Lecture 34 - Turbulent Premixed Flames. - Chp 12

Outline

- Applications
- Turb. Flame Speed
- Flame Regimes
- Flame Stabilization.

- Turb Premixed flames are an area of ongoing Research
- Many theoretical models
- Here, Treatment is empirical and largely Qualitative
- Key Quantity is The Turbulent flame Speed.

Applications.

- Spark ignition Engines
  - Inject liq. fuel → vaporizes, mixes (not perfectly)
  - gases are Turbulent
    - Injection jets / exhaust
    - Piston speeds.
- Gas Turbine Engines
  - Run premixed (partial)
    - Reduce NOx : Dilution / Lean operation
    - Reduce CO : Lean operation.
    - Reduce Soot : lean + less soot in ~~or~~ premixed as There are no rich regions, unlike nonpremixed flames.
- Industrial / Residential Heaters / burners
- Issues include - Safety, : flashback + blowout → inject Premixture → ignite a large volume
  - Flame Stability → Blowout
    → noise
    → emissions : unburnt fuel

Turbulent Flame Speed

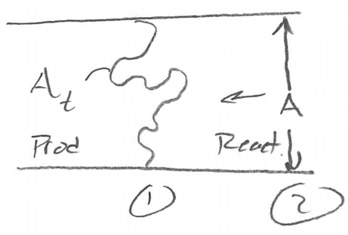
- Consider a turbulent "flame brush"
- Turb. flames thought of as a regular laminar flame, which is wrinkled by the turbulence.

(*) - Turbulent flame speed S_t is the speed of the flame brush, relative to reactants, in a direction normal to itself, and towards the reactants.

- Same as the laminar speed, but flame brush, instead of the flame.

Q: How does the turbulent flame speed compare to the laminar speed
Higher ?
Lower ? → Higher
Same ? → why ?

- Note, unlike S_L, S_t is not a purely thermochemical property, but depends on the flow itself.



$\dot{m} = \rho A U \longrightarrow \rho_R A_t \cdot S_L = \rho_R A \cdot S_t$

$$\longrightarrow \boxed{S_t = S_L \cdot \frac{A_t}{A}}$$

or $S_t = \dfrac{\dot{m}}{\rho A}$ (A is ∥ to the flame brush)

- Turbulence wrinkles the flames → $A_t > A$ → $S_t > S_L$
- In a sense, the turbulence "pushes" the flame forward by curving it → higher area.
- Consider from 2 points (1) at flame, (2) upstream

To calc S_t, need (S_L, A_t), or, $(\dot{m}, \rho, A)$
(A_t: hard; $(\dot{m}, \rho, A)$: easier.)

See Example 12.1

Premixed Combustion Regimes.

- Last Time we saw That The turb. jet at two Re had The Same Large Scale Character, but the Small Scales got Smaller For high Re.
- There are 2 important Turbulent Scales.

  ① Integral : L_o, u' → $\tau_o = L_o/u_o$ — Large

  ② Kolmogorov : η, u_η, $\tau_\eta = \eta/u_\eta$ — Small

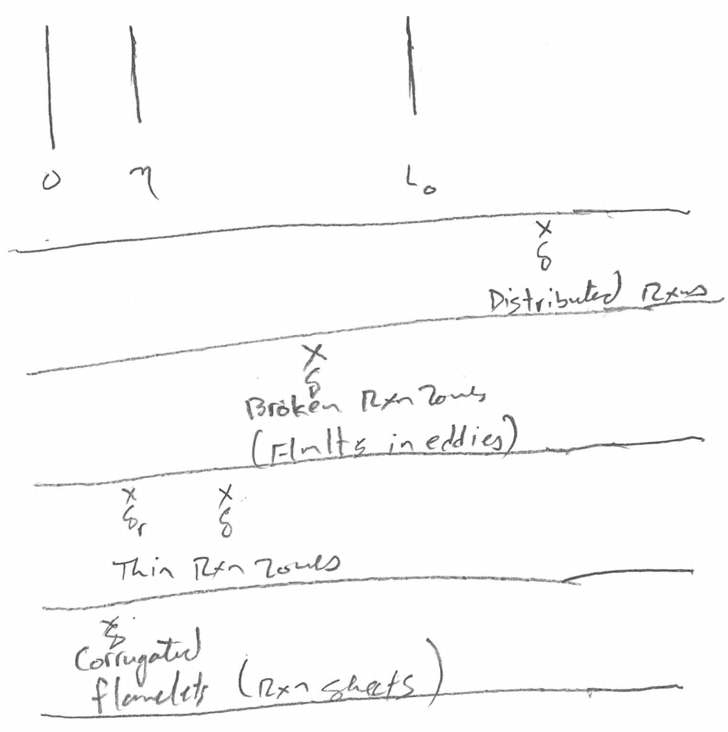
- Consider a turbulent premixed flame.

