- **Thank you Prof. Moshe Matalon**
- **Thank you Prof. Fred Gouldin**

9th International Workshop on Premixed Turbulent Flames

Saturday July 31, 2004

10 - 11 CMCS Data entry demonstration and future plans. Discussion leader: Robert Cheng

11 - 12:30 Discussion on oblique flames Discussion leader: Fred Gouldin
"Displacement Speed Statistics from DNS" Evatt Hawkes, Sandia National Laboratory
"Simulation of Turbulent V-flames" Marc Day, LBNL

2 - 3:30 Discussion on envelop flamesDiscussion leader: Jim Driscoll
"Burning Velocity Correlation of Turbulent Premixed Flames at High-Pressure and High-Temperature" Hideaki Kobayashi, Tohoku University

4 - 5: 30 Discussion on unattached flames Discussion: Ian Shepherd
"Actively Controlled Unattached Turbulent Flame Simulations." Jor Grcar, LBNL
"Cross stream PIV measurements in a low-swirl burner" Robert Cheng, LBNL

Sunday August 1, 2004

10 - 11:30 Merging theories, models, and simulations with experiments Discussion leader: Friedrich Dinkelacker
"Modelling of pressure influence taking advantage of experimental data series", Friedrich Dinkelacker, University of Erlangen
"Turbulent Flame Propagation with Large Chemical Heat Release" Ralph Aldredge, UC Davis
"Wrinkling spectra of flames in Hele-Shaw cells" Paul Ronney, USC

12:00 - 1 Close-out discussion and solicit volunteers for beta-testing CMCS. Discussion leader: Robert Cheng

Database Plan

- **Portal: Collaboratory Multi-Scale Chemical Science (CMCS) (http://cmcs.org).**
  - **Support - US Department of Energy**
  - **Objective - Enhance chemical science research by developing an adaptive informatics infrastructure and demonstrating proof-of-concept by publicly deploying an integrated set of key collaboration tools and chemistry-specific applications, data resources, and services**
  - **Features - Sophisticated and powerful web tool for remote collaboration (data sharing, threaded discussions, and group notifications) as well a service to enable publication of group- or community-reviewed data with supporting web documentation**
  - **Current CMCS combustion teams - chemical kinetic and HCCI areas have form CMCS teams**
  - **Site Development - David Leahy of Sandia**
  - **Participation – registered user or guest**

1st Objective: Catalog of experimental data for low-shear stationary premixed turbulent flames

- **Process**
- **Workshop attendees agreed on annotations generated from last workshop**
  - —Very important because changing them in the future will cause inconsistency
- **Finalized Excel sheets for standard information entry**
  - —Demonstration and discussion here
- **Conversion of Excel files into xml files**
  - —Needs at least three participants for beta-testing
- **David Leahy convert xml into html for CMCS website**
- **CMCS tracks requests of datasets to authors**

Growing Categories of Premixed Turbulent Flames

- **Low-shear stationary flames**
  - **Sub-categories: oblique, envelope, unattached**
  - **Important Properties: flame wrinkling ……..**
- **Transient flames**
  - **Sub-categories: point-symmetrical flame kernels or balls, 2D channel flame propagation, flame vortex interaction**
  - **Important properties: time dependent reaction rates …….**
- **High-shear stationary flames**
  - **Sub-categories: heavily piloted jet flames, bluff-body stabilized flames, high-swirl flames**
  - **Properties: extinction and reignition …….**

Three Sub-Categories of low-shear Stationary Premixed Turbulent Flames

Oblique Flames	Envelope Flames	Unattached Flames

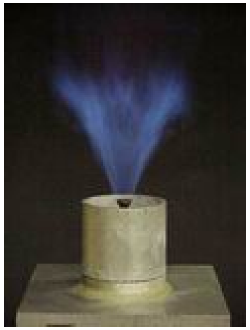
- **Common features of stationary flame experiments:**

  Flow uniformity **– plug flow with flat mean and rms velocity distributions across burner opening**
  Isotropic turbulence **- controlled by turbulence generator (grid or perforated plate) with relative low or no shear**
  Homogeneous mixture **- thoroughly mixed upstream with emphasis on stoichiometric to lean conditions**

Oblique Flames

- **Generated by a flame holder at the center of the burner**
- **Turbulent flame brushes interact with incident turbulence and grow thicker downstream of the stabilizer**
- **The sizes of the flame holder kept to a minimum so to reduce its influences on the developing turbulent flame brush**
- **Larger stabilizers for investigating the contributions of the stabilizer wake (i.e. shear turbulence) to flame characteristics and blow-off**

Plane-Symmetric Oblique Flame
A V-flame stabilized by a small rod is the most common rendition of a plane-symmetric laboratory oblique flame. Over 40 publications on this configuration



Axi-symmetric Oblique Flame
A small bluff body or pilot flame generate an axi-symmetric oblique flame that shapes like an inverted cone.

