LES and Experiments of a Low Swirl Stratified Lean Premixed Methane/Air Flames

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Low Swirl Flames – Recent Works

- R. K. Cheng, *Combust. Flame* 101 (1995) 1-14.
- B. Bédat, R.K. Cheng, *Combust. Flame* 100 (1995) 485-494.
- R. K. Cheng, I. G. Sheperd. B. Bédat, L. Talbot, *Combust. Sci. Tech.* 174 (2002) 29-59.
- I. G. Shepherd, R.K. Cheng, T. Plessing, C. Kortschik, N. Peters, *Proc. Combust. Inst.* 29 (2002) 1833-1840.
- C. Kortschik, T. Plessing, N. Peters, *Combust. Flame* 136 (2004) 43-50.
- M. R. Johanson, D. Littlejohn, W. A. Nazeer, K. O. Smith, R. K. Cheng, *Proc. Combust. Inst.* 30 (2005) 2867-2874.

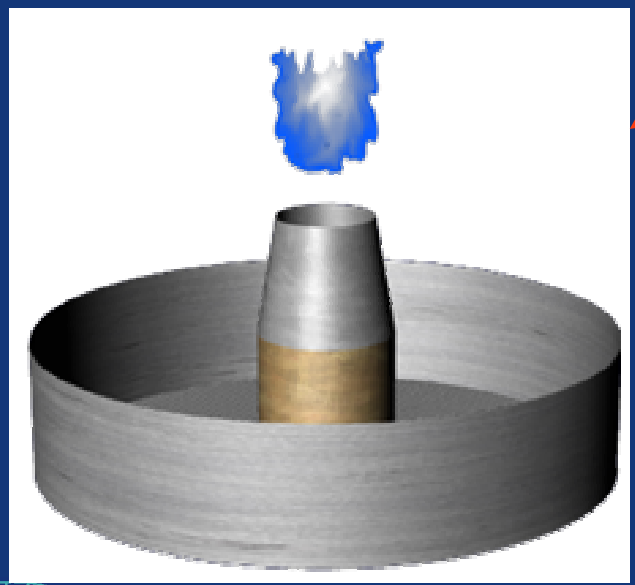
- K.J. Nogenmyr, et al., *Proc. Combust. Inst.* 31 (2006)
- J. Bell, *Proc. Combust. Inst.* 31 (2006)

Recent works at LTH and TU Darmsdadt

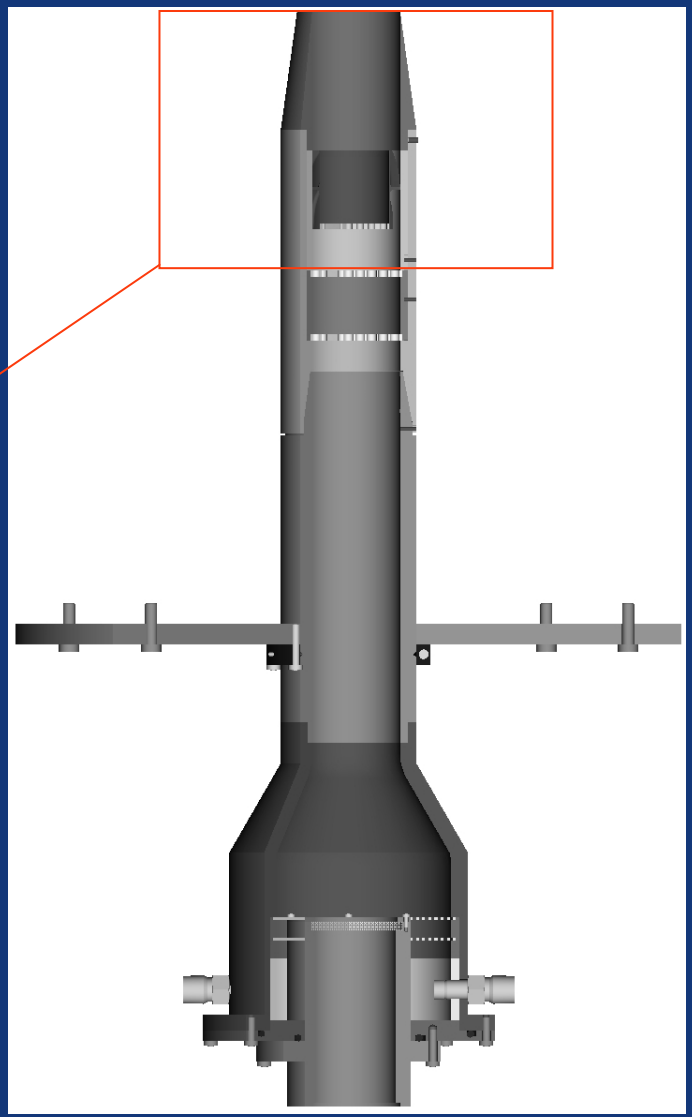
- A rig has been developed
  - 8-vane swirler different from original Cheng's design, with optical access from the bottom along the axial direction
- Using laser diagnostics to study
  - Leading edge flame interacting with intense turbulence
    - simultaneous PIV + OH PLIF
    - FRS temperature (to do simultaneously with PIV)
  - Trailing edge flame quenching/re-ignition
    - simultaneous PIV + OH PLIF
  - Create a validation database for modeling
- Development of models for stratified premixed flames
  - based on LES and level-set approach

