FACULTY OF ENGINEERING
AND ARCHITECTURE

DEPARTMENT FLOW, HEAT & COMBUSTION MECHANICS
COMBUSTION, FIRE AND FIRE SAFETY

CASE 2: TURBULENT POOL FIRES WITH GASEOUS FUEL

Dr. John Hewson (Sandia National Laboratories, USA)
Prof. Bart Merci (Ghent University, Belgium)

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NNSA National Nuclear Security Administration
U.S. DEPARTMENT OF ENERGY

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COURTESY

- Dr. Georgios Maragkos (Ghent University).
- Dr. Randall McDermott (NIST).

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OVERVIEW

- Experimental set-up:
  - 'Sandia_Flames'
  - 'McCaffrey_Flames'
- Simulation results
- Concluding comments
- Open discussion

EXPERIMENTAL SET-UP

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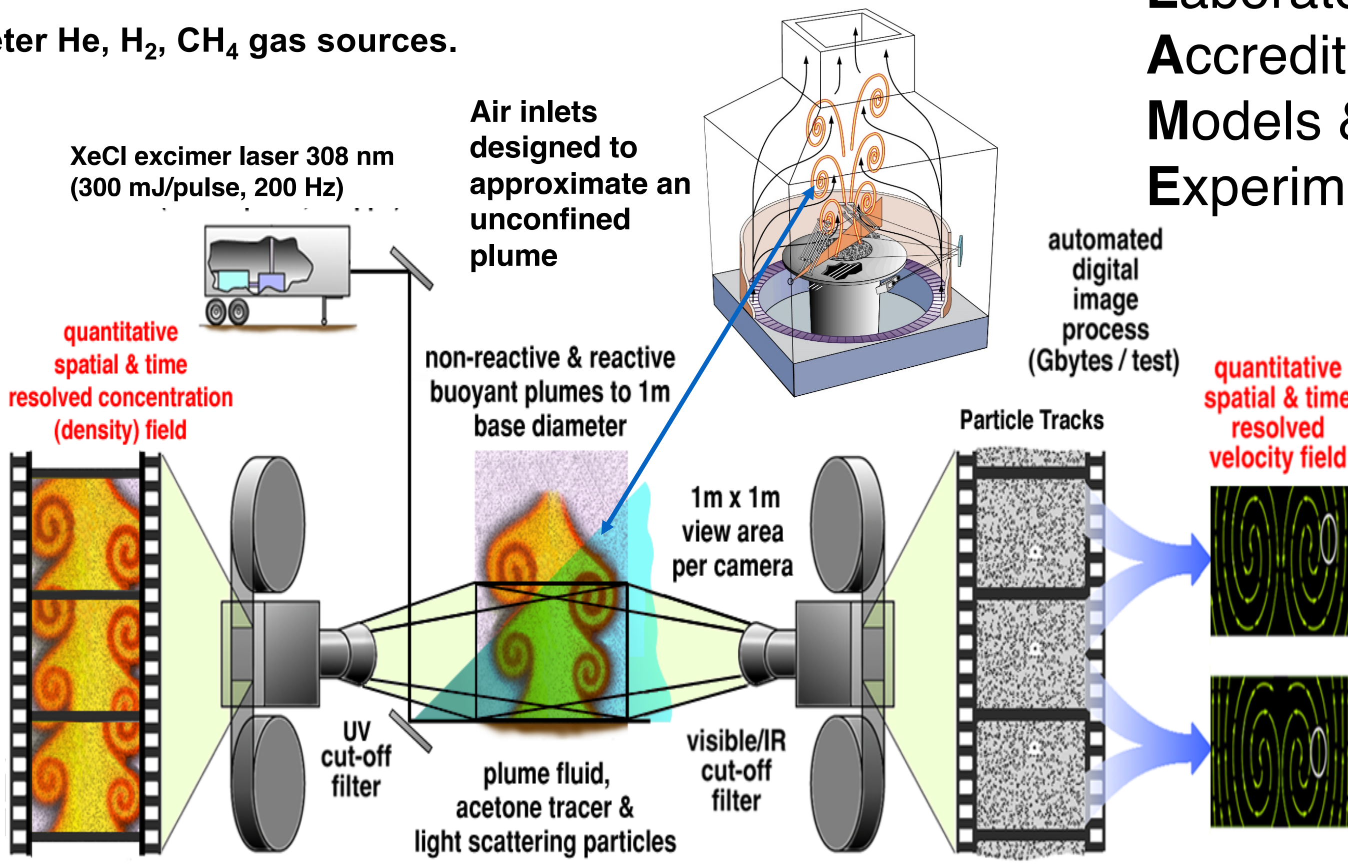
SANDIA_FLAMES

2-D FLOWFIELD DIAGNOSTICS FOR VELOCITY STATISTICS

Fire
Laboratory for
Accreditation of
Models &
Experiments

1 meter He, H_2, CH_4 gas sources.



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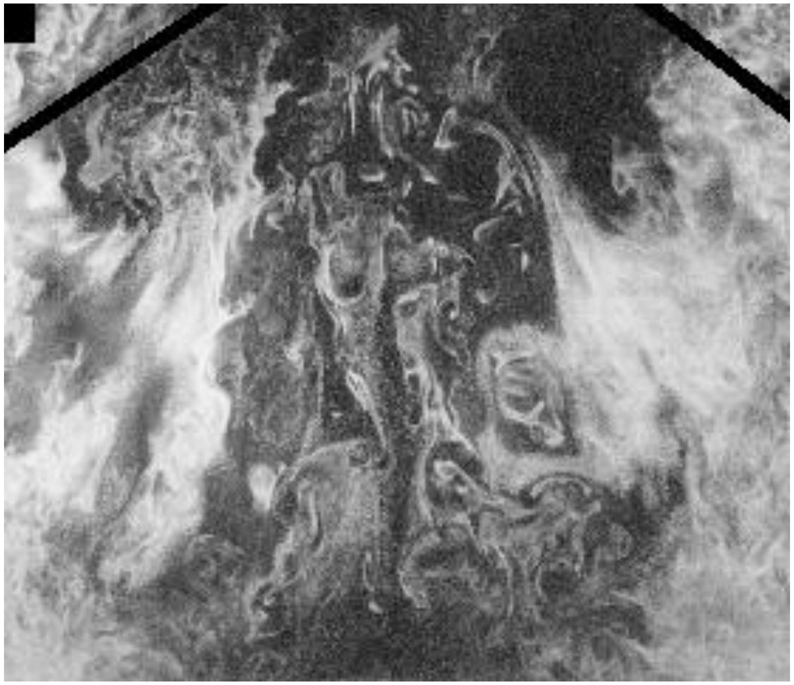
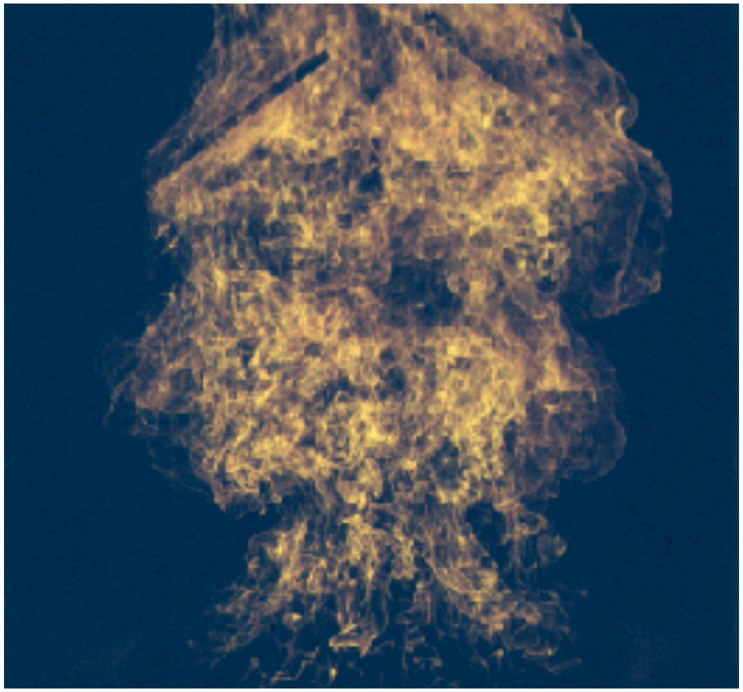
METHANE RESULTS



Raw PIV – 200 fps



Visible Image – 200 fps

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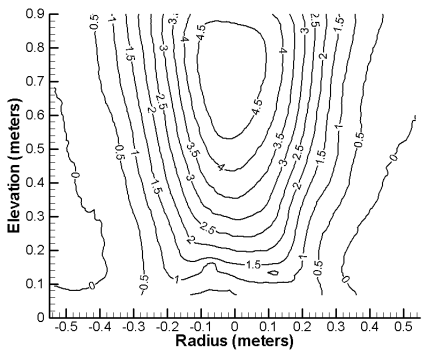
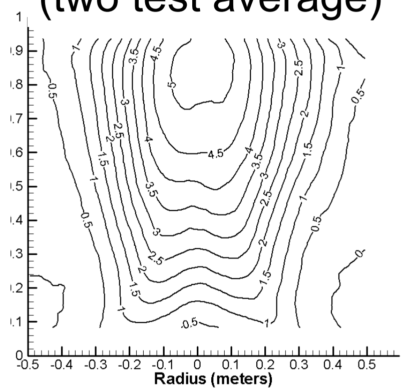
CH_4 PIV DATA

