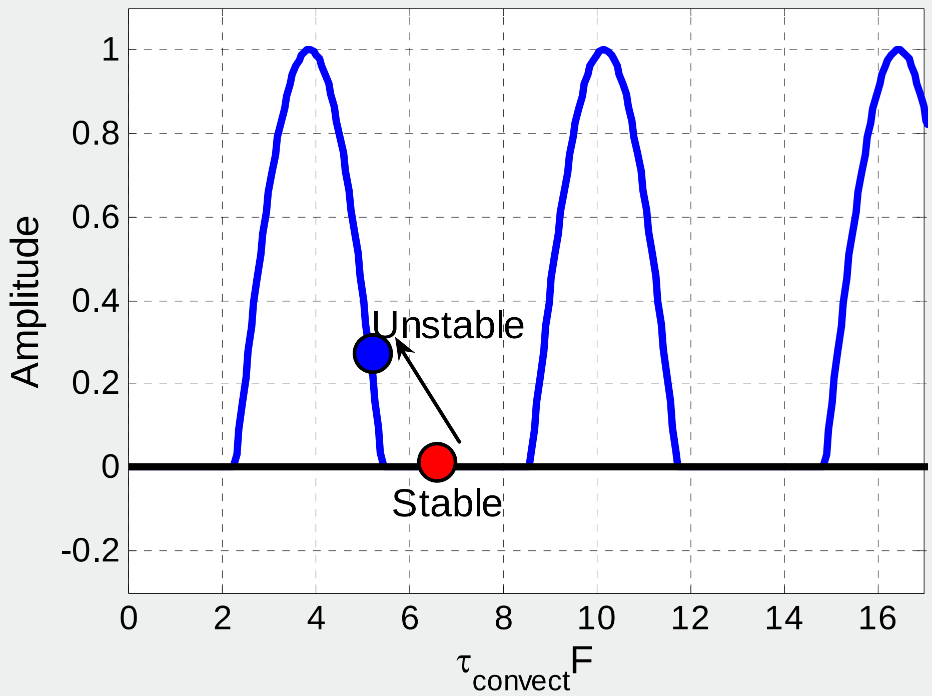
- **Fuel composition variations impact stability through changing time delays**
  - Flame shape
  - Standoff location
- **3 Different Flame Shapes/Locations with Very Different Combustion Instability Characteristics**



Effects of Fuel/Operating Conditions on Conditions of Occurrence

- **Key effect of fuel/operating conditions on dynamics is through alteration of flame shape/location**





