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Heat release and turbulence statistics from a DNS of reacting jet in cross-flow parameterized in a jet natural coordinate system developed from scalar quantities

NC'11

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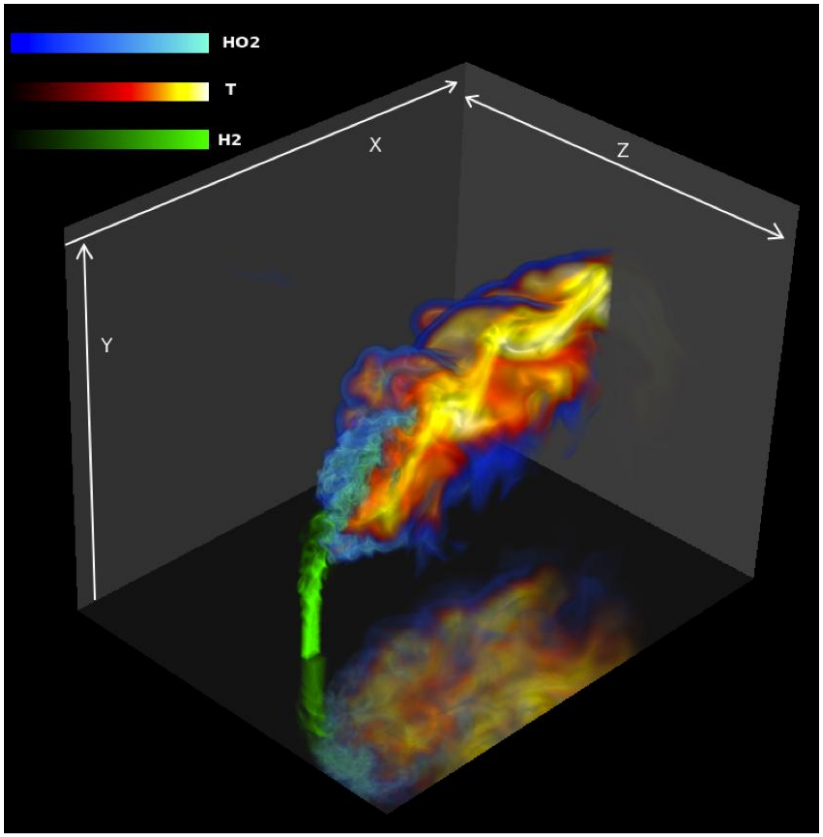
Overview

- Motivation & previous work
- Jet parameterization
  - Formulation
  - Centerline of jet path
- Conditional statistics
  - Flame position
  - Velocity magnitude
  - Dissipation rates
  - Heat release
- Summary and future work

