Worldwide Pollution Control Association

WPCA-Duke Energy

FF/HAPS Seminar

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Flow Modeling and Testing of Fabric Filters

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Duke Energy FF Seminar
October 12-13, 2011

Outline

- Introduction
- Performance Goals for Fabric Filters
- Flow Modeling Methods
- Field Testing Techniques
- Case Study
- Conclusions
- Questions

Introduction

- Why are Flow Characteristics Important to APC Equipment?
  - Performance
    - Flow uniformity
    - Chemical species or particulate injection
    - Ash capture / build-up
  - Operating costs
    - Pressure drop
    - Injected chemical or solids cost
  - Maintenance issues
    - Erosion
    - Corrosion
    - Pluggage
    - Vibration

Introduction

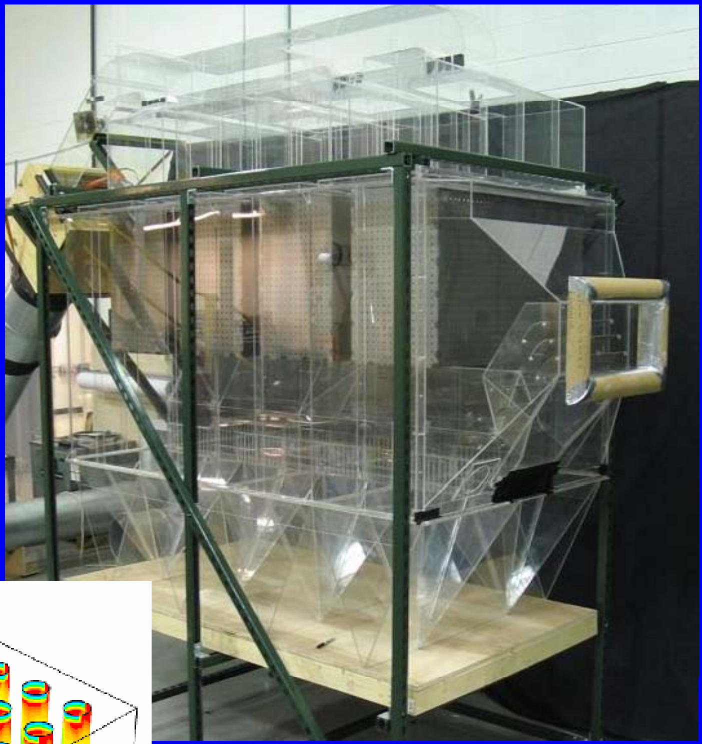
- Flow Modeling and Field Testing Applications
  - Design of new equipment
  - Retrofit of existing equipment
  - Solving operational or maintenance issues

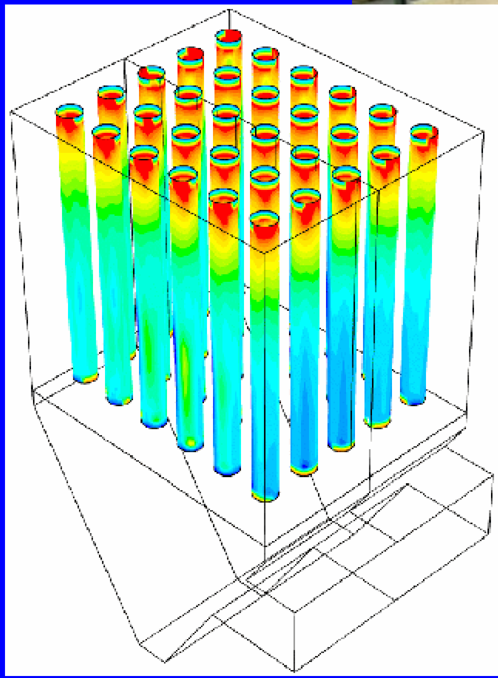
Outline

- Introduction
- Performance Goals for Fabric Filters
  - Flow distribution and balance
  - Pressure loss
  - Thermal mixing
  - Sorbent injection
  - Particle deposition
- Flow Modeling Methods
- Field Testing Techniques
- Case Study
- Conclusions
- Questions

Performance Goals

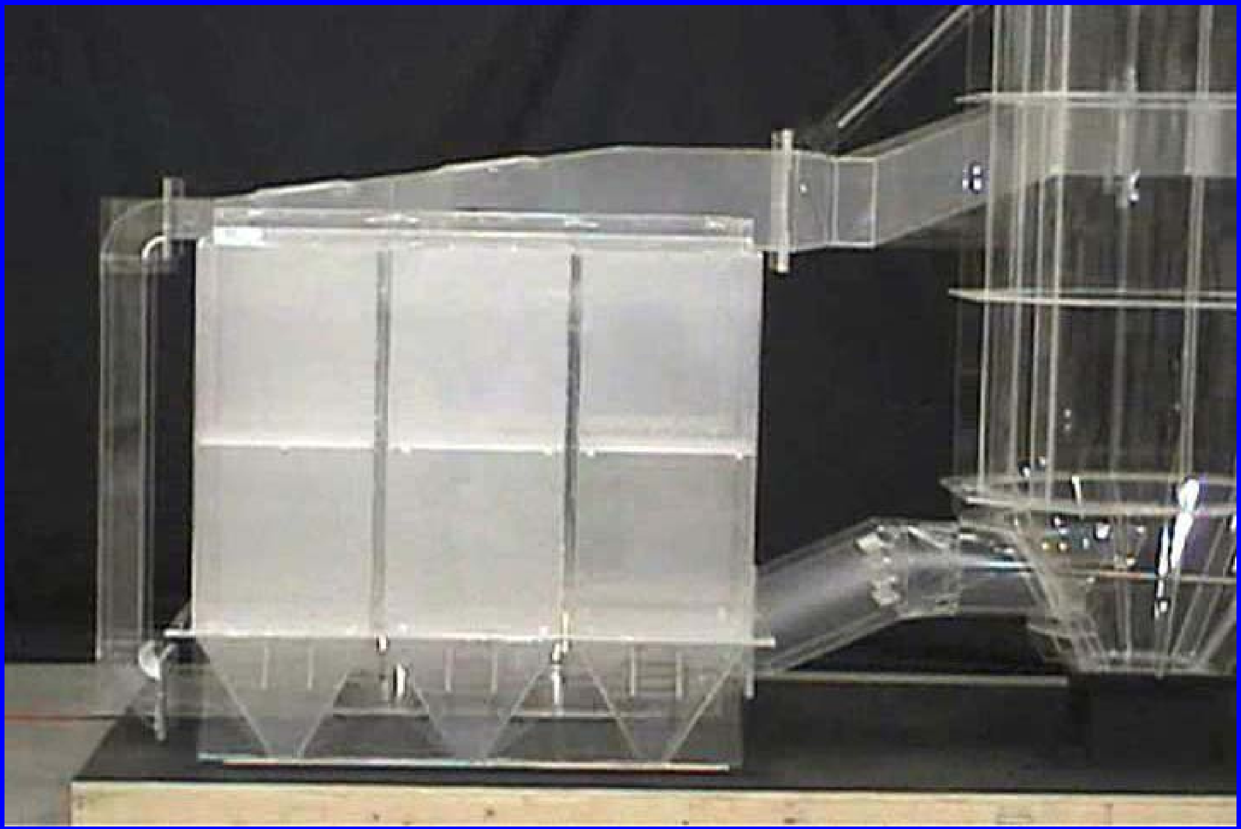
- ❖ Flow distribution
- ❖ Flow balance
- ❖ Pressure loss
- ❖ Thermal mixing
- ❖ Sorbent injection
- ❖ Particle deposition

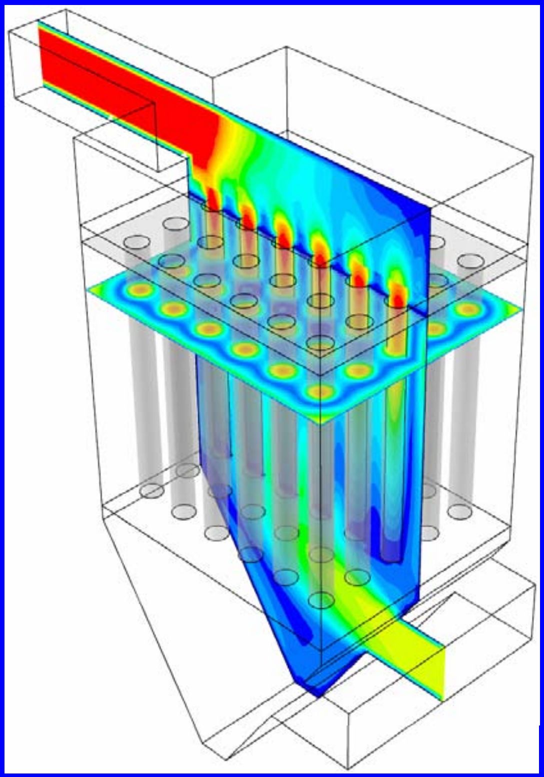




Fabric Filter Velocity Distribution

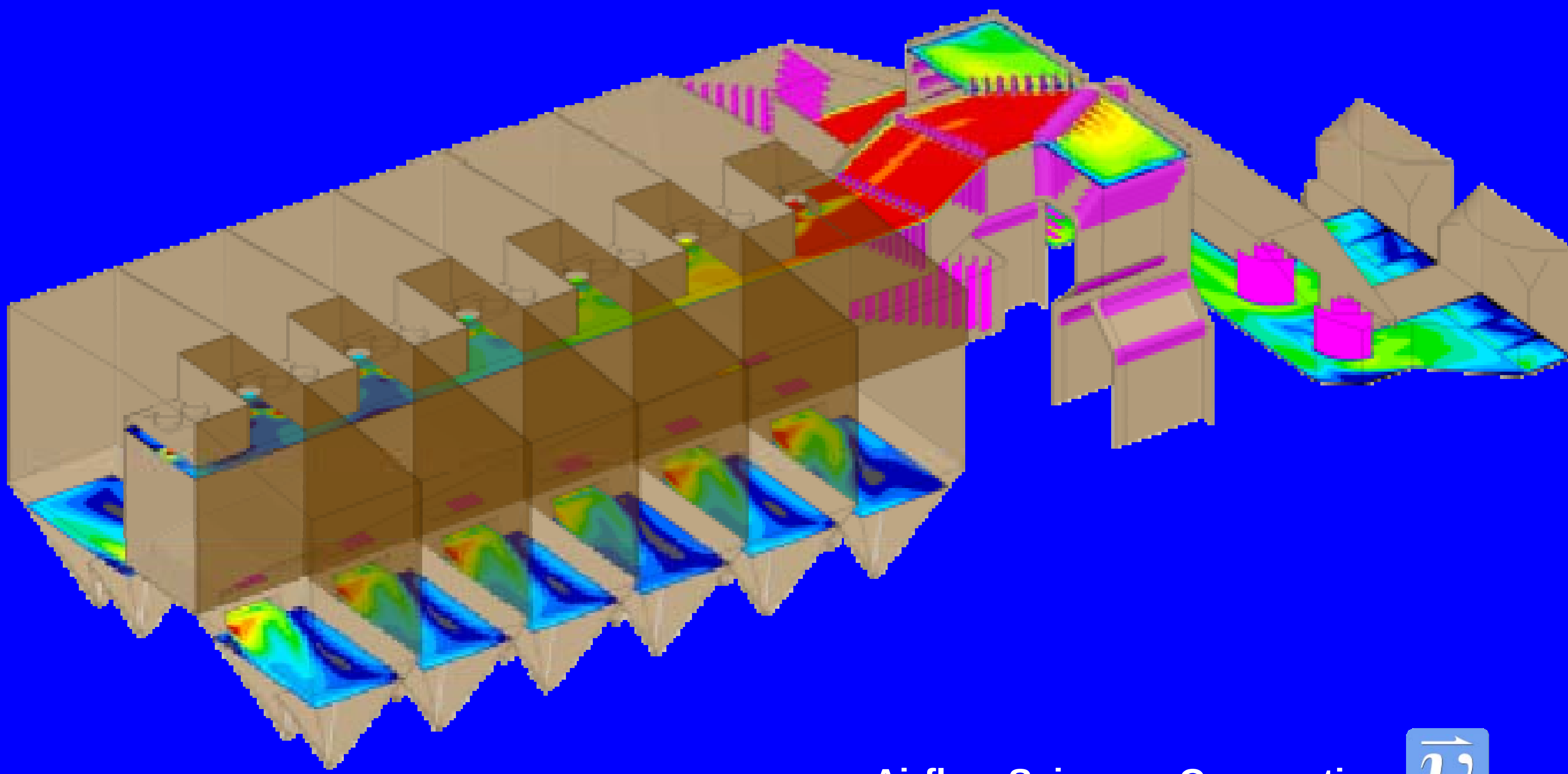
- ❖ Uniform velocity at plenum inlet flange (7.5% RMS)
- ❖ Avoid high velocities impinging bags





