Assessment of Counter Flow Arrangement to Measure Laminar Burning Velocities using Direct Numerical Simulations

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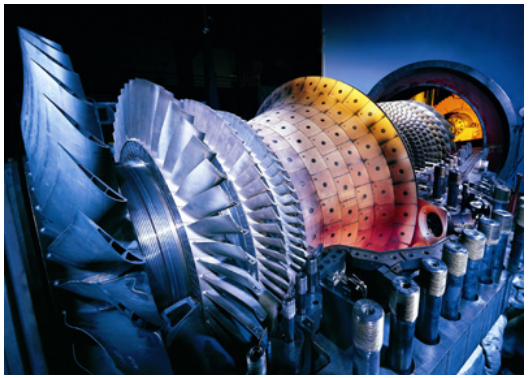
Laminar Burning Velocity

- Important parameter in the characterization of premixed combustion processes
- Appears in turbulent combustion models
- Accurate measurement of the burning velocity not easy



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Burning Velocity Measurement

- Premixed counter-flow twin-flame arrangement[1]
- Burning velocity is measured at different strain rates
- Unstretched burning velocity obtained using non-linear extrapolation to zero stretch
- Extrapolation based on similarity assumptions about the pressure field

1: C. Ji, E. Dames, Y.L. Wang, H. Wang, F.N. Egolfopoulos, "Propagation and Extinction of Premixed C5-C12 n-Alkane Flames," Combustion and Flame, doi: 10.1016/j.combustflame.2009.06.011, 2009

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Objective

- Verify if the extrapolation based on 1D theory works

- Conduct DNS studies of the counter-flow arrangement with a two-dimensional code
- Verify that results are the same between the codes
  - Auto-ignition –> test chemistry
  - Unstretched premixed flame –> test coupling
- Compare results from 2D DNS to
  - Experimental measurements
  - One-dimensional code simulations
- Analyze if strain rate has the same effect in one-dimensional formulation as in experiments

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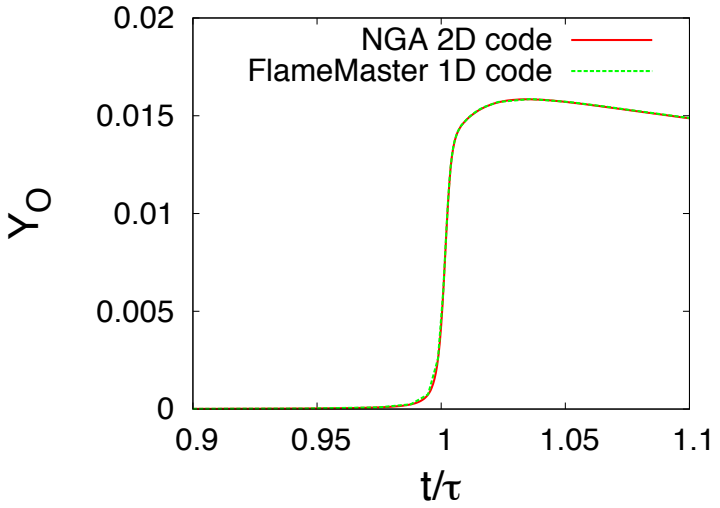
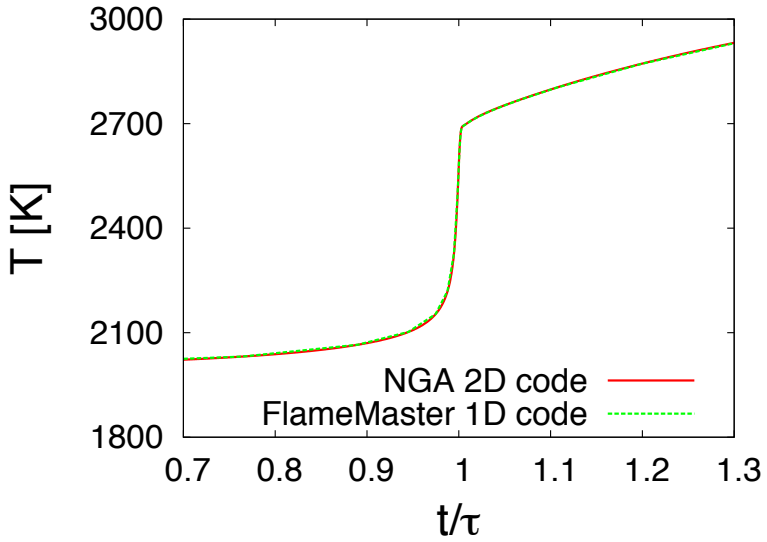
Simulation Infrastructure

