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

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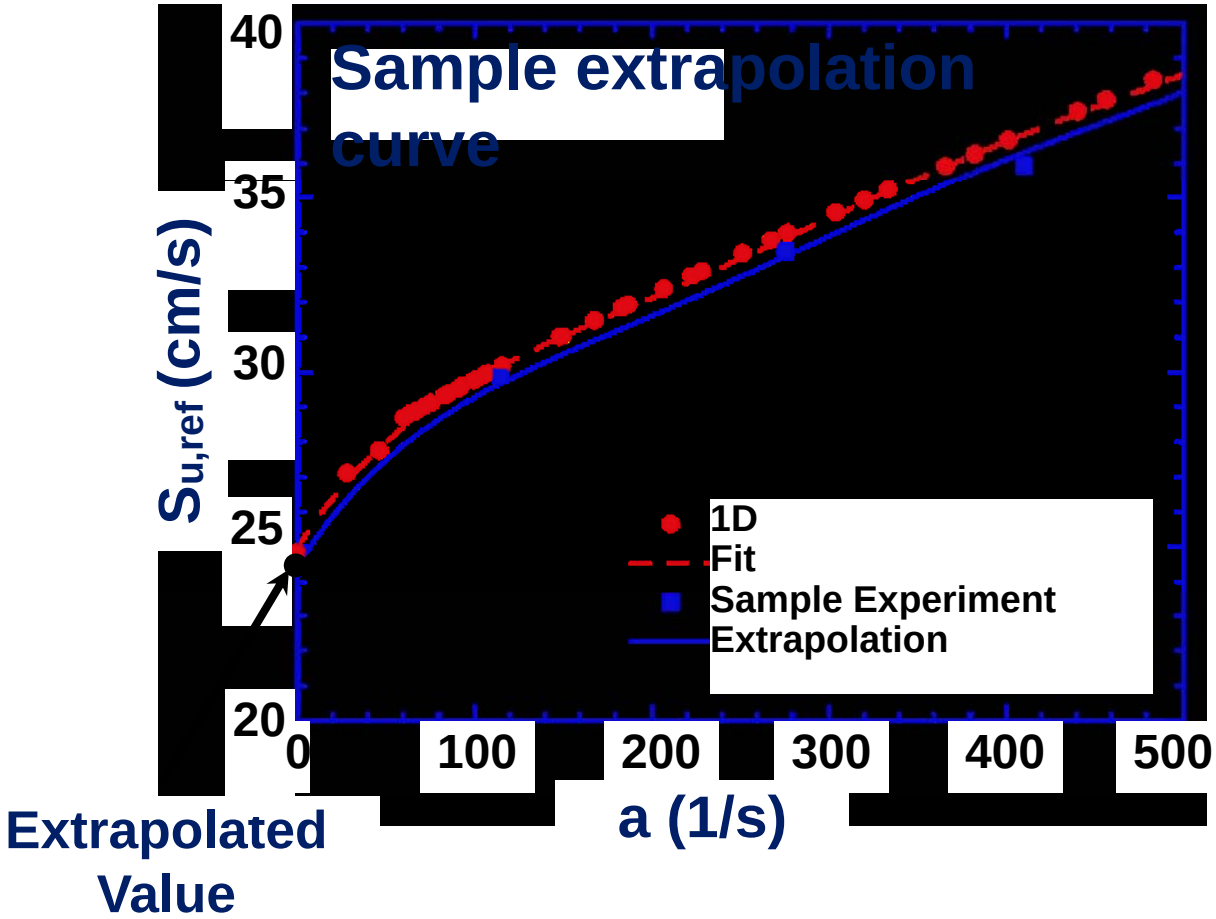
Non-linear Extrapolation Procedure For Burning Velocity Measurement

- Curve obtained through **1D formulation**
- Translate curve to experimental data
- Obtain the correct extrapolated curve



1D formulation assumptions

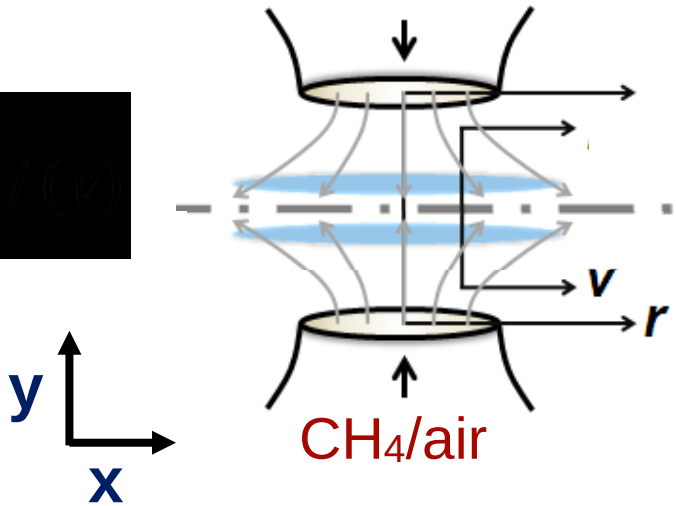
- **Main assumptions**

[redacted]

[redacted]

[redacted]

