FLASHBACK CHARACTERISTICS OF SYNGAS-TYPE FUELS UNDER STEADY AND PULSATING CONDITIONS

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Gas Turbine Need

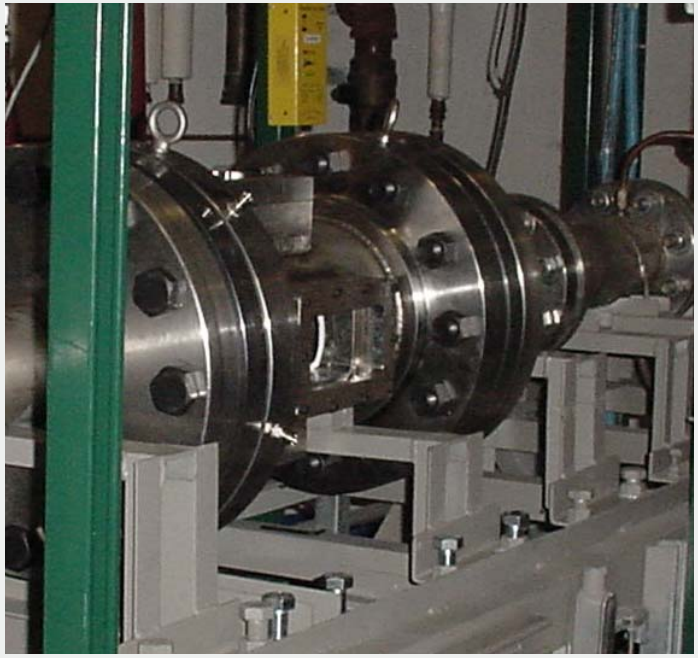
- ***Need:*** **Gas turbines with sufficient flexibility to cleanly and efficiently combust a wide range of fuels, particularly coal-derived gases**
  - *Problem:* Inherent variability in composition and heating value of coal-derived and other alternative fuels provides significant barriers towards their usage
- **Flame stability**
  - Flashback — flame propagates upstream into the premixer
- **What are the key variables characterizing fuel influences?**
  - Flame temperature (Heating value)
  - Flame speed
  - Percentage of H_2

Project Approach

- **Task 1:**
  - Determine fuel compositions in various IGCC, landfill, process gas plants
  - Determine test conditions of other ongoing efforts
  - Statistical design of experiments
  - Obtain input from industry

- **Tasks 2 and 3:**
  - Characterize fuel composition, static effects upon flashback (Task 2) and pulsating amplitude (Task 3) conditions
  - Correlate results with chemical kinetics calculations
  - Communicate with industrial partners

Combustor Testbed



Accomplishments

- **High impact accomplishments to date**
  - **Developed facility for flashback measurements**
  - **Initiated series of flashback tests that systematically isolate fuel composition effects**
  - **Identified two modes of flashback**
  - **Prepared combustor for future high pressure testing**

- **Results are improving understanding of flashback in fuel flexible combustors**