Q: What Does The turbulence Do to The flame?
How Does The turb. interact?
How Do interactions vary?

→ **Turbulence** – Fluctuations, Eddies of various Sizes but mainly
- Consider Integral, Kolmogorov.
- These eddies fluctuate at given Scale

Flame – Given length, Speed, → τ.

Turbulence interacts w/ Flame as Turbulence Scales interact w/ Flame Scales.



Quantify These w/ Dimensionless Ratios.

Damköhler Numbers

$$Da = \frac{\tau_{mix}}{\tau_{Rxn}} = \frac{\text{Reaction Rate}}{\text{Mixing Rate}}$$; High Da → Fast Rxns

$$Da = \frac{L_0 / u'_{Rms}}{\delta_L / S_L} = \frac{L_0}{\delta_L} \cdot \frac{S_L}{u'_{Rms}}$$; based on Large-Scale Mixing Rate.

Reynolds Number

$$Re = \frac{L_0 u'_{Rms}}{\nu}$$

High Re → Turb.
→ High u'_{RMS}
→ wide Range of Scales $\frac{L_0}{\eta}$

$$= \frac{L_0 U'_{RMS}}{S_L \delta}$$; $\delta = \frac{\alpha}{S_L}$ → $\alpha = \delta S_L$
with $Pr = \frac{\nu}{\alpha} = 1$

↳ a mixed up Da!

Karlovitz Number.

$$Ka = \frac{\tau_F}{\tau_\eta} = \frac{\delta^2}{\eta^2} = \frac{V_\eta^2}{S_L^2}$$

- (Small Scale Mixing Rate)/(Rxn Rate)
- Like an inverse Da, But w/ Small, not large-Scale Mixing.

Peters' Regime Diagram.

→ See PPT

Corrugated Flamelets (and Thin Rxn zones) most important in practice.

Correlations:
- Damkohler: $S_t/S_L = 1 + V'_{Rms}/S_L$
- Klimov: $S_t/S_L = 3.5\,(V'_{Rms}/S_L)^{0.7}$; $V'_{Rms}/S_L \gg 1$
- Clavin, Williams: $S_t/S_L = \left\{ 0.5 \left[1 + \left(1 + 8\,C\,V'^2_{Rms}/S_L^2 \right)^{1/2} \right] \right\}^{1/2}$

See Fig. 12.10. $C \approx 1$ but low V'_{RMS}/S_L

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Combustion Processes

Turbulent Premixed Flames

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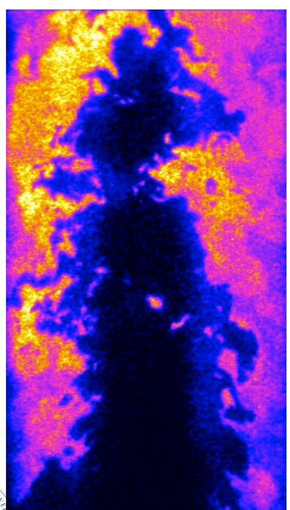
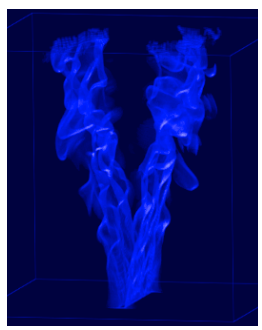
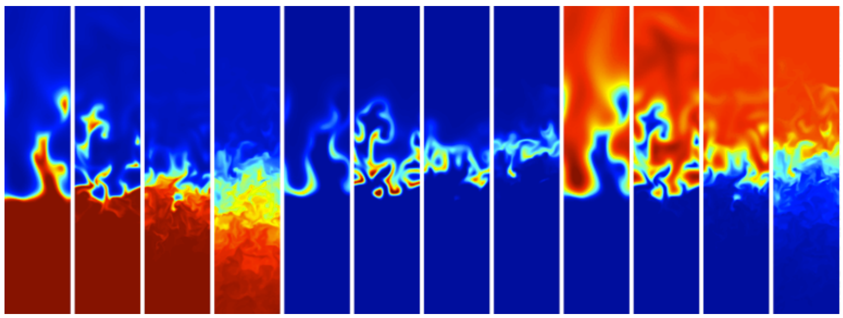
OH-PLIF