Fabric Filter Flow Balance

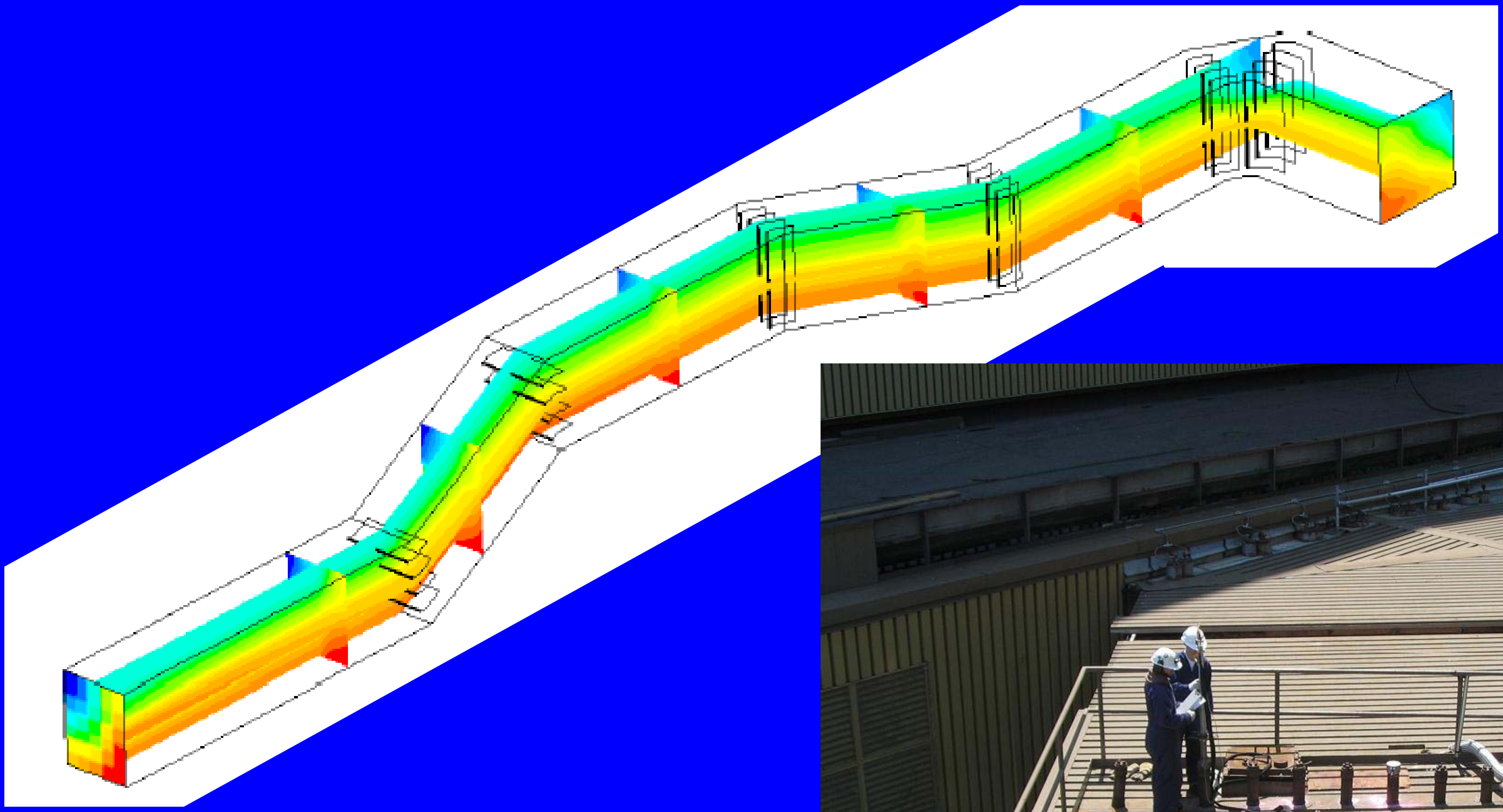
- ❖ Equal balance to compartments (each within 10%)
- ❖ Equal particulate balance to compartments



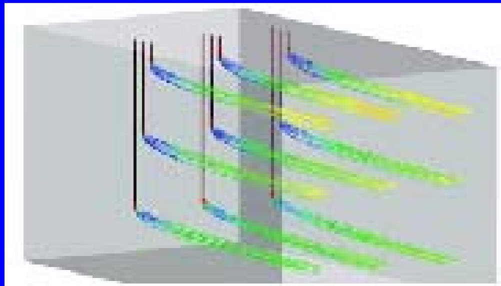
Pressure Drop

- General goal:
  - Minimize DP
- Methods
  - Vanes
  - Duct contouring
  - Area management

Fabric Filter Temperature Stratification

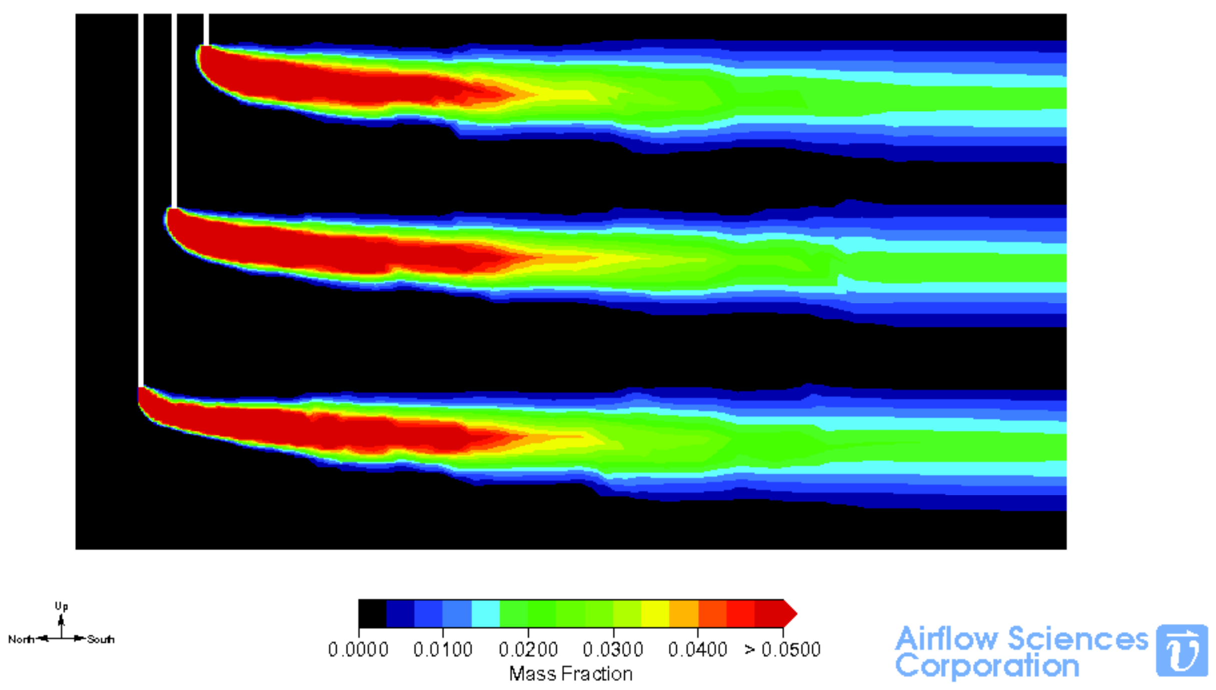


Particulate Injection



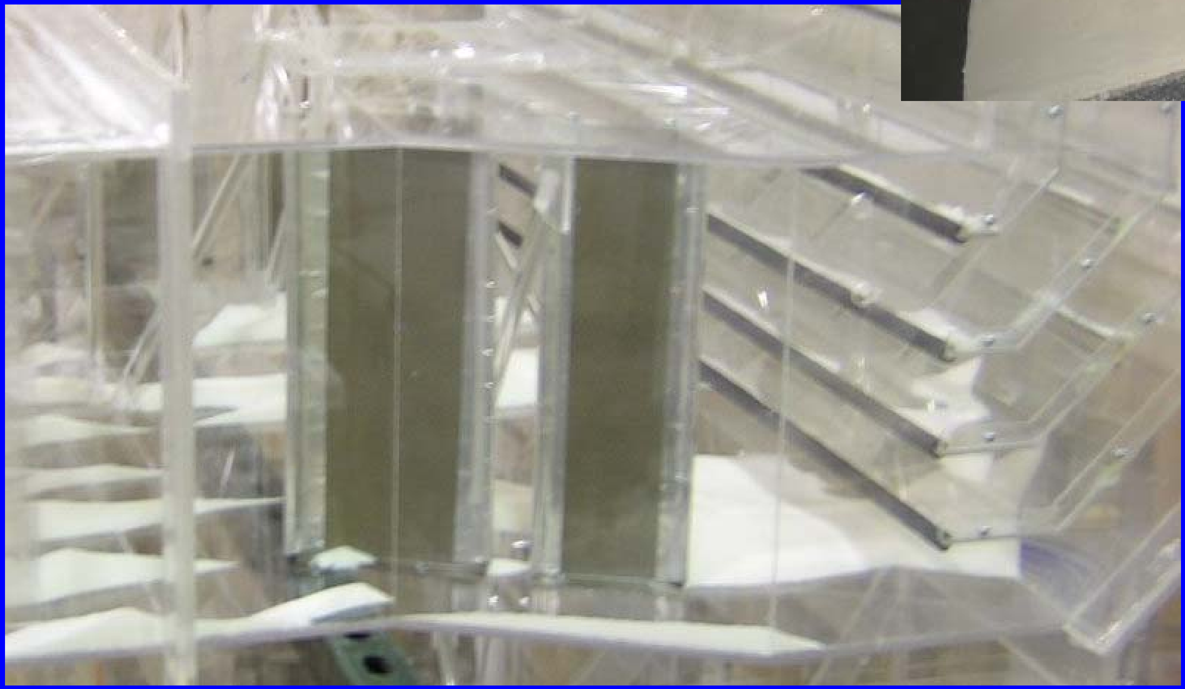
Total velocity of particles leaving lances.

- Mercury absorption
  - Activated carbon
  - Other
- SO3 mitigation
  - Limestone
  - SBS
  - Trona
  - Etc.