Experimental setup

Fuel:	Methane
ϕ_{inlet}:	0.62
T_{inlet}:	298 K
p:	1 atm
Re:	20,000
Sw:	0.55

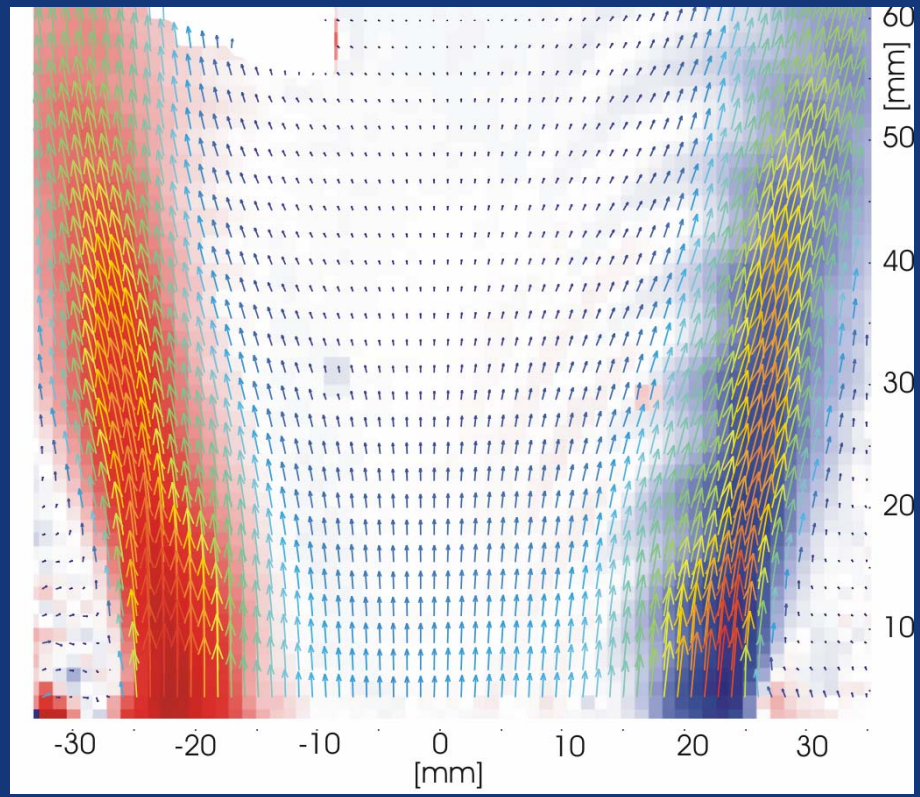


Side view



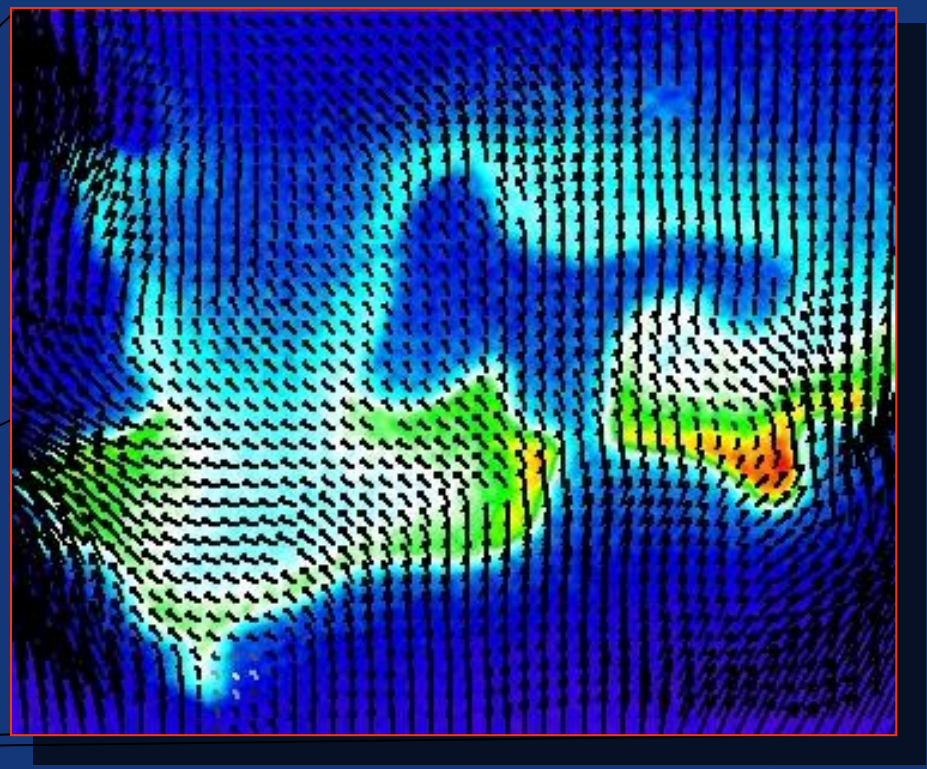
Experimental results – model validation database

- ’Inflow turbulence’ 1mm above the burner exit
- three velocity components
  - mean
  - variance
  - snap-shots
- temperature
  - mean
  - variance
  - snap shots
- 1-d Raman/Rayleigh simulatanous
  - CH4, O2, N2
  - H2O, CO2, H2
  - scalar/thermal dissipation rates
- sequantial OH-PLIF
  - flame front tracker
- conditional velocity to deduce scalar fluxes
  - simultaneous PIV + OH-PLIF

