NY STAR Center for Environmental Quality Systems

Strategically Targeted Academic Research

Challenges in Evaluating Turbulence Models with Benchmark Cases

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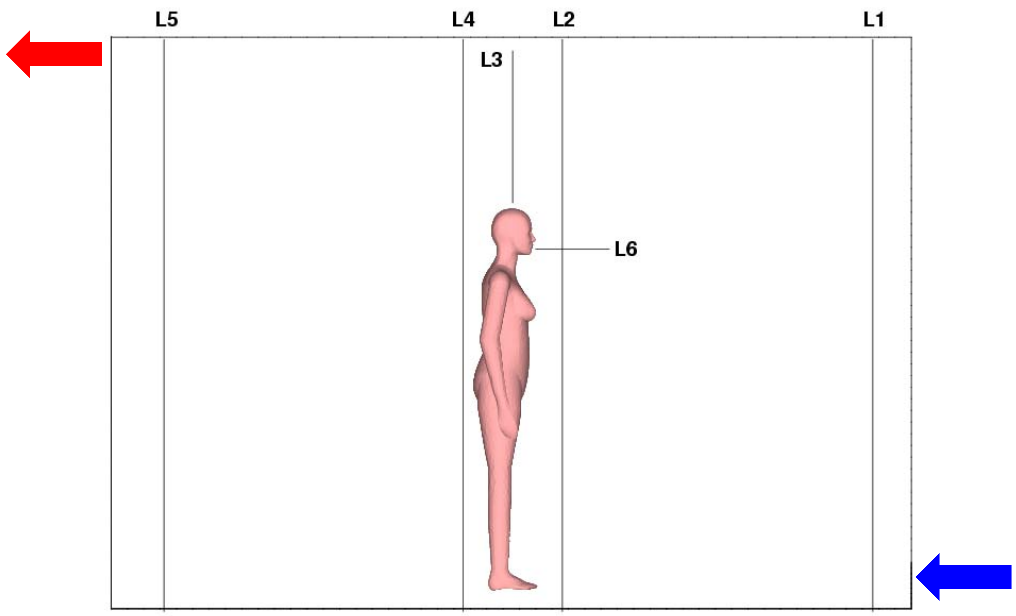
Background

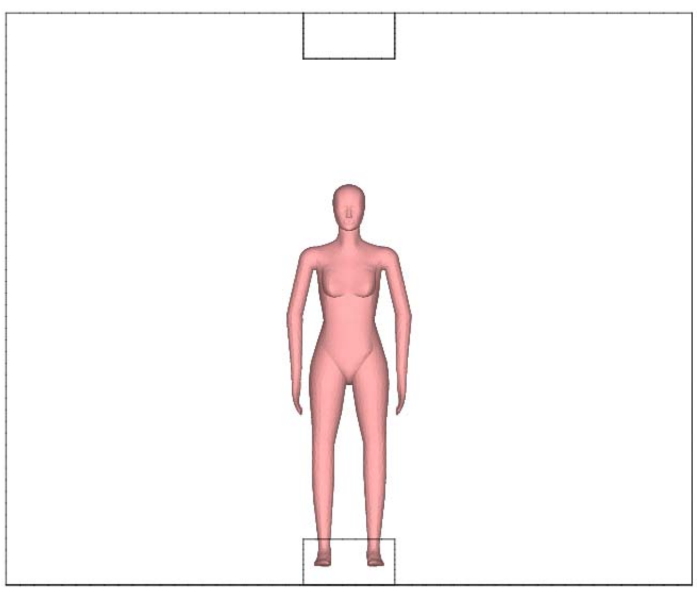
- Why is turbulence modeling important in the Personal Micro-Environment (PME)?
  - *Is almost always encountered in PME flows*
  - *Turbulence is often on the same order as the mean flow*
  - *Important for other assessments (thermal comfort, personal exposure)*
- Why is turbulence modeling difficult in the PME?
  - *Few canonical benchmark cases with high fidelity data of known error to validate models*
  - *Often involve one or several known problematic turbulent phenomena*
    1. Jet flows
    2. Transitional Reynolds number flows
    3. Thermal buoyancy
- Example: PME benchmark case
  - *Displacement ventilation with standing heated manikin*