Ash Deposition

- Drop out
- Re-entrainment

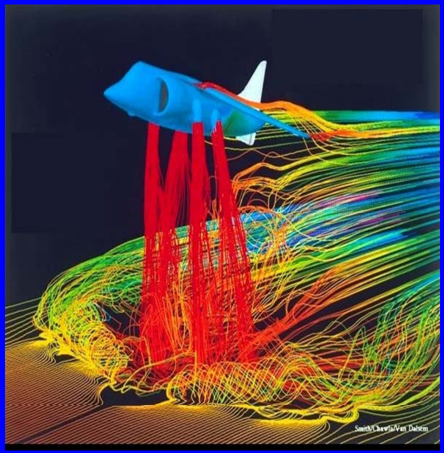


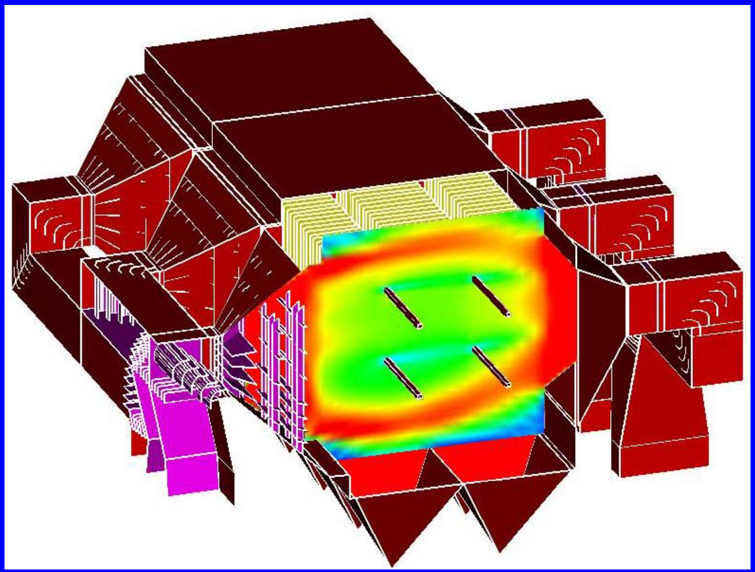
Outline

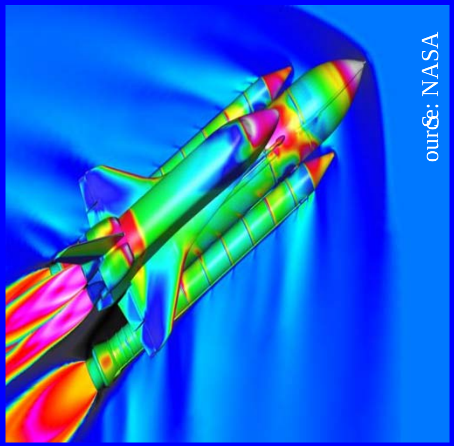
- Introduction
- Performance Goals for Fabric Filters
- Flow Modeling Methods
  - Computational Fluid Dynamics (CFD)
  - Physical Flow Modeling
  - Advantages / Disadvantages / Comparisons
- Field Testing Techniques
- Other Industry Applications
- Conclusions
- Questions

CFD – Background

- Developed in the aerospace industry c.1970 (with the advent of “high speed” computers)
- Used in the power industry for > 25 years
- As computing power and software have progressed, accuracy has improved and more complicated problems have been analyzed

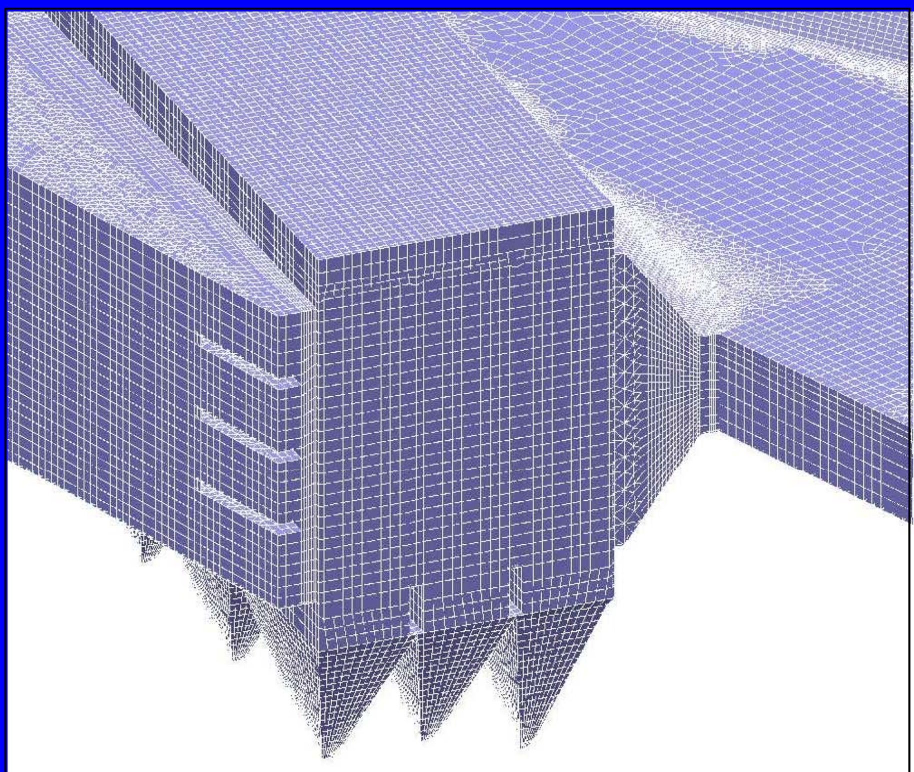


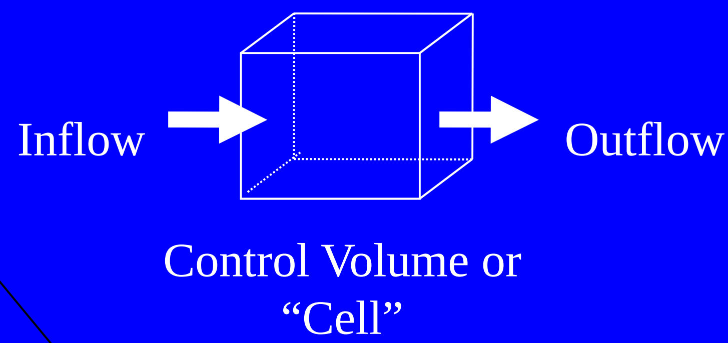


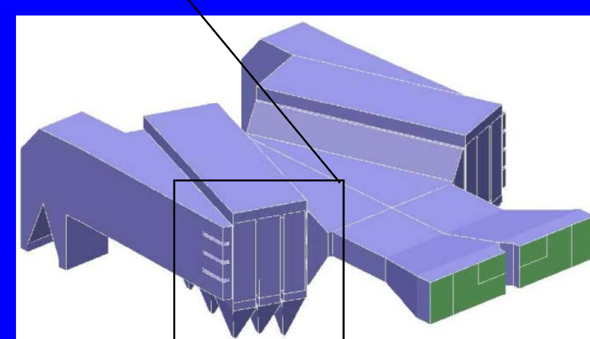


CFD – Methodology

- Control Volume Approach
  - Divide the flow domain into distinct control volumes
  - Solve the Navier-Stokes equations (Conservation of Mass, Momentum, Energy) in each control volume

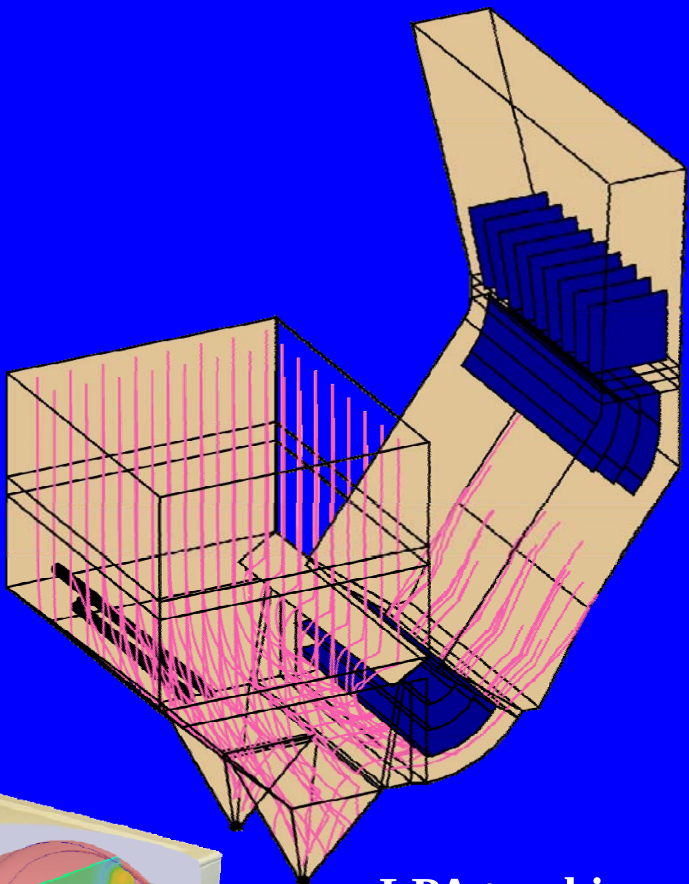




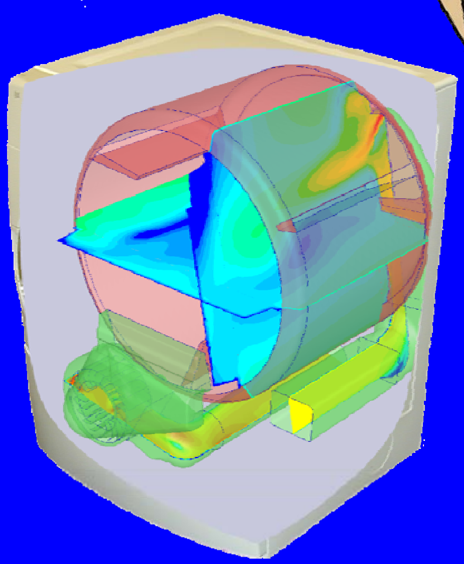


CFD – Methodology

- Additional physics can be implemented into the simulation
  - Chemical reaction
  - Mass transfer
    - Evaporation
    - Drying
  - Particulate tracking
  - Two-phase momentum exchange
  - Species diffusion
  - Radiative heat transfer
  - Mechanical motion