Parametric study - Four tests covering mass application mass flux rate range

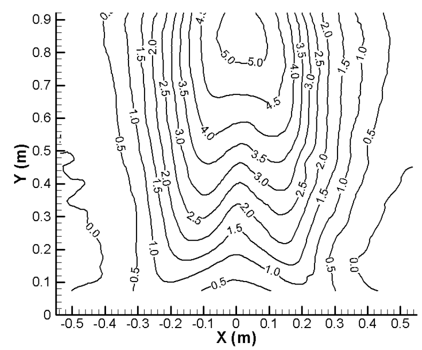
(two test average)



0.040 kg/m^{2}s



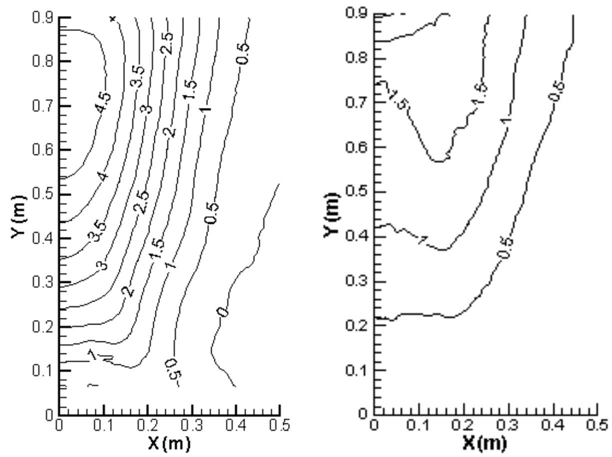
0.054 kg/m^{2}s



0.066 kg/m^{2}s

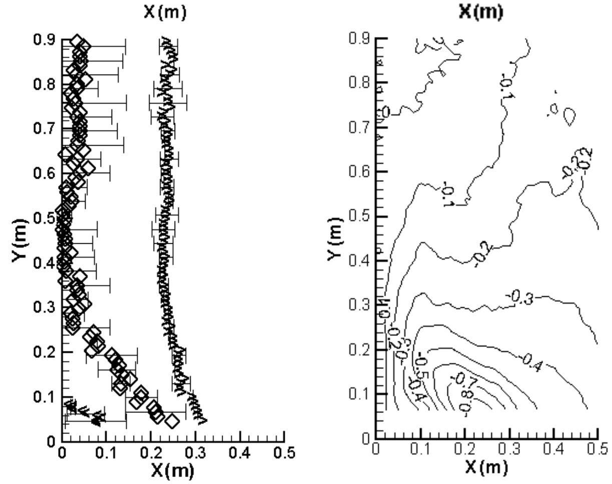
Data Set for CH_4 at 0.040 kg/m^{2}s

Vertical Velocity (m/s)



Turbulent Kinetic Energy (m^2/s^2)

Radial Position of Maximum Reaction Rate (m)



Horizontal Velocity (m/s)

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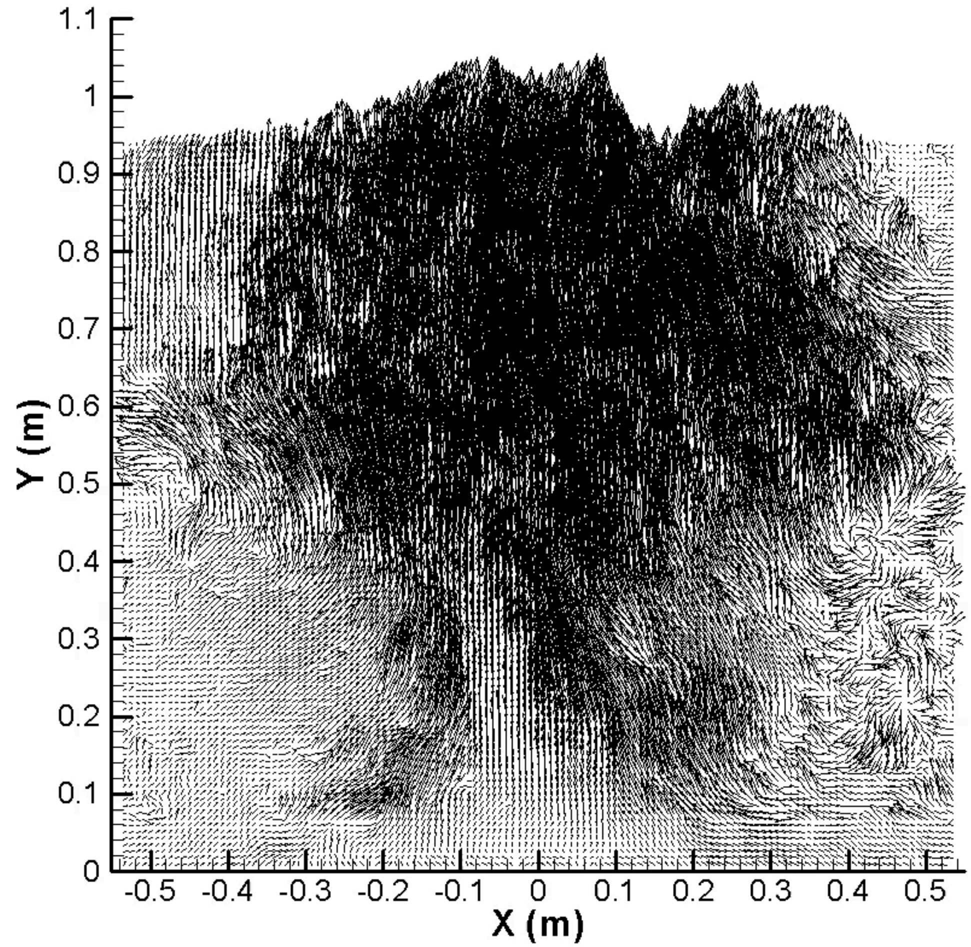
METHANE RESULTS



Vectors from PIV

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MCCAFFREY_FLAMES

- ✧ Fuel: Methane
- ✧ Burner: 0.3 m x 0.3 m
- ✧ Burner position: 0.75 m above the floor / flush to the floor
- ✧ Measurements: T & U (centerline/radial)
  - ✧Uncertainties in thermocouple, differential pressure gauges

Q (kW)	14.4	21.7	33.0	44.9	57.5
Q*	0.19	0.29	0.44	0.60	0.77

$$\dot{Q}^* = \frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g} D^{5/2}}$$

*B.J. McCaffrey, Purely Buoyant Diffusion Flames: Some Experimental Results, Report No. NBSIR 79-1910, NIST, 1979.

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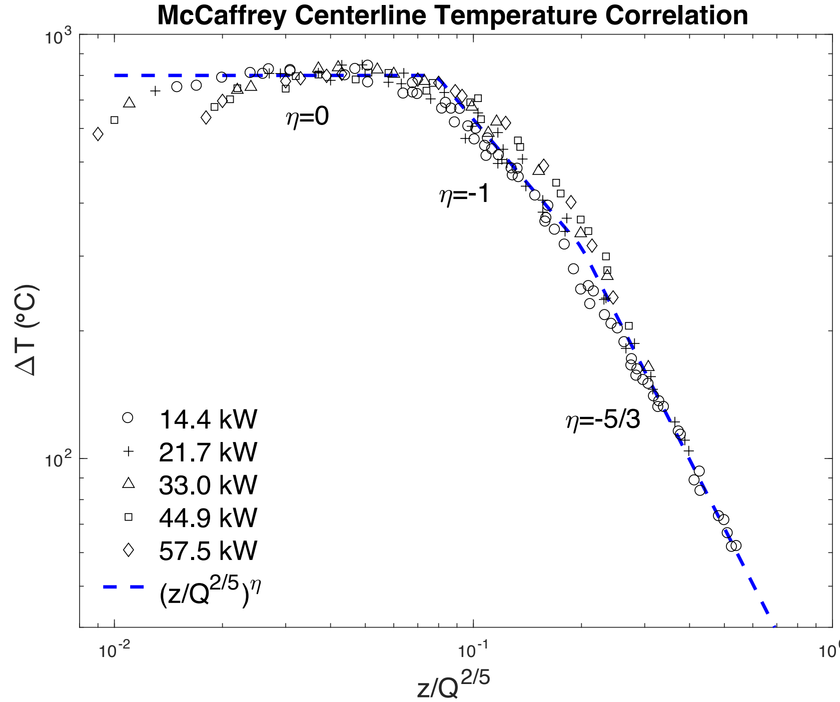

