

# Worldwide Pollution Control Association

**Ameren Seminar**  
**August 19–20, 2008**  
**Effingham, IL**



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# Understanding Gas Flow to Improve ESP Performance

Robert Mudry, P.E.  
Vice President – Engineering  
Airflow Sciences Corporation  
rmudry@airflowsciences.com

WPCA / Ameren Seminar  
August 19-20, 2008



# Outline

- ❖ Introduction
- ❖ ESP Fluid Flow Basics
- ❖ Assessing Flow Characteristics
- ❖ ESP Flow Modeling
- ❖ Movies and Animations
- ❖ Questions



# Introduction

## ❖ Why Worry About Fluid Dynamics?

- Strong influence on performance of pollution control equipment (ESP, FF, SCR, LNB, FGD, etc.)
- Relatively low cost performance enhancements are possible

## ❖ Example Cases

## ❖ About Your Speaker



# Example Cases

## ❖ How important is flow distribution?

Plant	Baseline Performance	After Flow Improvements
Mississippi Power Watson Unit 5	Full load opacity 25%	Full load opacity less than 5%
Dominion Generation Bremono Unit 4	Hot side ESP requires outage and wash every 2-3 months	Opacity reduced and duration between washes extended to annual outage
Essroc Materials Nazareth Unit 1	High opacity (14%) and high pressure loss cause high operating costs	Improved dust capture reduces opacity to 7%; system pressure loss reduced by 5 inches H <sub>2</sub> O



# About Your Speaker

- ❖ BSE, MSE Aerospace Engineering – University of Michigan
- ❖ 19 years as fluid dynamics consultant to industry
- ❖ Involved in 500+ testing/modeling projects
- ❖ Institute of Clean Air Companies (ICAC) member
- ❖ WPCA Director and Treasurer
- ❖ Author of 10 power industry technical papers
- ❖ Registered Professional Engineer in four states



# Outline

- ❖ Introduction
- ❖ ESP Fluid Flow Basics
  - Gas Velocity Distribution
    - Ductwork
    - Collection Region
  - Gas Flow Balance
  - Pressure Drop
  - Gas Temperature
  - Injection Systems
- ❖ Assessing Flow Characteristics
- ❖ ESP Flow Modeling
- ❖ Movies and Animations
- ❖ Questions



# Gas Velocity Distribution – Ductwork

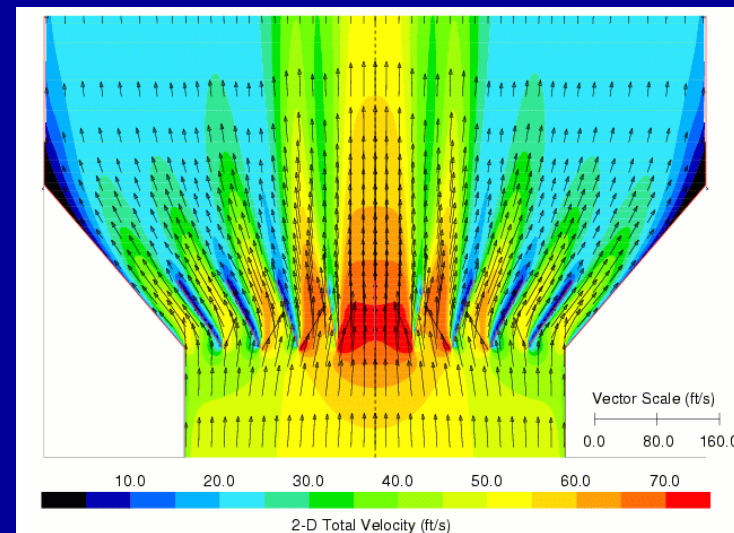
## ❖ Ductwork Design Criteria

- Maintain minimum velocity requirements to avoid particle dropout
- Provide good flow characteristics to ESP



## ❖ Considerations

- Horizontal surfaces
- Cross sectional area
- Bends
- Structure



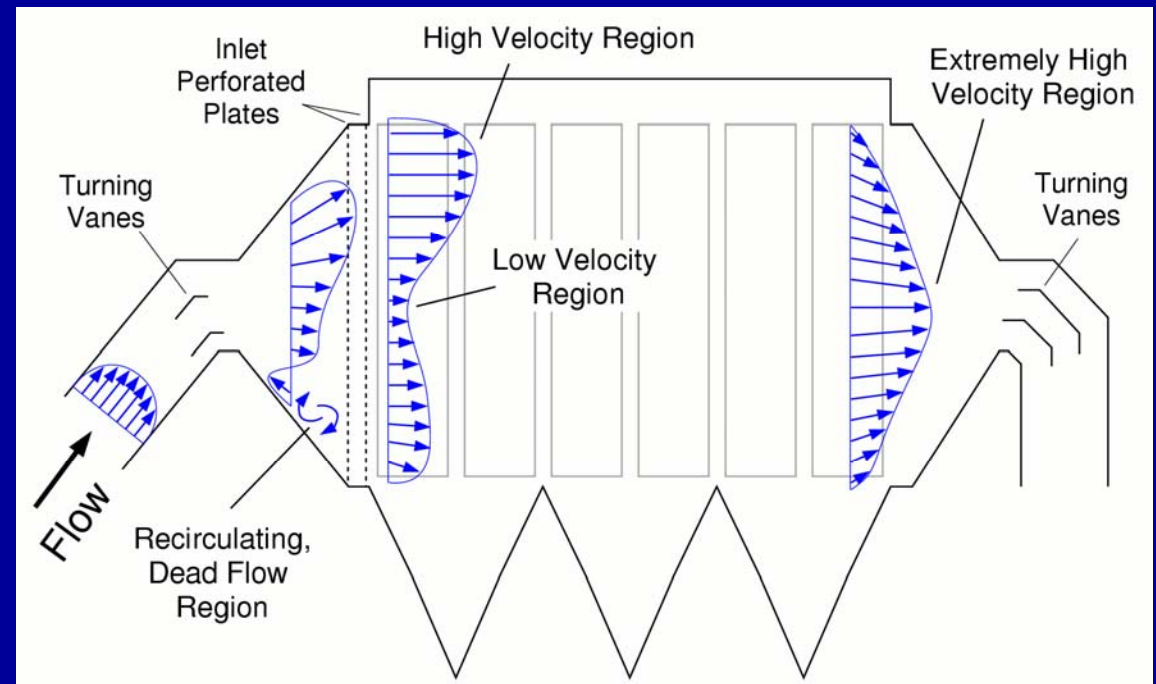
# Gas Velocity Distribution – Collection Region