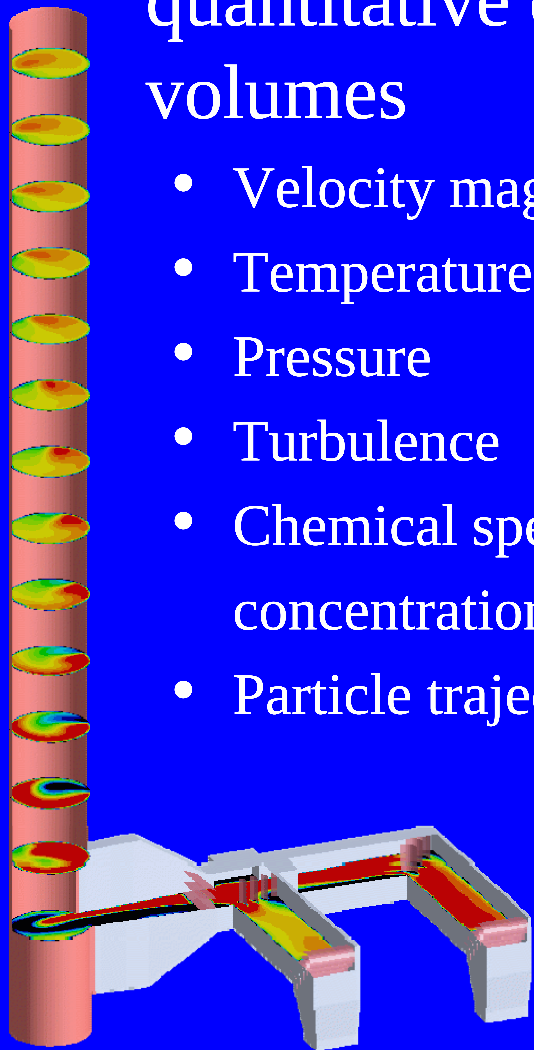
LPA tracking

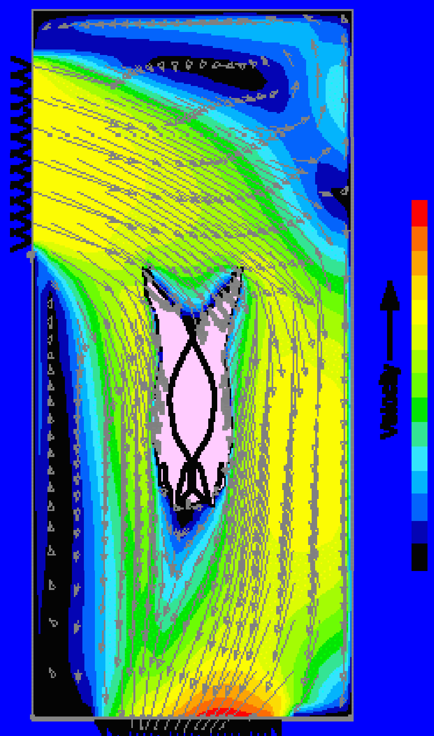


Time dependent simulation of clothes drying

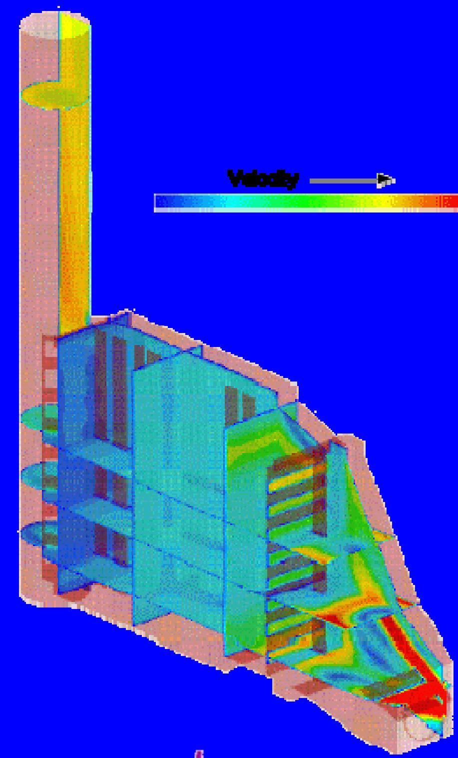
CFD – Results Analysis

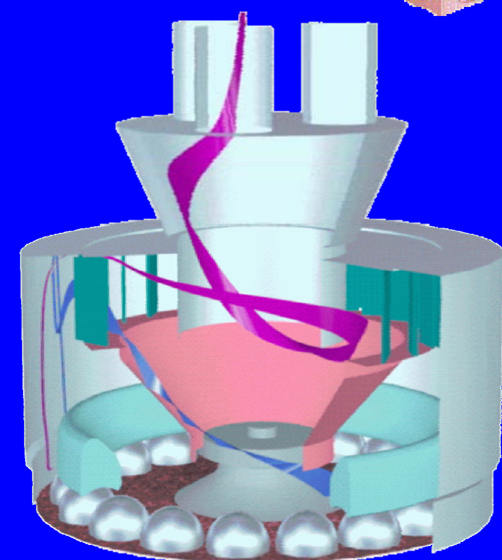
- Simulation results provide quantitative data at all control volumes
  - Velocity magnitude, directionality
  - Temperature
  - Pressure
  - Turbulence
  - Chemical species concentrations
  - Particle trajectories





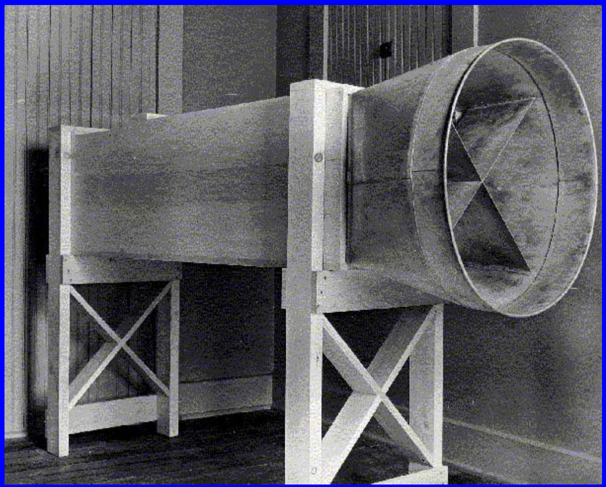
Hog carcass cooling

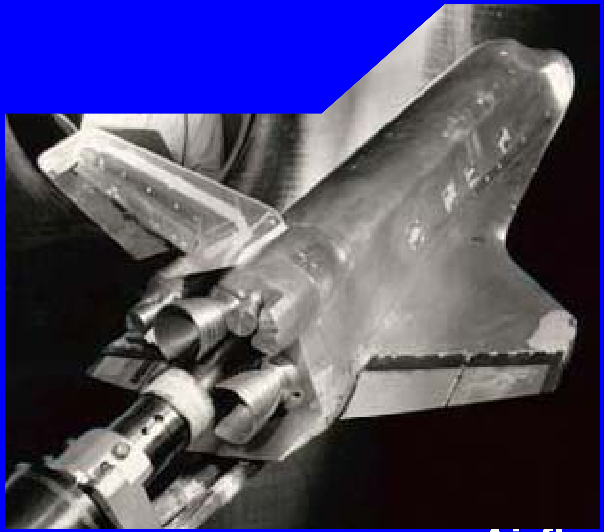




Physical Flow Modeling

- Utilized for fluid flow analysis for a century … or more?
- Applied to power plant equipment for decades
- Underlying principle is to reproduce fluid flow behavior in a controlled, laboratory environment





Physical Models – Methodology

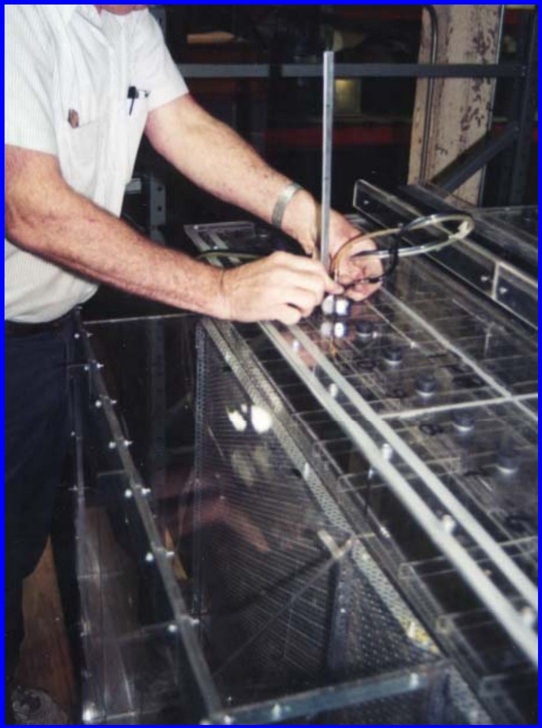
- Key criteria is to generate "Similarity" between the scale model and the real-world object

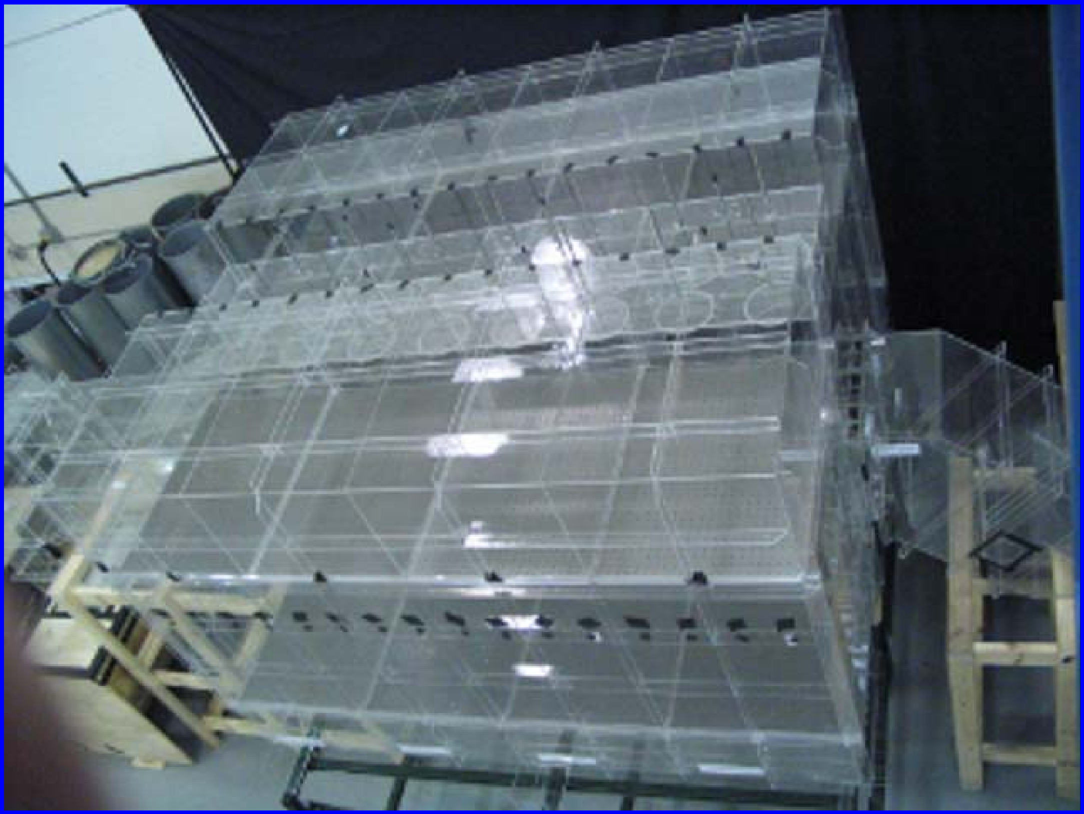
  - Geometric similarity
    - Accurate scale representation of geometry
    - Inclusion of all influencing geometry
    - Selection of scale can be important
  - Fluid dynamic similarity
    - Precise Reynolds Number (Re) matching is not feasible
    - General practice is to match full scale velocity or velocity head but ensure that Re remains in the turbulent range throughout the model

$$Re = \frac{\rho\ v\ D_h}{\mu}$$

Physical Models – Methodology

- External fan provides flow to model
- Velocities, pressures measured at select locations



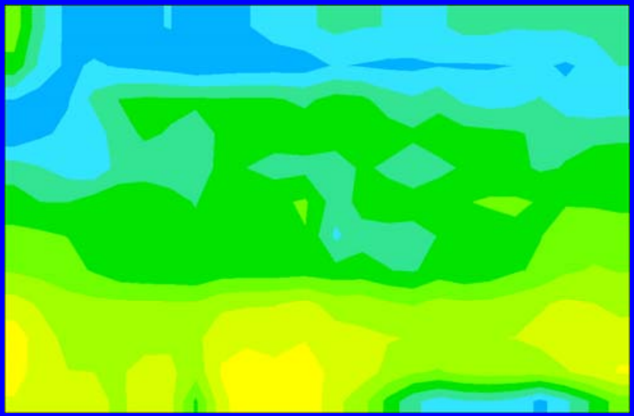


Physical Models – Methodology

- Chemical injection, species and thermal gradients simulated using a tracer gas
- Particulate deposition and travel represented via various dusts (cork, salt, glass beads, etc.)

