EPSRC
Engineering and Physical Sciences Research Council

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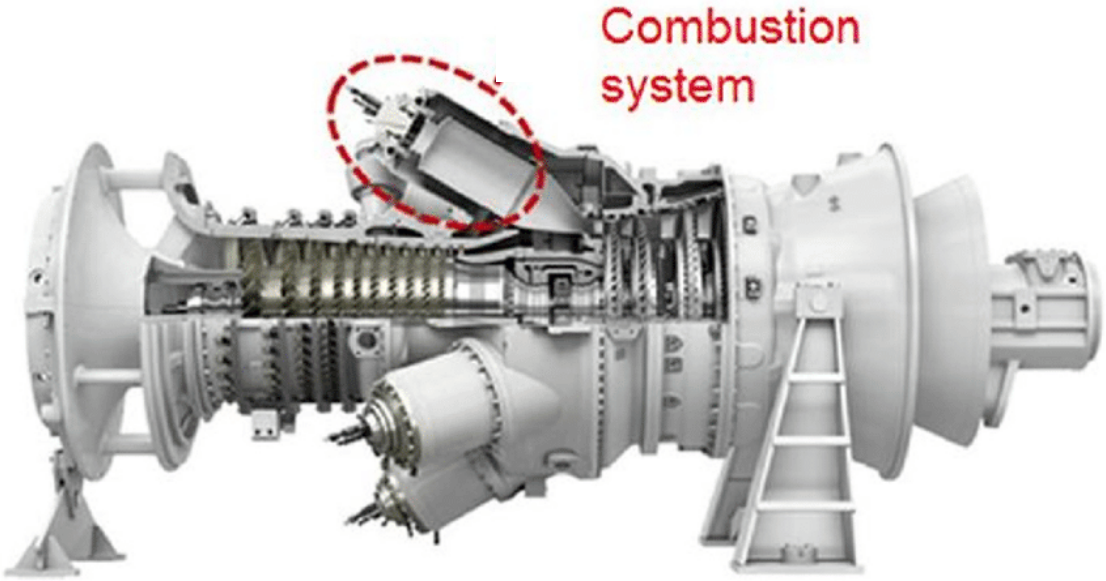
The Effect of Swirl on Boundary Layer-Flashback Processes for Hydrogen-Rich Gas-Turbine Combustion

James Bailey

Edward Richardson

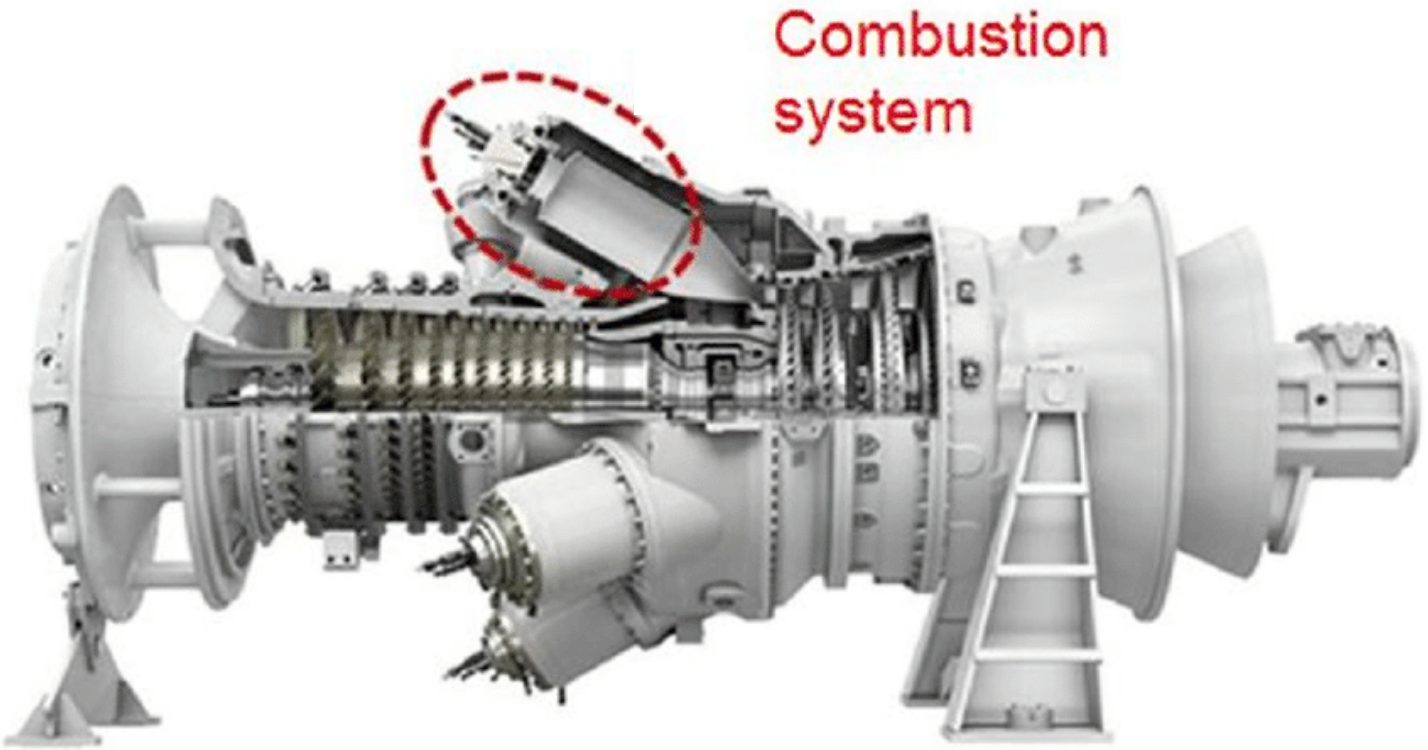


12/09/2019

We acknowledge financial support from the EPSRC Centre for Doctoral Training in Next Generation Computational Modelling grant EP/L015382/1.

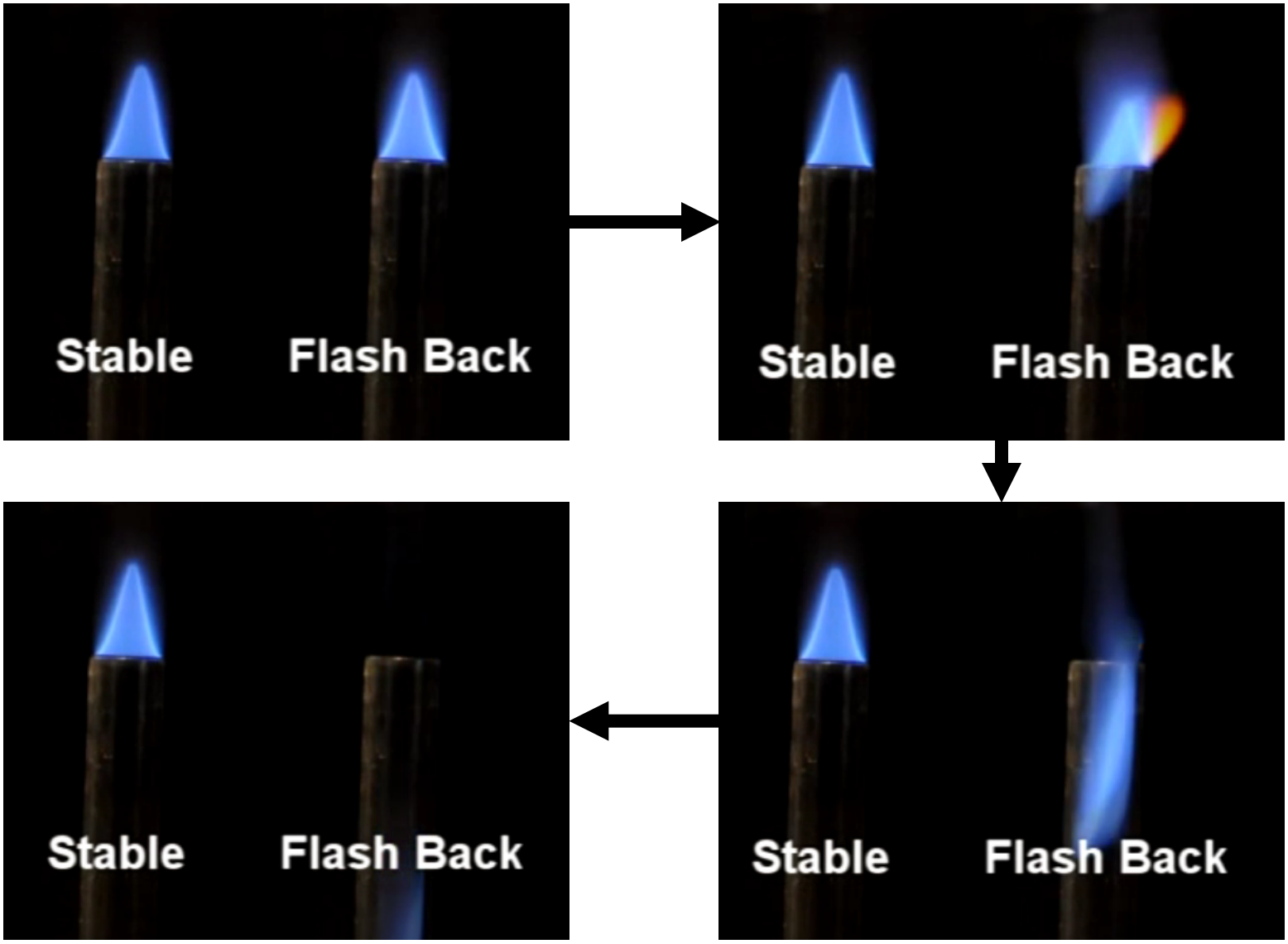
Background

- Industrial gas turbines
- Fuel-flexible burner and alternative fuels

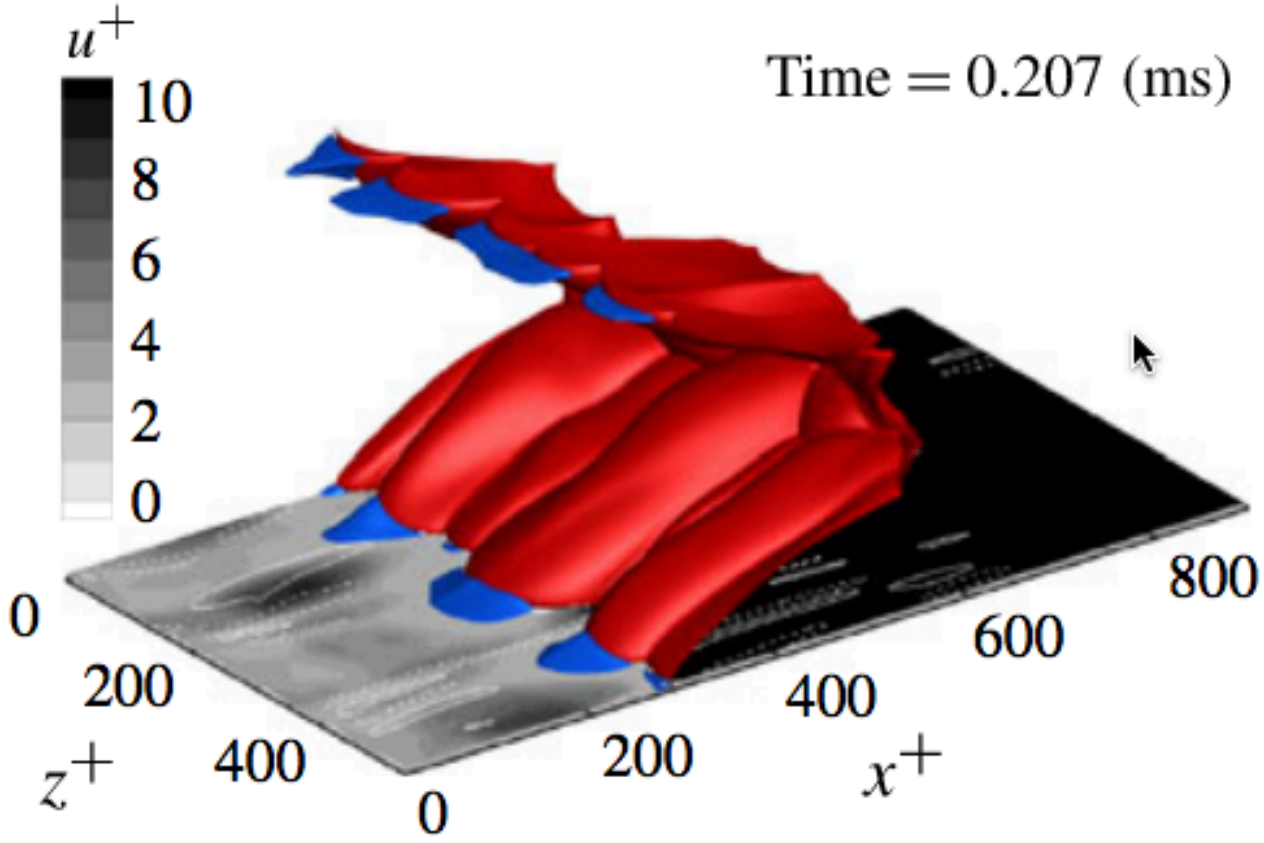


https://www.researchgate.net/profile/Ieuan_Owen/publication/282796815/figure/fig14/AS:668870398464013@1536482538619/A-Siemens-industrial-gas-turbine-engine-showing-the-components-of-a-generic-DLE.png