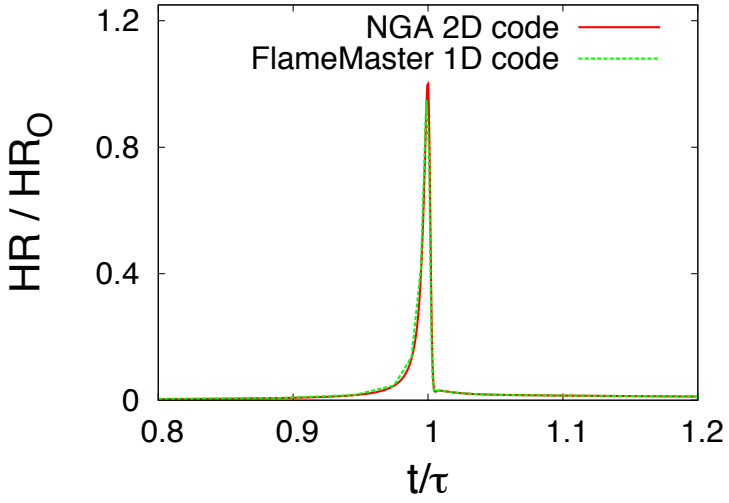
- 1D code : FlameMaster
- 2D code : NGA
  - High-order energy conserving code using finite-rate chemistry
  - Allows for realistic simulation of the experimental setup
- Detailed chemical mechanism used with 28 species in both codes

Comparison Between Codes

- Auto-ignition
  - Methane/air
  - Tests chemistry handling between codes

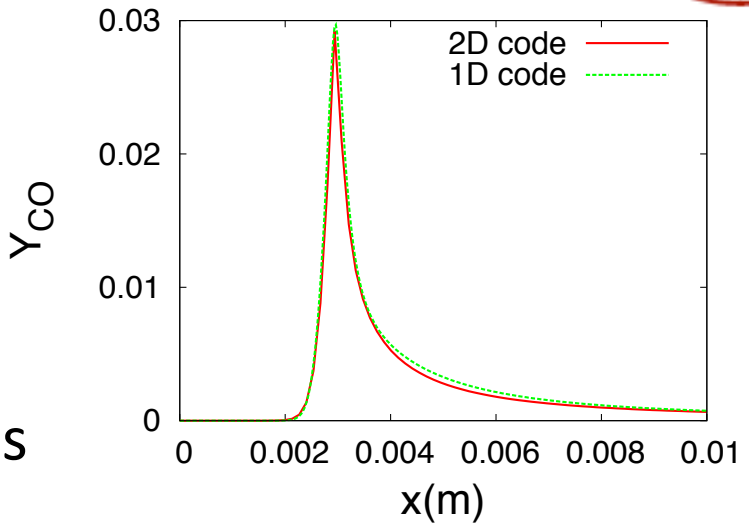


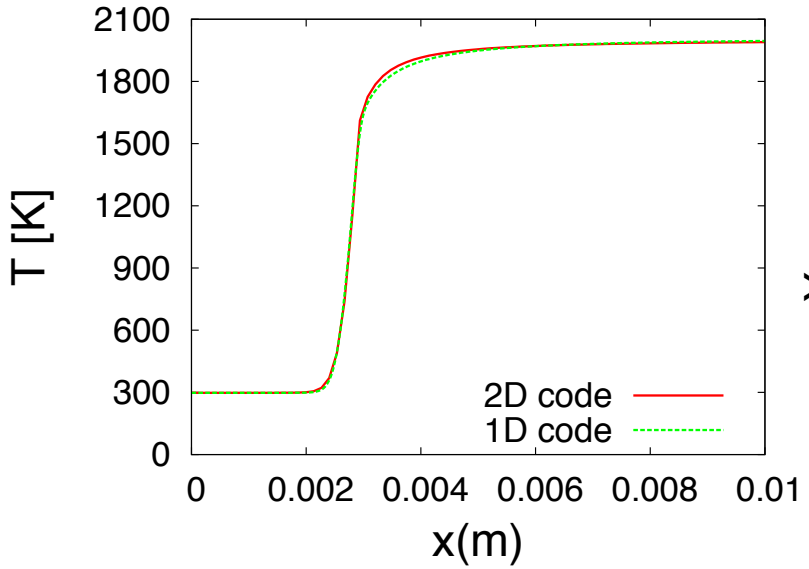


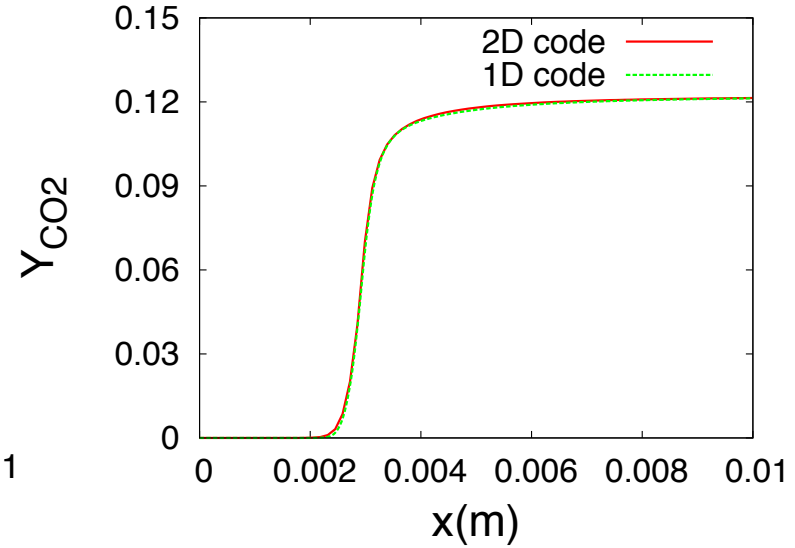


Comparison Between Codes

- Unstretched Premixed Flame
  - Burning velocity for methane at phi = 0.8
    - 1D code : 25.6 cm/s
    - 2D code : 25.5 cm/s
- Conclusion:
  Codes give very similar results