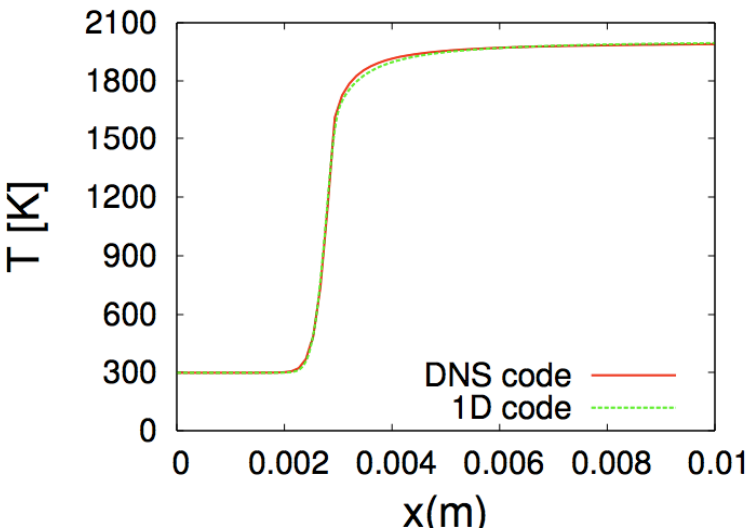
- 2D laminar DNS studies done to check if these are valid



Counterflow Setup

Simulation Parameters

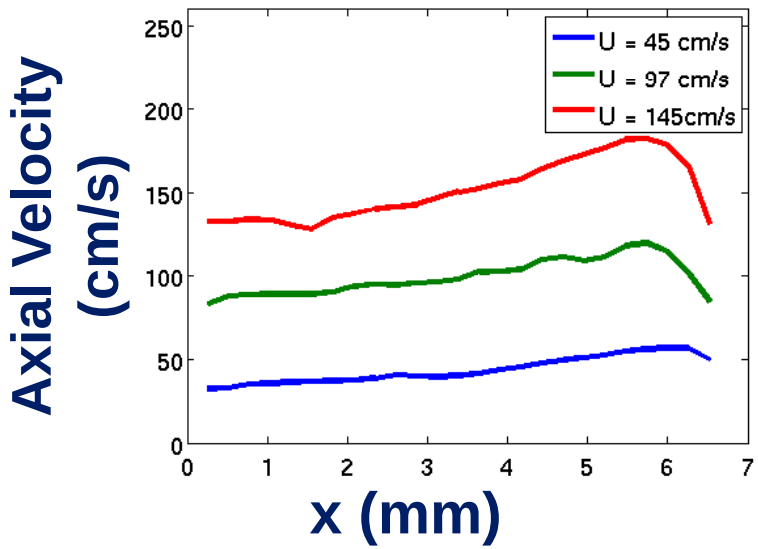
- Detailed finite-rate chemistry used
- Results verified between the two formulations for canonical problems
- Mean inlet velocity
  - 45 cm/s – **low strain rate**
  - 97 cm/s
  - 145 cm/s – **high strain rate**