Flashback

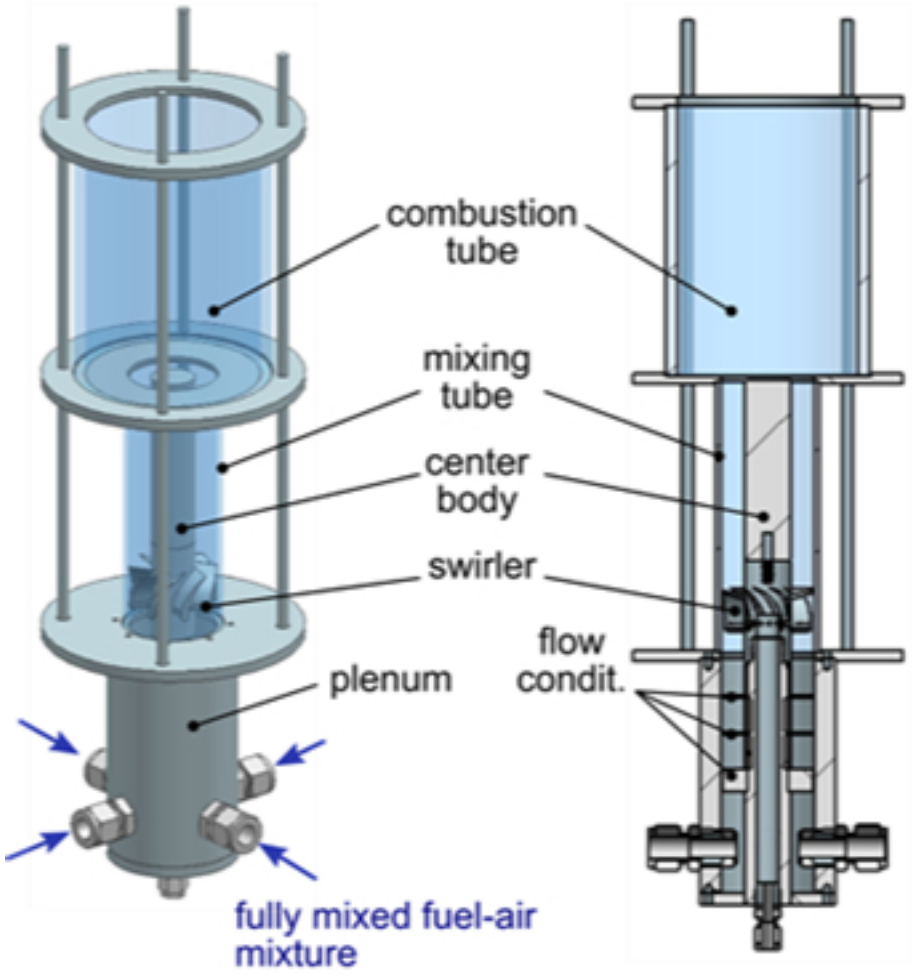

Stable
Flash Back
Stable
Flash Back
Stable
Flash Back
Stable
Flash Back

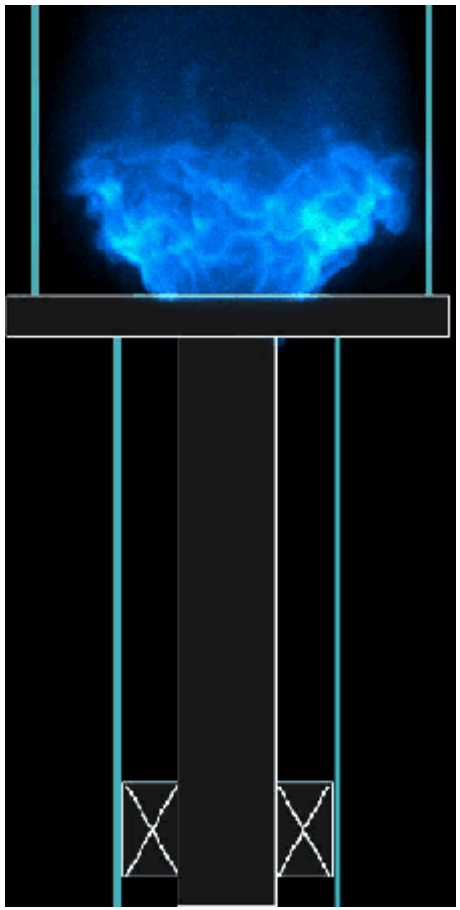
Flashback in Planar Channels



Gruber et al., Journal Fluid Mechanics, 2012, 709, 516-542

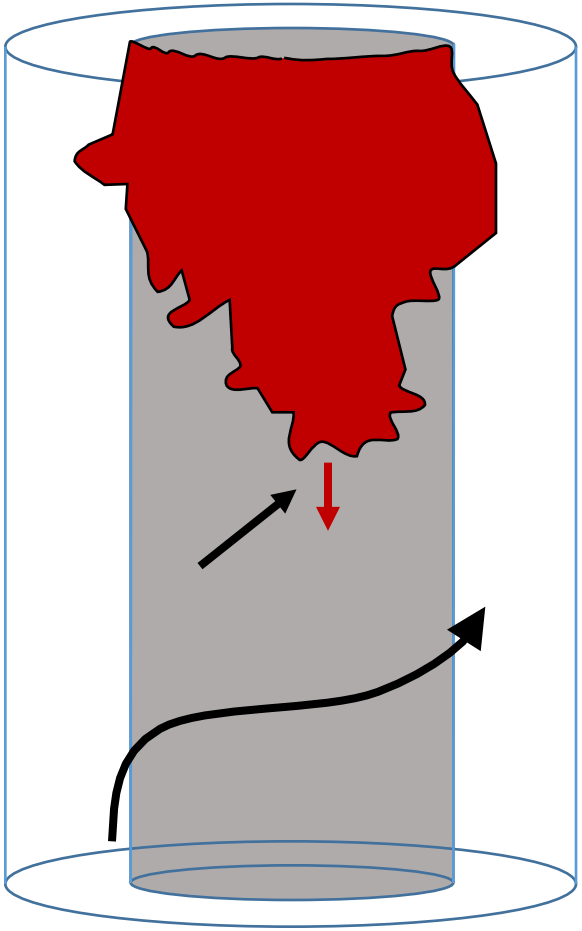
Flashback in Swirling Flows

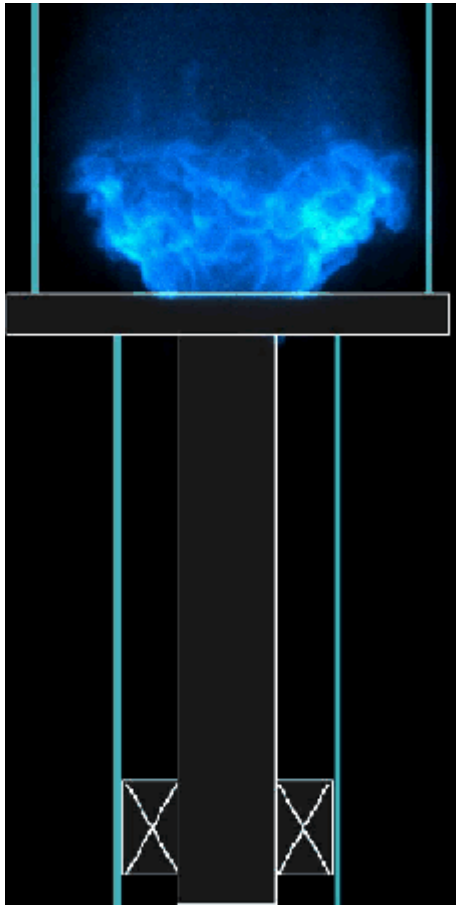




Ebi and Clemens, Combustion and Flame, 2016, 168, 39-52

Flashback in Swirling Flows

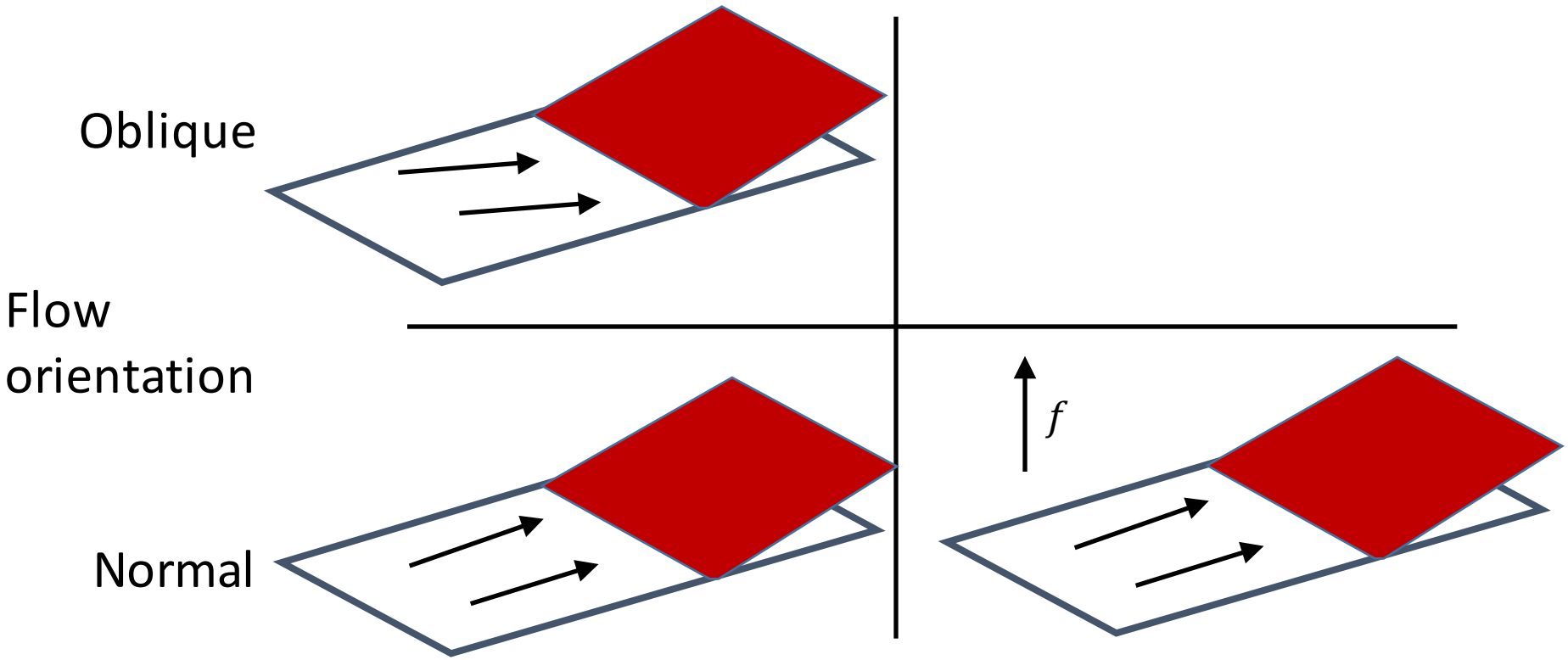




Ebi and Clemens, Combustion and Flame, 2016, 168, 39-52

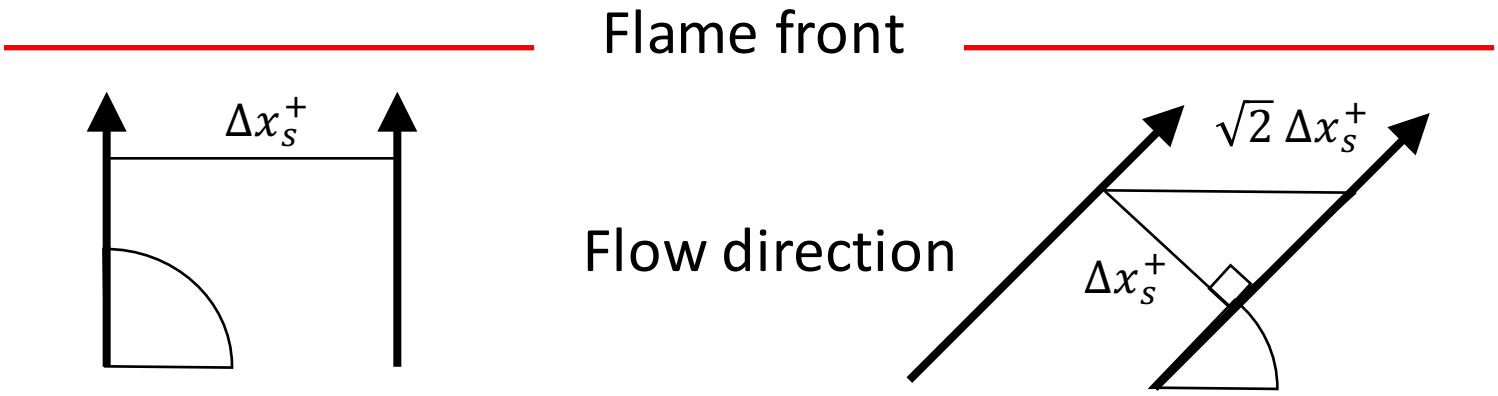
Methodology

Methodology



Methodology

- Physical aspects of swirl:
  - Flow orientation



$\theta = 90°$

Normal flow

$\theta = 45°$

Oblique flow

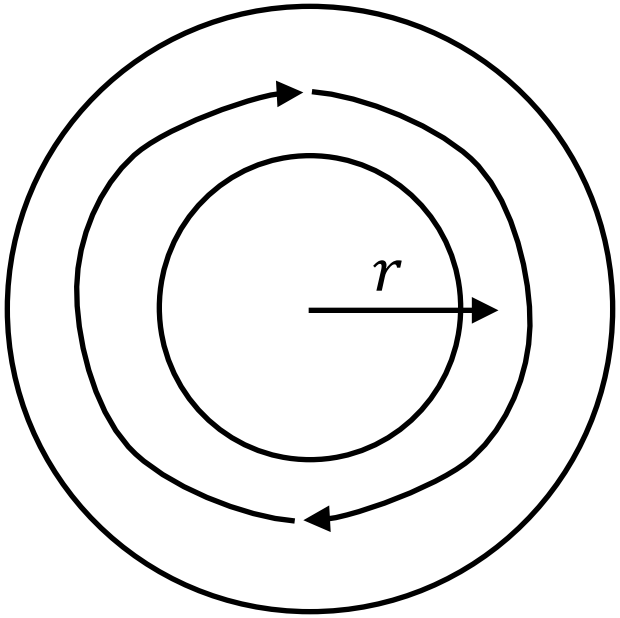
Methodology

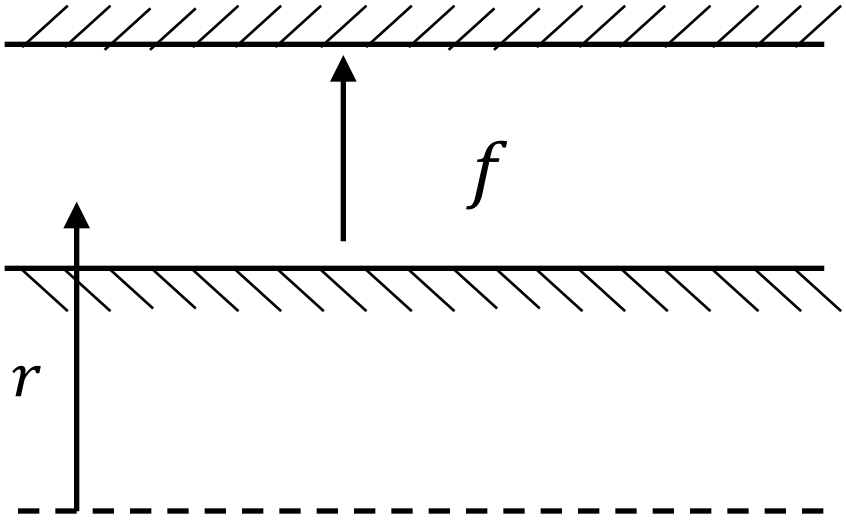