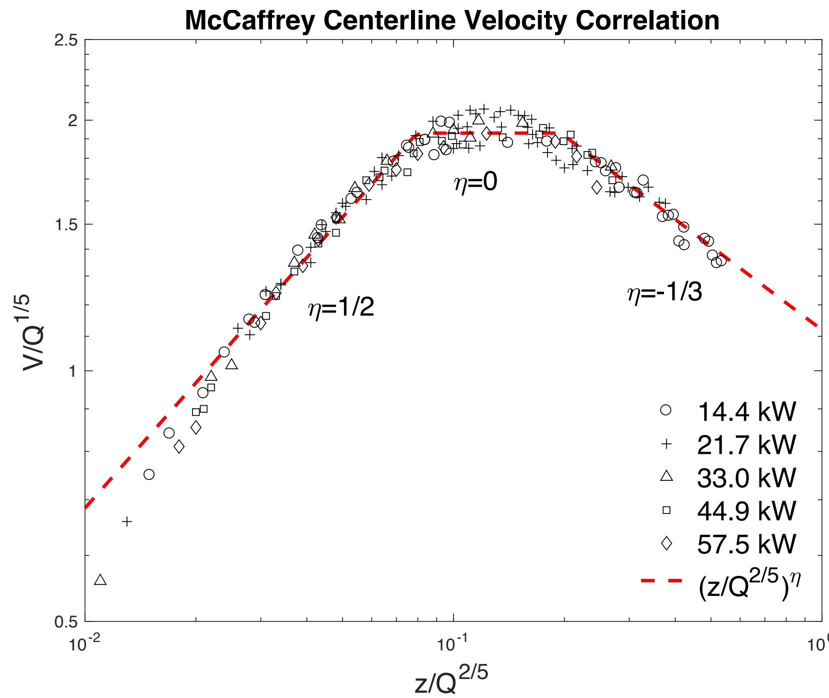

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$$\dot{Q}^* = \frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g} D^{5/2}}$$

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SIMULATION RESULTS

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CONTRIBUTING TEAMS

- FM Global (McCaffrey only): FM
- Ghent University: UGent
- NIST: NIST
- Sandia (Sandia only): Sandia
- Universidad de Cantabria (Sandia only): UCantabria

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SANDIA_FLAMES

Institute	FM	UGent	NIST	Sandia	UCantabria
Code	-	FireFOAM 2.2.x	FDS6.5.3	Fuego 4.44	FDS6.5.3
Turbulence model	-	Const. Smag. (cs=0.1, Prt=0.7)	Mod. Deardorff (C_DEARDORFF=0.1, SC_T=0.5, PR_T=0.5)	Ksgs, Const Smag. (C=0.1, Pr=0.9)	Vreman (C_Vreman = 0.07, SC_T=0.5, PR_T=0.5)
Combustion model	-	EDM (cEDM=4, cdiff=2)	EDC (C_U=0.4)	Flamelet library	EDC (C_U=0.4)
Radiation model	-	Grey gas 48 solid angles, Predicted CHI_R = 0.248	Grey gas 104 solid angles, CHI_R=0.2	none	Grey gas 100 solid angles, CHI_R=0.2
Soot model	-	-	Y_SOOT=0.01	none	Y_SOOT=0
Mesh (minimum cell size)	-	1.5 cm	1.5 cm	1.0, 2.5, 4.0 cm	5 cm (extraction hood incl.)

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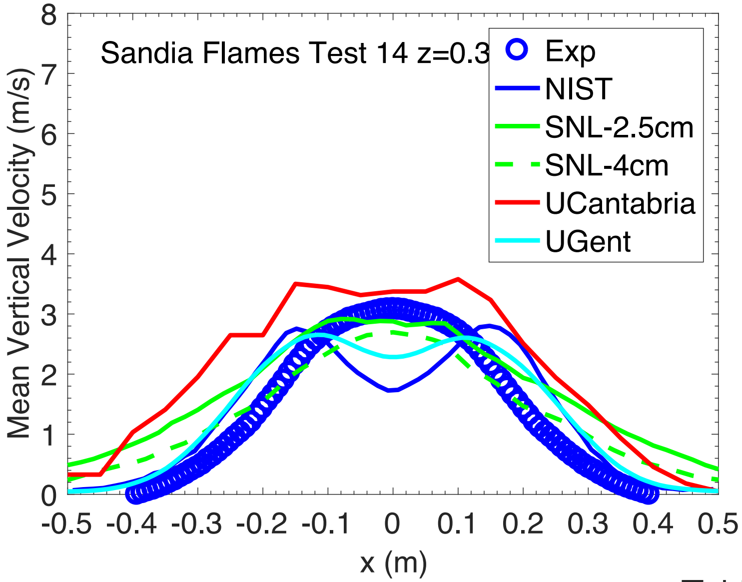
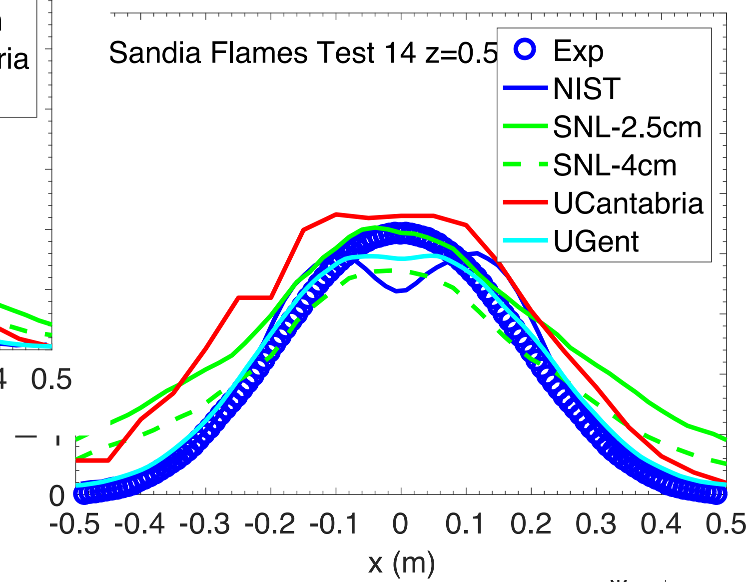
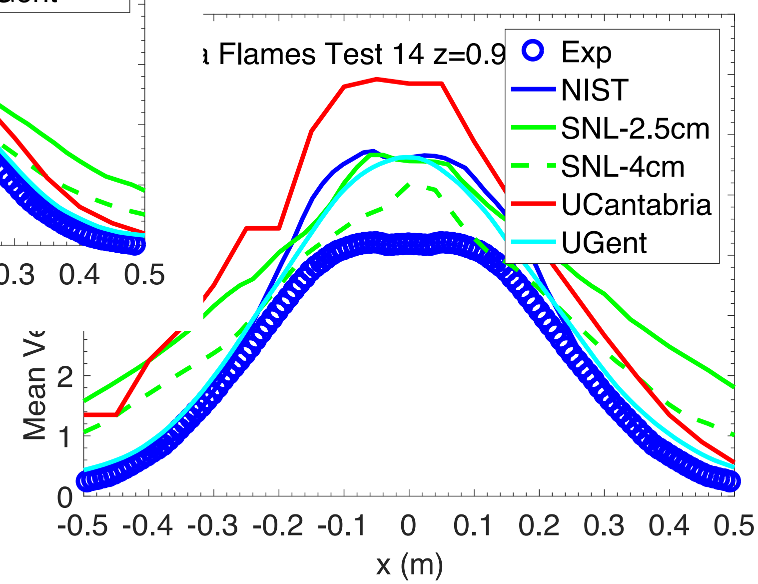
SANDIA_FLAMES

– Test 14, all positions, W







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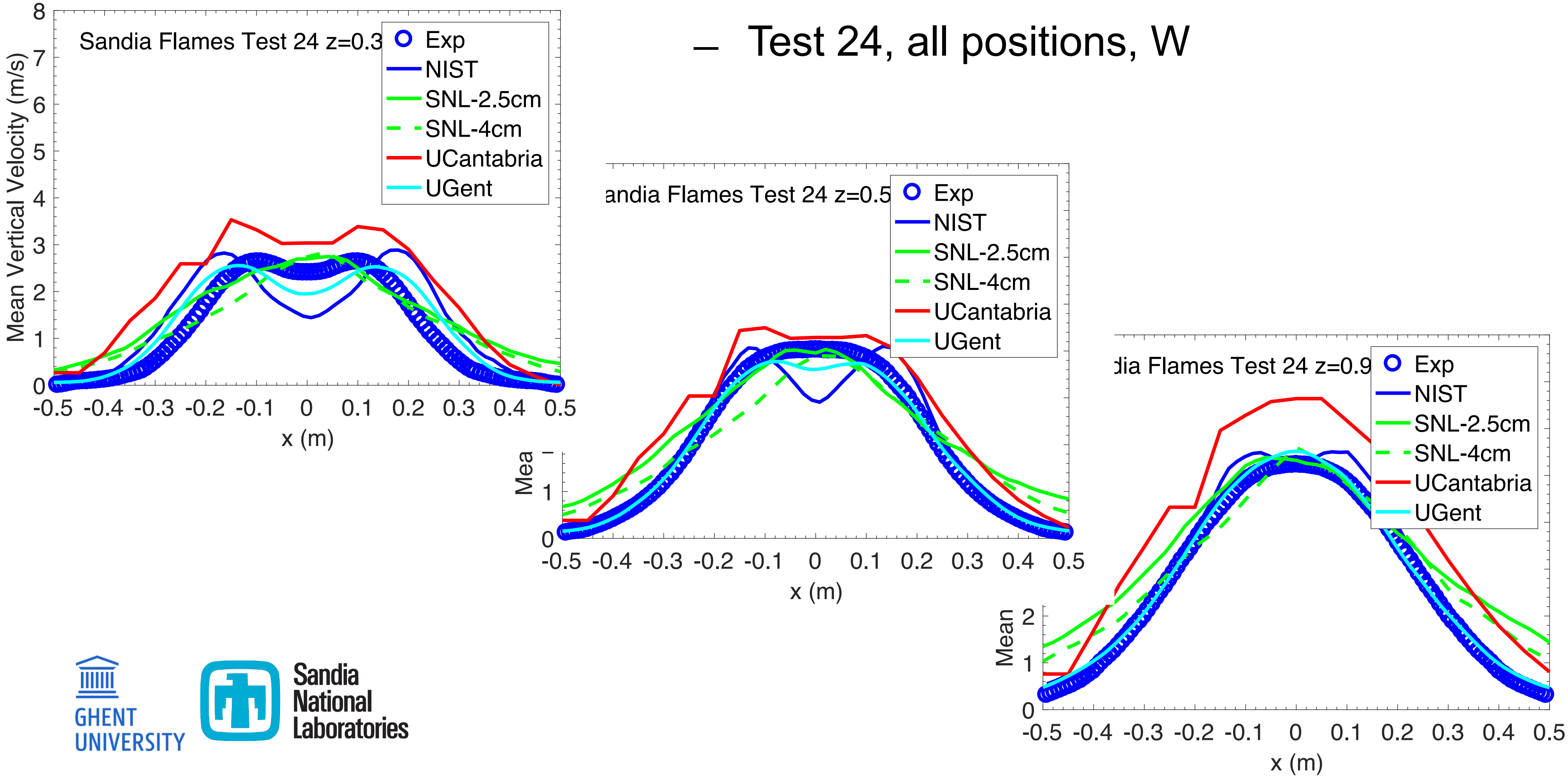
– Test 24, all positions, W