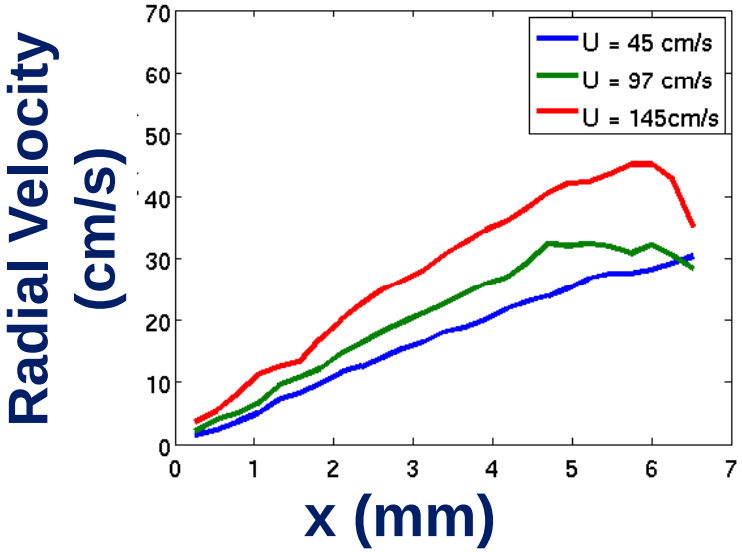


Sample premixed flame temperature profile comparison

Inlet Velocity Profile

- Velocity profile from the nozzle not completely uniform

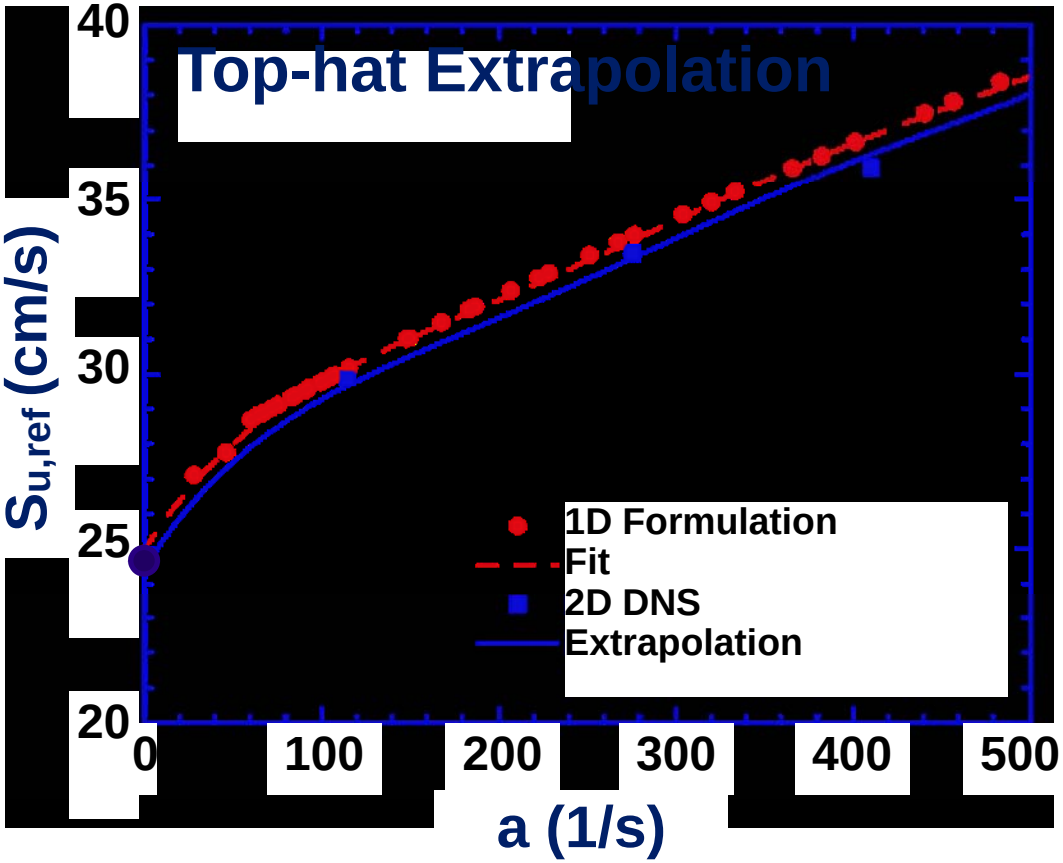




- To assess the sensitivity of profile, we simulate
  - **Top-hat inflow profile**
  - **Actual experimental profile**