Displacement Ventilation Set-up

- Standing thermal manikin in displacement type ventilation
- Flow now has a low-speed wall jet, thermal buoyancy and recirculating room flow



Standing Thermal Mannequin in Disp. Type Ventilation: side view

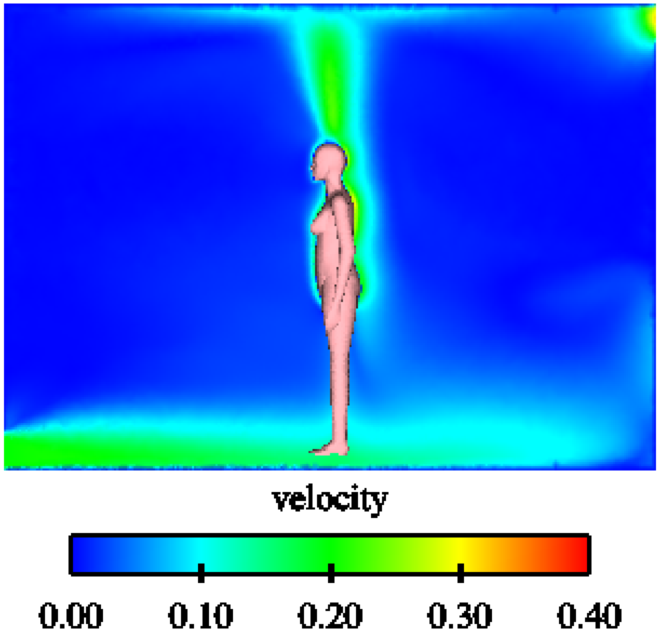


Standing Thermal Mannequin in Disp. Type Ventilation: front view

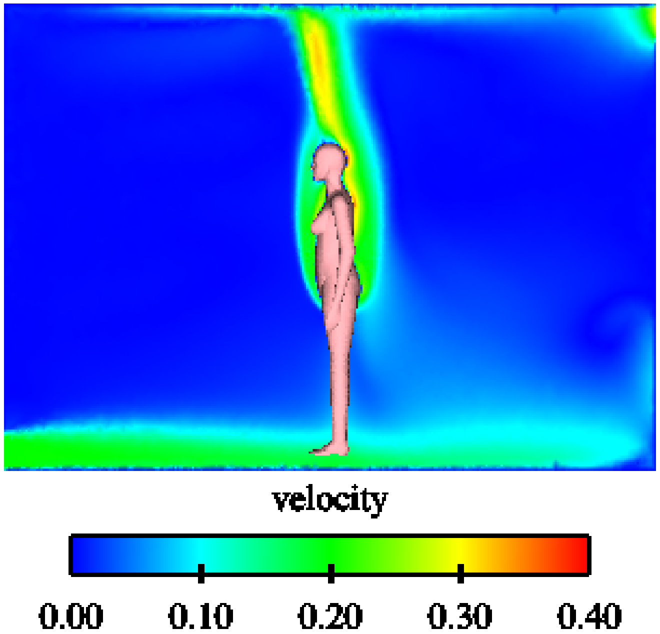
CFD Calculations - Thermal Plume

- Thermal plume of v^2-*f* much thicker than standard *k*-ε
- Data as well LES confirmed that v^2-*f* better predicts thermal plume