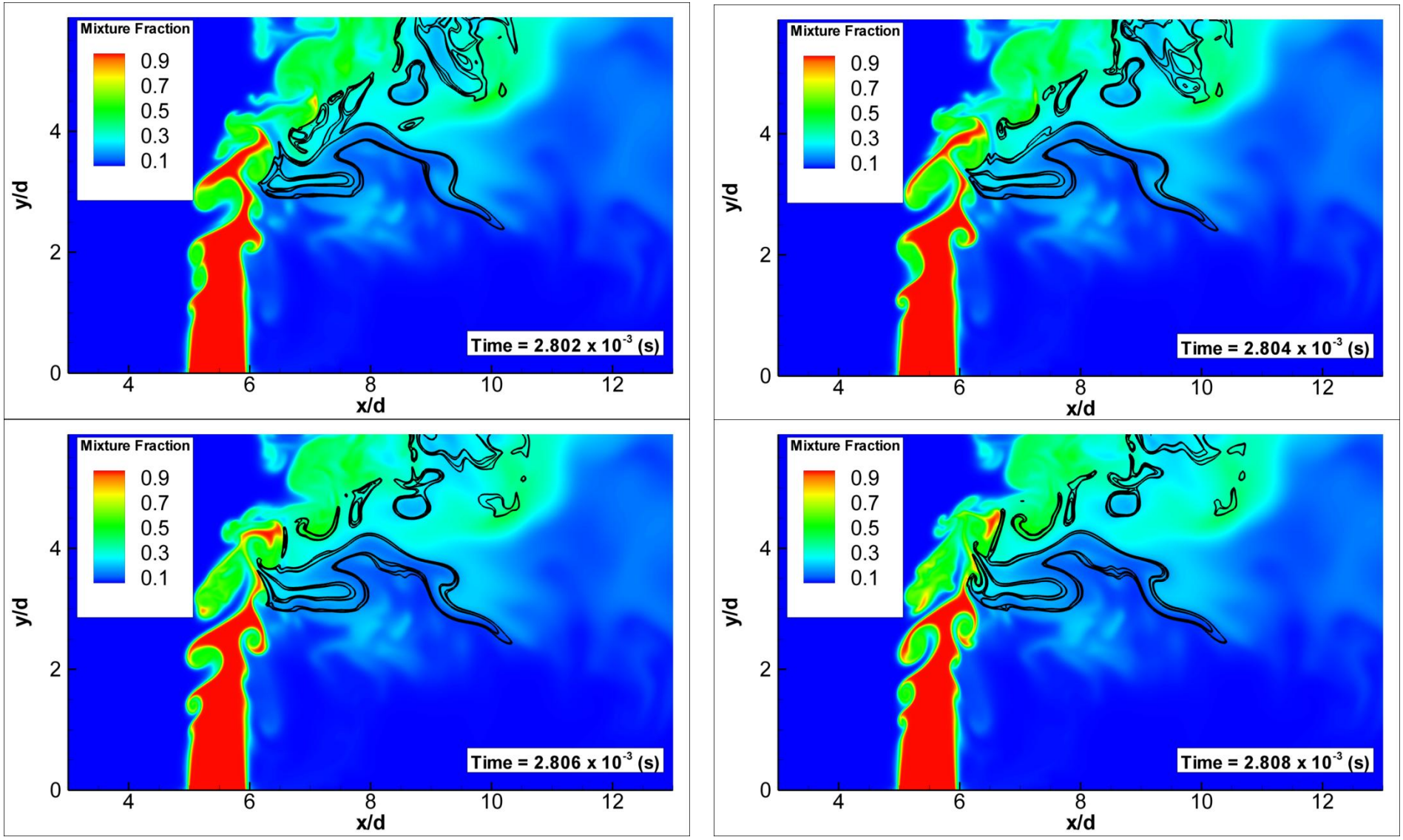
Jet in Cross Flow Anchoring: Background

- Understanding & control of flame anchoring key to operating with hydrogen rich fuels
- Coupling between complex flow structure and flame in near field
  - Jet shear layer vorticity
  - Counter-rotating vortex pair
  - Wake vortices
  - Horseshoe vortex
- Ongoing parametric exploration of hole shape, injection angle and fuel sensitivity



Grout et al. "Direct numerical simulation of flame stabilization downstream of a transverse fuel jet in cross-flow". Proc. Combust. Inst. 33 (2011), p. 1629-1637.

