Process/Equipment Co-Simulation of a Pulverized Coal Plant With Cooling Tower

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Motivation

- Improve water conservation through the cooling tower process. Most of the water consumed in a power plant process is lost in the cooling tower.
- Specific Goals
  - Develop computational tools for cooling tower prediction
  - Develop a cooling tower Reduced Order Model (ROM) which will be a component of a process simulator for a pulverized coal plant.
  - Develop tool for prediction of water vapor/droplets within the cooling tower for use on enhanced water capturing technologies.

Current Status

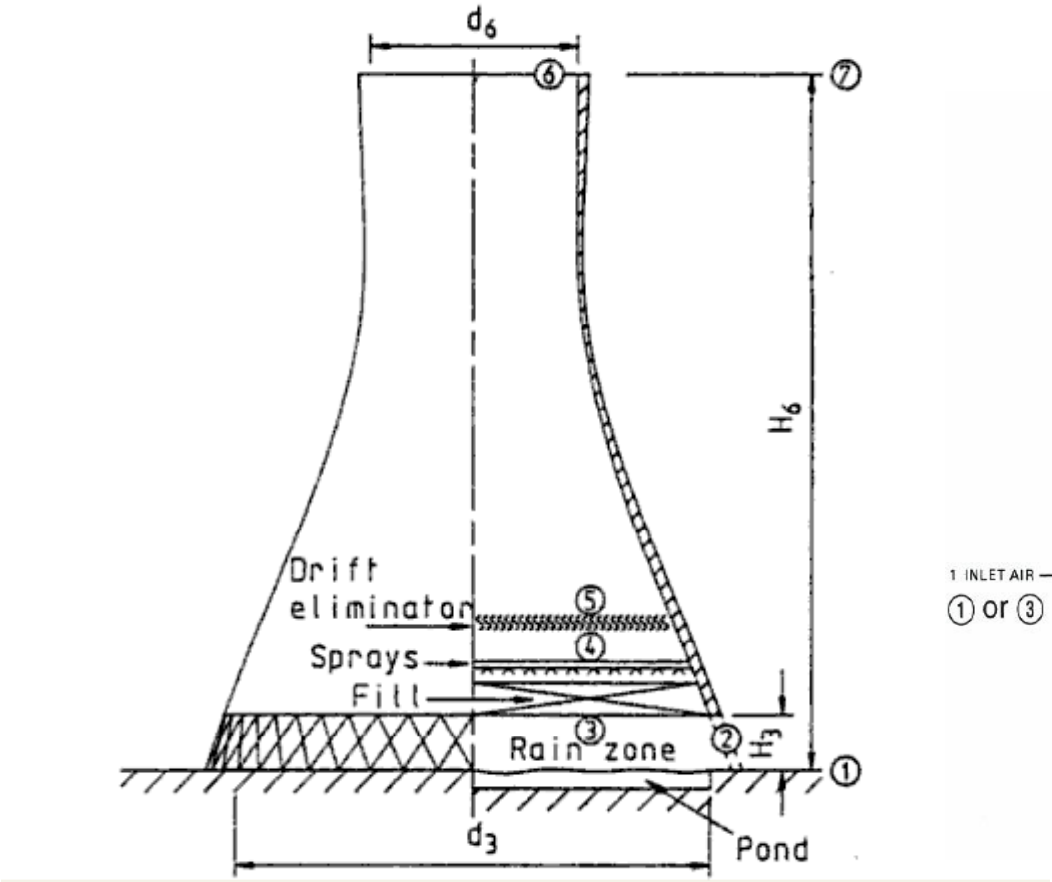
- Focus on Natural Draft Wet Cooling Towers (NDWCT)
- Analysis of Existing Computational Fluid Dynamic (CFD) Models
- Ongoing Review of Literature
- Analysis of Available 1-D Models
- Analysis of Commercially Available Cooling Tower Design Tools (CTI)
- Development of Advanced CFD Cooling Tower Models
  - Global Tower Models
  - Localized High Fidelity Zonal Modeling

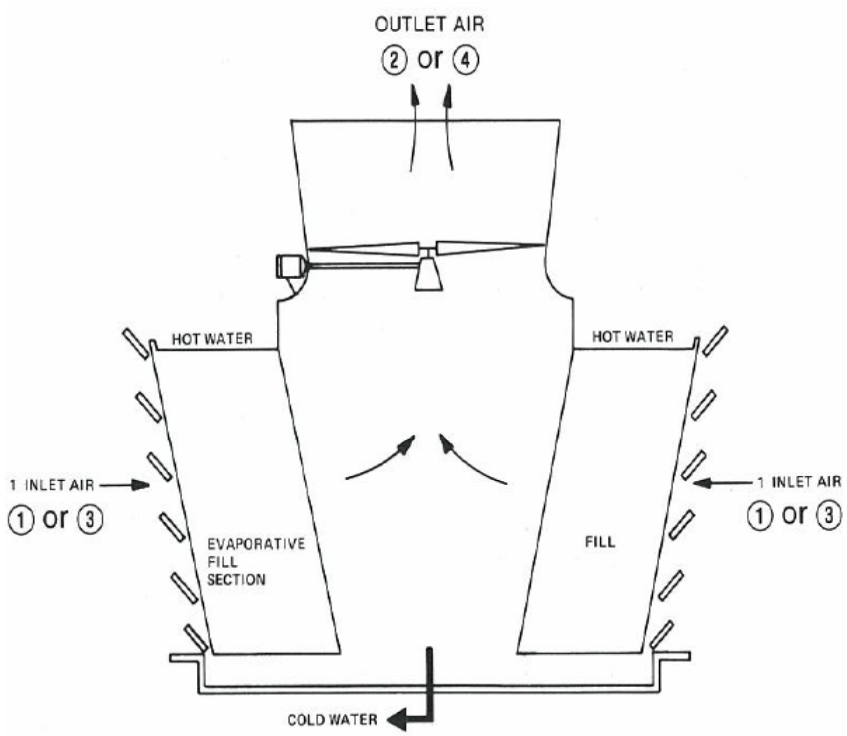
Outline

- Cooling Tower Background
- Relevant Literature
- Overview of Computational Tools
- Current Computational Results
- Reduced Order Model
- Future Work

