

# **REINHOLD ENVIRONMENTAL Ltd.**



## **2012 APC Round Table & Expo Presentation**

July 16-17, 2012, in Baltimore, MD / Hosted by Duke Energy, Entergy,  
FirstEnergy, Southern Company & TVA

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# Flow Modeling and Testing of Fabric Filters

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July 16-17, 2012



# 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



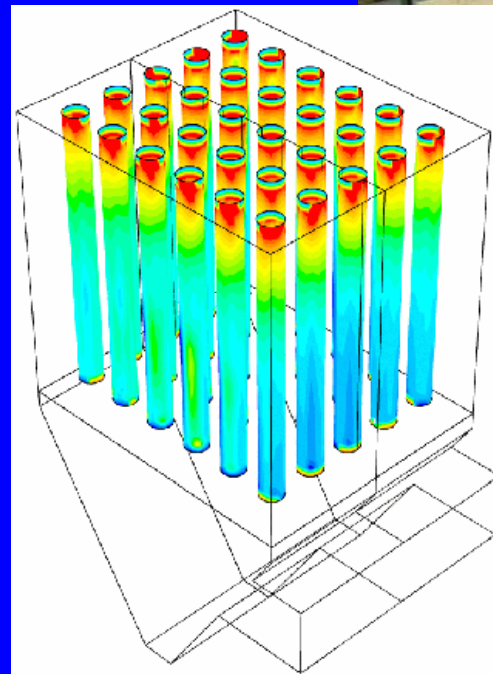
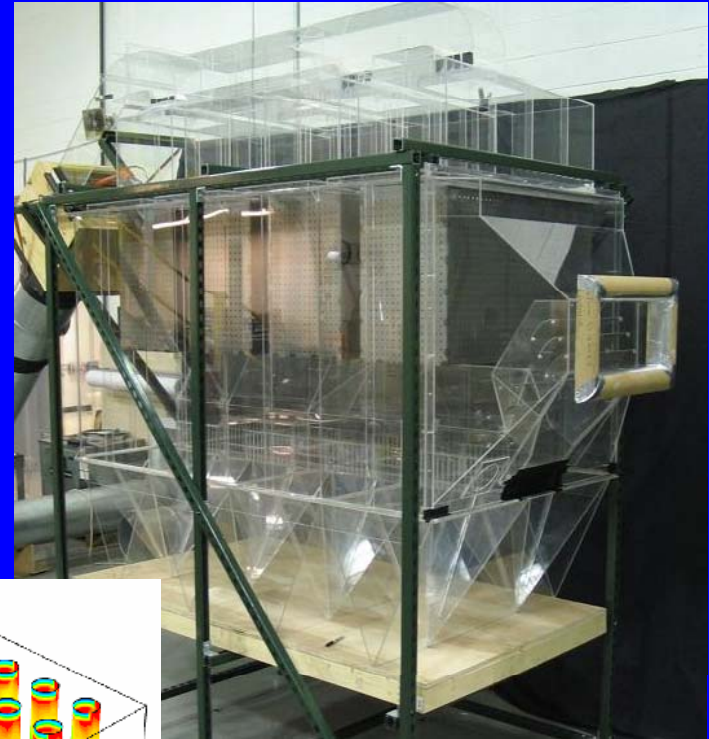
# Outline

- ❖ 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



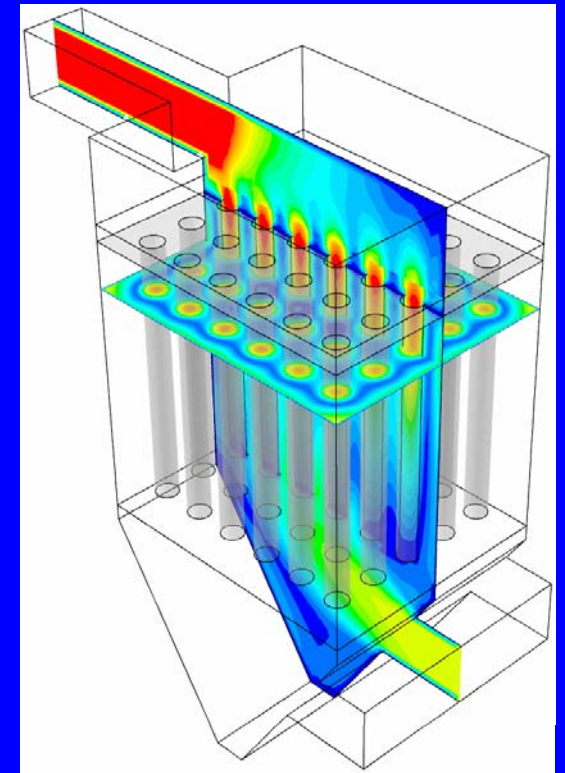
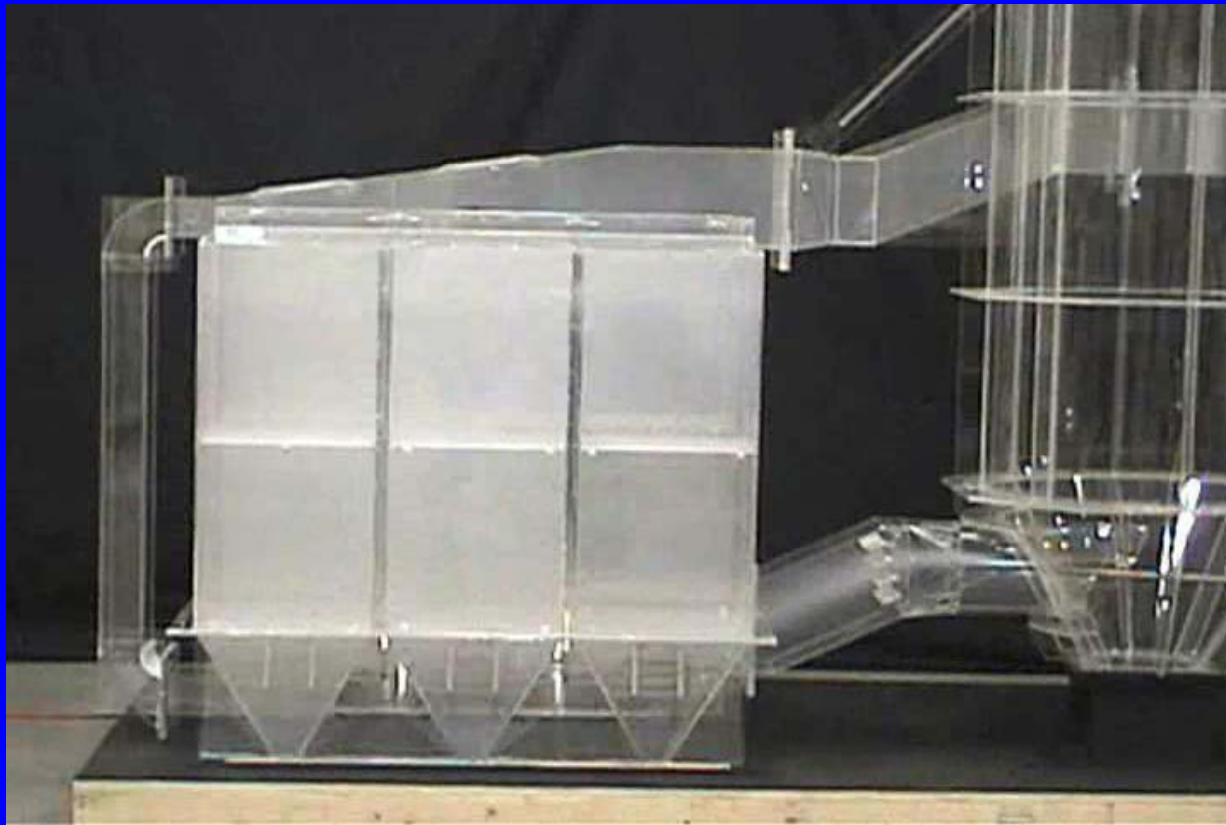
# Performance Goals

