Turbulent Buoyant Plumes

Comparison of Sandia Helium Plume Experiment

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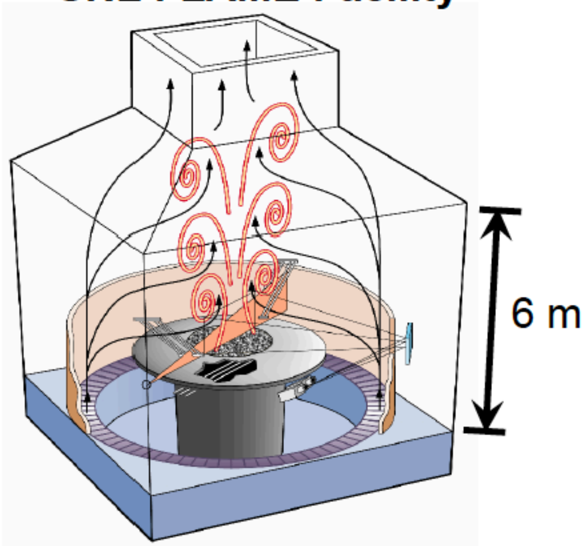
Experiments

- Experimental database from Sandia National Laboratories (SNL) Fire Laboratory for the Accreditation of Models by Experimentation (FLAME)
- 1-m in diameter non-reacting helium-air and reacting methane-air, hydrogen-air, JP-8 flames
- Detailed measurements of velocity and species using Planar Laser Induced Florence (PLIF) and Particle Image Velocimetry(PIV)
- Well documented experimental uncertainties

SNL FLAME Facility



FLAME Facility

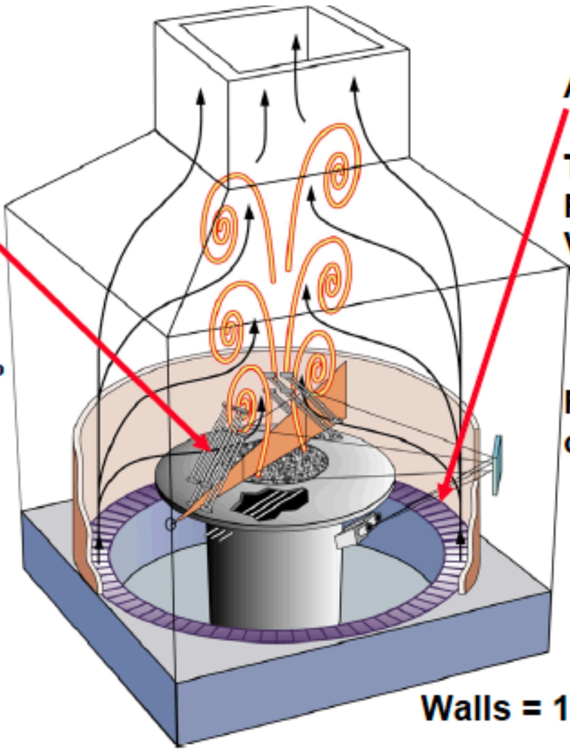
Figure 5. Photograph of the Fire Laboratory for Accreditation of Models and Experiments (FLAME).

Experimental Setup

Plume Source:

T = 11°C ± 3°C
Composition
He = 96.4% ± 0.1%
O_2 = 1.9% ± 0.2%
Acetone = 1.7% ± 0.1%
MW = 5.43 g/mol ± 2.4%
V = 0.325 m/s ± 2.6%

Pretest Characterization of Spatial Uniformity over the Diffuser
±8.5% for velocity
< 4% for acetone



Air Source:

T = 13°C ± 3°C
RH = 14% ± 3%
V = 0.15 m/s ± 8%
± 8% per quad
± negligible temporal

Pretest Characterization of Velocity Uniformity
± 10% panel to panel
± 28% for scales < 3cm

Walls = 13°C ± 3°C

Pressure = 80.9 kPa ± 0.4 kPa

- *T.K. Blanchat. Characterization of the air source and plume source at FLAME. Technical Report SAND01-2227, Sandia National Laboratory, Albuquerque, New Mexico, 2001.*
- *P. E. DesJardin, T. J. O'Hern, and S. R. Tieszen. Large eddy simulation and experimental measurements of the near-field of a large turbulent helium plume. Phys. Fluids, 16(6):1866–1883, 2004.*
- *T.J. O'Hern, E.J. Weckman, A.L. Gerhart, S.R. Tieszen, and R.W. Schefer. Experimental study of a turbulent buoyant helium plume. J. Fluid Mech., 544:143-171, 2005.*

Experiment Acknowledgements

- Sheldon Tieszen (Sandia)
  - Project oversight, FLAME modifications, gas flow systems, data analysis
- E.J. (Beth) Weckman (and students) (Waterloo)
  - PLIF analysis, experimental setup
- Tim O'Hern (Sandia)
  - Laser Diagnostics, FLAME modifications, Data analysis
- Bob Schefer (Sandia)
  - Laser diagnostics, PLIF analysis consulting
- Andy Gerhart (NM)
  - PIV analysis

Experimental Runs

Run no.	Helium inlet velocity	Test type	Re	Ri	Meas. puffing freq.	Puffing freq. (a)
	(m/s) ± 1.3%		± 0.6%	± 6.5%	(Hz)	(Hz)
20	0.314	PIV	3344	80.57	1.20	1.33
22	0.319	PIV	3300	78.06	1.41	1.34
23	0.303	PIV	3198	86.72	1.36	1.32
25	0.340	PIV/PLIF	3306	68.75	1.53	1.36
26	0.315	PIV	3253	80.20	1.39	1.33
27	0.305	PIV	3242	85.32	1.37	1.32
29	0.352	PIV/PLIF	3256	64.32	1.42	1.37
30	0.337	PIV	3176	70.20	1.19	1.36
32	0.349	PIV/PLIF	3275	65.32	1.42	1.37
36	0.316	PIV/PLIF	2933	79.74	1.41	1.33
10 test ave	0.325		3228	75.74	1.37	1.34
4 Favre ave	0.339		3194	69.53	1.45	1.36

(a) given by f = V0 (0.8 Ri^(0.38))/D [Cetegen & Kasper, 1996]

Example Measurements

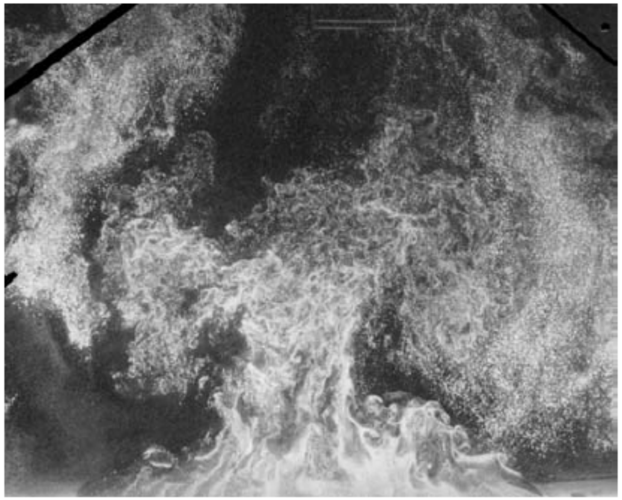


FIGURE 2. Sample raw PIV image in 1 m diameter helium plume (from Test 25).

