Comparison of CFD Softwares to Model Pollutant Dispersion

Evan Dienstman, Emily Ho, Justin Sun, Alex Wang

HKUST

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Outline

Outline

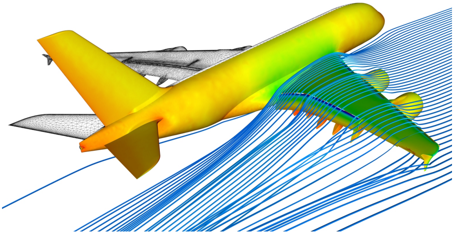
1. Introduction
2. Setting Up the Model
3. Results
4. Analysis
5. Conclusions

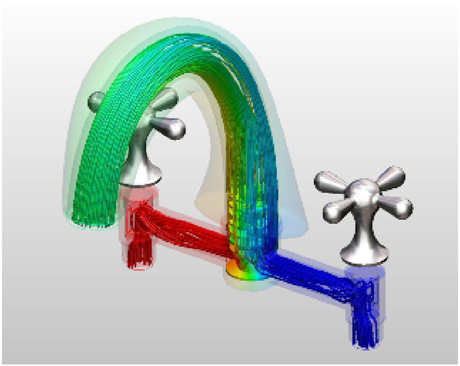
A globally recognized engineering firm that offers technical and management solutions, specialising in construction, engineering, environmental services, etc.

Air Pollution

[3]

Computational Fluid Dynamics (CFD)





[1] [4]

The Navier-Stokes Equations (Incompressible)

- Equation of continuity:

$$\frac{\partial u_i}{\partial x_i} = 0$$

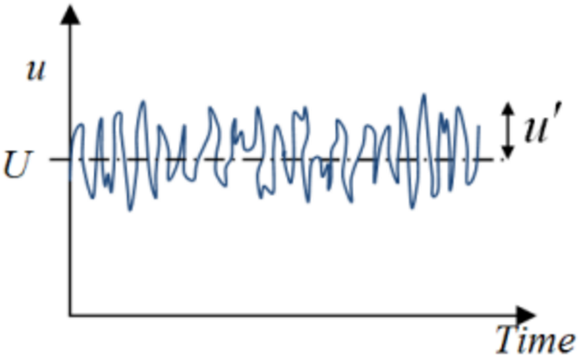
- Equation of momentum:

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}(2\mu s_{ji}) + p g_i,$$

where $s_{ji} = \frac{1}{2}(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i})$.

Reynolds Averaging

Mean component + Fluctuating component



$$u = U + u'$$

[5]

Reynolds Averaging Cont.

For a generic variable $u(\mathbf{x}, t)$, we have

$$u(\mathbf{x}, t) = U(\mathbf{x}) + u'(\mathbf{x}, t),$$

where Reynolds time-averaging is defined as

$$U(\mathbf{x}) =: \bar{u}(\mathbf{x}, t) = \lim_{\tau \to \infty} \frac{1}{\tau} \int_t^{t+\tau} u(\mathbf{x}, t)\, \mathrm{d}t.$$

[2]

The Reynolds-Averaged Navier-Stokes (RANS) Equations

- Equation of continuity:

$$\frac{\partial U_i}{\partial x_i} = \frac{\partial u_i'}{\partial x_i} = 0$$

- Equation of momentum:

$$\frac{\partial}{\partial t}(\rho U_i) + U_j \frac{\partial}{\partial x_j}(\rho U_i) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}(2\rho\nu \overline{S_{ji}}) - \frac{\partial}{\partial x_j}(\rho \overline{u_i' u_j'}),$$

where $S_{ji} = \frac{1}{2}(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i})$ is the mean strain rate tensor.

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where $S_{ji} = \frac{1}{2}(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i})$ is the mean strain rate tensor.

Note: the nonlinear term $\rho\overline{u_i' u_j'}$ is called the Reynolds stress.

[2]

The Boussinesq Eddy Viscosity Assumption

- For an incompressible flow, the Reynolds stress is modeled as

$$\rho\overline{u_i'u_j'} = \mu_t\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \frac{2}{3}k\rho\delta_{ij}.$$

The Boussinesq Eddy Viscosity Assumption

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The scalar property μ_t is called the eddy viscosity.