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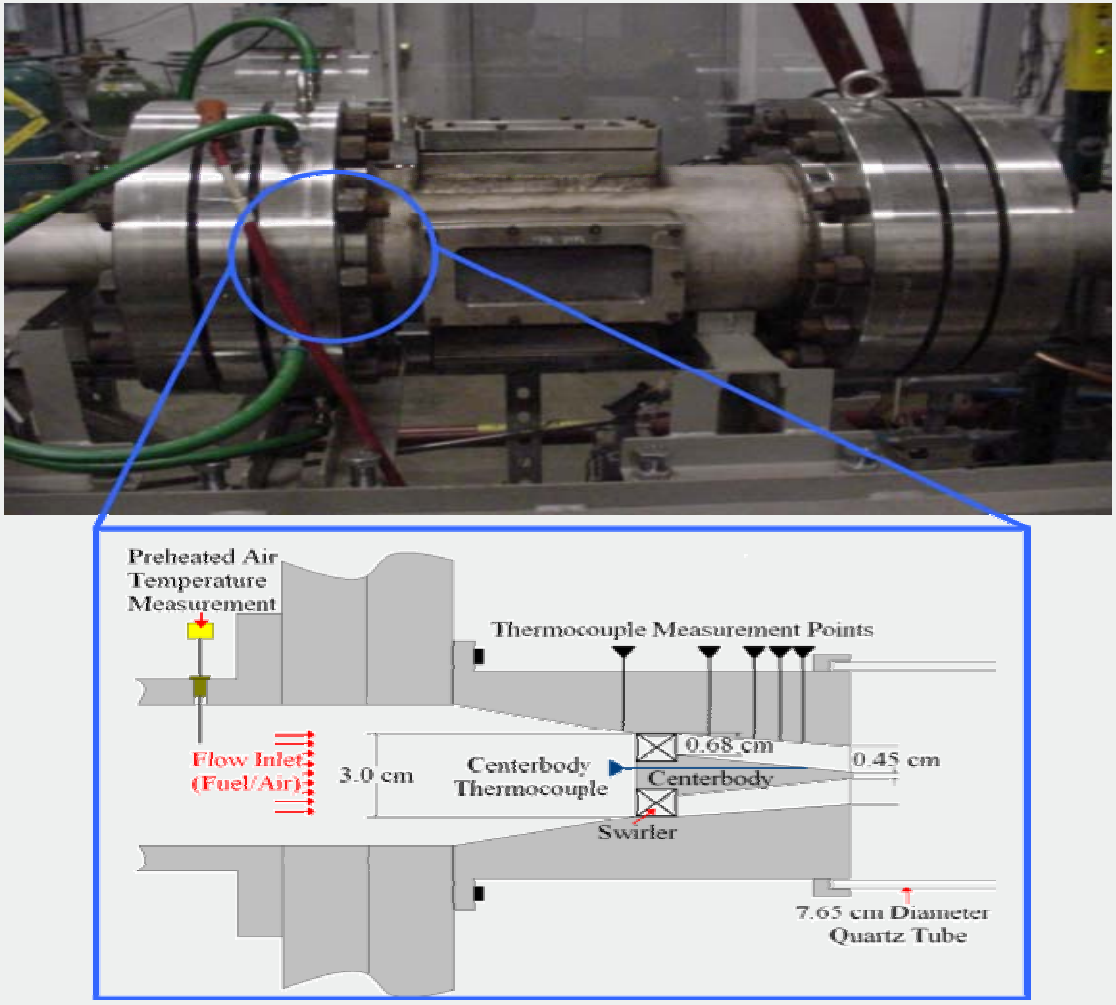
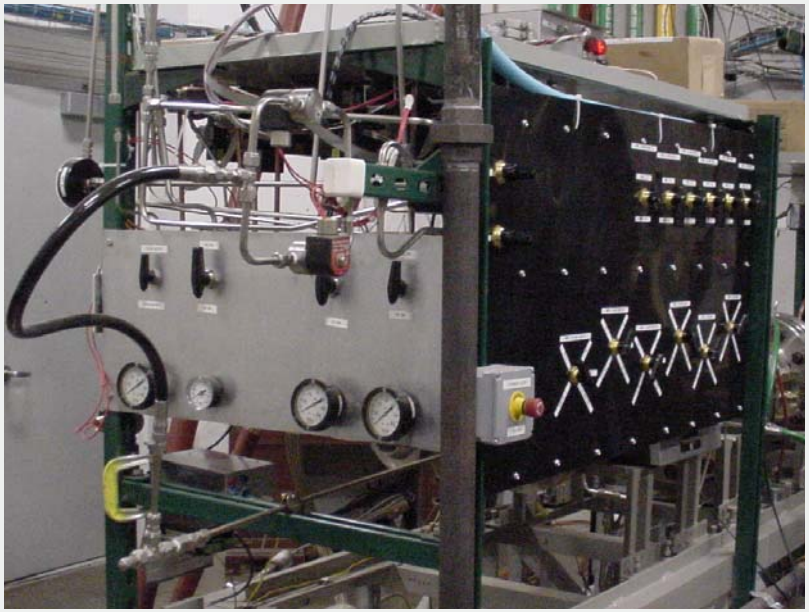
Fuel Flexible Combustor Facility

Combustor Facility



SYNGAS Mixing Facility



- **Gas Mixing Facility can generate arbitrary $H_2/CO/CH_4/N_2/CO_2$ mixtures**
- **7 Mass Flow Controllers**
  - 0-10 SLM
  - 0-50 SLM
  - 0-200 SLM (x3)
  - 0-1000 SLM
- **2 Remote Back Pressure Controllers**