SANDIA_FLAMES

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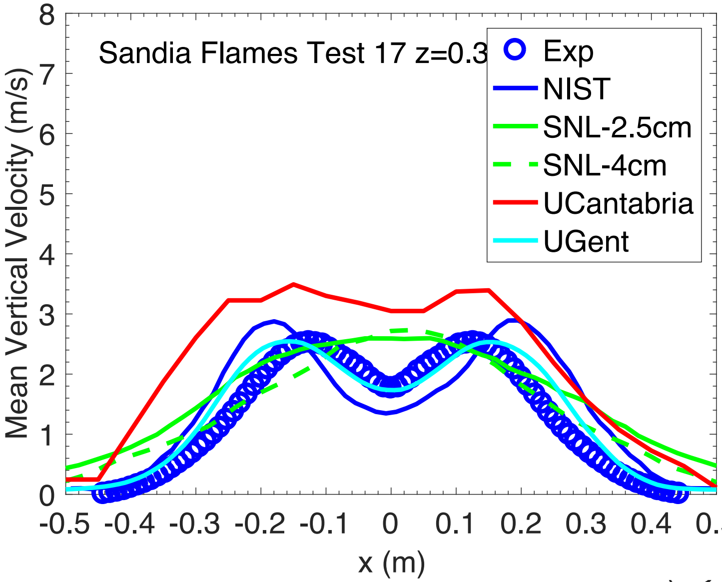

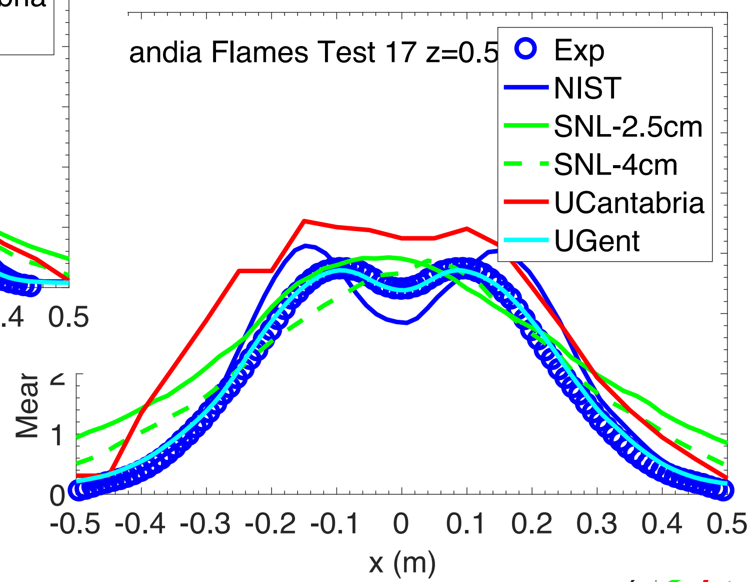

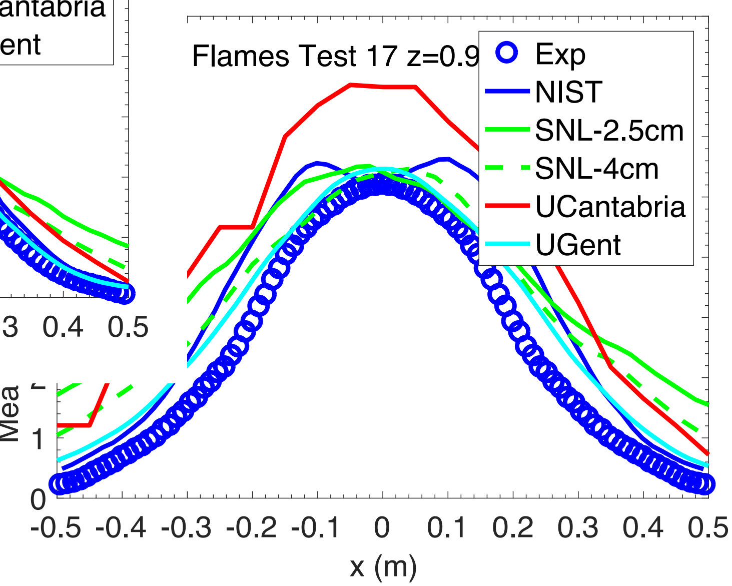

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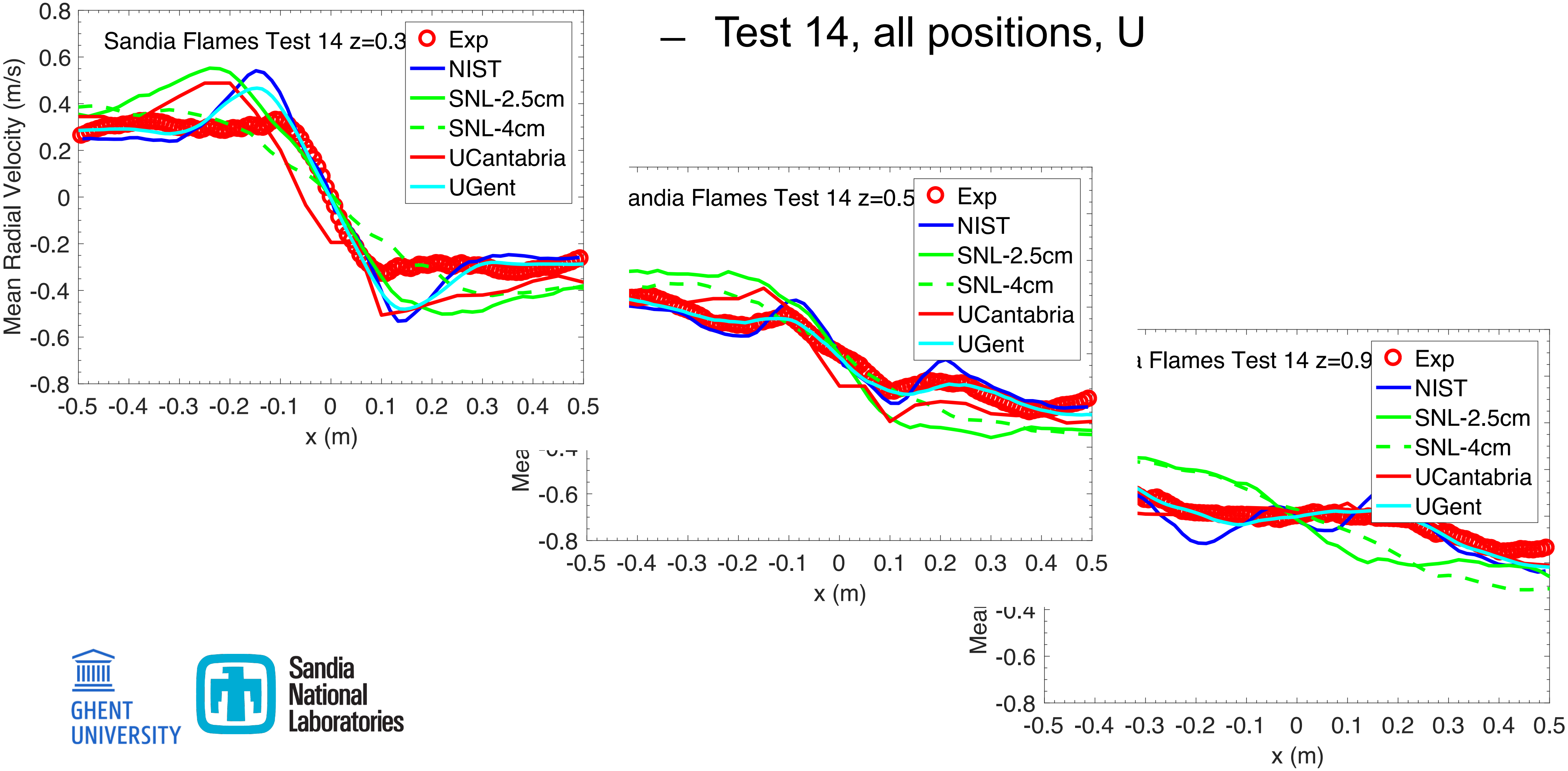
– Test 14, all positions, U