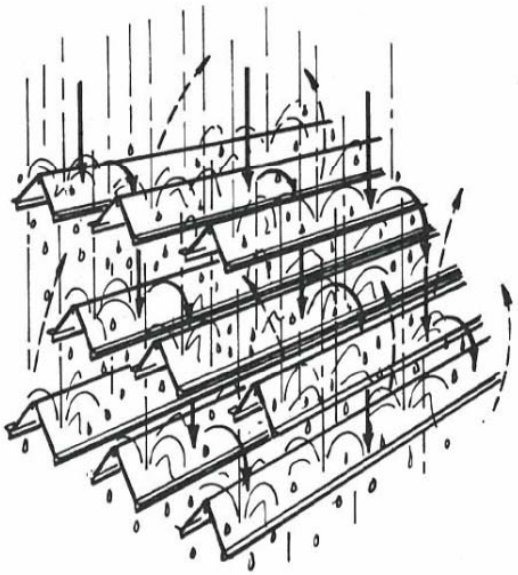
Cooling Tower Types

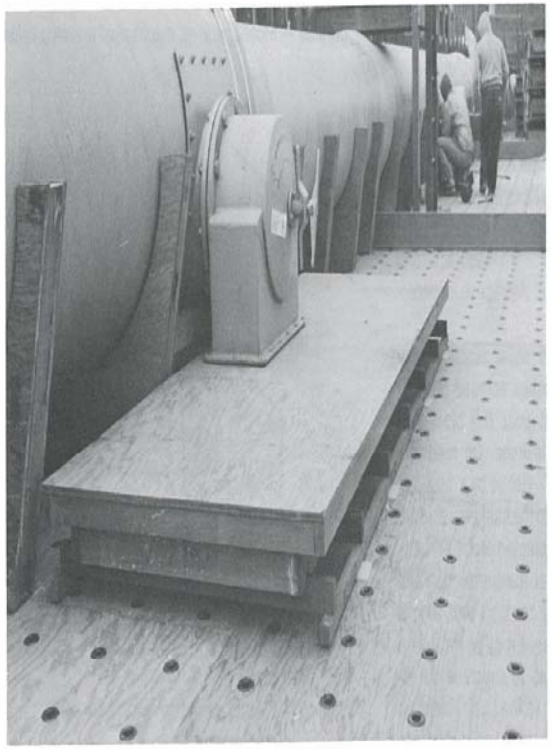
Global Cooling Tower Process





Local Cooling Tower Components





Challenges in CFD Modeling

- Competing Physical Scales
  - Overall Cooling Tower ϑ(m) vs. Droplet Dimensions ϑ(μm)
- Complexity of Internal Components
  - Intricate Fill Geometries / Drift Eliminator Variations
  - Spray Nozzle Designs and Distributions
- Dimensionality
  - 2-D Axi-symmetric (Loss in Physics / Cost Savings)
  - 3-D (Plume Tracking Capable)
- Physical Sub-model Integration
  - Multiphase / Turbulence / Thermodynamics / Heat Transfer

Literature Summary

Citation	Code	Complexity	Objectives
Williamson, N., M. Behnia, and S. Armfield. "Comparison of a 2D Axisymmetric CFD Model of a Natural Draft Wet Cooling Tower and a 1D Model." International Journal of Heat and Mass Transfer 51 (2008): 2227-2236.	FLUENT	1D/2D AXI	Model a specific Cooling tower in Australia
Al-Waked, Rafat, and Masud Behnia. "CFD Simulation of Wet Cooling Towers." Applied Thermal Engineering 26 (2006): 382-395.	FLUENT	3D	Model to Produce Water Outlet Temperature considering effects of droplet diamter and crosswinds
Milosavlejevic, Nenad, and Pertti Heikkila. "A Comprehensive Approach to Cooling Tower Design." Applied Thermal Engineering 21 (2001): 899-915.	FLUENT	3D/2D	Determine Efficiency of Different fill geometries

ROM Methods

- Piecewise multiple linear regression
- Artificial Neural Networks
- Proper Orthogonal Decomposition

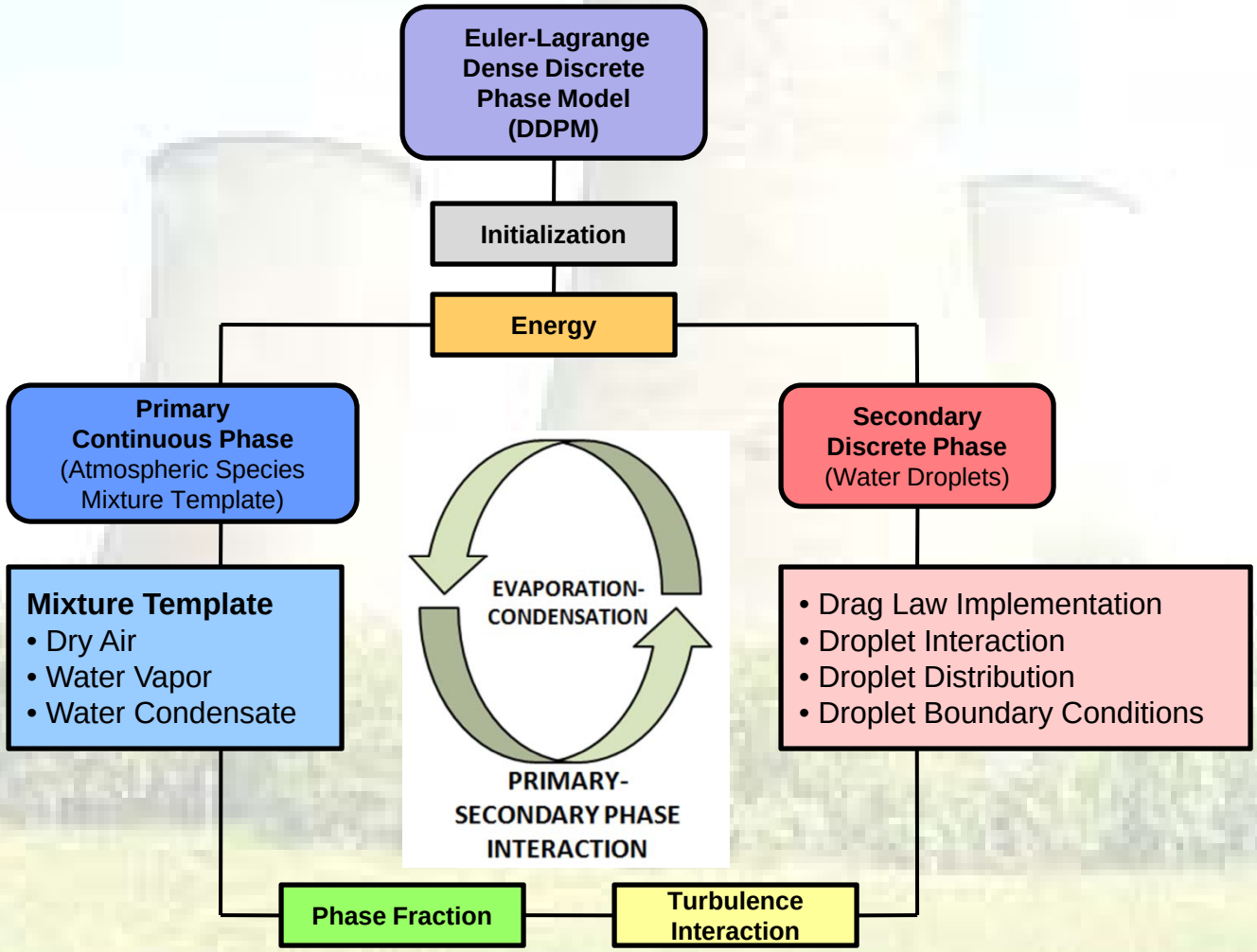
ROM and APECS

- APECS allows detailed CFD simulations to be run as part of a larger simulation in a process simulator.
- CFD simulations can require significant time to produce results, and most process simulators require multiple results from a single block, resulting in substantial time for the process simulation.
- Incorporating a ROM will reduce the computational time and still maintain most of the details from the CFD model.