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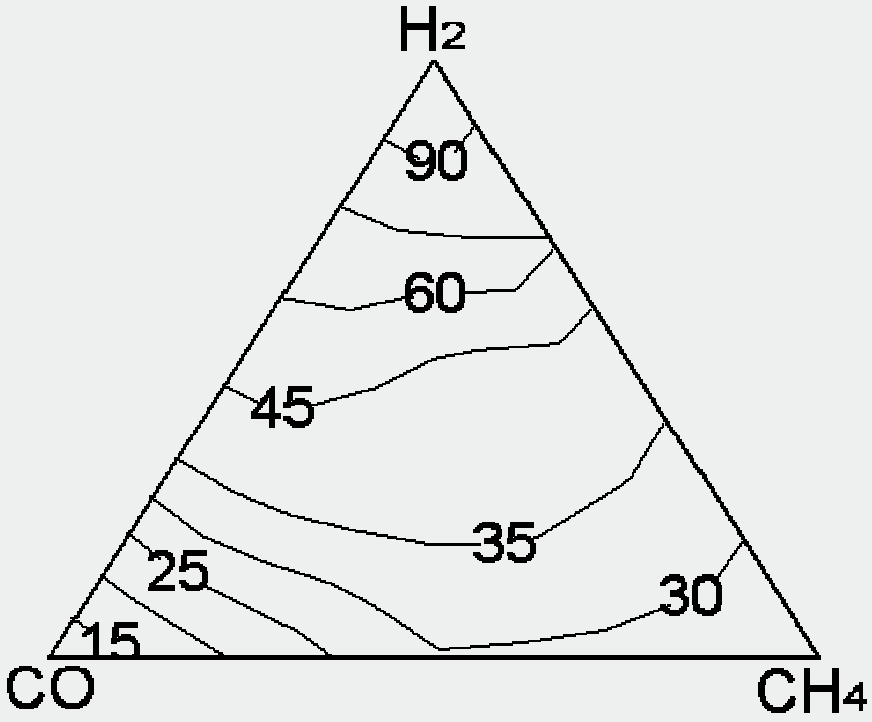
Flashback Study

Static Testing Objective

- **Determine key variables that represent effects of fuel composition and mechanisms that describe flashback**

- **Key variables may need to be calculated, based upon measured quantities**
  - e.g., T_{ad}, S_L, S_T, Lewis number, Markstein number (Ma), chemical time (τ_c)
  - Calculations performed with CHEMKIN using GRI 3.0 mechanism

Fuel Composition Effects on $S_{L,0}$ and T_{ad}

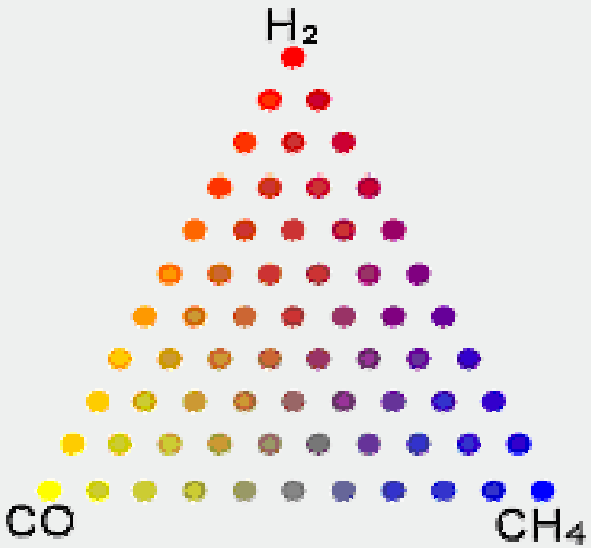


$S_{L,0}$ (cm/s) at T_{ad}=2000 K

Test Matrix

- **Three Fuels Used In Various Compositions:**
  - CH_4, H_2, and CO
- **Test Conditions:**
  - Premixer exit velocity: ~ 20 - 60 m/s
  - Pressure: 1.7 - 4.4 atm
  - Inlet Temperature: 300 - 460K
- **Test Procedure**
  - Flashback: Increase mixture equivalence ratio (at constant U_0, T_i, and P) until the mixture enters premixer

