Propagation characteristics of premixed ammonia flames under different turbulent conditions

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Introduction

- Towards decarbonizing combustion technology, **ammonia** (NH_3) combustion is considered a promising solution in power generation and transportation sectors

Pros:
1)Large hydrogen density
2)Energy storage
3)CO_2 free

Cons:
1)Slow laminar flame speed
2)Low adiabatic flame T
3)Narrow flammability limit
4)High ignition energy
5)NO_x emissions

- The advantages are more attractive over the disadvantages which could be overcome by blending with more reactive fuels (e.g., H_2)

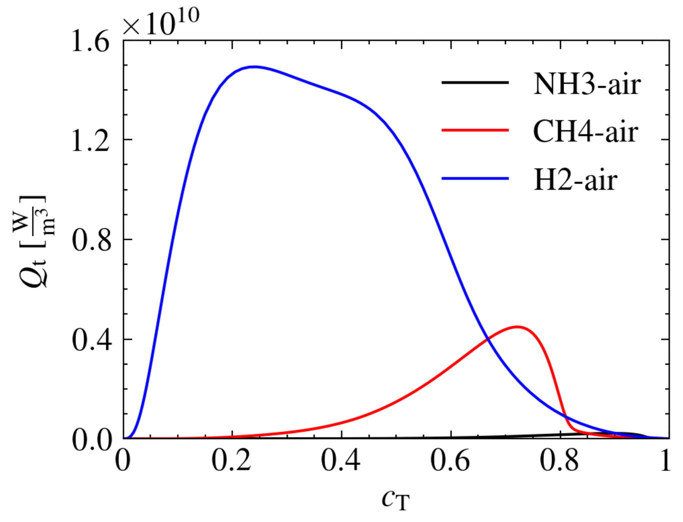

Fig.1. Heat release profile in progress variable space for NH_3-air, CH_4-air, and H_2-air flame

- Turbulent flame characteristics are expected to be different from general hydrocarbon and/or hydrogen flames

- This study is aimed at understanding the turbulence-flame interaction of NH_3-air mixtures through high-fidelity direct numerical simulations (DNS), considering the flame-in-a-channel configuration under forced turbulence at a wide range of turbulent conditions
- **Turbulent flame speed** statistics are discussed in terms of global fuel consumption rates and local flame displacement speed

Methodology

- DNS of NH_3-air turbulent premixed flames in a turbulence-in-a-box configuration are conducted by employing the KARFS code (KAUST Adaptive Reacting Flows Solver)
- The following mixtures are considered:
  - **A1R-5 (rich ammonia):** NH_3/air premixed flame $\varphi = 1.2$, T = 500 K (S_L = 0.211 m/s), $Le = 1.12$
  - **A1L (lean ammonia):** NH3/air premixed flame $\varphi = 0.81$, T = 600 K (S_L = 0.211 m/s), $Le = 0.90$

Tab.1. Turbulent parameters

Case	l_T/δ_L [-]	u'/S_L [-]	Re [-]	Da [-]	Ka [-]	$\delta_L/\Delta x$ [-]	Grid [M]
A1R	1	10	72	0.1	85	12	1.7
A2	1	5	36	0.2	30	12	1.7
A3	3.5	15.2	386	0.2	85	12	16.6
A4	3.5	10	254	0.4	45	11	11.7
A5	3.5	7.6	192	0.5	30	11	11.6
A1L	1	10	56	0.1	75	12	0.69

