

Worldwide Pollution Control Association

FirstEnergy ESP Seminar
November 27th – 28th, 2007

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ESP Gas Flow Fundamentals

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WPCA / First Energy Seminar
November 27-28, 2007



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 ₂ O |



About Your Speaker

- ❖ BSE, MSE Aerospace Engineering – University of Michigan
- ❖ 18 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 8 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

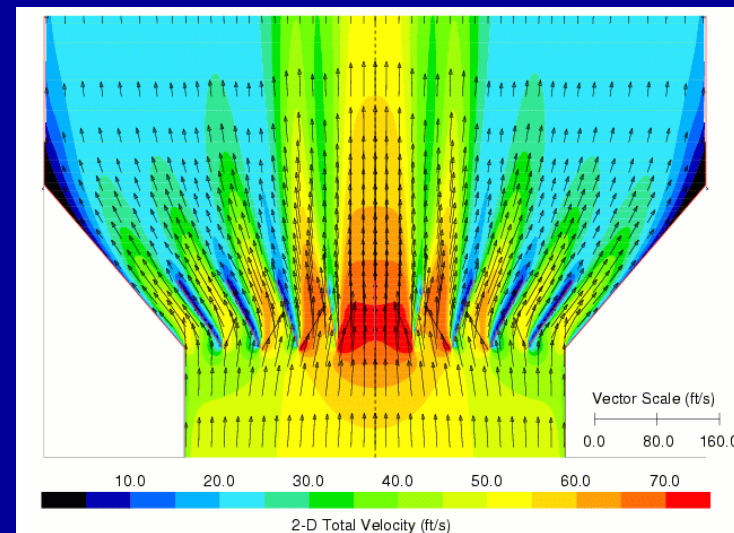
❖ Ductwork Design Criteria

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



❖ Considerations

- Horizontal surfaces
- Cross sectional area
- Bends
- Structure



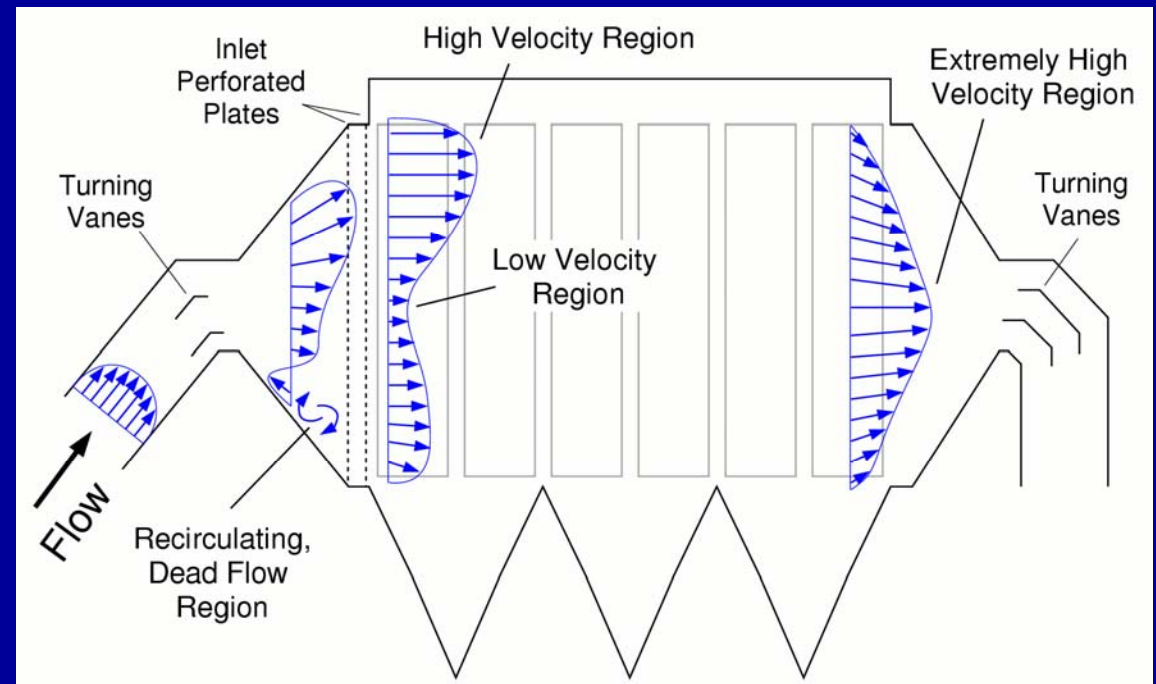
Gas Velocity Distribution – Collection Region

