DNS of EGR-type combustion in Mild condition

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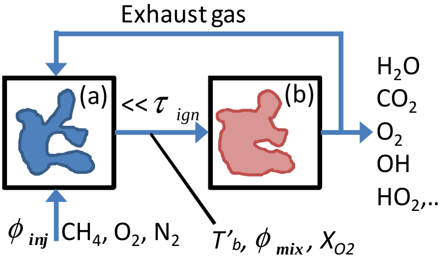
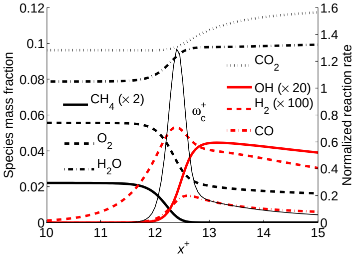
Moderate and Intense Low-oxygen Dilution (Mild) Technique

- Preheat unburnt mixture ($> T_{ign}$)
- Dilute reactants ($X_{O_2} \sim 0.03 - 0.1$)



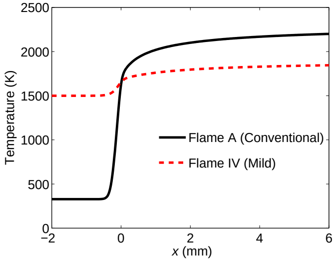
Exhaust gas recirculation (EGR) system



Mild flame
(Flame IV, X_{O_2}=0.05)

Mild Combustion: Benefits

- High inlet and low maximum temperature (uniform temperature)
  - High efficiency
  - Pollutant reduction (NO_x)
  - Less thermall stress (wall confinement)



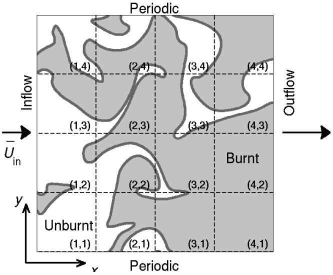
Temperature profiles (conventional vs Mild)

- T_u=1500 K
- T_b=1864 K ($\Delta T \approx 350$ K)
- Sufficient time for thermal NO formation [1]
  - Seconds for 1900 K
  - A few milliseconds for 2300 K

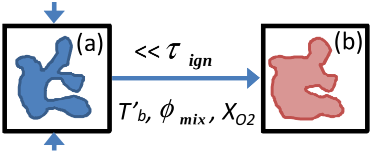
[1] J. A. Wünning and J. G. Wünning (1997) Prog. Energy Combusti. Sci.

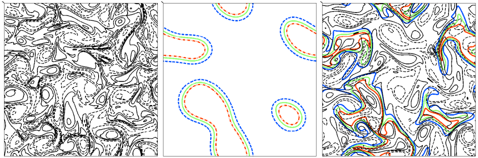
Direct Numerical Simulation (DNS)

- Fully compressible governing equations
- A two-step (6 species) and skeletal (15 species, 25 steps) mech.



Schematic flame configuration





Turbulence, Initial *c* field & Mixing DNS result

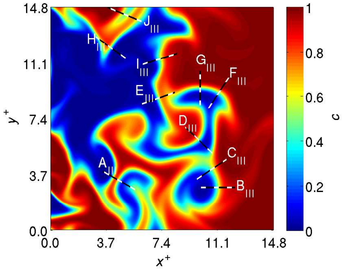
Numerical Methods & Conditions

Case	X_{O_2}	T_b' (K)	u'/S_L	$\bar{U}_{in}/S_L$	l_0/δ_F	l_0/δ_{th}	Da	Ka
I	0.194	1200	2.62	10.1	33.7	1.75	12.9	0.73
II	0.194	1200	5.71	10.1	50.2	2.61	8.79	1.93
III	0.095	1200	2.38	8.70	20.9	1.12	8.79	0.80
IV	0.048	1500	2.76	6.25	15.5	2.60	5.62	1.16

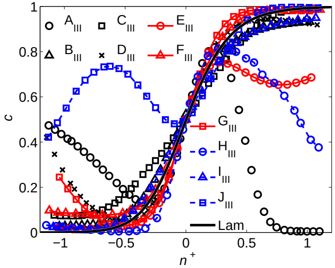
- 10th order explicit central difference
- 3rd order explicit Runge-Kutta method
- Navier-Stokes Characteristic Boundary Condition (NSCBC) for outflow boundary

Results (instantaneous & movie)

- Case III (20 × 20 mm)
  - Temperature
  - $-\omega_{CH_4}$
- Case IV (13 × 13 mm)
  - Temperature
  - $-\omega_{CH_4}$



Instantaneous c field and locations of cross section (Case III)



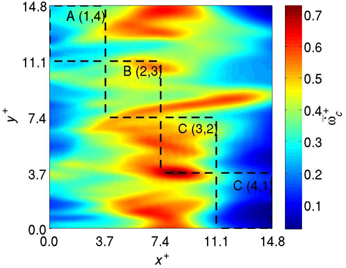
c variation along the normalized flame normal distance (Case III)

Results (mean)

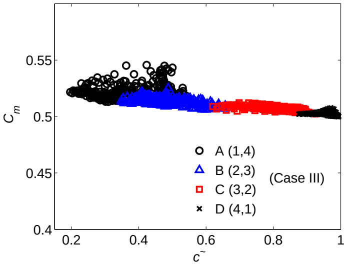
BML approach [2,3]:

$$\bar{\omega}_c = \frac{2}{2C_m - 1}\bar{\rho}\tilde{\epsilon}_c \qquad (1)$$

[2] K. N. C. Bray (1979) Proc. Combust. Inst. [3] P. A. Libby et al, (1980) Combust. Flame



Mean reaction rate, $\bar{\omega}_c$



Model constant, C_m.

Summary

- Two-dimensional DNS of EGR-type combustion has been carried out.
- The instantaneous and averaged data show that the simulated flames have flamelet-like behaviour.