## ❖ Uniform Flow Concept

- ESP inlet & outlet planes

## ❖ Industry Standards

- ICAC
- % RMS Deviation



ICAC: 85% of velocities  $\leq 1.15 * V_{avg}$   
99% of velocities  $\leq 1.40 * V_{avg}$

Other: % RMS Deviation  $\leq 15\%$  of  $V_{avg}$

# Gas Velocity Distribution – Collection Region

## ❖ Flow Control Methods

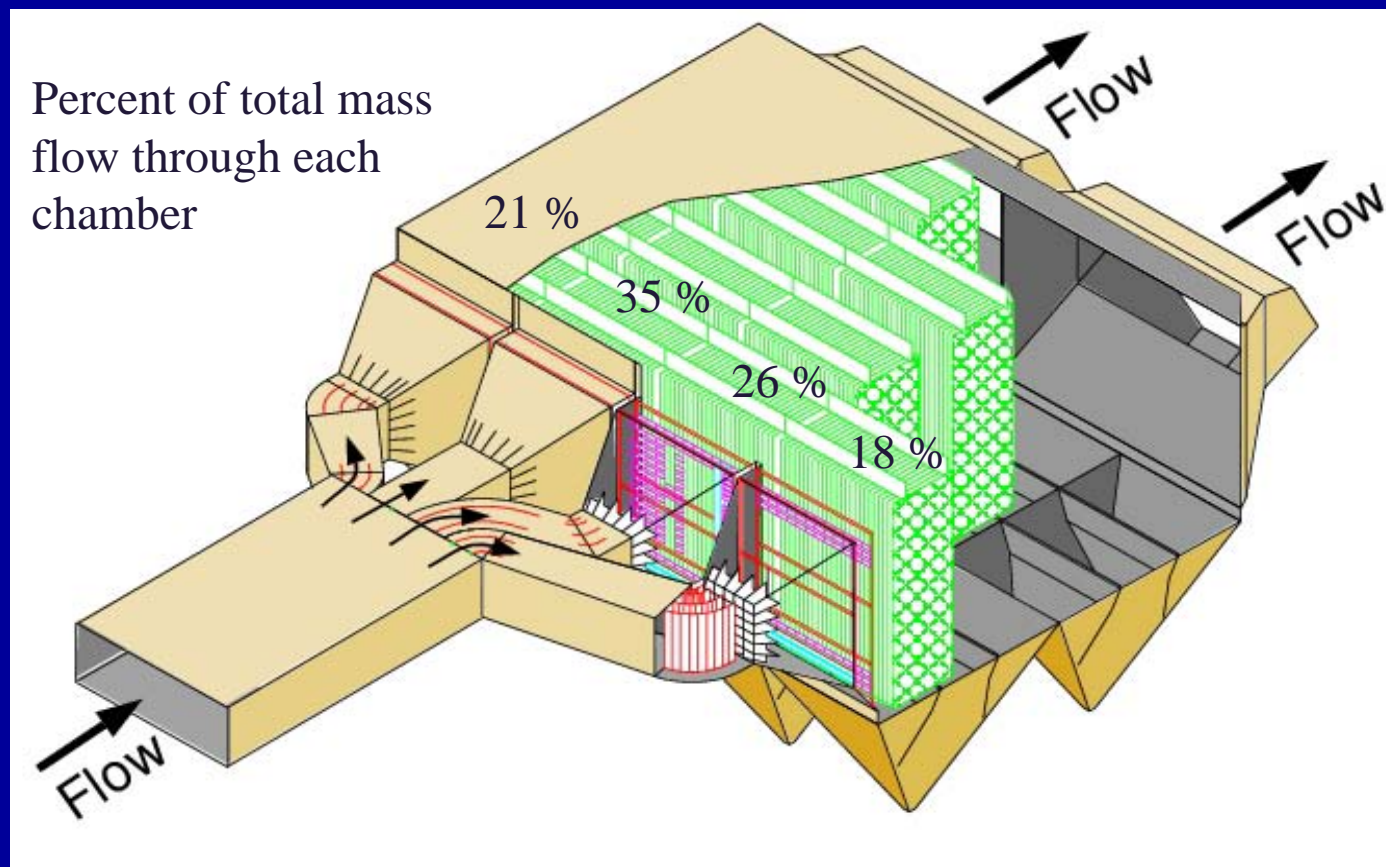
- Vanes, baffles
- Flow straighteners
- Perforated plates