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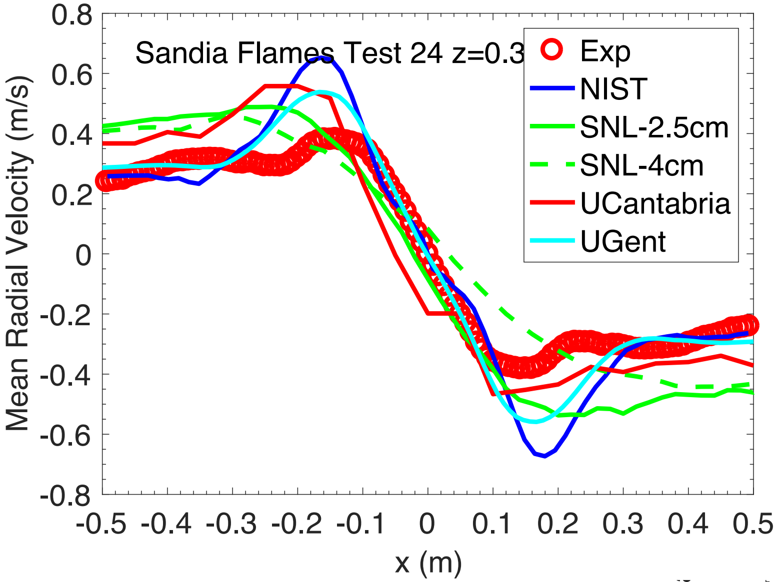
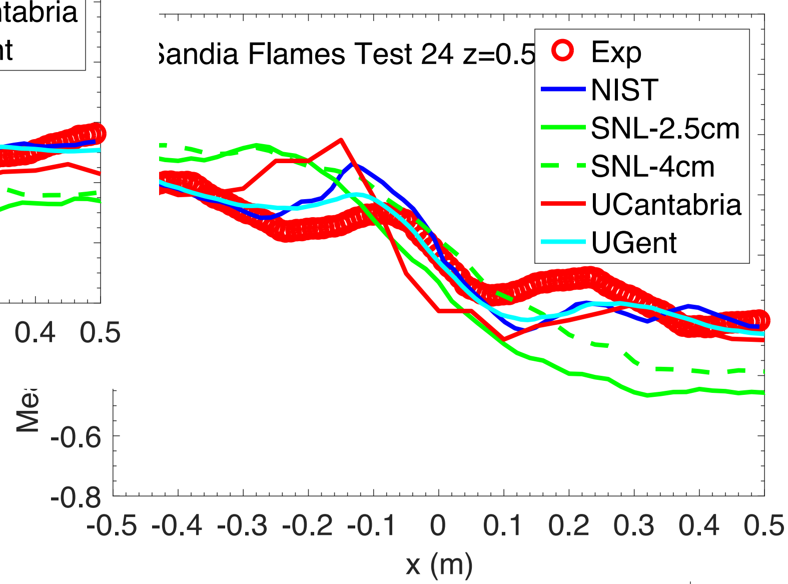
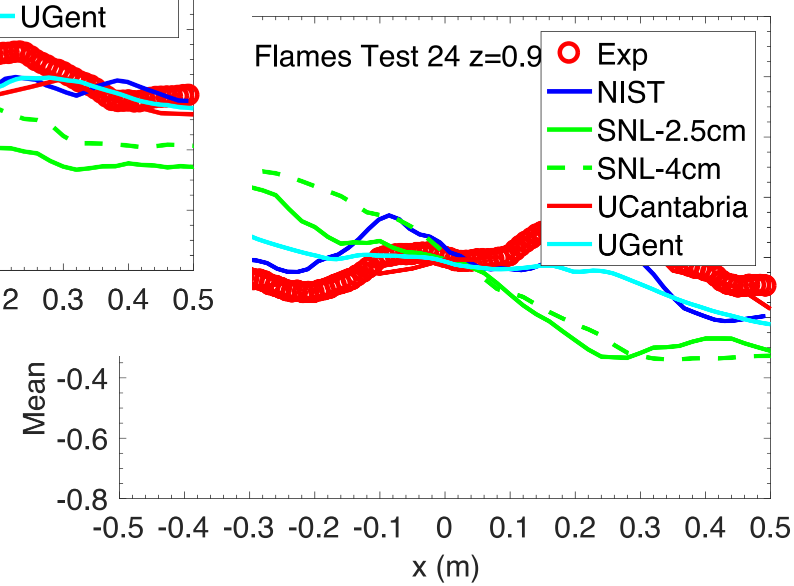
SANDIA_FLAMES

– Test 24, all positions, U







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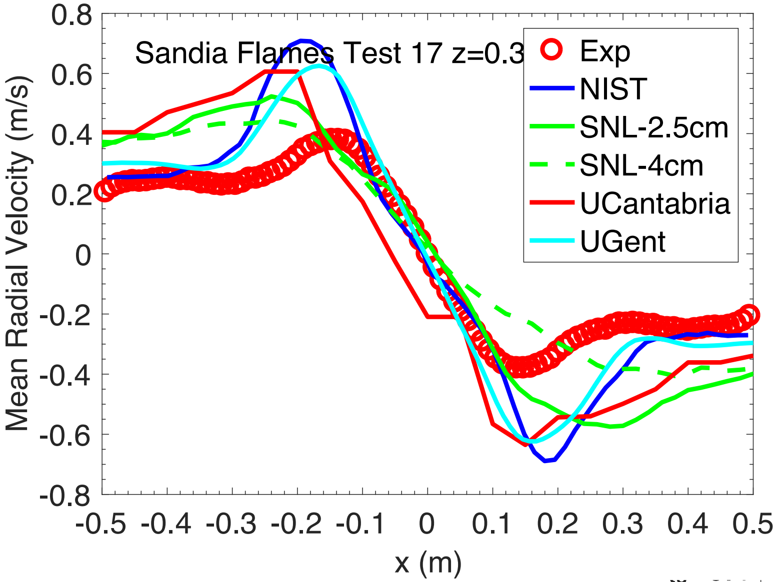
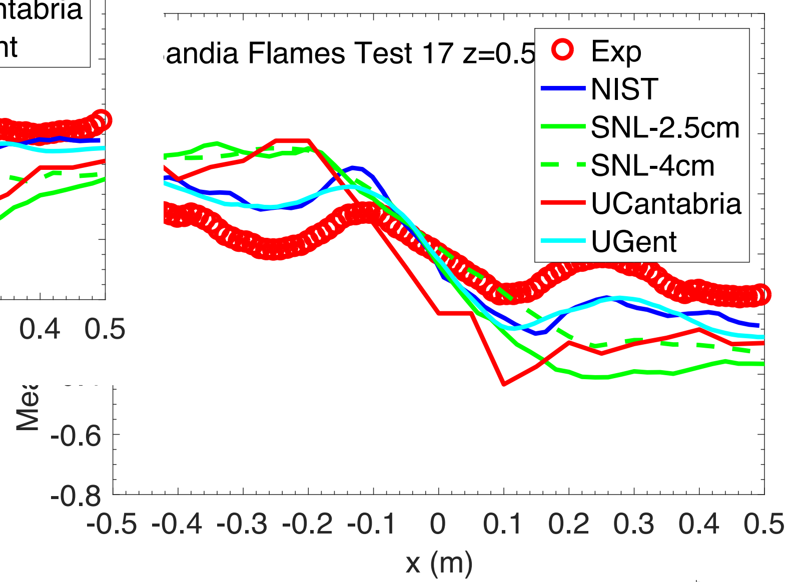
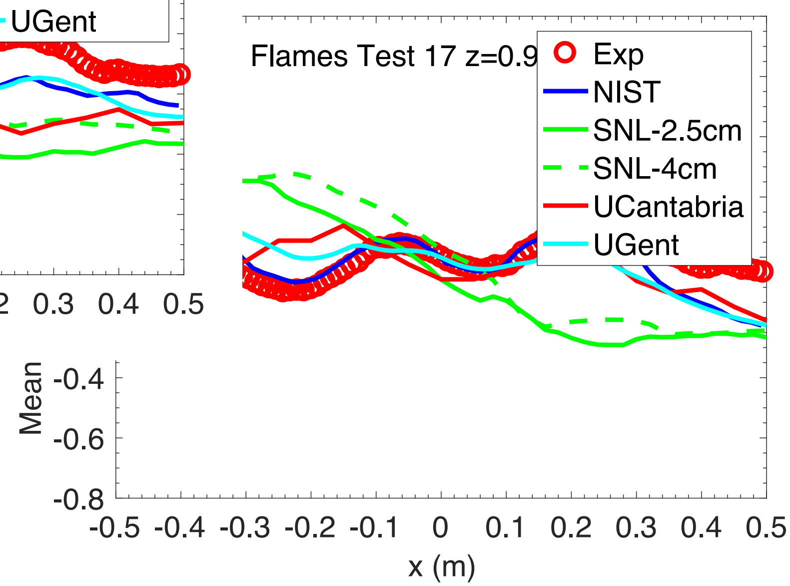