- Physical aspects of swirl:
  - Radial pressure gradient

$$\frac{\partial p}{\partial r} = \rho \frac{V_\theta^2}{r} = g$$

$$g' = g\left(\frac{\rho_u - \rho_b}{\rho_u}\right)$$

$$Fr = \frac{S_L}{\sqrt{g'\delta_l}}$$





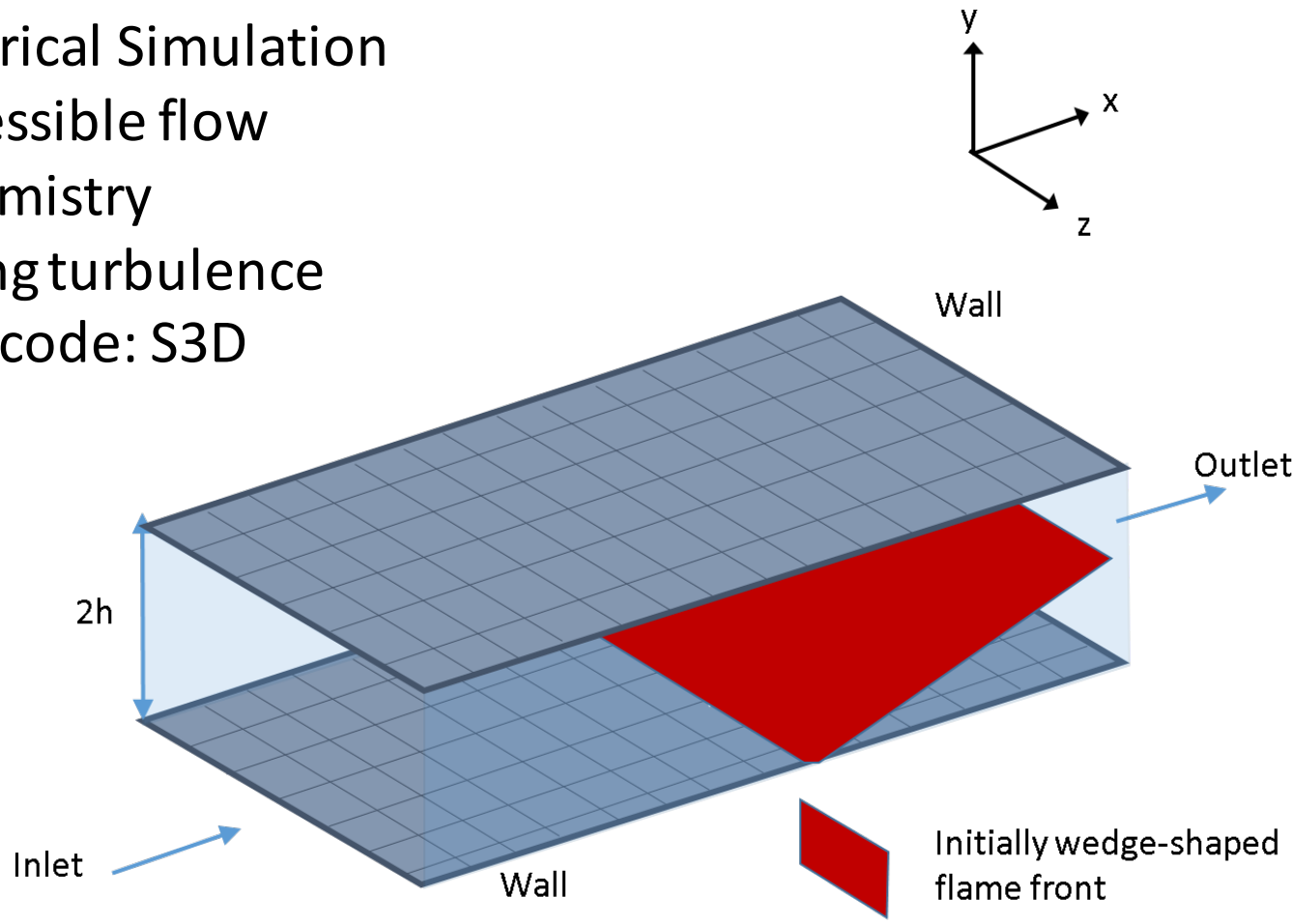
Methodology

- Reacting, turbulent channel flow
- Direct Numerical Simulation
- Fully compressible flow
- Detailed chemistry
- Time-evolving turbulence
- Combustion code: S3D

$Re_\tau = 180$

$h = 5.76\,mm$

$U_{bulk} = 43\,m/s$



Methodology

$$\frac{S_T}{S_L} = f\, I_0 \frac{A_T}{A_l}$$

S_T	Turbulent flame speed
S_L	Laminar flame speed
f	Flow factor
I_0	Intensification factor
A_T	Turbulent flame area
A_l	Laminar flame area

Methodology

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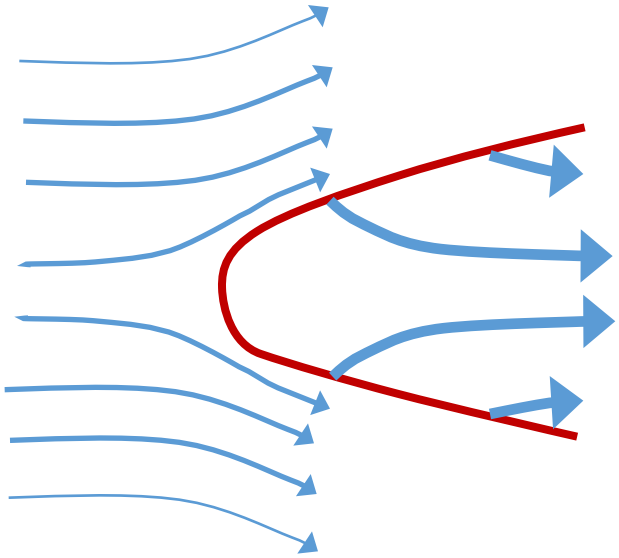
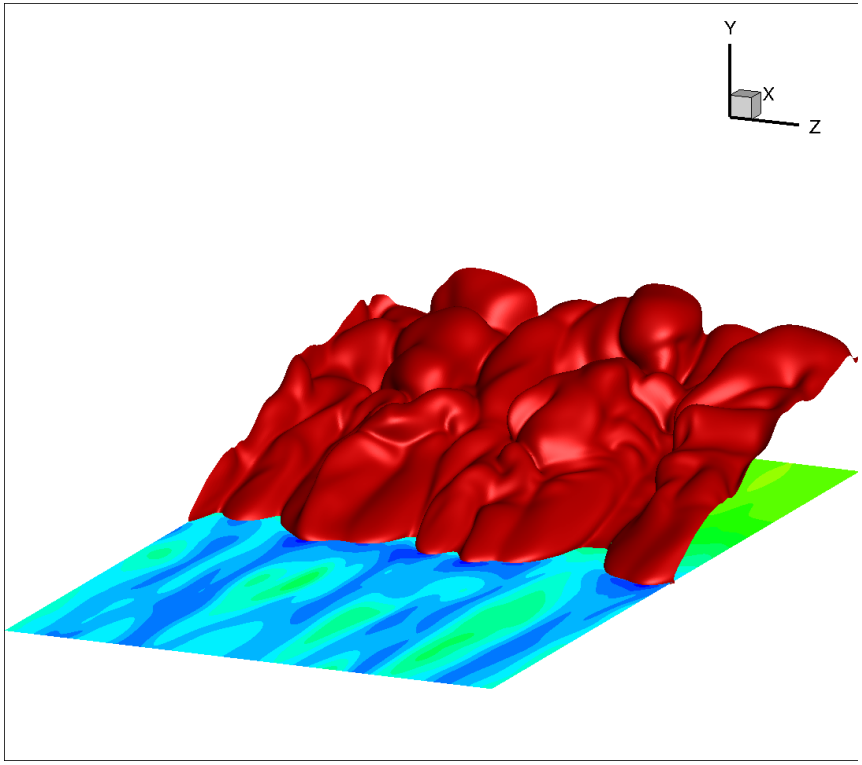