Color scheme



Previously Identified Flashback Types

- **Flashback:**
  - Due to conditions in the boundary layer
  - Due to turbulent flame propagation in the core flow
  - Induced by combustion instabilities
  - Caused by combustion induced vortex breakdown

Key Mechanism in Bunsen Flames

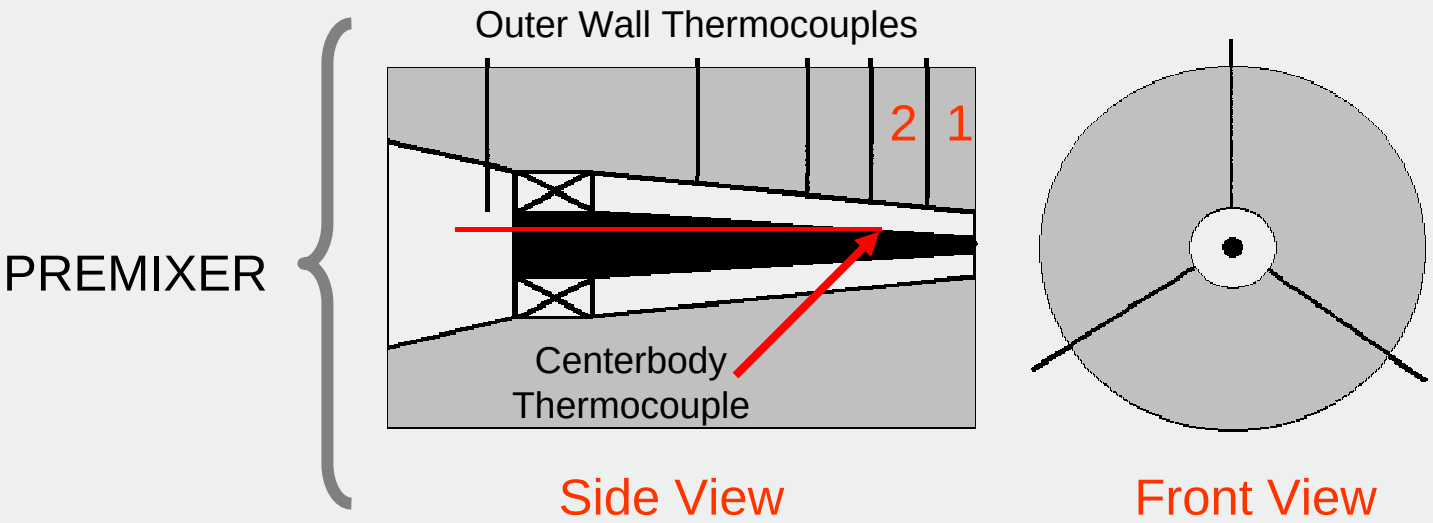
Identified here at high H_2 concentrations

Identified here at low H_2 concentrations

Ref. Fritz et al., 2001

Definition of Flashback for Experiments

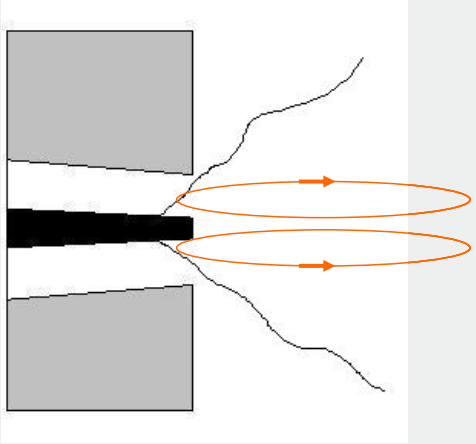
- **Flashback was detected with radially placed outer wall thermocouples and a centerbody thermocouple**