Physical Modeling – Results Analysis

- Velocity magnitude, directionality
- Pressure, forces
- Chemical species distribution
- Particle tracking, build-up patterns
- Temperature

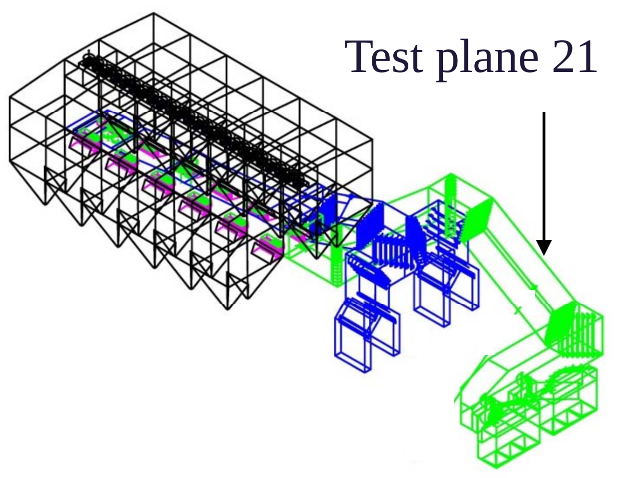


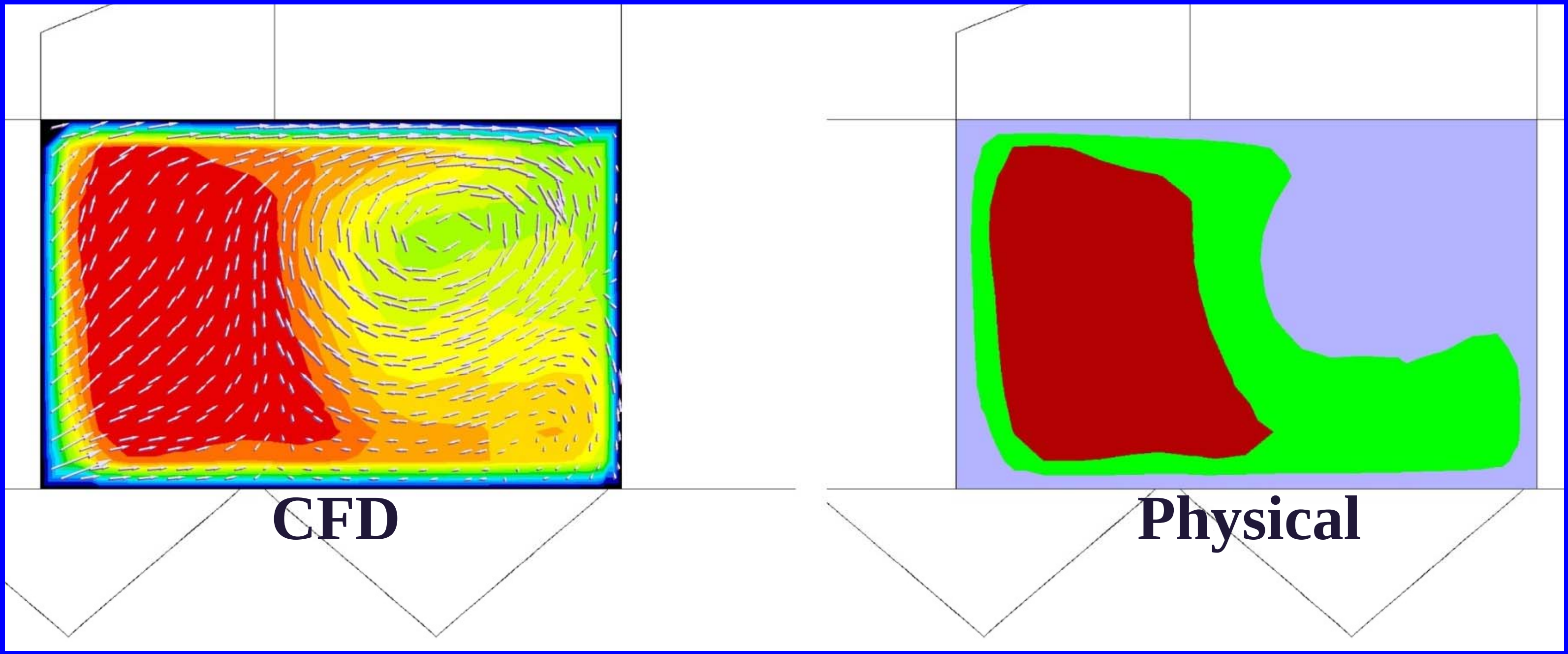
CFD / Physical Comparison

Comparison	**CFD**	**Physical**
Technical accuracy	Very good	Very good
Include complicated physics (evaporation, combustion, particle tracking, …)	Yes	Some, with inherent assumptions
Quantity of measurement points	Millions	Tens or Hundreds
Predict particulate build up	Limited	Good
Flow visualization	Good (2d planes and 3d animation)	Excellent (smoke, string, bubbles, …)
Industry experience, comfort	Very Good	Strong
Schedule	Generally faster (can run parallel designs)	
Cost	Dependent on work scope	
Model archive	Simple	Space consuming
Future advancements	Considerable	Small

FF Model Results Comparison

- CFD and 1/12 scale physical model comparison
  - Velocity profiles in ductwork very similar
  - Flow balance to compartments within 3% points





Outline

- ❖ Introduction
- ❖ Performance Goals for ESPs and Fabric Filters
- ❖ Flow Modeling Methods
- ❖ Field Testing Techniques
  - Objectives
  - EPA Methods
  - Other Tests
- ❖ Other Industry Applications
- ❖ Conclusions
- ❖ Questions

Field Testing Objectives

- Inlet / Exit Ductwork
  - Velocity, temperature, pressure
  - Particulate sampling
  - Species concentration
- Fabric Filter Compartments
  - Flow balance, peak velocities

EPA Testing Methods (40 CFR 60)

- Method 1
  - Test port installation advice
- Method 2, 2F
  - Velocity, temperature, pressure, flow rate
  - S-probe or 3D probe
- Method 5, 17
  - Isokinetic particulate sampling
  - S-probe, nozzle, vacuum, sample train

Outline

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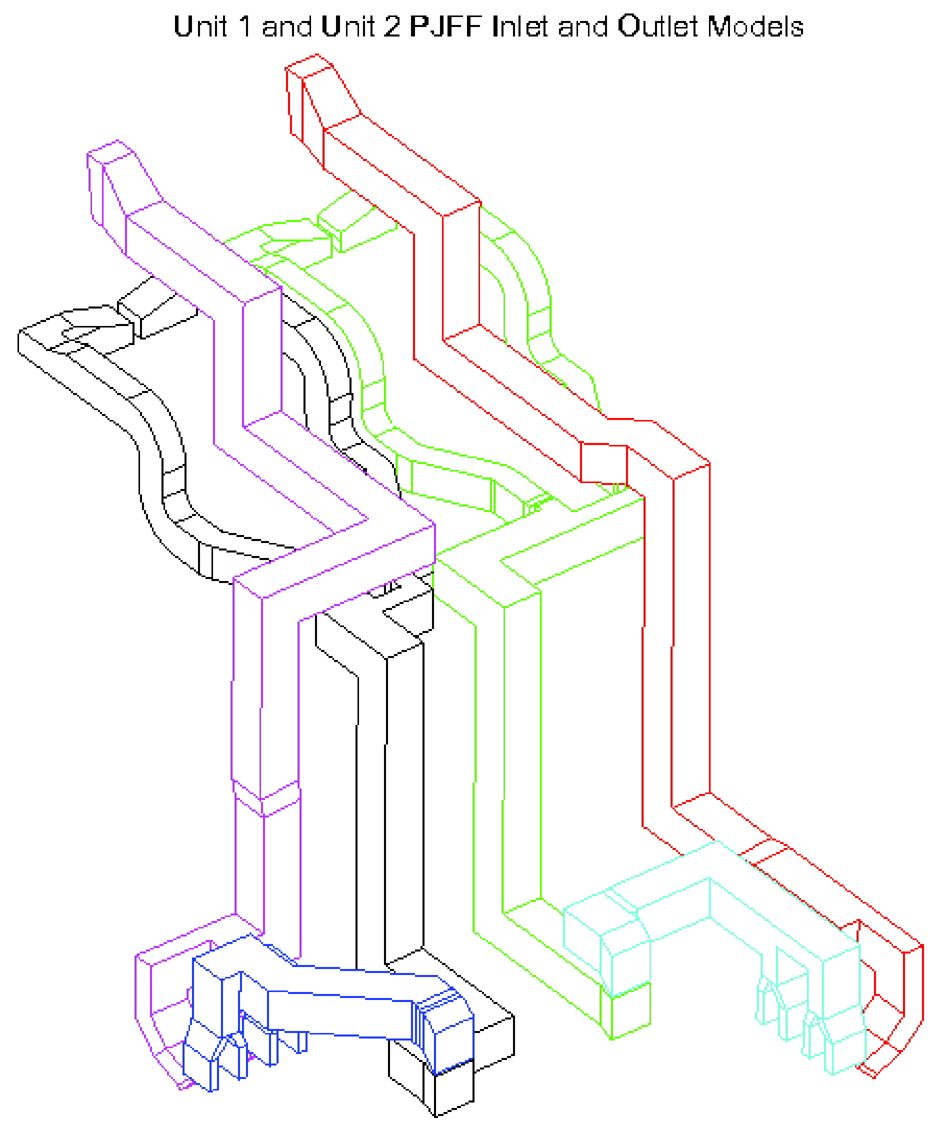
- ❖ Case Study
- ❖ Conclusions
- ❖ Questions

Case Study

- Mid-sized US plant
- Two new PJFF
- Activated Carbon Injection
- Trona Injection