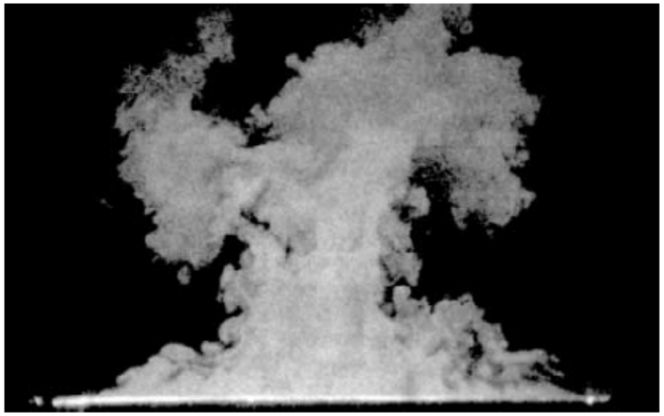
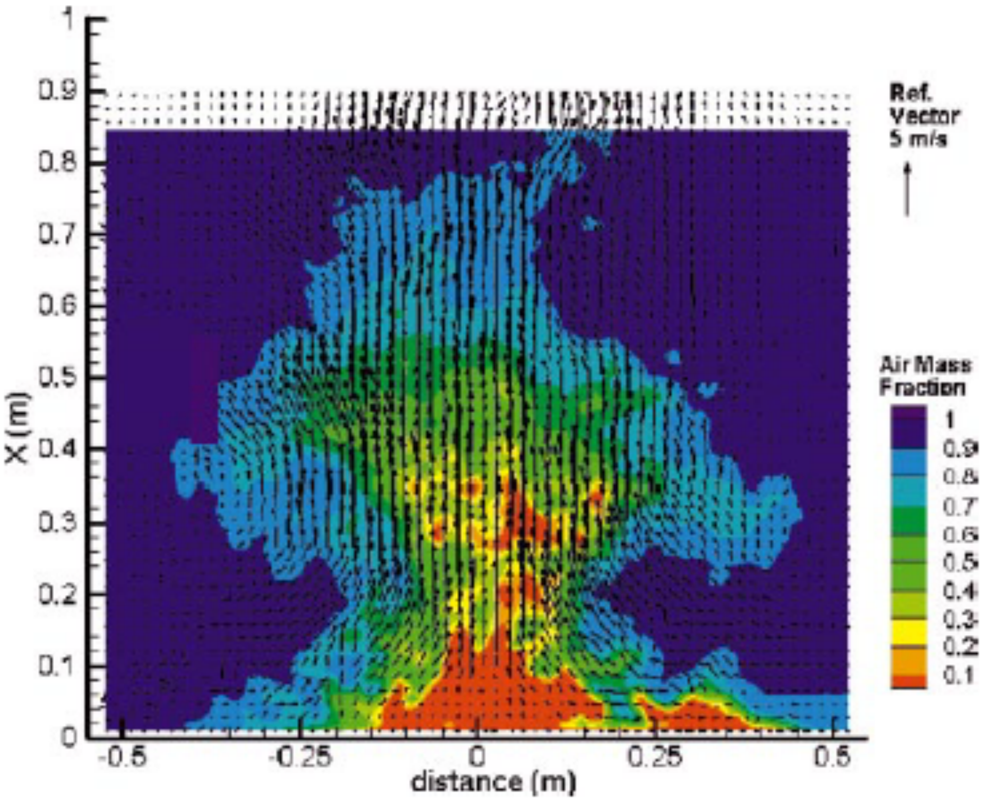
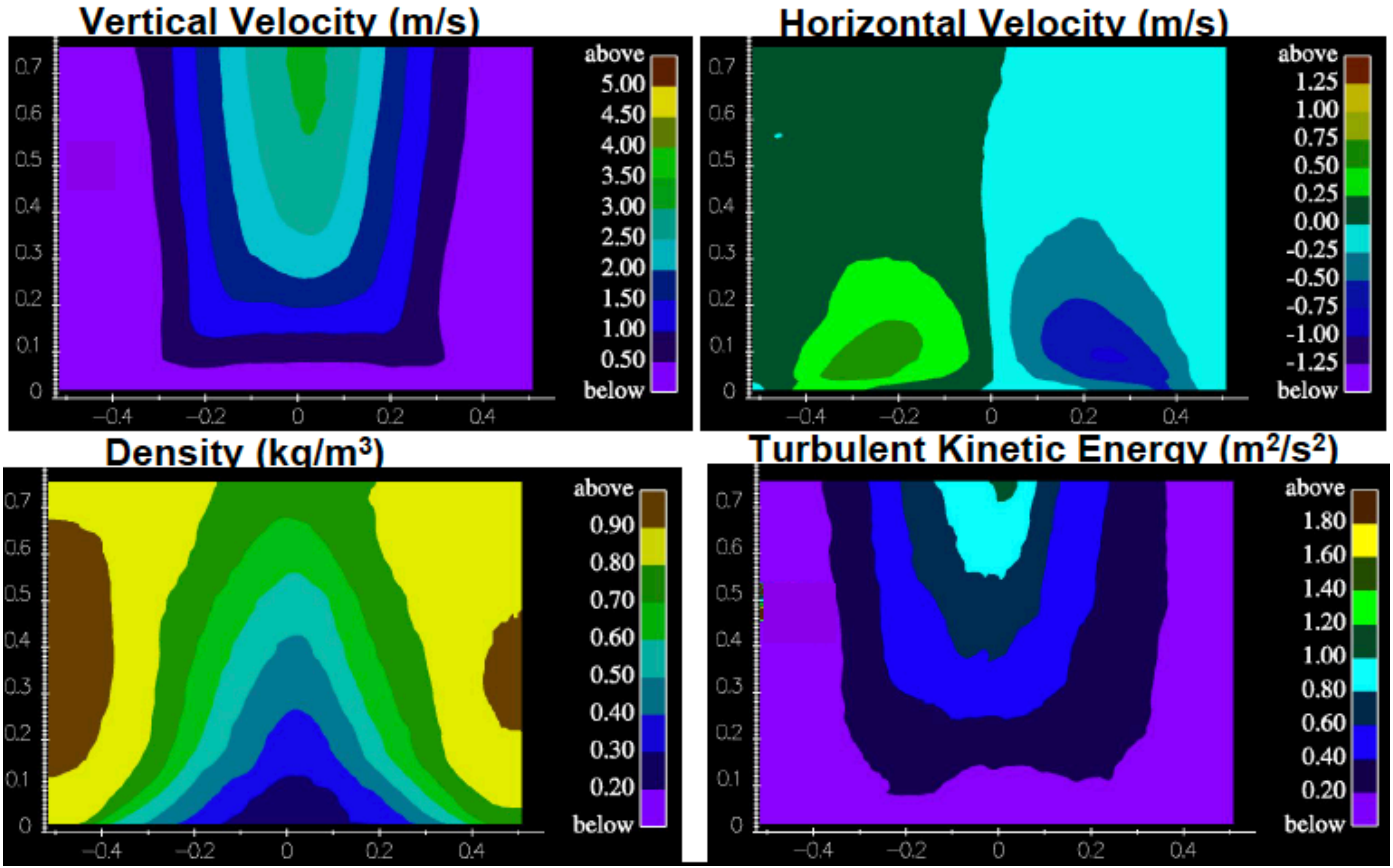


FIGURE 3. Sample raw PLIF image in 1 m diameter helium plume, acquired simultaneously with the PIV image in figure 2.

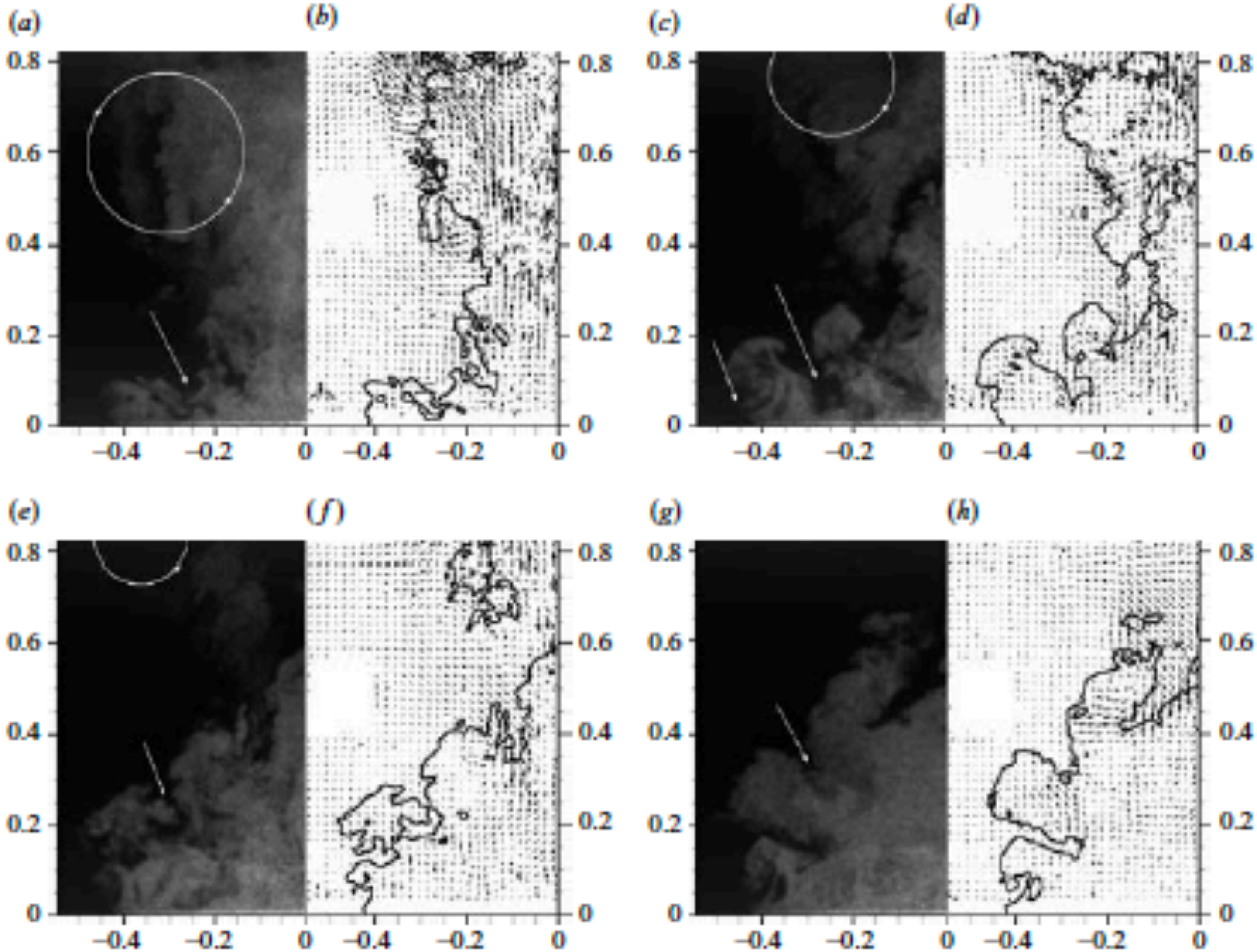
- PIV (V) and PLIF (Y_{He})



