Chemical Flame Structure for Turbulent Lean Premixed Flames

Debolina Dasgupta, Tim Lieuwen

Ben T. Zinn Aerospace Combustion Laboratory

Daniel Guggenheim School of Aerospace Engineering, Georgia Institute of Technology

Introduction

The kinetics of laminar, premixed flames are well established and extensively used for determining the physics of turbulent flames [1]

The motivation behind this study is whether the basic picture remains the same or is altered in turbulent flames. This can be altered by:

- Tangential straining K_S and curvature $\mathbb{K}_C$ of scalar iso-surfaces leads to flame stretch, κ given by:

$$\kappa = K_S + s_d \mathbb{K}_C$$

Strongly stretched flames respond differently to curvature and tangential strain. Stretch can change local temperatures and relative concentrations of major and minor species.

- Instantaneous rates of reactions and their relative roles in heat release can change if the response of one or more reactions to unsteady stretch is not quasi-steady, i.e., $Ka_i \sim \tau_{chem}\kappa \sim$ O(1).
- Turbulence can modify the contributions of different reactions by the "stirring" action of small scale eddies within the flamelet, introducing spatially differentiated convective transport of species along the flamelet.

Methods

- Direct numerical simulations (DNS) of highly stretch-sensitive flames, described by Aspden et al. [2,3,4]. H_2/Air flames (ϕ = 0.4, *Le*=0.37), CH_4/Air flames (ϕ = 0.7, *Le*=0.96), *n*-$C_{12}H_{26}$/Air flames (ϕ = 0.7, *1*=4.37) at low and high turbulent intensities.
- Unstretched and stretched flame calculations are performed for different transport models:
  - Mixture-averaged transport

$$D_{i,m} = \frac{1 - Y_i}{\sum_{j \neq i} \frac{X_j}{D_{ji}}} \qquad \alpha_{mix} = \frac{k_{mix}}{\rho_{mix} c_{p_{mix}}}$$

  - *Le*=1 transport

$$\alpha_{mix} = D_{i,m}$$

  - Mixture-averaged transport with constant diffusivity

$$Le_T = \alpha_T / D_T = 1 \quad D_T = 10^{-6} \quad 10^{-5} \quad 10^{-4} \quad 10^{-3} \quad 10^{-2}$$

$$D_{i,m_T} = D_{i,m} + D_T$$

$$\alpha_{mix,T} = \alpha_{mix} + D_T$$

Heavier species | Most species | Light species

Objectives

WHAT?

To investigate the effect of turbulence on chemical flame structure for lean premixed flames.

HOW?

Conditional means of heat release, species concentration and reaction rates for turbulent flames are compared with equivalent laminar unstretched and stretched flame.