# Gas Flow Balance

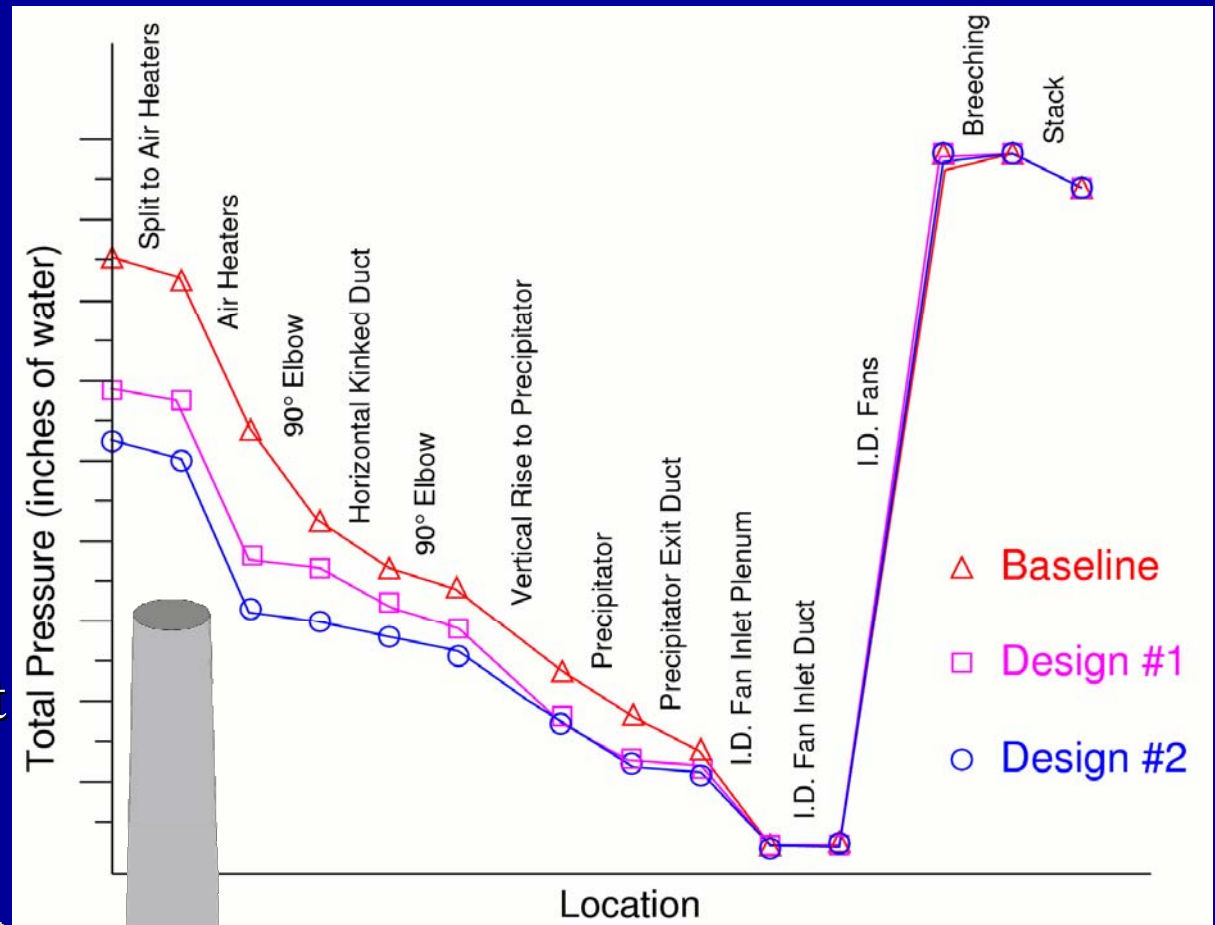
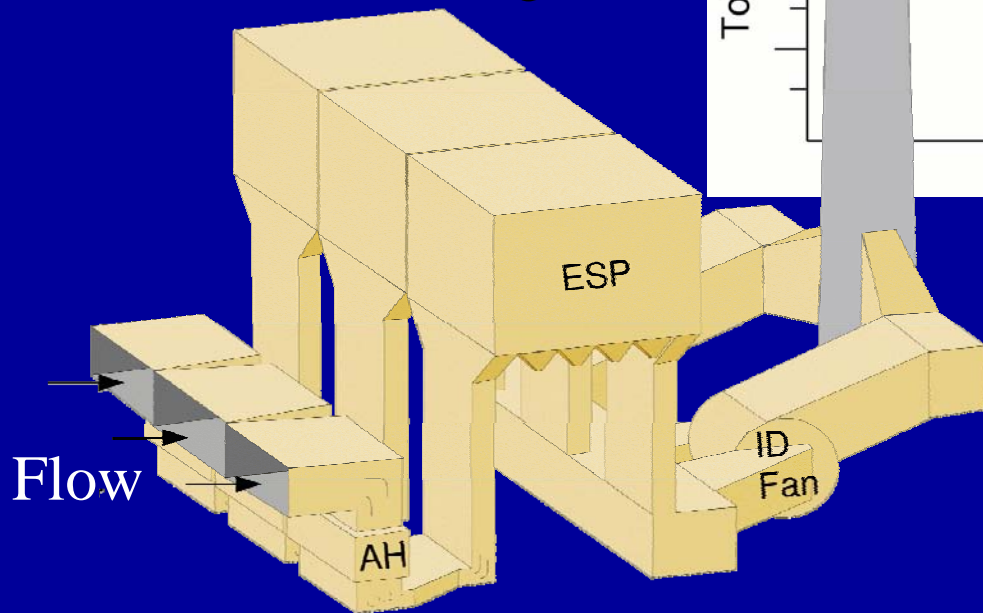
- ❖ Industry Standards
- ❖ Control Methods

ICAC: Flow within each chamber to be within  $\pm 10\%$  of its theoretical share