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



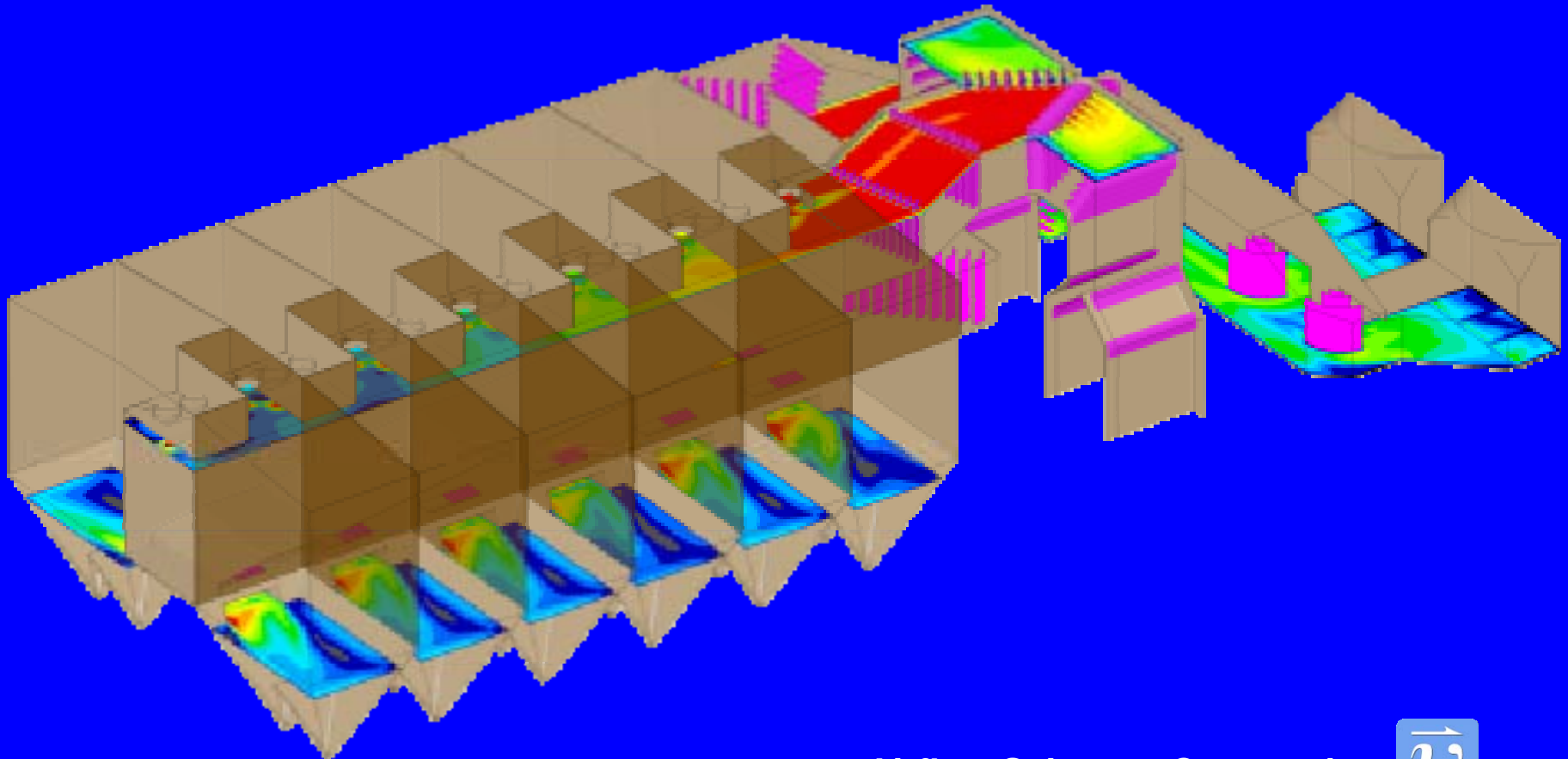
# Fabric Filter Velocity Distribution

- ❖ 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:

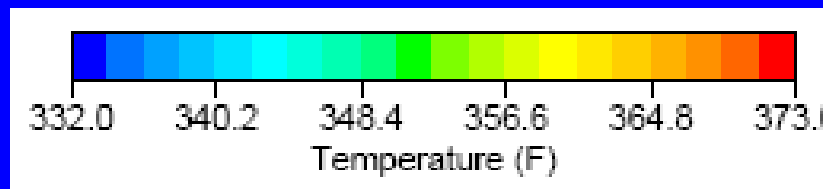
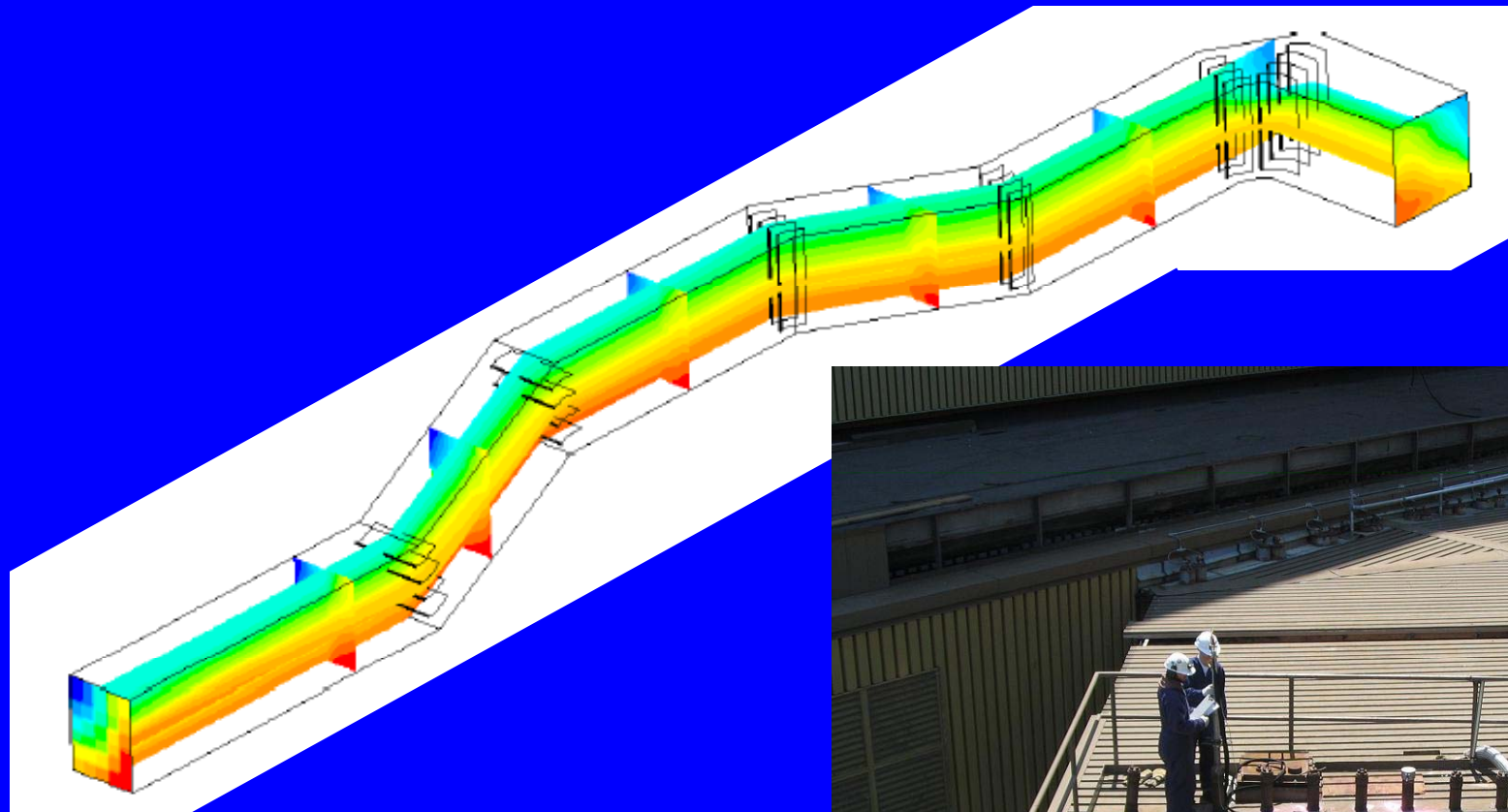
- Minimize DP

## ❖ Methods

- Vanes
- Duct contouring
- Area management



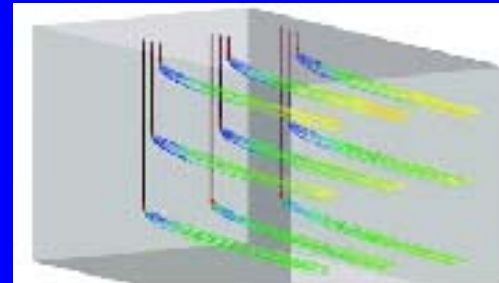
# Fabric Filter Temperature Stratification



# Particulate Injection

## ❖ Mercury absorption

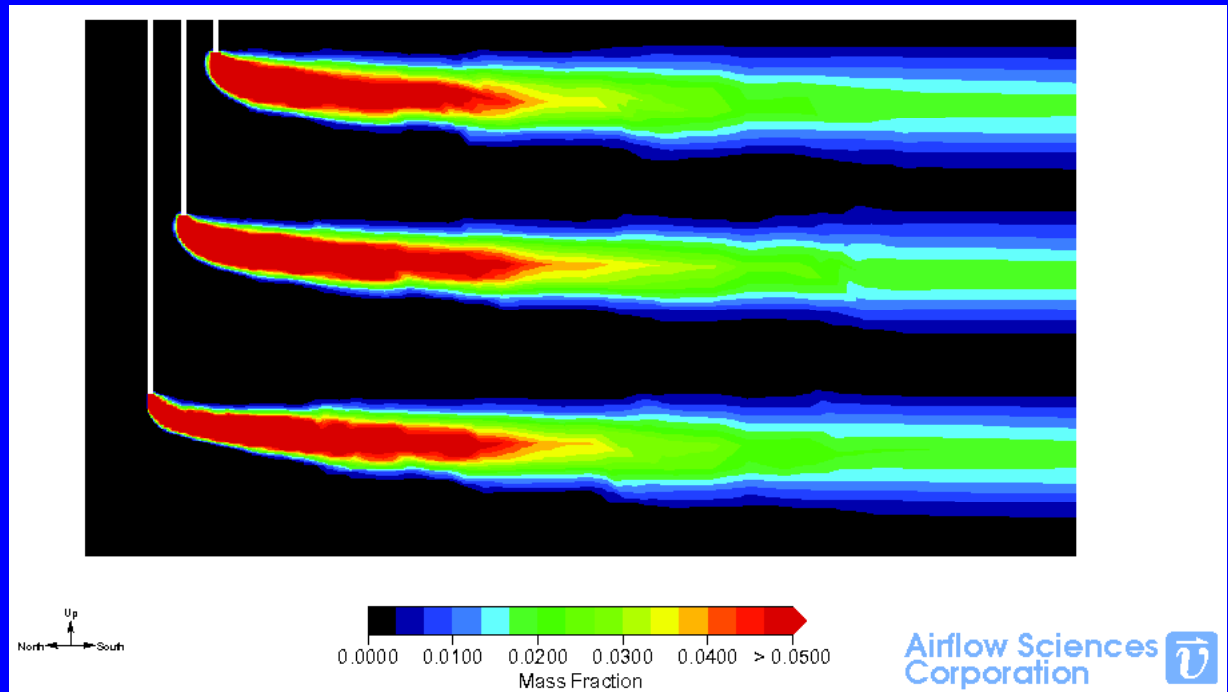
- Activated carbon
- Other



*Total velocity of particles leaving lances.*

## ❖ SOx mitigation

- Limestone
- SBS
- SBC
- Trona
- Etc.