Results : Heat release

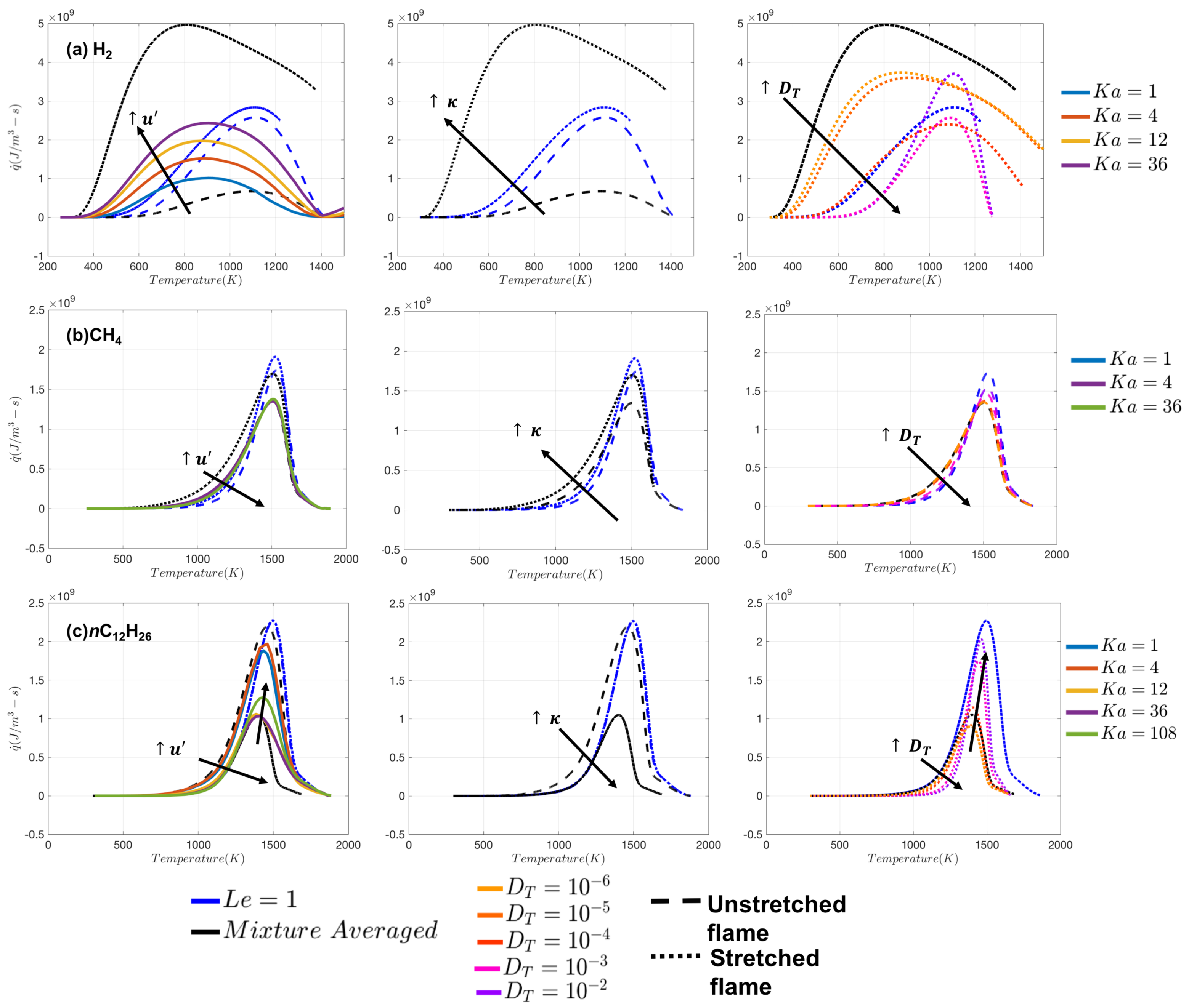

Figure 1. Heat release variation for (a) H_2 (b) CH_4 (c)*n*$C_{12}H_{26}$

Observations

1. **H_2:** Heat release evolution with increasing turbulence similar to increasing stretch.
2. **CH_4:** Heat release profiles similar to unstretched laminar flame. Changes due increasing turbulence similar to increasing diffusivity.
3. ***n*$C_{12}H_{26}$:** Heat release rate changes are non-monotonic with increasing turbulence. This behavior is similar to the effect of increasing diffusivity on highly stretched flame.