[2]

Generic Scalar Transport Equation

- For a generic scalar variable ϕ, we have

$$\frac{\partial(\rho\phi)}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i \phi) = \frac{\partial}{\partial x_i}\left[\Gamma \frac{\partial \phi}{\partial x_i}\right] + S,$$

  where S is the source term, and Γ is the diffusion coefficient.

Turbulence Models

The Realizable $k - \epsilon$ (RKE) Model:

$$\begin{cases} \frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho U_j k)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right) + \tau_{ij}\frac{\partial U_i}{\partial x_j} - \rho\epsilon \\ \\ \frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho\epsilon U_j)}{\partial x_j} = \left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\nabla^2\epsilon + C_1 S\rho\epsilon - C_2\frac{\rho\epsilon^2}{k+\sqrt{\nu\epsilon}} \end{cases}$$

[8]

Turbulence Models Cont.

The Shear-Stress Transport (SST) Model:

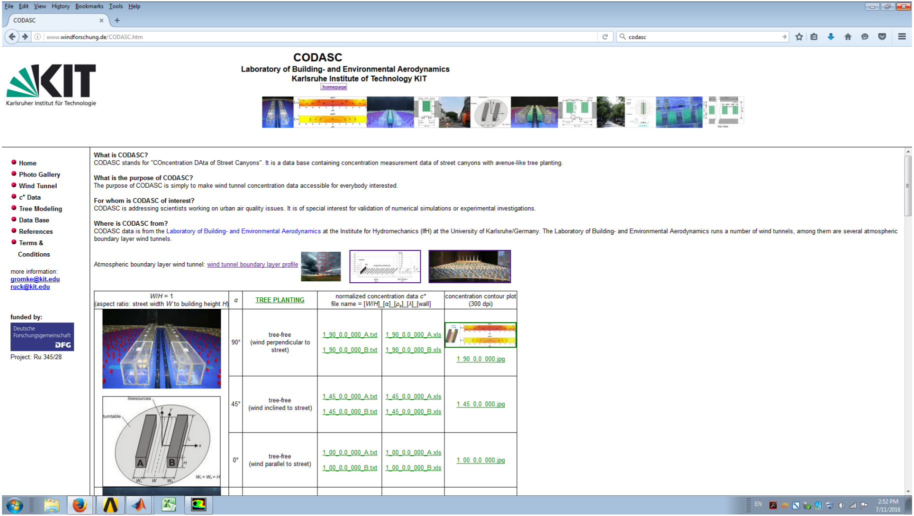
$$\begin{cases} \frac{\partial \rho k}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho u_j k - (\mu + \sigma_k \mu_t)\frac{\partial k}{\partial x_j}\right) = P_k - \beta^* \rho \omega k \\ \\ \frac{\partial \rho \omega}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho u_j \omega - (\mu + \sigma_\omega \mu_t)\frac{\partial \omega}{\partial x_j}\right) = P_\omega - \beta \rho \omega^2 + 2(1 - F_1)\frac{\rho \sigma_{\omega 2}}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} \end{cases}$$

[6]

Outline

- Introduction to the model
- Constructing the model geometry
- Making the mesh
- Discussion of boundary conditions and other parameters

Concentration Data of Street Canyons (CODASC)



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CODASC

www.windforschung.de/CODASC.htm

CODASC

Laboratory of Building- and Environmental Aerodynamics

Karlsruhe Institute of Technology KIT

homepage

Karlsruher Institut für Technologie

- Home
- Photo Gallery
- Wind Tunnel
- c⁺ Data
- Tree Modeling
- Data Base
- References
- Terms & Conditions

more information:
gromke@kit.edu
ruck@kit.edu

funded by:
Deutsche Forschungsgemeinschaft DFG
Project: Ru 345/28

What is CODASC?
CODASC stands for "COncentration DAta of Street Canyons". It is a data base containing concentration measurement data of street canyons with avenue-like tree planting.

What is the purpose of CODASC?
The purpose of CODASC is simply to make wind tunnel concentration data accessible for everybody interested.

For whom is CODASC of interest?
CODASC is addressing scientists working on urban air quality issues. It is of special interest for validation of numerical simulations or experimental investigations.