Favre Averaged Measurements

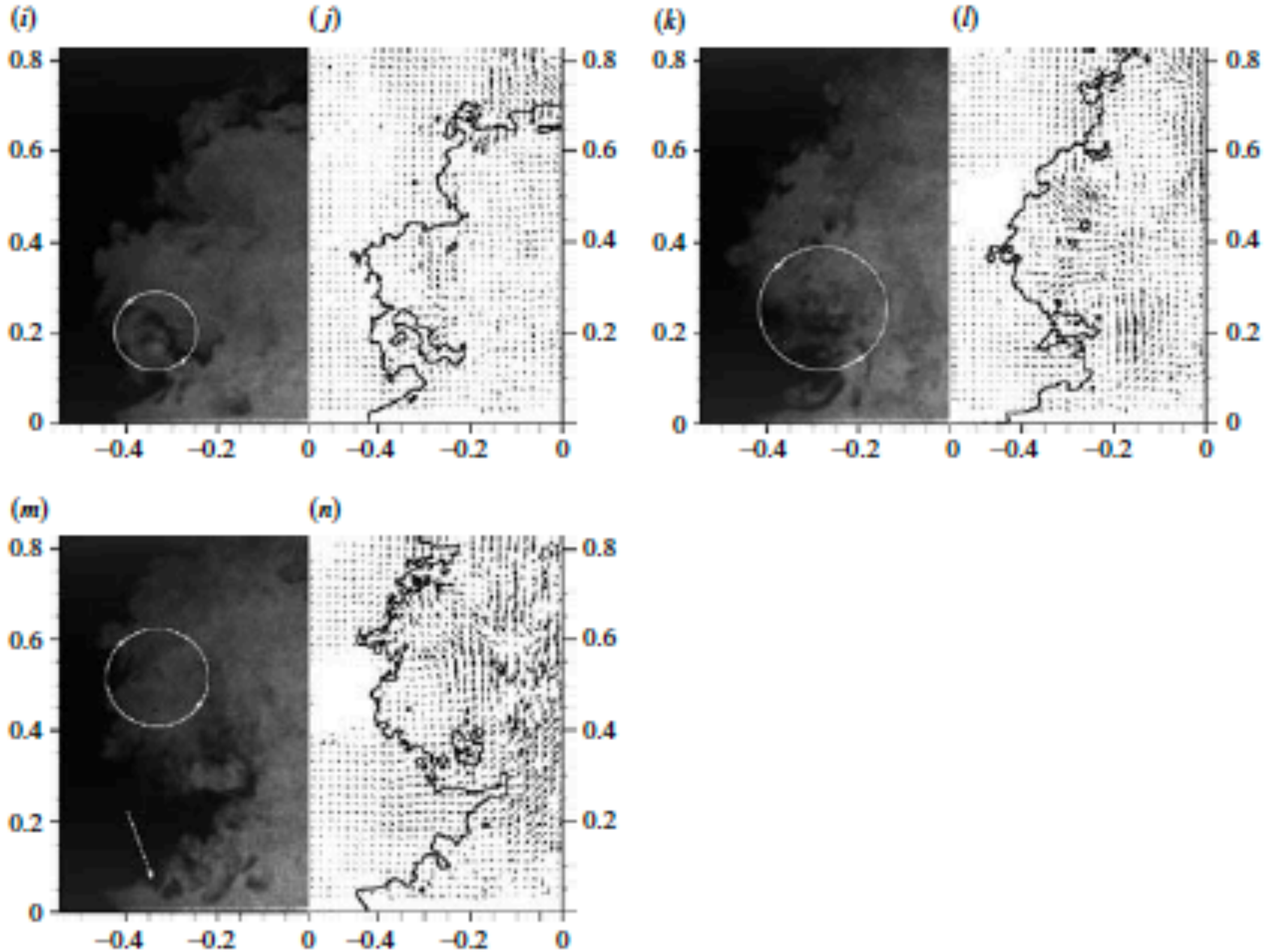


Behavior of the Plume



- *P. E. DesJardin, T. J. O'Hern, and S. R. Tieszen. Large eddy simulation and experimental measurements of the near-field of a large turbulent helium plume. Phys. Fluids, 16(6):1866–1883, 2004.*

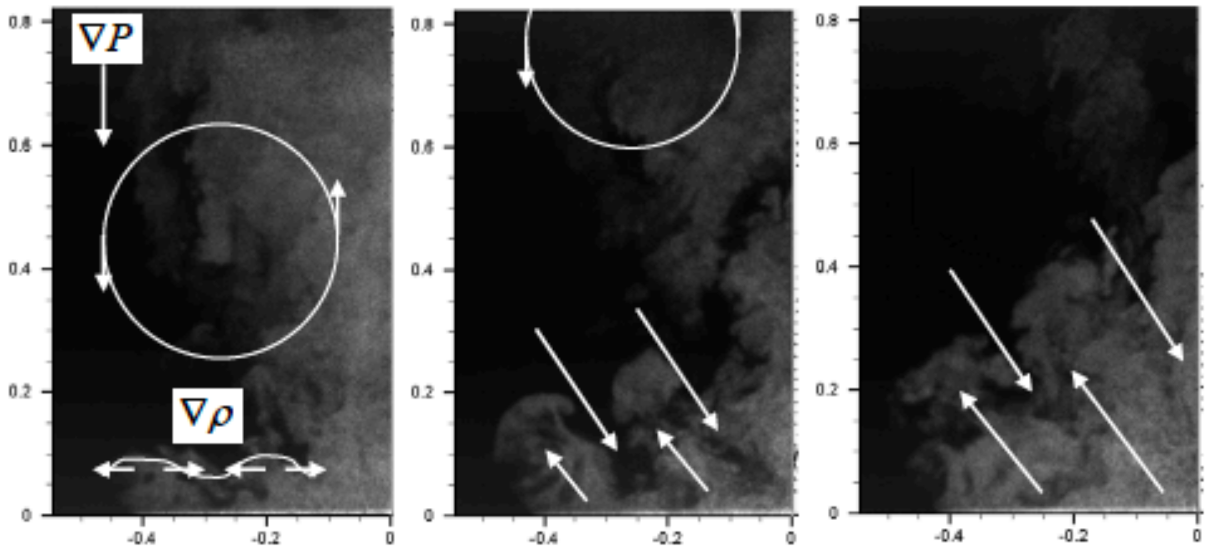
Behavior of the Plume



- *P. E. DesJardin, T. J. O'Hern, and S. R. Tieszen. Large eddy simulation and experimental measurements of the near-field of a large turbulent helium plume. Phys. Fluids, 16(6):1866–1883, 2004.*

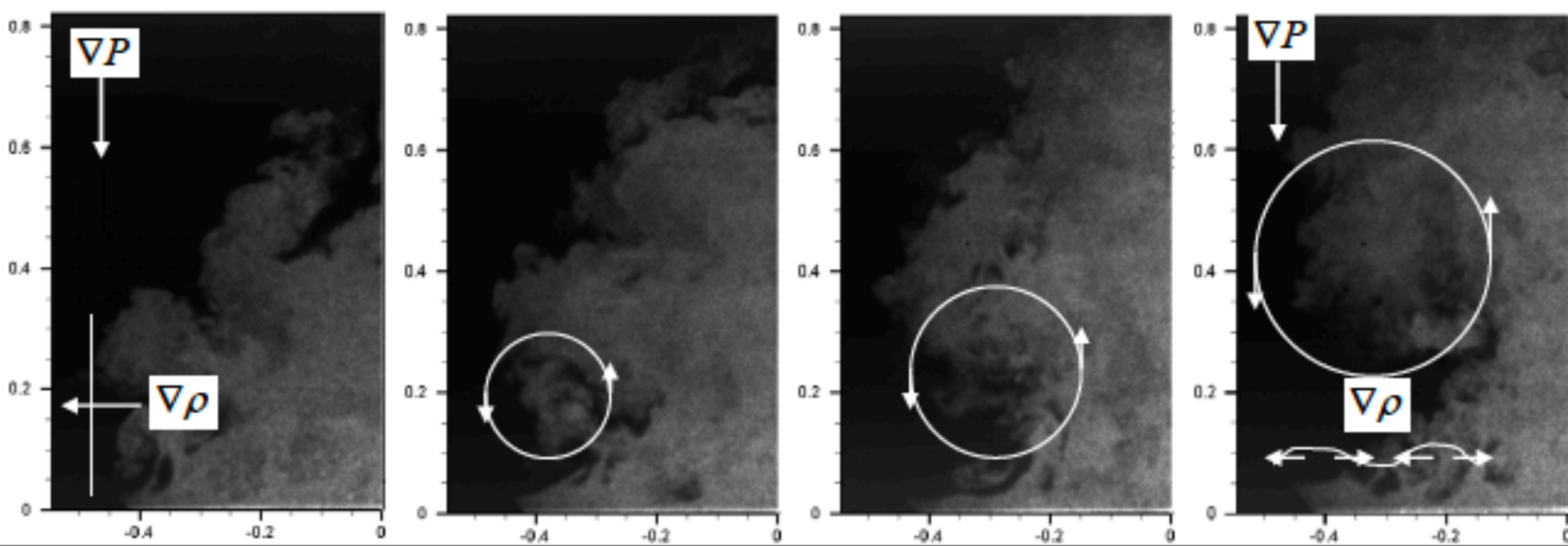
Puff Cycle Sequence

- **Instability I**
- **Leads to bubble and spike structures**
- **Resets the conditions for instability II**



- **Start of next cycle**

- **Instability II**
- **Leads to formation of large vortical structure**
- **Resets the conditions for instability I**



Heinz Pitsch, Guillaume Blanquart, SnezhanaAbarzhi, Frank Ham, Sheldon Tieszen, Tim O'Hern, LES Simulation of Buoyant Plumes, CTR Summer School Program Results