Standard *k*-ε

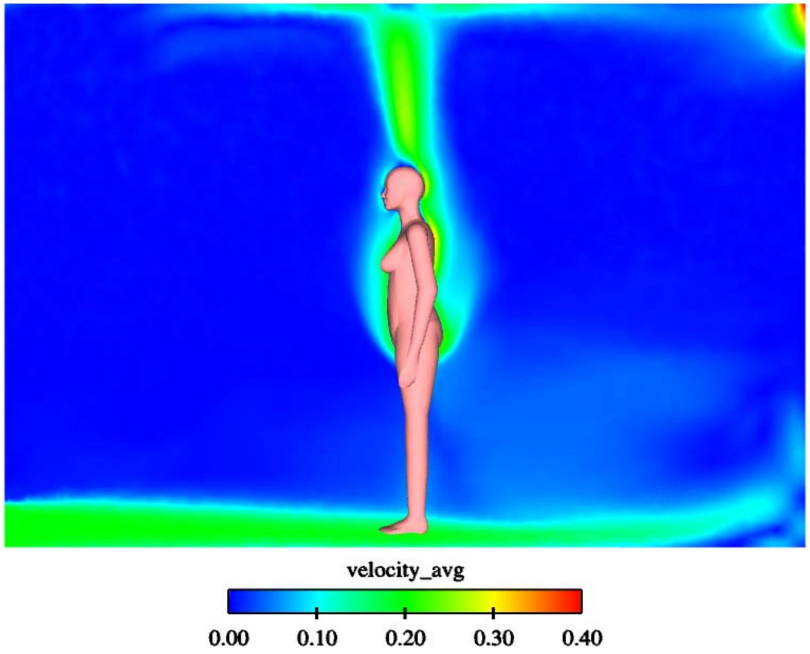


v^2-*f*



Large-Eddy Simulation – Thermal Plume

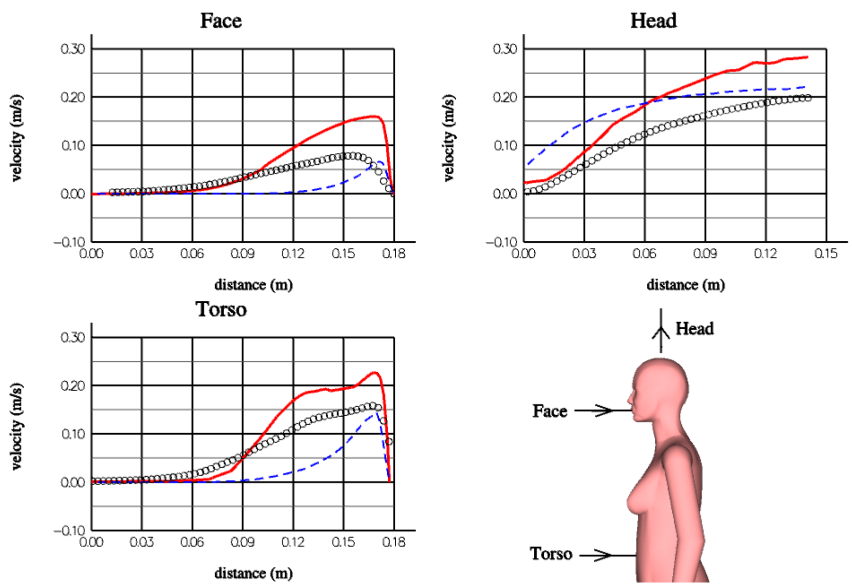
- Large Eddy Simulation (dynamic Smagorinsky-Lilly)
  - *~7 million cells*
  - *Δt = 1/5000 sec. (min. cell length / max. velocity)*
  - *180 sec. (flow-time) then saved 20 sec. (flow-time) data*



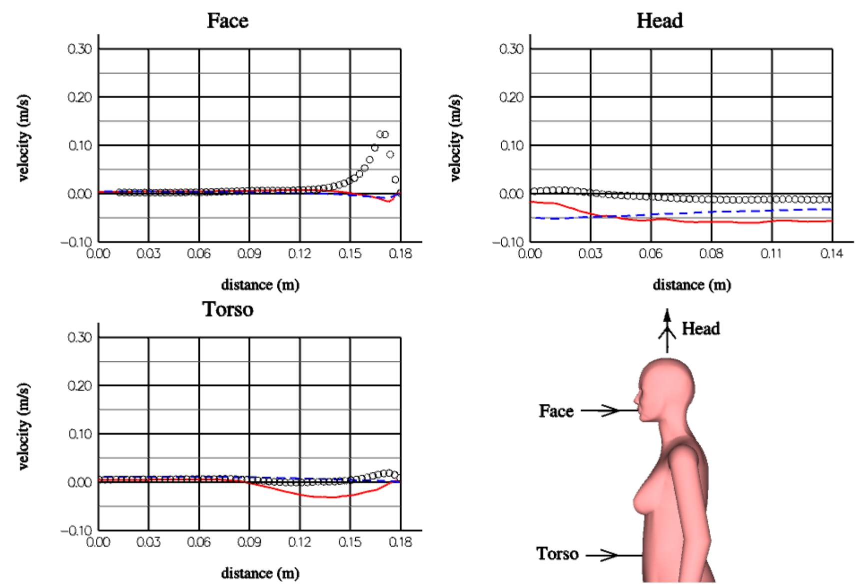
Animation: LES (1), LES (2)