❖ 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

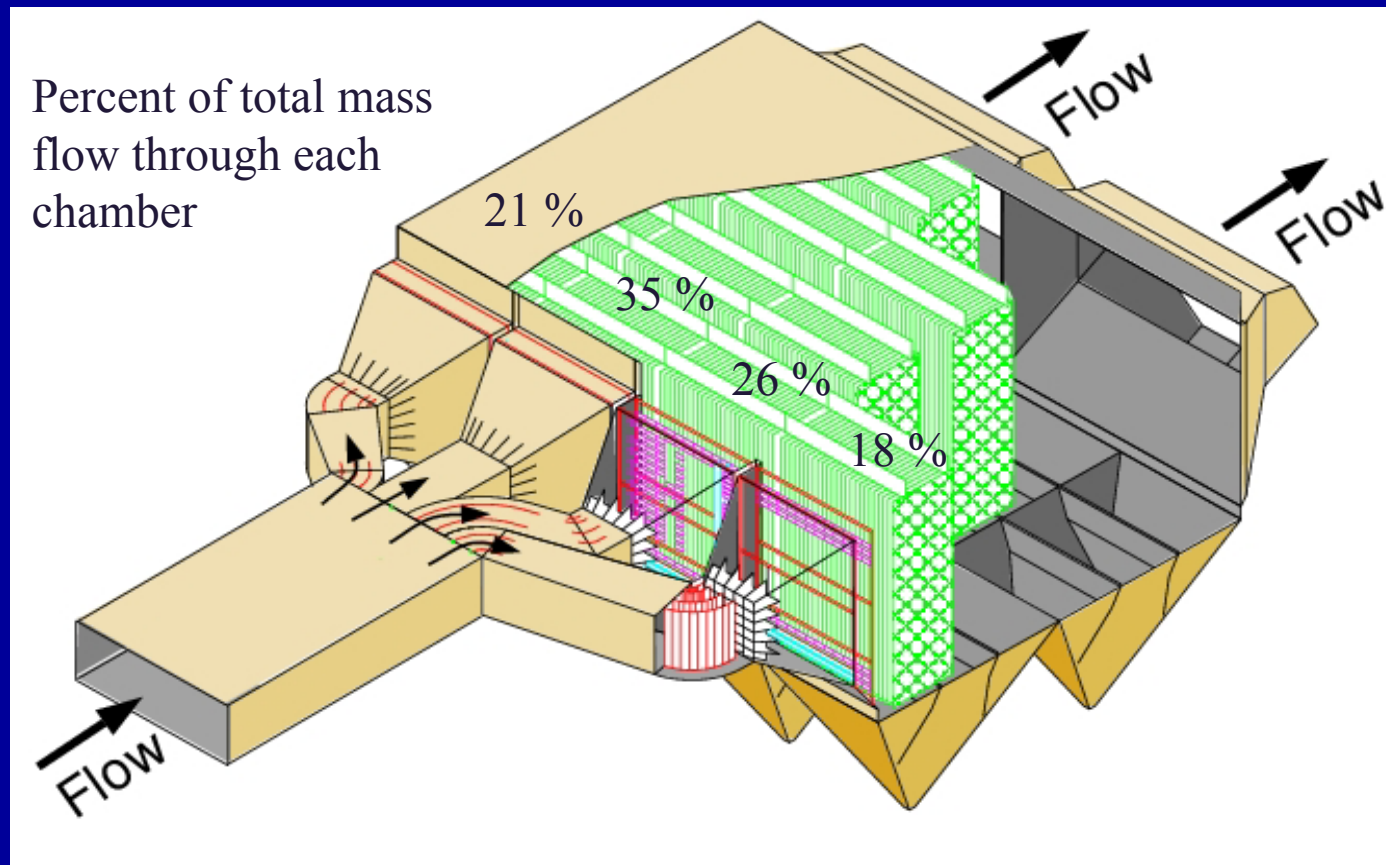
- Vanes, baffles
- Flow straighteners
- Perforated plates