# Pressure Drop

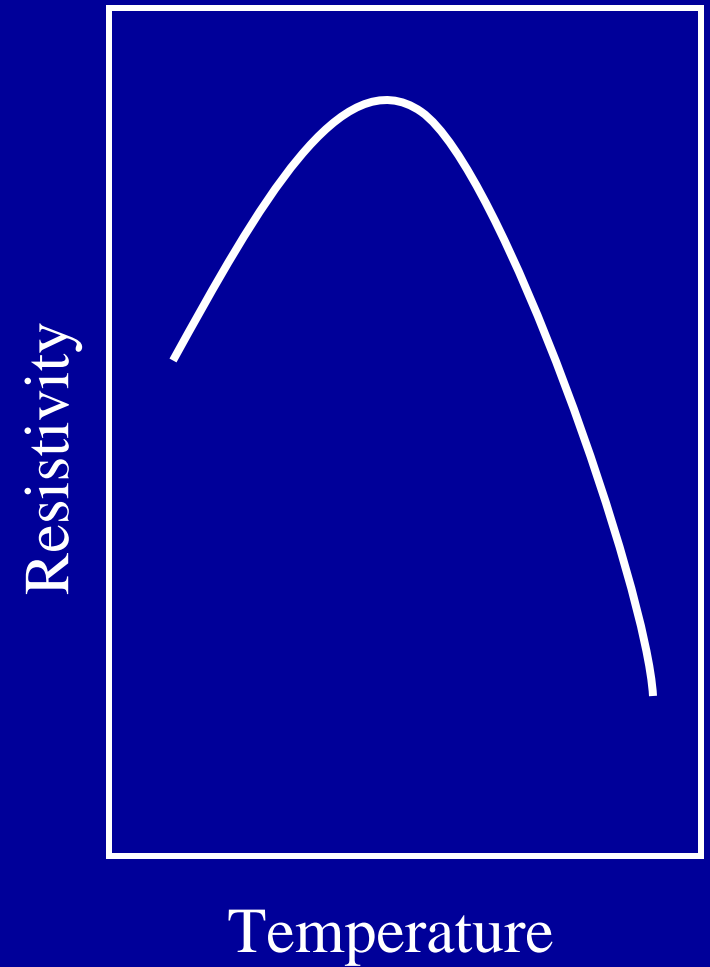
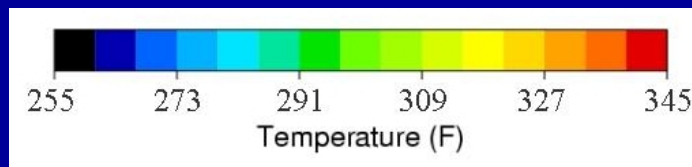
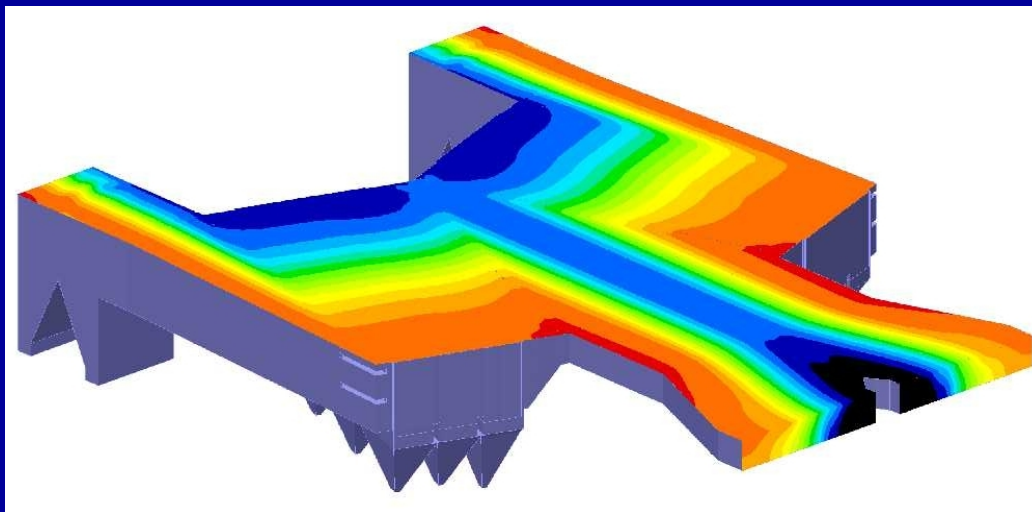
- ❖ General goal:
  - Minimize DP
- ❖ Methods
  - Vanes
  - Duct contouring
  - Area management



Ductwork redesign saves  
2.1 inches H<sub>2</sub>O over baseline

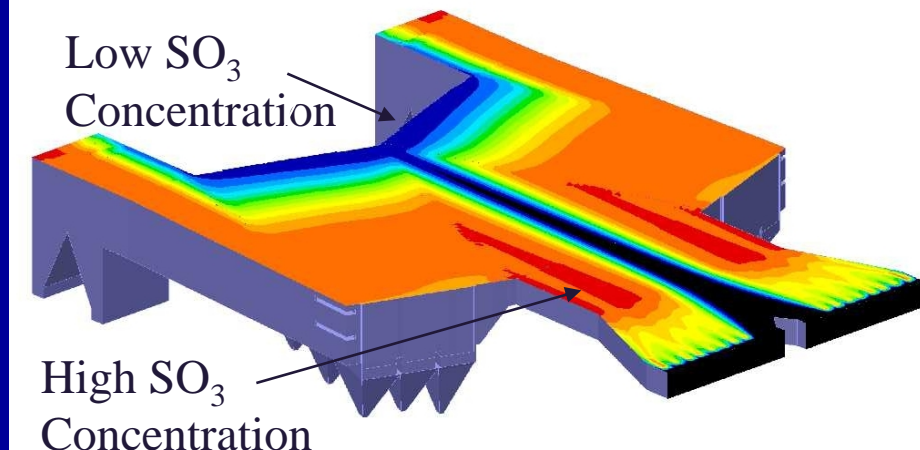
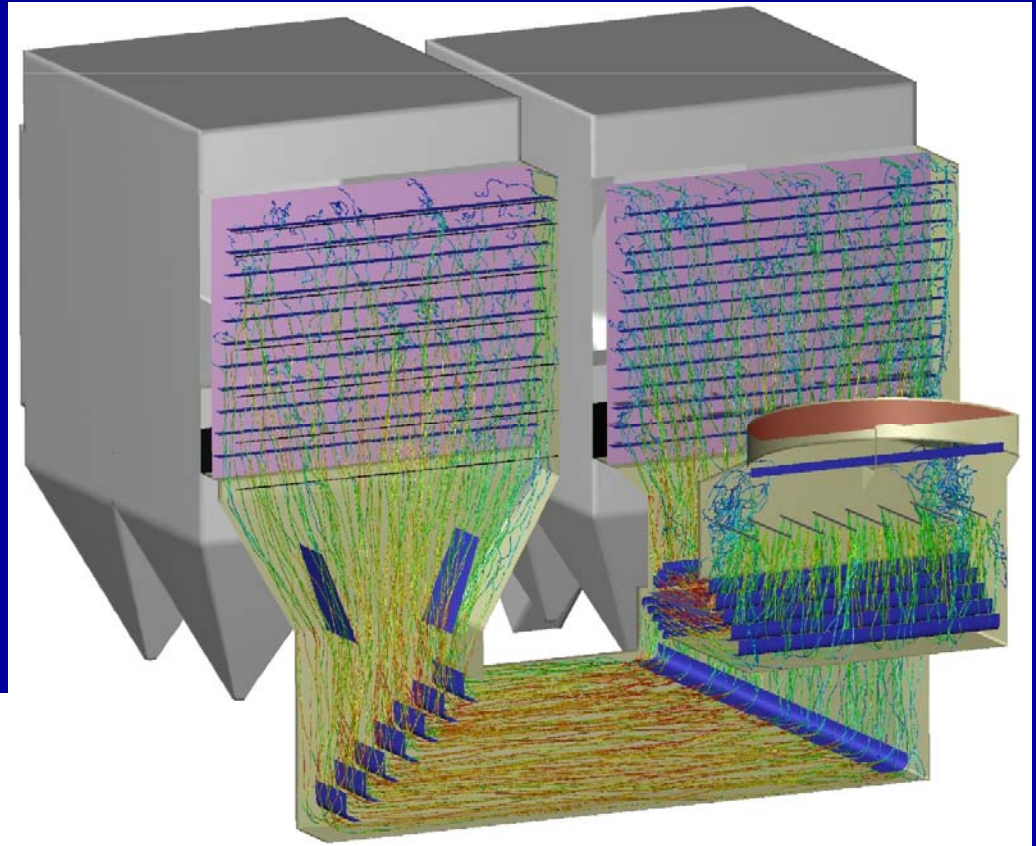
# Gas Temperature

- ❖ Average temperature
- ❖ Temperature stratification
- ❖ Inleakage



# Injection Systems

- ❖ Gaseous injection
  - $\text{SO}_3$ ,  $\text{NH}_3$ , others
- ❖ Particulate injection
  - Activated carbon
  - Trona, SBS, lime, etc.