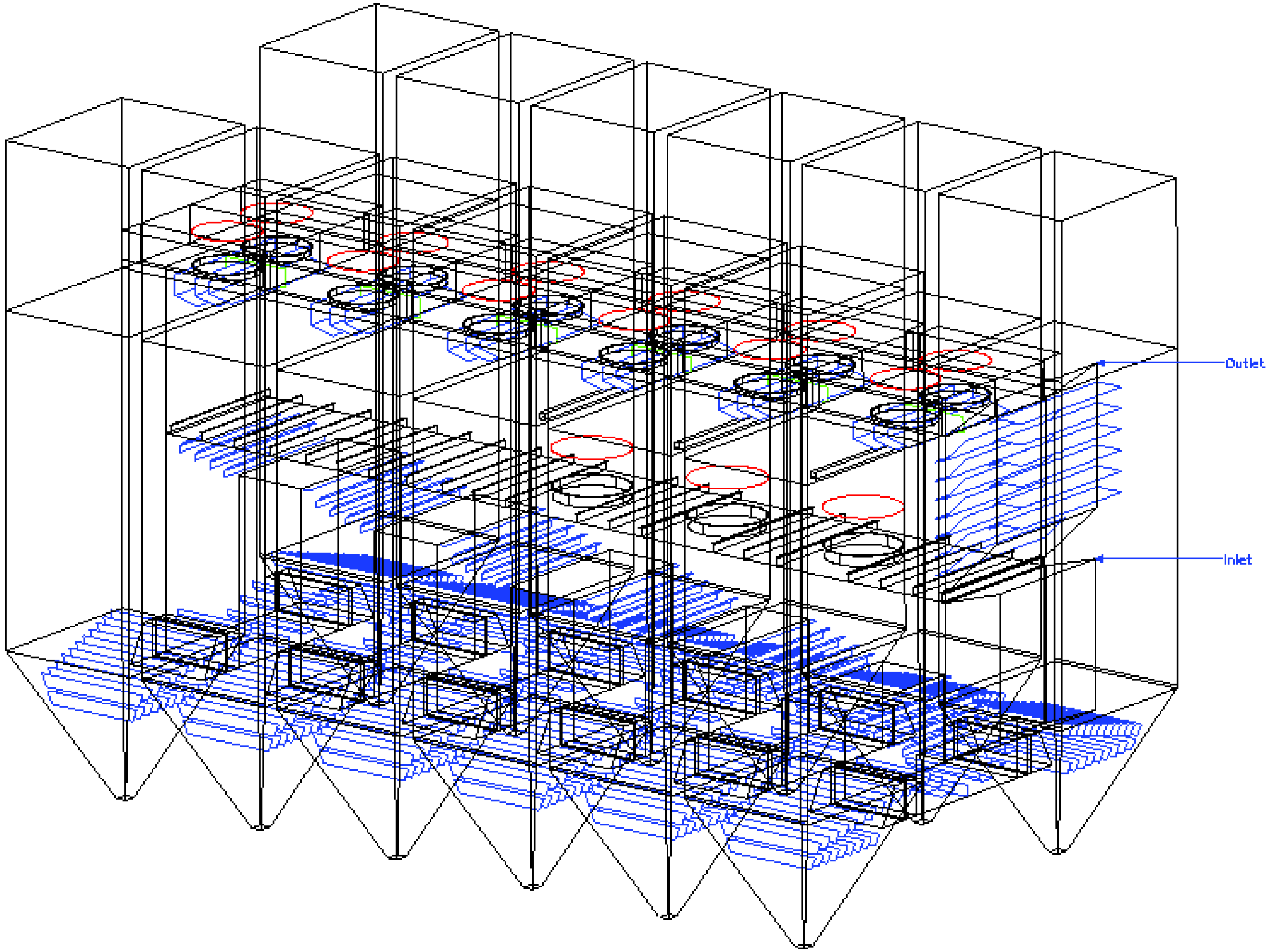
Geometry

- AH to FF
- FF to I.D. fan
- I.D. fan to stack



Schematics

Isometric View: Fabric Filter

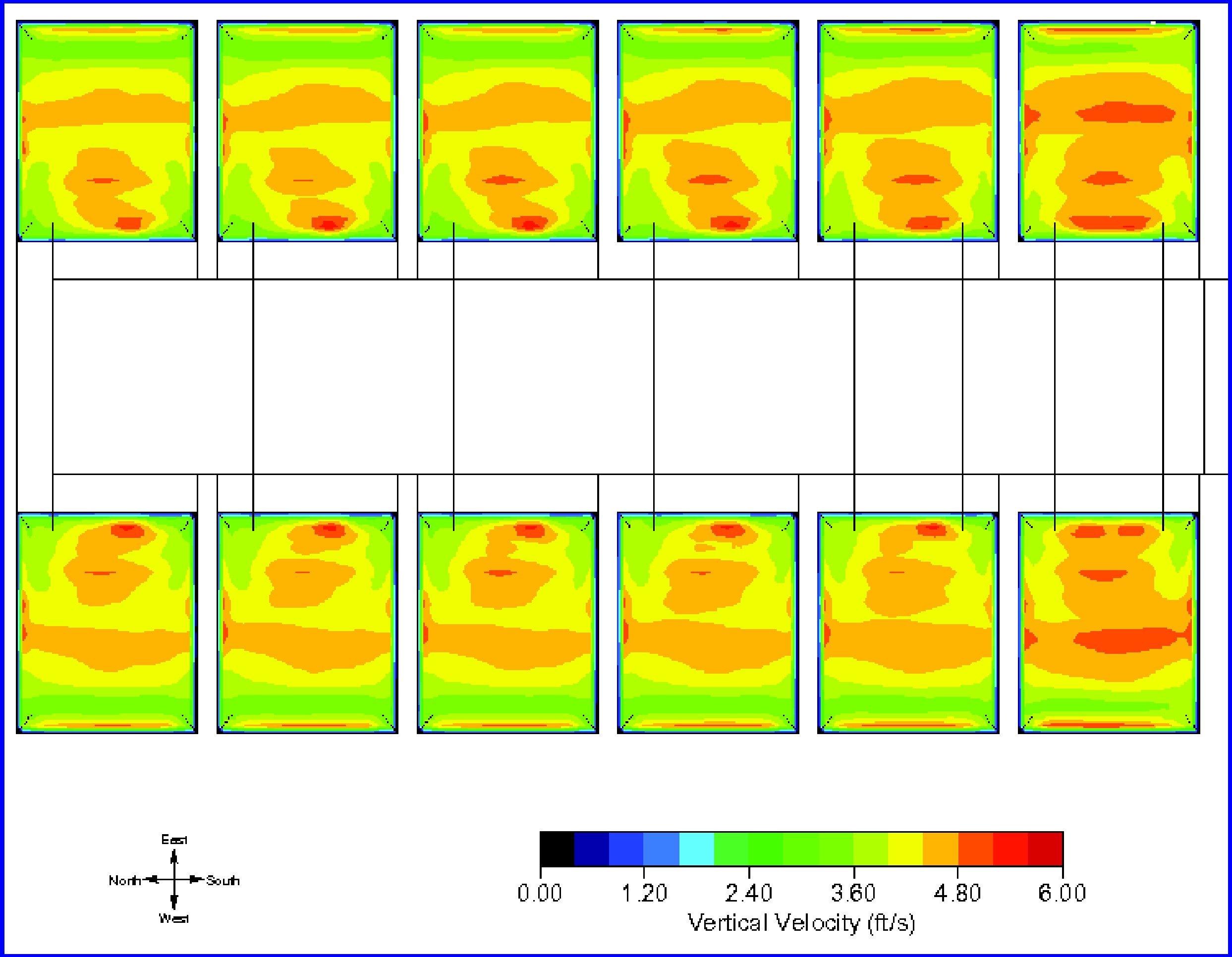


Results

❖ Velocity uniformity goals

		Goals	Baseline	Design
Axial Velocity RMS 2 ft Upstream Trona Injection Plane	(%)	< 15	7.7	7.8
Axial Velocity RMS 2 ft Upstream Carbon Injection Plane	(%)	< 15	22.9	22.0
East ID Fan – East Pantleg Outlet Axial Velocity RMS	(%)	< 15	6.9	6.9
East ID Fan – West Pantleg Outlet Axial Velocity RMS	(%)	< 15	6.5	6.6
West ID Fan – East Pantleg Outlet Axial Velocity RMS	(%)	< 15	6.8	6.8
West ID Fan – West Pantleg Outlet Axial Velocity RMS	(%)	< 15	6.7	6.8
PJFF				
16 Points				
FF Inlet Test Plane (After Transition)				
RMS	(%)	< 15	15.8	15.8
Within 115% V_axial_avg	(%)	> 85	75.0	100
Within 140% V_axial_avg	(%)	> 99	100	100
FF Outlet Test Plane (After Transition)				
RMS	(%)	< 15	13.1	12.8
Within 115% V_axial_avg	(%)	> 85	93.8	93.8
Within 140% V_axial_avg	(%)	> 99	100	100