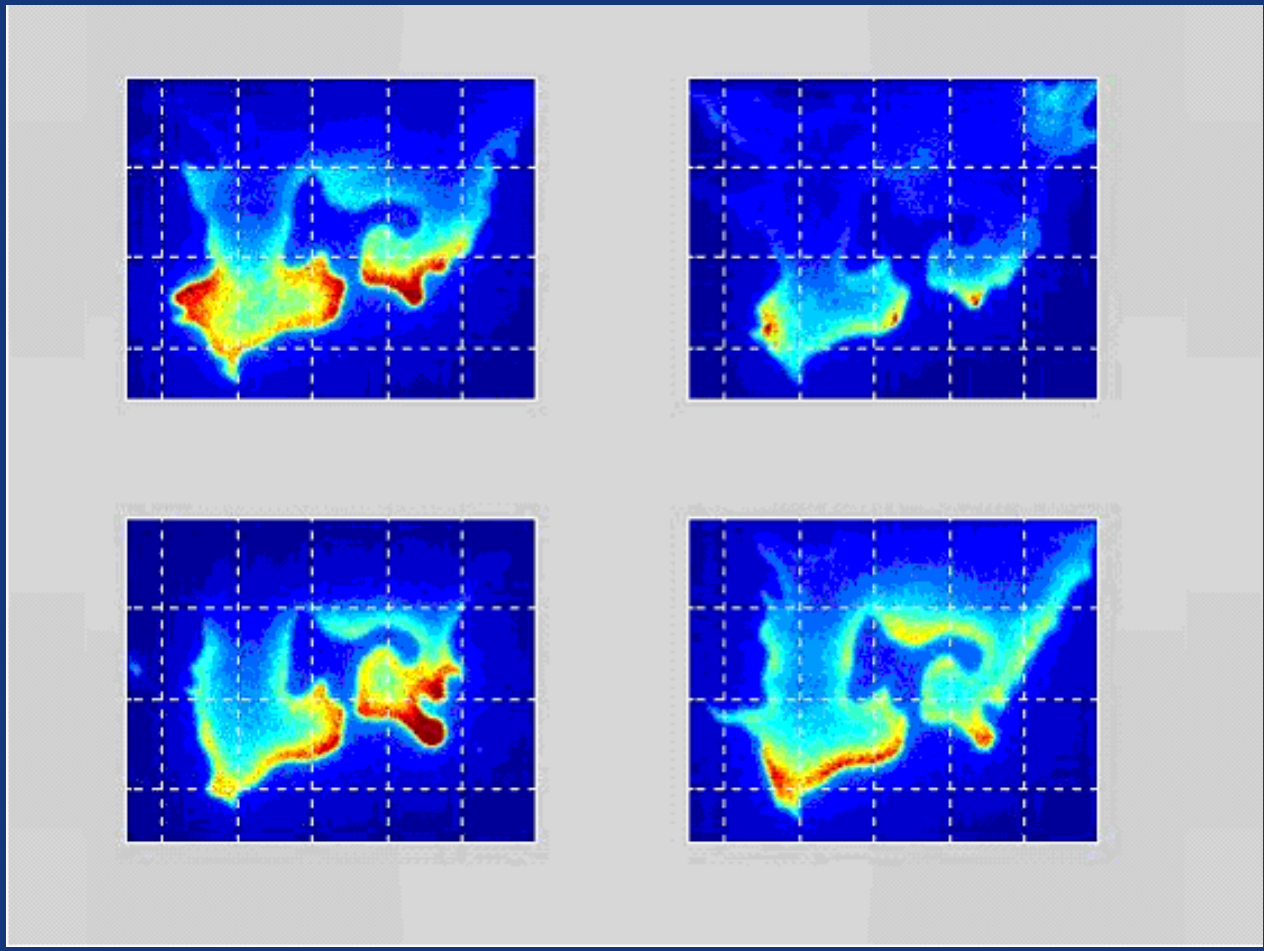


Results - simultaneous PIV / OH-PLIF

The combined PIV / OH-PLIF results showing the flame front structure and its position in the flow field.