Example where dynamics made worse

Effects of Fuel/Operating Conditions on Conditions of Occurrence

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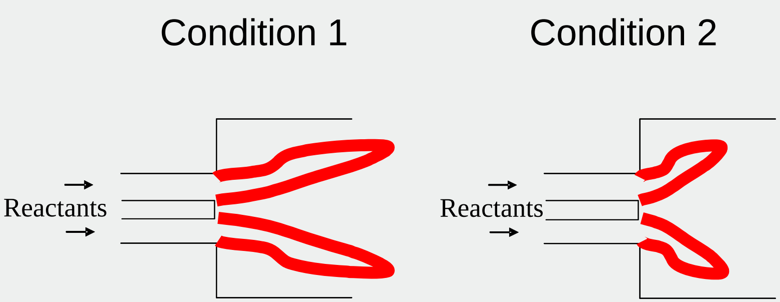
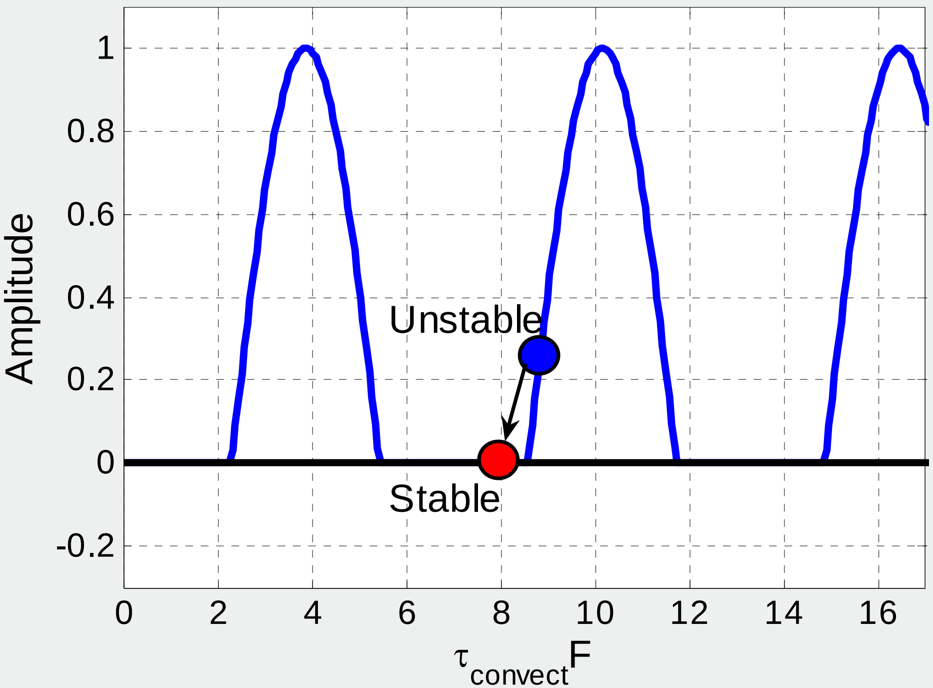
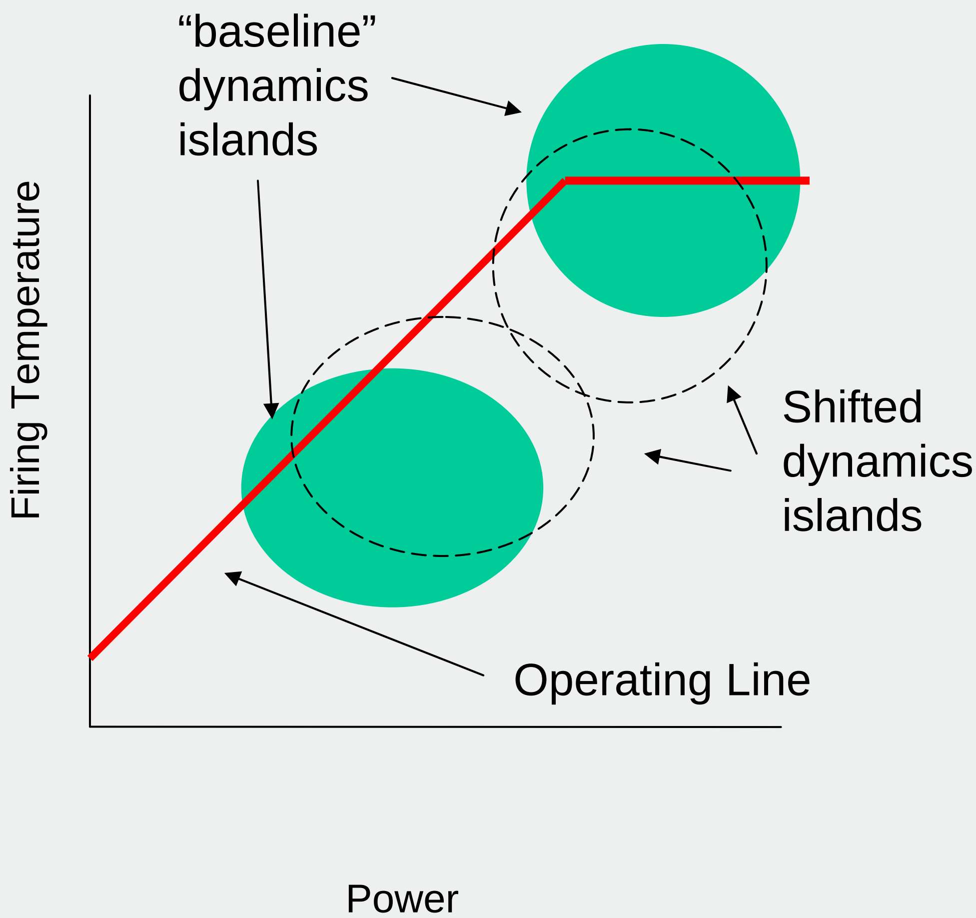