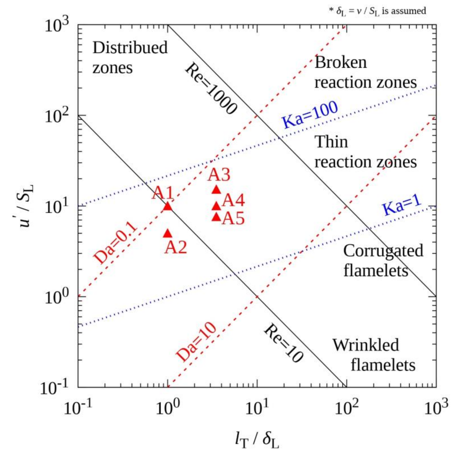

Fig.2. Simulation conditions on the Borghi-Peters diagram

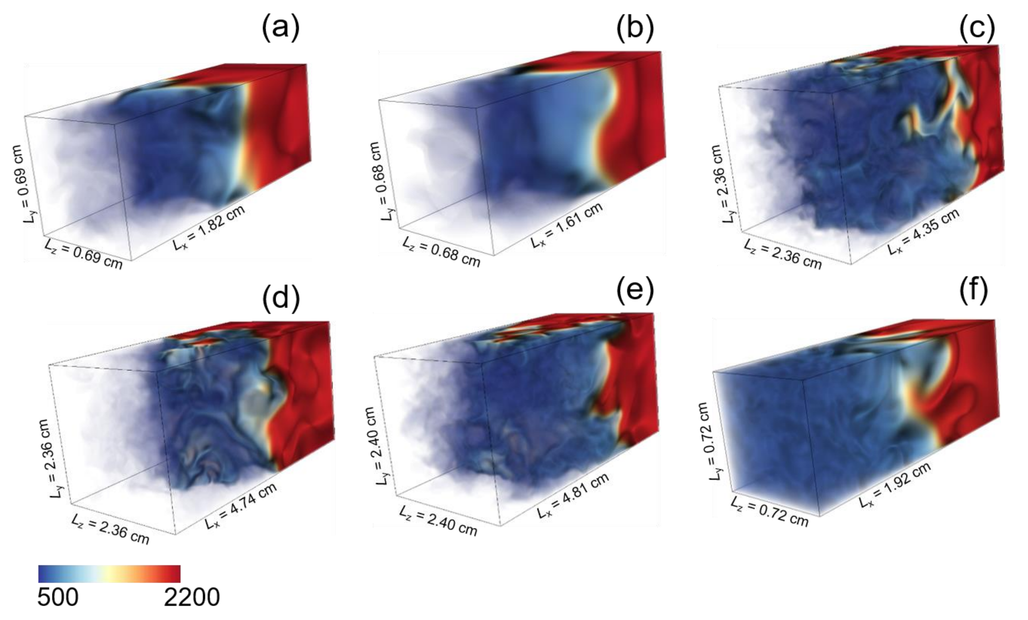

Fig.3. Temperature distribution for the case (a) A1R, (b) A2, (c) A3, (d) A4, (e) A5, and (f) A1L