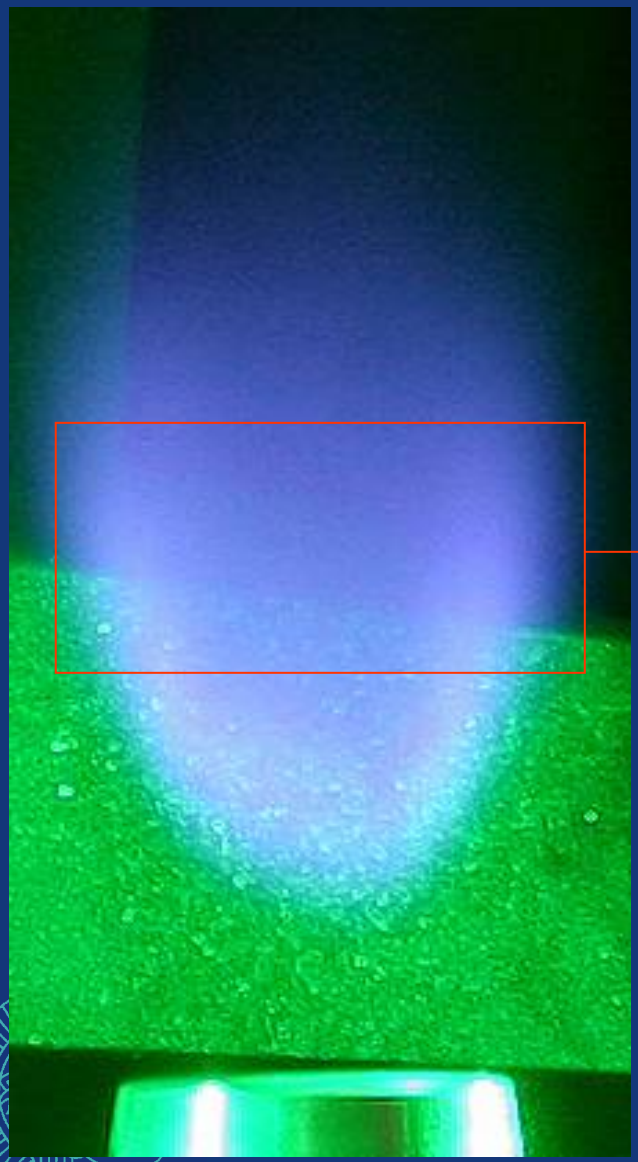


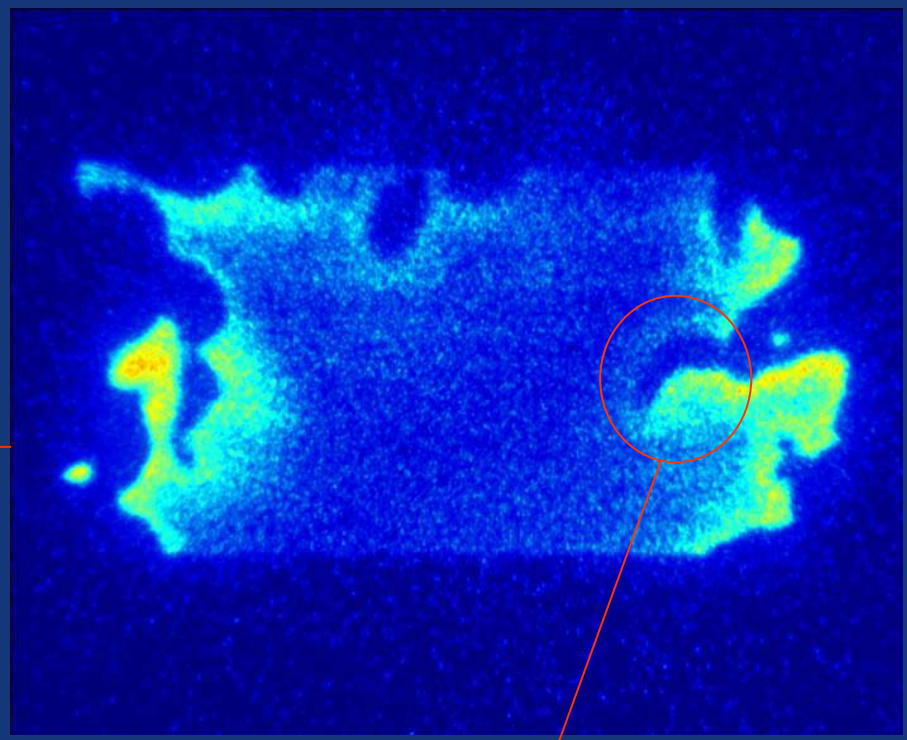
Scalars via rapid framing OH-PLIF



A sequence of four OH-PLIF images. The time separation between the images is 400μs.

Results – trailing edge OH-PLIF



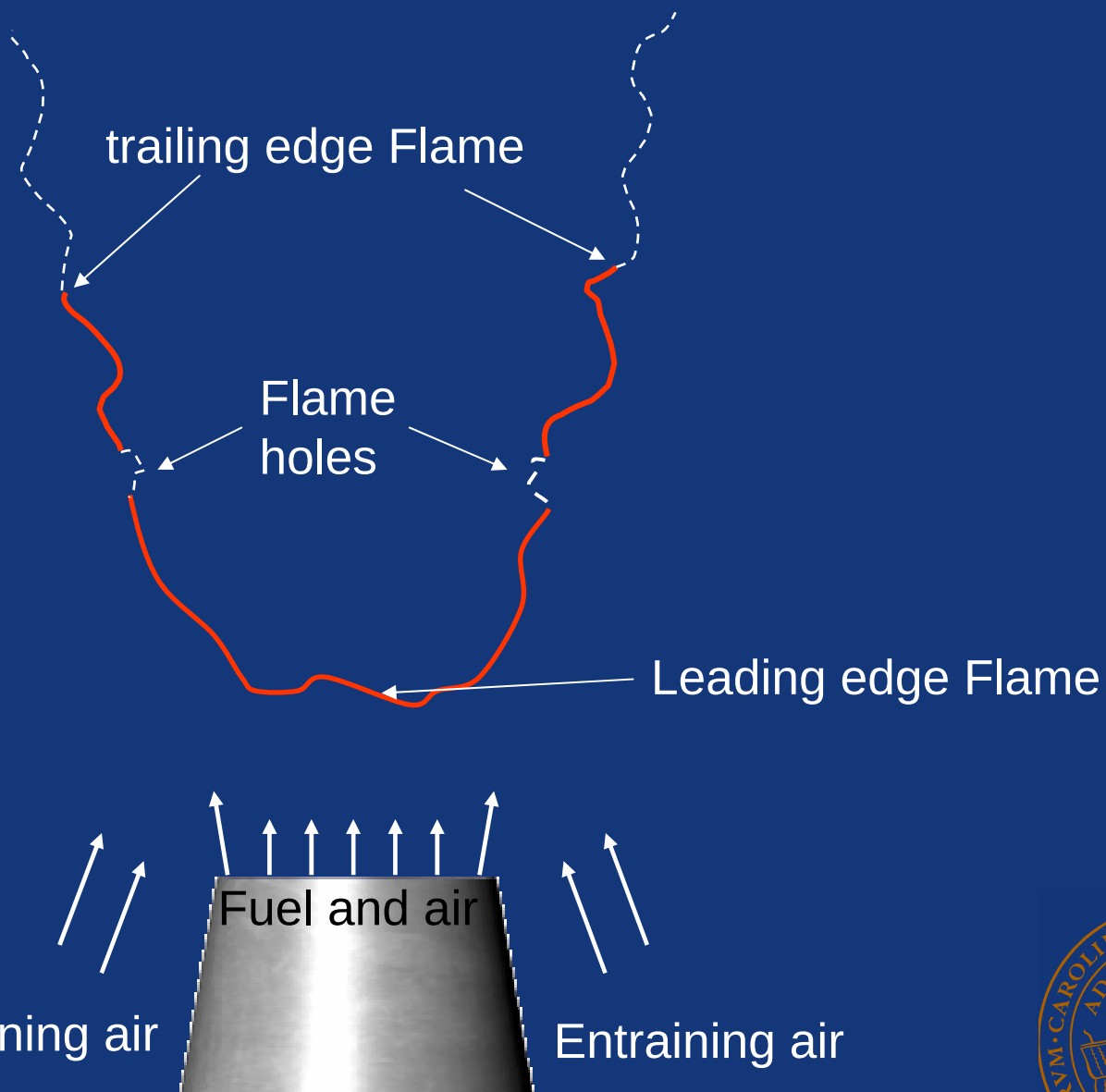


- flame quenching ?
- how to model it?