Flashback Phenomenon Varied with Composition

- **High H_2 mixtures – rapid flashback**

- **Low H_2 mixtures – flame leading edge moves back into premixer**



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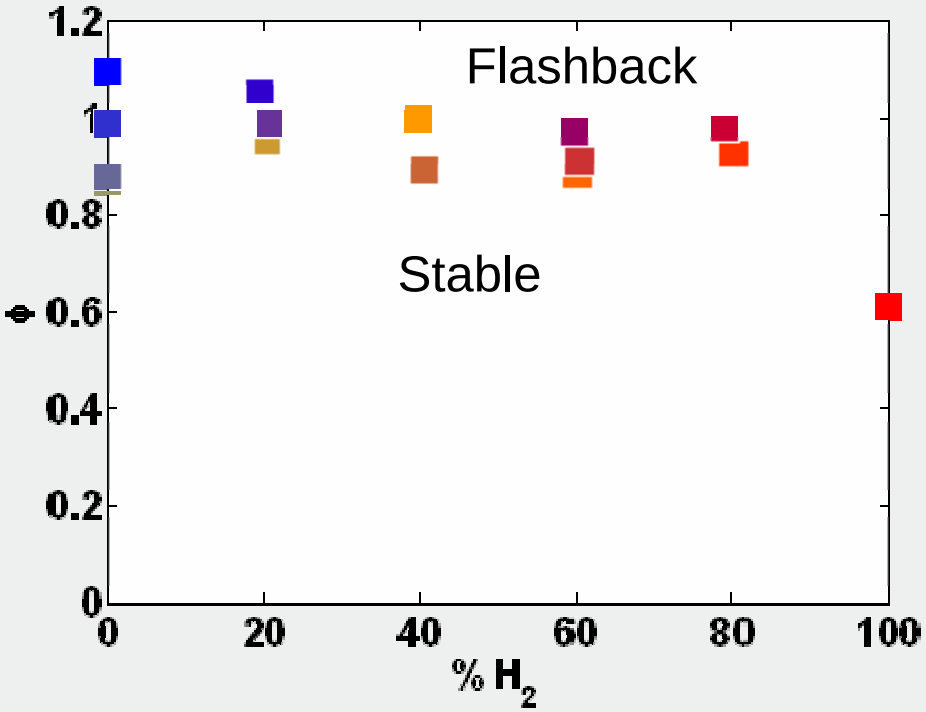
Experimental Results

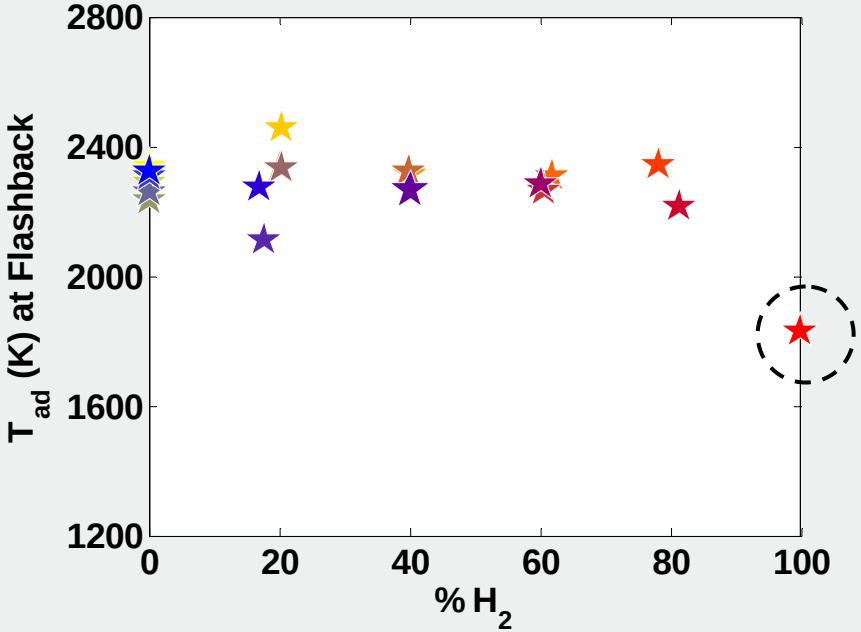
Flashback Boundary

- **U_0=36 m/s, T_i=300K, P=1.7atm**
- The slow flashback mech result is independent of percentage of H_2