Gas Flow Balance

- ❖ Industry Standards
- ❖ Control Methods

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



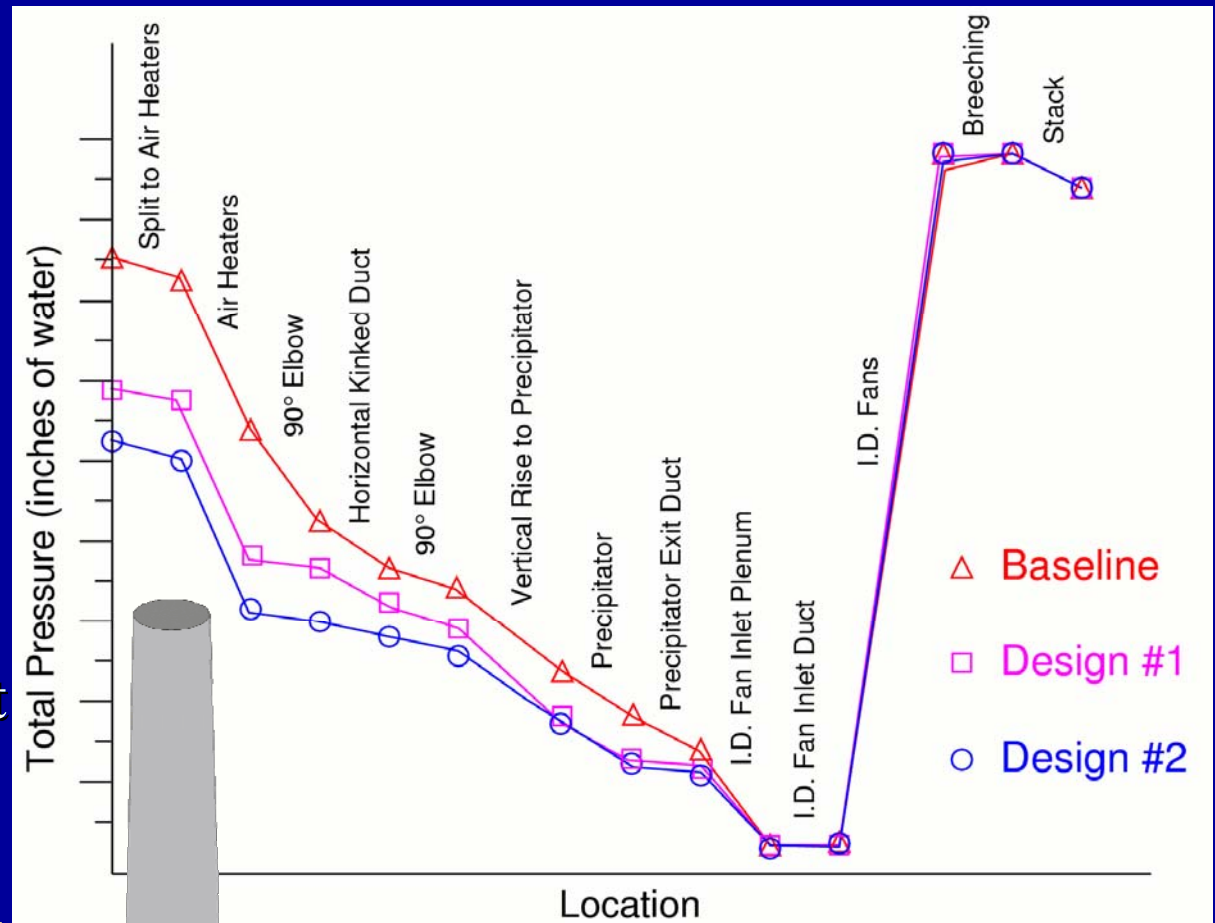
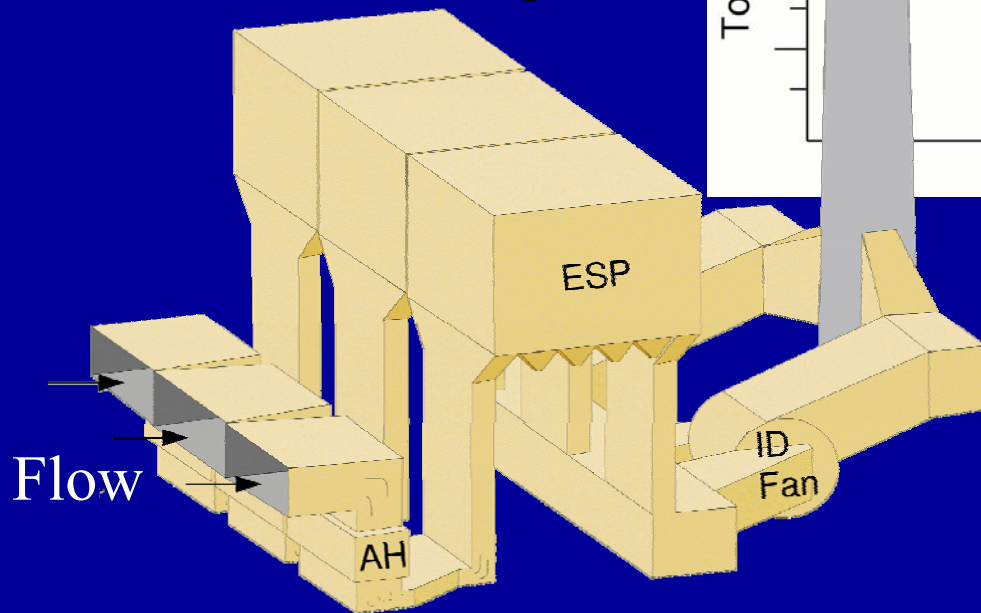
Pressure Drop