Experimental Data – Thermal Plume

- PIV measurements near the manikin
- *v^2-f* predicts shape of thermal boundary layer much better than standard *k-ε*
- Spike in data horizontal velocity at face



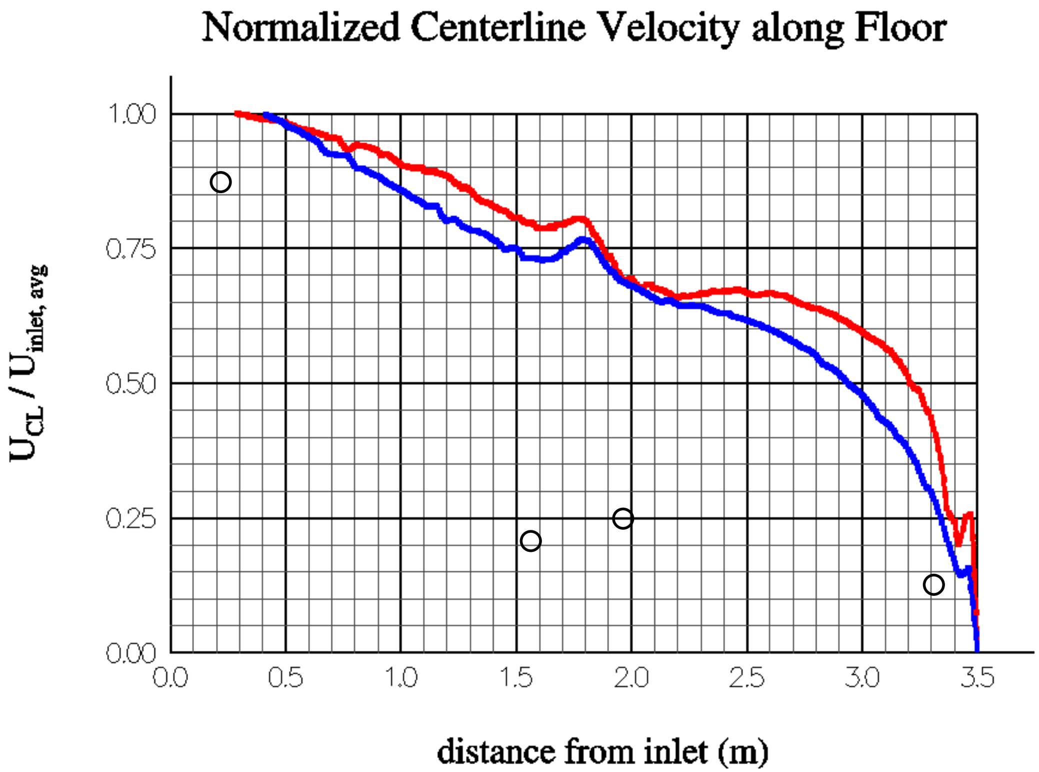
Vertical Velocity: **CFD – v^2-f**, **CFD – ske**, **Kato PIV data** ○



Horizontal Velocity: **CFD – v^2-f**, **CFD – ske**, **Kato PIV data** ○

Displacement Ventilation – Inlet Jet

- Ultra-sonic anemometer measurements
- Experimental data shows rapid decay of CL jet velocity
- Predictions show CL jet velocity decreases slower