Where is CODASC from?
CODASC data is from the Laboratory of Building- and Environmental Aerodynamics at the Institute for Hydromechanics (IfH) at the University of Karlsruhe/Germany. The Laboratory of Building- and Environmental Aerodynamics runs a number of wind tunnels, among them are several atmospheric boundary layer wind tunnels.

Atmospheric boundary layer wind tunnel: wind tunnel boundary layer profile

W/H = 1 (aspect ratio: street width W to building height H)	α	TREE PLANTING	normalized concentration data c⁺ file name = [W/H]_[α]_[ρ_s]_[λ]_[wall]		concentration contour plot (300 dpi)
	90°	tree-free (wind perpendicular to street)	1_90_0.0_000_A.txt 1_90_0.0_000_B.txt	1_90_0.0_000_A.xls 1_90_0.0_000_B.xls	1_90_0.0_000.jpg
	45°	tree-free (wind inclined to street)	1_45_0.0_000_A.txt 1_45_0.0_000_B.txt	1_45_0.0_000_A.xls 1_45_0.0_000_B.xls	1_45_0.0_000.jpg
	0°	tree-free (wind parallel to street)	1_00_0.0_000_A.txt 1_00_0.0_000_B.txt	1_00_0.0_000_A.xls 1_00_0.0_000_B.xls	1_00_0.0_000.jpg

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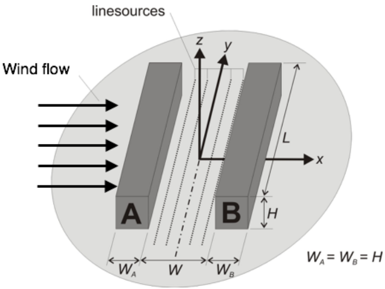
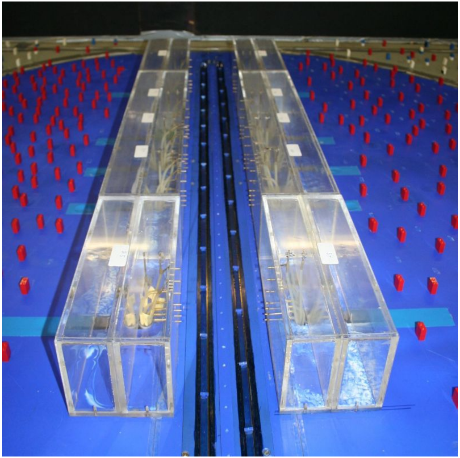
[7]