Velocity Distribution Under Bags

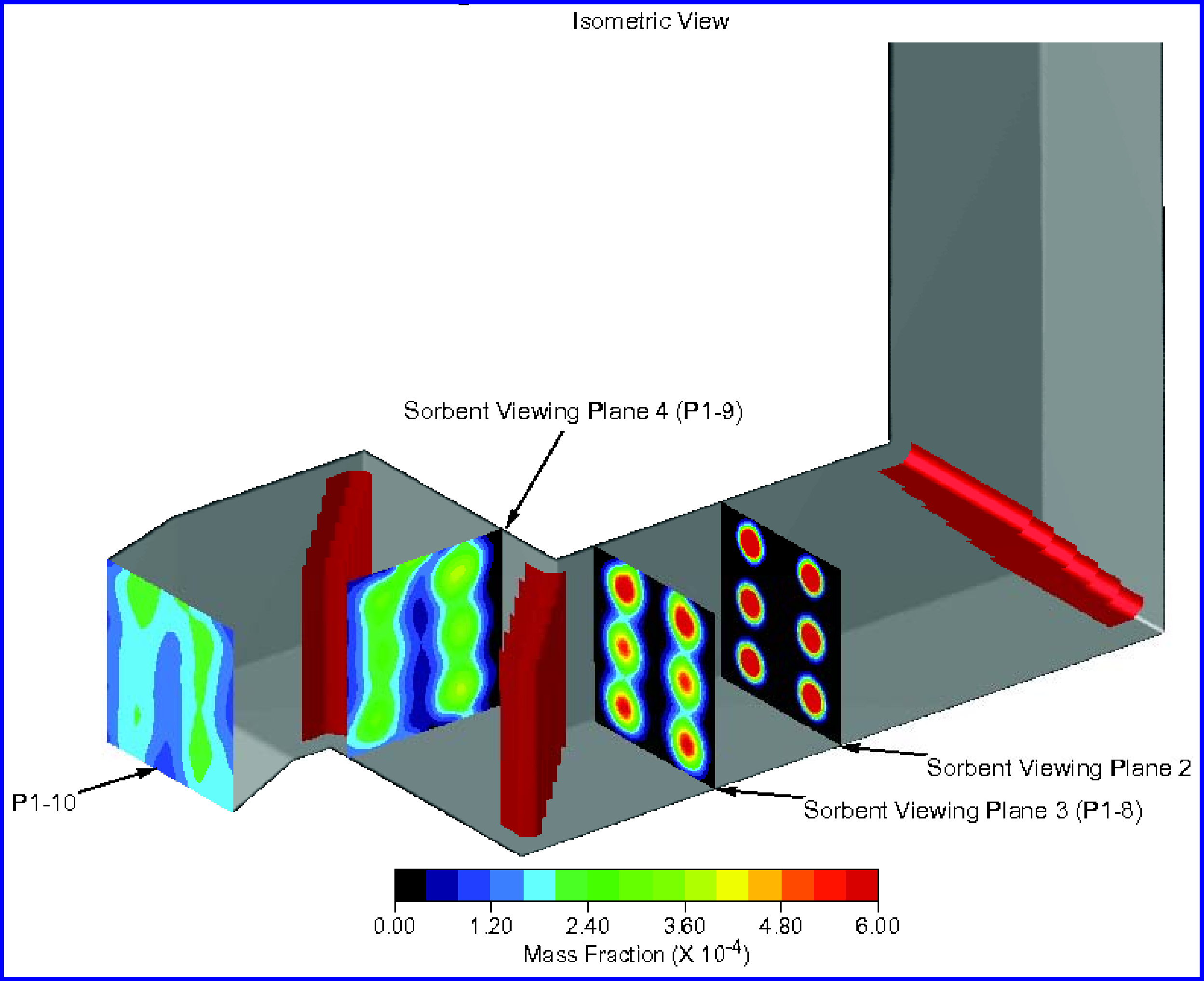


Results

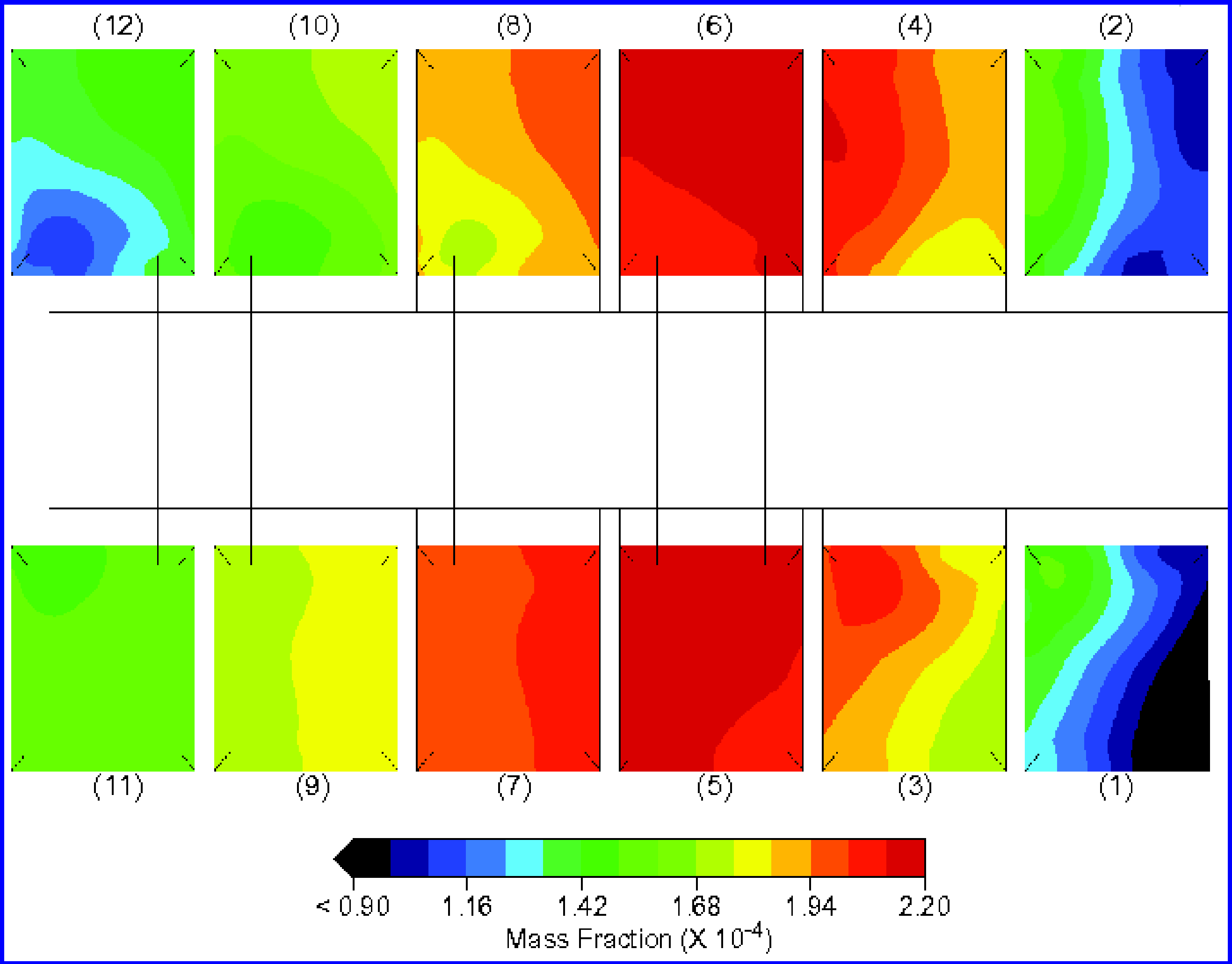
- Activated carbon distribution

	Compartment	Baseline: Carbon Mass (lb)	Baseline: % of Total Carbon Mass	Baseline: % Deviation from PJFF Average (Goal: < +/-15%)	Design: Carbon Mass (lb)	Design: % of Total Carbon Mass	Design: % Deviation from PJFF Average (Goal: < +/-15%)
Fabric Filter	1	0.0041	5.9%	-29.3%	0.0059	8.5%	2.3%
	2	0.0045	6.4%	-22.8%	0.0057	8.2%	-2.2%
	3	0.0064	9.2%	10.1%	0.0058	8.3%	-0.2%
	4	0.0066	9.6%	14.8%	0.0056	8.0%	-3.4%
	5	0.0072	10.3%	23.8%	0.0057	8.2%	-2.1%
	6	0.0071	10.2%	22.1%	0.0056	8.0%	-3.9%
	7	0.0067	9.7%	15.8%	0.0058	8.3%	0.0%
	8	0.0063	9.0%	8.1%	0.0056	8.1%	-2.4%
	9	0.0059	8.5%	1.4%	0.0059	8.5%	2.3%
	10	0.0053	7.6%	-9.0%	0.0059	8.5%	2.5%
	11	0.0051	7.4%	-11.5%	0.0059	8.5%	2.2%
	12	0.0044	6.4%	-23.5%	0.0061	8.7%	5.0%
	Total:	0.069	100.0%		0.069	100.0%	