❖ General goal:

- Minimize DP

❖ Methods

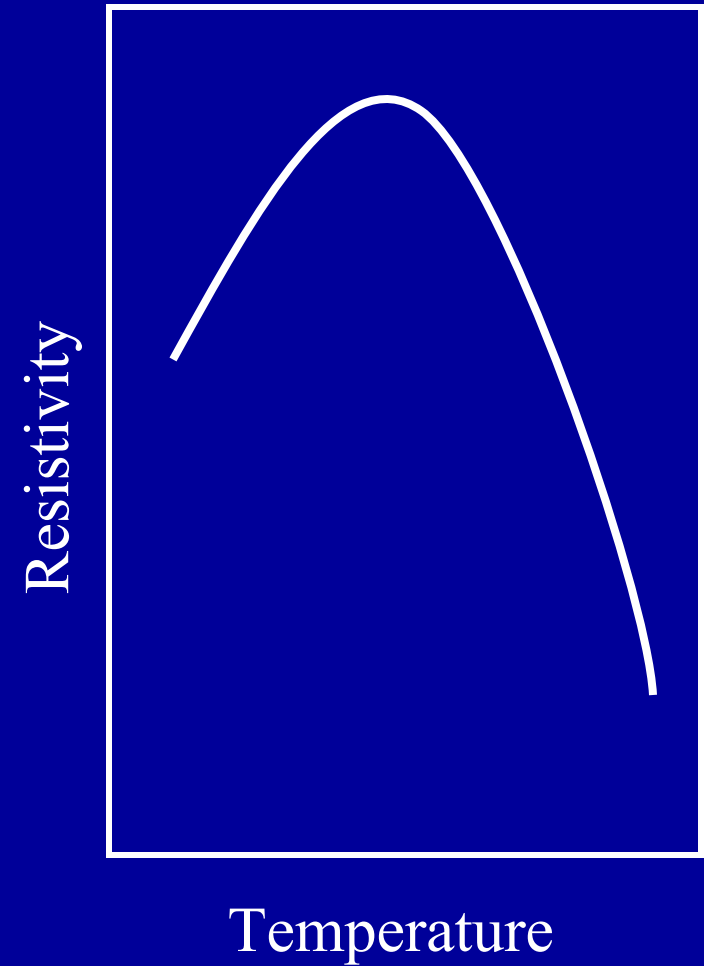
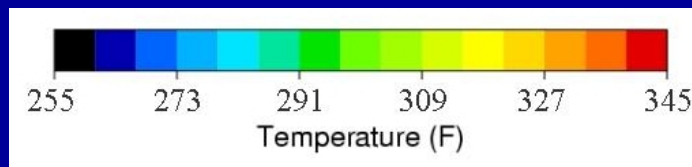
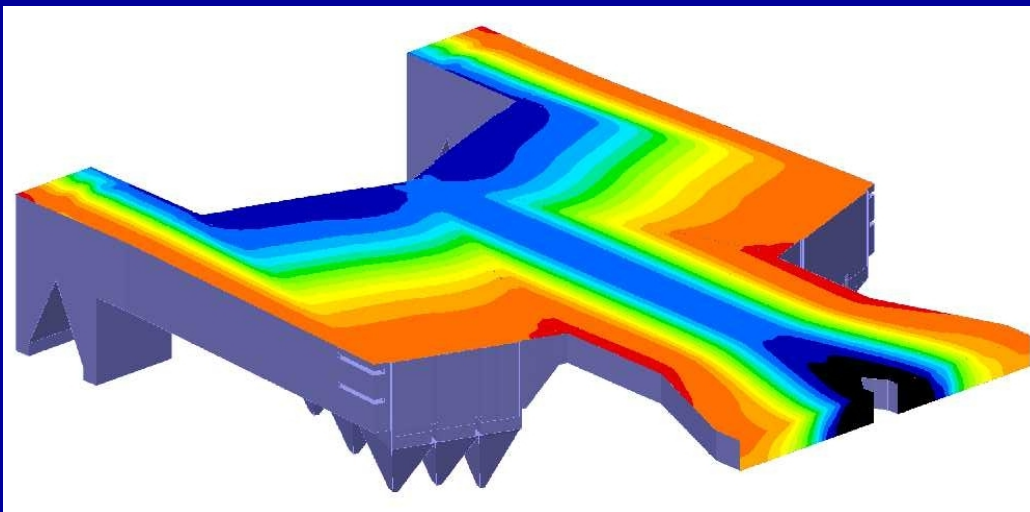
- Vanes
- Duct contouring
- Area management