SIMULATIONS

Simulation Parameters

Institute	UGent[1]	IRSN	NIST	Sandia[2]
Code	FireFOAM 2.2.x	ISIS 4.8.0	FDS 6.5.3	Fuego
Turbulence model	constant Smagorinsky (cs=0.1, Prt=0.7)	dynamic Smagorinsky (Cs=0.12; Sc_t = 0.5)	Deardorff (C_DEARDORFF=0.1), SC_T=0.5, PR_T=0.5	Dynamic Smagorinsky (cs=0.1, Prt=0.7)
Domain	4 x 4 x 4 m (cylindrical)	3 x 3 x 4 m	3x3x4 m	4 x 4 x 4 m
Time	30 s (avg. 10 s)	10 s (avg. 3 s)	20 s (avg. 10 s)	20 S (avg. 10 s)
Mesh (minimum cell size)	1.23 / 5.39 cm	2.5 cm	1.5 cm	5 cm, 3 cm

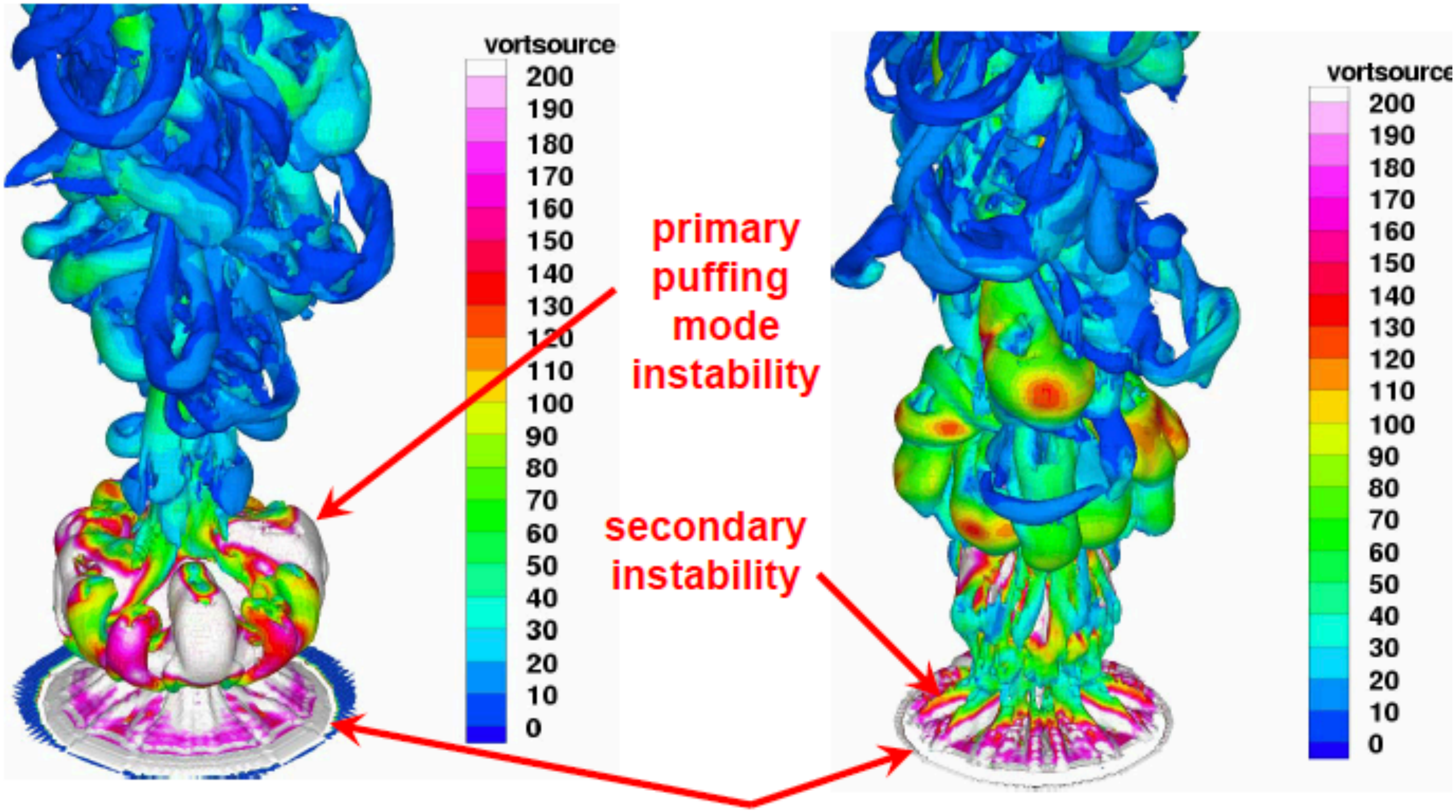
[1]*G. Maragkos, P. Rauwoens, Y. Wang, B. Merci, Large Eddy simulations of the flow in the near-field region of a turbulent buoyant helium plume, Flow Turbul. Combust. 90:511-543 (2013)*

[2]*P. E. DesJardin, T. J. O'Hern, and S. R. Tieszen. Large eddy simulation and experimental measurements of the near-field of a large turbulent helium plume. Phys. Fluids, 16(6):1866–1883, 2004.*

Simulation Results (Sandia)

Instantaneous Snapshots of Vorticity Isocontour at 5% of Maximum

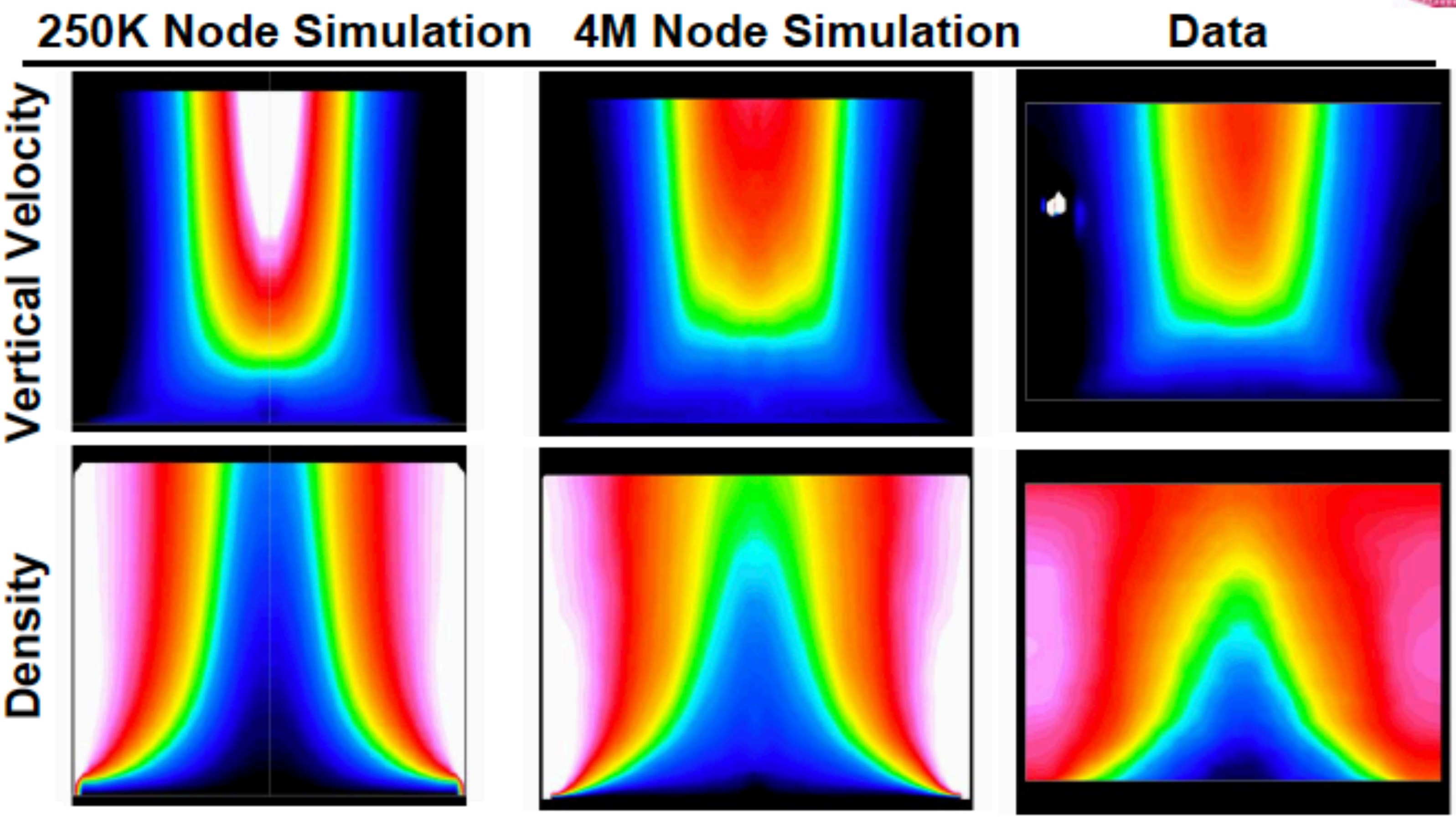
$$vortsource = \rho_\infty \,|\nabla \rho \times \vec{g}\,| \,/\, \rho^2$$



Peak production occurs at base of plume at small scales of motion

P. E. DesJardin, T. J. O'Hern, and S. R. Tieszen. Large eddy simulation and experimental measurements of the near-field of a large turbulent helium plume. Phys. Fluids, 16(6):1866–1883, 2004.