Edge flame

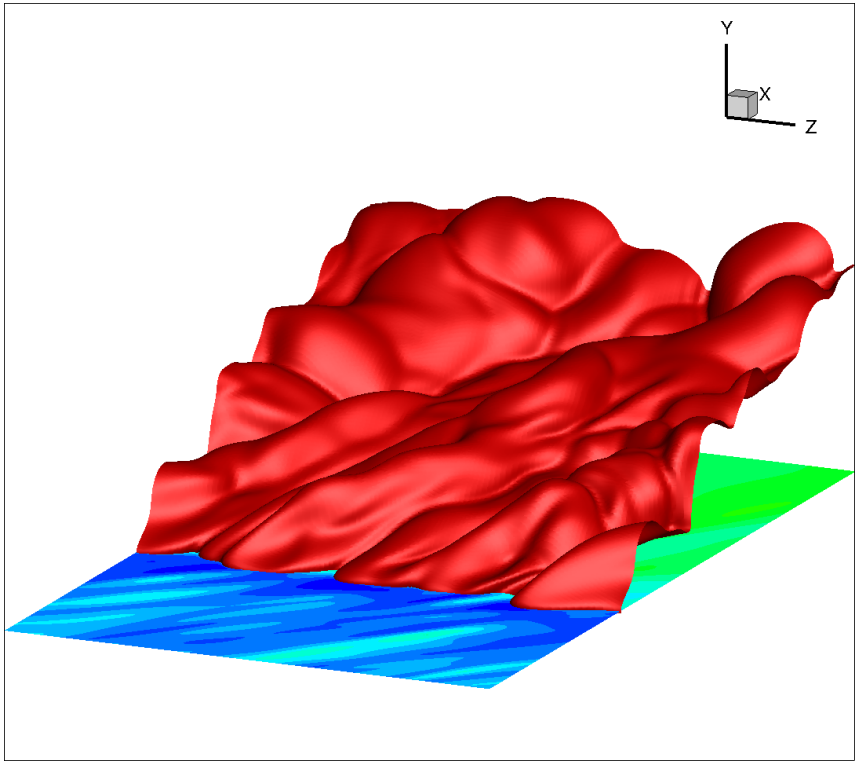
$$\frac{U_f}{S_L^0} \sim \left(\frac{\rho_u}{\rho_b}\right)^{1/2}$$