Ductwork redesign saves
2.1 inches H₂O over baseline

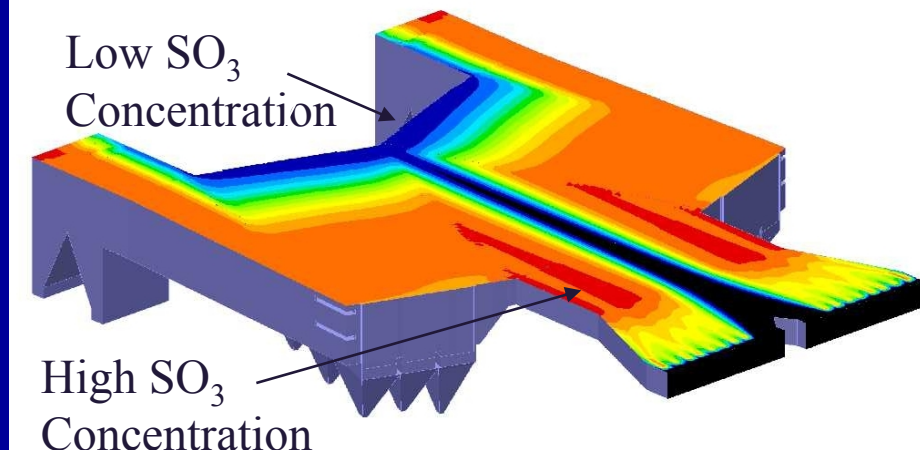
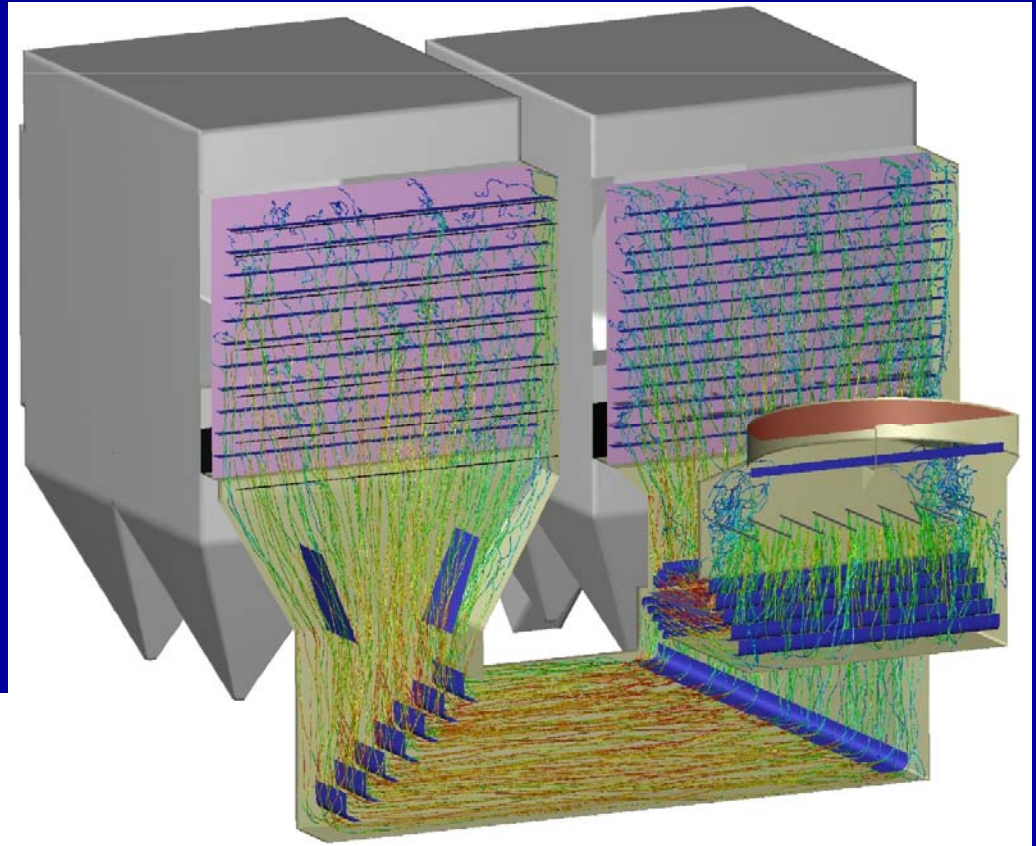
Gas Temperature

- ❖ Average temperature
- ❖ Temperature stratification
- ❖ Inleakage



Injection Systems

- ❖ Gaseous injection