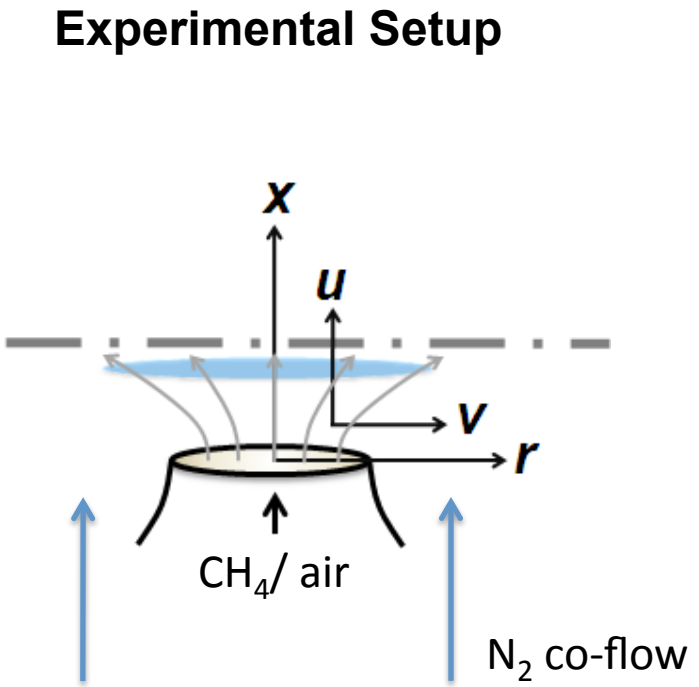






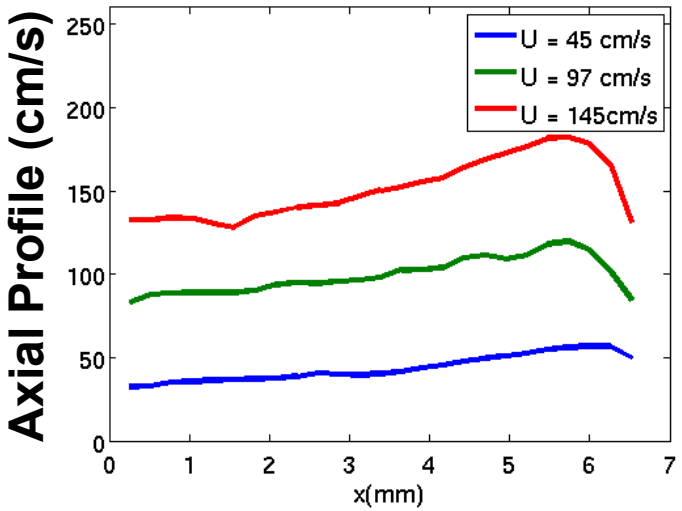
Experimental Setup

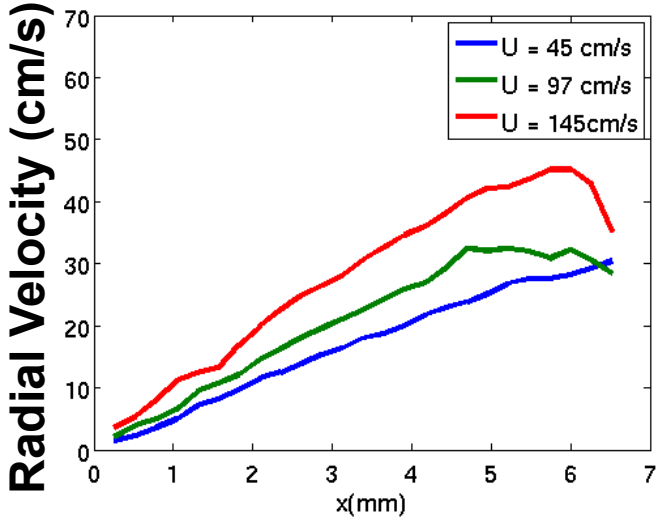
- Counter-flow symmetric arrangement
- CH_4/air, P = 1 atm,
- T = 294 K, phi = 0.8
- Mean nozzle exit velocity
  - 45 cm/s – lowest strain
  - 97 cm/s
  - 145cm/s – highest strain