Results – Oblique Flow

Flame Shape

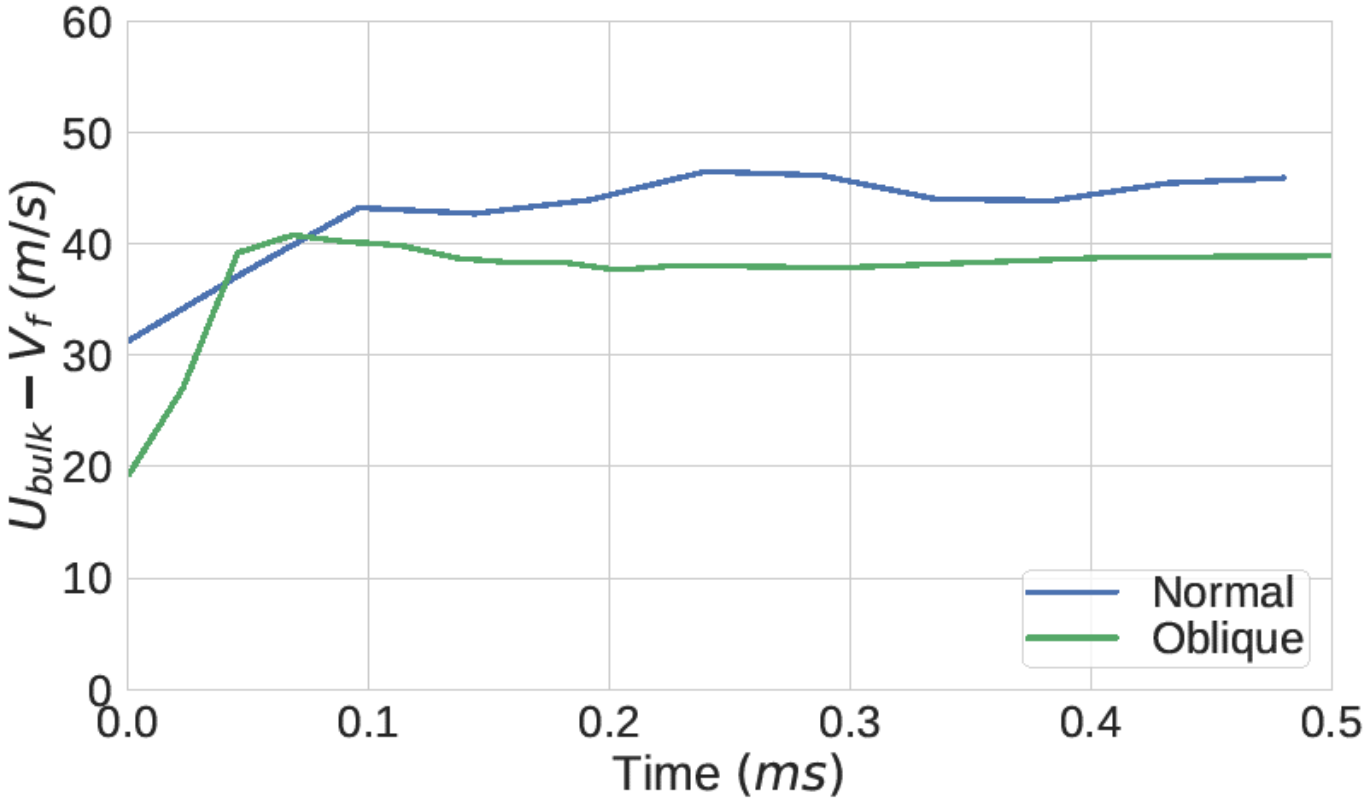


Normal Flow

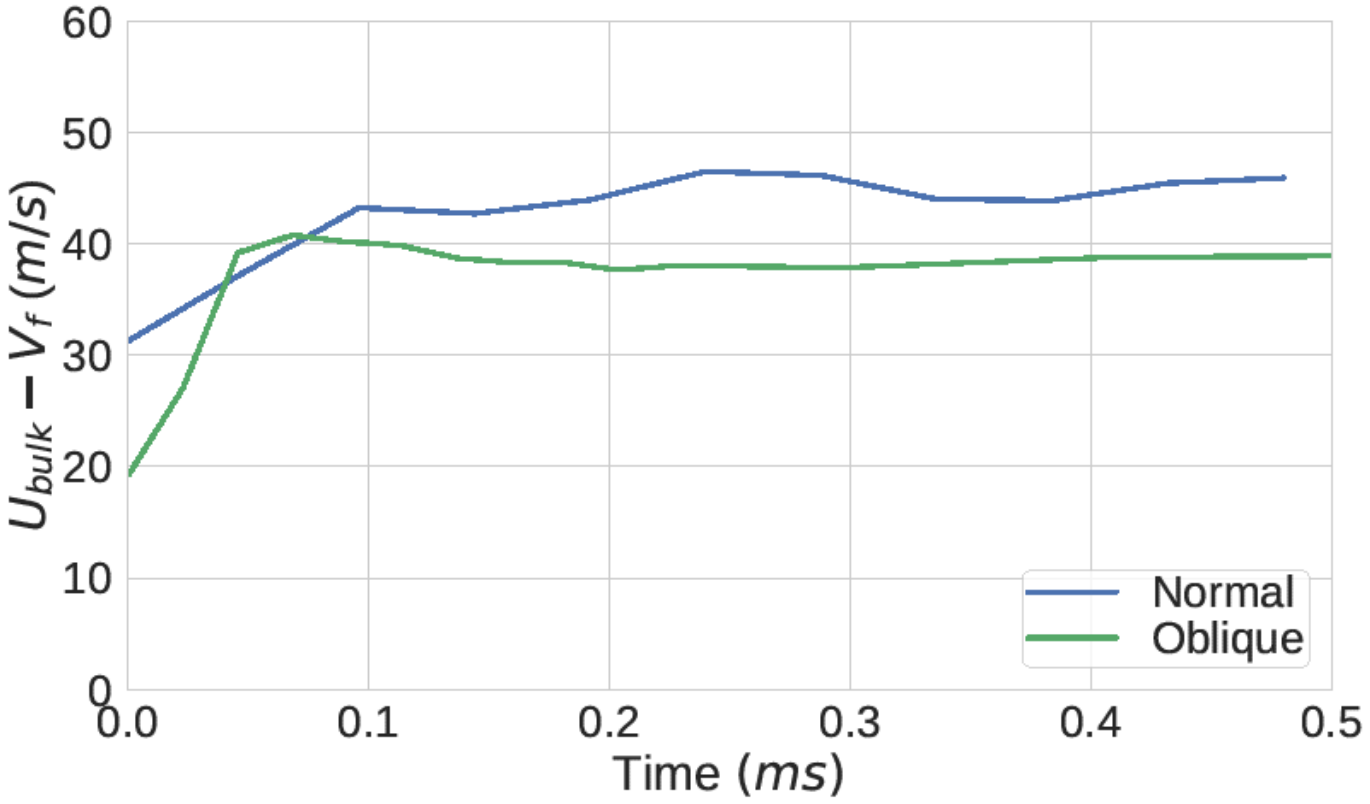


Oblique Flow

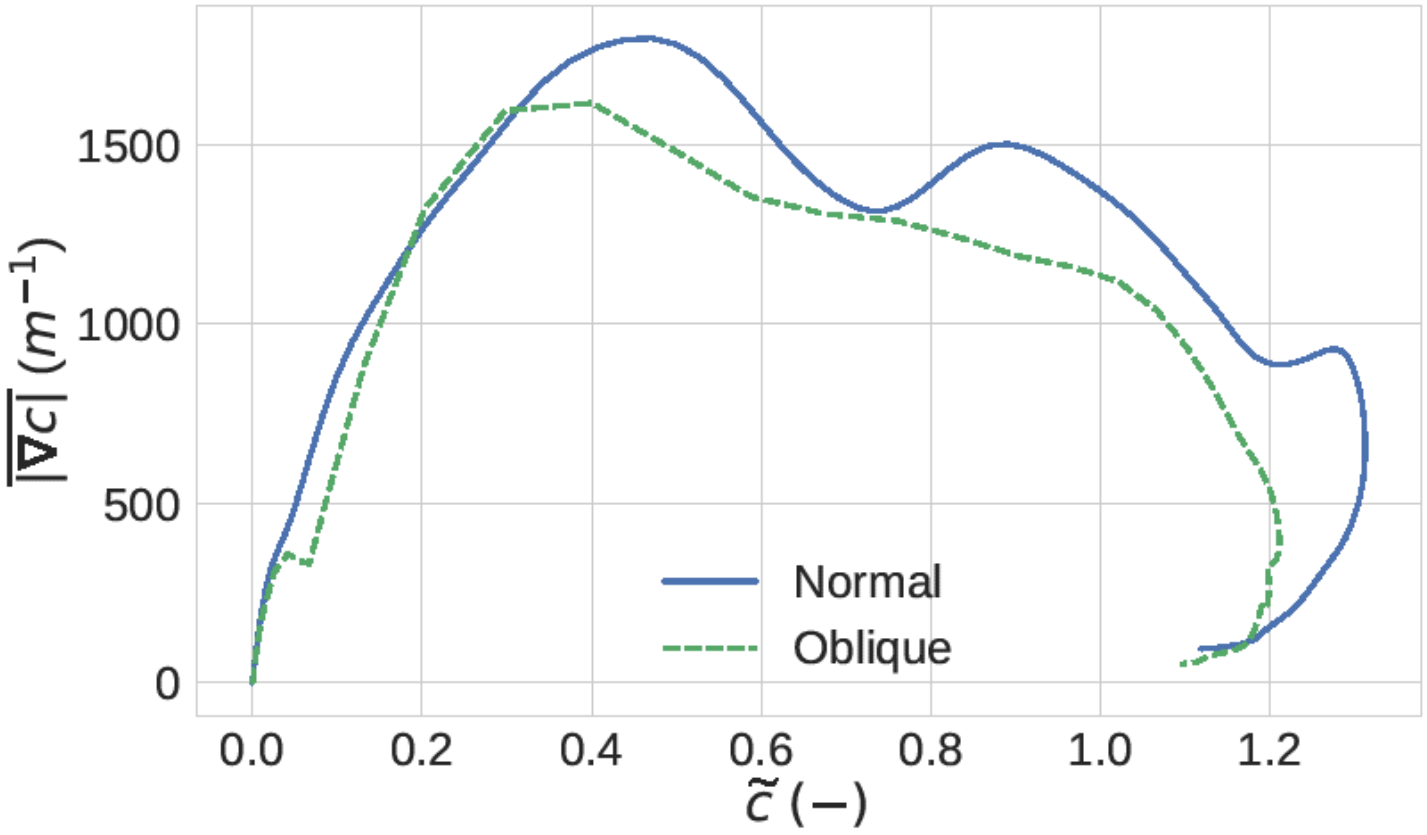
Flashback Speed



	f	I_0	A_T / A_L	S_T / S_L
Normal	-	-	-	-
Oblique				↓
Body force				



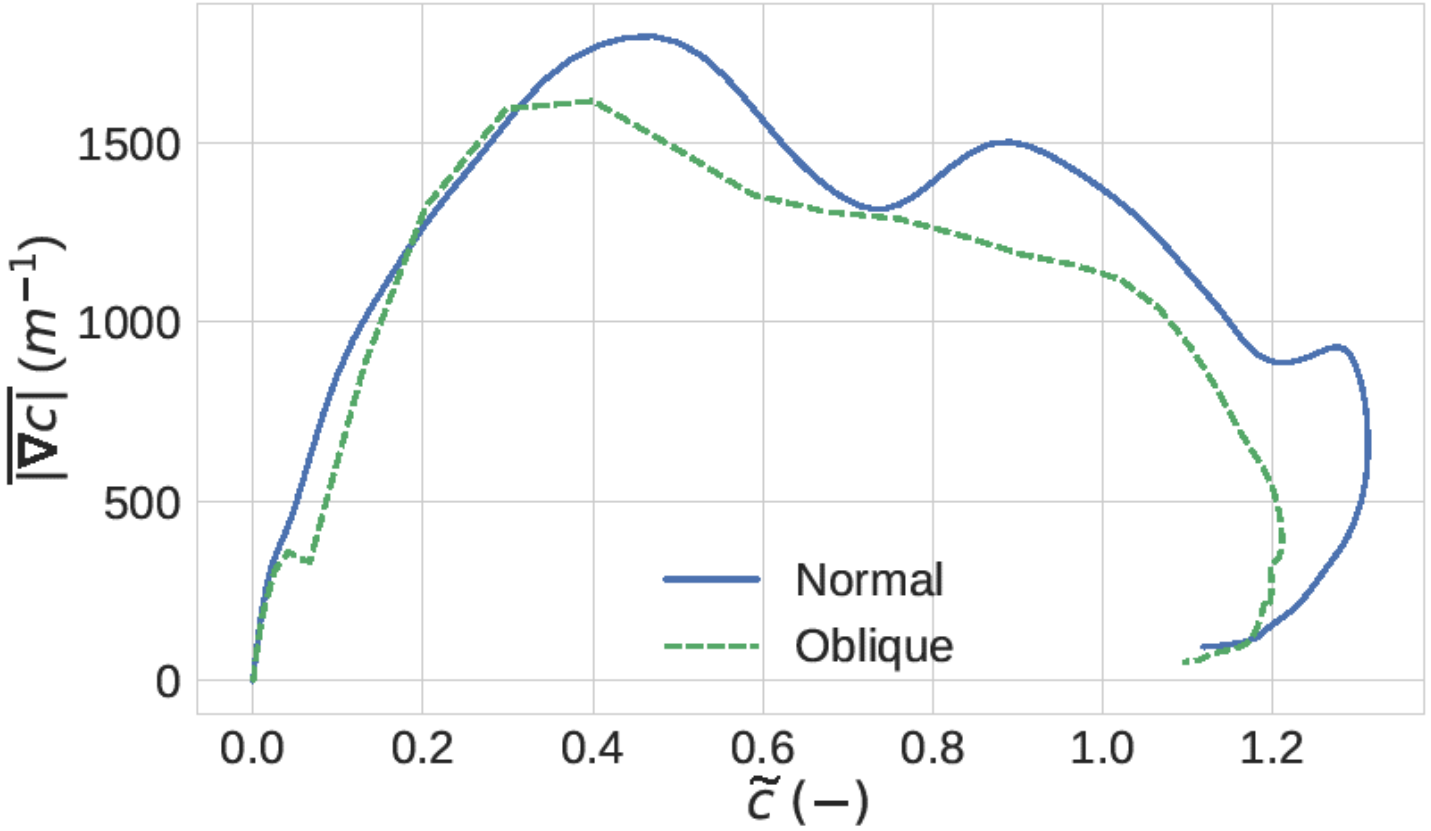
Flame Surface Density



$y^+ = 5$

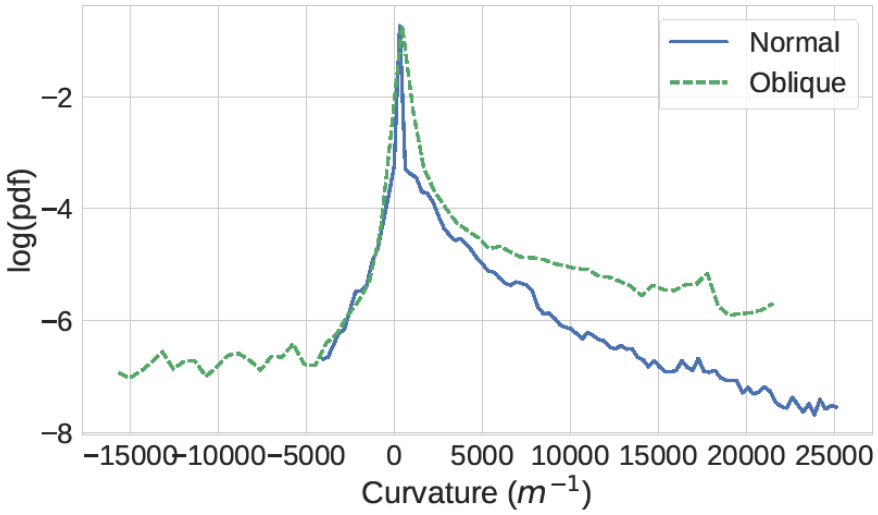
	f	I_0	A_T / A_L	S_T / S_L
Normal	-	-	-	-
Oblique			↓	↓
Body force				