Geometry





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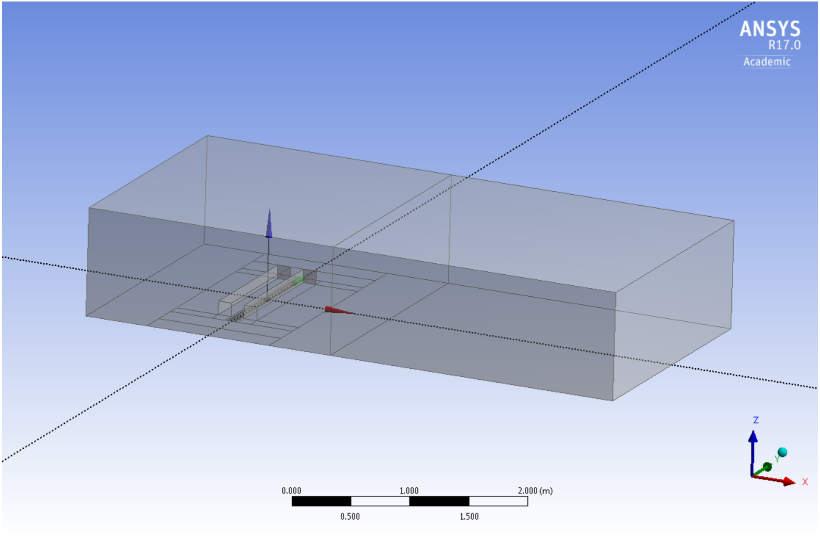
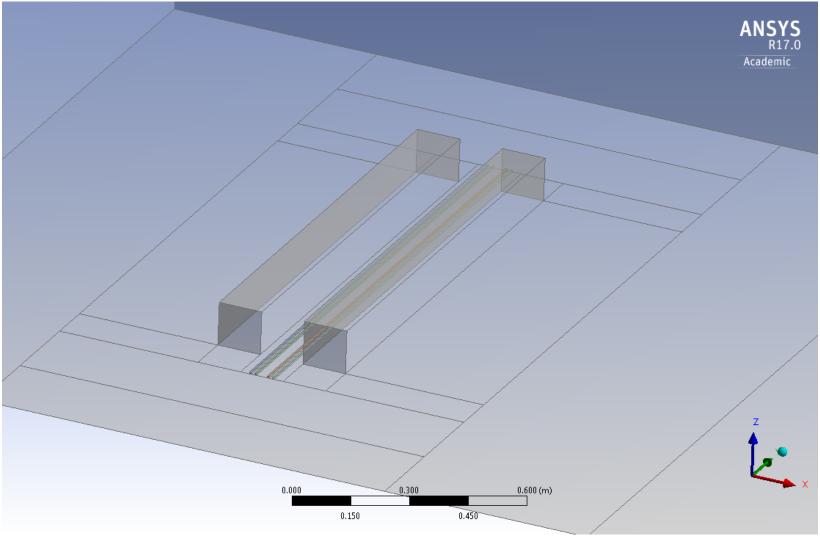
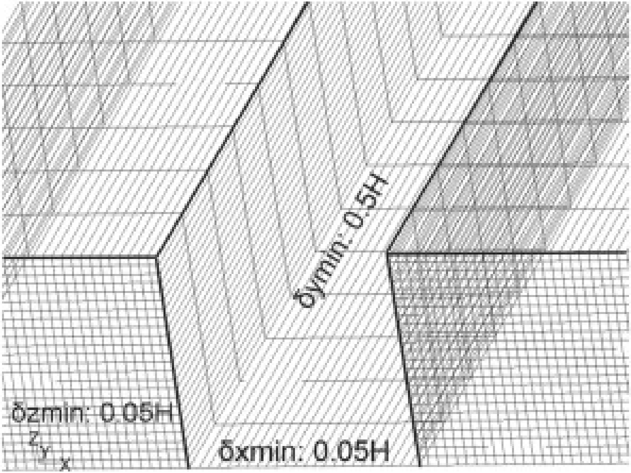
Geometry Cont.



Geometry Cont.



Mesh



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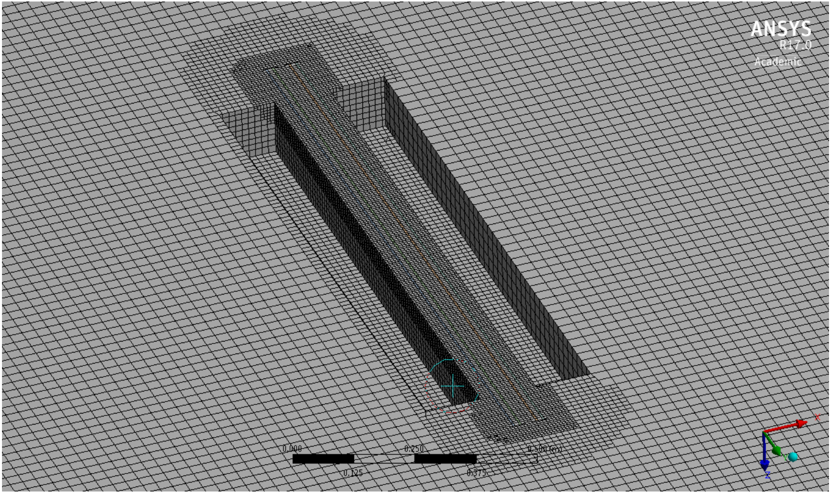
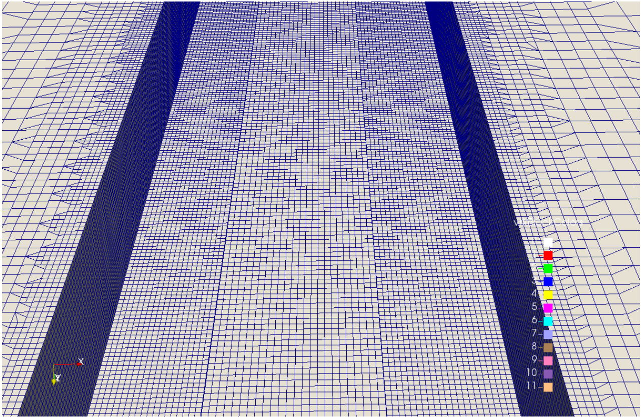
Meshing Cont.

