TOMOGRAPHIC LASER-INDUCED FLUORESCENCE OF OH IN LAMINAR AND TURBULENT JET FLAMES

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Motivation

- Turbulent flow phenomena are three-dimensional in nature
- Planar OH-LIF is a common tool to investigate turbulent flame characteristics
- Information in 3rd dimension, however, is lost in planar techniques
- Turbulent flame features such as flame holes can only be characterized by fully three-dimensional measurements
- Tomographic OH-LIF imaging as an approach to yield the full three-dimensional OH distribution

Experimental setup

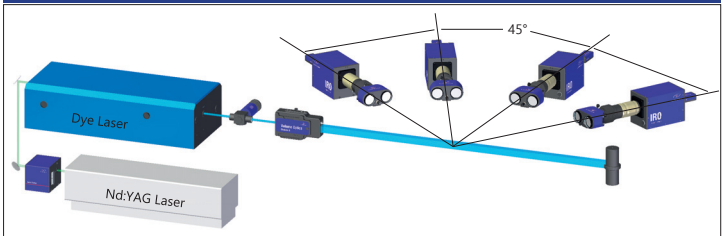


Figure 1: Experimental setup for tomographic LIF imaging.

Detection

- Four intensified CCD cameras in one plane at 45° angle separation
- UV lenses f/8 combined with LaVision Image doubler
- 8 simultaneous views

Excitation

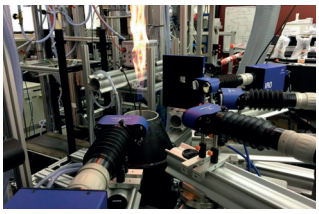
- Frequency-doubled output of a dye laser tuned to excite the Q1(8) transition (λ = 283.55 nm) of the $A^2\Sigma \leftarrow X^2\Pi$ (v'=1, v"=0) band of hydroxyl radicals
- 20 mJ at probe volume of 3x3x3 cm^3

Flame and setup photographs

Laminar Bunsen flame

Turbulent Bunsen flame

Turbulent lifted jet



Turbulent lifted jet flame and experimental setup

Spatial resolution and measurement uncertainty

Structural analysis and distribution of noise

- Residual noise in xy-planes of reconstructed single-shot (Fig. 2a, 2x2 binning) is obtained from subtraction of the same data but using a 9x9 Gaussian filter before reconstruction
- Structure of the noise pattern is analyzed by spatial autocorrelation in x- and y-direction (Fig. 2b) within the red rectangle in Fig. 2a
  → Spatial resolution limit due to noise is found at near-zero spatial correlation at 4-7 voxel = 450^3-1050^3 µm^3
- Signal-to-noise ratio of SNR = 30 is determined from average count number of 5 and a standard deviation of 0.17 for the near Gaussian distributed noise within the red rectangle (Fig. 2c)

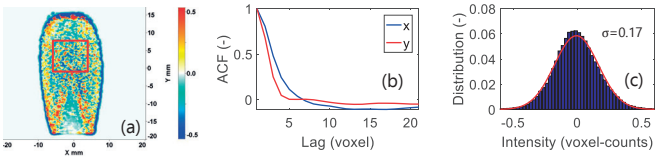
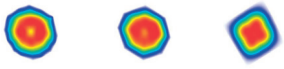


Figure 2: a) Residual spatial noise pattern in tomographic reconstruction of laminar Bunsen flame. b) Averaged autocorrelation function in x and y direction within the red rectangle. c) Distribution of residual spatial noise.