– Test 17, all positions, U





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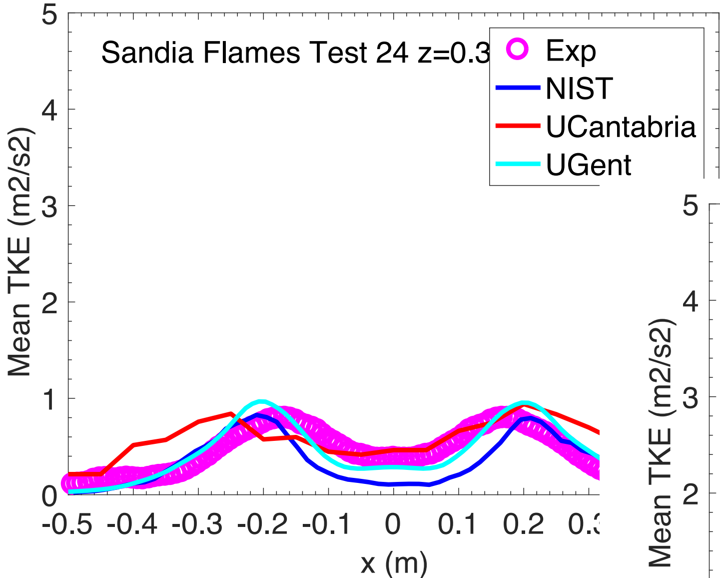
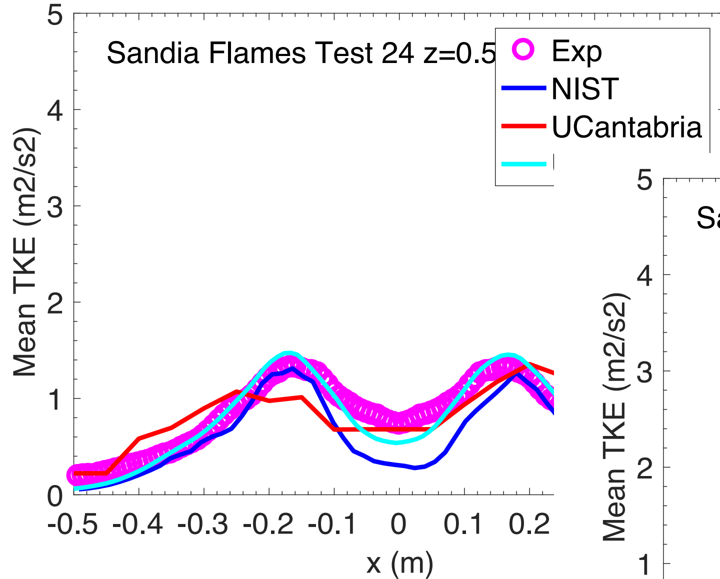
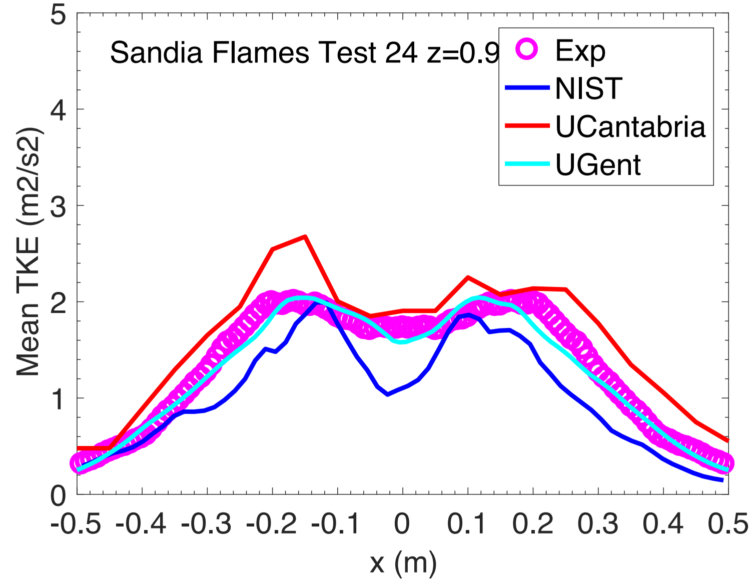
– Test 24, all positions, TKE







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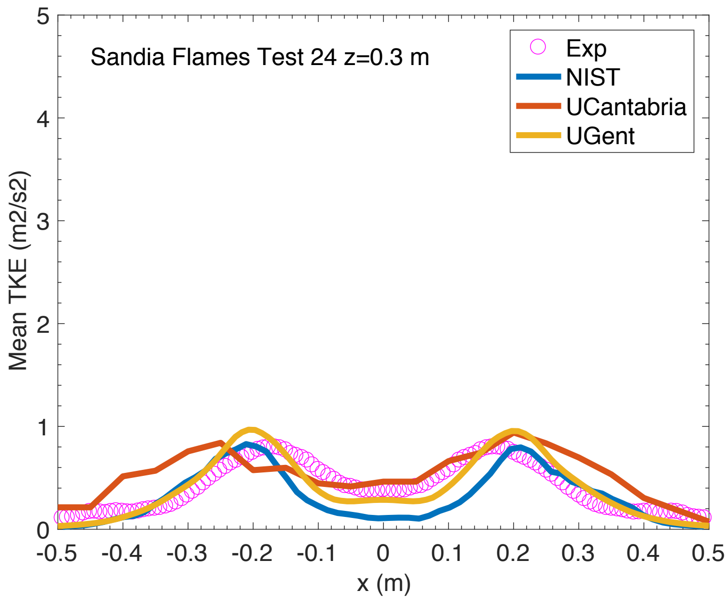
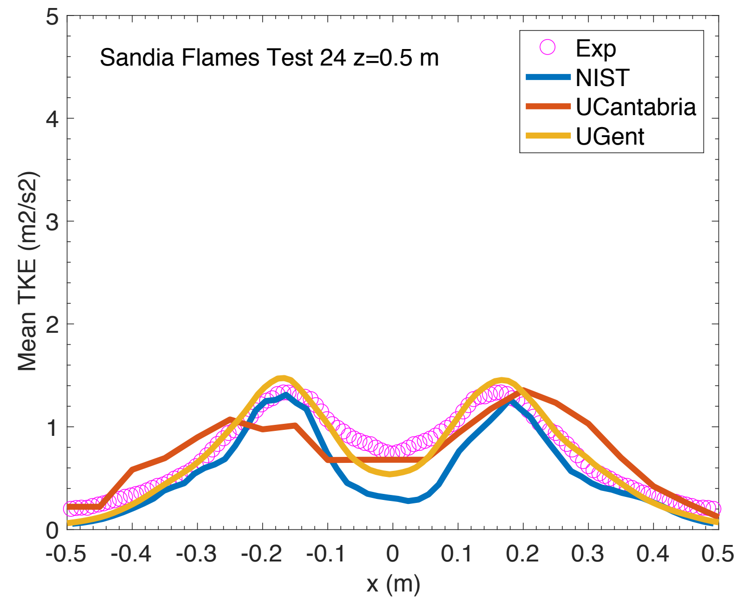
– Test 24, all positions, TKE





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Institute	FM	UGent	NIST	Sandia	UCantabria
Code	FireFoam - dev	FireFoam 2.4.x	FDS6.5.3	-	-
Turbulence model	kEqn (Ck=0.03, Prt=1.0)	Dyn. Smag. (Pr_T = 0.7)	Mod. Deardorff (C_DEARDORFF=0.1, SC_T=0.5, PR_T=0.5)	-	-
Combustion model	EDM (C_EDC=4, C_Diff=0)	EDM (version FDS6.1.2)	EDC (C_U=0.4)	-	-
Radiation model	fvDOM (Chi_R prescribed)	fvDOM 48 solid angles, CHI_R = 0.2 (Prescribed)	Grey gas 104 solid angles, CHI_R=0.2	-	-
Mesh (minimum cell size)	1.25cm	1.25cm	1.43cm	-	-

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MCCAFFREY_FLAMES

Institute	FM	UGent	IRSN	NIST	Sandia	UCantabria
Code	FireFoam - dev	FireFoam 2.4.x	ISIS 4.8.0	FDS6.5.3	-	-
Turbulence model	kEqn (Ck=0.03, Prt=1.0)	Dyn. Smag. (Pr_T = 0.7)	Dyn. Smag. (C_s < 0.12, Sc_T = Pr_T = 0.5)	Mod. Deardorff (C_DEARDORFF=0.1, SC_T=0.5, PR_T=0.5)	-	-
Combustion model	EDM (C_EDC=4, C_Diff=0)	EDM (version FDS6.1.2)	EDC (transp. Eq. for fuel mass fraction)	EDC (C_U=0.4)	-	-
Radiation model	fvDOM (Chi_R prescribed)	fvDOM 48 solid angles, CHI_R = 0.2 (Prescribed)	P1 - WSGGM	Grey gas 104 solid angles, CHI_R=0.2	-	-
Mesh (minimum cell size)	1.25cm	1.25cm	1cm	1.43cm	-	-