Example where dynamics made better

Fuel Effects

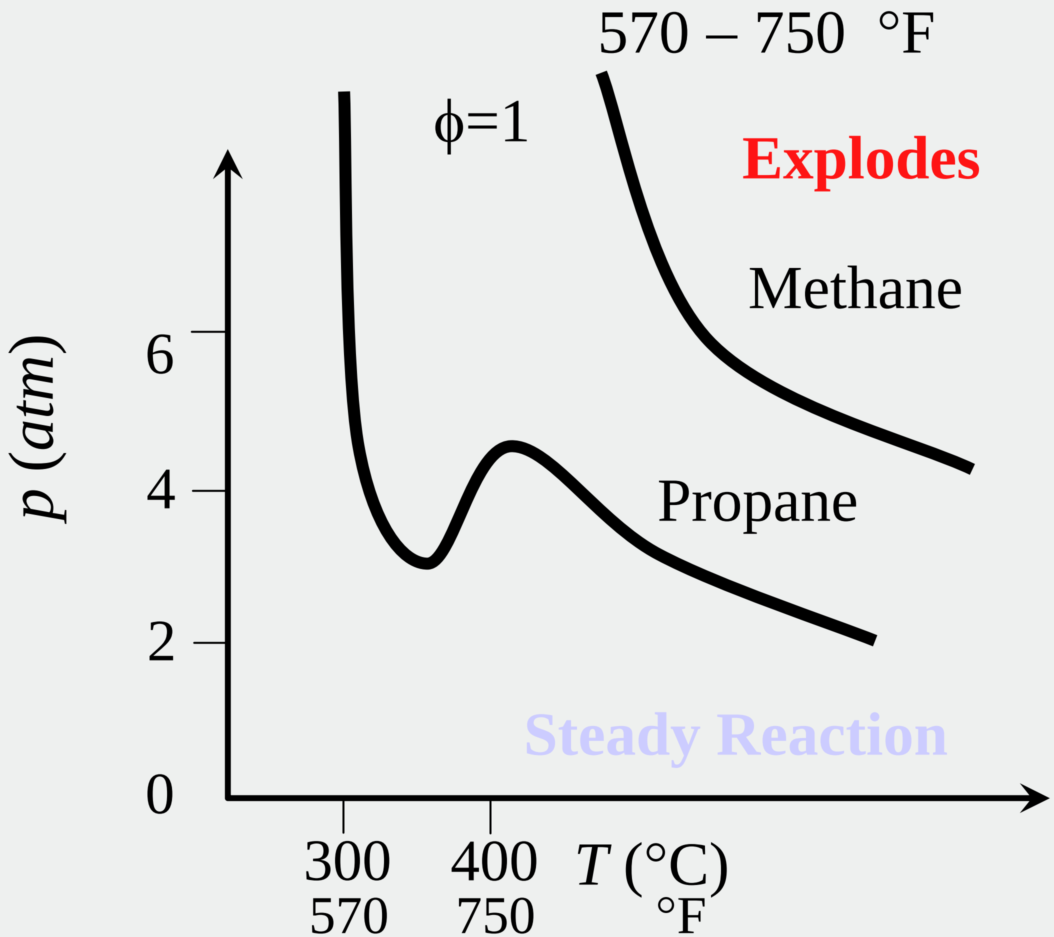
- **Change in fuel does not change susceptibility to dynamics (either for better or for worse), rather it moves instability islands**
  - Very system and operating condition dependent
- **Cannot make definitive comments on whether dynamics will be "better" or "worse:**
- **Research needs:**
  - Flame shapes – extinction strain rate and turbulent flame speed
  - Swirling flow fluid mechanics
  - Limit cycle mechanisms



Operability Issues – Autoignition

Explosion Limits

- **Methane is hard to autoignite**
- **Higher hydrocarbons autoignite at succesively lower temperatures**
  - Addition of small amounts of higher hydrocarbons to methane can substantially decrease ignition times
  - Important consideration for LNG, particularly with high pressure ratio aeroderivatives