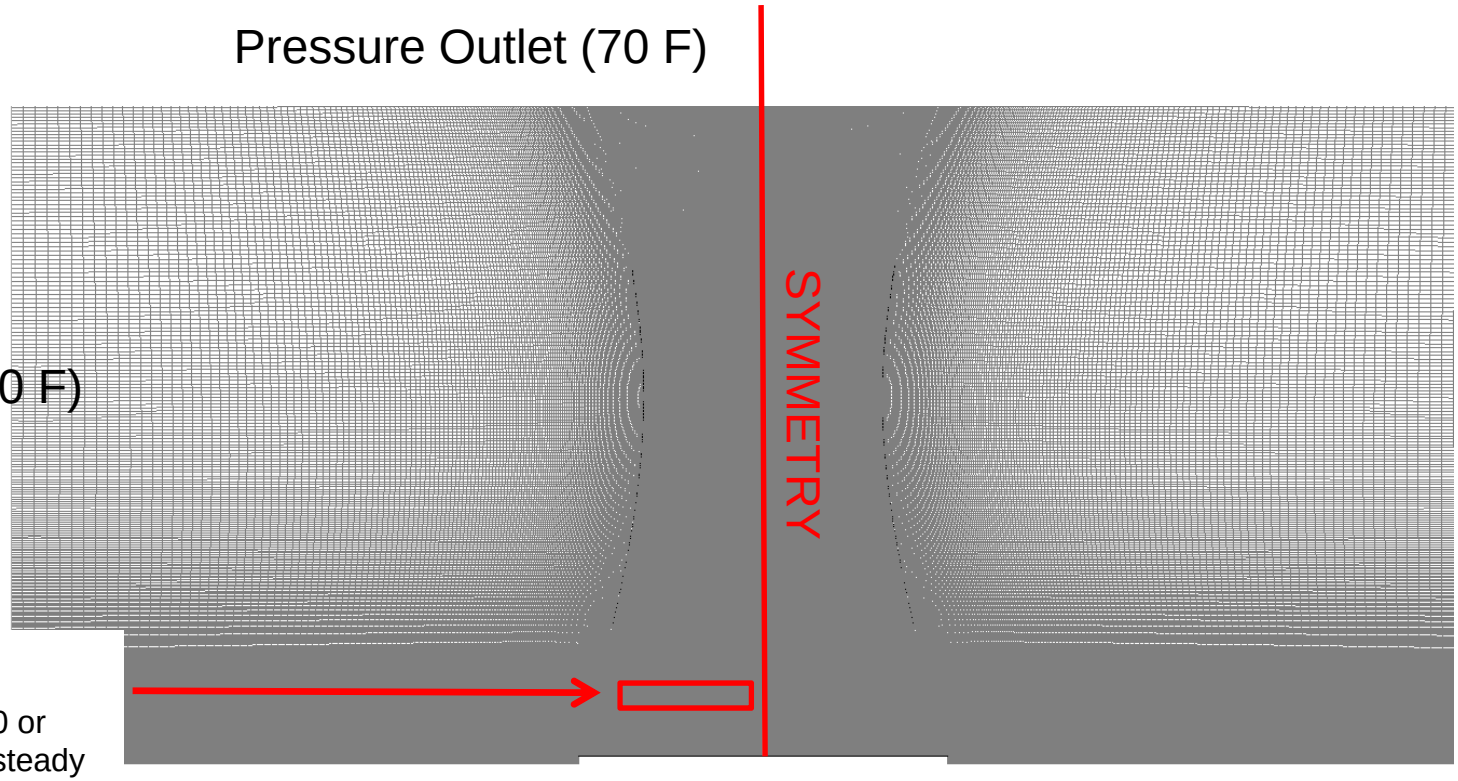
Current Progress Paths

- Development of a 2-D Axi-symmetric model of a hyperbolic NDWCT and a separate detailed model of the fill zone.
  - Stagnant Far Field Boundary Conditions
  - Thermal Conditions Properly Employed
  - Refined Mesh Resolution Results
  - Deflector Interaction
  - Droplet Interaction
  - Numerical Stability
- Examining CFD Code developed and provided by researchers at the University of Sydney.