# Ash Deposition

- ❖ Drop out
- ❖ Re-entrainment



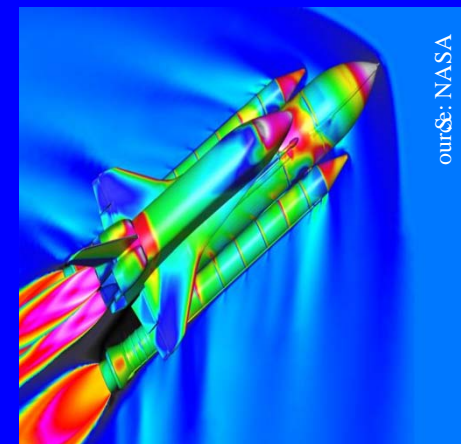
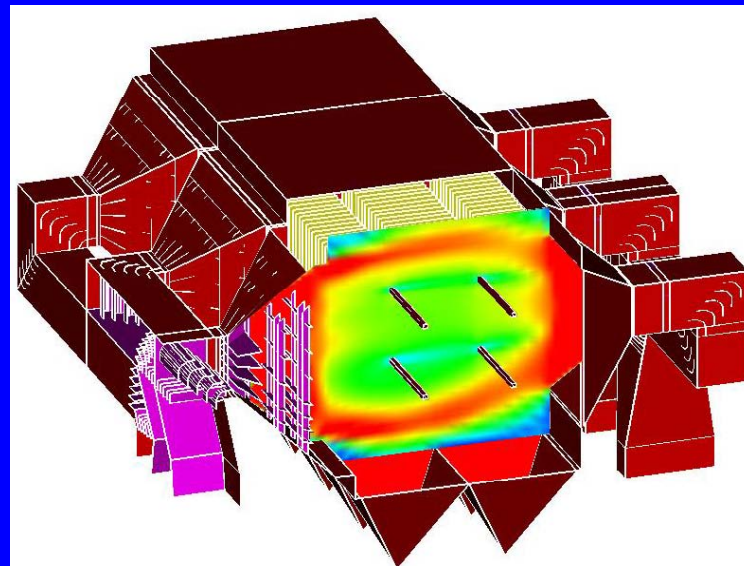
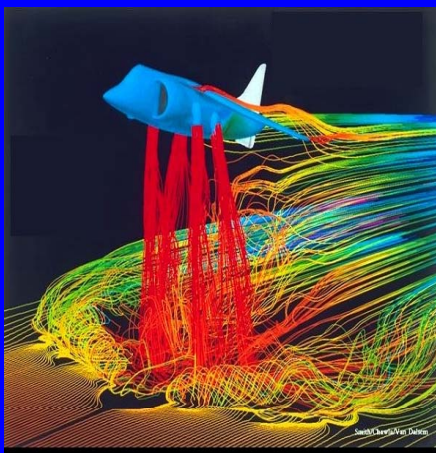
# Outline

- ❖ 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

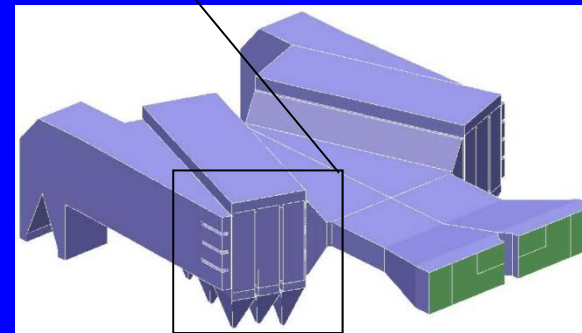
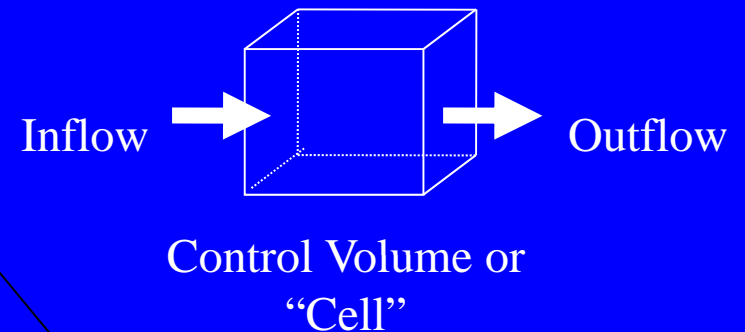
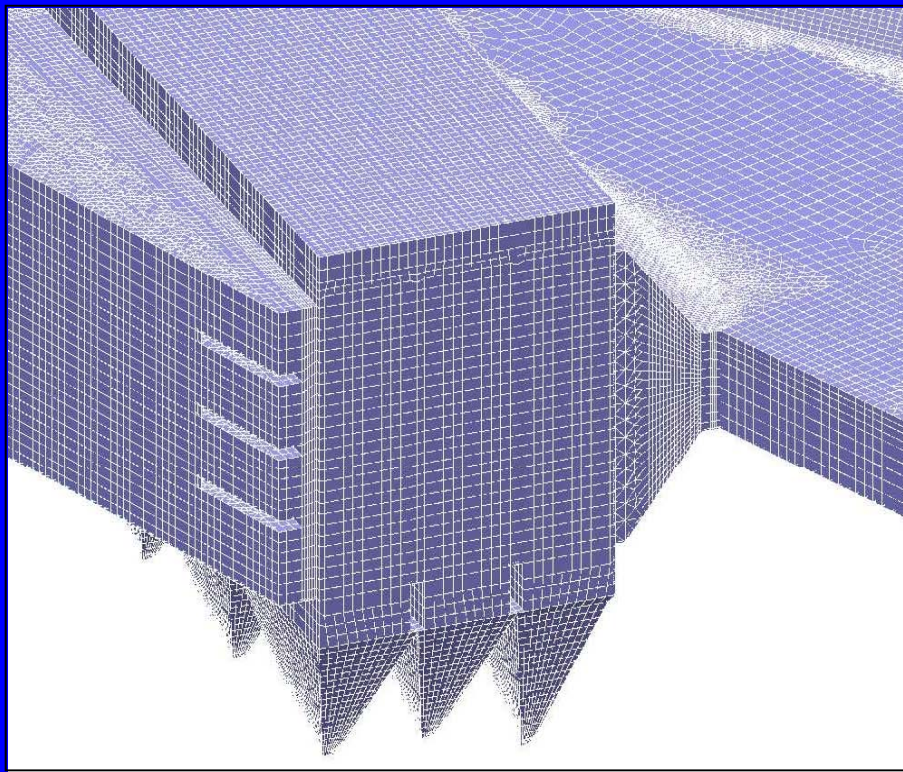
- ❖ Developed in the aerospace industry c.1970 (with the advent of “high speed” computers)
- ❖ Used in the power industry for  $> 25$  years
- ❖ As computing power and software have progressed, accuracy has improved and more complicated problems have been analyzed



# CFD – Methodology

## ❖ Control Volume Approach

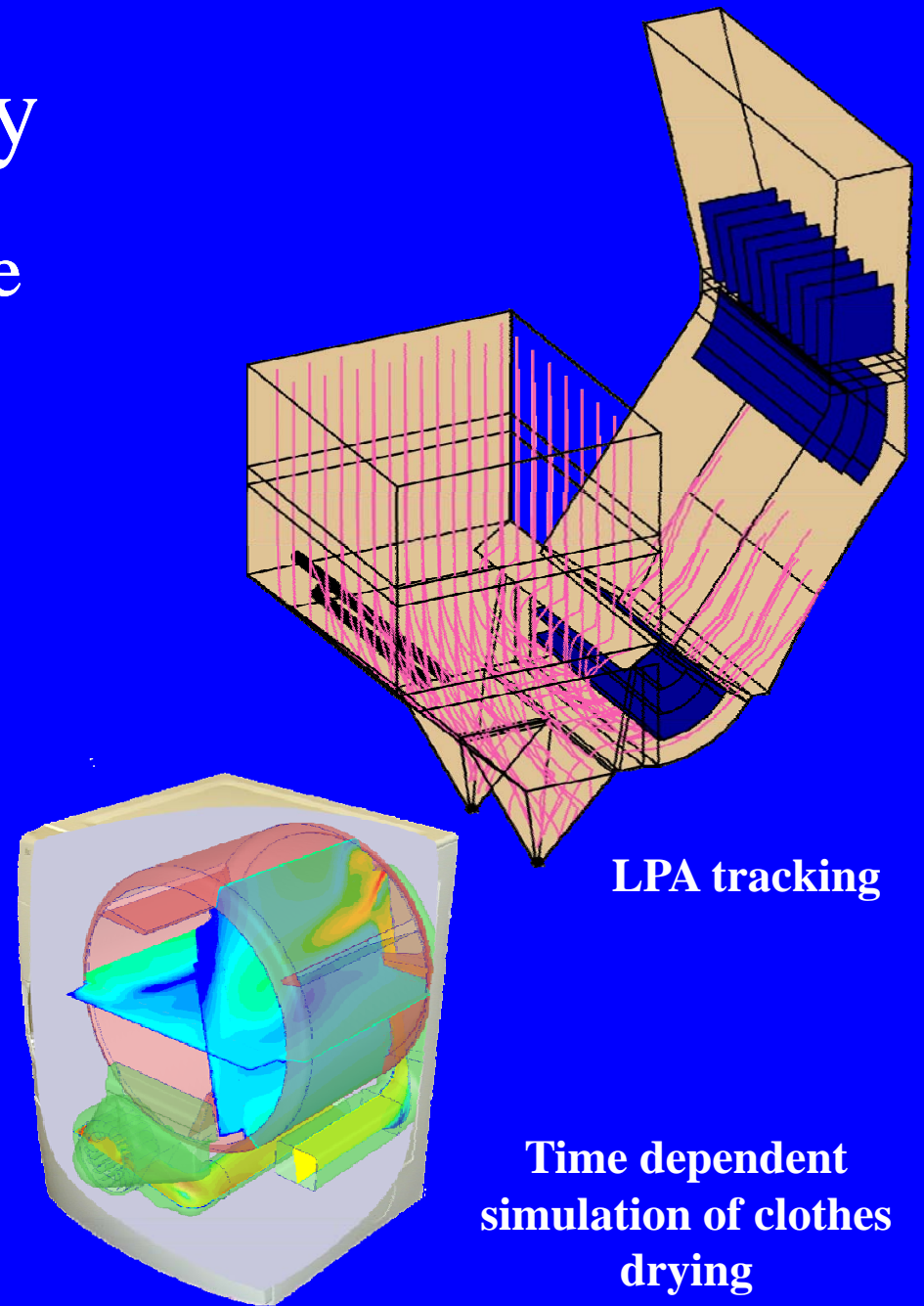
- Divide the flow domain into distinct control volumes
- Solve the Navier-Stokes equations (Conservation of Mass, Momentum, Energy) in each control volume