Activated Carbon Injection  
– Particle Tracking

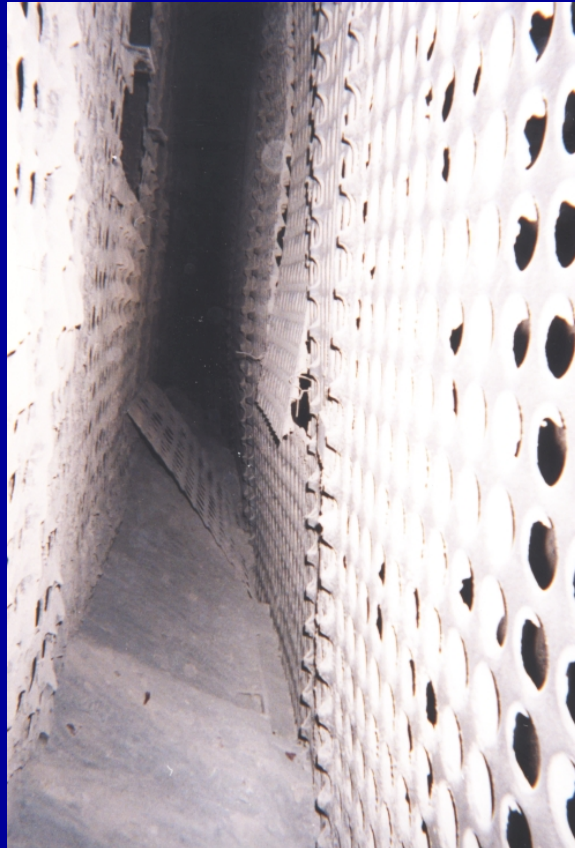
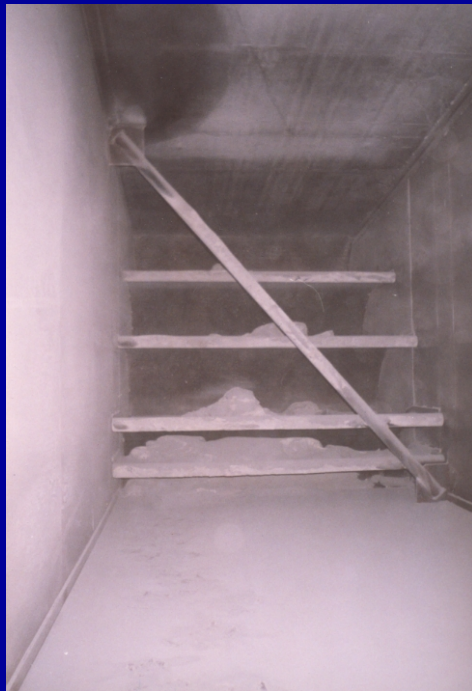
# Outline

- ❖ Introduction
- ❖ ESP Fluid Flow Basics
- ❖ Assessing Flow Characteristics
  - Inspections
  - Field Testing
    - Ductwork
    - Collection Region
- ❖ ESP Flow Modeling
- ❖ Movies and Animations
- ❖ Questions



# Inspections

- ❖ Ash Patterns
- ❖ Geometry Influence on Fluid Dynamics
- ❖ Irregularities



# Field Testing – Ductwork

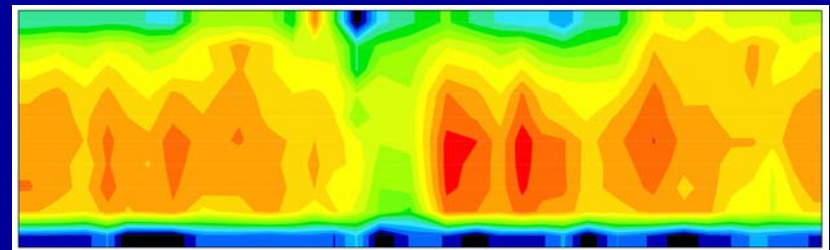
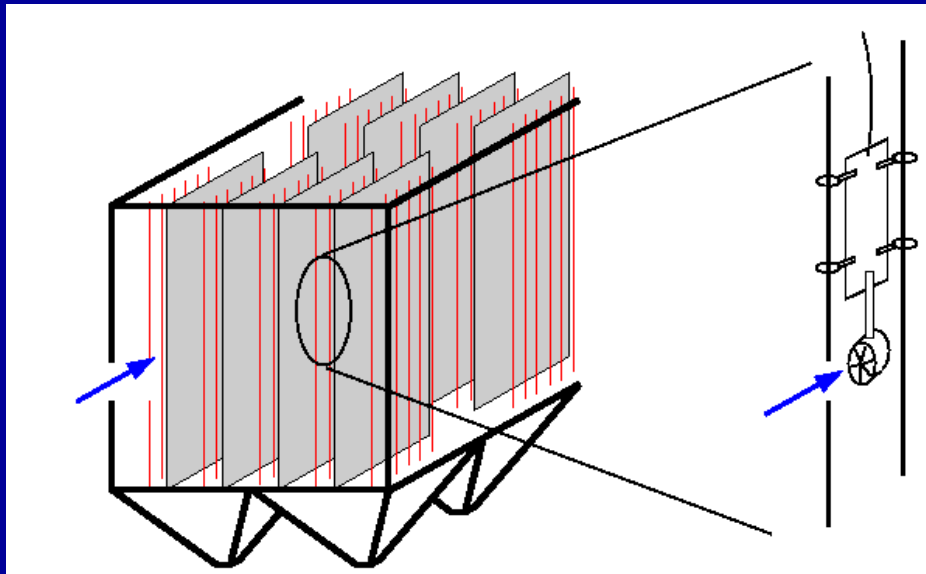
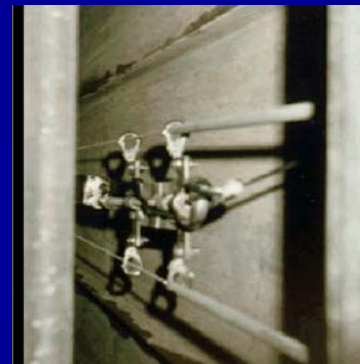
- ❖ Velocity
- ❖ Temperature
- ❖ Pressure
- ❖ Particulate
- ❖ Resistivity
- ❖ Chemical Species