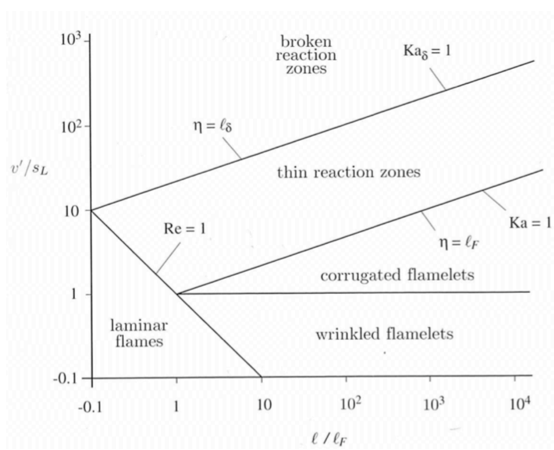


Lean Premixed Flames

Lean, Premixed, H2 flames (E.R.=0.31-0.4, density, HR, Temperature)
Ka = 10, 100, 260, 1560
LBNL



Regime Diagram



Many versions of these diagrams
Here, use Peters (1999)

Summary

Laminar Flames	Re<1
Wrinkled Flamelets	Re>1; Da>1; $u/S_L<1$
Corrugated Flamelets	Re>1; Da>1; $u/S_L>1$; Ka<1
Thin Reaction Zones	Re>1; Da>1; Ka>1; $Ka_\delta<1$
Broken/Distributed Reactions	Re>1; Da<1 or $Ka>Ka_\delta$

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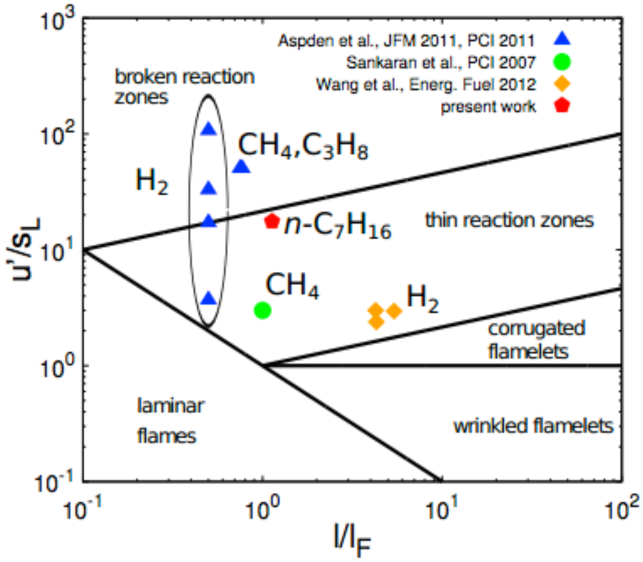
WSSCI Research Paper



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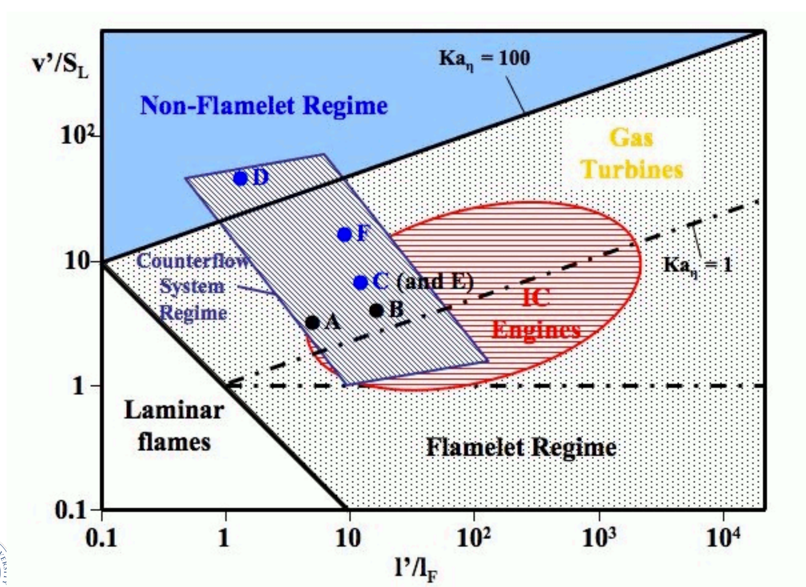
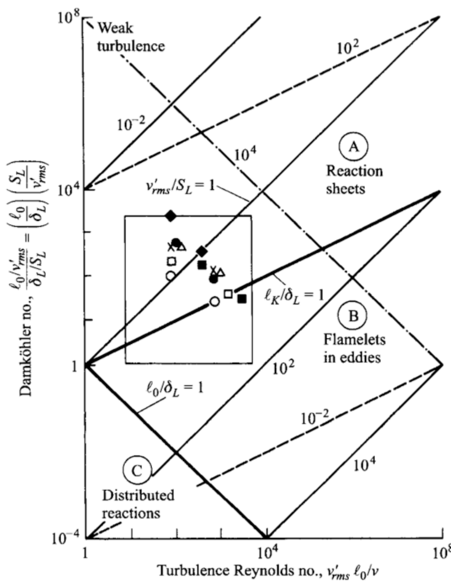


Regime Diagram in Turns



Flame Speeds for Flamelets