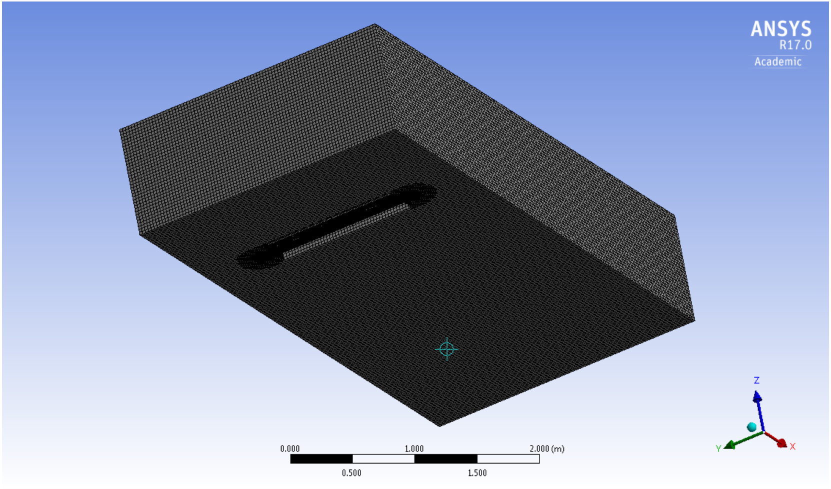


Meshing Cont.

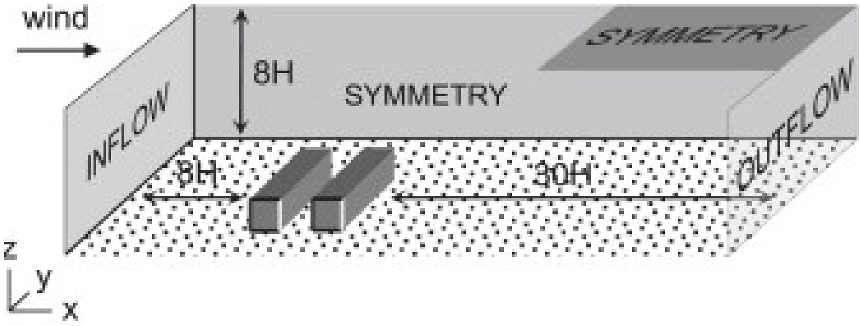


$$y^+ = \frac{y u_\tau}{\nu}$$

Meshing Cont.



Boundary Conditions and Parameters



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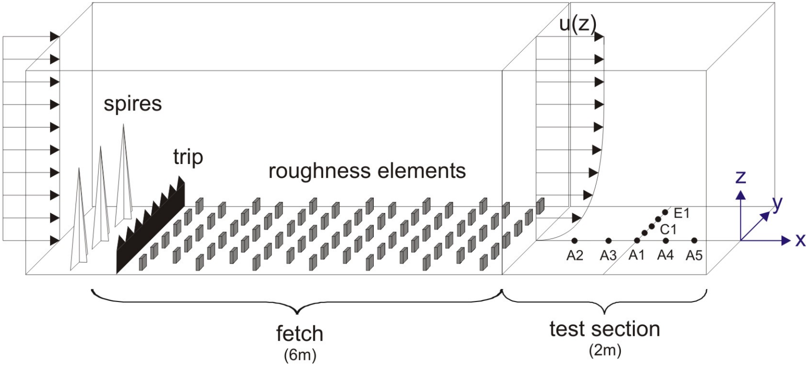
Boundary Conditions and Parameters Cont.