Velocity Magnitude: **CFD – v²-f**, **CFD – ske**, **Kato U-S Anen, data** ○

Axi-Symmetric Free Jet

- Looked at two fundamental jet problems to evaluate turbulence models
  - *Axi-symmetric free jet*
  - *3D wall jet (unconfined)*
- RANS models can predict the important features of the axi-symmetric free jet:
  - *Spread rate*
  - *Centerline velocity decay*

	Experiment	**Standard** ***k-ε***	**v^2-f**	**RSM**
Spread rate	0.10	0.123	0.090	0.113
B	6.0	4.93	6.33	5.18

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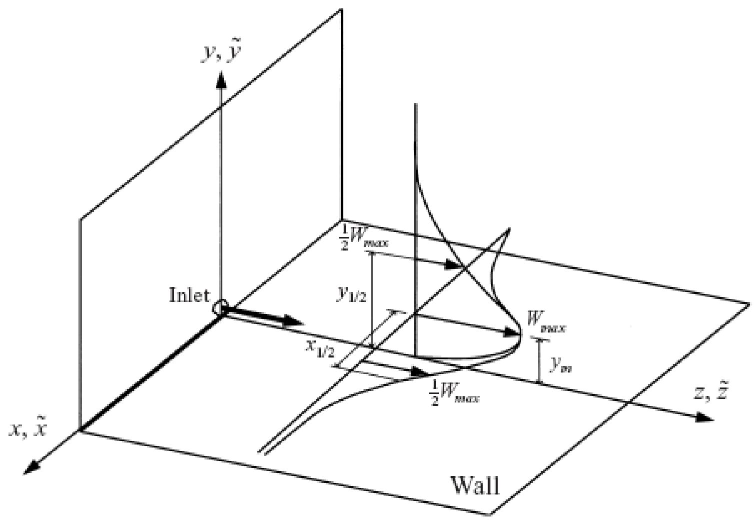
3D Wall Jet

- Eddy-viscosity RANS models have difficulty predicting the 3D wall jet
- Experiments show lateral spreading rate 5-6x higher than normal
- Due to creation of streamwise vorticity from imbalance of fluctuating normal Reynolds stresses *(Kraft and Launder JFM 2001)*