Experimental Nozzle Exit Profile

- Exit profile from the nozzle in the experiment not completely uniform

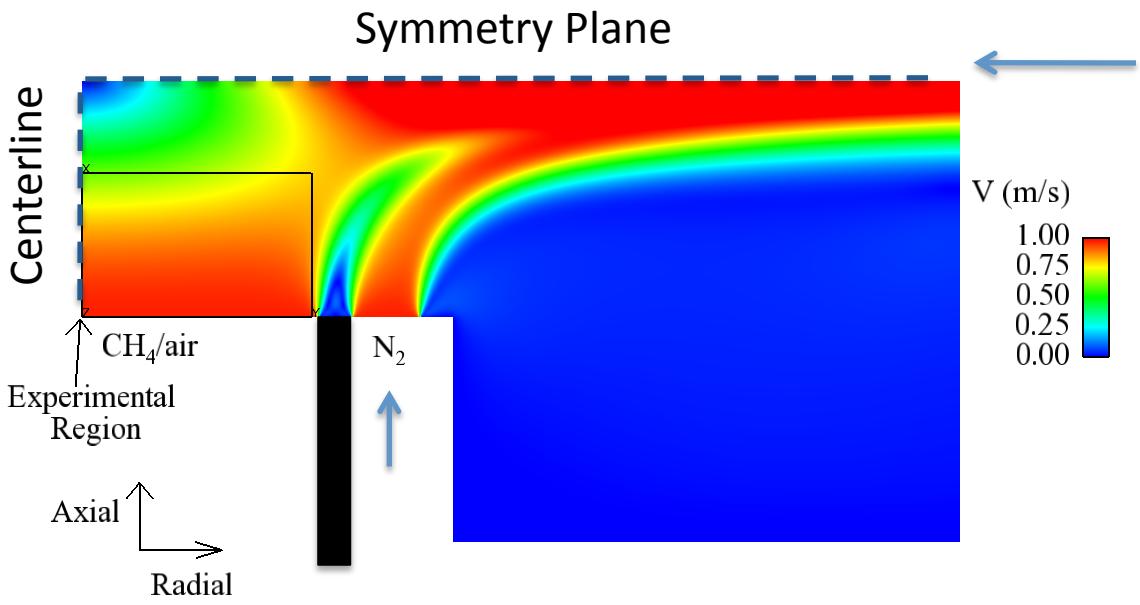




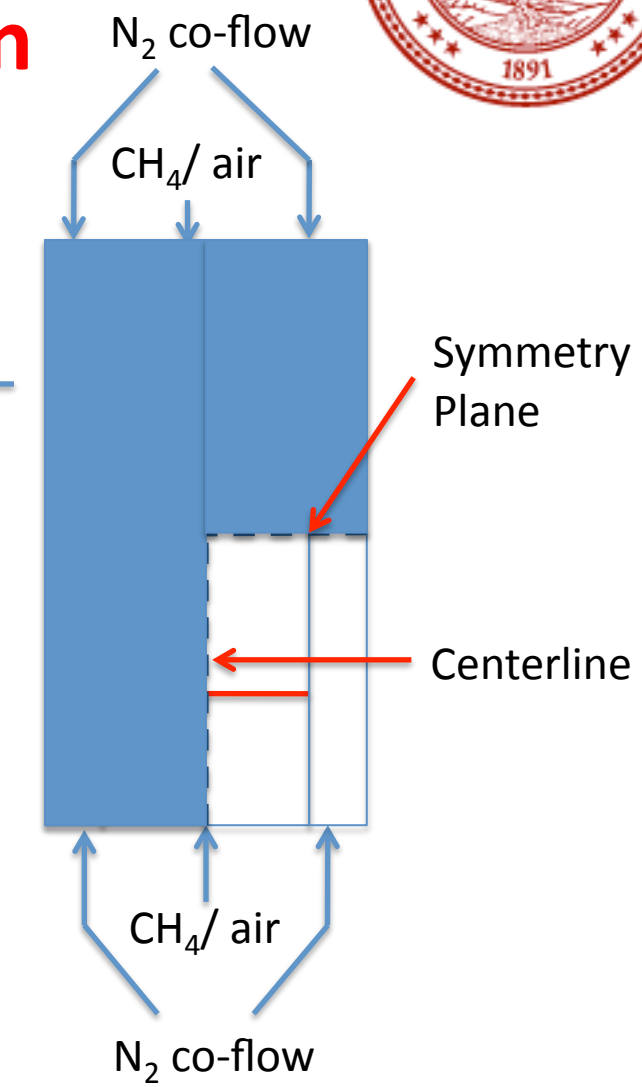
- To assess the sensitivity of profile, we simulate
  - top-hat inflow profile (bulk)
  - real experimental profile (actual)