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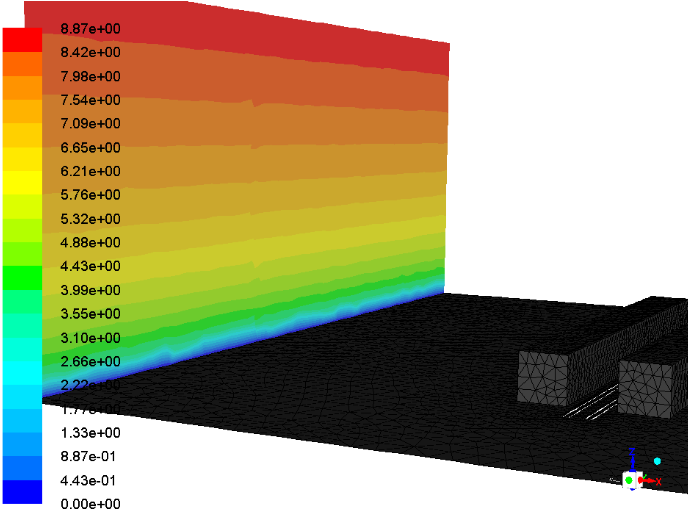
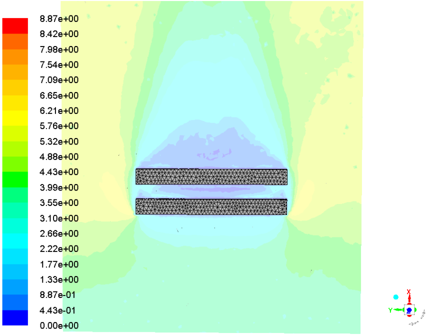
Boundary Conditions and Parameters Cont.

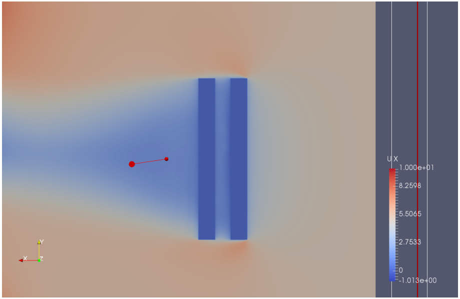


Outline

Results

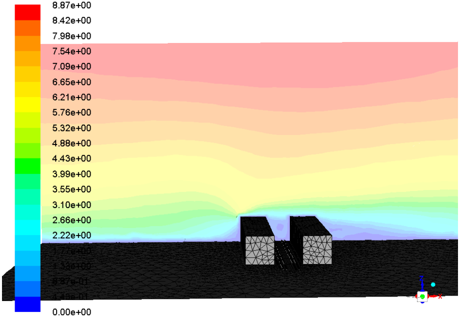


Fluent

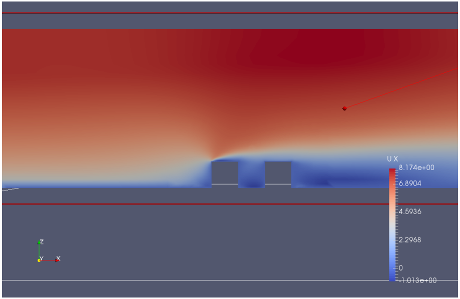


OpenFOAM

Results Cont.



Fluent



OpenFOAM

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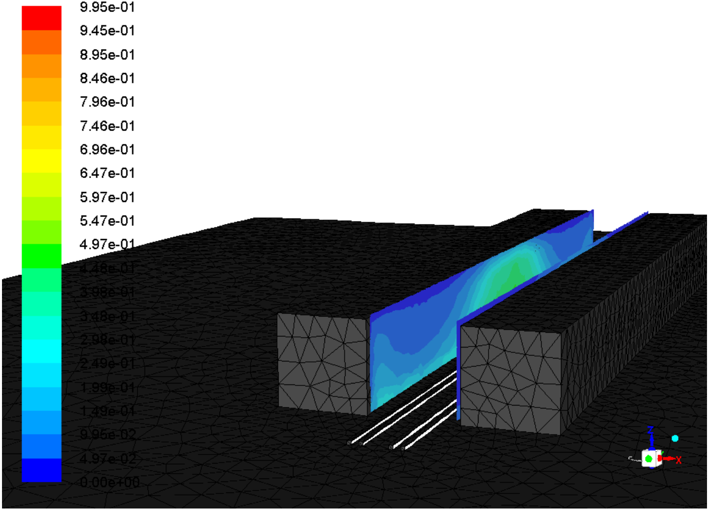
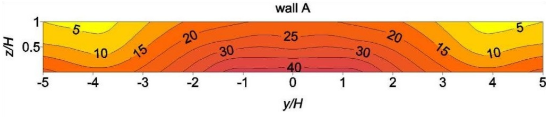


Fluent Results Cont.