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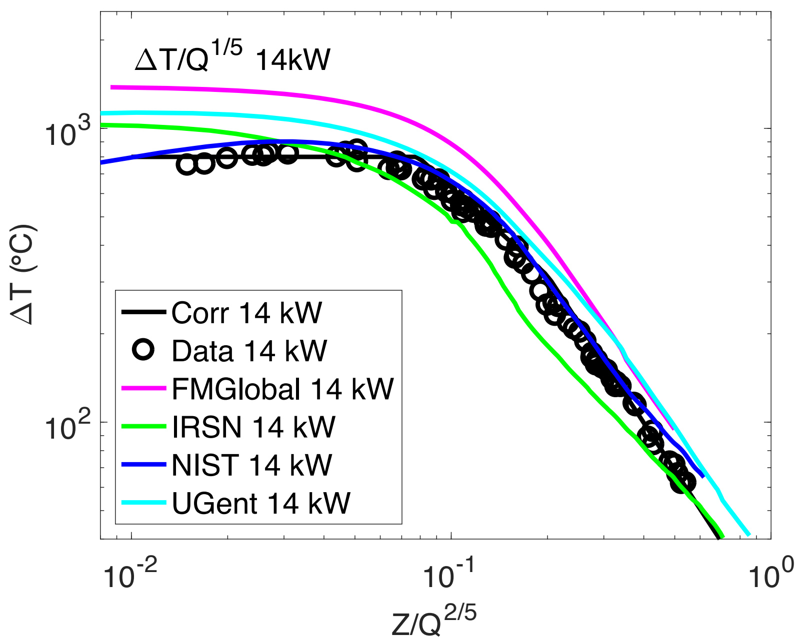
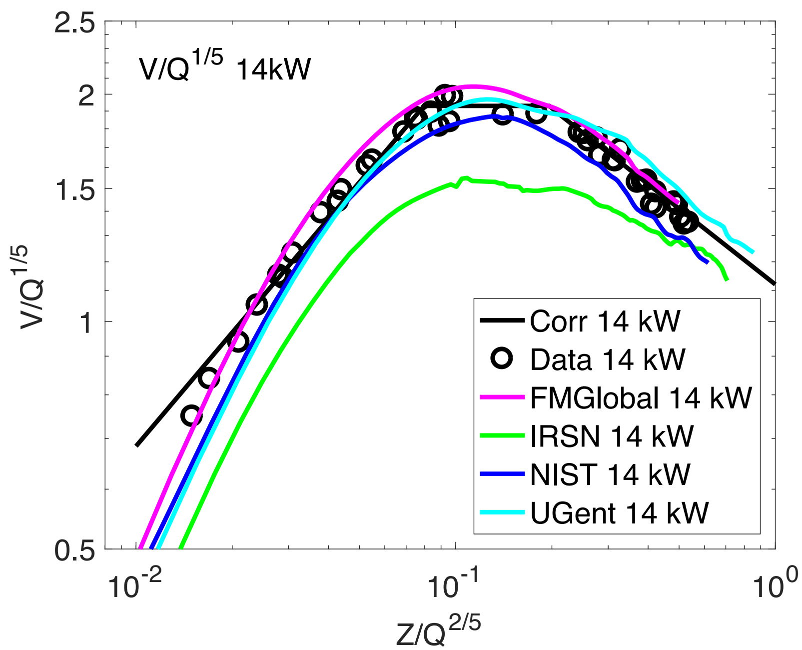
MCCAFFREY_FLAMES

– 14kW,





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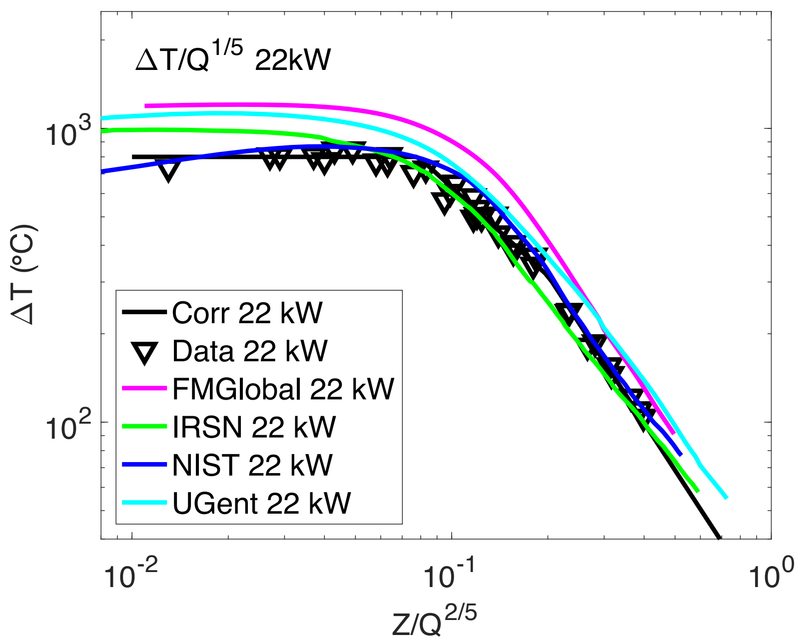
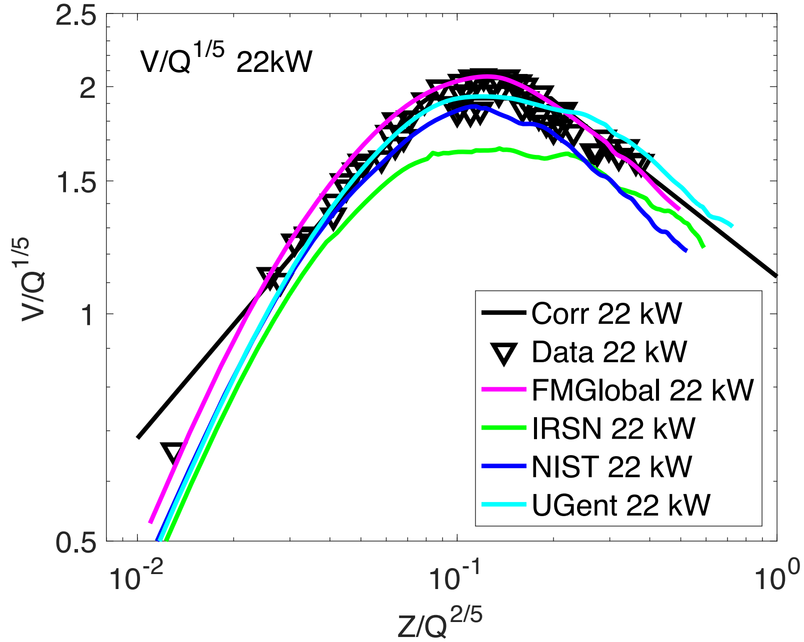
– 22kW,





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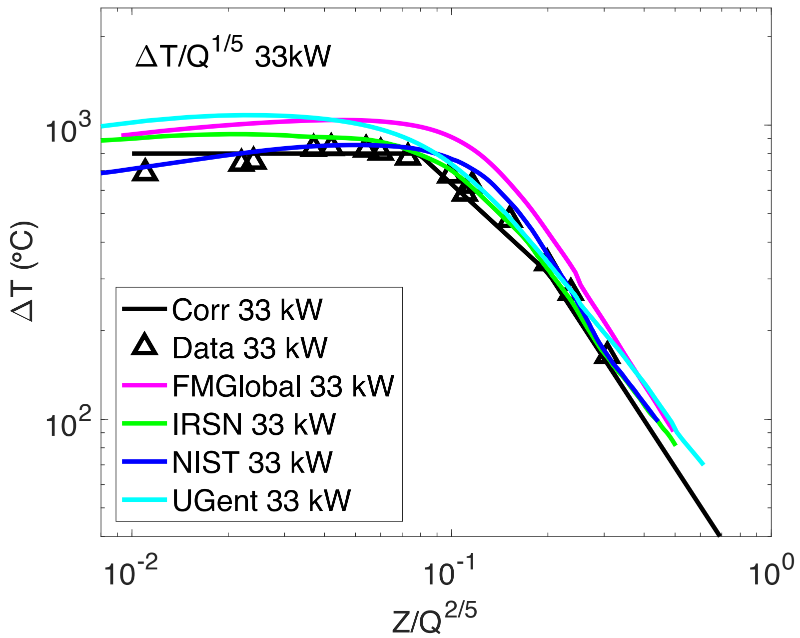
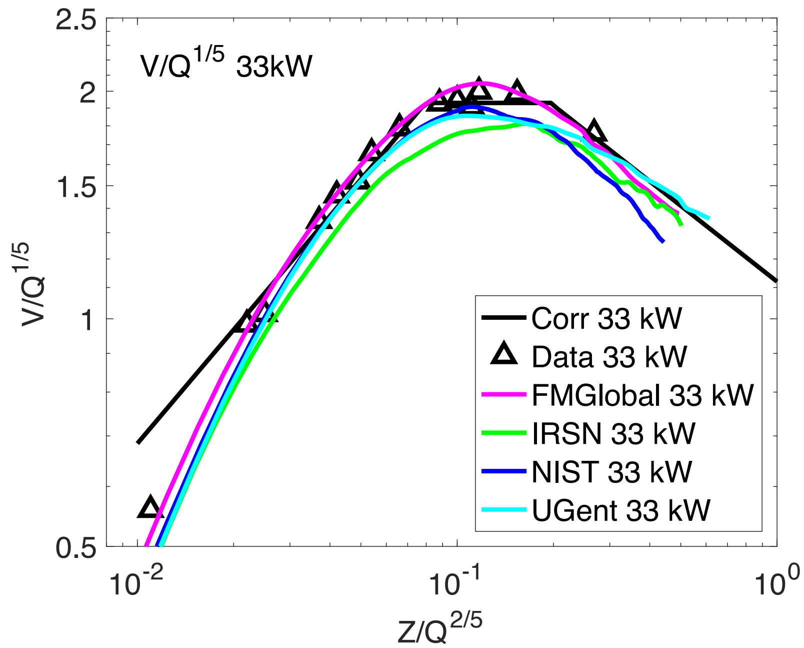
– 33kW,