Jet in Cross Flow Anchoring: Instantaneous Fields



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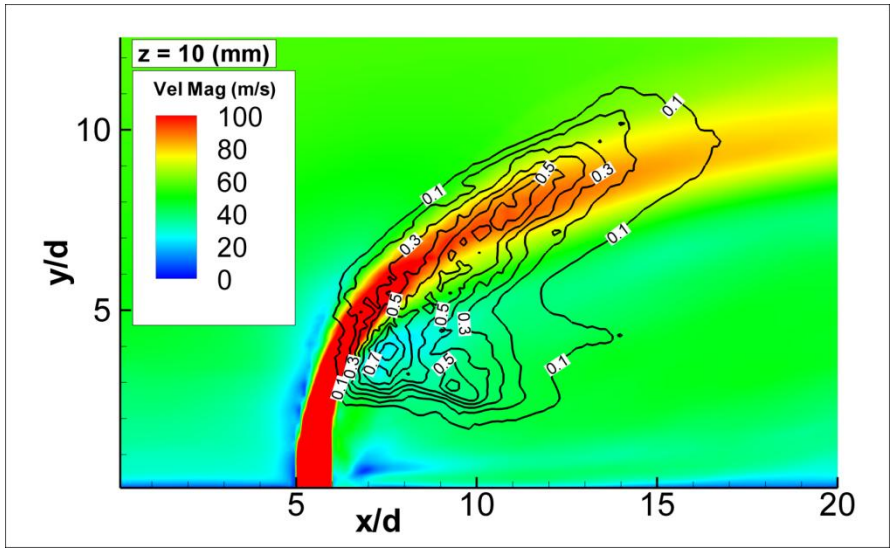
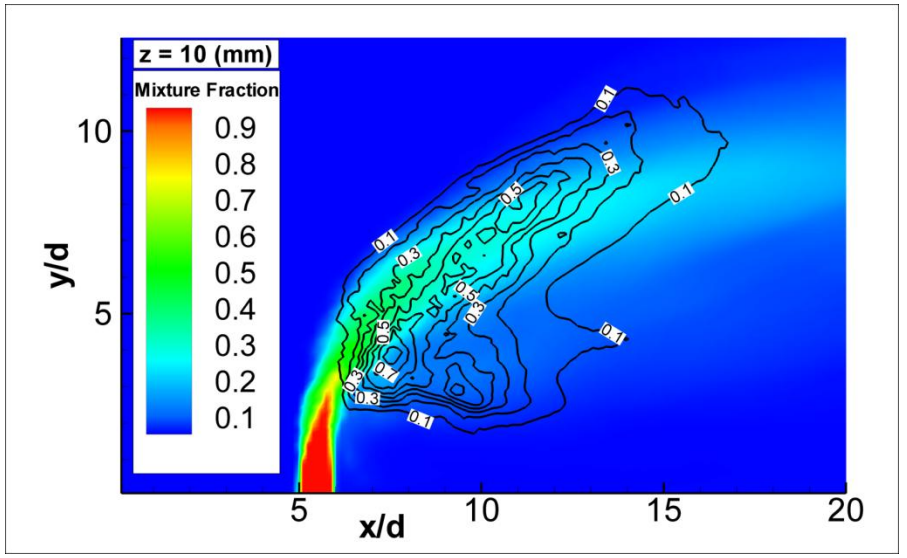
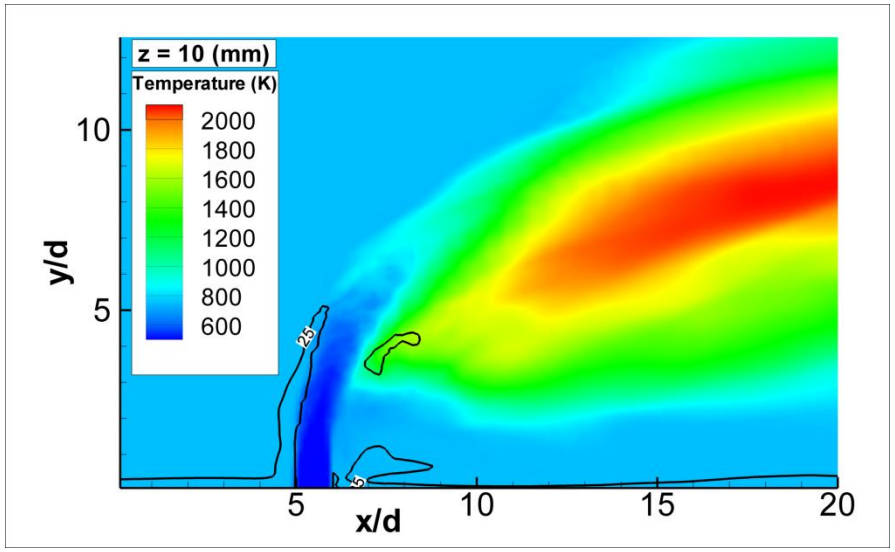
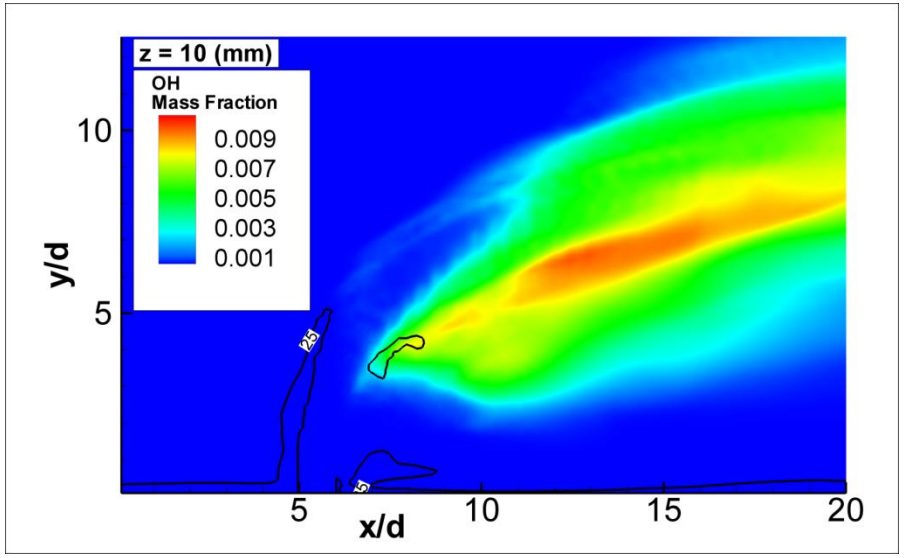
Jet in Cross Flow Anchoring: Averaged Fields