Modeling of stratified premixed flames

- Approaches based on reaction progress variable & mixture fraction
  - Bradley et al (1998)
  - Bondi & Jones (2002)
  - ...
- Approaches based on level-set G-equation & mixture fraction
  - Peters (2000), lifted partially premixed flames
  - Freitag & Janicka (2006) stratified premixed flames
  - ...
- Present work – Level-set G-equation & mixture fraction
  - leading edge flame similar to premixed flame
  - trailing edge flame – flame holes

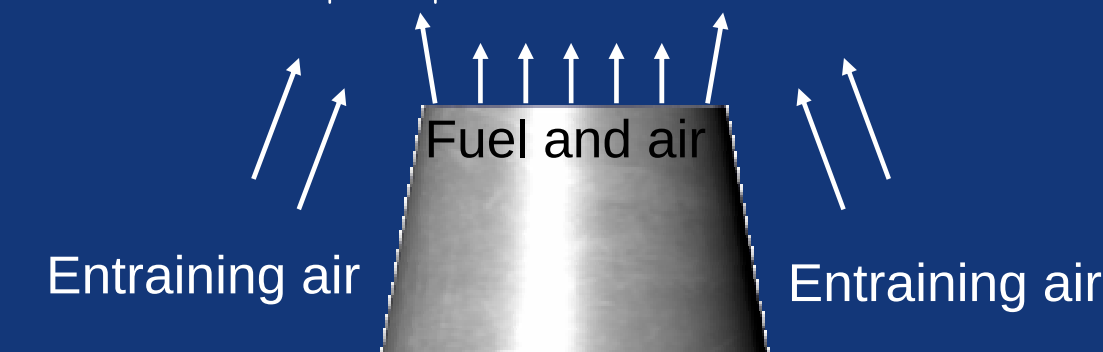
Flame front tracker and level-set approach



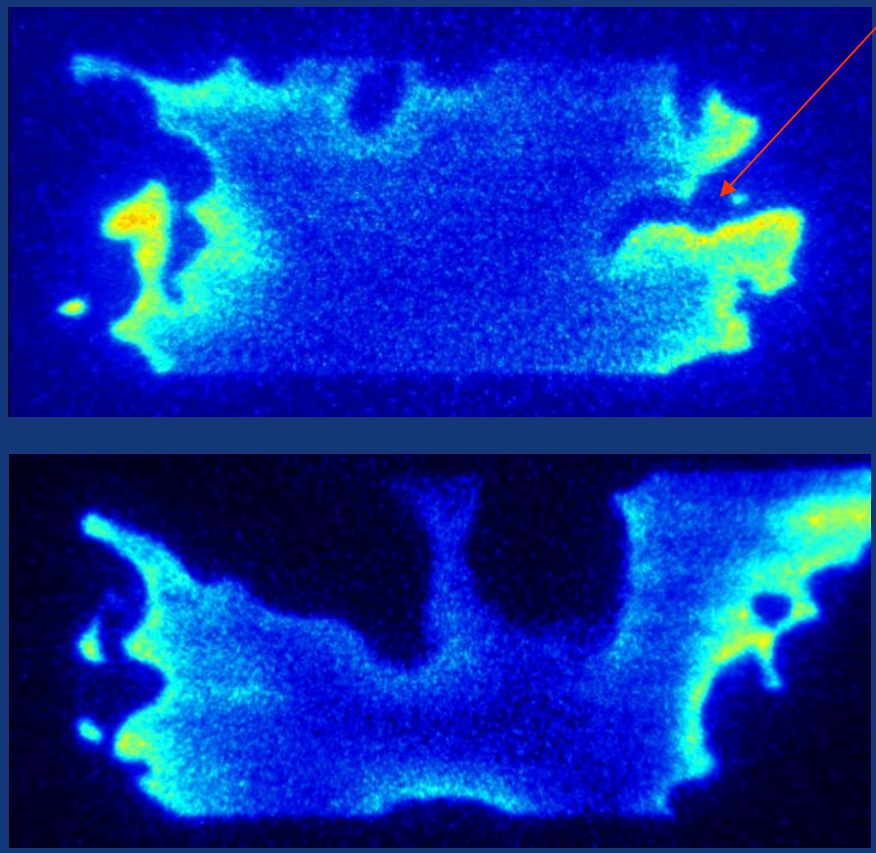
Flame front tracker and level-set approach