# CFD – Methodology

## ❖ Additional physics can be implemented into the simulation

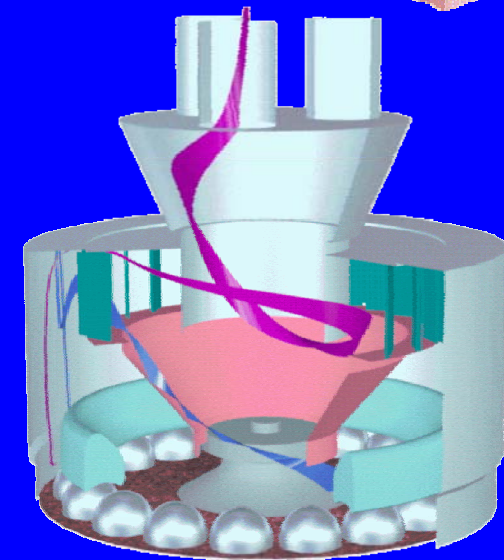
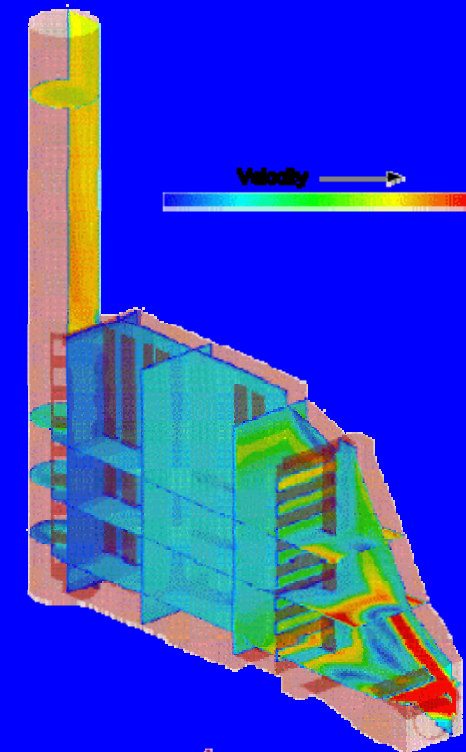
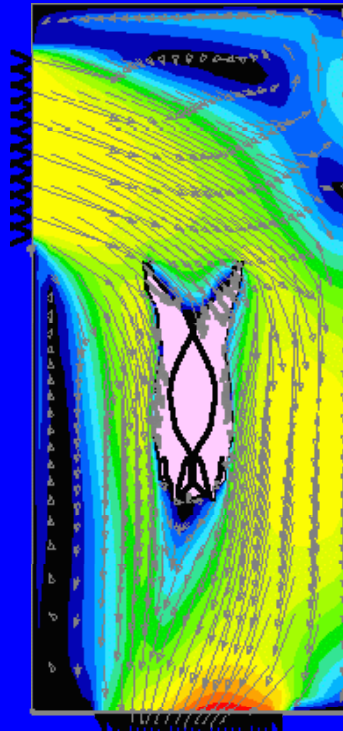
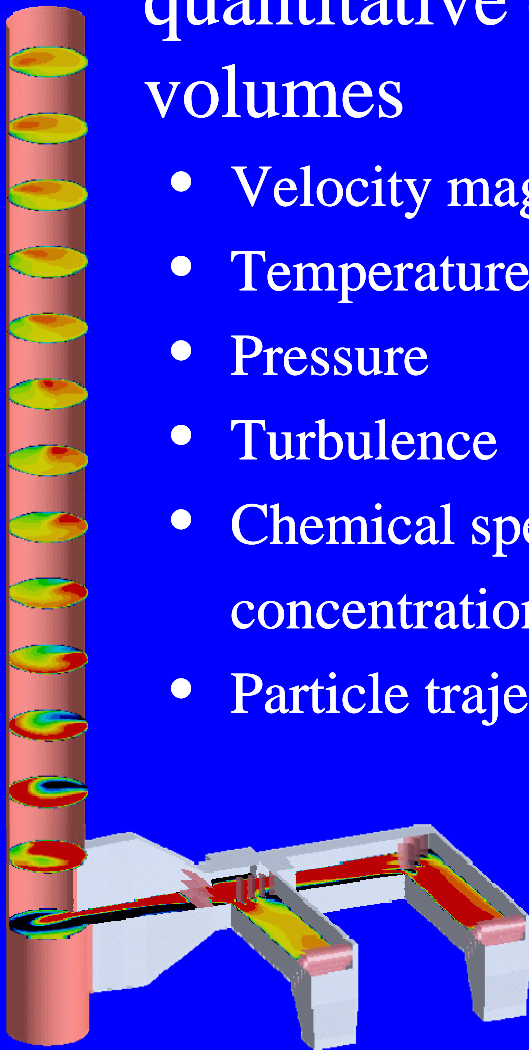
- Chemical reaction
- Mass transfer
  - Evaporation
  - Drying
- Particulate tracking
- Two-phase momentum exchange
- Species diffusion
- Radiative heat transfer
- Mechanical motion



# CFD – Results Analysis

❖ Simulation results provide quantitative data at all control volumes

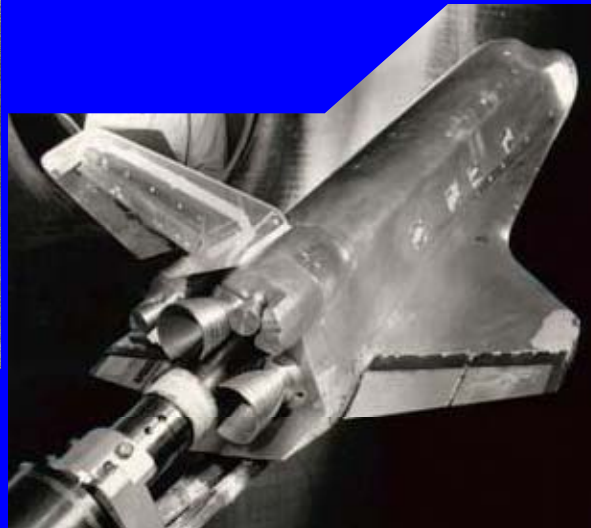
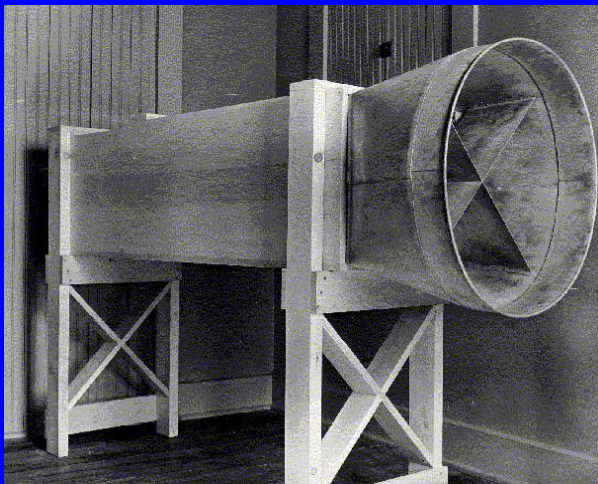
- Velocity magnitude, directionality
- Temperature
- Pressure
- Turbulence
- Chemical species concentrations
- Particle trajectories