Previous Study Results (Sandia/Stanford)



- 250K simulation did not show bubble and spike structure and thus underpredicts centerline density and overpredicts centerline velocity by a factor of 2
- 4M node mesh results is much closer to the data

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Previous Study Conclusions

- **Buoyancy does not generate turbulence. It generates vorticity that leads to advection. Advection generates turbulence.**

- **Coherent structure growth from two instabilities are primarily responsible for mixing in both plumes and fires**
  - **Plumes: instability occurs at plume/air interface**
  - **Fires: instability occurs at the flame-product/air interface when the fuel is heavier than air**

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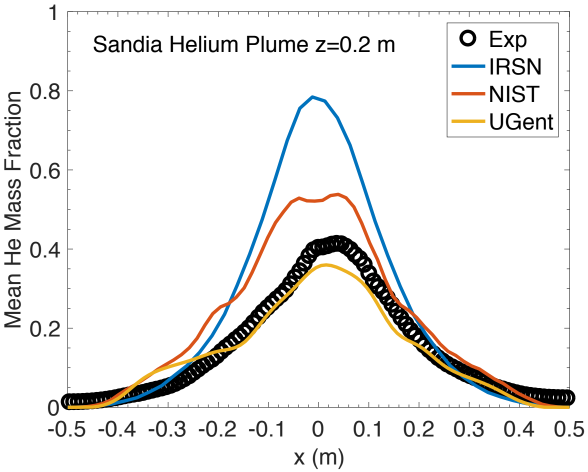
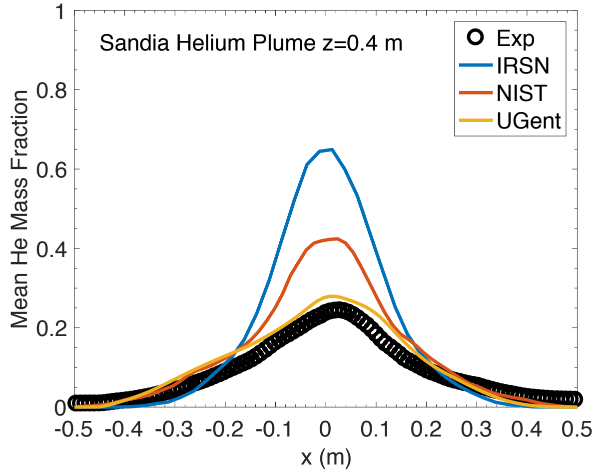
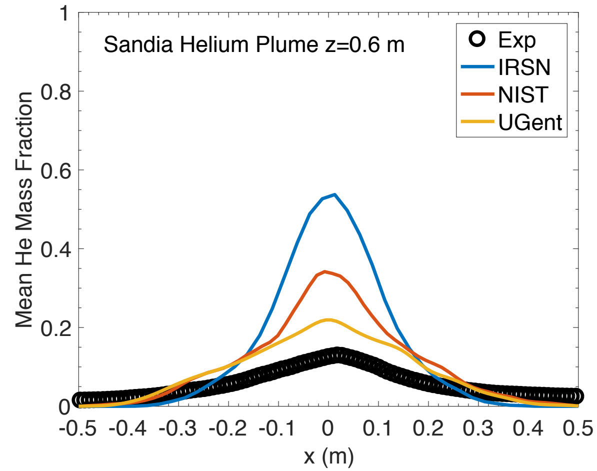
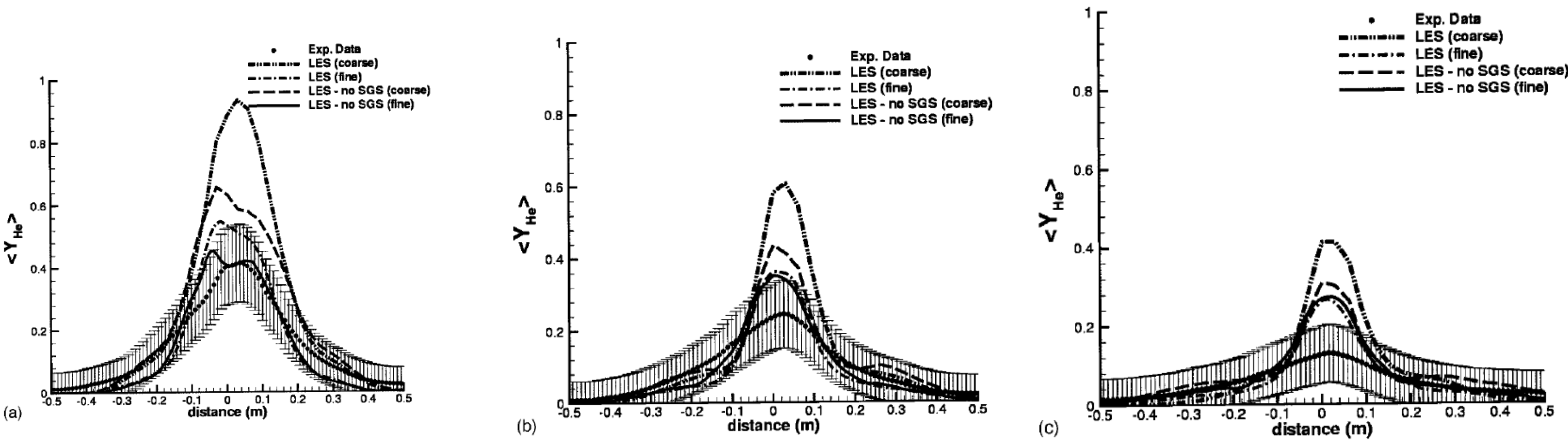
Mean He Mass Fraction