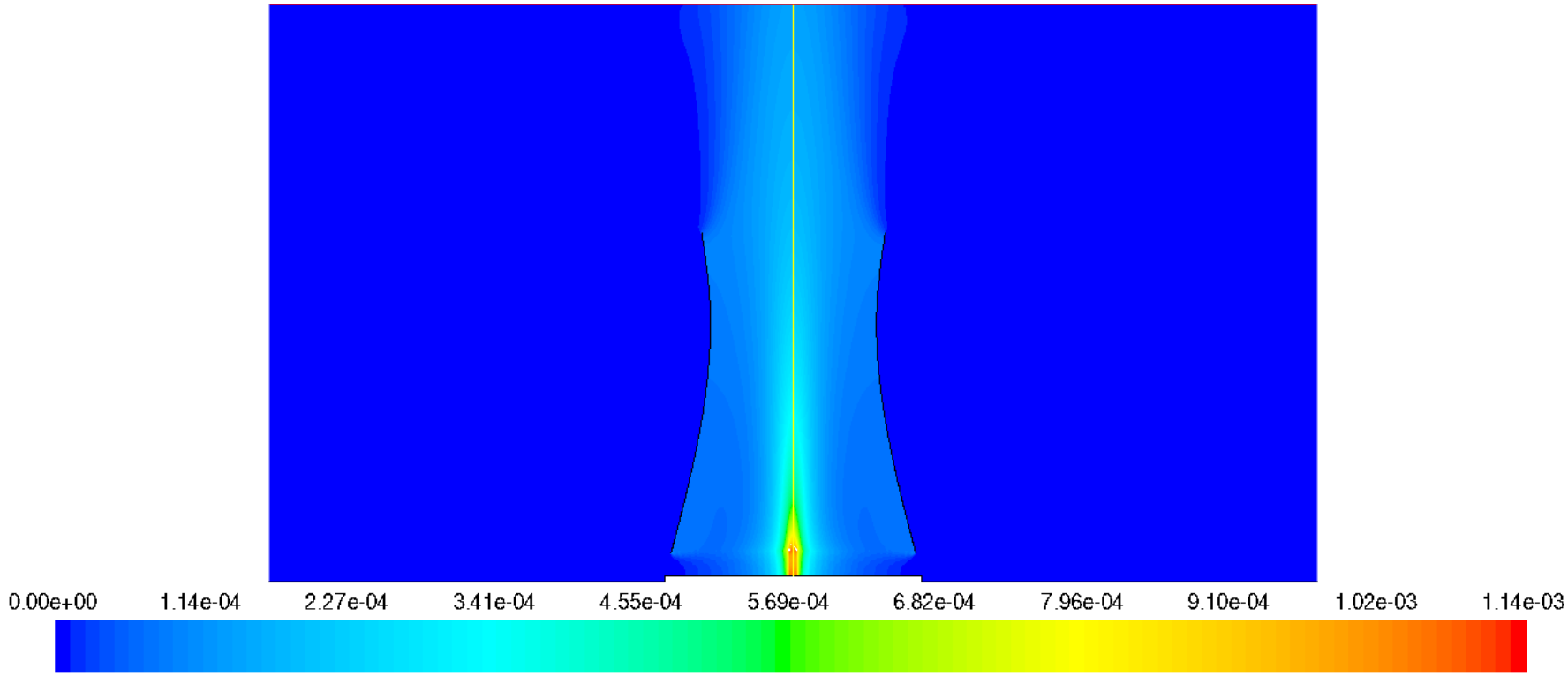
CFD Model Framework



2-D Axi-symmetric CFD Model



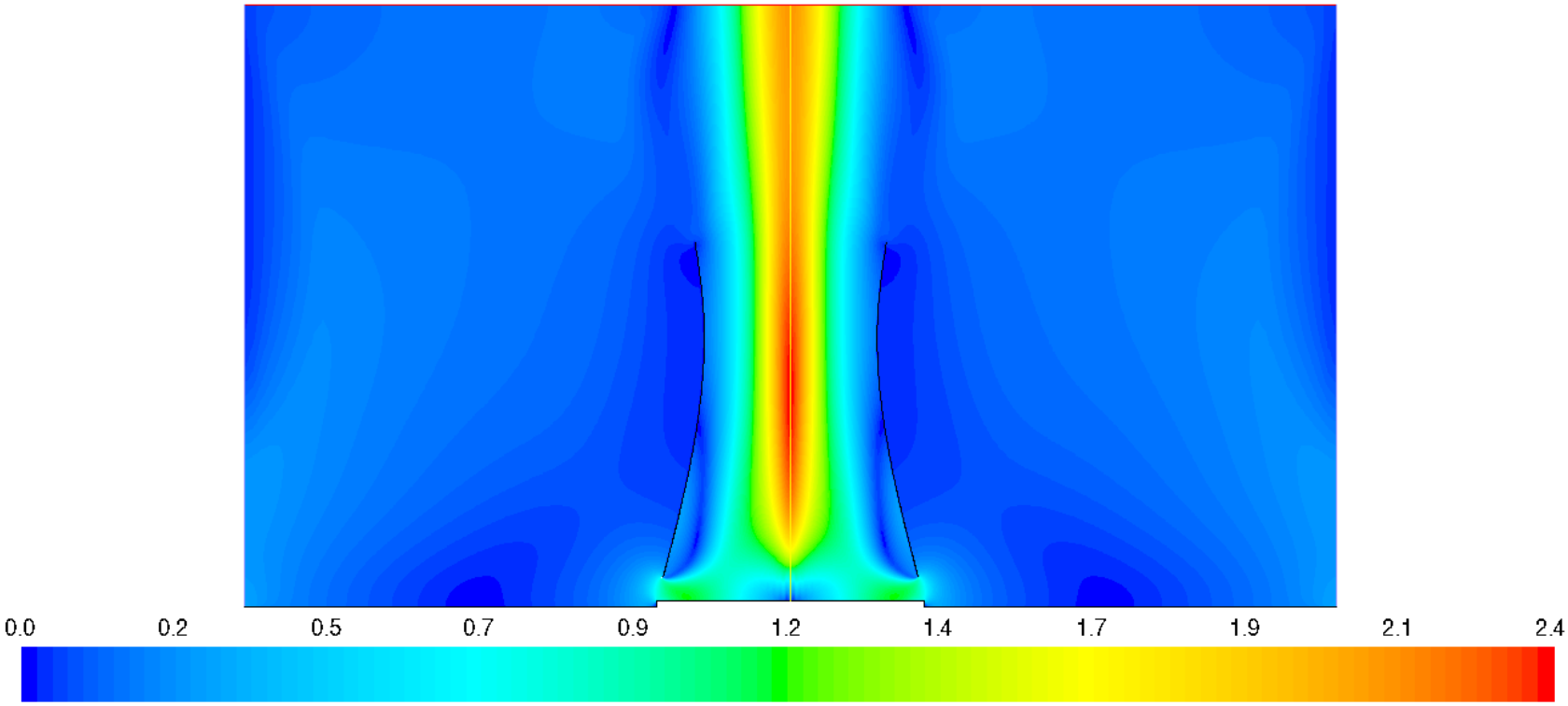
Contours of Mass Fraction of Atmosphere (H_2O)



Contours of Mass fraction of h2o (atmosphere)

Sep 15, 2009
ANSYS FLUENT 12.0 (axi, dp, pbns, eulerian, spe, ske)

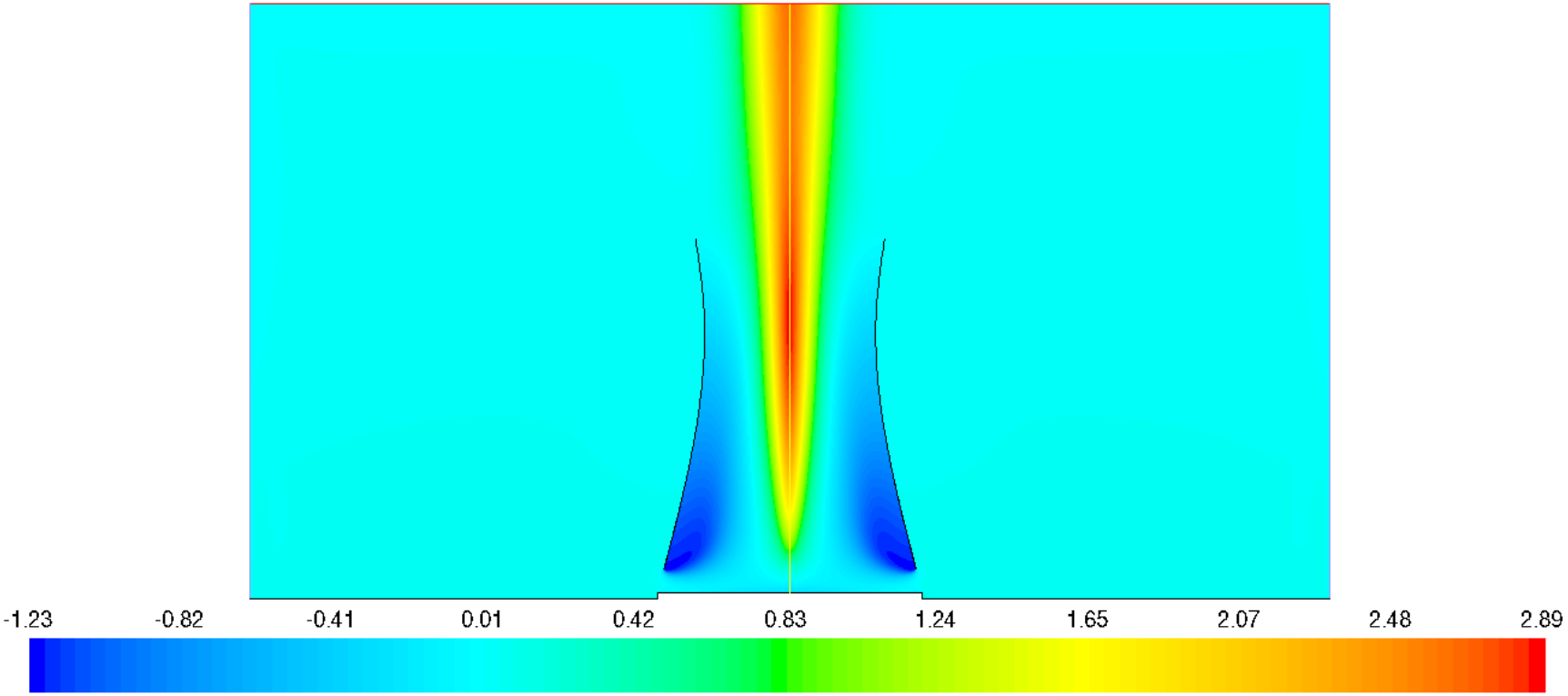
Contours of Velocity Magnitude



Contours of Velocity Magnitude (atmosphere) (m/s)

Sep 15, 2009
ANSYS FLUENT 12.0 (axi, dp, pbns, eulerian, spe, ske)