Simulation Domain

- Axisymmetry is assumed



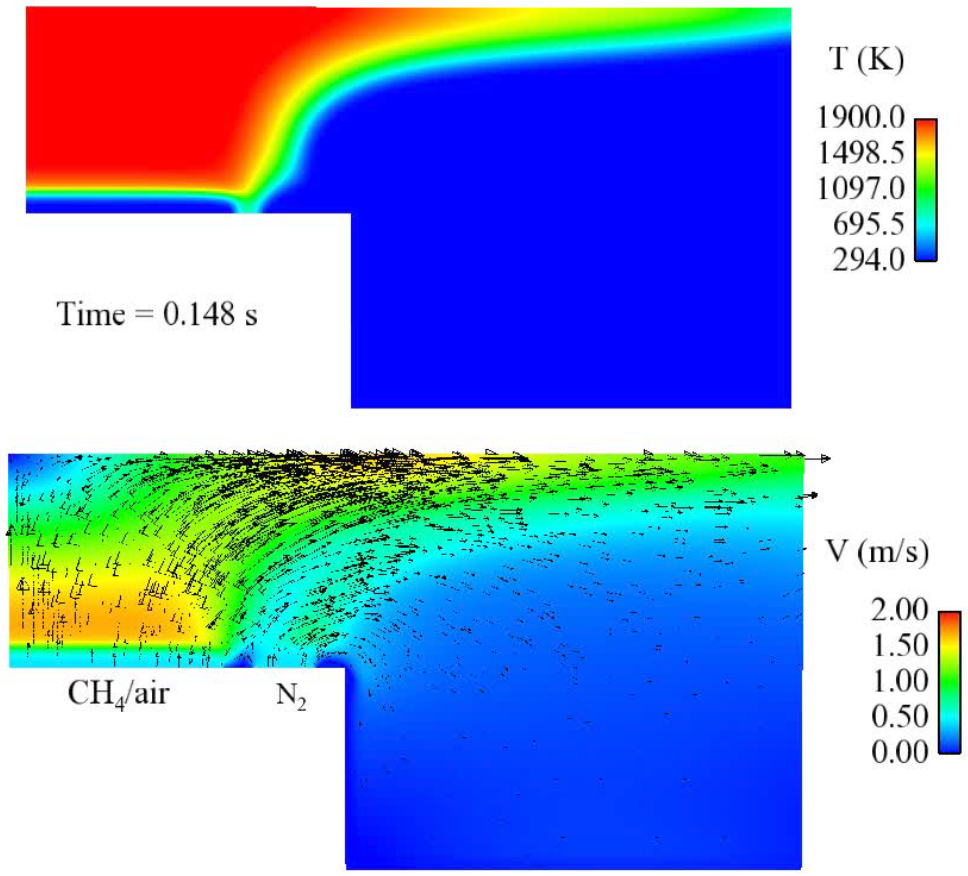
Simulation Domain



Experimental Setup

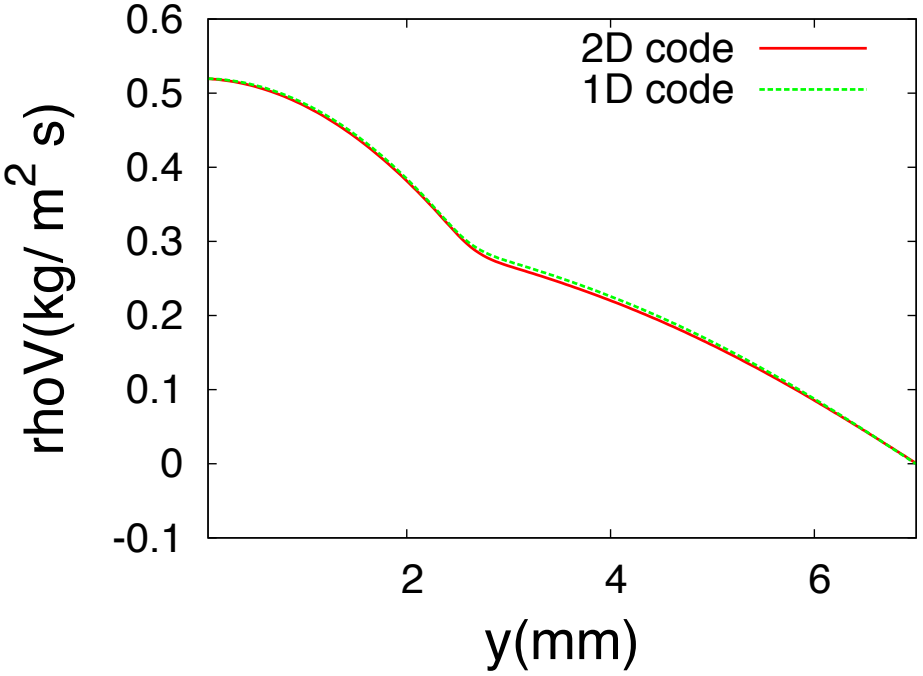
Bulk Nozzle Exit Profile