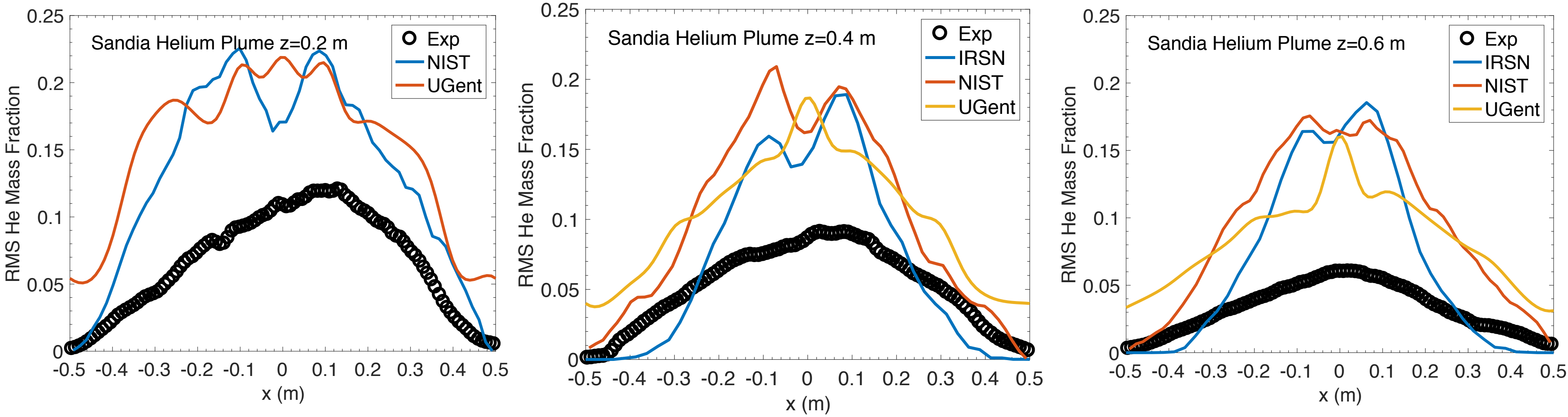


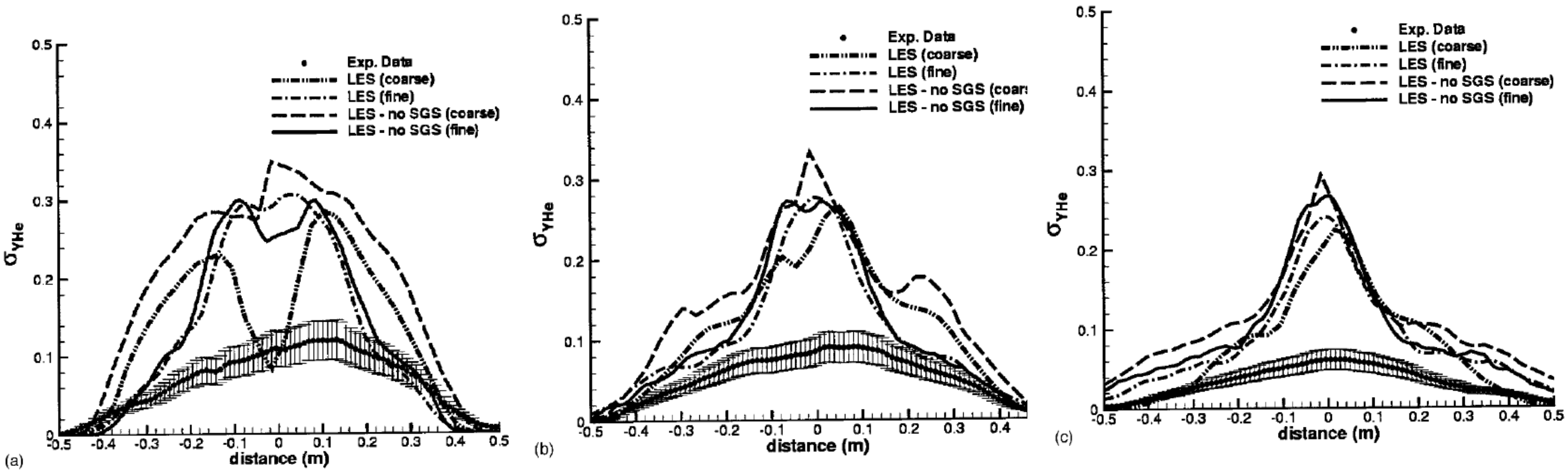




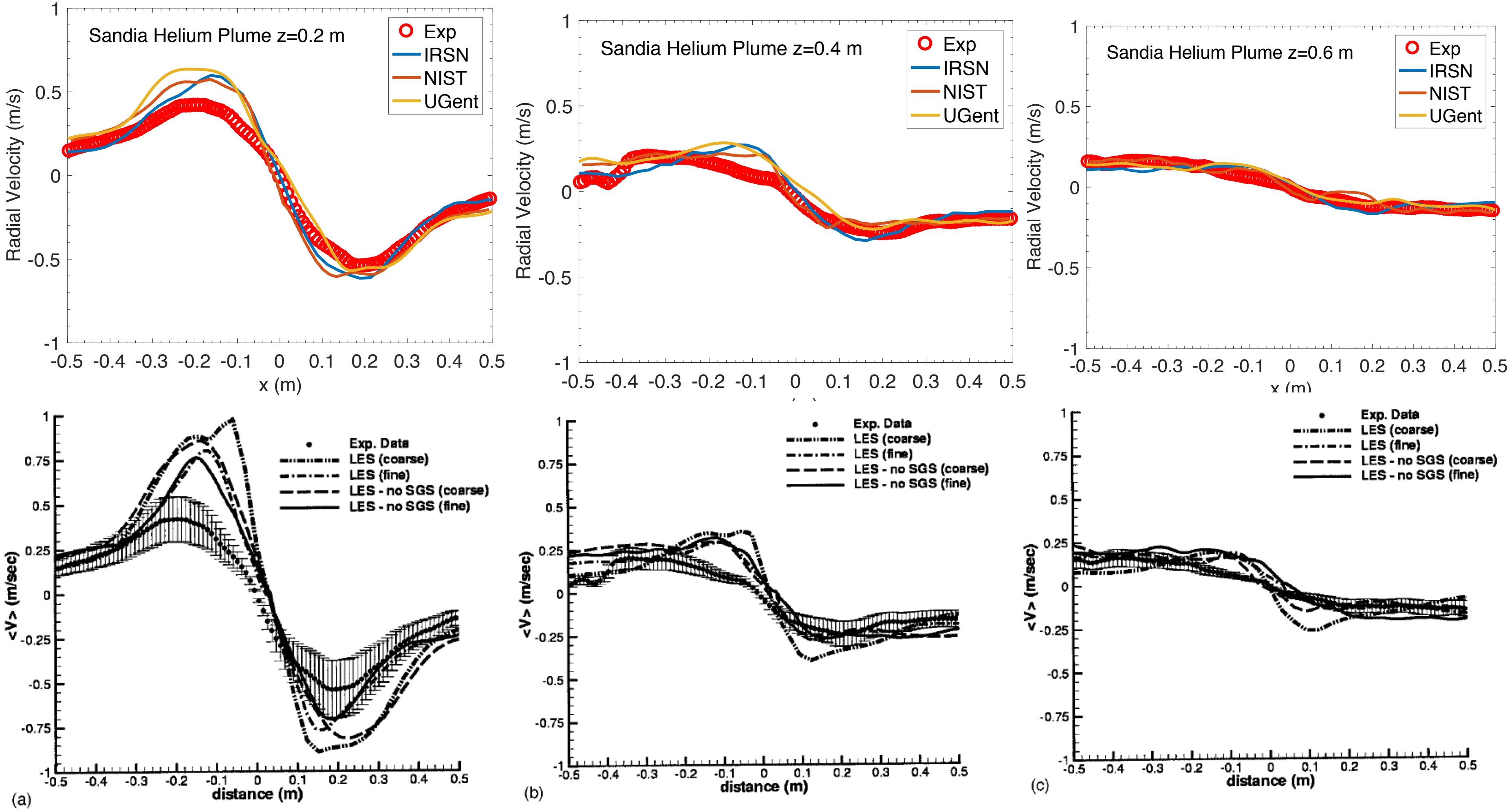


RMS He Mass Fraction

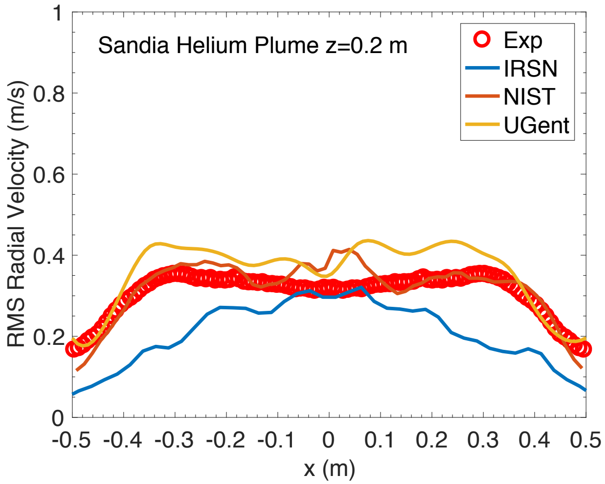


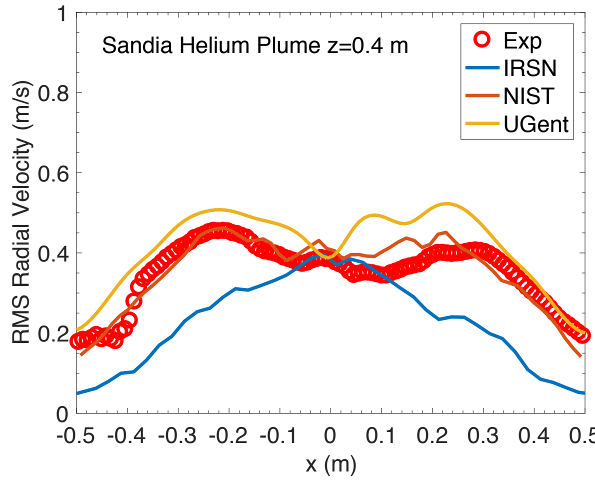


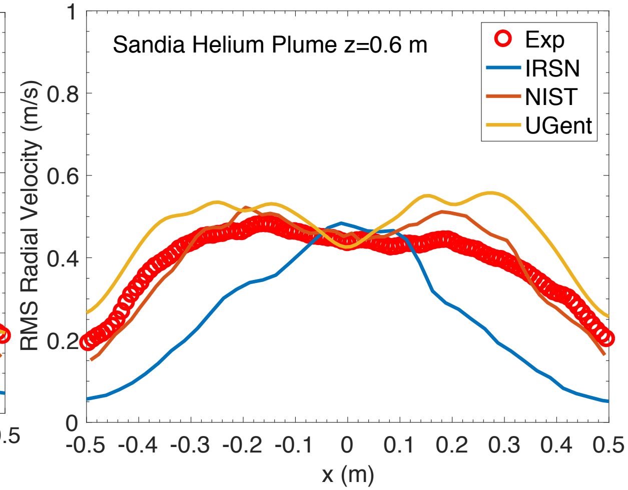
Radial Velocity

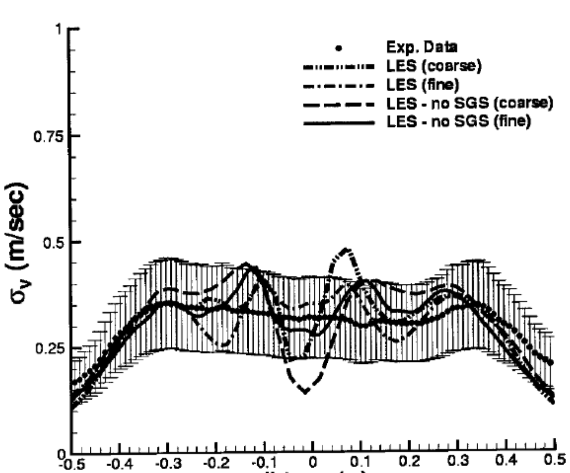


RMS Radial Velocity

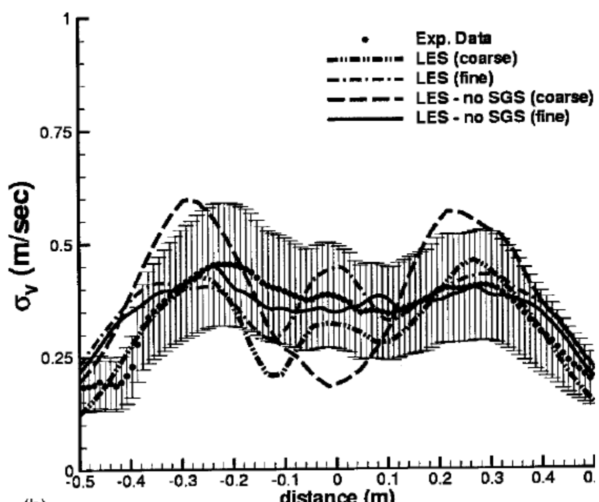




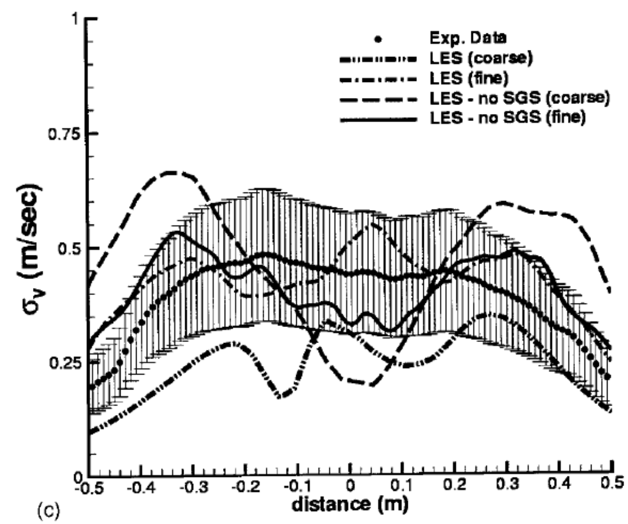




(a)