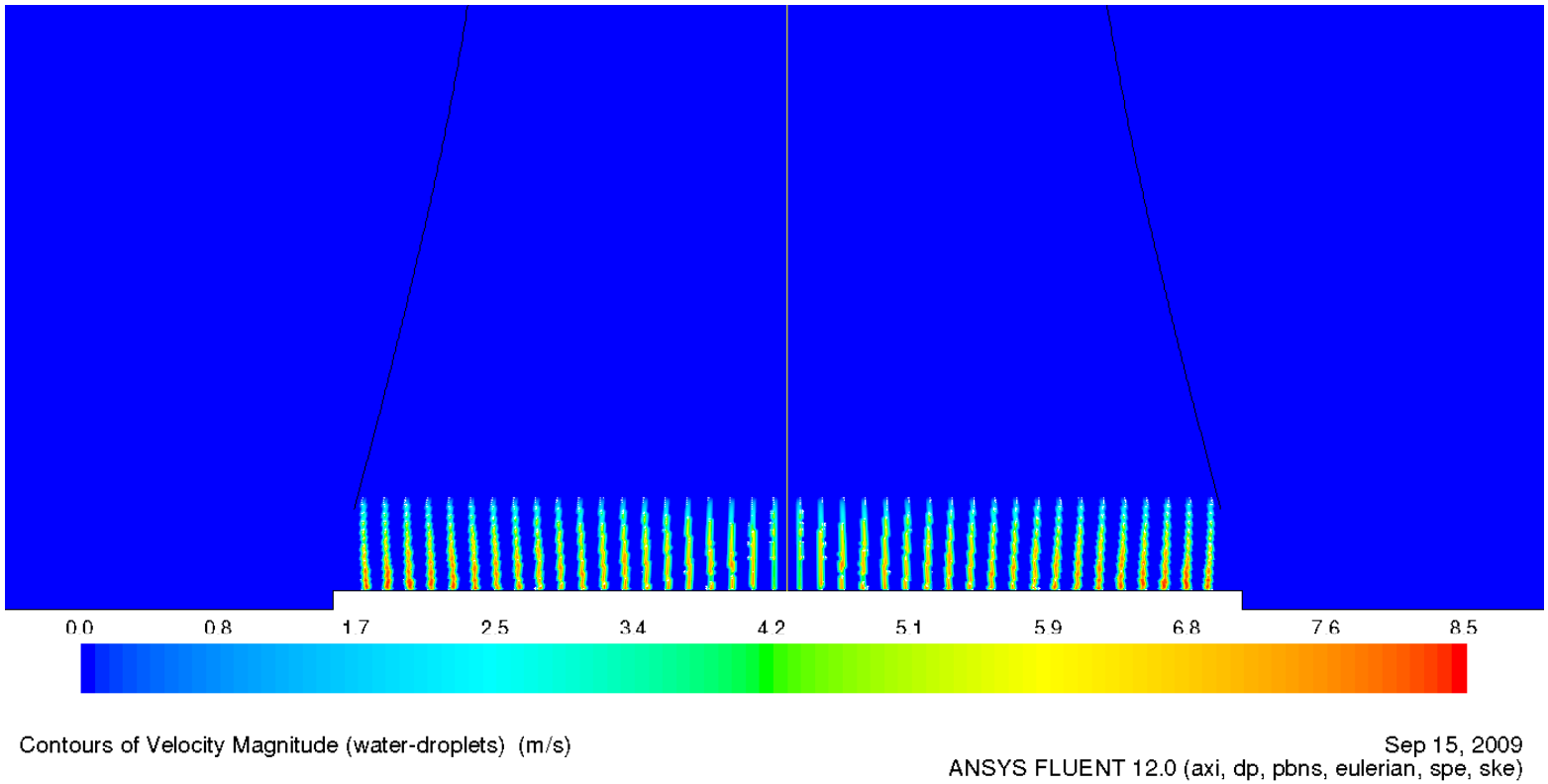
Contours of Total Pressure



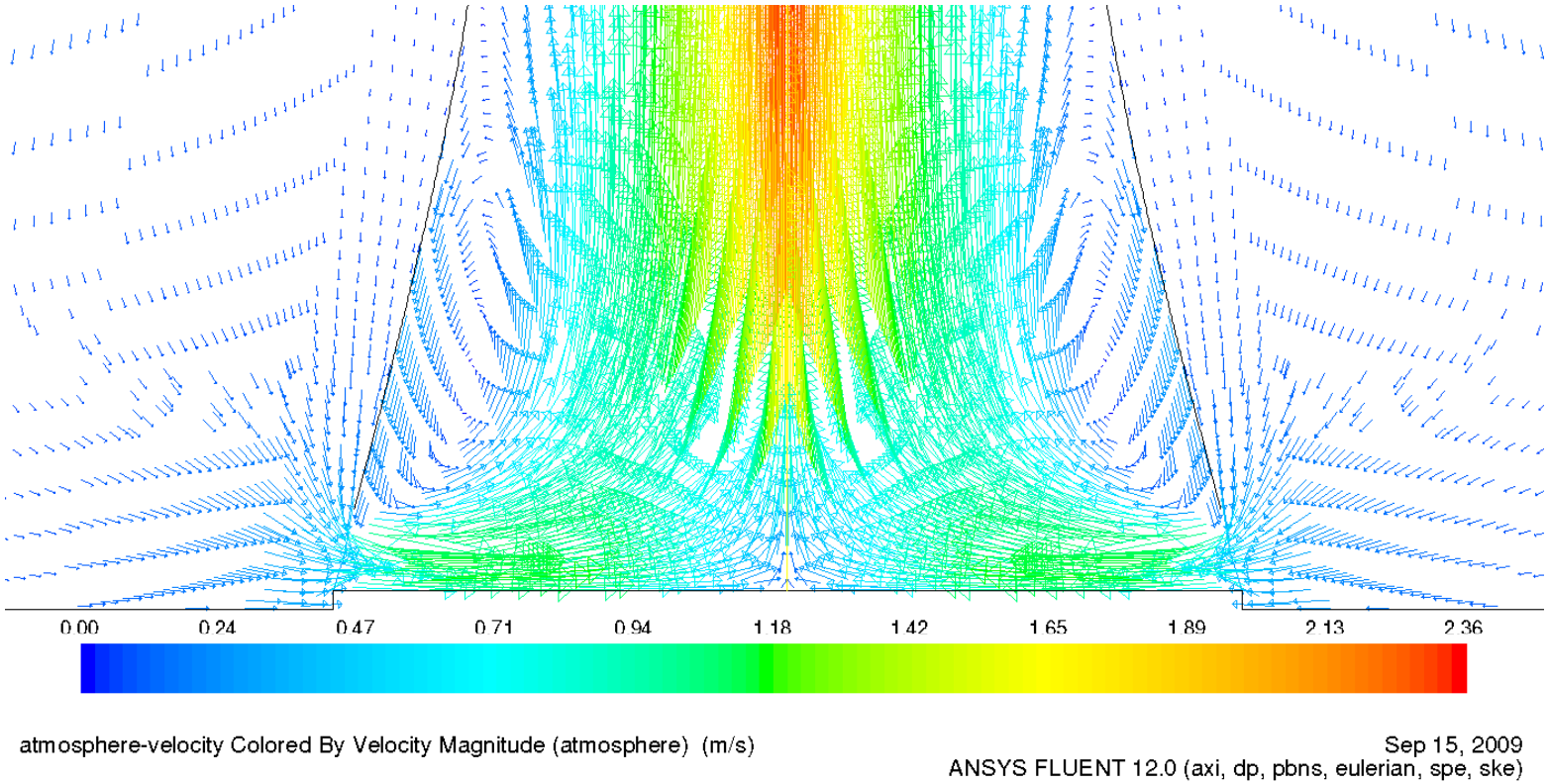
Contours of Total Pressure (atmosphere) (pascal)