Results : Species profiles

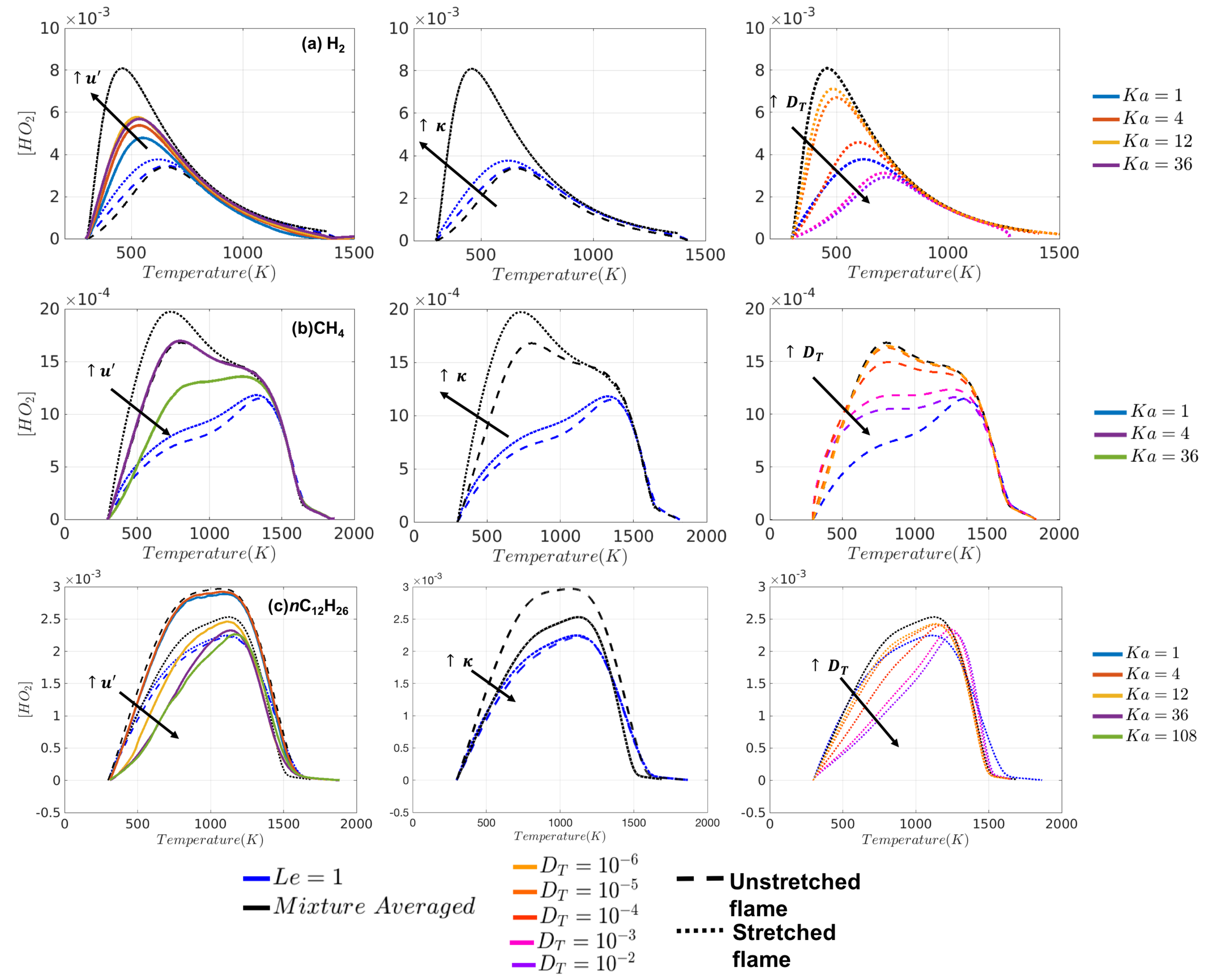

Figure 2. HO_2 concentration variation for (a) H_2 (b) CH_4 (c)*n*$C_{12}H_{26}$

1. **H_2:** Increasing turbulence increases HO_2 concentration across all temperatures similar to increasing stretch response.
2. **CH_4:** Increasing turbulence pushes the HO_2 profile towards *Le*=1 transport similar to the response of unstretched flames with increasing diffusivity.
3. ***n*$C_{12}H_{26}$:** Increasing turbulence pushes profiles beyond *Le*=1. A strong correlation is seen in the profile evolution of stretched flames with increasing diffusivity and with increasing turbulence.

Conclusions

1. Lean hydrogen/air flames (Le<1) have a stronger response to increasing stretch than increasing diffusivity.
2. Lean methane/air flames (Le~1) have a stronger response to increasing diffusivity and show very limited stretch effects.
3. Lean n-dodecane/air flames (Le>1) show a more complex response of combined stretch and diffusivity.

Acknowledgements

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