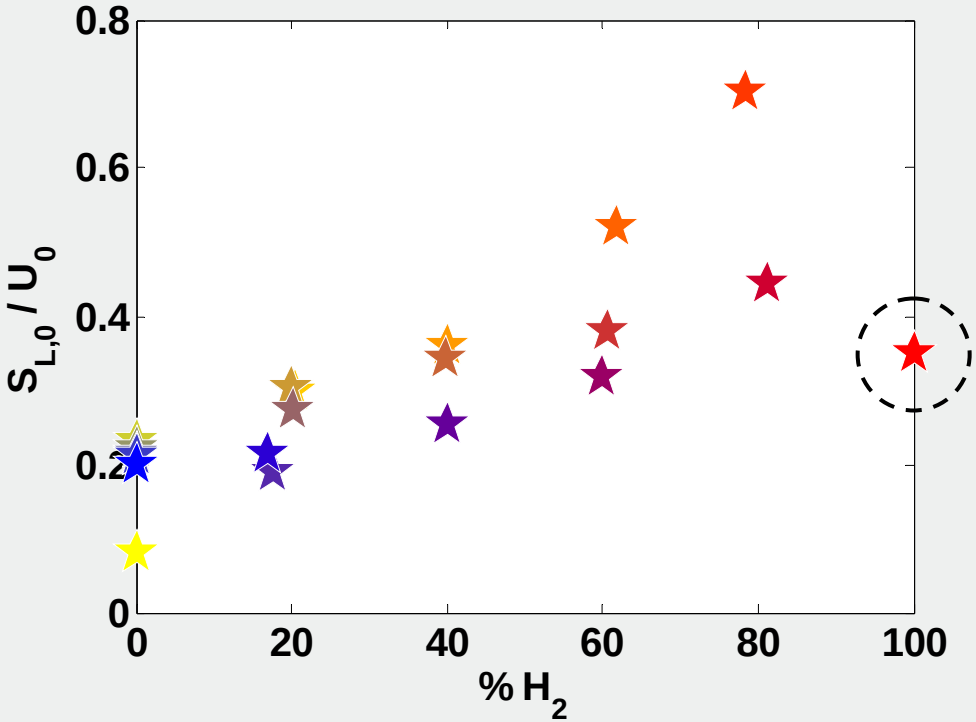
Typical Flashback Tendencies

- Dependence of T_{ad} at flashback upon percentage of H_2
- U_0=36 m/s, T_i=300K, P=1.7atm
- Circled flashback points indicate occurrence of rapid upstream propagation flashback mechanism



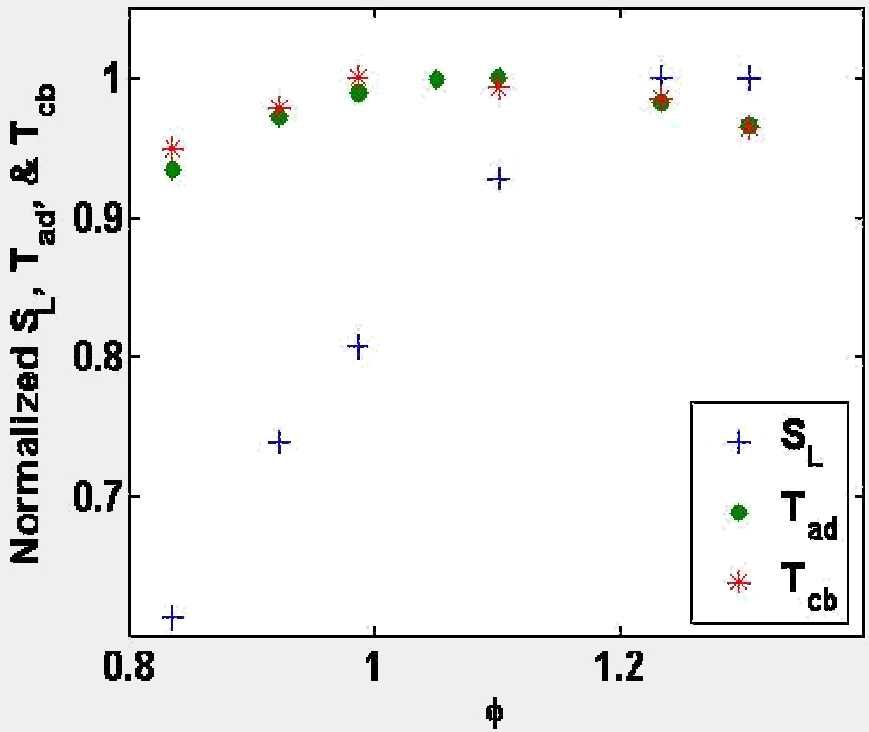
Laminar Flame Speed Correlation of Results

- **Significant variation in flame speed values at flashback**
  - Flame temperature more adequately correlates slow flashback data