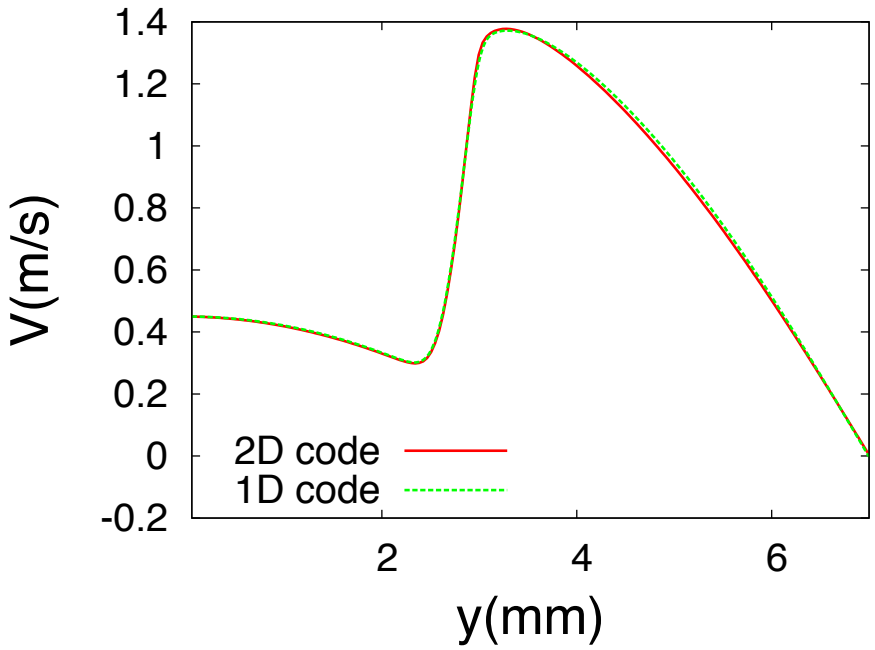
- Mean axial velocity : 45 cm/s



Bulk Nozzle Exit Profile

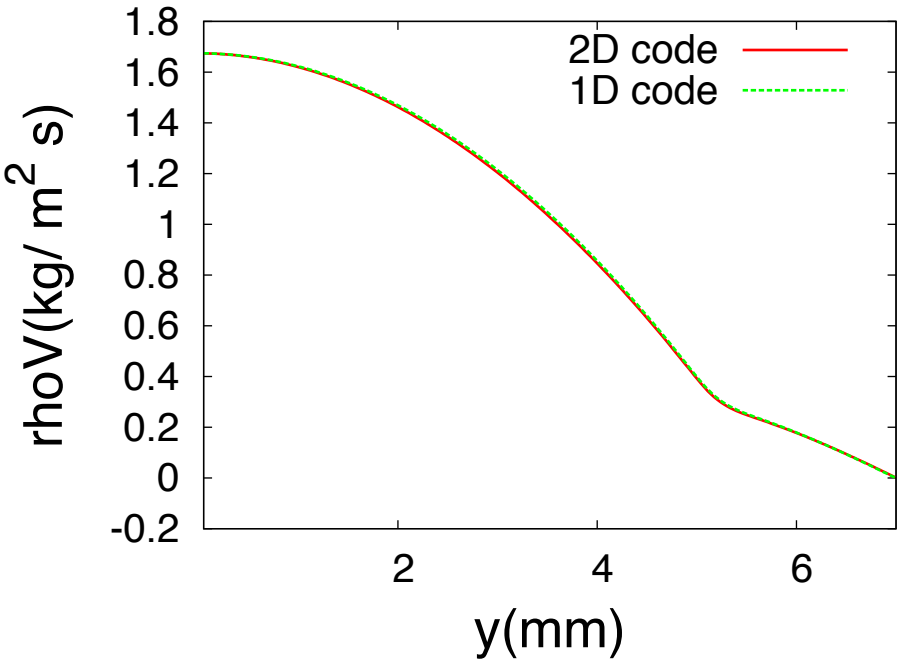
- Mean axial velocity : 45 cm/s
  - Centerline comparison with 1D code