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



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



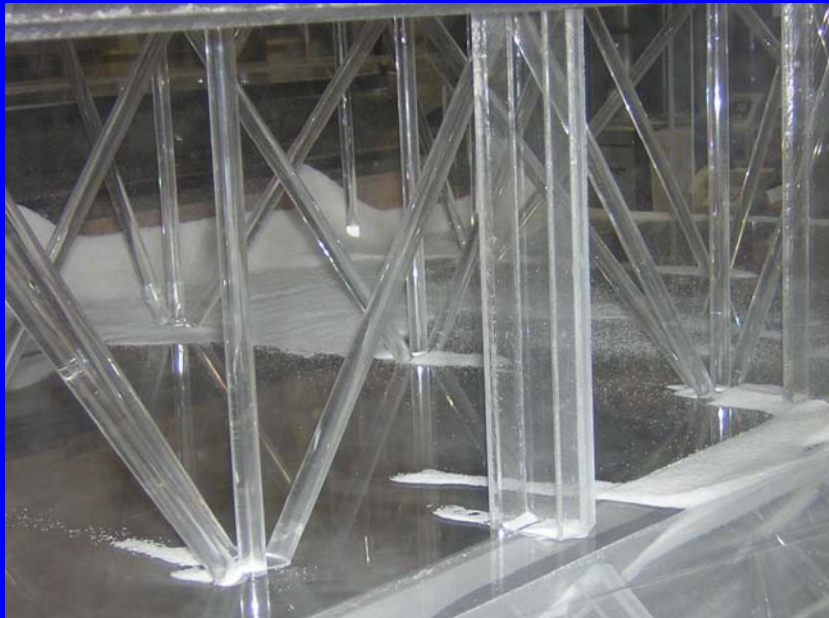
# Physical Models – Methodology

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



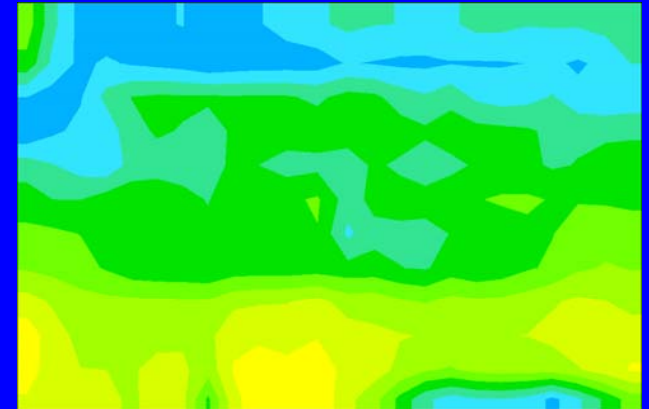
# Physical Models – Methodology

- ❖ 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

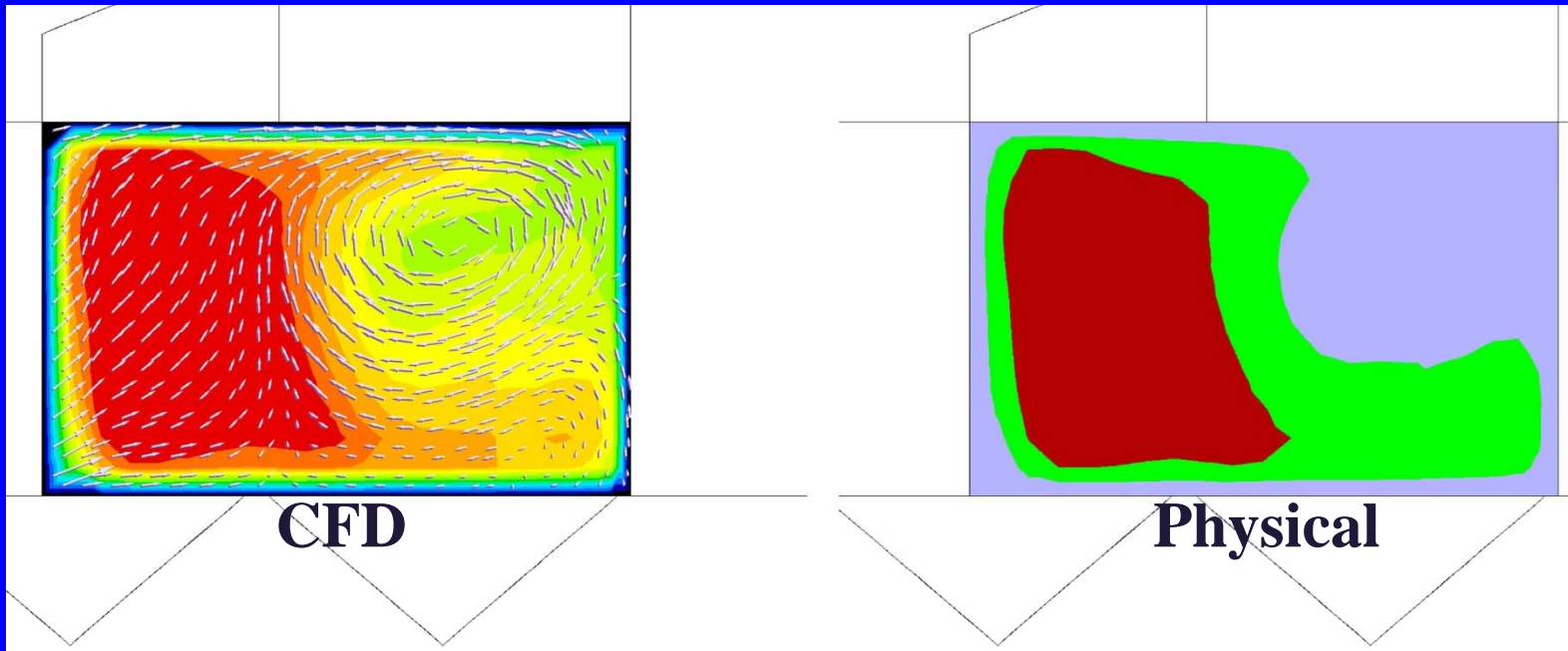
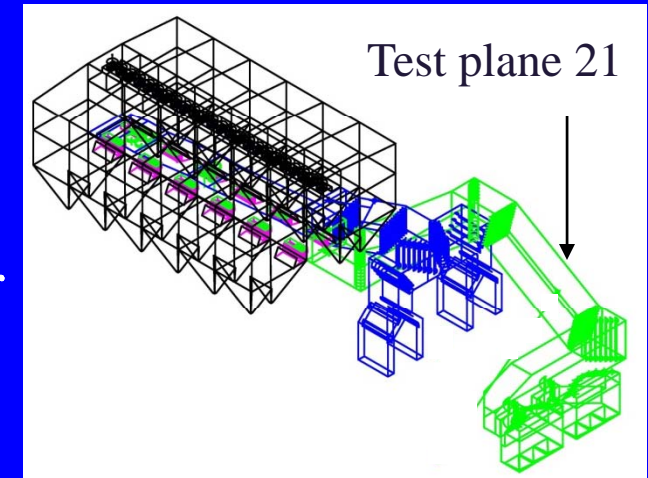
<u>Comparison</u>	<u>CFD</u>	<u>Physical</u>
Technical accuracy	Very good	Very good
Include complicated physics (evaporation, combustion, particle tracking, ...)	Yes	Some, with inherent assumptions
Quantity of measurement points	Millions	Tens or Hundreds
Predict particulate build up	Limited	Good
Flow 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 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