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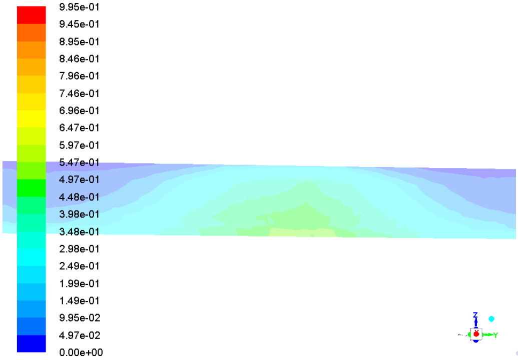
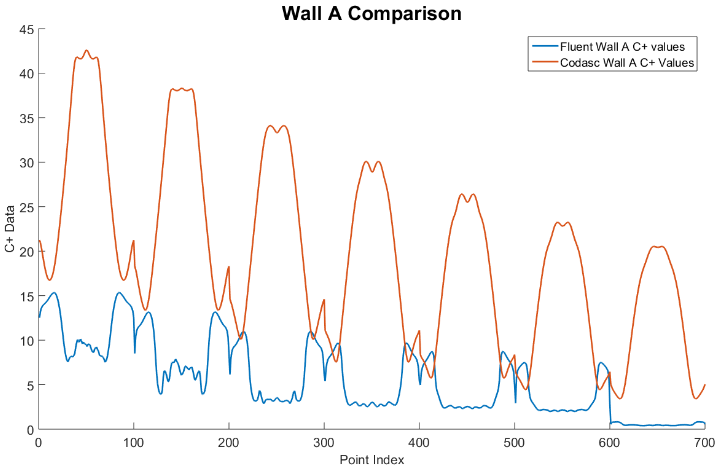
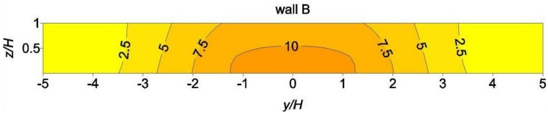


Fluent Results Cont.



Fluent Results Cont.



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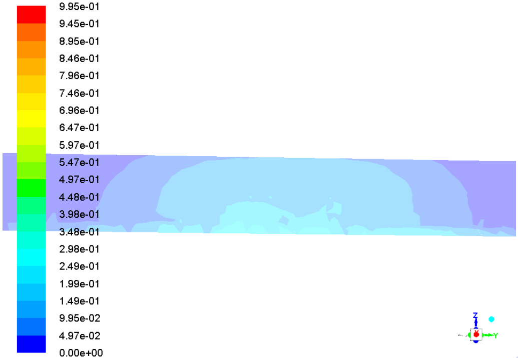
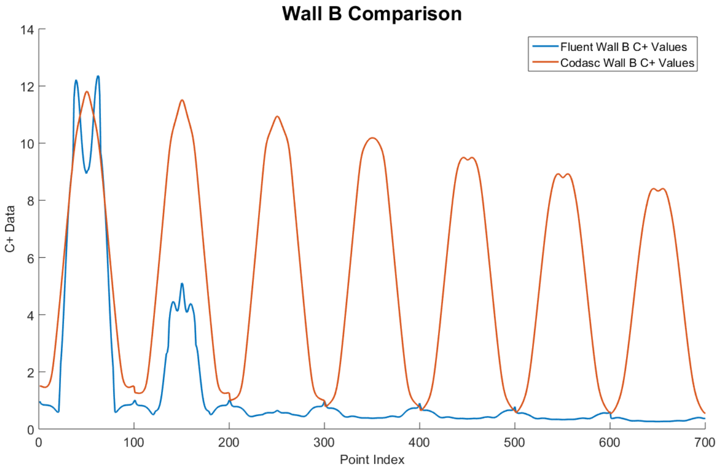
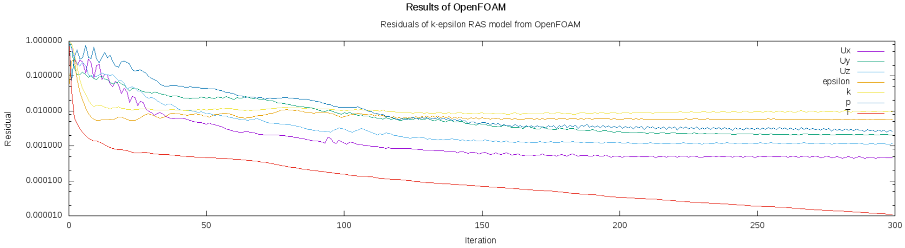
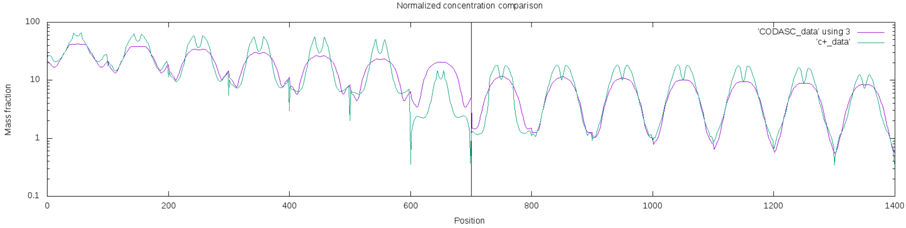