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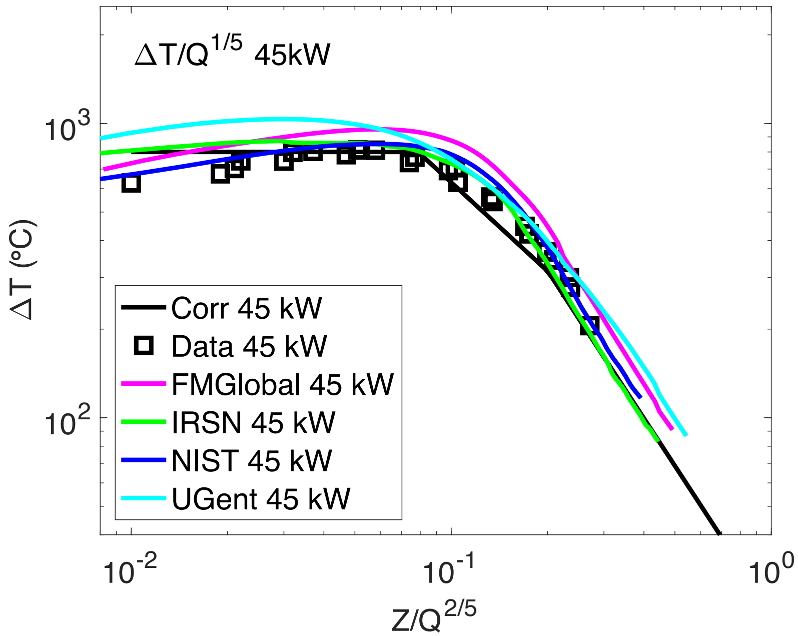
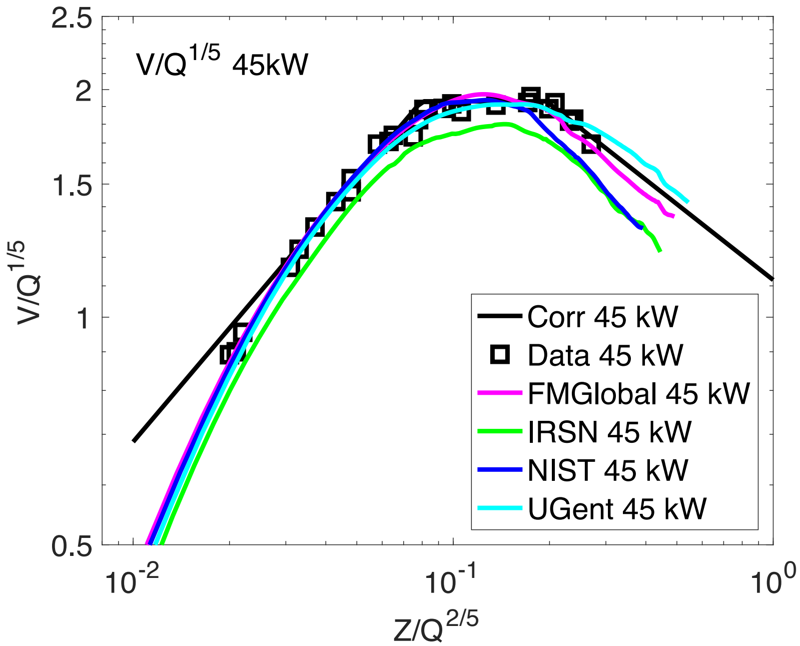
MCCAFFREY_FLAMES

– 45kW,





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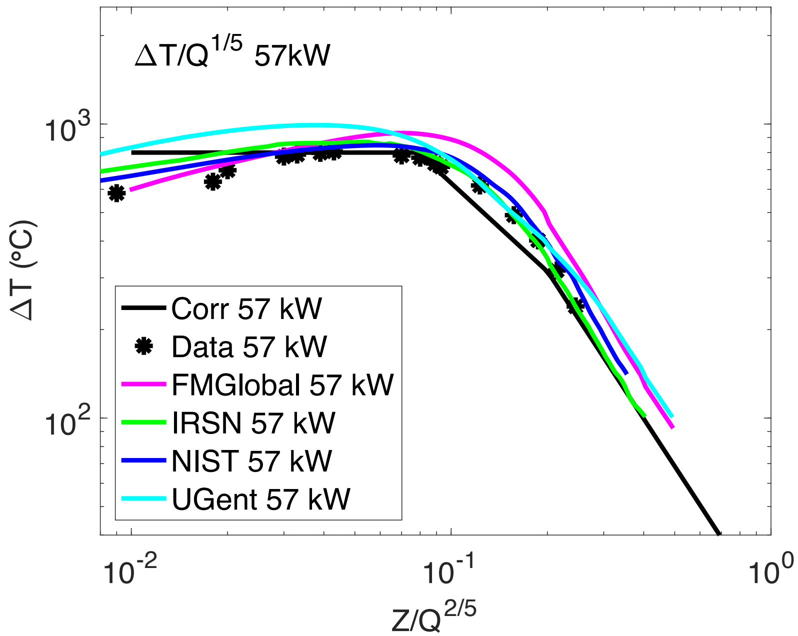
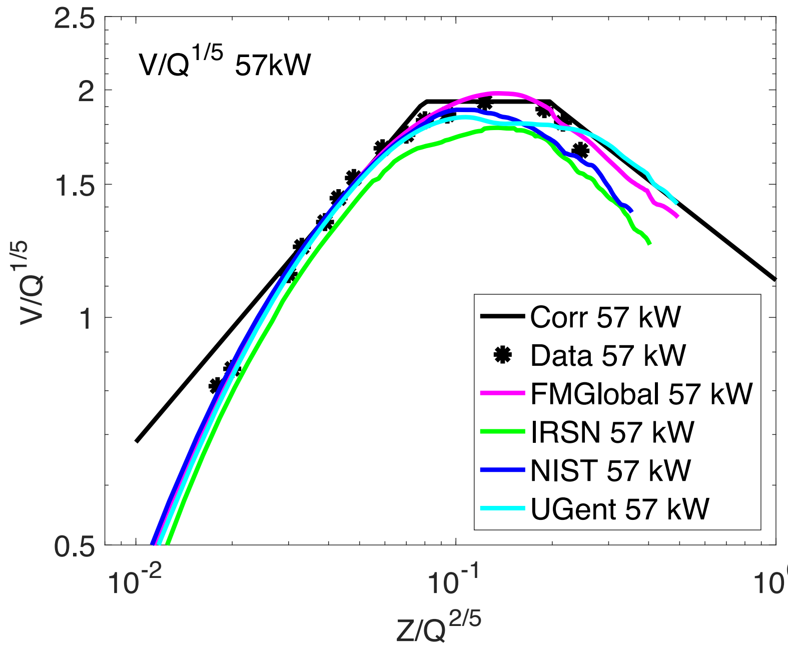
MCCAFFREY_FLAMES

– 57.5kW,





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CONCLUDING COMMENTS

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CONCLUDING COMMENTS

- Need for revisiting the experiments:
  - Combined velocity, temperature and species measurements;
  - Well-defined boundary conditions;
  - Additional information on second-order statistics.

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CONCLUDING COMMENTS

- Sandia flame simulations:
  - NIST and UGent results are close to each other at the level of mean flow fields, despite differences in code, turbulence model and combustion model → the mesh is very important (confirmed by UCantabria results, performed on a coarser mesh, with other than that very similar settings as the NIST results).
  - The TKE is higher (and in closer agreement with experimental data) in the UGent results. Yet, hard to draw a firm conclusion, not knowing the temperature (mass density) field.

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CONCLUDING COMMENTS

- McCaffrey flame simulations:
  - Radiation correction required for temperatures → it would be nice to have updated measurements.
  - Velocities are on the lower end with IRSN results.
  - Intermittency region?
  - Flame height prediction, related to intersection of flame and plume regions.
  - Changes in fineness in the grid are visible in the results.

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OPEN DISCUSSION

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