 - SO_3 , NH_3 , others
- ❖ Particulate injection
 - Activated carbon
 - Trona, SBS, lime, etc.



SO_3 Concentration →

Activated Carbon Injection
– Particle Tracking

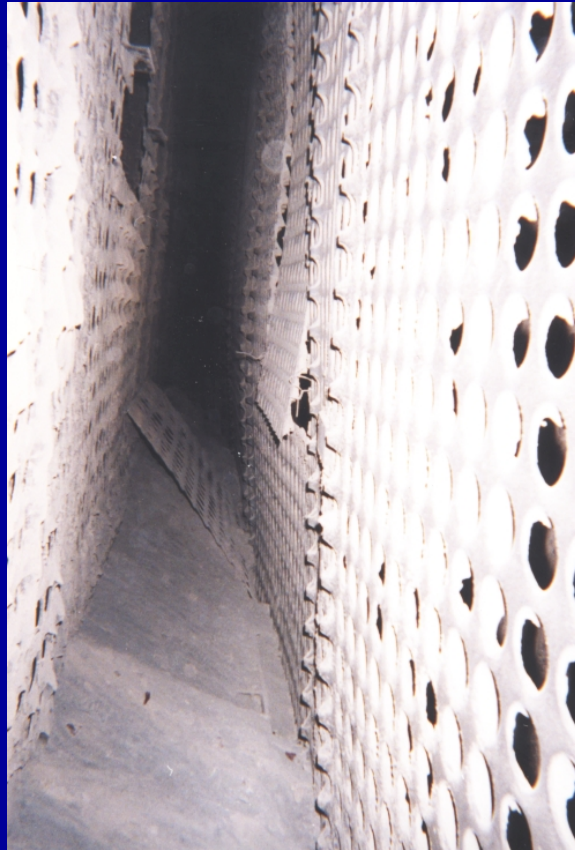
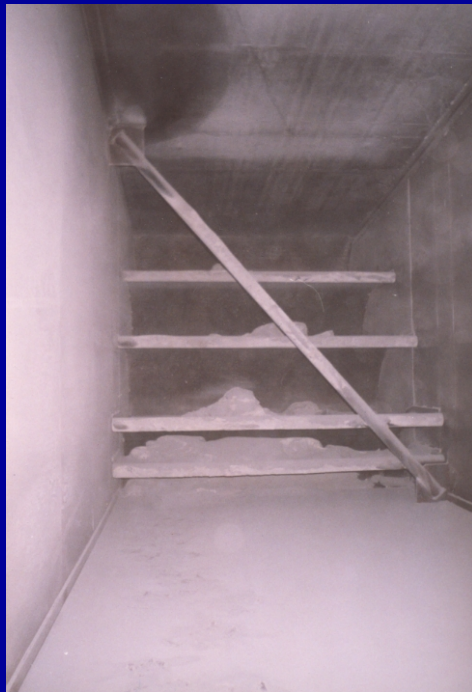
Outline