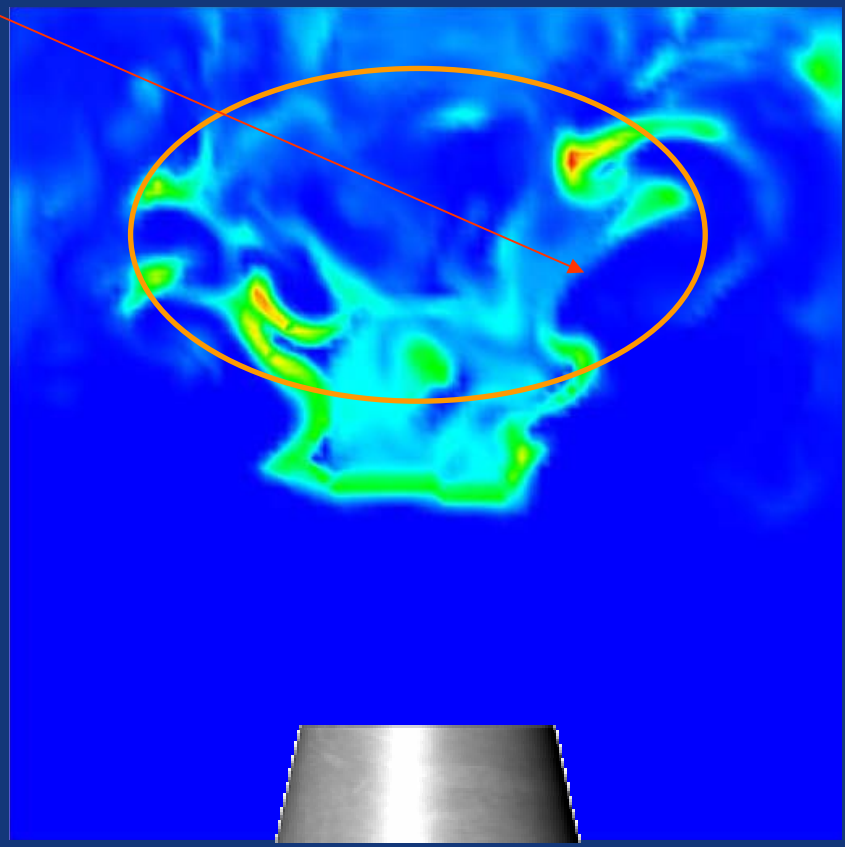
$$\frac{\partial \bar{G}}{\partial t} + \tilde{u}_i^{*} \frac{\partial \bar{G}}{\partial x_i} = 0$$

$$\frac{\partial \bar{G}}{\partial t} + \tilde{u}_i \frac{\partial \bar{G}}{\partial x_i} = S(Z, s, u'_{SGS}) \left| \nabla \bar{G} \right|$$