Impact of number of views on reconstruction in laminar Bunsen flame

- Integrated volume projections of shot-avg of reconstructed volume:



8 Views 4 Views 2 Views (90°)

→ Reconstruction with only 2 views possible but notably distorted

Tomographic reconstruction

- Simultaneous Multiplicative Algebraic Reconstruction Technique (SMART)
- 100 iterations
- Computational time for 8 views @ 16 cores (3.10 GHz, 128 GB RAM):
  - 5 min for 100M voxel of 75^3 µm^3, no binning,
  - 45 s for 12M voxel of 150^3 µm^3, 2x2 binning

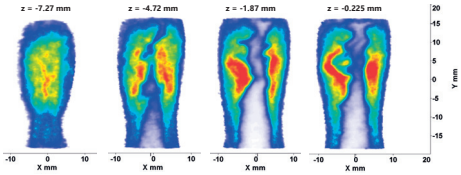


Figure 3: Reconstructed z-planes of turbulent Bunsen flame

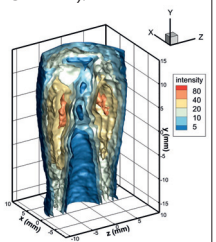


Figure 4: 3D-Isosurfaces

Comparison with 2D PLIF measurements

- Tomographic LIF and PLIF at same location, see Fig. 5
- Laminar premixed methane flame, d = 13 mm
- Center plane
- One side of OH-LIF profile
- 4 mm above the nozzle exit

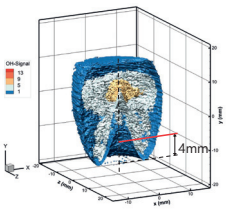


Figure 5: Reconstructed single-shot laminar flame and location of extracted intensity profiles.

- Different filter sizes for PLIF and different volume-sheet thicknesses for tomographic LIF

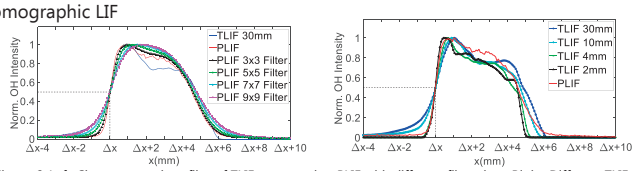


Figure 6: Left: Shot-averaged profiles of TLIF compared to PLIF with different filter sizes. Right: Different TLIF sheet thickness。Distance between 50% intensity and jet centerline Δx ≈ 4.5mm.

→ PLIF using 5x5 filter shows similar gradient at large OH intensity

→ Steeper gradient with decrease of sheet thickness

- Spatial width and fluctuation of intensity profiles

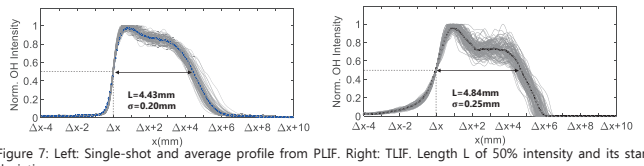


Figure 7: Left: Single-shot and average profile from PLIF. Right: TLIF. Length L of 50% intensity and its standard deviation σ.

→Slightly broader than PLIF but high resolution preserved

Turbulent lifted jet flame

- A lifted turbulent methane jet flame, jet diameter =8mm, lift-off height ≈28 mm
- Central jet Reynolds number 5000, outlet velocity of 10 m/s
- Jet surrounded by a laminar air co-flow of 0.2 m/s
- 100 interations, voxel of 75^3 µm^3, no binning

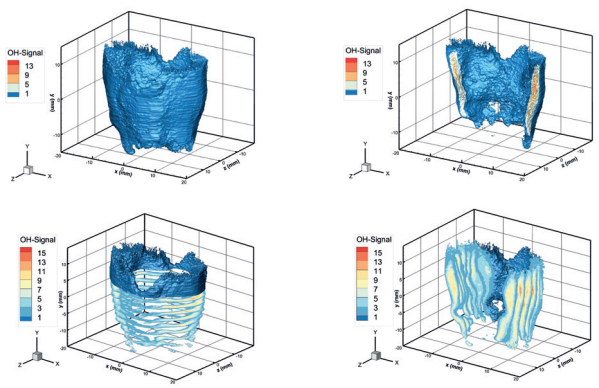


Figure 8. Single-shot visualization of a jet flame by different views using Isosurfaces. Top-left: outer contour; top-right: section through center line; down: parallel horizontral and vertical cross sections.