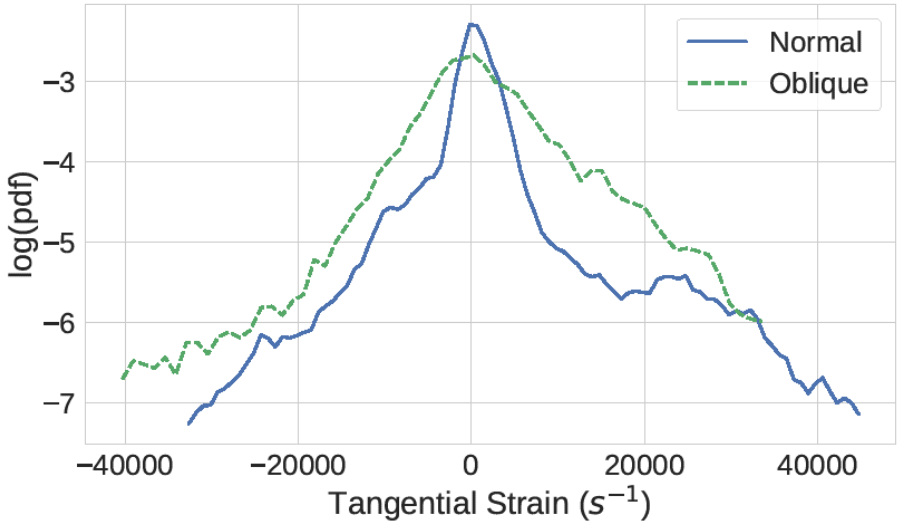
$y^+ = 5$



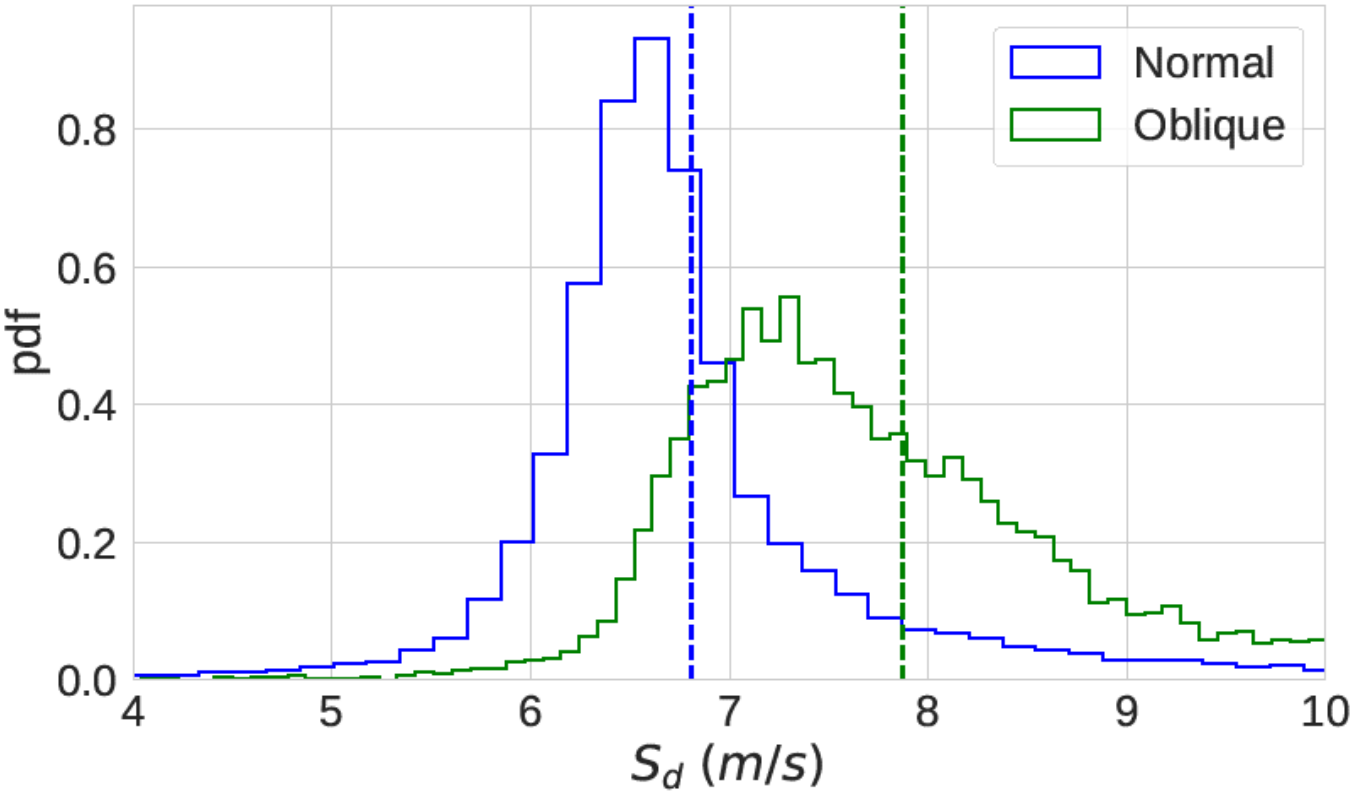
Stretch

$y^+ = 5$

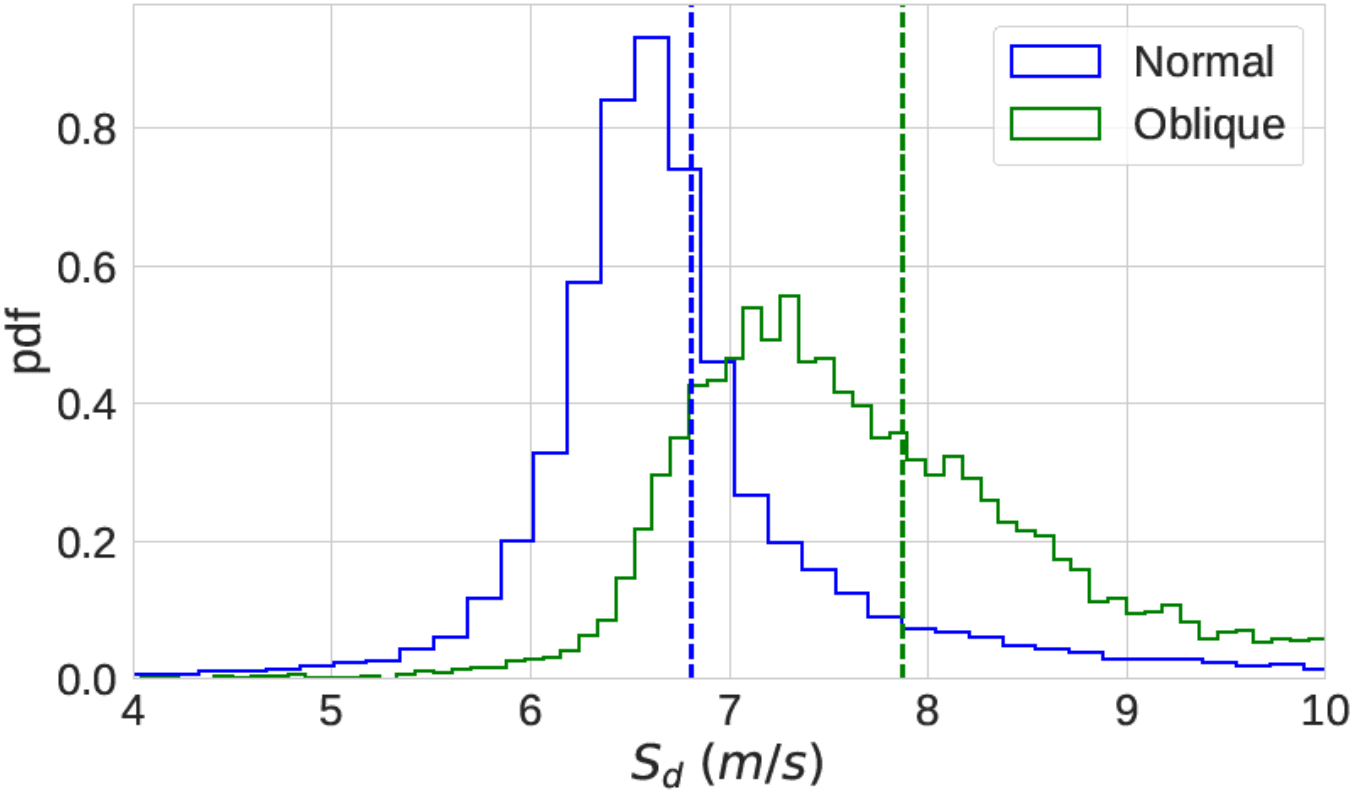

Normal
Oblique
log(pdf)
−2
−4
−6
−8
−15000 −10000 −5000 0 5000 10000 15000 20000 25000
Curvature (m^{-1})


Normal
Oblique
log(pdf)
−3
−4
−5
−6
−7
−40000 −20000 0 20000 40000
Tangential Strain (s^{-1})