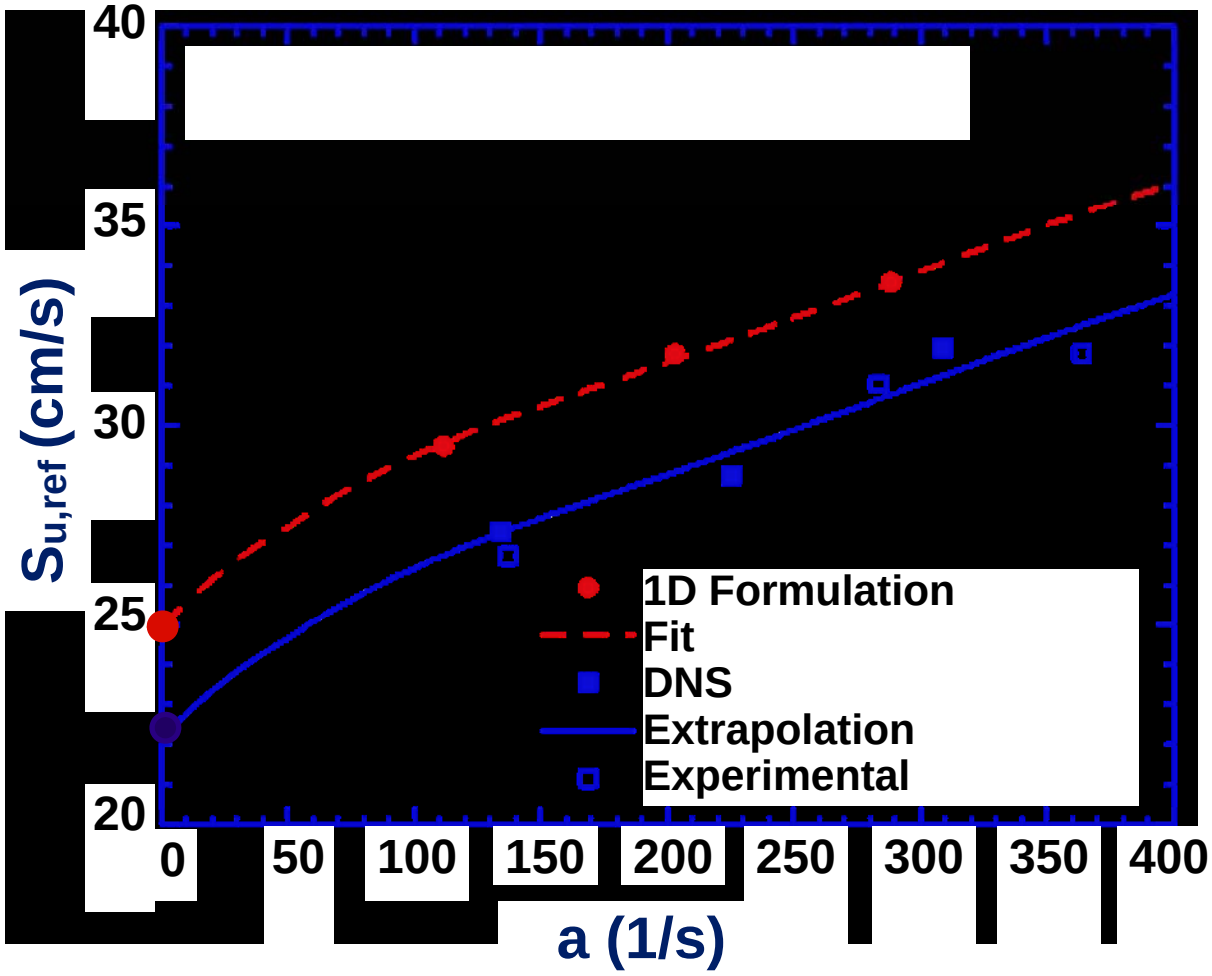
Extrapolation for Top-hat Profile

- Correct unstretched burning velocity - 24.85 cm/s
- DNS data extrapolation leads to the correct value
- Extrapolation **works** for **top-hat nozzle profile**



Experimental Profile Extrapolation

- **Computed S_L**
  - **1D** :
    - 24.85 cm/s
  - **DNS** :
    - 22.05 cm/s
- Values are significantly **different**
- Procedure is not accurate



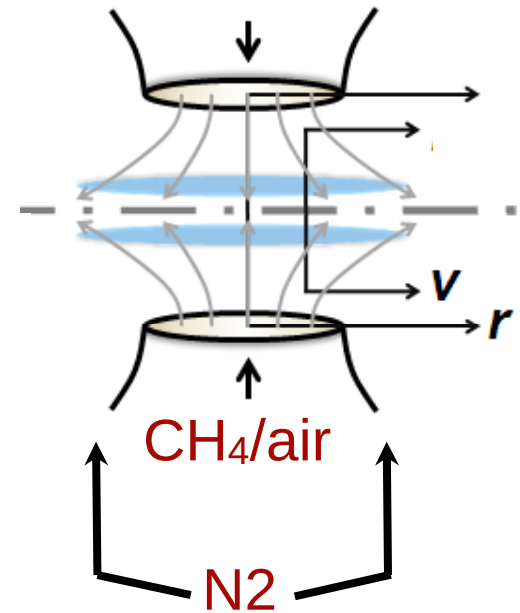
Analyzing the 1D formulation assumptions

- **Main assumptions**

[redacted] ✓

[redacted] [redacted] X

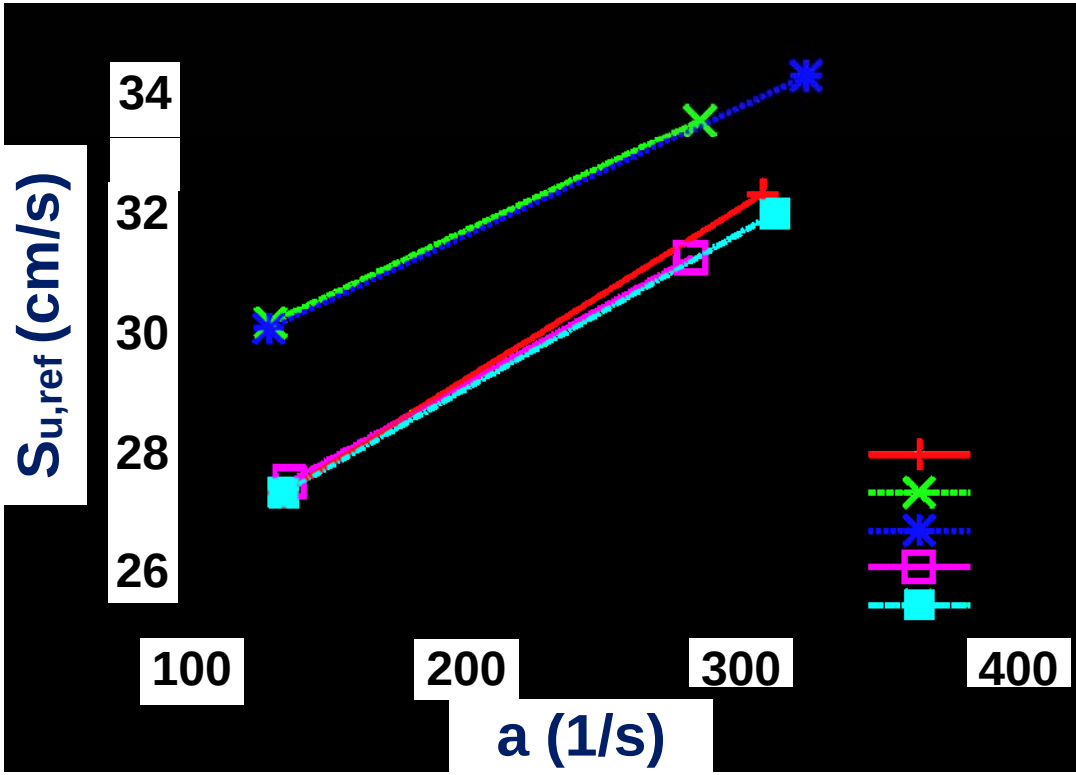
[redacted] X



- Last two assumptions are not valid
- To test if T and P Curvatures are the issue, we include them into

Testing assumptions in the formulation

- Velocity fields match after including non-uniform pressure and temperature radial curvatures
- Including only the Temperature curvature is sufficient to obtain the correct relation
- **This curvature should be measured** to obtain a more accurate burning velocity