# Field Testing – Collection Region

## ❖ Velocity Distribution

- Cold flow conditions
- Vane anemometer
  - Accuracy 1% in 3-10 ft/sec range
  - Lightweight, portable
  - Sensitive to flow angularity, turbulence, dust



# Outline

- ❖ Introduction
- ❖ ESP Fluid Flow Basics
- ❖ Assessing Flow Characteristics
- ❖ ESP Flow Modeling
  - Physical Models
  - Computational Fluid Dynamics (CFD) Models
- ❖ Movies and Animations
- ❖ Questions



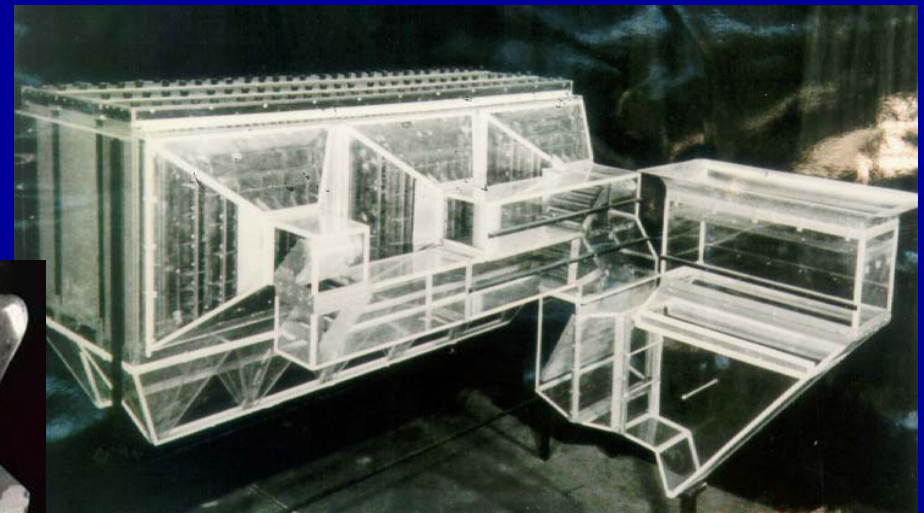
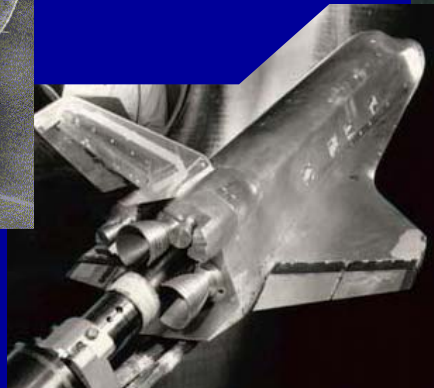
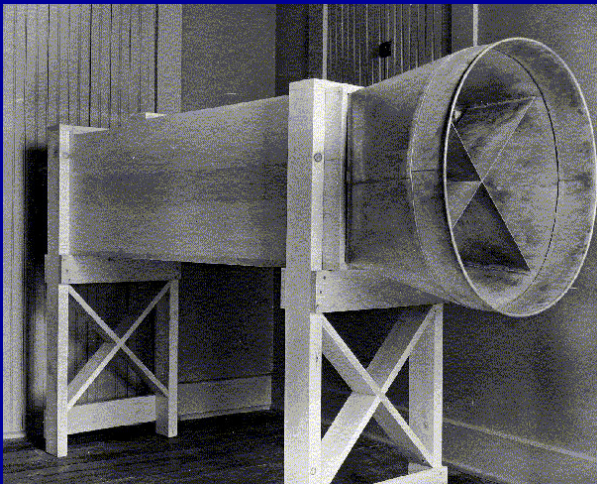
# ESP Modeling – Physical Models

- ❖ Background
- ❖ Theory
- ❖ Simulation Parameters (how the model is set up)
- ❖ Results Analysis (what you get from the model)



# Physical Models – Background

- ❖ Utilized for fluid flow analysis for a century ... or more?
- ❖ Applied to ESPs for decades
- ❖ Underlying principle is to reproduce fluid flow behavior in a controlled, laboratory environment



# Physical Models – Theory

- ❖ 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 elements (typically those >4”)
    - 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 but ensure that Re remains in the turbulent range throughout the model

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



# Physical Models – Simulation Parameters

## ❖ ESP geometry

- 1/8th to 1/16th scale representation
- Include features >4” in size

## ❖ Flow conditions

- Scaled air flow rate (ambient temperature)
- Reproduce velocity profile at model inlet
- Simulated chemical injection
- Simulated particle tracking



# Physical Models – Results Analysis

- ❖ Quantitative data available at discrete measurement points
  - Velocity magnitude, directionality
  - Pressure (corrected to full scale)
  - Chemical species concentrations
- ❖ Integrated/reduced data
  - Mass balance between ESP chambers
  - Comparison to ICAC conditions or target velocity profiles
  - Correlation to test data
- ❖ Qualitative data
  - Flow directionality (smoke, tufts)
  - Particle behavior, drop-out