Centerbody Temperature Peak vs. Flame Speed and Flame Temperature Peaks

20%CH_4—20%H_2—60%CO



- High CO cases useful for separating flame speed and flame temperature effects as they peak at significantly different ϕ values
- Centerbody temperature corresponds to flame temperature more so than flame speed
- One case out of 21 fuel combinations shown

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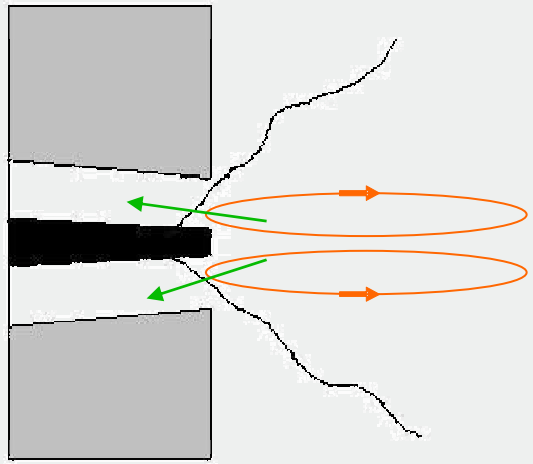
CIVB Flashback Mode

Combustion Induced Vortex Breakdown

- Results consistent with work of Sattelmayer and co-workers who have suggested a CIVB flashback mechanism

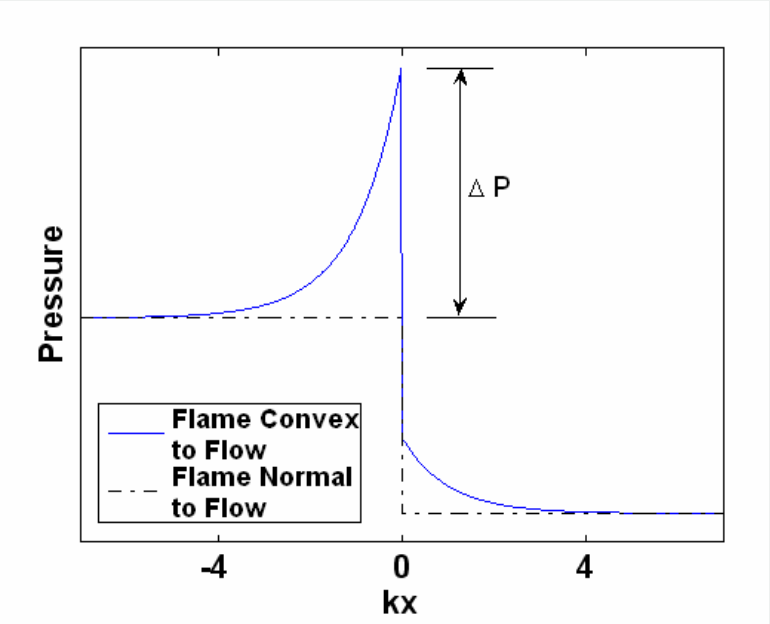
- Key idea:
  - Presence of flame induces vortex breakdown upstream
  - Flame propagates upstream

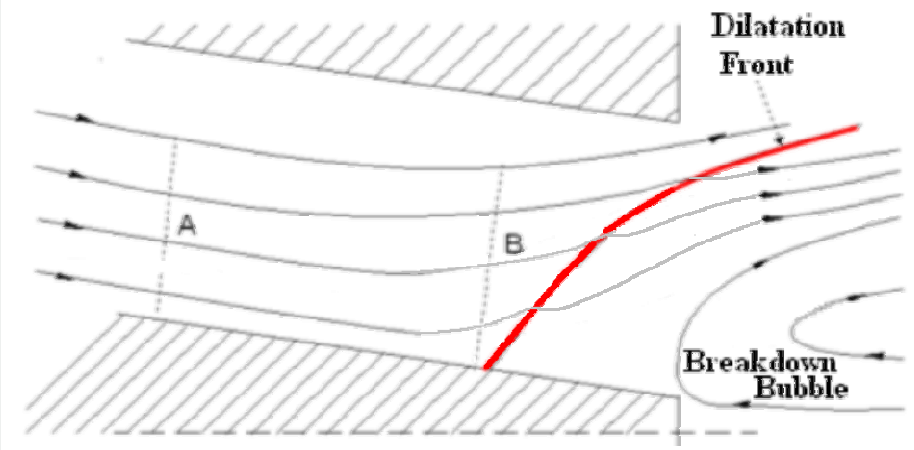


Hypothesis of Why T_{ad} is Dominant Parameter

- **Inclined flame causes**
  - Downstream pressure drop
  - Upstream pressure rise