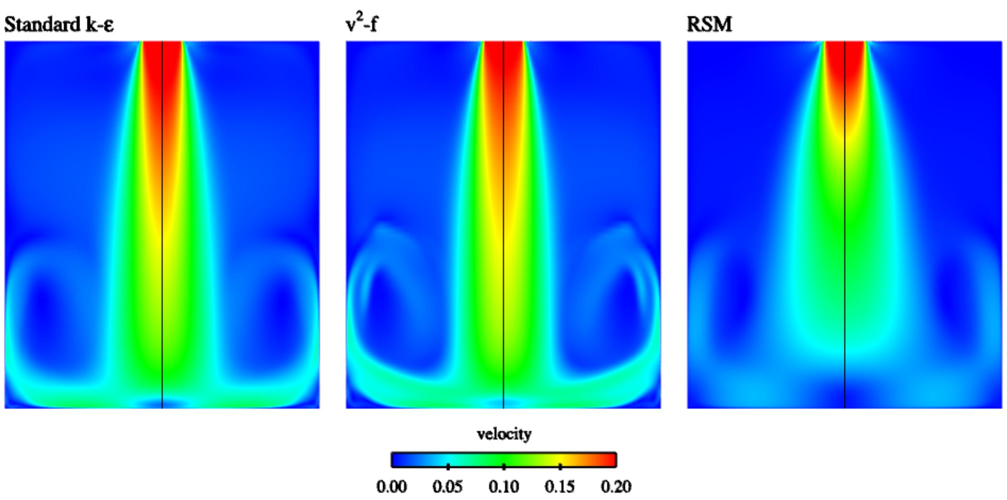


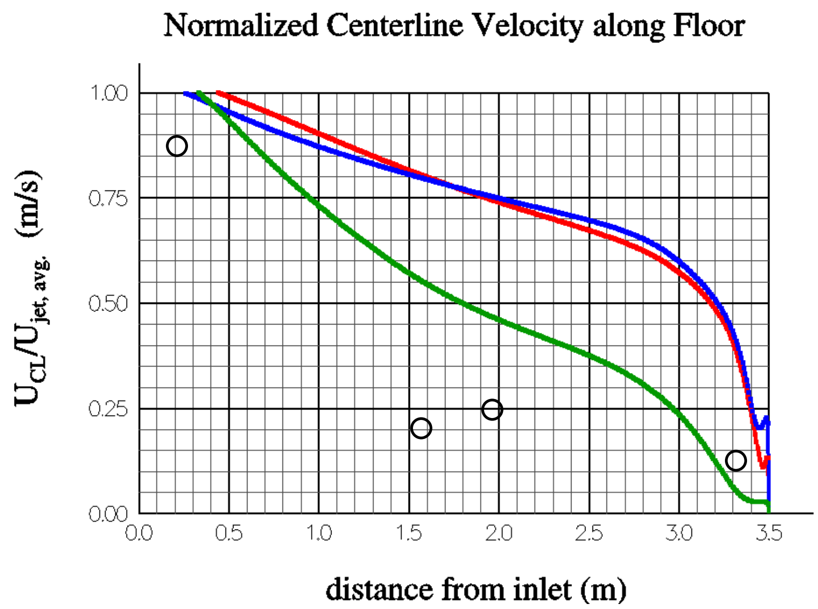
3D Unconfined Wall Jet Schematic: figure from Kraft & Launder JFM 2001

	Exp.	Standard k-ε	v^2-f	RSM
Normal $\frac{dy_{1/2}}{dz}$	0.065	0.089	0.078	0.050
Lateral $\frac{dx_{1/2}}{dz}$	0.320	0.085	0.076	0.646
Ratio	4.92	0.96	0.96	12.92

Confined 3D Wall Jet

- 3D jet from inlet confined by walls – spread and decay rates affected by walls
- Investigated this affect by using same displacement room <u>without</u> manikin





Velocity Magnitude: **CFD – v^2-f**, **CFD – ske**, **CFD – RSM**, **Kato U-S Anen, data ○**

Inlet Non-Uniformity

- Inlet not uniform and average magnitude less than assumed
- Including non-uniformity did not improve prediction – normalized profiles nearly the same

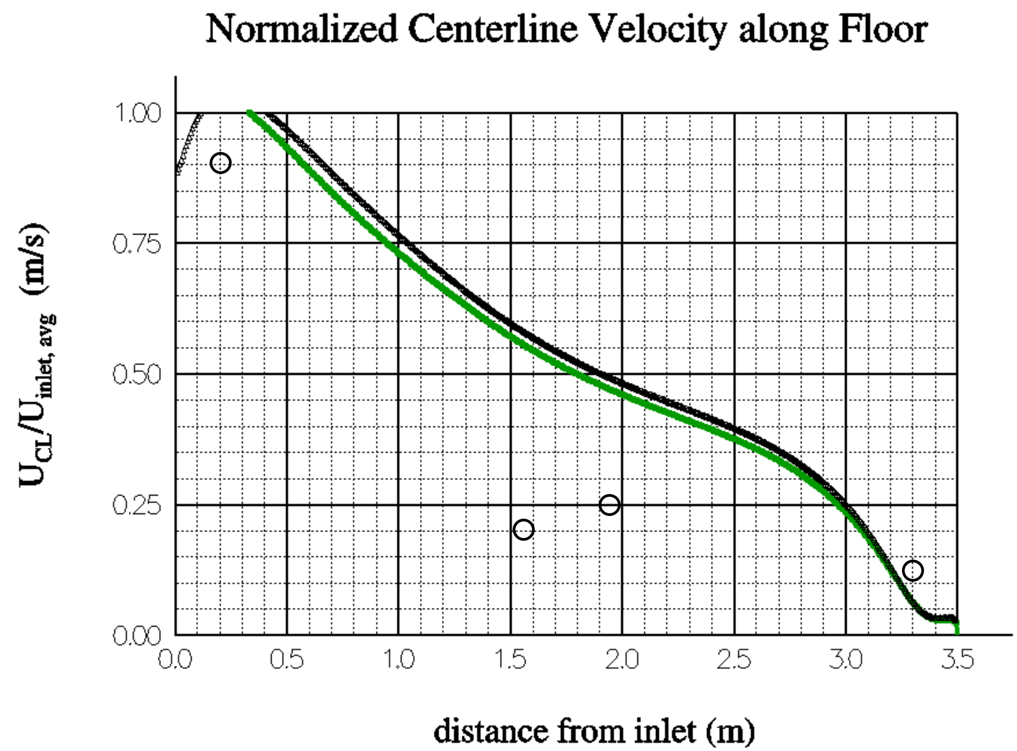
$\overline{U}_{inlet} = 0.181$ m/s, $std.\ dev. = 0.0275$ m/s