Results

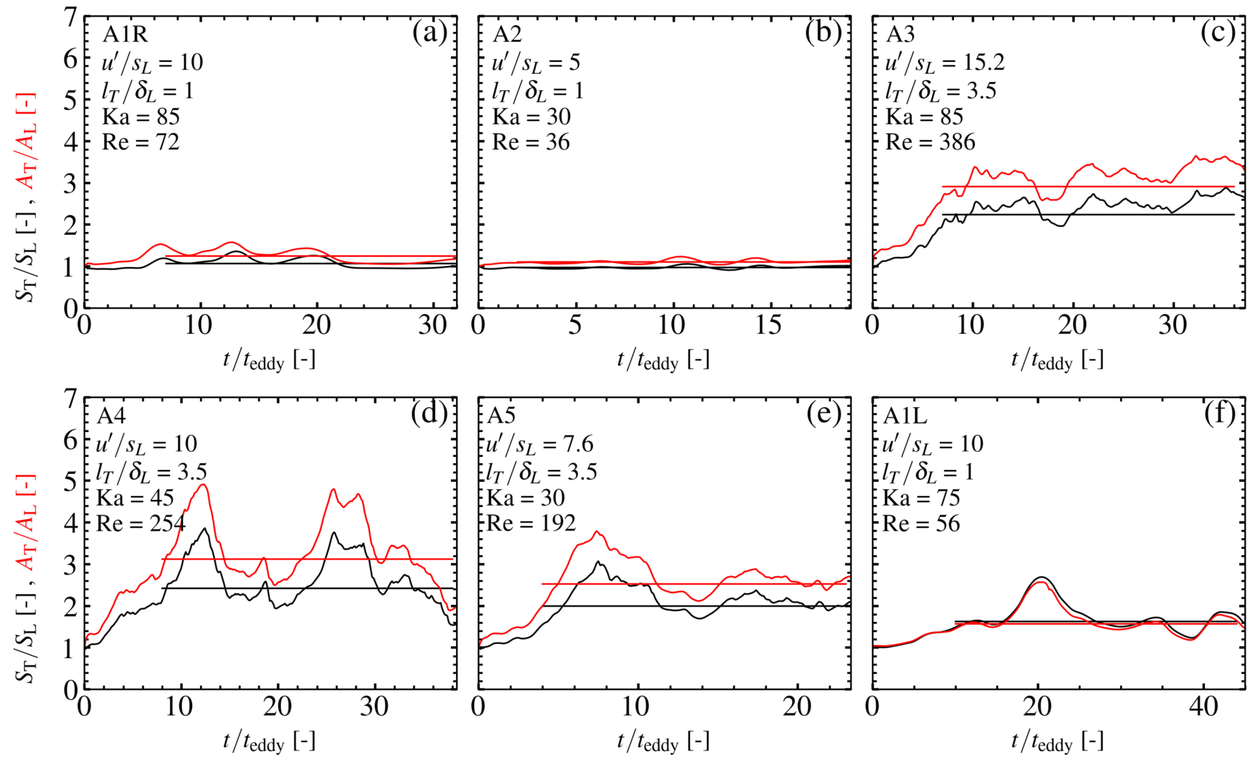

Fig.4. Temporal evolution of the normalized turbulent flame speed (black line) and flame surface area (red line). The horizontal lines indicate the mean quantities computed for the shown period of time

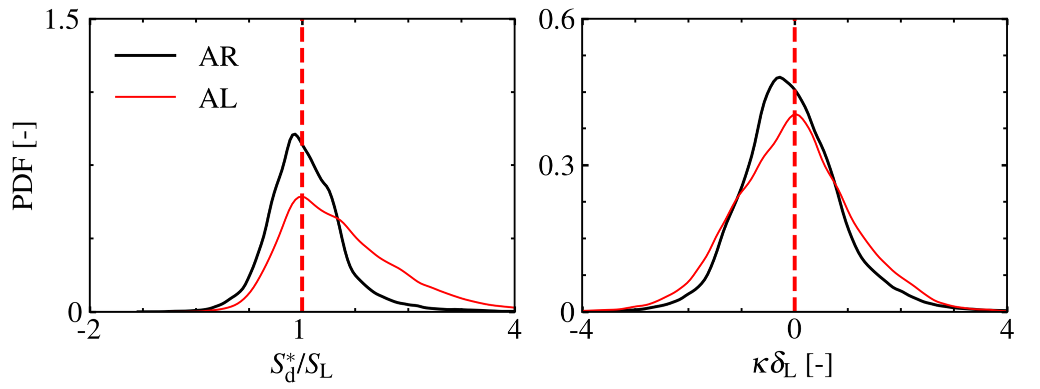

Fig.5. Probability density functions of the (a) local flame displacement speed and (b) flame curvature evaluated at the isosurface of the maximum heat release rate

Summary

- The stretch factor ($\bar{I}_0 = (\bar{S}_T/S_L)/(\bar{A}_T/A_L)$) is less than unity for fuel-rich ammonia flame, and for larger turbulent eddies, the stretch factor decreases more
- The rich ammonia flame exhibits flame surface area reduction due to the H_2 diffusion from down- to upstream direction
- The turbulent flame speed displays a strong correlation with the size of the most energetic turbulent eddies
- The stretch factor for high l_T/δ_L flames is decreasing, i.e. the gap between flame area and flame speed enhancement is getting larger
- For the rich ammonia flames, the PDF of S_d^* peaks at a value smaller than the one from 1D laminar flame, and flames have mostly negative curvature

Ongoing Work

- Flame structure analysis of premixed NH_3-air and $NH_3/H_2/N_2$-air flames under different turbulent condition

- Analysis of Lewis number effect on turbulent premixed ammonia flame