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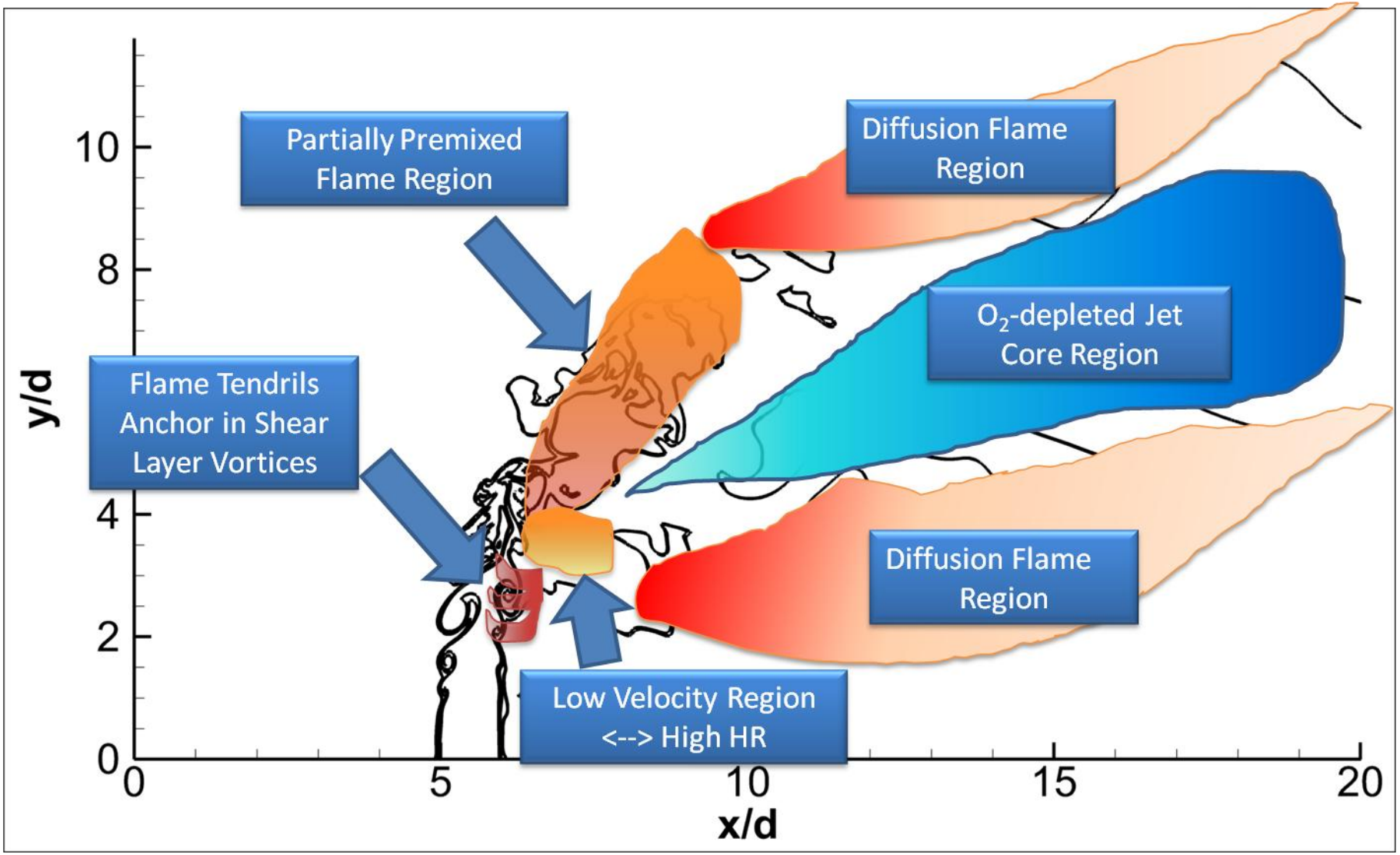
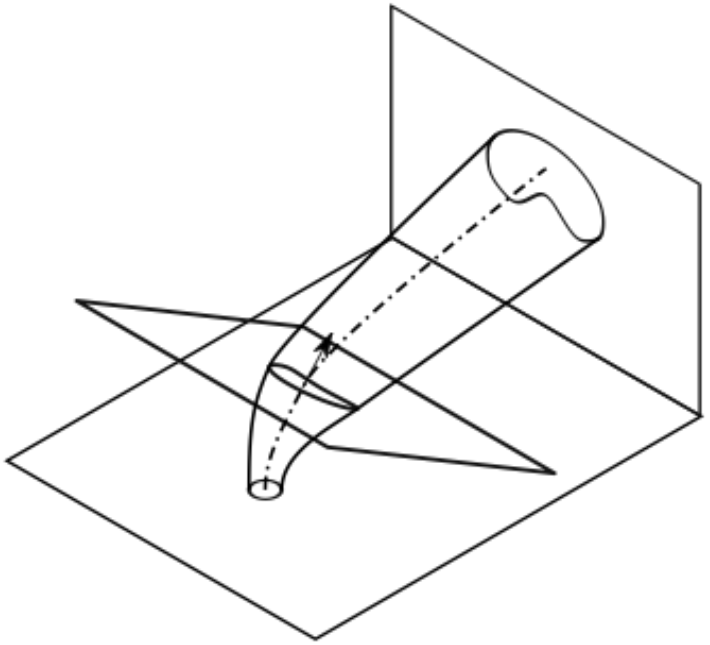
Jet in Cross Flow Anchoring: Summary Previous Work



Jet in Cross Flow Anchoring: Transverse Jet "Natural Reference"