Petersen's Data – Ethane Effects

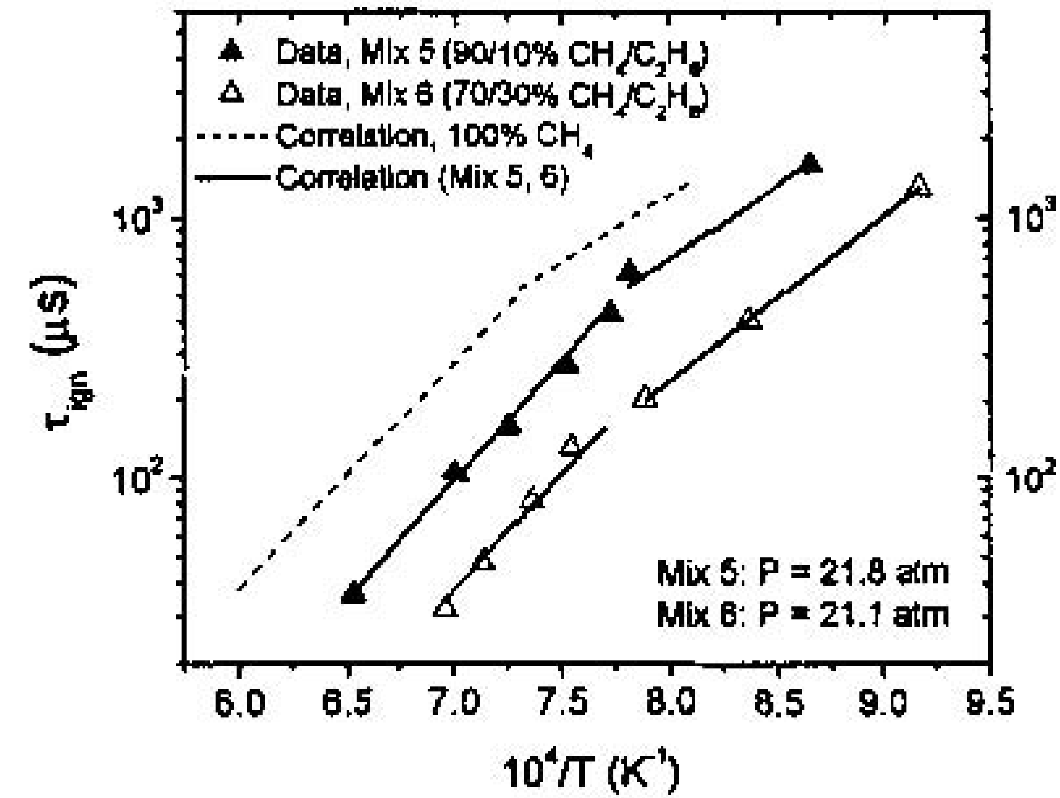
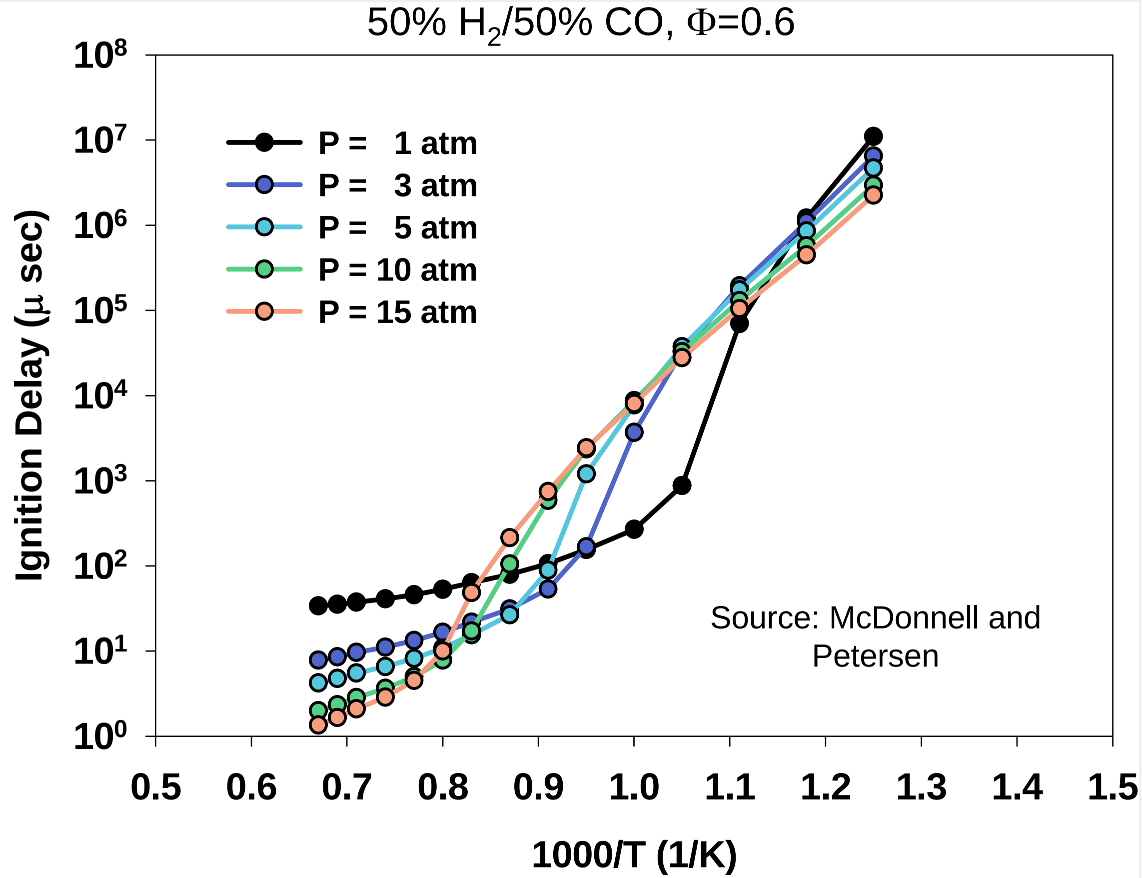