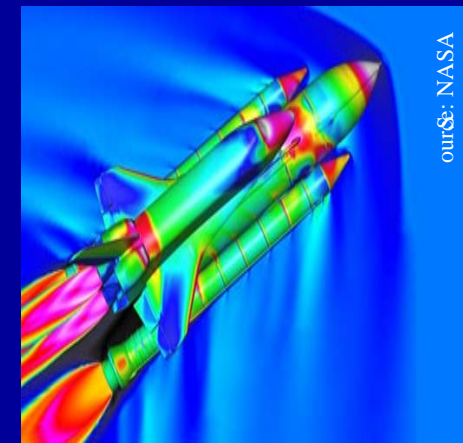
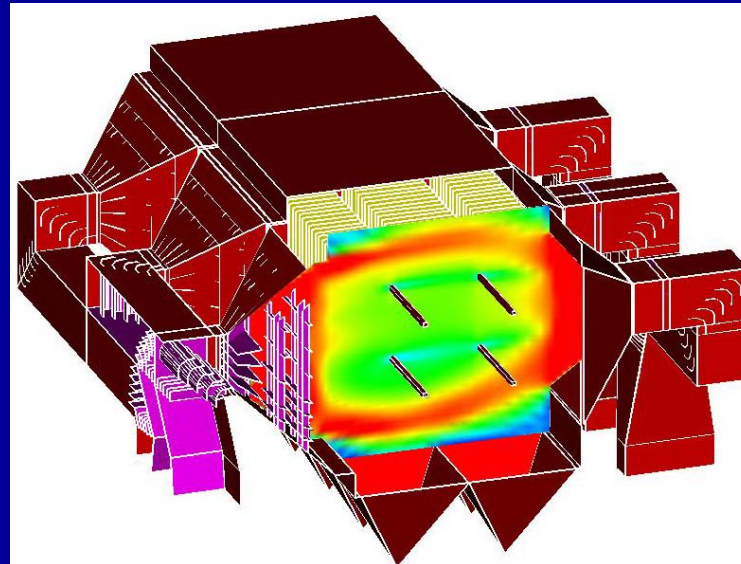
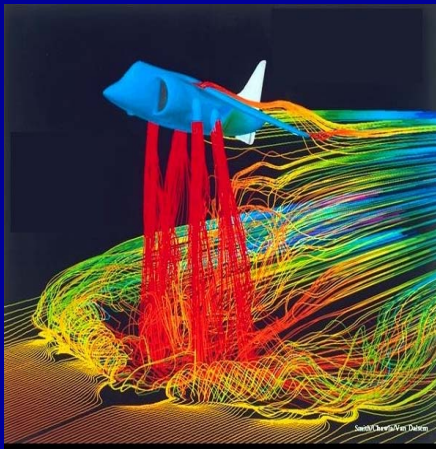
# Flow Modeling – Computational Fluid Dynamics (CFD)

- ❖ Background
- ❖ Theory
- ❖ Simulation Parameters (how the model is set up)
- ❖ Results Analysis (what you get from the model)



# CFD – Background

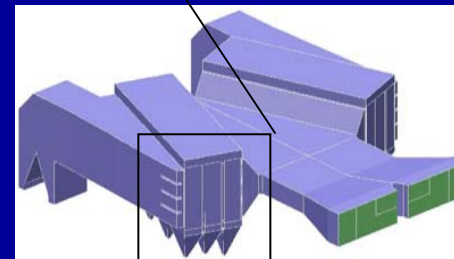
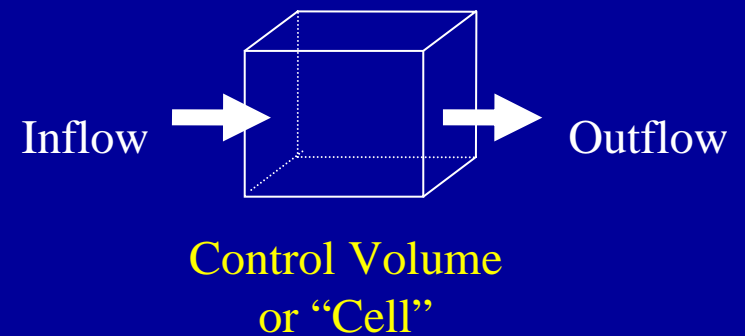
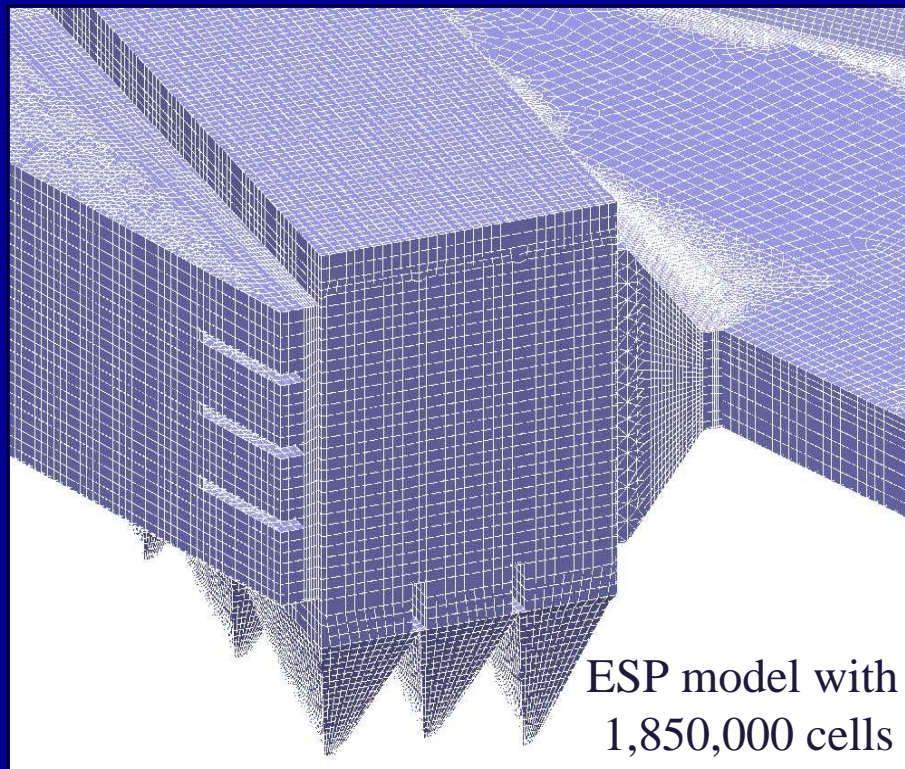
- ❖ Developed in the aerospace industry c.1970 (with the advent of “high speed” computers)
- ❖ Applied to ESPs for 18+ years
- ❖ Underlying principle is to solve the first-principles equations governing fluid flow behavior using a computer