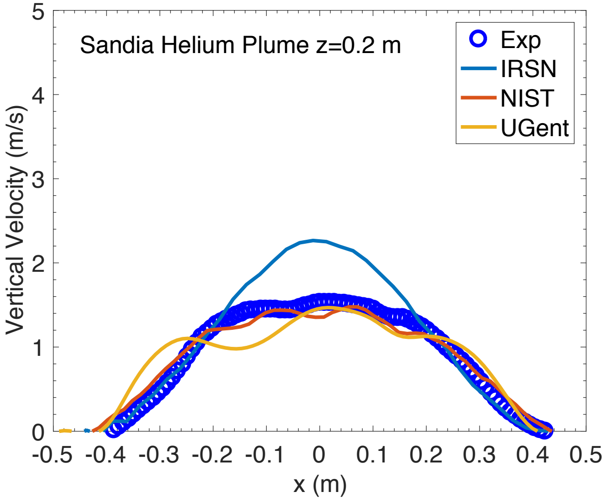


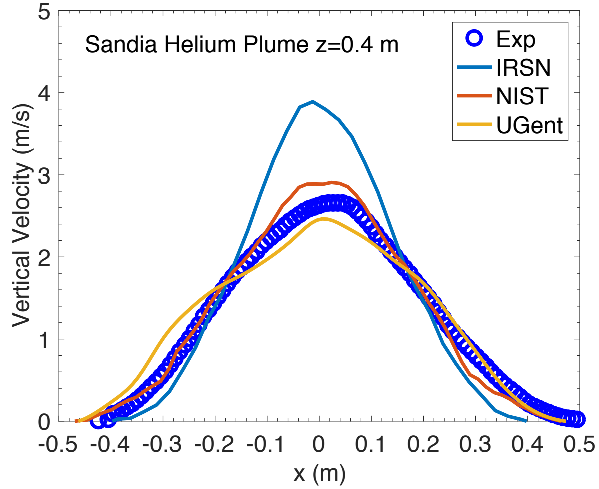
(b)

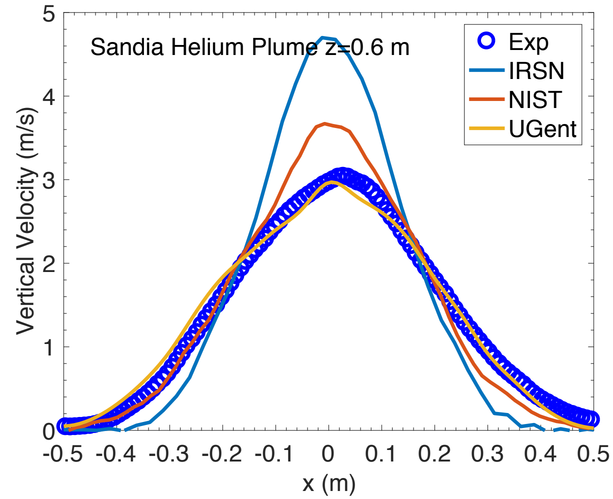


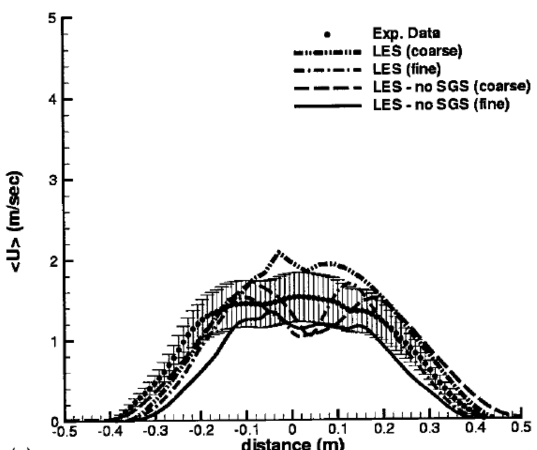
(c)

Vertical Velocity

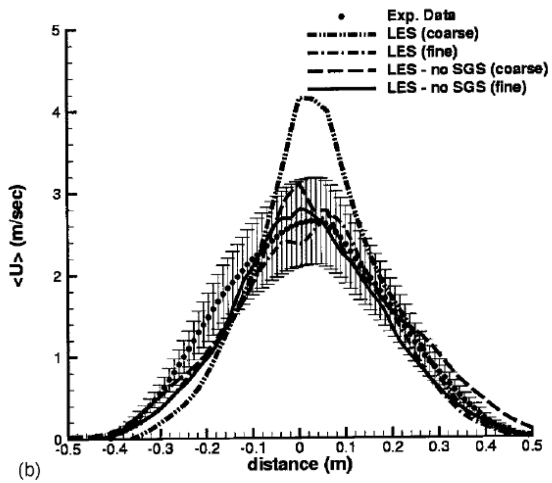








(a)



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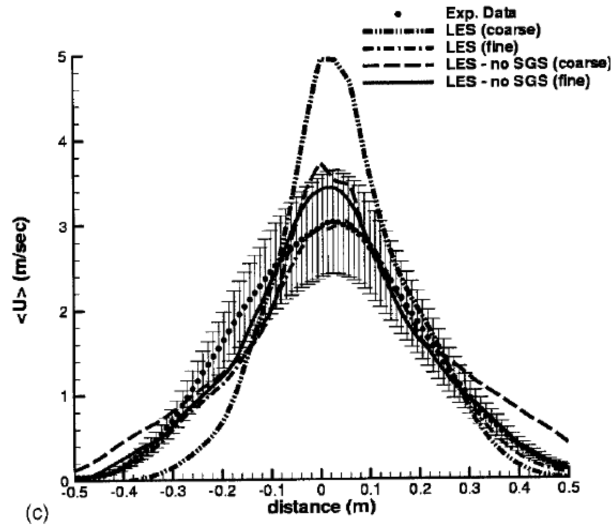
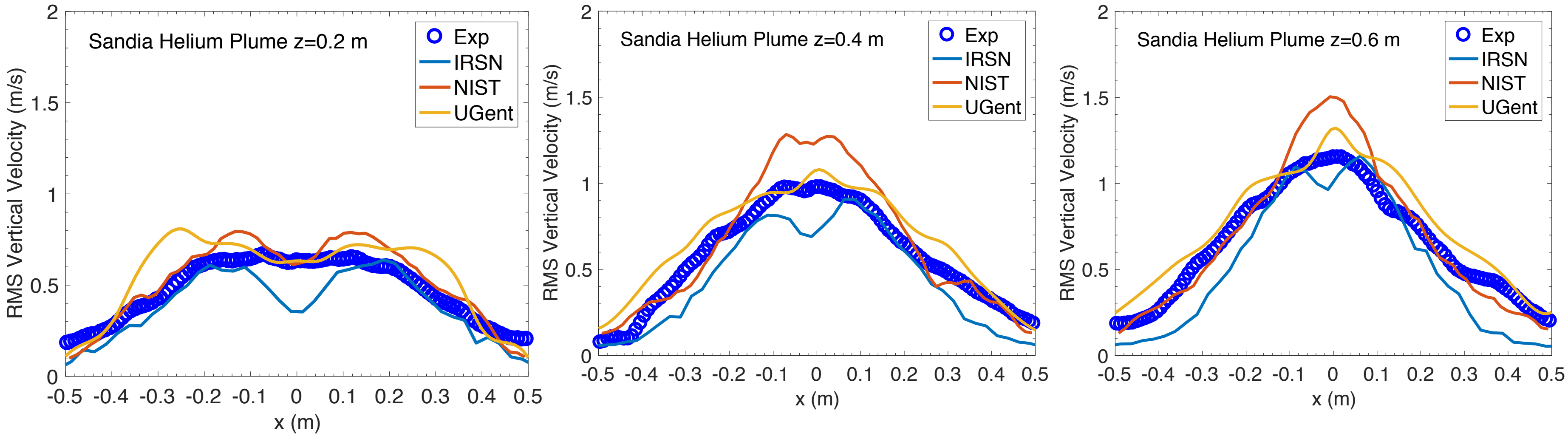
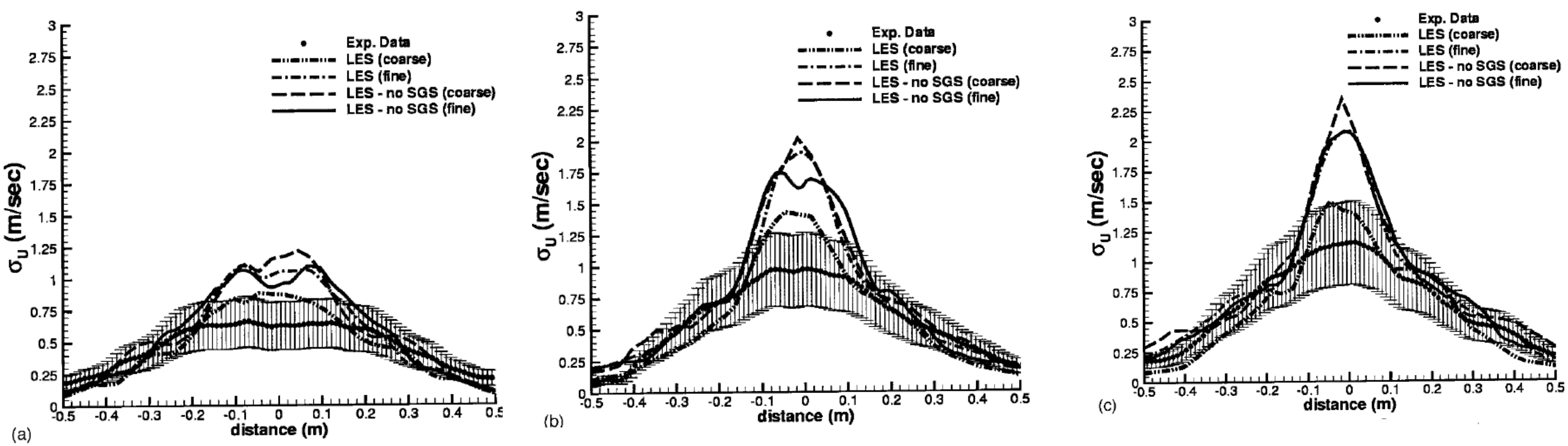