- ❖ 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

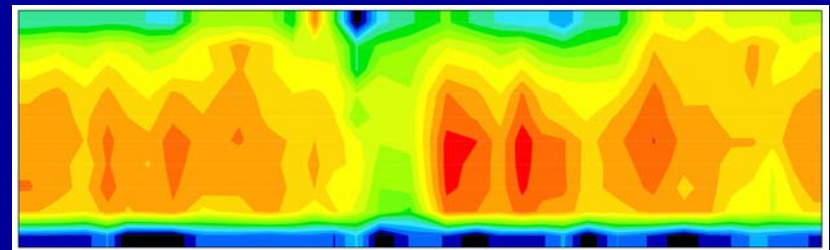
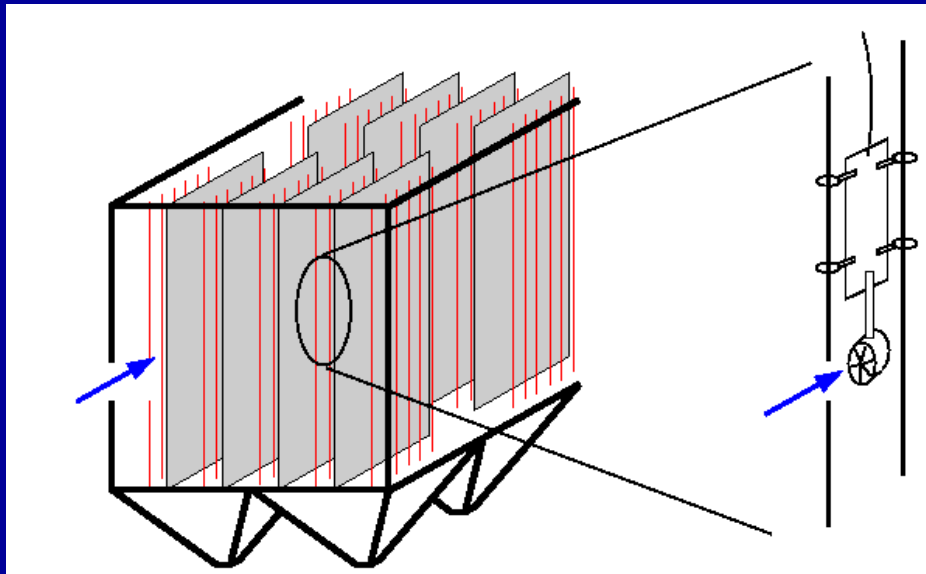
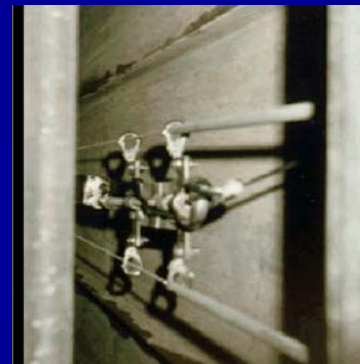
- ❖ Velocity
- ❖ Temperature
- ❖ Pressure
- ❖ Particulate
- ❖ Resistivity
- ❖ Chemical Species