Oblique Flames

- ***Relevant Properties for Validating Theories and Simulations:***
  - —flame brush orientation (define by a mean scalar contour)
  - —brush thickness and growth rate (define by scalar contours)
- ***Properties not recommended for analysis***
  - —displacement flame speed (large variations & uncertainties)
- ***Experimental parameters affecting flame properties***
  - —size and shape of the stabilizer
  - —energy addition by heated bluff body (wire) or pilot flame
  - —use of co-flow
- ***Practical Relevance:***
  - —After burners in jet engines
  - —Commercial make-up air furnaces

Envelope Flame

- **Generated by anchoring the flames at the rim of the burner**
- **Turbulent flame brushes burn towards the center and merge to form an envelope over the premixture**
- **Under moderate flow and turbulence levels where open flame tip and local extinction (or quenching) are not likely to occur, the premixture cannot escape without burning**
- **Most studies use pilot flames to extend the test matrix because the burner rim is not a very effective flame stabilizer**

Waiting for picture from Driscoll

Plane-Symmetric Envelope Flame
Generated in a rectangular shaped burner (or slot burner) with flame brushes originating at two opposite edges. To preserve the "envelope" features, the two remaining sides of the burner need to be confined.

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Axi-symmetric Envelope Flame
Also known as conical flames.

Envelope Flame

- ***Relevant properties for validating theories and simulations:***
  - —mean flame height (defined by intersection point of mean scalar contour at apex)
  - —global turbulent burning velocity (defined by inferred mean flame surface area and premixture flow rate)
- ***Properties not recommended for analysis***
  - —local displacement flame speed (large variations & uncertainties, ambiguity at the flame tip)
- ***Experimental parameters affecting flame properties***
  - —pilot flames adding energy to the system (some up to 30%)
  - —deviation from plug flow to jet flow at high *Re*
  - —turbulence intensities decay towards the flame tip
- ***Practical Relevance:***
  - —domestic and commercial air heating furnaces

Unattached Flames

- **Unattached flames do not need flame stabilizers**
- **Sustain in divergent flows by virtue of the propagating nature of premixed flames**
- **Flame brushes are locally normal to the approach flow and free to respond to incident turbulence without being constrained or "pinned down" at the flame attachment point.**

Unattached flames in impinging flows

The divergent flow generated by impingment on a stagnation plate or against each other allows the flame to position itself at a short distrance upstream of the stagnation plane.

Unattached flames in swirl-generated diverging Flow

Low swirl produces a divergent flow with the swirling motion confined to the flow periphery. In the center region, the turbulent flame brush is swirl free.

Unattached Flames

- ***Fundamental properties for validating theories and simulations:***
  - —**displacement flame speed (defined at a mean scalar value)**
  - —**flame brush thickness (defined by scalar contours)**
- ***Experiment parameters affecting flame properties***
  - —**downstream heat loss to the stagnation plate**
  - —**shape and curvatures of stagnation plate**
  - —**flame to wall and flame brush to flame brush interactions**
  - —**swirl number**
  - —**co-flow**
- ***Practical Relevance:***
  - —**deposition**
  - —**commercial and industrial burners and gas turbines**

Quantifying Turbulent Burning Rate

- **Possible measures are**
  - local heat release rate
  - local flame front propagation
  - Local displacement flame speed (turbulent burning speed)
  - Global flame speed
  - flame surface density
  - burning rate integral
  - consumption speed.
  - others?
- **How are these quantities defined, measured, related?**
  - Some answers in next slide
- **On what do they depend?**
  - burner/flame configuration
  - hydrodynamic/thermal instabilities
  - turbulence properties
  - other?
- **What are governing parameters?**
- **How useful are these different measures? Why? Are some more useful than others?**

Definitions and Measurements of Burning Rate Parameters

- **Local heat release rate**
  - — Quantitative imaging of scalar of the flame fronts. Which one to use is debatable
- **Local flame front propagation, S_L**
  - — Flow velocity locally normal to the surface of a wrinkled flame.
  - — Measured by combined PIV with scalar imaging, error can be large due to extraction of small quantity (< 0.5 m/s) from much faster flow (> 3 m/s)
- **Local displacement flame speed (turbulent burning speed)**
  - — Flow velocity locally normal to the turbulent flame brush
  - — Unambiguous for unattached flames only
  - — Relatively easy to measure by using PIV or LDV.
- **Global flame speed, S_b**
  - — Flow velocity obtained from a mean flame surface and the premixed flow rate
  - — Meaningful only for envelope flames
- **Flame surface density, Σ**
  - — Scalar imaging to obtain wrinkling factor and statistics of flame front orientations
  - — Difficult to measure when flame is highly contorted
- **Burning rate integral, B_t**
  - — Integration of Σ through the flame brush
  - — Integration paths differ at different regions of the flame brush
- **Consumption speed, S_c**
  - — Deduced by applying a correction factor to S_T to account for the effect due to divergence
  - — S_c and B_t Should be consistent