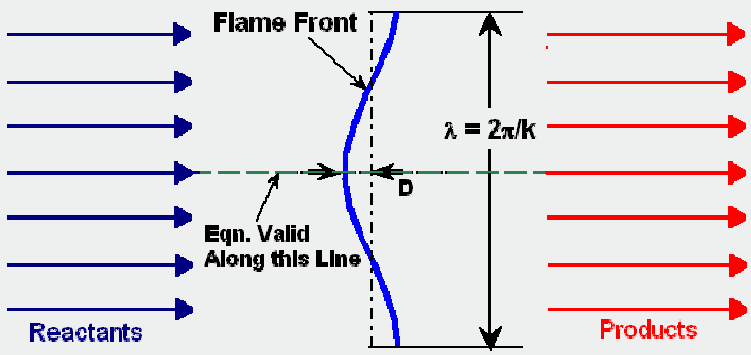
- **Adverse pressure gradient stimulates vortex breakdown**
  - Similar to rapid flow expansion

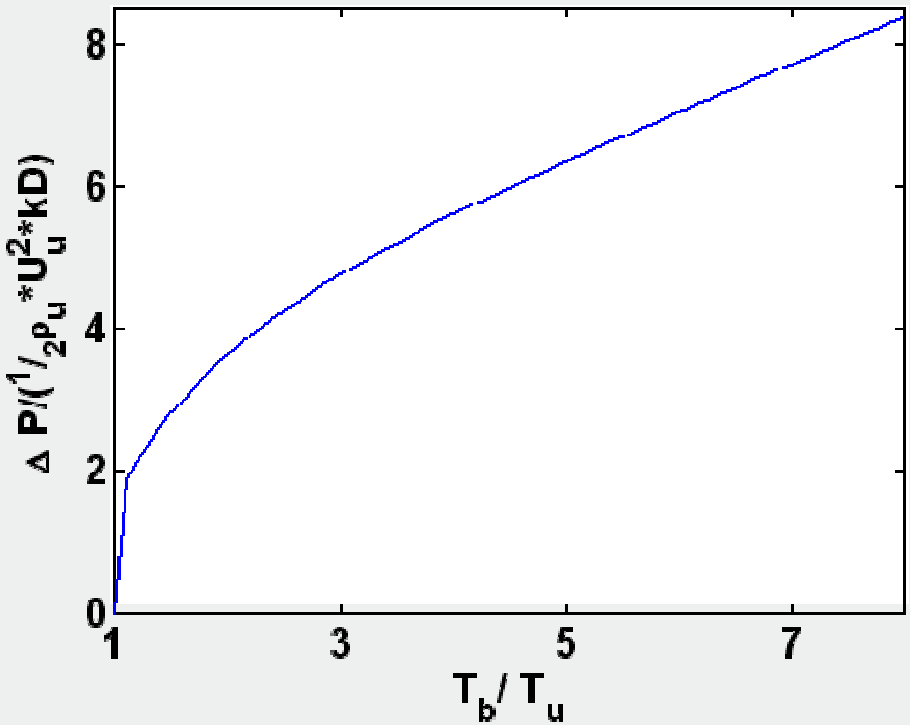




Darrieus-Landau Flame Stability Analysis

- **D-L analysis with small sinusoidal wrinkles**
  - Spatial wavenumber *k*
  - Amplitude *D*
  - Flame temperature ratio T_b/T_u
- **Result shows adverse pressure gradient growing with temperature ratio across flame**
  - T_{ad}/T_{air}





Conclusions

- **Two flashback modes were prevalent**
  - Combustion Induced Vortex Breakdown
    - For H_2 less than 80%
    - Adiabatic flame temperature was found to be a key parameter
  - Rapid Flashback
    - For H_2 greater than 80%
    - Future tests will focus on lower velocity conditions where rapid flashback is more prevalent

Thank You/Questions