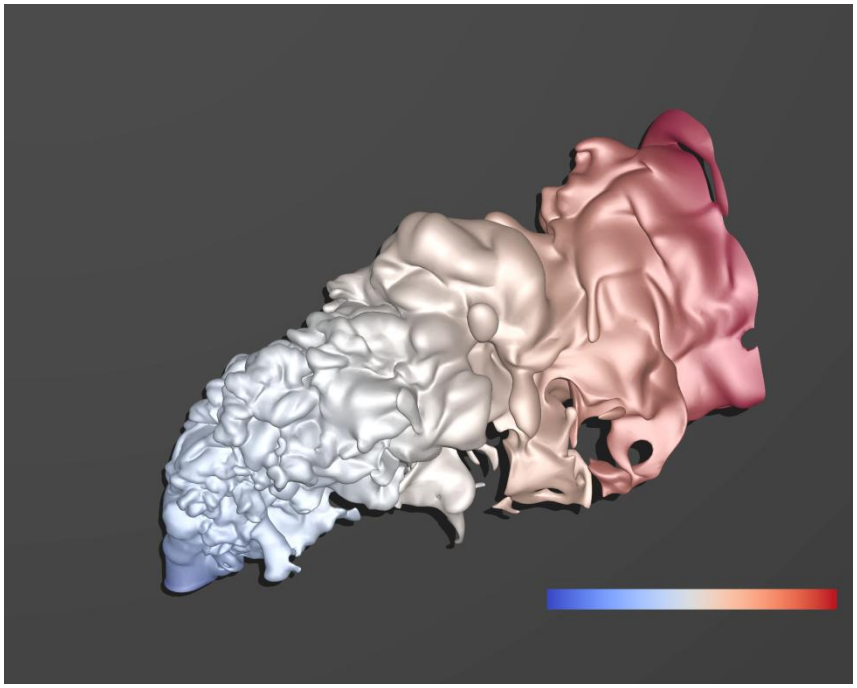
- Bulk position of flame is controlled by large-scale fluid motion with relatively long timescale
  - We want to study small scale, near field effects
  - Analysis in jet-based coordinate system removes confounding trajectory variations
- Distance along jet path
  - Centerline is difficult to define
  - Planes extrapolated from centerline aren't appropriate near edges of jet (intersect / diverge)



A parameterization of the jet path based on a tracer field allows combustion quantities – temperature, dissipation rates, fluid mechanical strain – to be assessed independent of bulk jet trajectory

Jet in Cross Flow Anchoring: New Methodology for Analysis

- Solving Laplace's equation on the jet surface captures trajectory at boundaries and varies these smoothly from entrance to exit, even for convoluted surfaces
- Extending this to the jet interior by solving Laplace's equation gives us an effective parameterization of the jet trajectory



Multistep solution procedure

1. Extract mixture fraction isosurface with parallel marching cubes algorithm (S3D in situ)
2. Simplify triangulated surface (qslim)
3. Solve Laplacian on surface

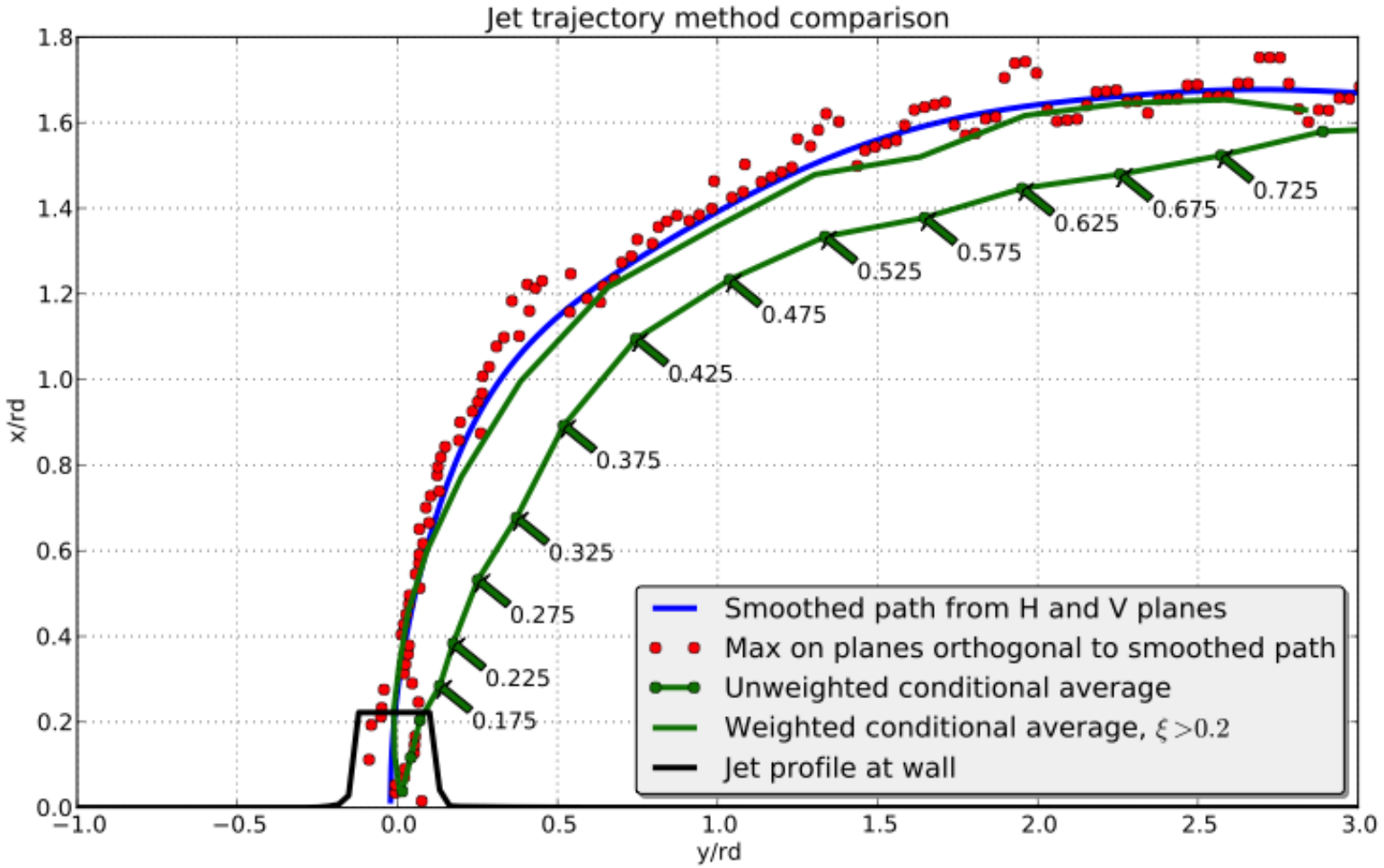
$$\int_{\Omega_{\xi=0.05}} (\nabla\pi \cdot \nabla v)\, dA = 0 \quad \forall v \in H^1_{\Gamma_D} \qquad \begin{aligned} \pi &= 0 \text{ on } \Gamma_{y=0} \\ \pi &= 1 \text{ on } \Gamma_{x=L} \end{aligned}$$