OH-PLIF vs OH LES





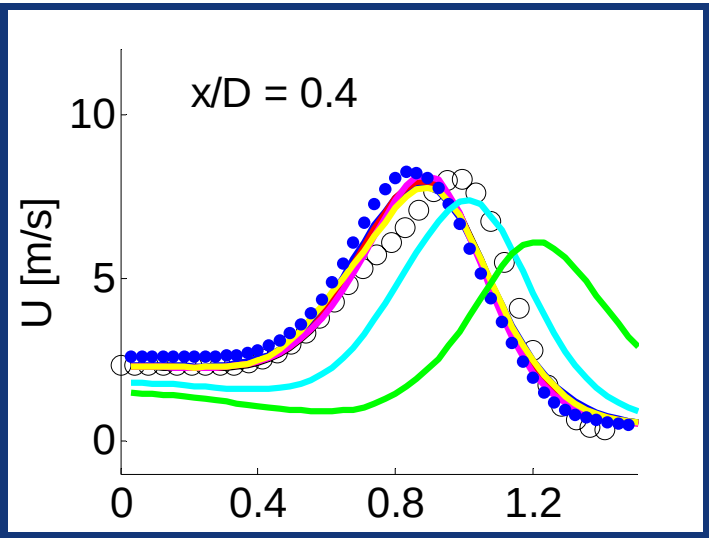
OH-PLIF

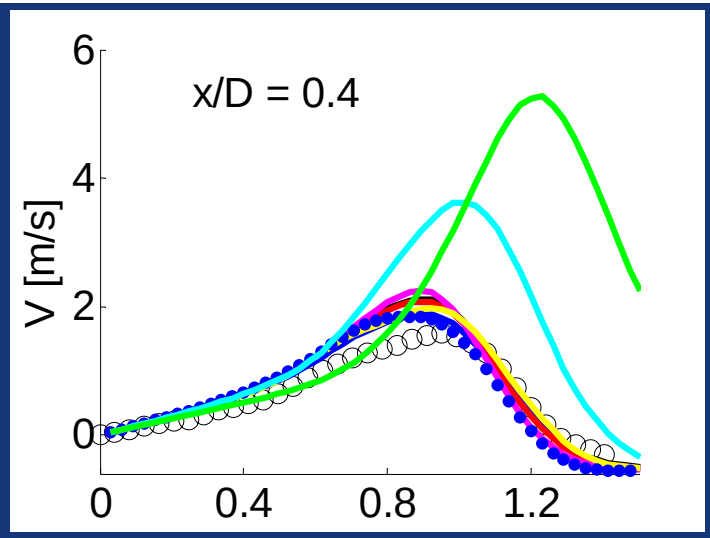
OH from LES

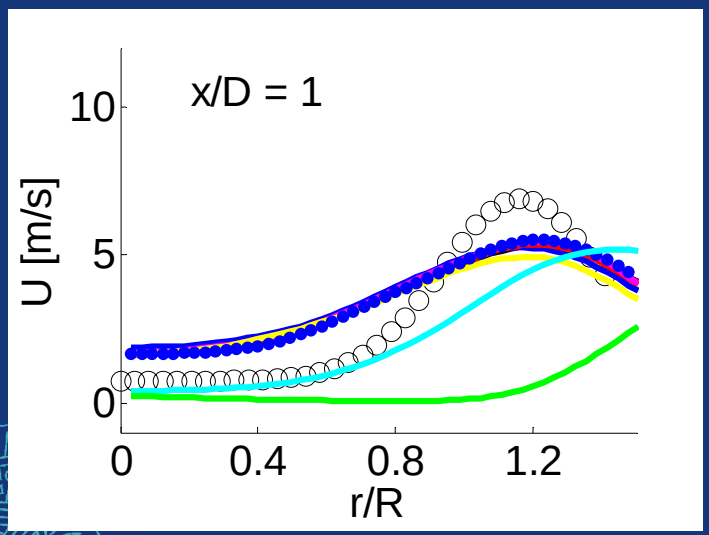
Model validation

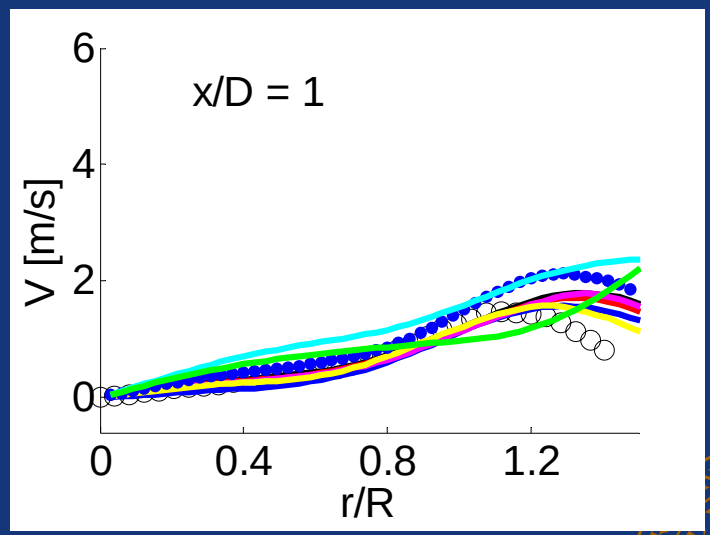
- Comparison with the exp
  - Mean, variance: velocity, temperature, major species
- Sensitivity to swirl number
- Sensivity to fuel/air ratio
- Sensitivity to SGS model
- Sensitivity to grid resolution
- Sensitivity to inflow conditions
  - Mean flows – influence of swirler geometry
  - Re-scaled turbulent inflow
  - Digital filter based inflow (Klein et al, 2002)
    - Inflow turbulence length scale

Standard case
Larger length scale
SSM
No peaks
Amplified peaks
finer grid
20% extra swirl
50% extra swirl
o Exp data