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



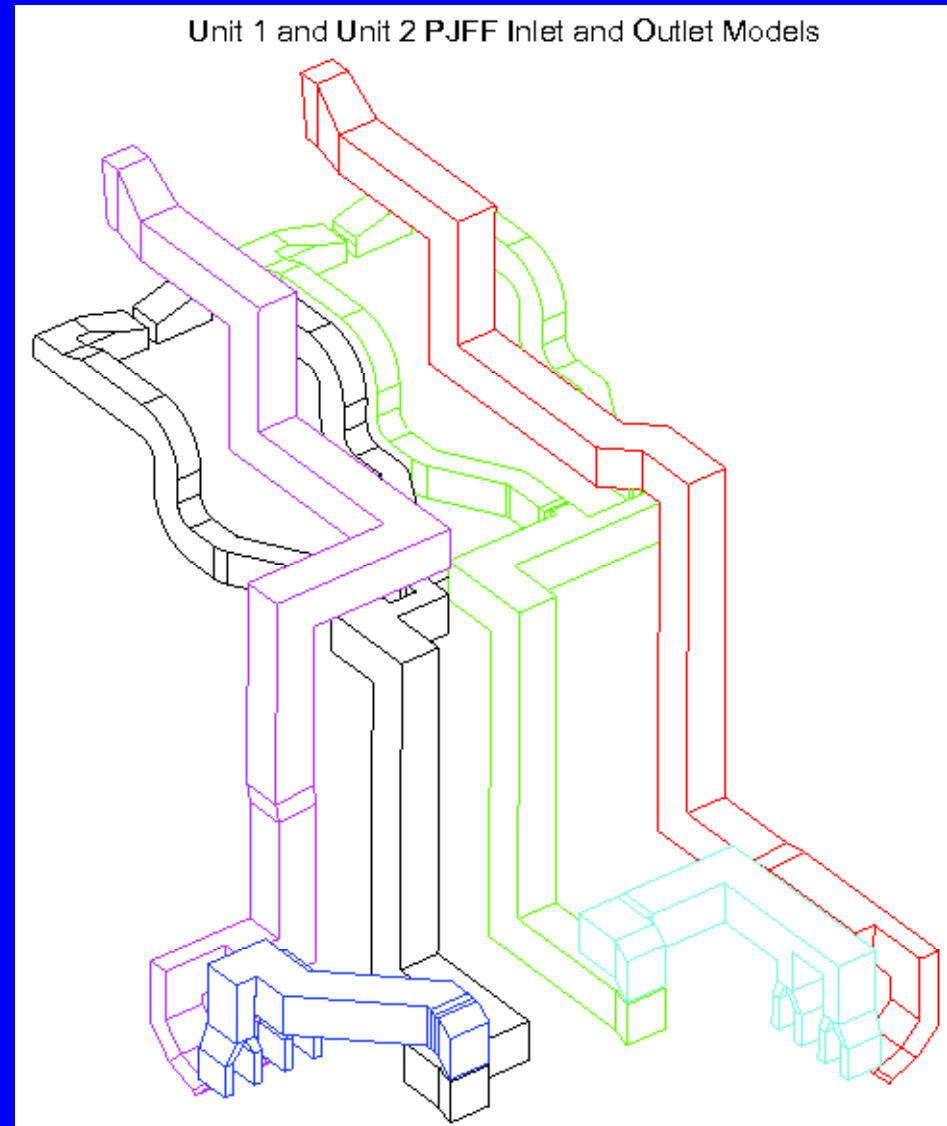
# Case Study

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



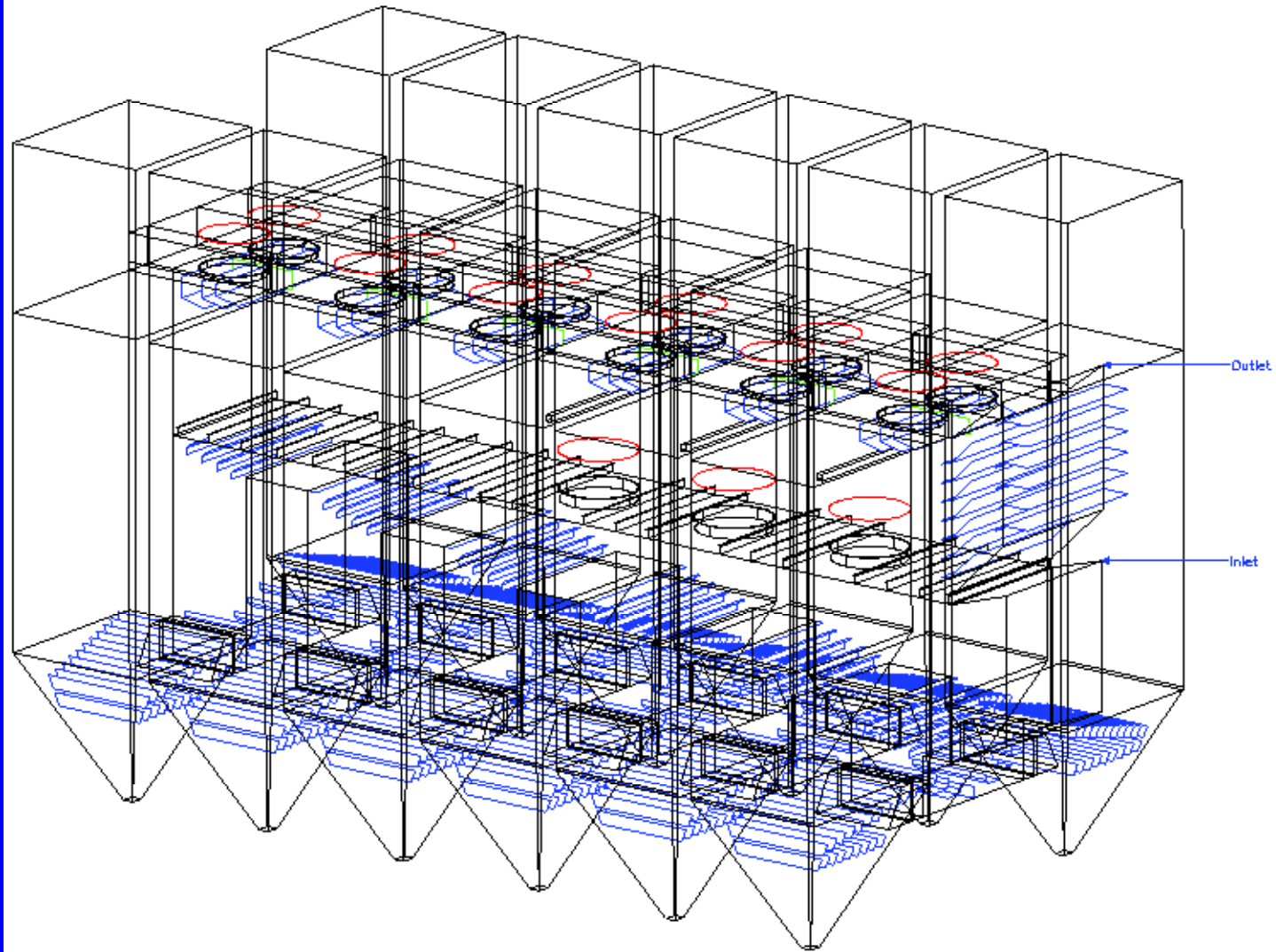
# Geometry

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



# Schematics

Isometric View: Fabric Filter

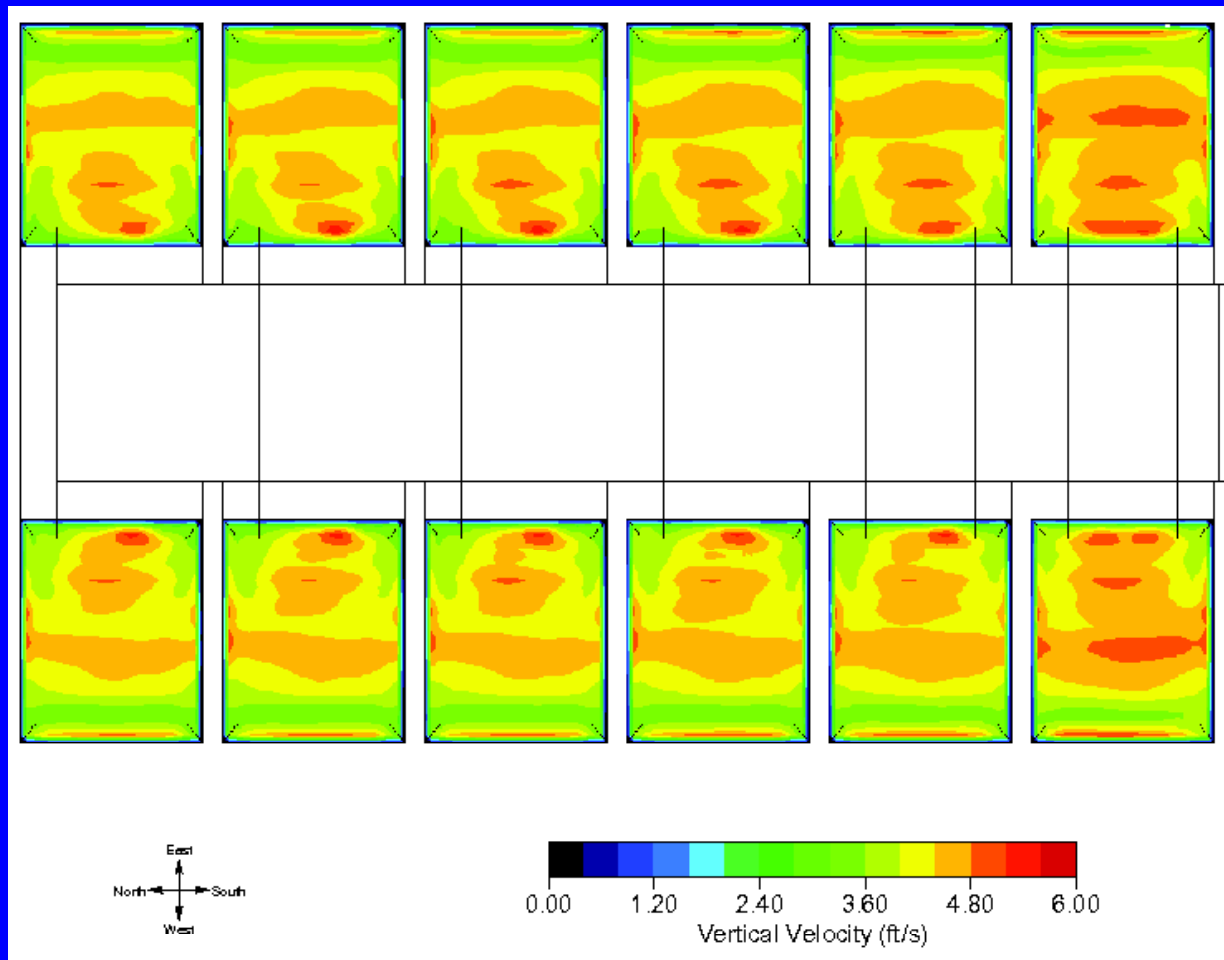


# Results

## ❖ 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
<b>PJFF</b>				
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