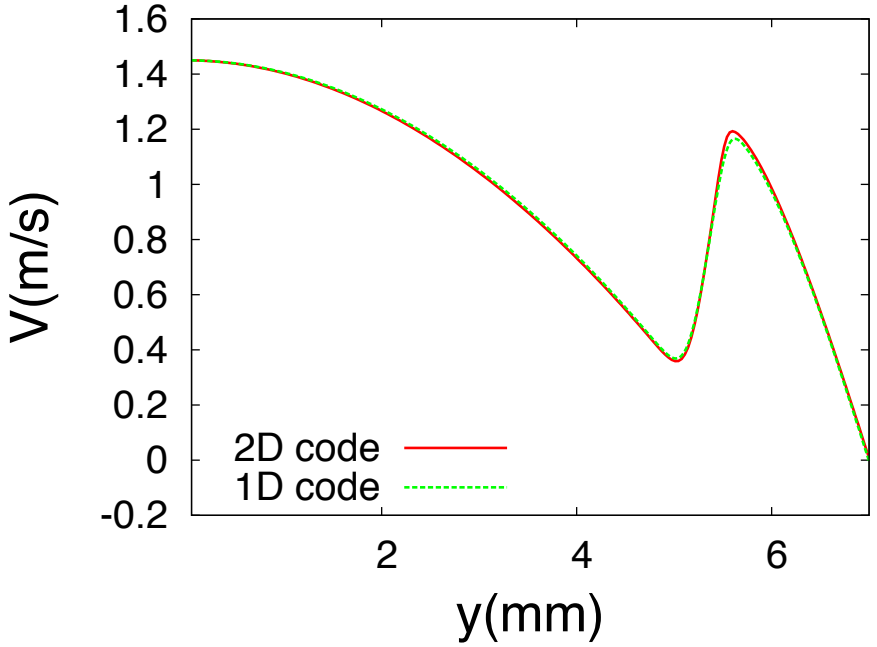




Bulk Nozzle Exit Profile

- Mean axial velocity : 145 cm/s
  - Centerline comparison with 1D code





Bulk Nozzle Exit Comparison

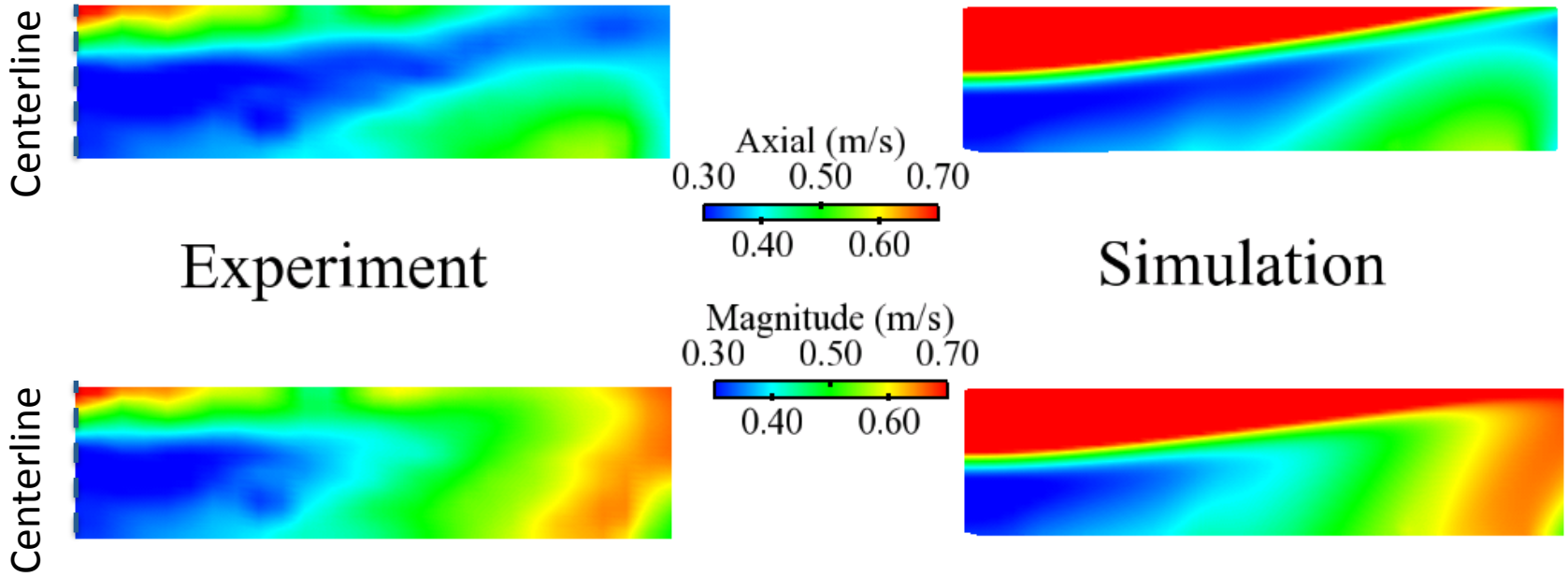
- Top-hat profile assumed at nozzle exit

Bulk Inflow Velocity	Burning Velocity (cm/s)		Strain Rate K (1/s)		Flame Location (mm)	
	1D code	2D code	1D code	2D code	1D code	2D code
45 cm/s	29.89	30.53	114.5	115.6	9.34	9.39
97 cm/s	33.46	33.99	275.8	278.3	11.30	11.29
145 cm/s	35.90	36.88	410.2	412.0	12.01	12.01