Sep 15, 2009
ANSYS FLUENT 12.0 (axi, dp, pbns, eulerian, spe, ske)

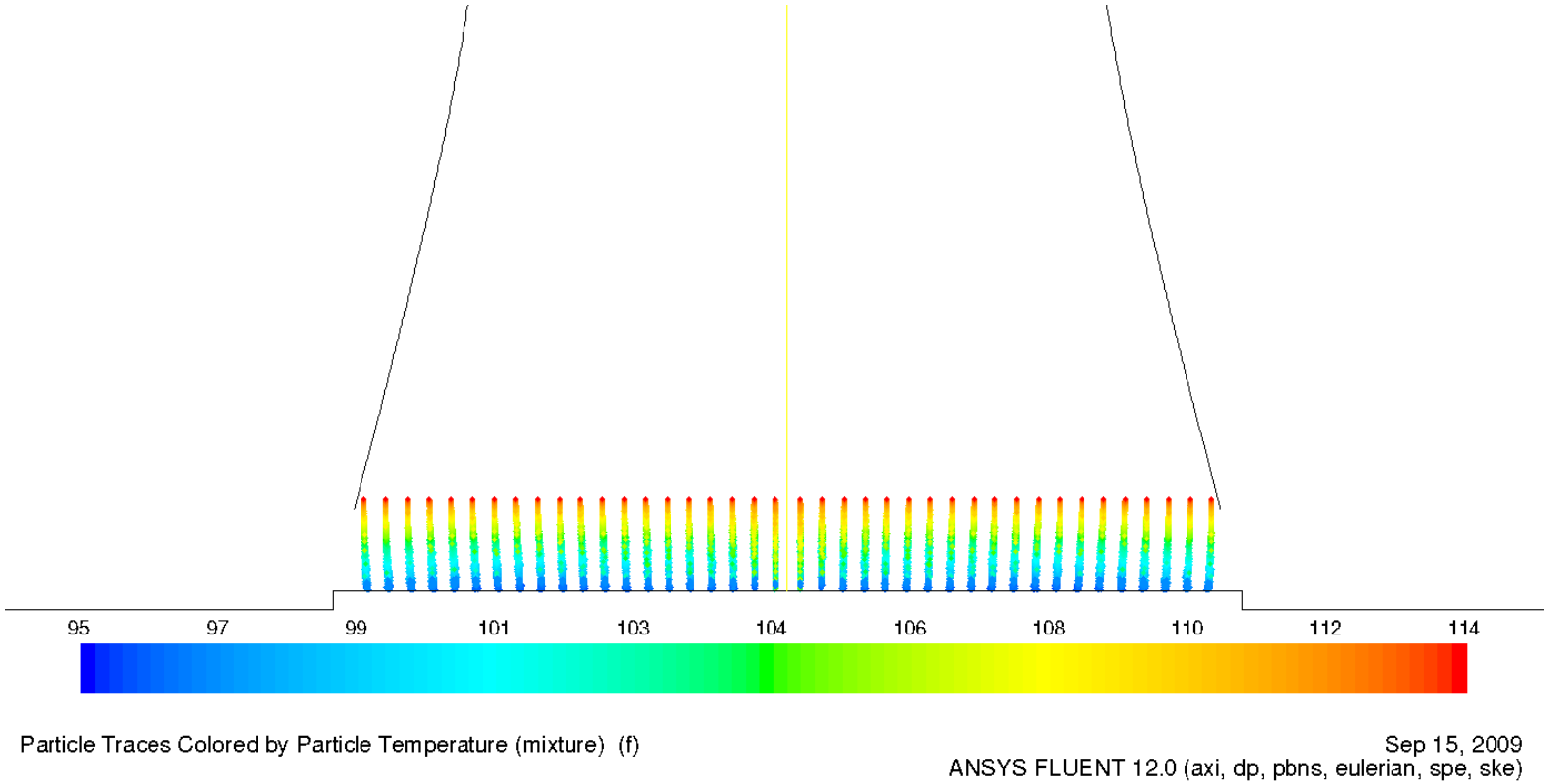
Contours of Velocity Magnitude (water-droplets)



Velocity Magnitude of Atmosphere



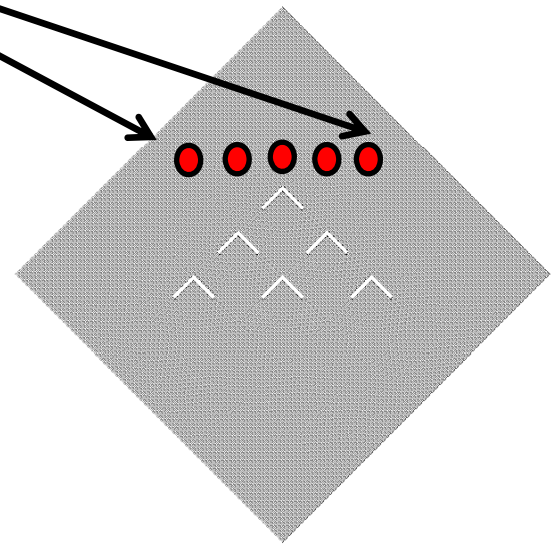
Particle Temperature Distribution



Test of Injections and Fill Model

5 DPM Injections (1.5 kg/s per Injection or 0.0015 kg per 0.001 sec Unsteady DPM Time step)

Test Bed



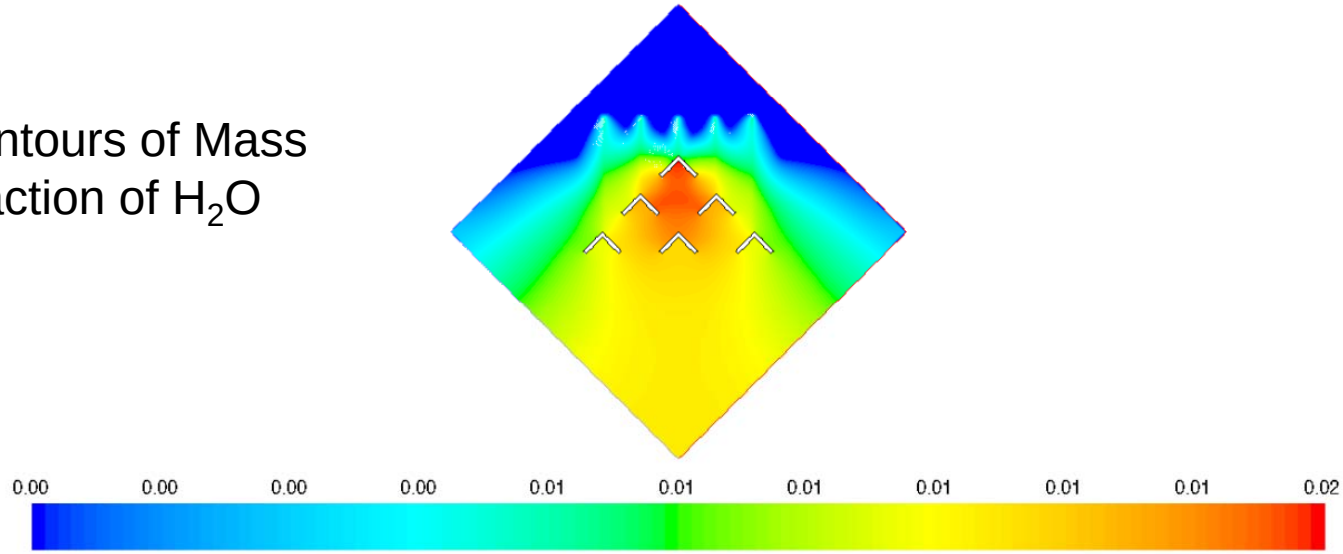
Pressure Inlet (70 F)