Displacement Speed



	f	I_0	A_T / A_L	S_T / S_L
Normal	-	-	-	-
Oblique		↑	↓	↓
Body force				

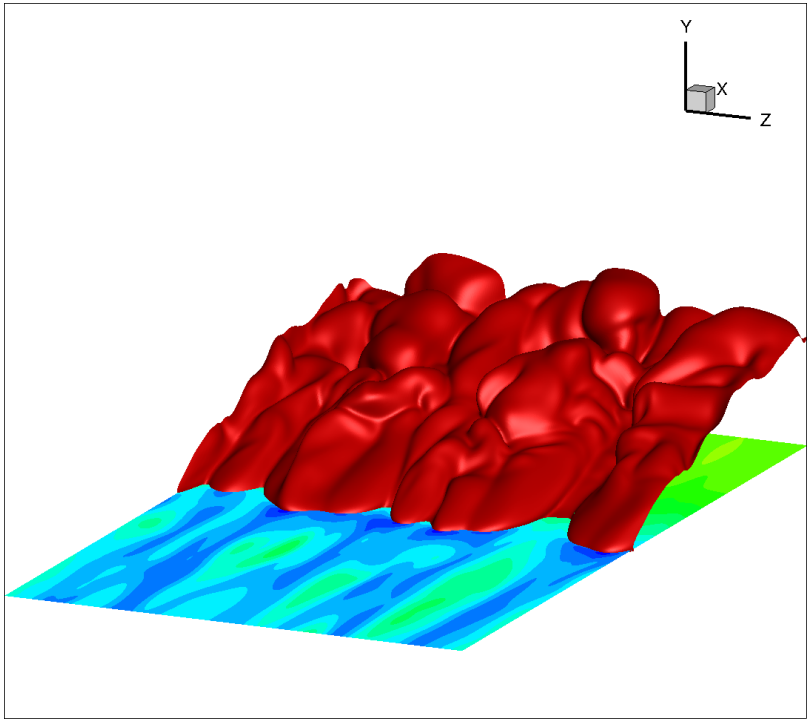


Flow factor

	f	I_0	A_T / A_L	S_T / S_L
Normal	-	-	-	-
Oblique	↓	↑	↓	↓
Body force				

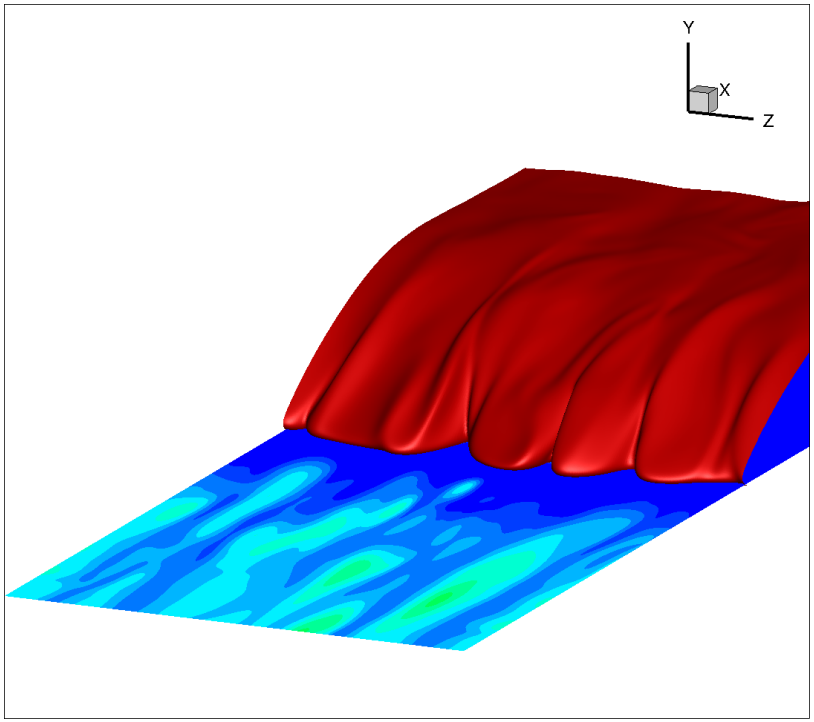
Results – Body Force

Flame Shape



No body force

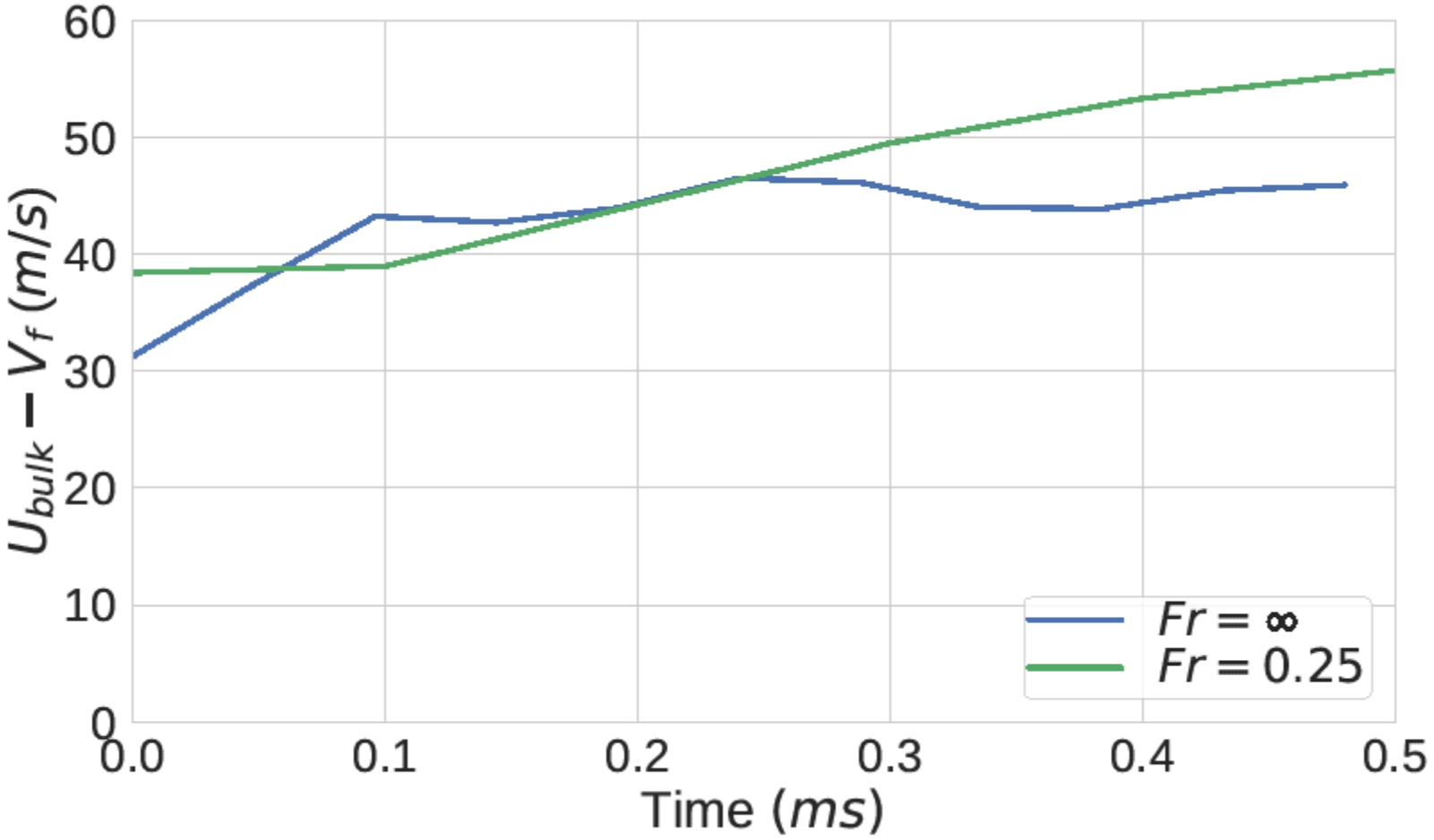
$Fr = \infty$



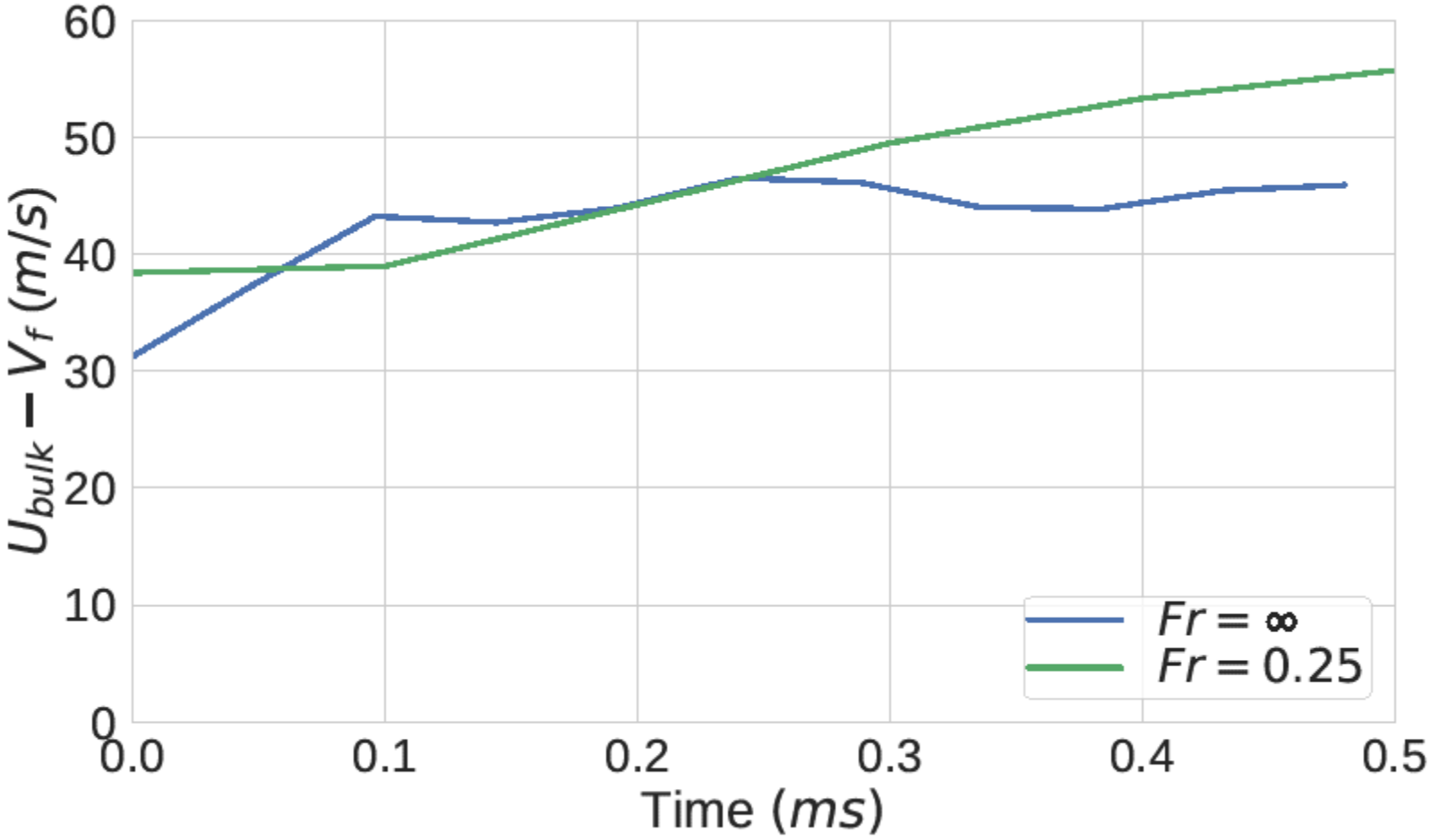
Body force

$Fr = 0.25$

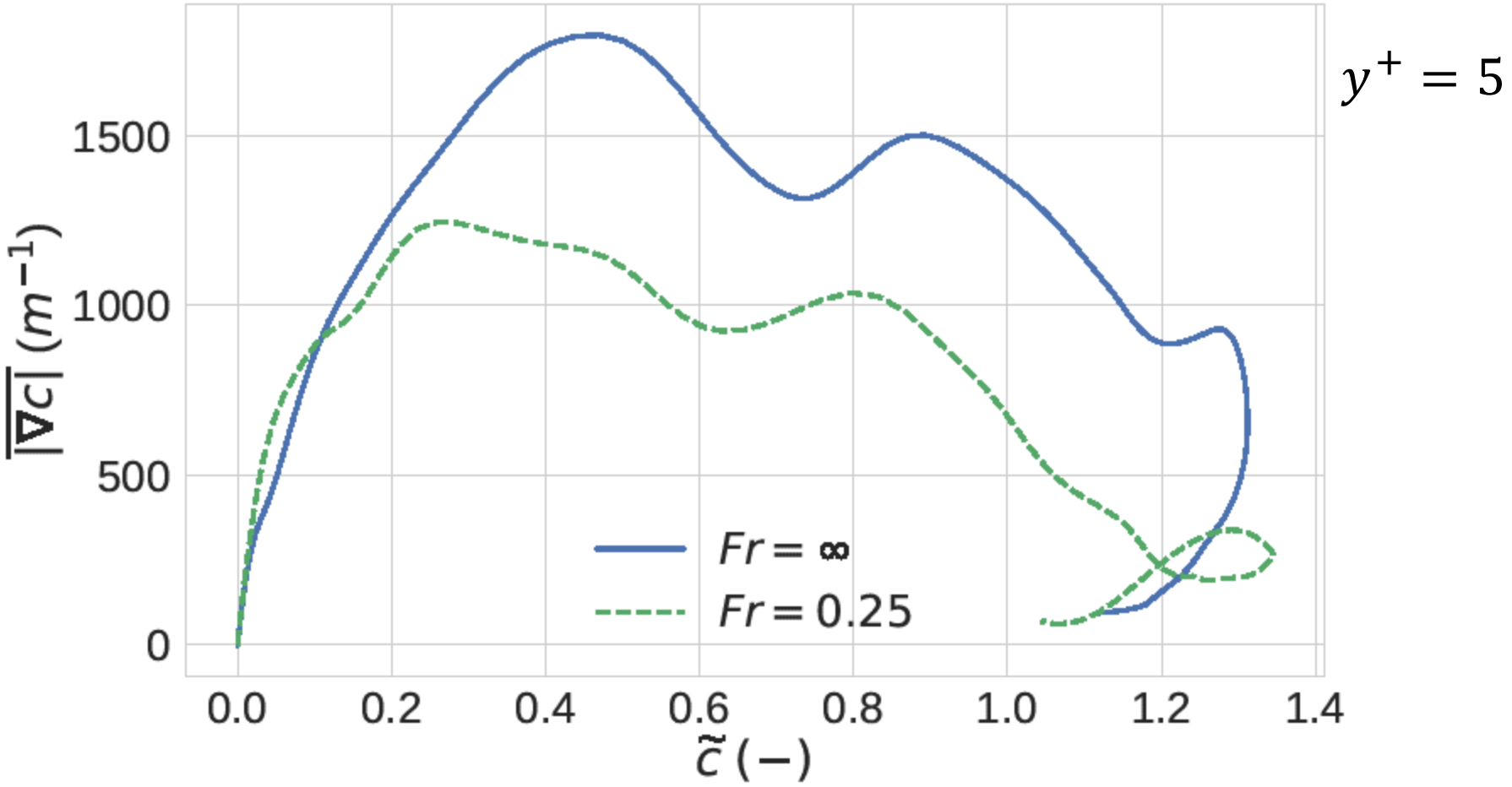
Flashback Speed



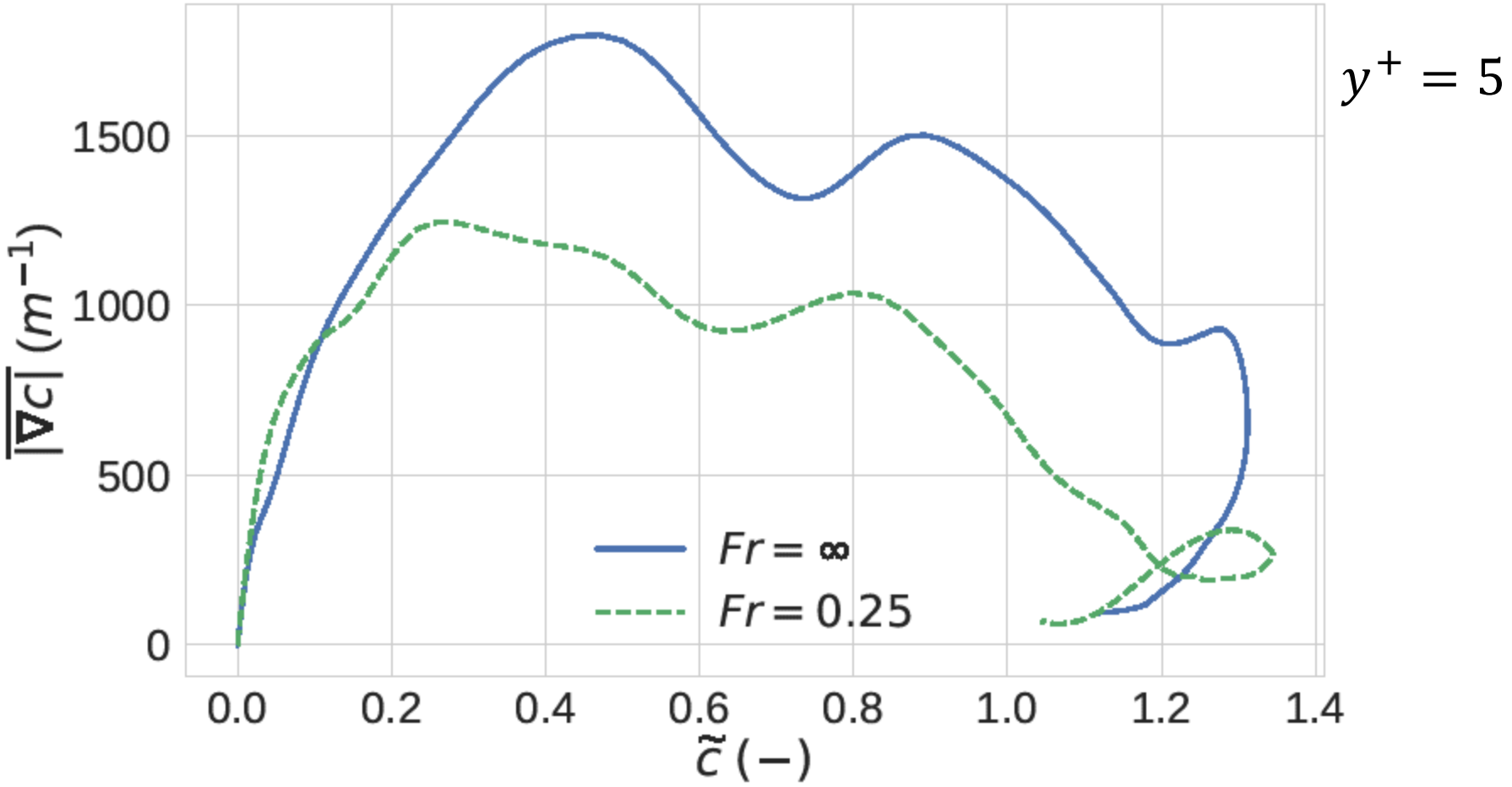
	f	I_0	A_T / A_L	S_T / S_L
Normal	-	-	-	-
Oblique	↓	↑	↓	↓
Body force				↑



Flame Surface Density

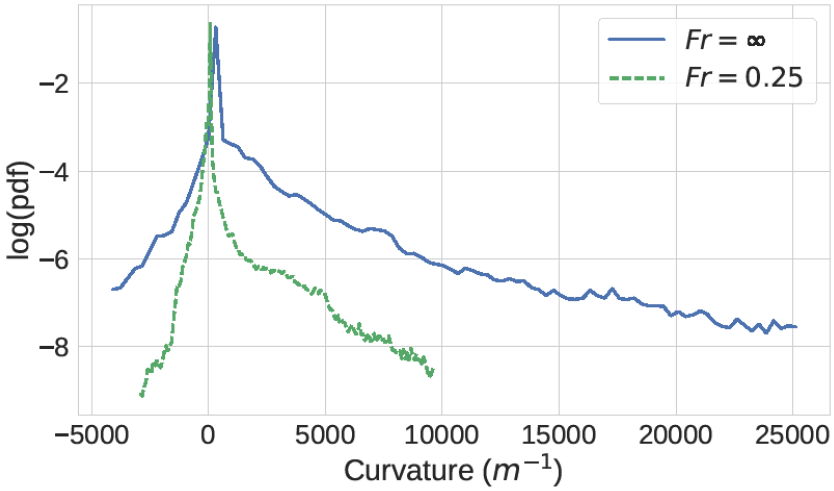


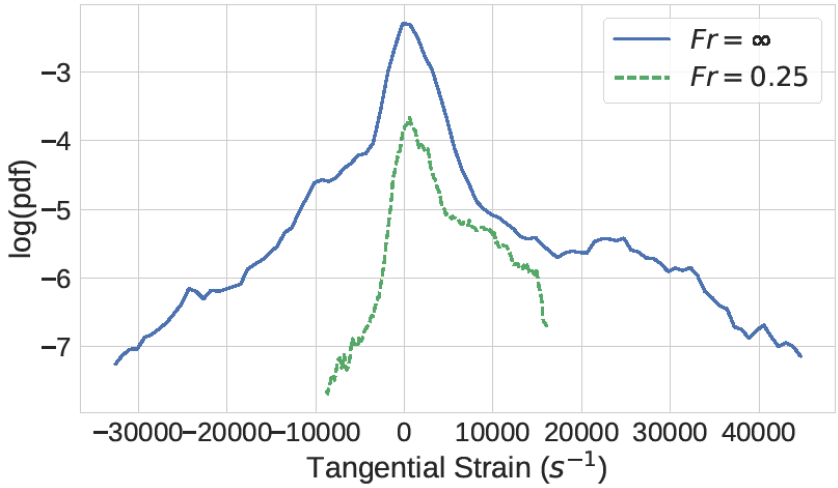
	f	I_0	A_T / A_L	S_T / S_L
Normal	-	-	-	-
Oblique	↓	↑	↓	↓
Body force			↓	↑