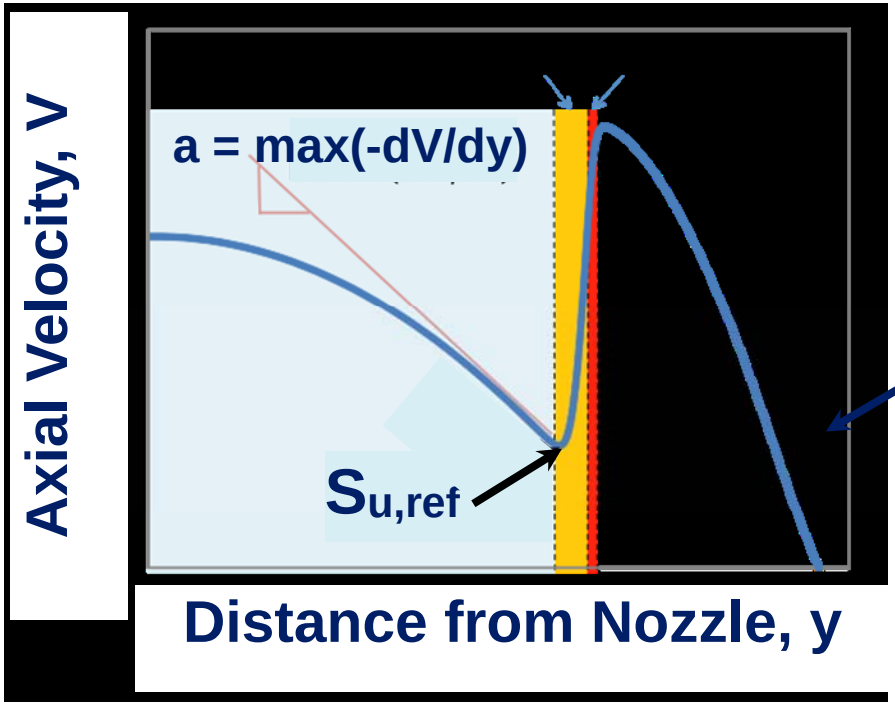
Summary

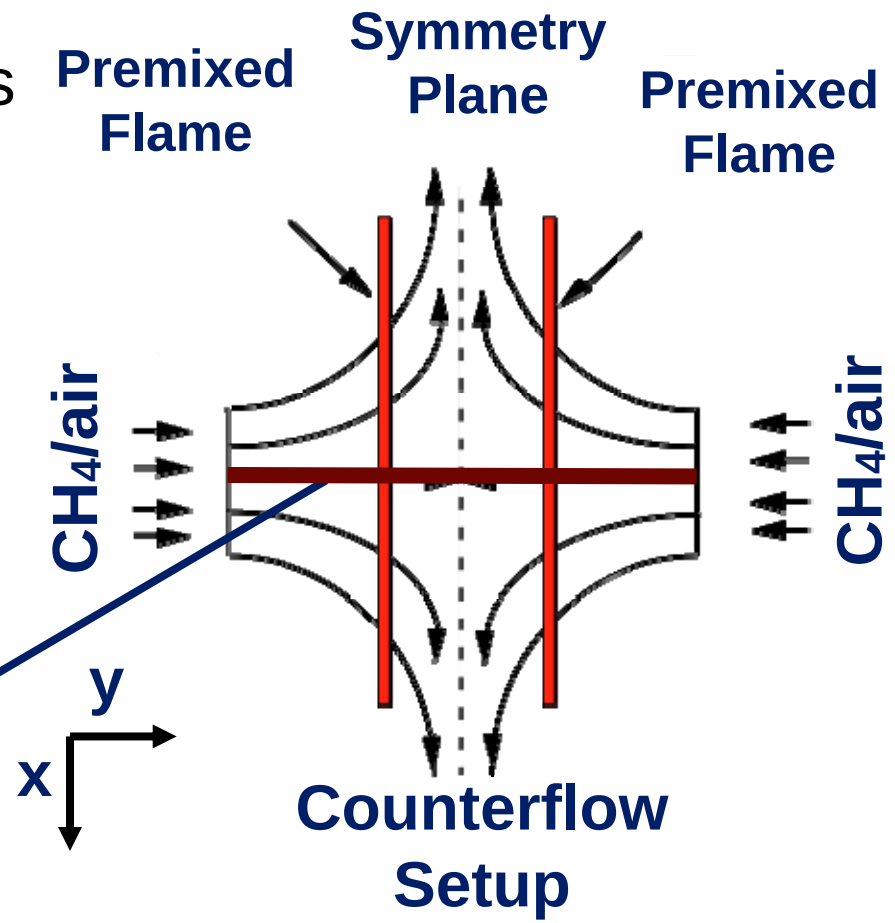
- Extrapolation method based on the 1D formulation tested using 1D and 2D simulations
- The method works well when the nozzle has a top-hat exit profile
- A non-uniform nozzle velocity profile leads to a radial temperature curvature that cannot be neglected
- A better extrapolation procedure is suggested