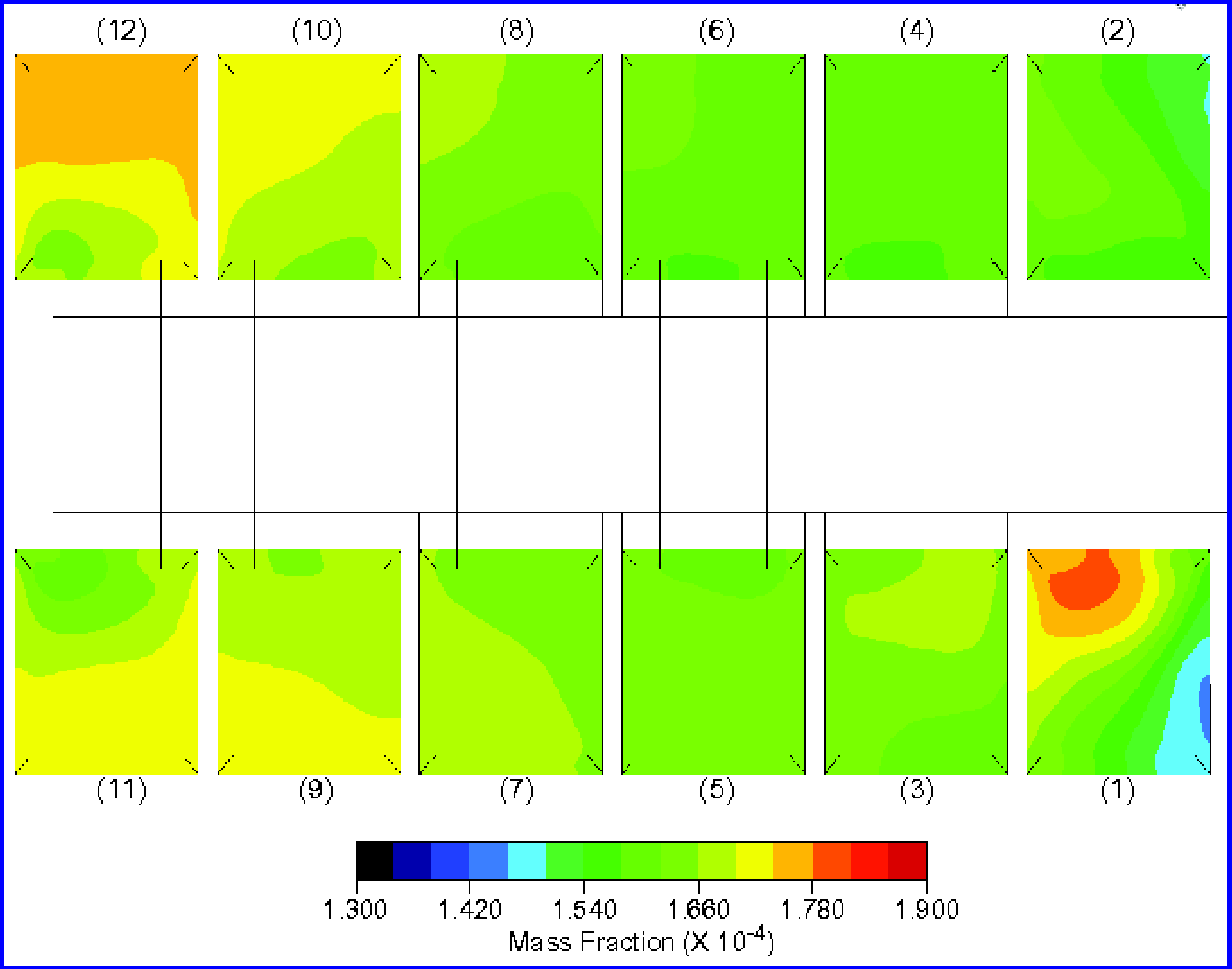
Activated Carbon Injection



Baseline Carbon per Compartment



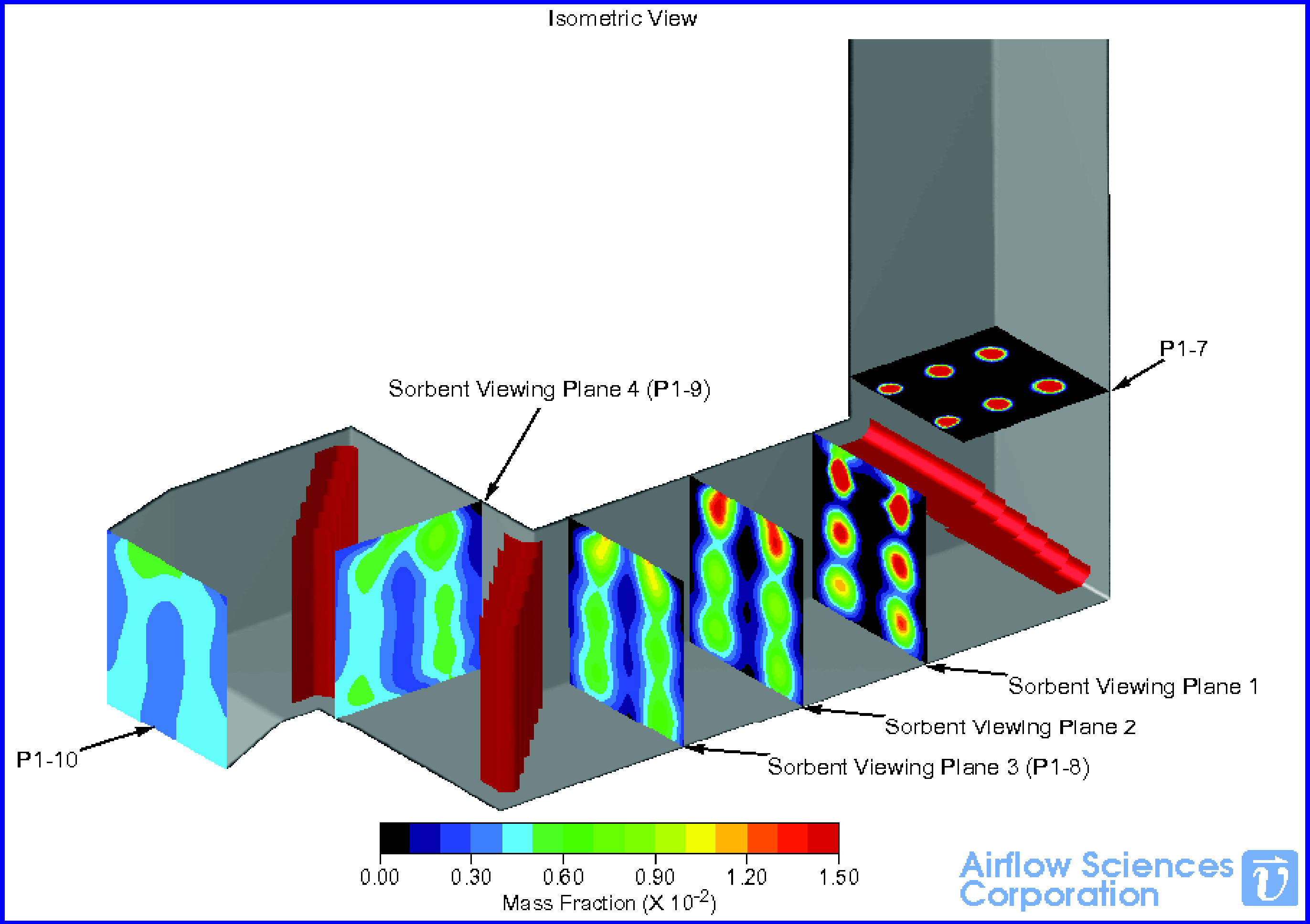
Final Design Carbon Distribution



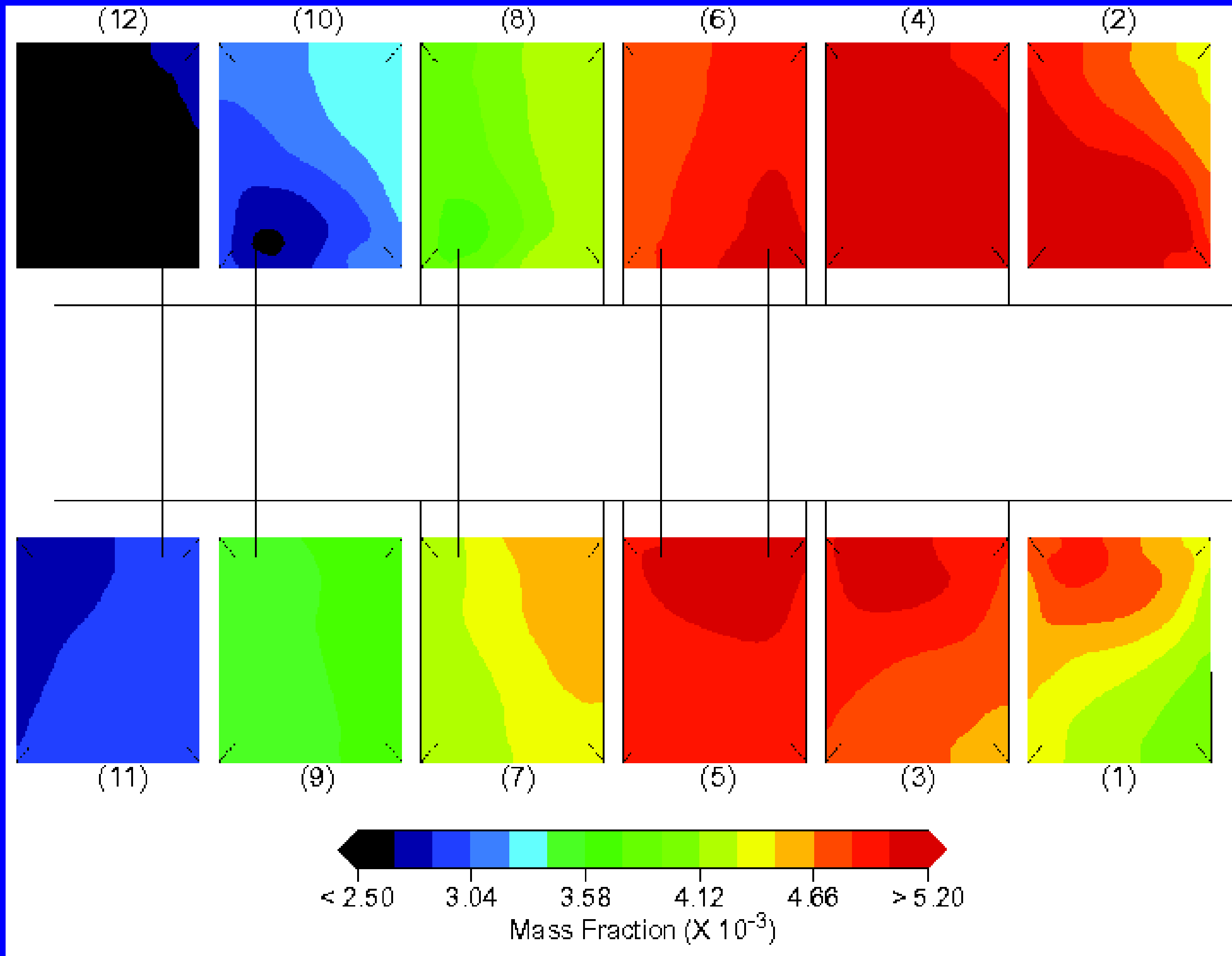
Trona Results

		Baseline			Design		
	Compartment	Trona Mass (lb)	% of Total Trona Mass	% Deviation from PJFF Average (Goal: < +/-15%)	Trona Mass (lb)	% of Total Trona Mass	% Deviation from PJFF Average (Goal: < +/-15%)
Fabric Filter	1	0.155	9.3%	11.6%	0.147	8.8%	5.9%
	2	0.173	10.4%	24.7%	0.140	8.4%	1.1%
	3	0.164	9.9%	18.3%	0.136	8.2%	-1.9%
	4	0.174	10.4%	25.0%	0.134	8.0%	-3.5%
	5	0.166	10.0%	19.6%	0.133	8.0%	-4.2%
	6	0.163	9.8%	17.7%	0.131	7.8%	-5.9%
	7	0.146	8.8%	5.2%	0.136	8.2%	-2.1%
	8	0.133	8.0%	-4.0%	0.133	8.0%	-4.3%
	9	0.117	7.0%	-15.5%	0.141	8.5%	1.5%
	10	0.101	6.1%	-27.4%	0.142	8.5%	2.5%
	11	0.096	5.7%	-31.1%	0.143	8.6%	3.0%
	12	0.078	4.7%	-44.0%	0.150	9.0%	7.8%
	Total:	1.666	100.0%		1.666	100.0%	

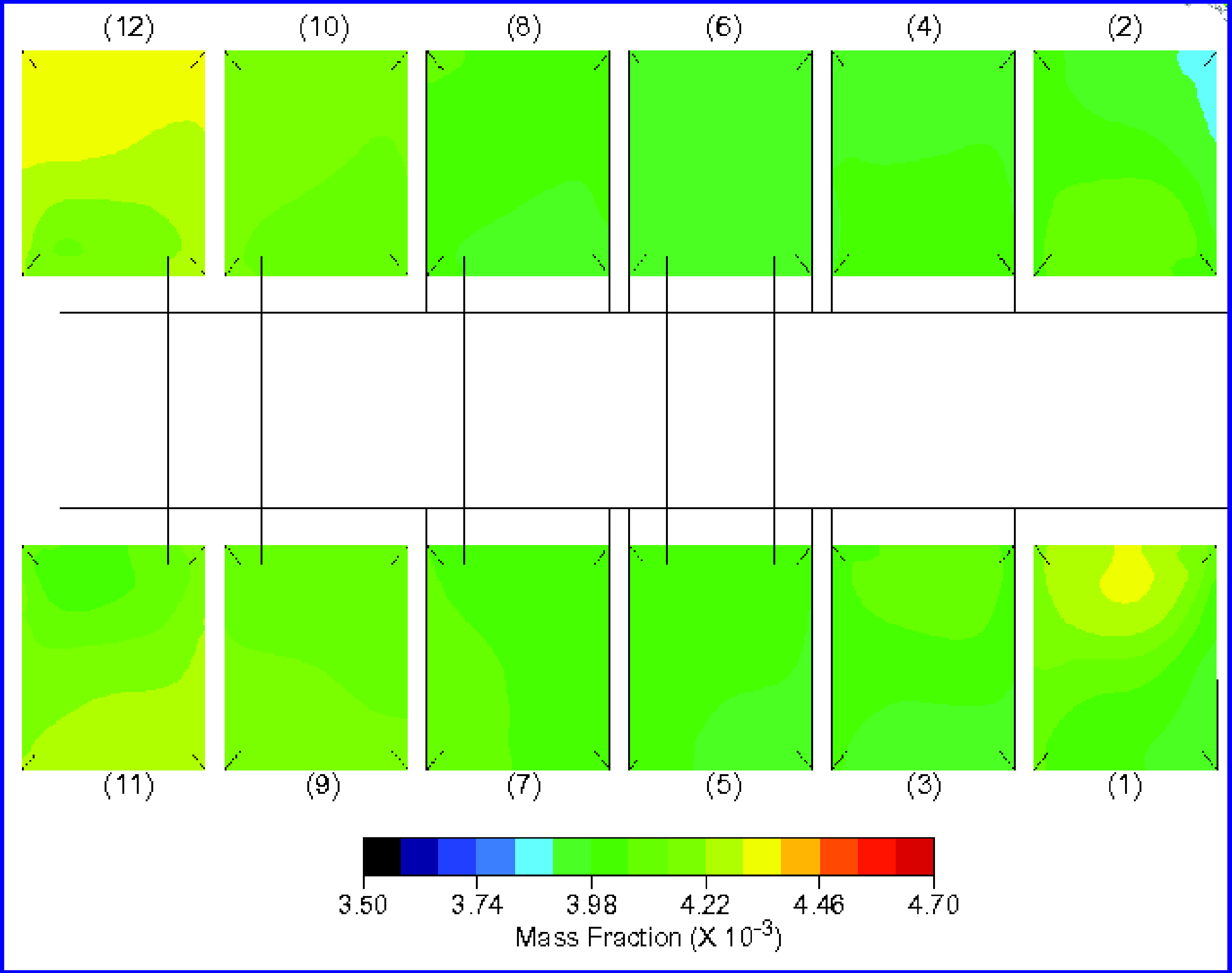
Trona Injection



Baseline Trona Distribution



Final Design Trona



Power Industry

- Modeling and testing have been applied to every component of a power plant that involves flow (air, gas, liquid, steam, particulate), heat transfer, combustion, or chemical reaction

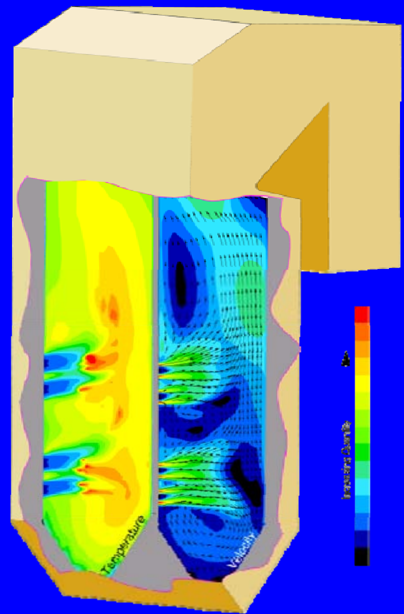
Performance
- Heat Rate
- Capacity
- Pressure Loss
- Combustion
- Instrumentation

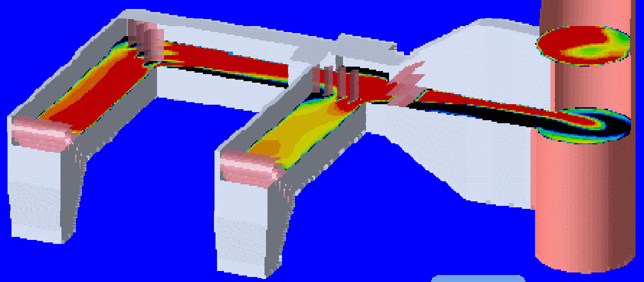
Environmental
- Particulate Capture
- NOx
- SOx
- CEMs

Maintenance
- Fouling
- Pluggage
- Erosion
- Corrosion
- Vibration

Power Industry

- Fans
- Ducts
- Pulverizers
- Windboxes
- Furnaces
- Air Heaters
- SCRs
- FGD
- Stacks
- Turbines
- Condensers
- HRSGs
- …





Conclusions

- Flow models (CFD and physical) are widely employed for pollution control equipment original design and retrofit
  - Each method has advantages and disadvantages
  - Provide accurate results to within typical engineering tolerances when used correctly
  - Should be correlated to field data when possible to maximize accuracy
- Field testing of flow parameters is widely used to diagnose problems and confirm design performance

Questions?

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