Fig. 5 Ignition delay times for the methane/ethane blends in comparison to the methane-only data at similar pressures.

- Petersen et. al. "Ignition of Methane Based Fuel Blends at Gas Turbine Pressures", ASME 2005-68517

Ignition Properties Not Necessarily Monotonic with Pressure/Temperature



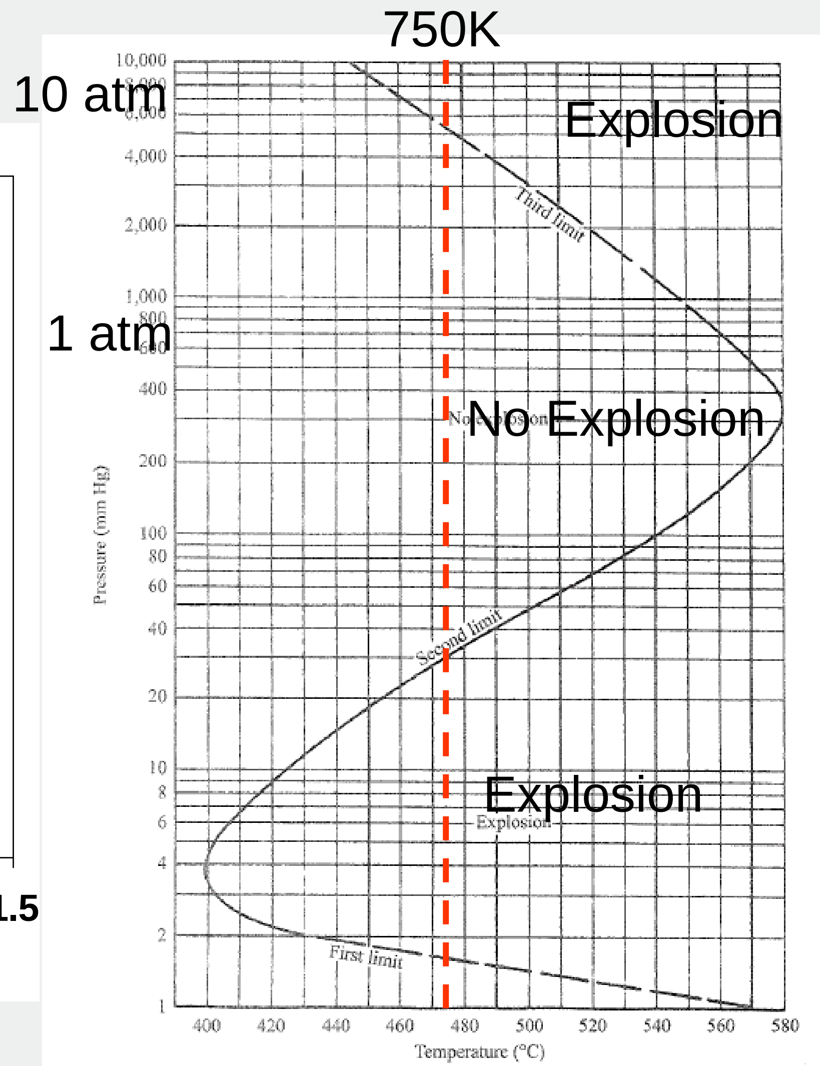


Figure 5.1 Explosion limits for a stoichiometric hydrogen–oxygen mixture in a spherical vessel.

Research Needs: Ignition properties at high pressure, “low temps”

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Concluding Remarks

- **Highlighted operability issues influenced differently by fuel chemistry**
  - Blowoff
    - extinction strain rates
  - Flashback
    - Turbulent flame speed
  - Combustion instabilities
    - Flame shape – extinction strain rates and turbulent flame speed
  - Autoignition
    - Ignition chemistry

- **Questions for discussion:**
  - Path forward for obtaining fundamental fuels properties at conditions of interest?
  - Prioritization for fundamental properties highlighted above?