Questions

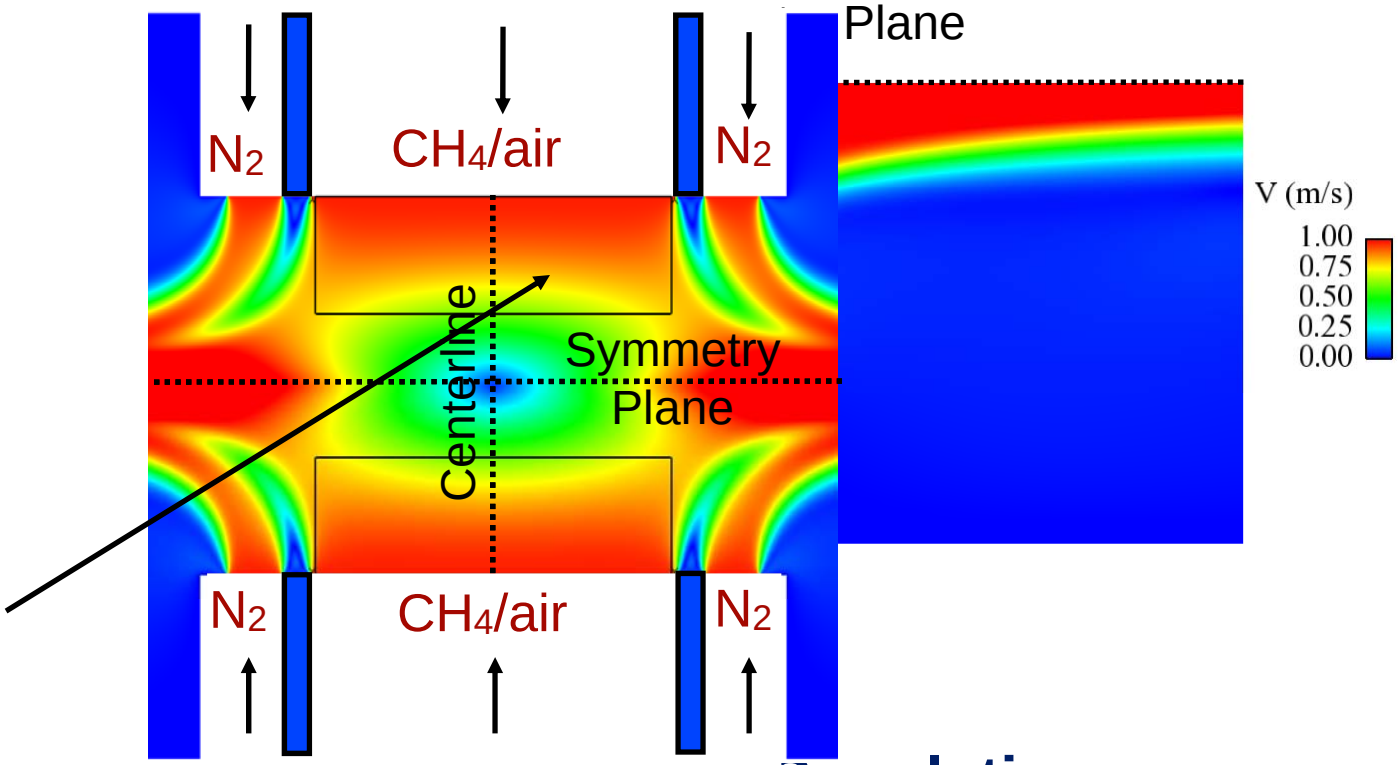
Burning Velocity Measurement

- Counterflow arrangement
- The inflow velocity controls the strain rate imposed





Simulation Domain Setup



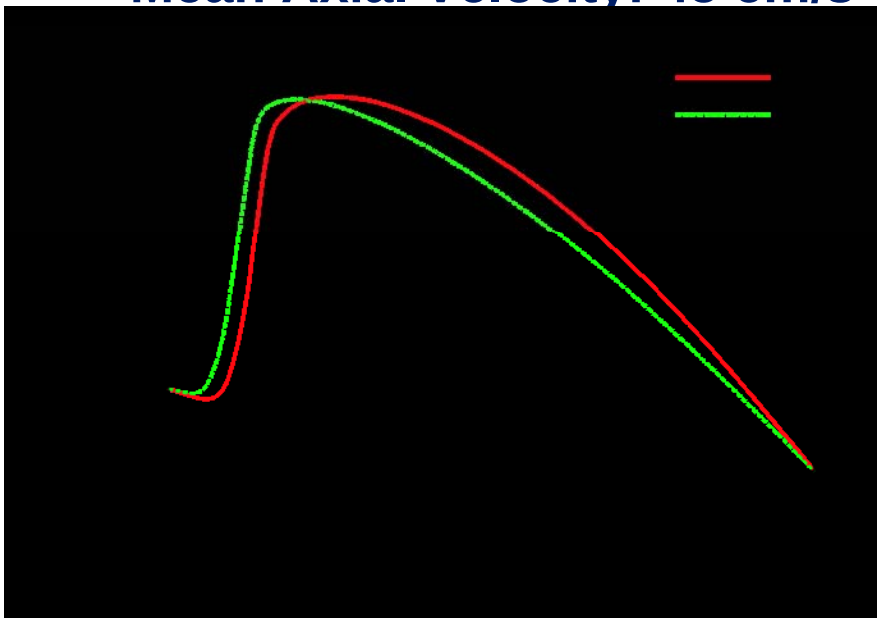
Experimental Setup

Simulation Domain