- One dimensional assumption works within ≈2%

Comparison With Experiment Results

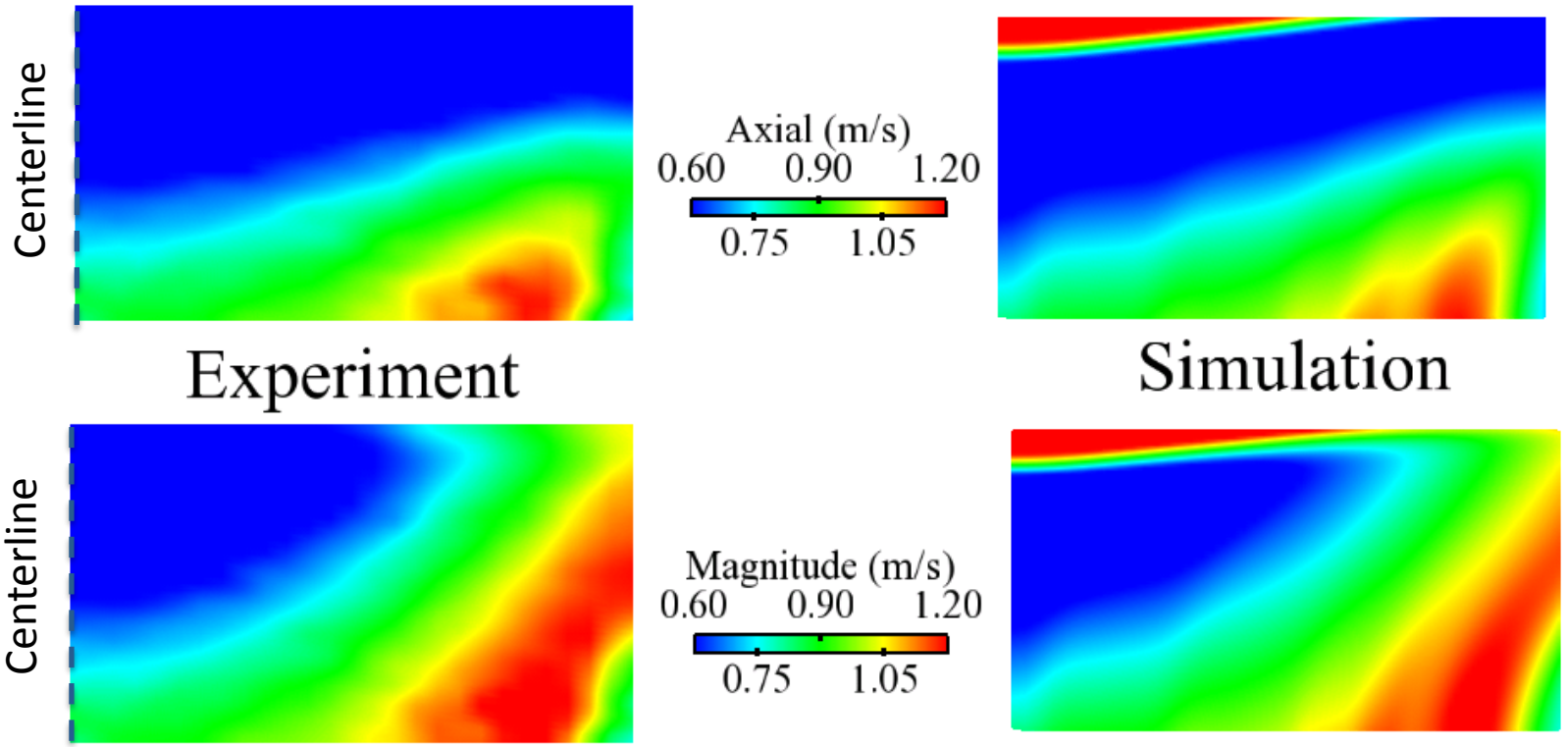
- Nozzle exit axial velocity = 45 cm/s



- Comparison good, but different flame position
- Better agreement not necessarily expected, because of simple chemical mechanism

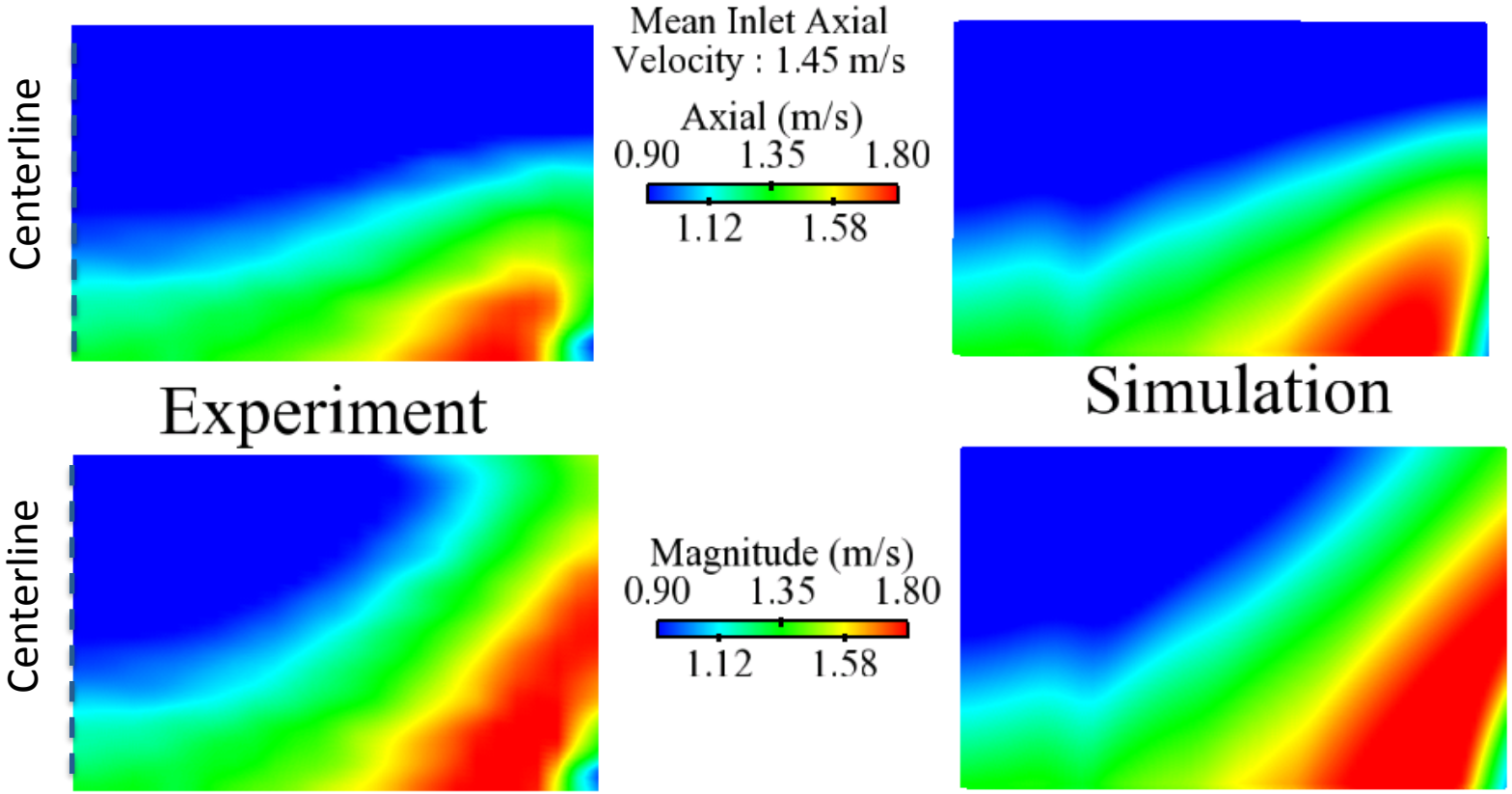
Comparison With Experiment Results

- Nozzle exit axial velocity = 97 cm/s



Comparison With Experiment Results

- Nozzle exit axial velocity = 145 cm/s



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Summary

- Analysis of the 1D assumption used to extrapolate stretched burning velocity
- 1D and 2D simulations performed
- DNS with top-hat inflow velocity compares well with 1D code results
- Next step: Analysis of 2D simulations with realistic inflow conditions