4. Generate tetrahedral mesh for interior of volume enclosed by jet (tetgen)
5. Solve Laplacian on tetrahedral mesh subject to boundary conditions from surface solution

$$\int_{\Omega_{\text{jet}}} (\nabla p \cdot \nabla v)\, dV = 0 \quad \forall v \in H^1_{\Gamma_D} \qquad \begin{aligned} p &= \pi \text{ on } \Omega_{\xi=0.05} \\ p &= 0 \text{ on } \Gamma_{y=0} \\ p &= 1 \text{ on } \Gamma_{x=L} \end{aligned}$$

1. Index verticies of tetrahedral mesh and solution values using ANN library (Approximate Nearest Neighbors)
2. Retrieve parameter value at arbitrary location from k-nearest points

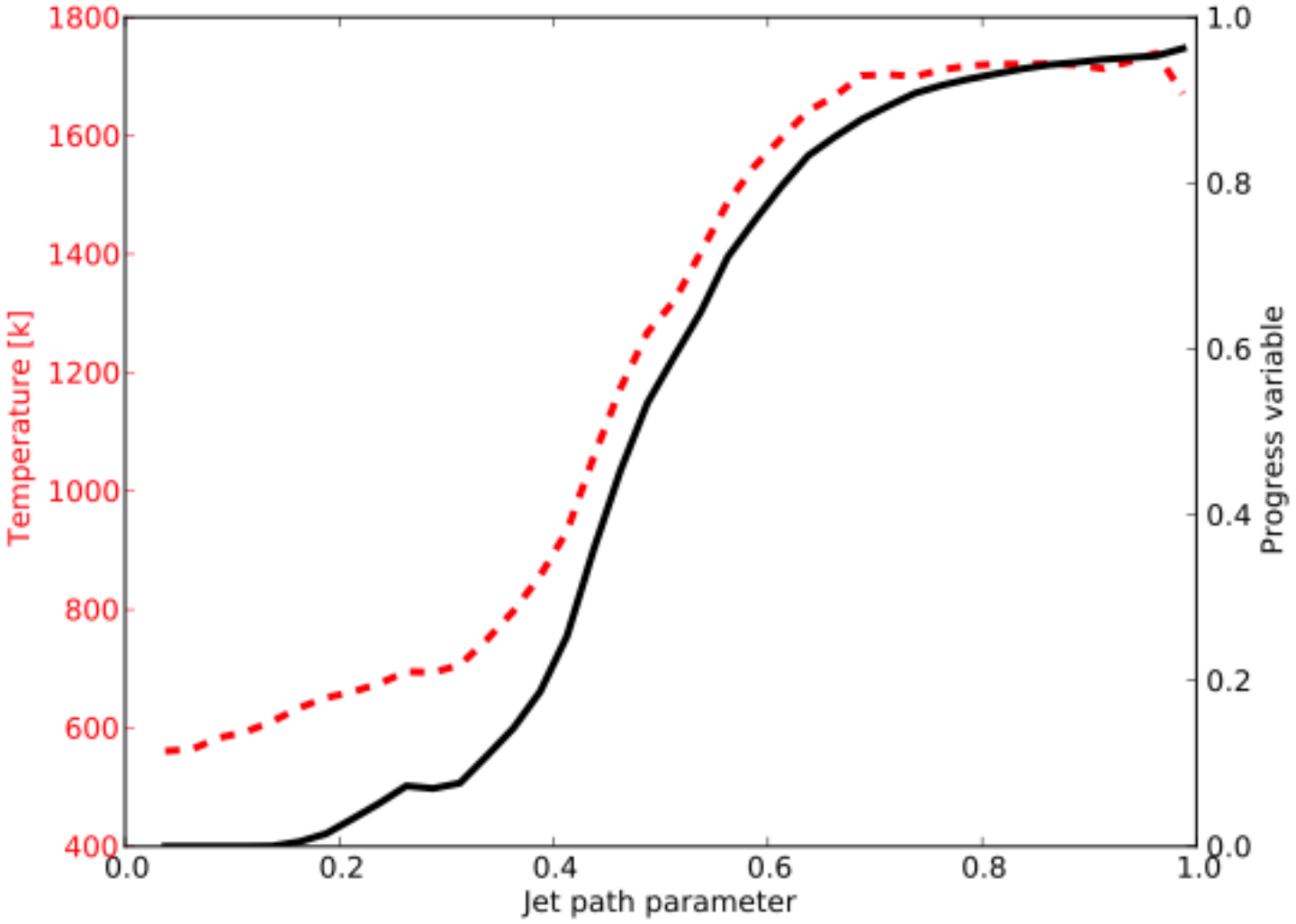
Centerline extraction



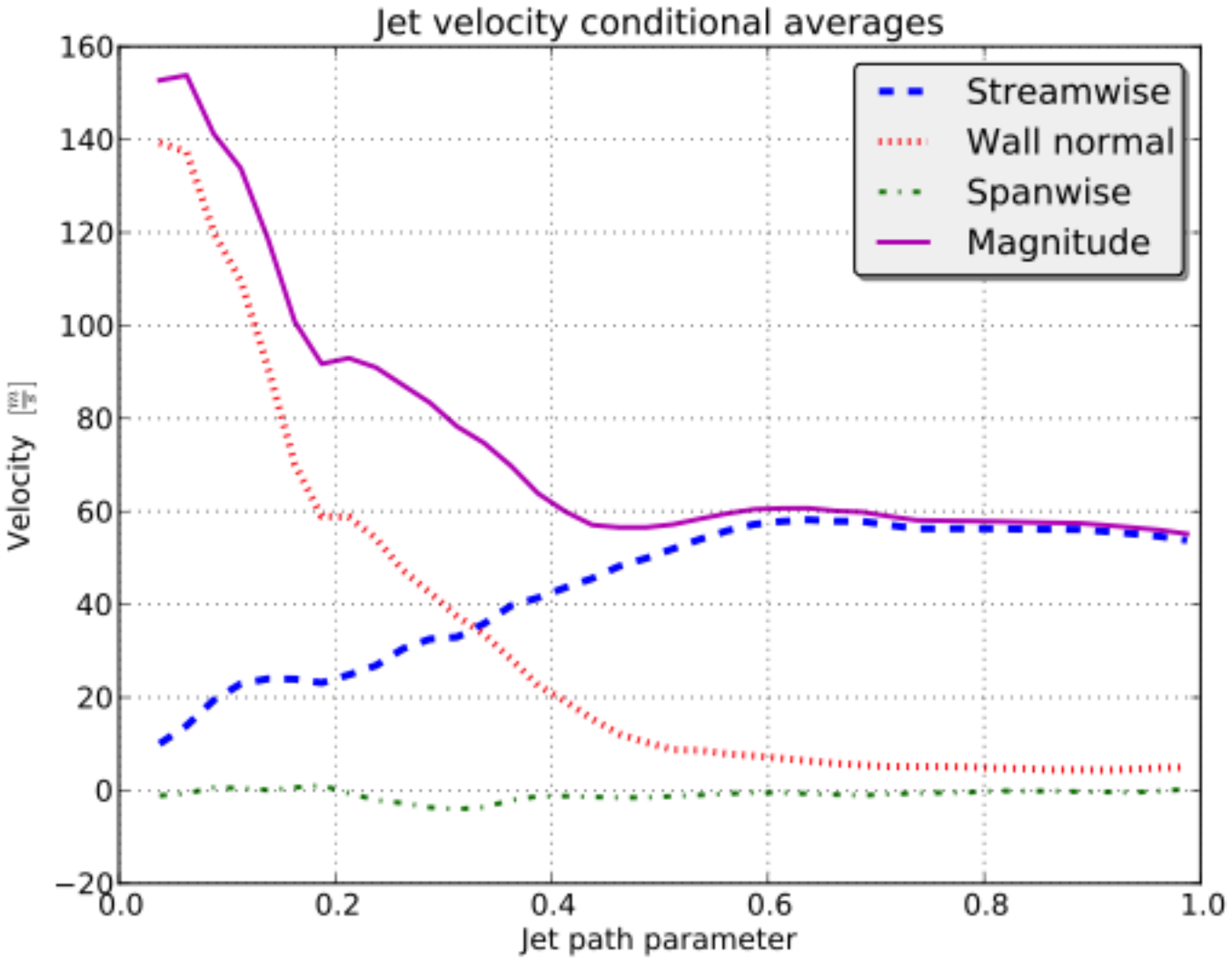
A selection of parametric quantities

- Temperature, progress variable