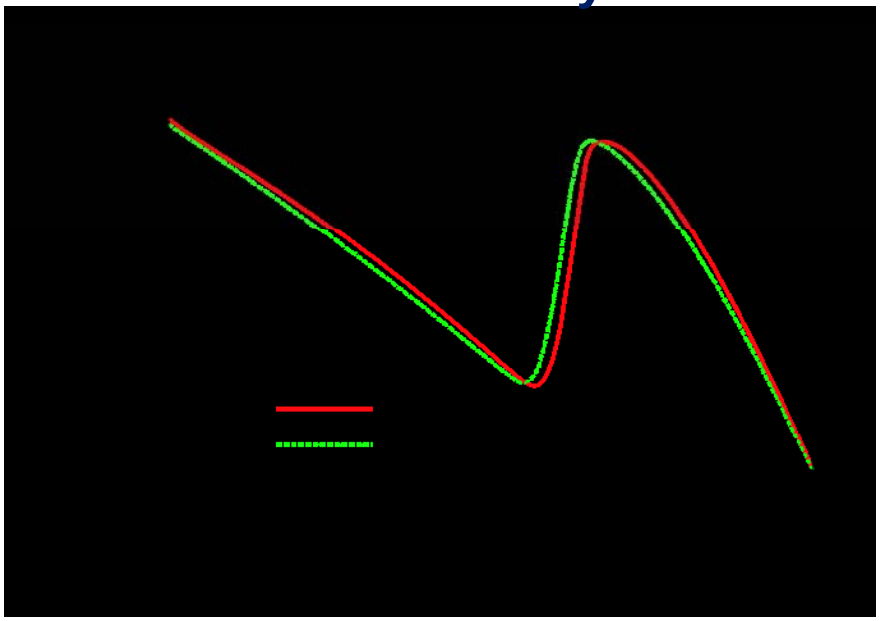
Actual Experimental Profile Comparison

- Centerline velocity profiles are different
- The inflow velocity profile has a strong effect

Mean Axial Velocity: 45 cm/s

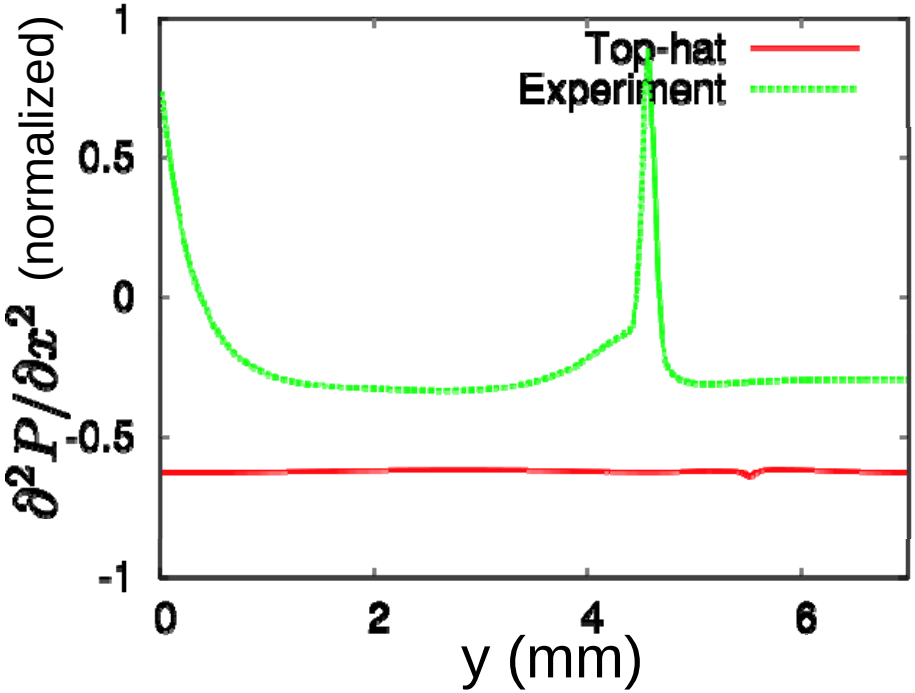


Mean Axial Velocity : 145 cm/s



Second Assumption : [redacted]