Pressure Outlet (70 F)

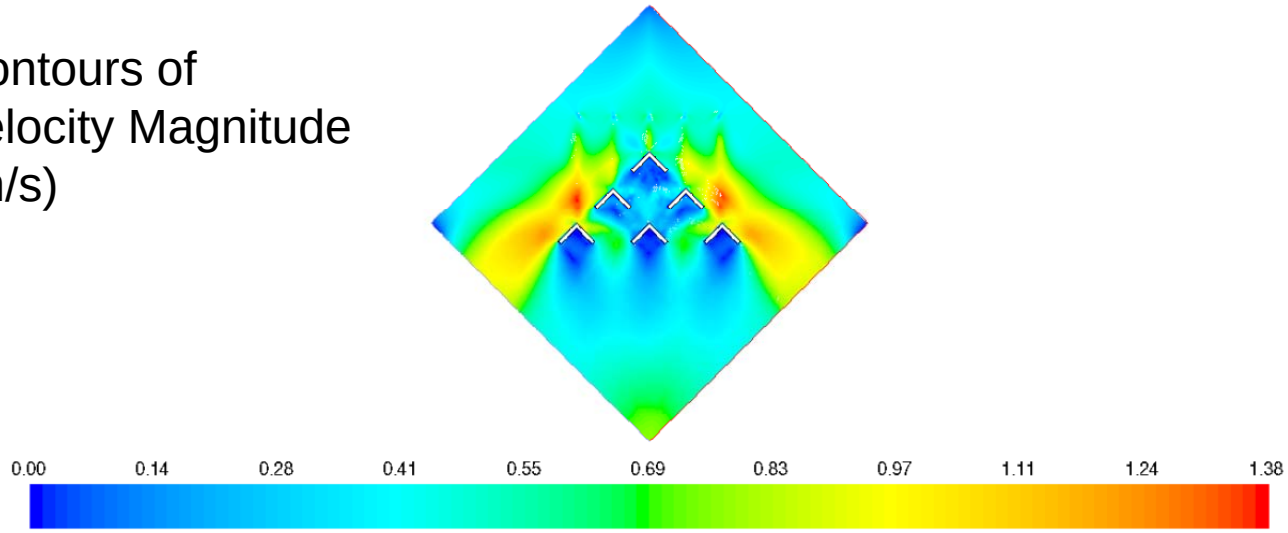
Mesh

Sep 04, 2009
ANSYS FLUENT 12.0 (2d, dp, pbns, eulerian, spe, ske)