- Jet velocities
- Heat release rate
  - Mixture fraction, velocity magnitude
  - Scalar dissipation rate, vorticity

Jet in Cross Flow Anchoring



Jet in Cross Flow Anchoring



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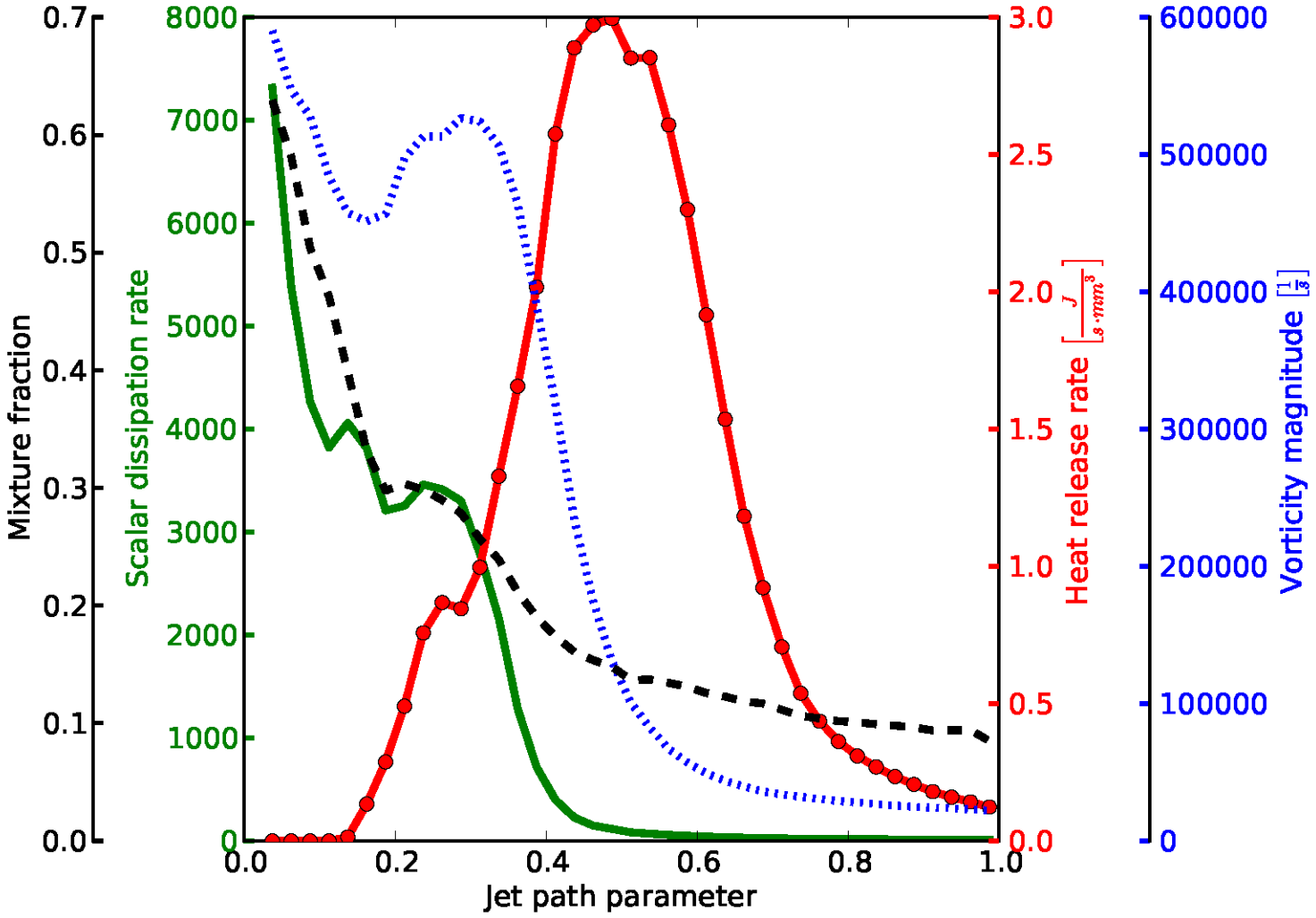

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Acknowledgements

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