Fluent Results Cont.



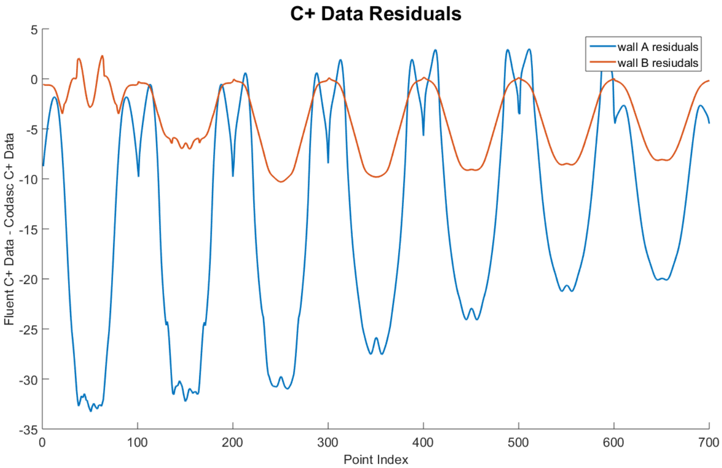
OpenFOAM Results



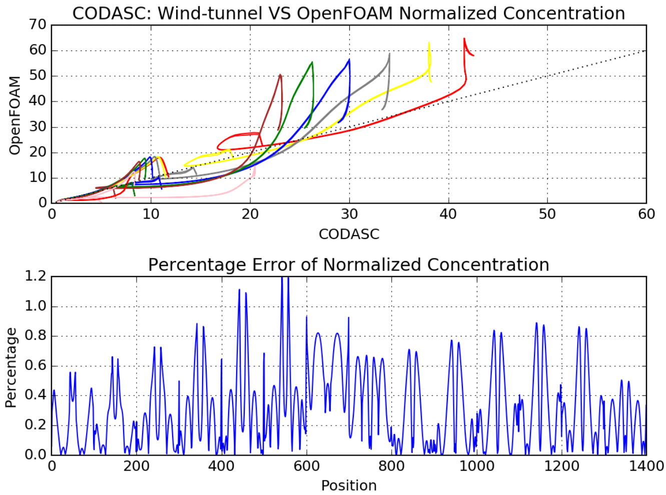


Outline

Fluent Analysis



OpenFOAM Analysis



Outline

Conclusions

- Early results confirm the robustness of the $k - \epsilon$ and species-transport models
- We cannot yet make comparisons between Fluent and OpenFOAM, but we are hopeful about OpenFOAM's performance
- Future work includes refining the mesh, tuning parameters, and using more sophisticated statistical measurements for comparing Fluent with OpenFOAM

Acknowledgements

AECOM

ipam
institute for pure & applied mathematics

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Thank you for listening.

Thank you for listening.
Any Questions?