# CFD – Theory

## ❖ 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



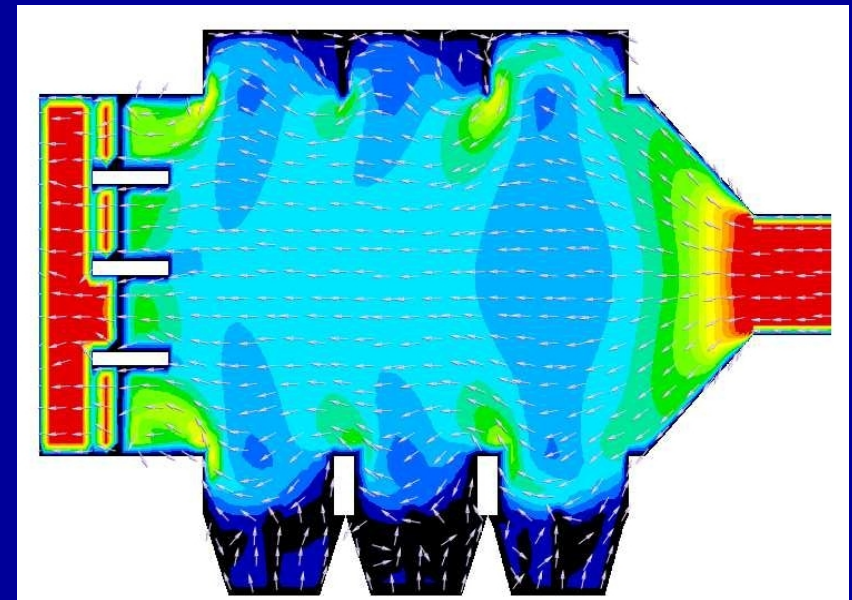
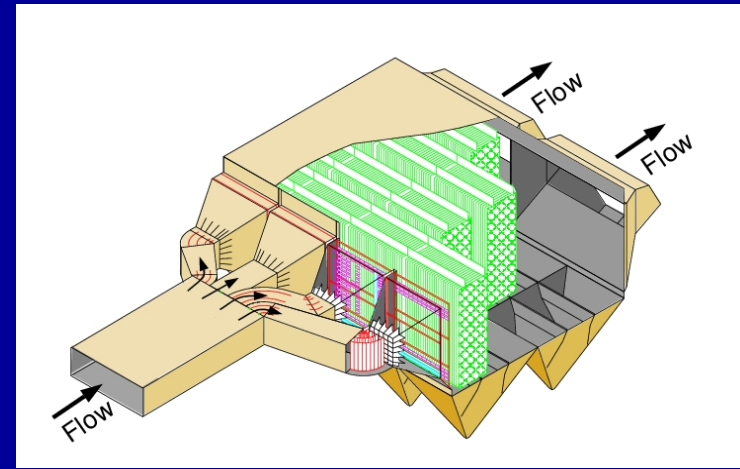
# CFD – Simulation Parameters

## ❖ ESP geometry

- Full scale representation
- Include features >4” in size, more detail if possible

## ❖ Flow conditions

- Full scale gas flow rate
- Reproduce velocity profile at model inlet
- Reproduce temperature profile at model inlet
- Simulated chemical injection
- Simulated particle tracking



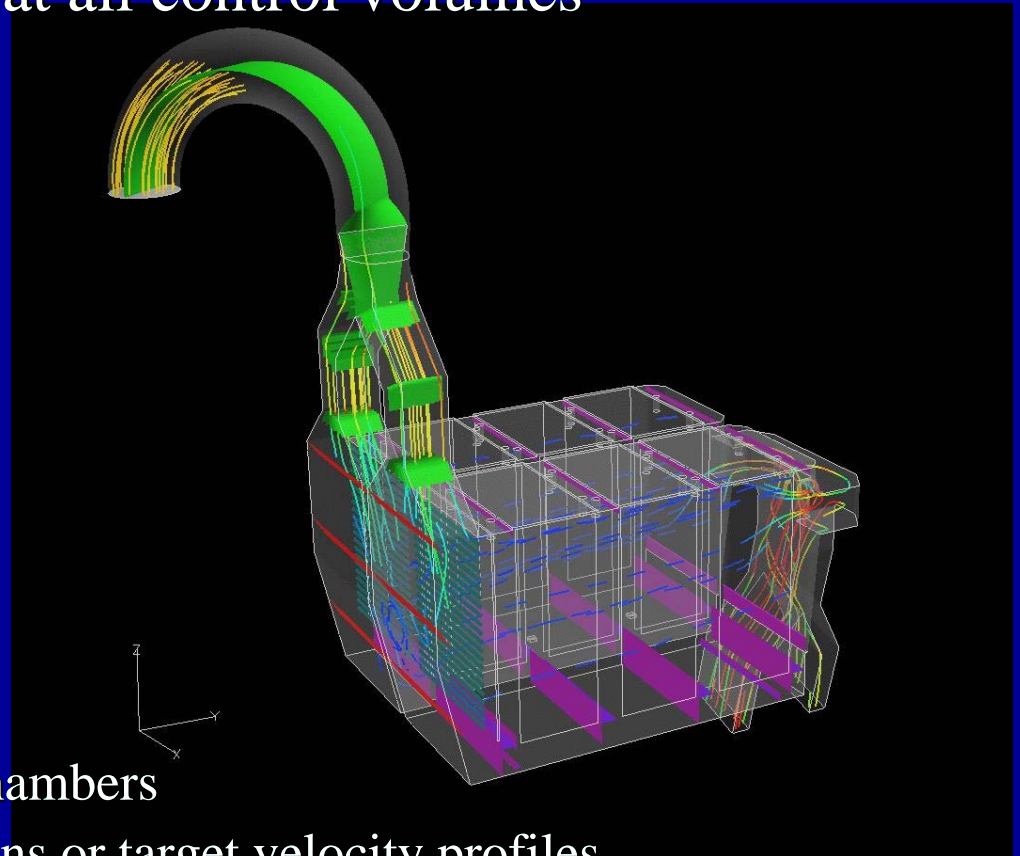
# CFD – Results Analysis

## ❖ Quantitative data available at all control volumes

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

## ❖ Integrated/reduced data

- Mass balance between ESP chambers
- Comparison to ICAC conditions or target velocity profiles
- Correlation to test data



# Movies and Animations

## ❖ Physical flow model movies

- Smoke flow
- Dust deposition

## ❖ CFD model animations

- Particle tracking
- Thermal mixing



# Questions?

If you would like an electronic copy of this presentation, please contact Rob Mudry as follows:  
rmudry@airflowsciences.com  
Tel. 734-464-8900