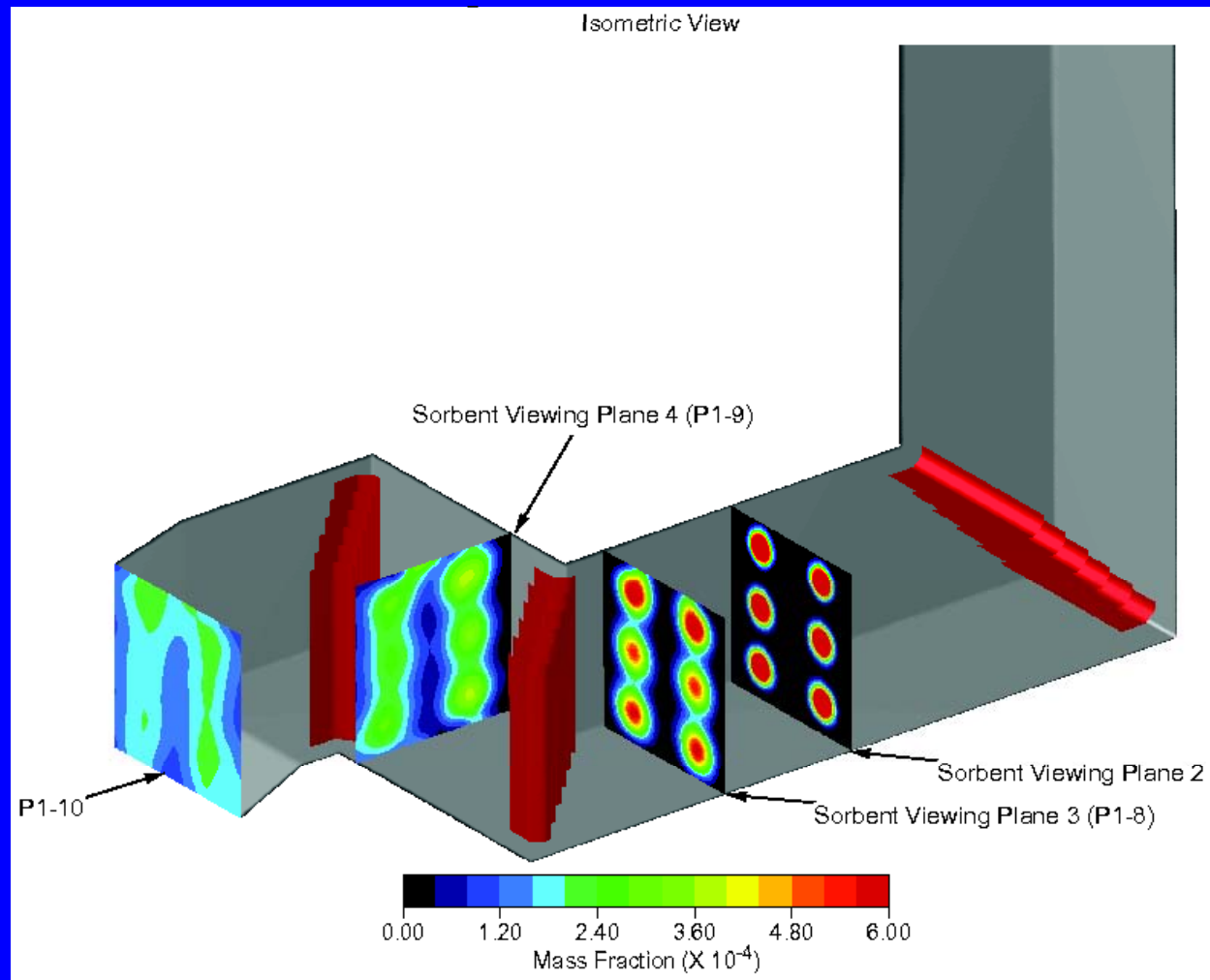


# Results

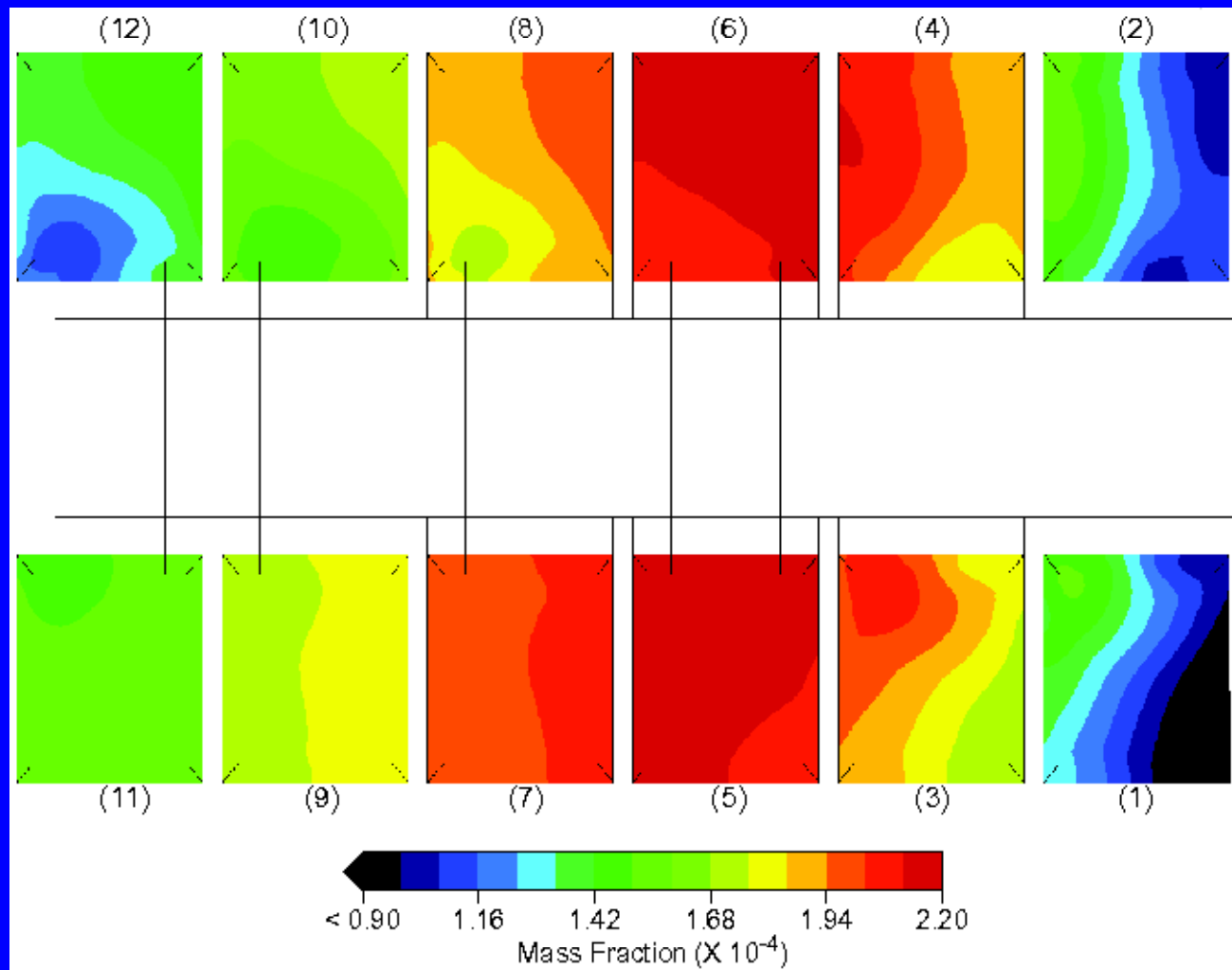
## ❖ Activated carbon distribution

		Baseline			Design		
	Compartment	Carbon Mass (lb)	% of Total Carbon Mass	% Deviation from PJFF Average (Goal: < +/-15%)	Carbon Mass (lb)	% of Total Carbon Mass	% Deviation from PJFF Average (Goal: < +/-15%)
	Fabric Filter	1	0.0041	5.9%	-29.3%	0.0059	8.5%
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%	