0.160	0.155	0.215	0.195	0.170
0.115	0.180	0.160	0.190	0.180
0.170	0.190	0.205	0.220	0.210

0.20 m

0.40 m

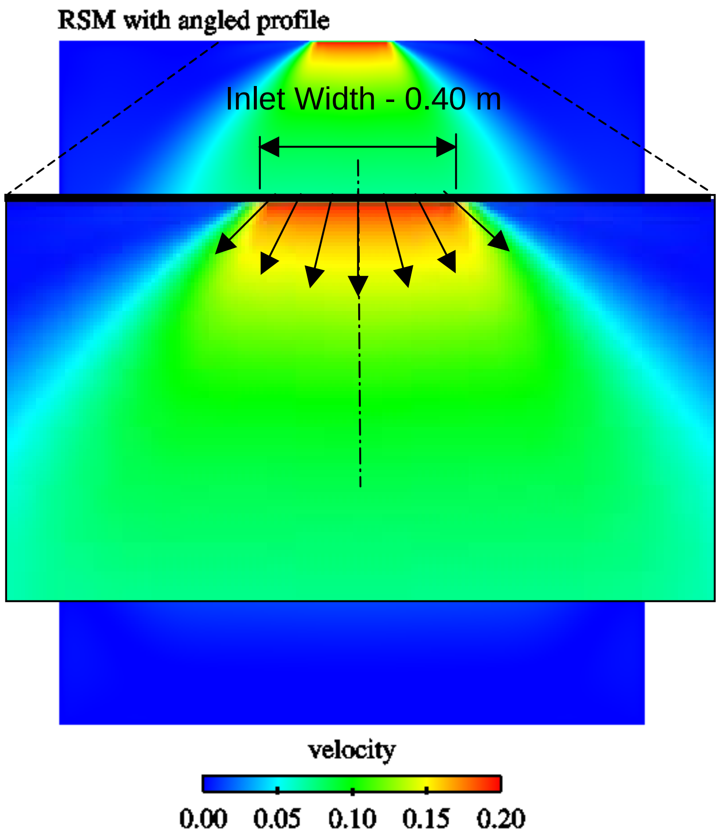
Velocity Magnitudes Measured at Inlet

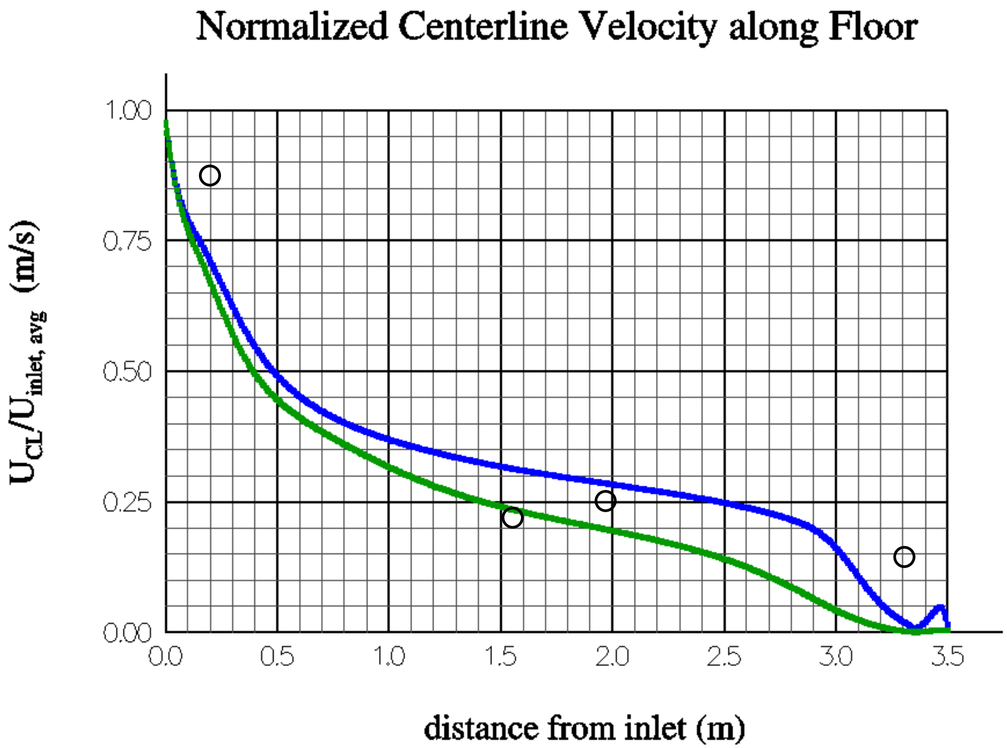


Normalized Velocity Magnitude: **CFD – RSM**, **Kato U-S Anen, Data** ○

Inlet Velocity Angle

- Magnitude was measured at the inlet but no components
- RSM could not account for low centerline velocities of data
- Varying the direction of inlet velocity angle could account for difference

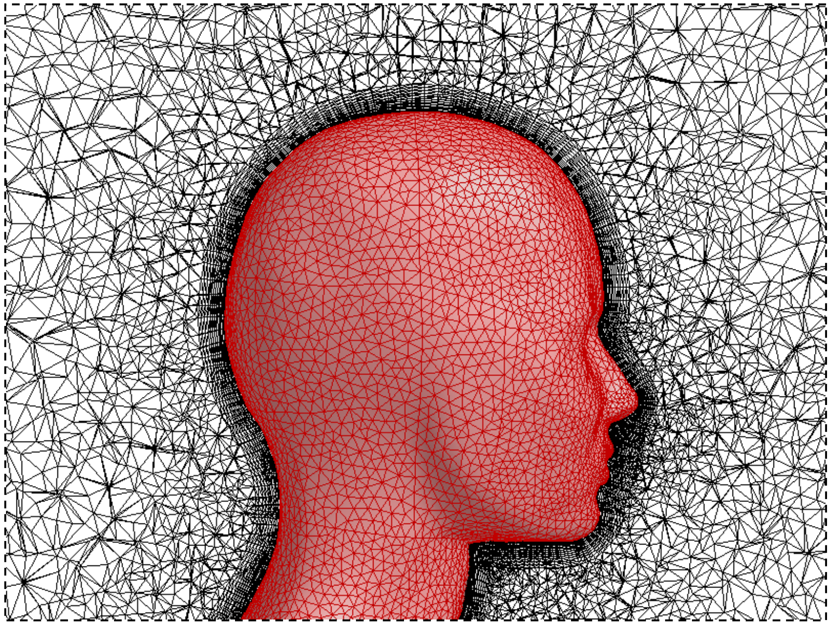




Normalized Velocity Magnitude: **CFD – ske**, **CFD – RSM**

Summary & Questions

- v^2-*f* predicts thermal plume better the standard k-e
- v^2-*f* and standard k-ε OK for axi-sym. jet but not for 3D wall jet – need full Reynolds stress
- RSM can not explain the trend in the centerline velocity data
- What is the interaction between the inlet jet and the thermal plume?
- Reliable measurement of mean and turbulence flow quantities – with know error estimates - needed for validation of PME flows



Acknowledgments

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