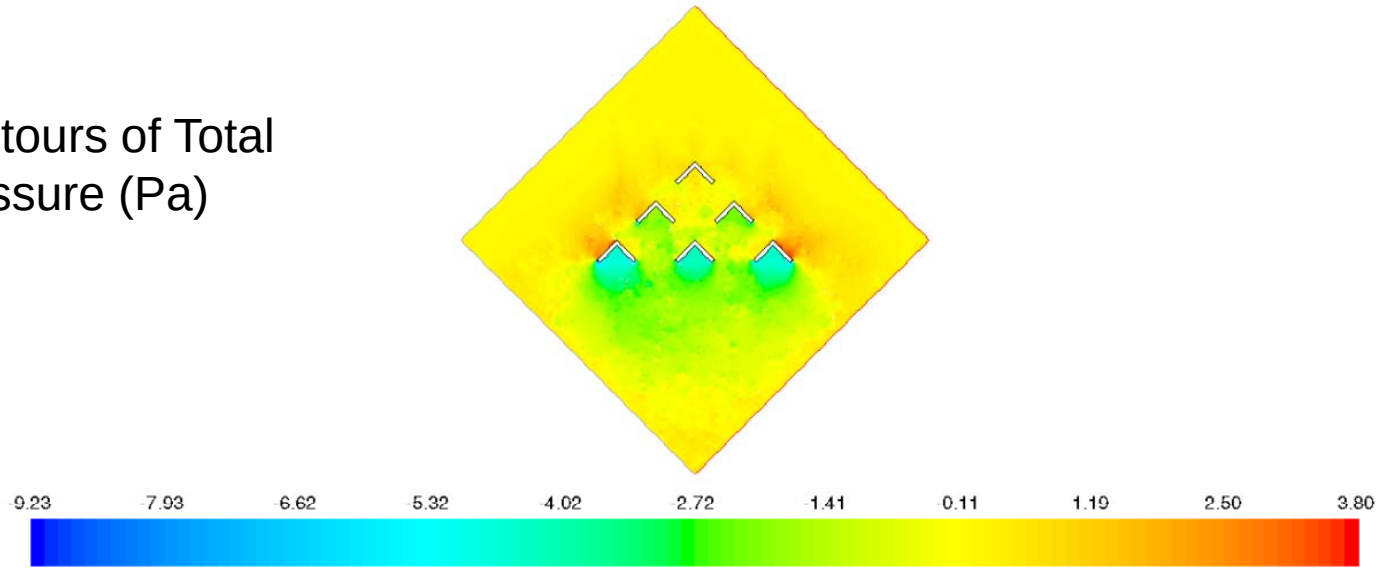
Contours of Mass Fraction of H_2O



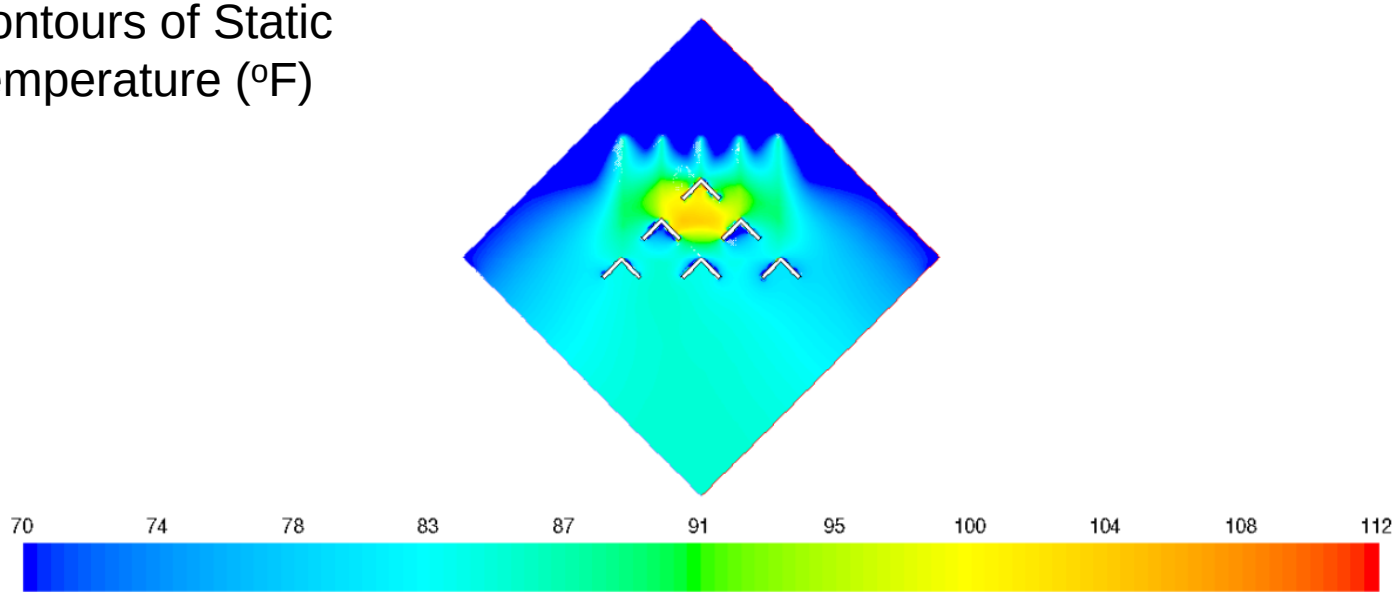
Contours of Velocity Magnitude (m/s)



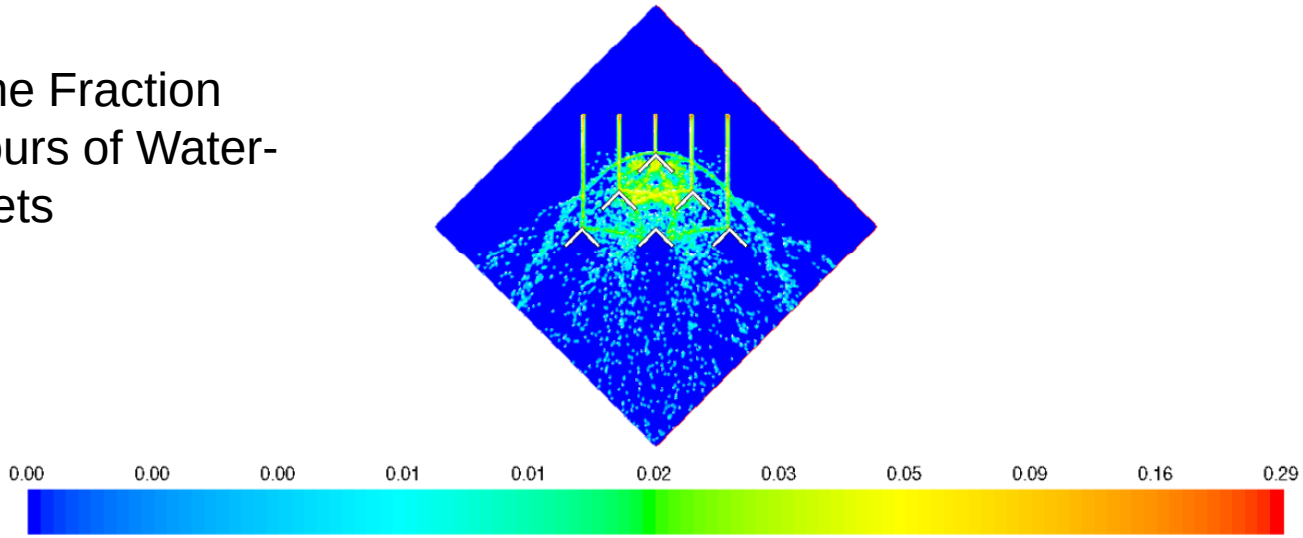
Contours of Total Pressure (Pa)



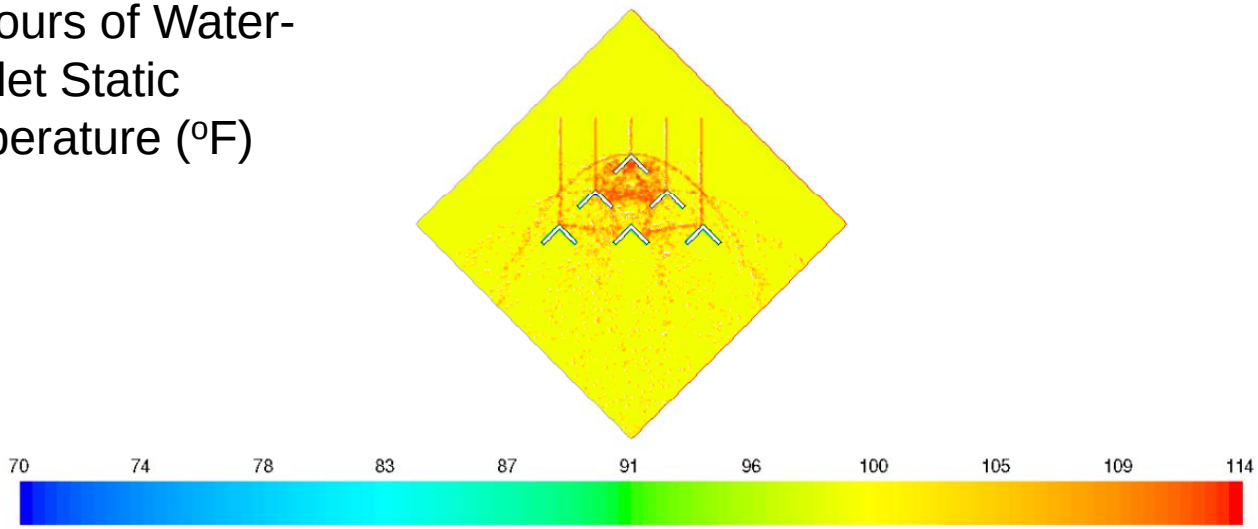
Contours of Static Temperature (°F)



Volume Fraction Contours of Water-Droplets



Contours of Water-Droplet Static Temperature (°F)



Comments on CFD Work

- Phase Change is happening between water droplets and water vapor phase
- Heat Transfer primarily a function of residence time, and secondarily droplet size.
- CFD Stability highly dependent upon grid spacing
- Far Field Static (0 Velocity) Boundaries can be easily maintained.
- Grid Resolution is a large driver of multiphase interaction.
- Coalescence / Break-Up stability governed by grid spacing stability

Williamson Dissertation Work

- Dr. Nicholas Williamson, University of Sydney provided WVU with his CFD files from a hyperbolic cooling tower simulation.
- Currently we are working on running the code and verifying the results with his dissertation.
- Also are examining UDFs and finding areas of improvement.
- Model was 2-D Axi-symmetric modeled in FLUENT 6.1

Global Perspective

- A reduced order model of the cooling tower will be developed and paired with APECS in order to allow the simulation to become part of a larger simulation in a process simulator such as Aspen Plus.

- Model will be employed to evaluate approaches to reduce water consumption of power plants.

Future Areas of Work

- Continue to work with Williamson Model
  - Run code and verify results
  - Further examine the UDF's
  - Further examine the 1D Matlab Code
- Determine the method of ROM to be employed, and begin looking into that model.
- Continue to work on the global and local cooling tower models developed at WVU.