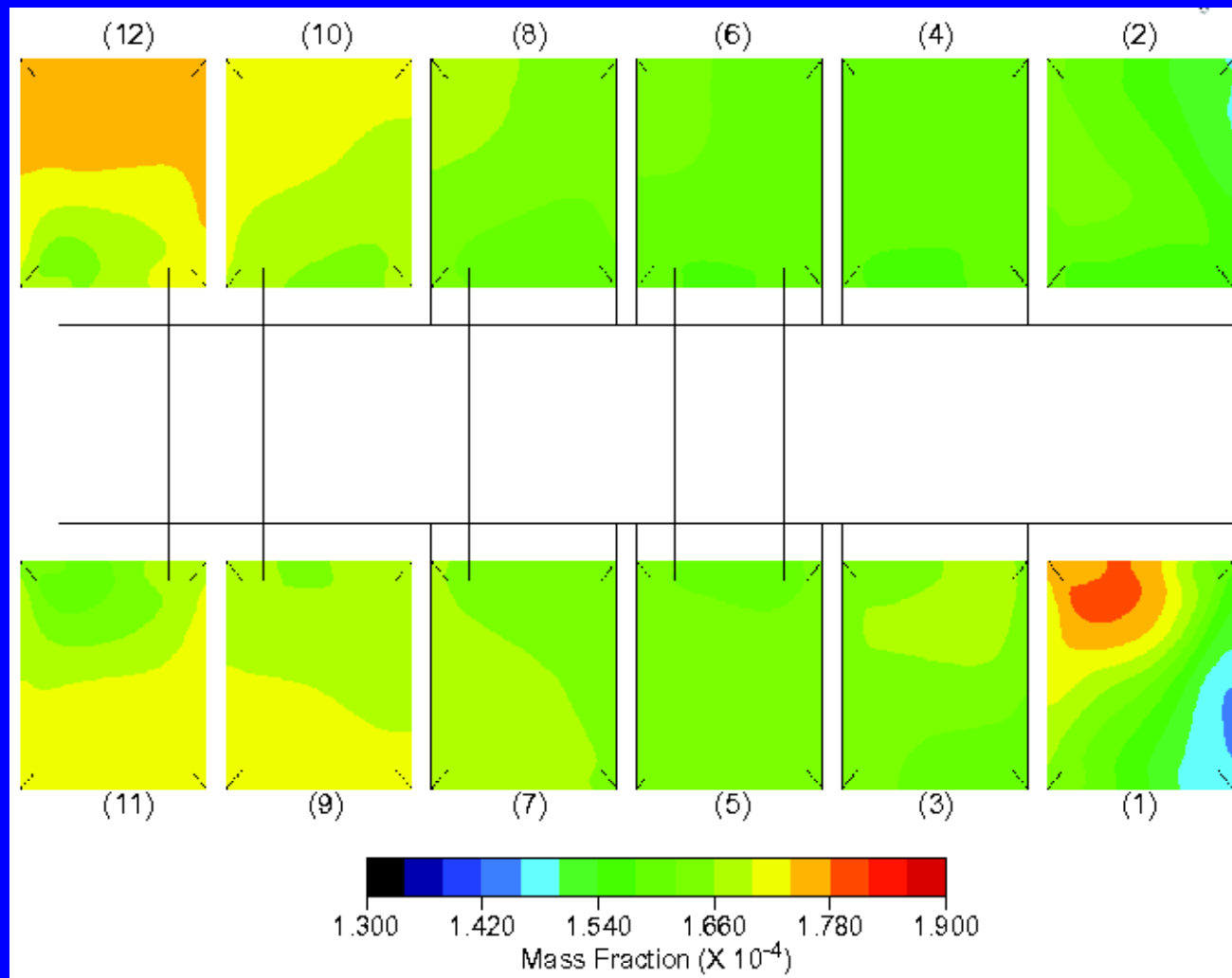
# Activated Carbon Injection



# Baseline Carbon per Compartment



# Final Design Carbon Distribution

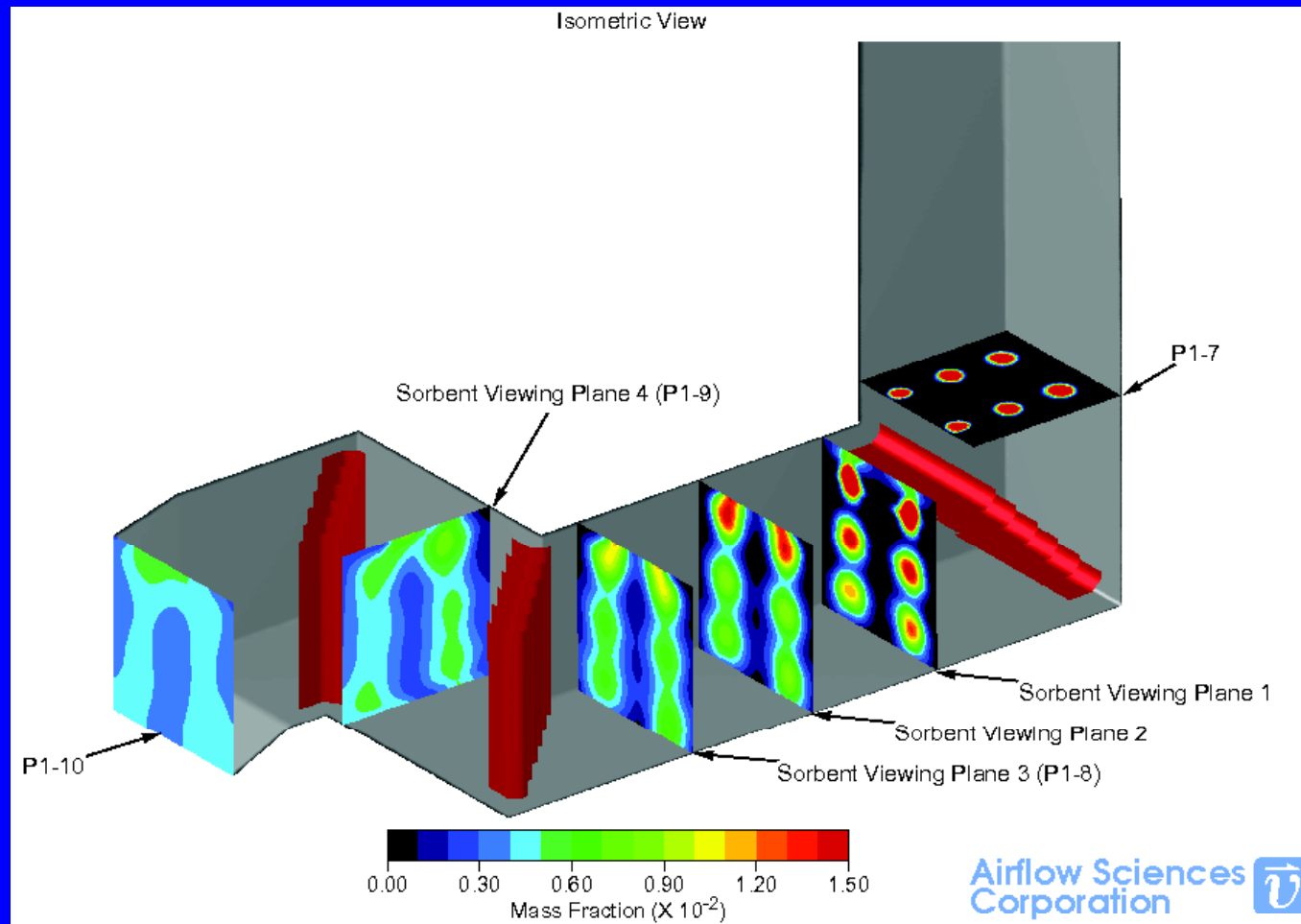


# Trona Results

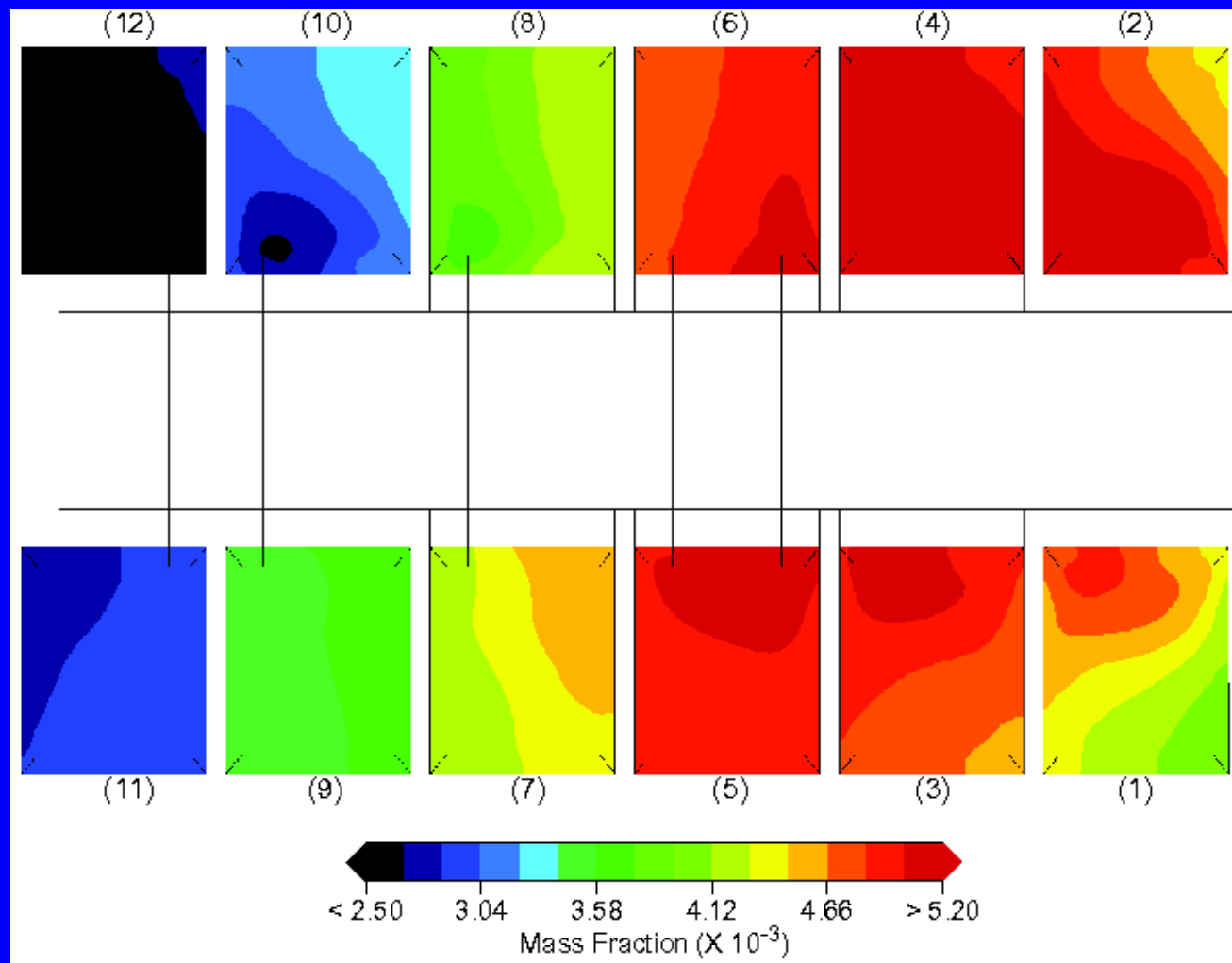
		Baseline			Design		
Fabric Filter	Compartment	Trona Mass (lb)	% of Total Trona Mass	% Deviation from PJFF Average (Goal: < +/-15%)	Trona Mass (lb)	% of Total Trona Mass	% Deviation from PJFF Average (Goal: < +/-15%)
		1	0.155	9.3%	11.6%	0.147	8.8%
	2	0.173	10.4%	24.7%	0.140	8.4%	1.1%
	3	0.164	9.9%	18.3%	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%	



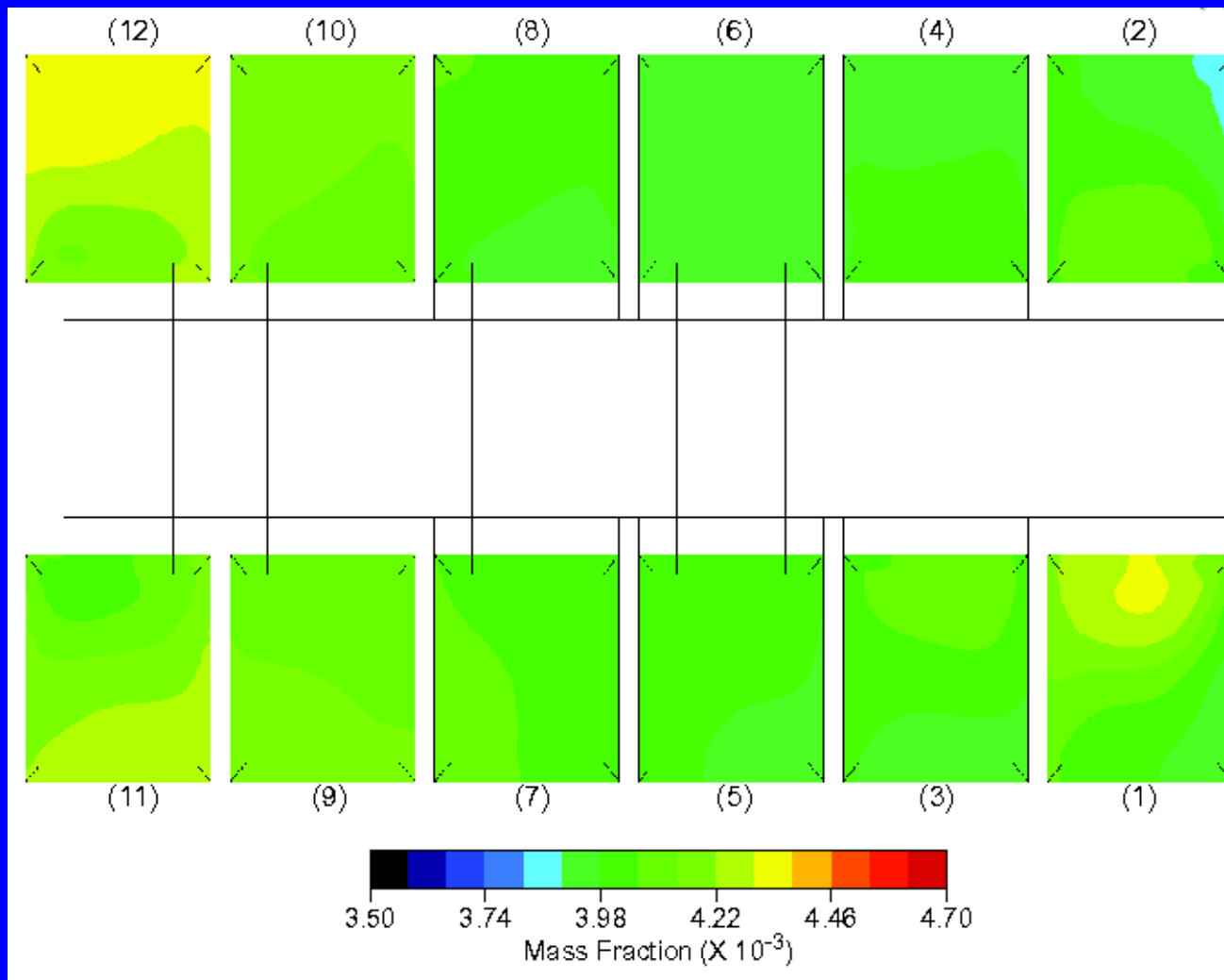
# Trona Injection



# Baseline Trona Distribution



# Final Design Trona



# 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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