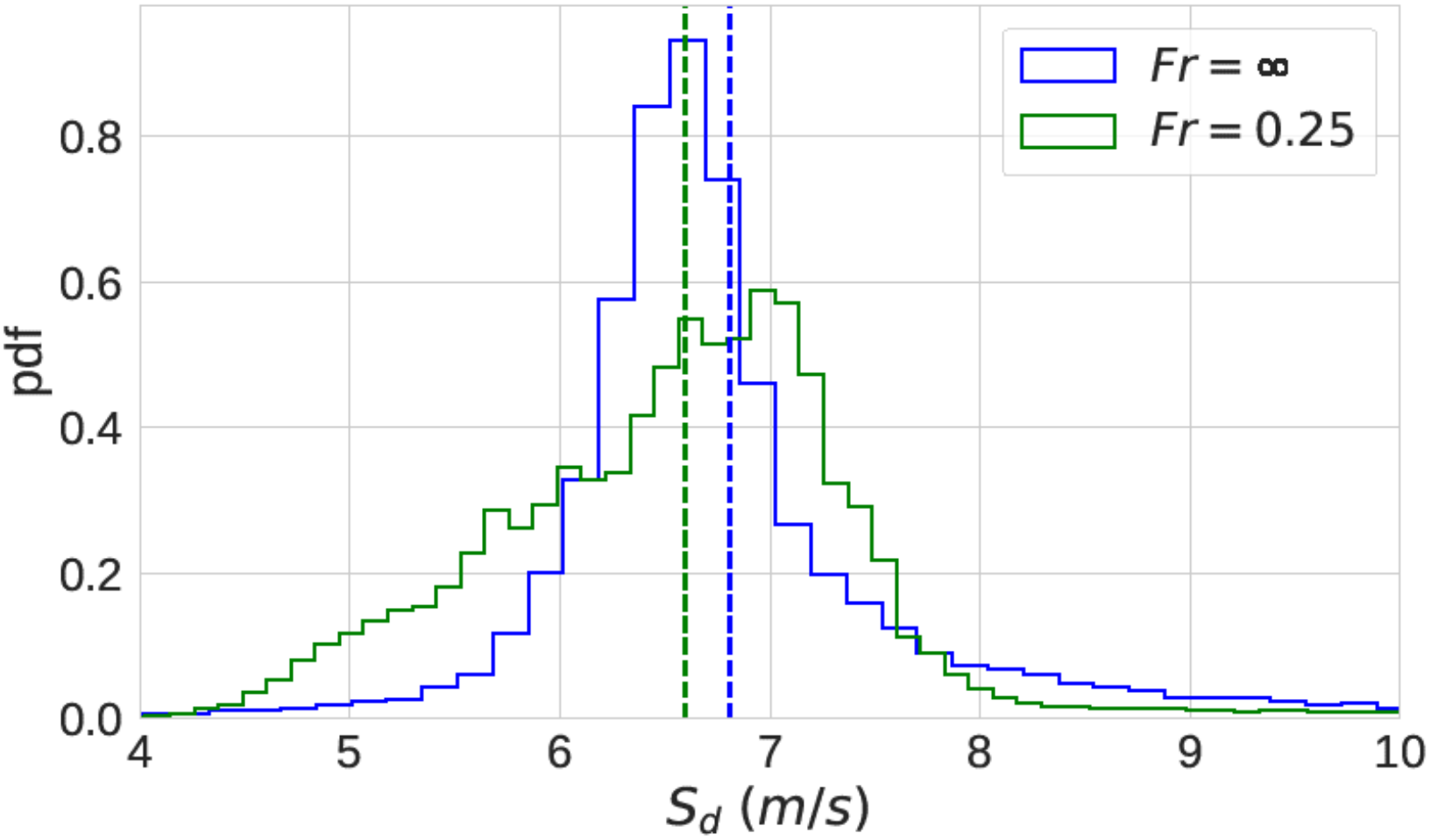
Stretch

$y^+ = 5$

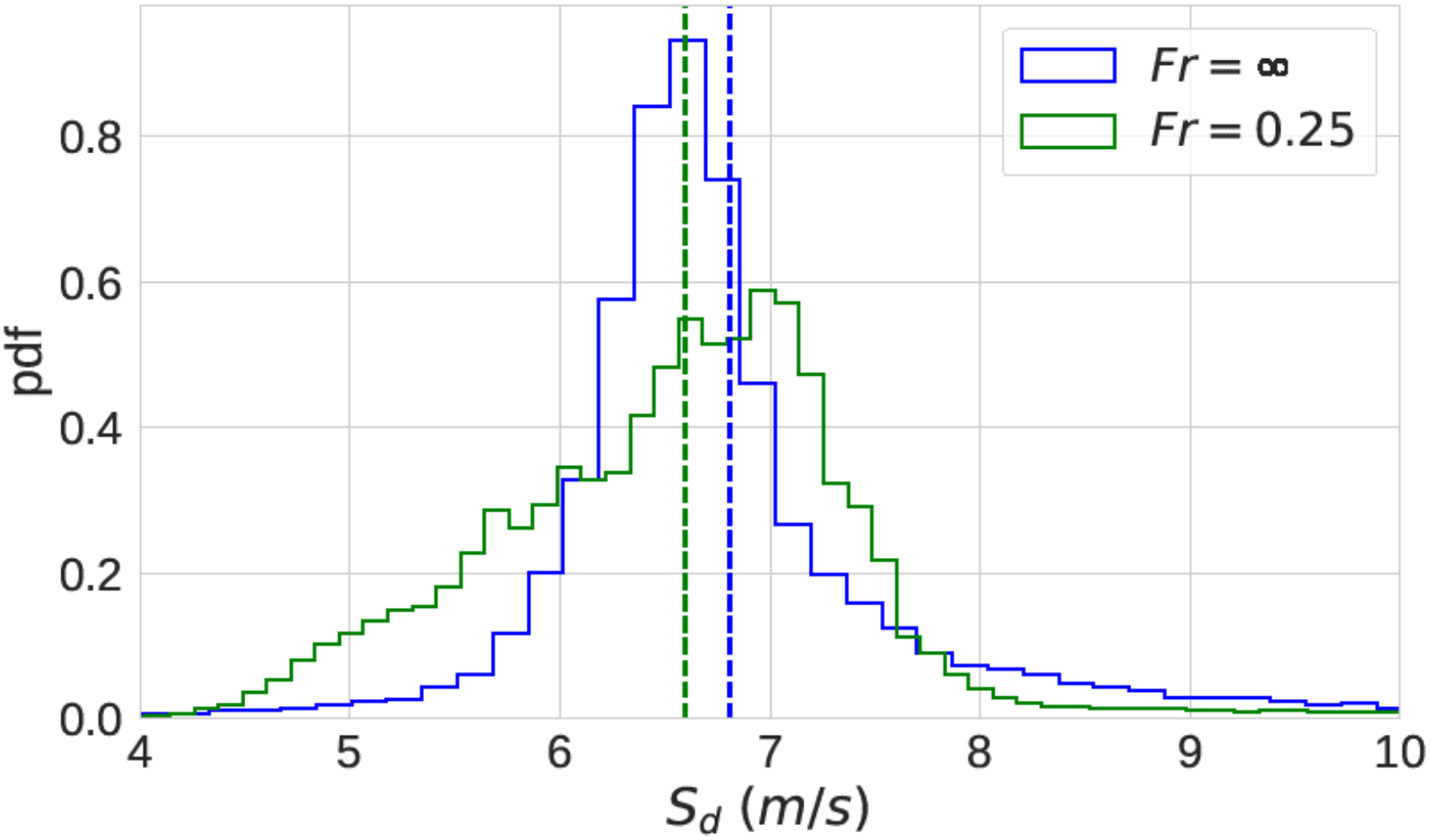

$Fr = \infty$
$Fr = 0.25$
log(pdf)
−2
−4
−6
−8
−5000
0
5000
10000
15000
20000
25000
Curvature (m^{-1})


$Fr = \infty$
$Fr = 0.25$
log(pdf)
−3
−4
−5
−6
−7
−30000
−20000
−10000
0
10000
20000
30000
40000
Tangential Strain (s^{-1})

Displacement Speed



	f	I_0	A_T / A_L	S_T / S_L
Normal	-	-	-	-
Oblique	↓	↑	↓	↓
Body force		↔	↓	↑



Flow Factor

	f	I_0	A_T / A_L	S_T / S_L
Normal	-	-	-	-
Oblique	↓	↑	↓	↓
Body force	↑	↔	↓	↑

Buoyancy

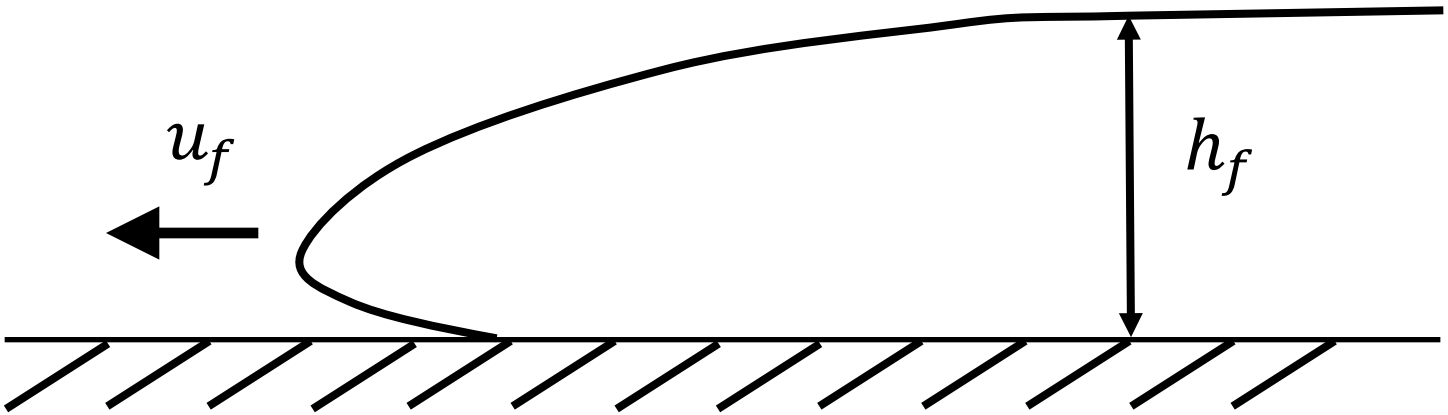
$$u_f = 0.7\sqrt{g\,\frac{(\rho_u - \rho_b)}{\rho_a}\,h_f}$$

$$g = \rho\frac{V_\theta^2}{r}$$

ρ_a Average density

$$U_{bulk} - u_f \approx 42\ m/s$$

$$U_{bulk} - V_f \approx 55\ m/s$$



Conclusions

Conclusions

- Darrieus-Landau hydrodynamic instability dominates effects of streaks
- Flow diversion and buoyancy have significant effects on flame propagation

Future Work

- Simulation of annulus using axi-symmetric co-ordinates

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archer

Thank you

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12/09/2019

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