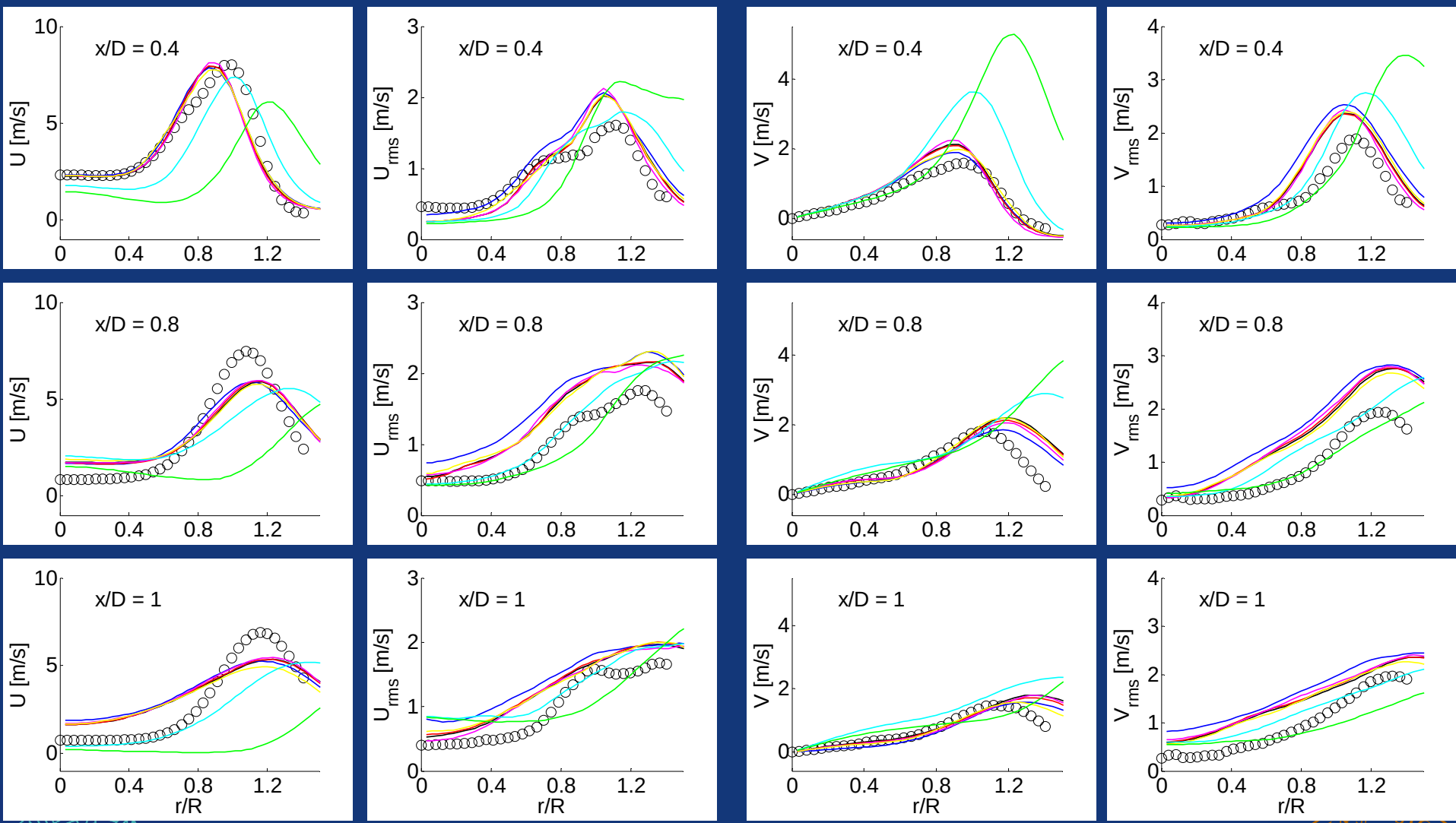






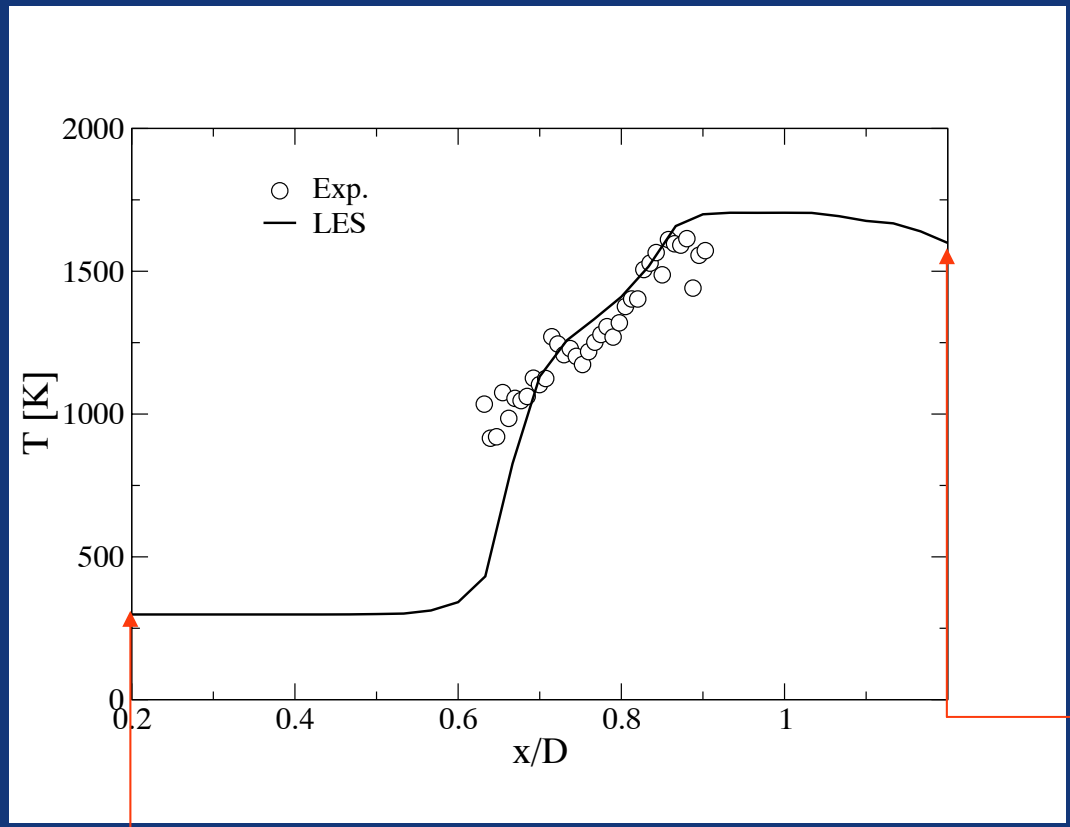
Axial velocity

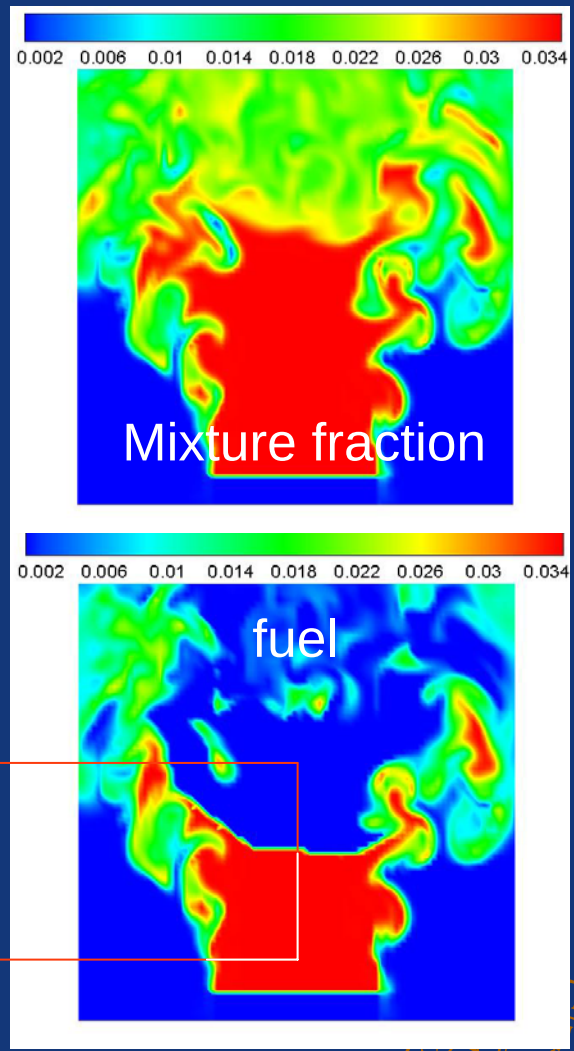
Radial velocity



Axial velocity | RMS of axial vel | Radial velocity | RMS of radial vel

Mixutre fraction, fuel mole fractions & temperature field from LES





Summary & Conclusions

- LSF experiments
  - a LSF has been developed based on the original design of R.K. Cheng
  - 3-D mean & variances of flow velocity near the burner exit - Stereo PIV
  - 2-D mean & variances of flow velocity over the entire flame domain - PIV
  - 2-D temperature field near the leading edge flame front - FRS
  - 2-D OH images – PLIF
  - Major species (CH_4, O_2, N_2, H_2O, CO_2, H_2) - 1-d Raman/Rayleigh
- Development and validation of Level-set G-equation approach
  - leading edge flame – G-equation approach is successful
  - trailing edge flames – modified G-equation is developed and tested
  - can be a candidate benchmark flame