(c)

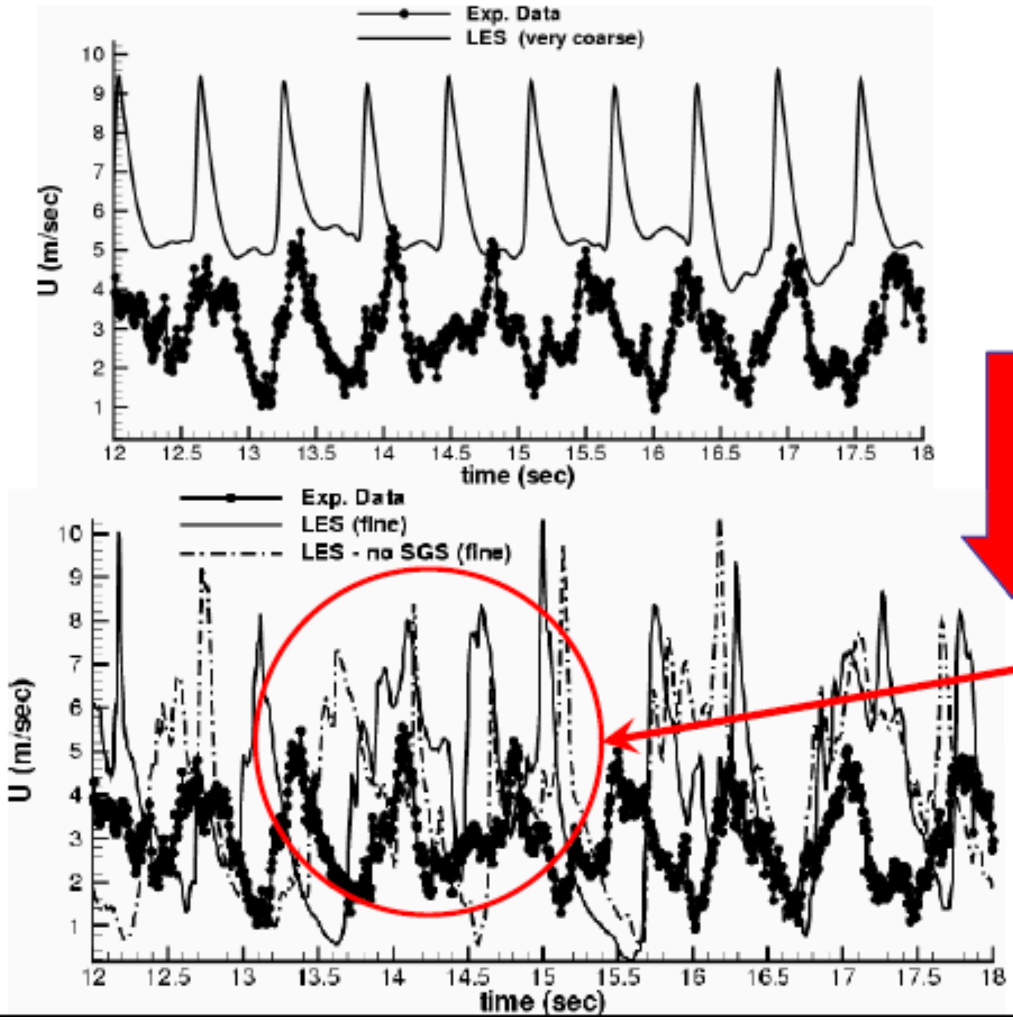
RMS Vertical Velocity





Puffing – Sandia Grid Resolution Results

Centerline Stream-wise Velocity Time History at x/D=1

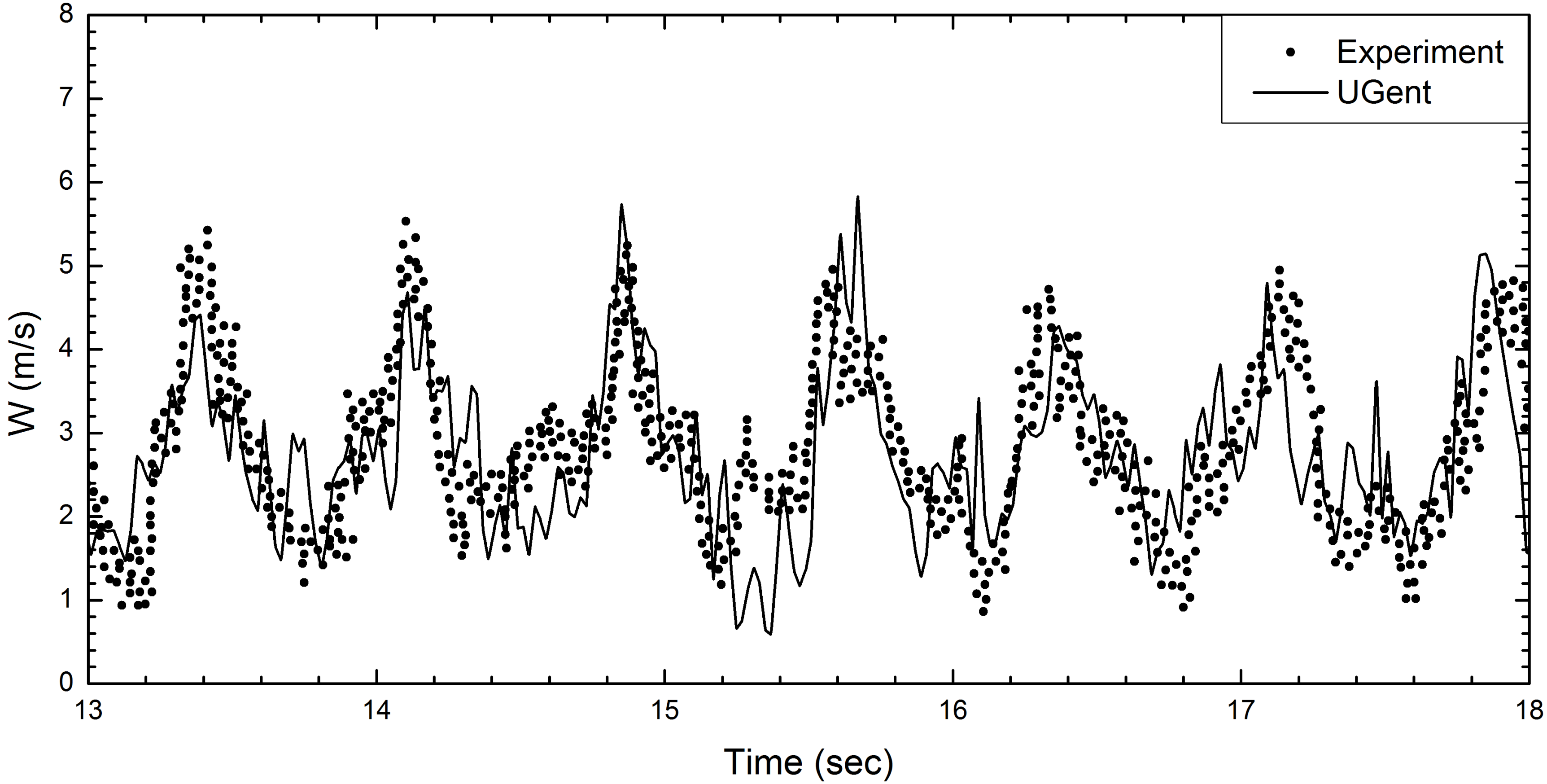


~ 0.25 Million Grid Pts

Additional resolution also captures secondary instabilitie resulting in a more irregular signal

~2.5 Million Grid Pts

Puffing Frequency Measurements



DISCUSSION