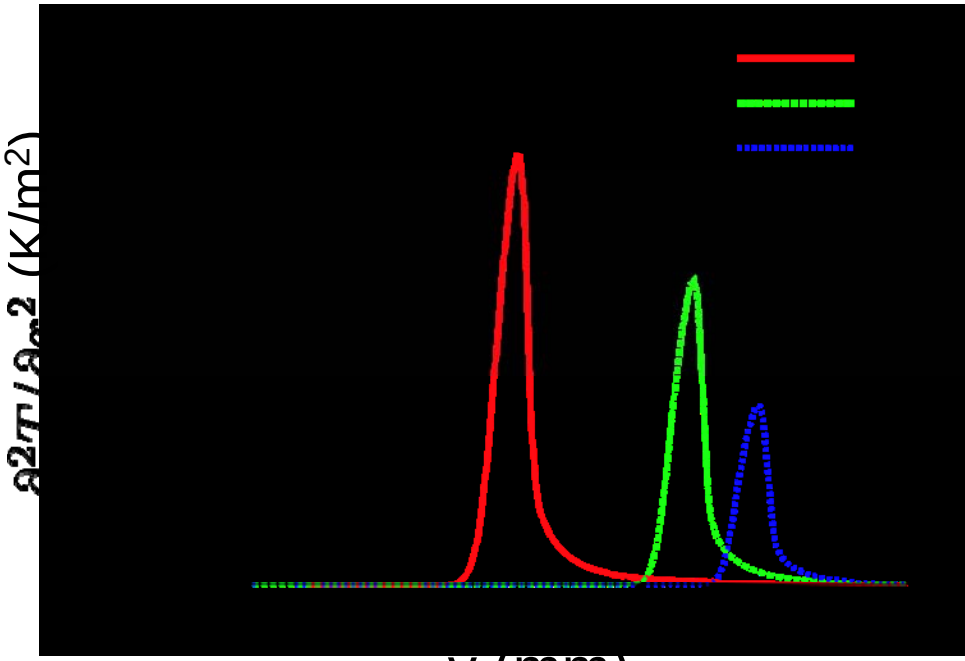
- [redacted] is constant for the top-hat profile case
- [redacted] changes for the [redacted]n-uniform profile
- Assumption is not good



Radial Pressure Curvature

Third Assumption : [redacted]

- [redacted] varies significantly for the experimental velocity profile case
- Testing the assumptions
  - T and P Curvatures from DNS are included in the 1D formulation



Radial Temperature Curvature

Comparison For Real Nozzle Exit

- Burning velocity is compared at different nozzle exit speeds
- Exit profile has an effect on the burning velocity

Mean Exit Velocity	Strain Rate		Burning Velocity (cm/s)	
	1D	2D	1D	2D
45 cm/s (actual) 45 cm/s (top-hat)	133.6 115.6	133.9 114.5	30.16 30.53	27.38 29.89
97 cm/s (actual) 97 cm/s (top-hat)	225.3 278.3	225.1 275.8	32.37 33.99	28.78 33.46
145 cm/s (actual) 145 cm/s (top-hat)	308.0 412.0	308.7 410.2	34.10 36.88	31.98 35.90

A better extrapolation procedure

Obtain Linear relation from 1D formulation

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Obtain the offset of the intercept from the unstretched burning velocity

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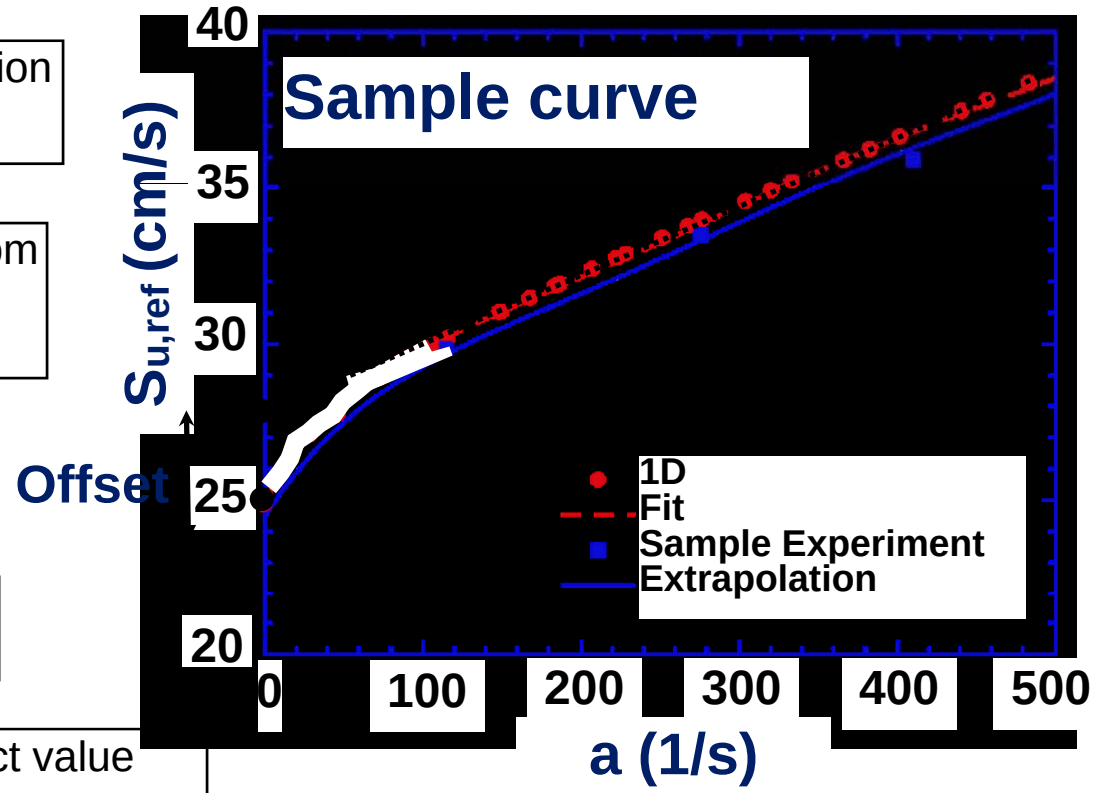
Fit a linear curve through the experimental data

↓

Extrapolate this curve to zero stretch

↓

Subtract the offset to obtain the correct value