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



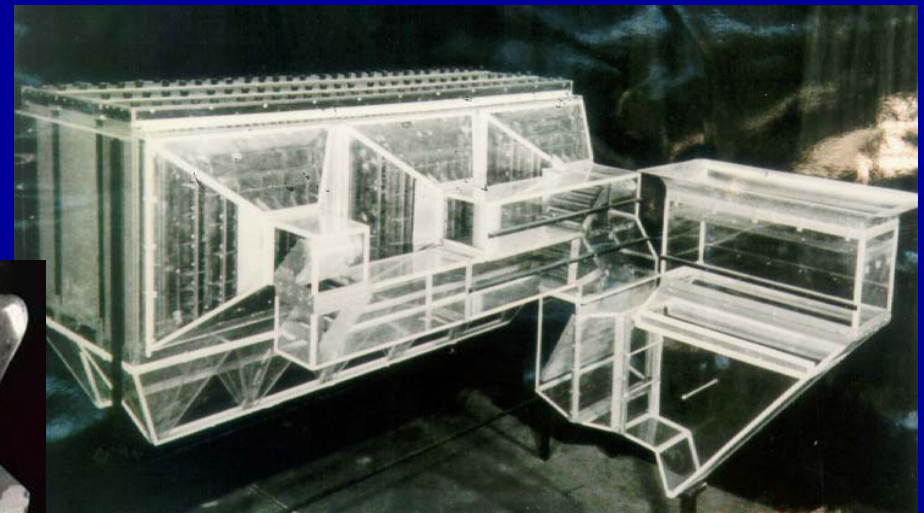
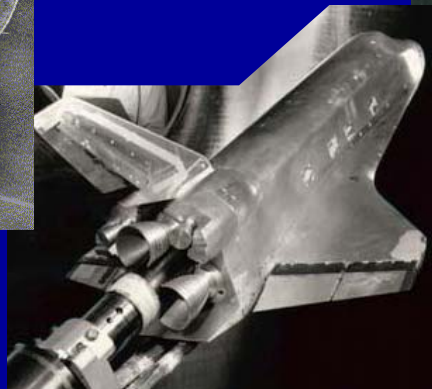
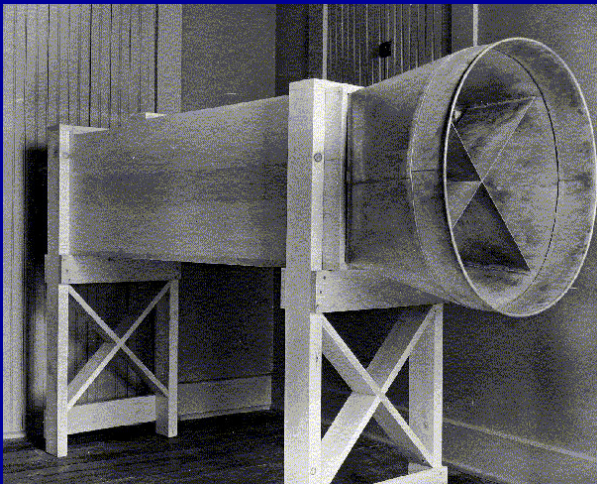
ESP Modeling – Physical Models

- ❖ 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



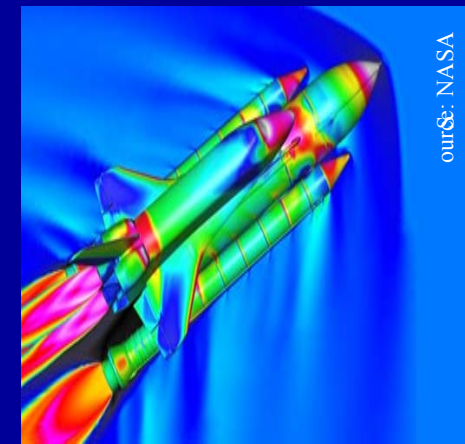
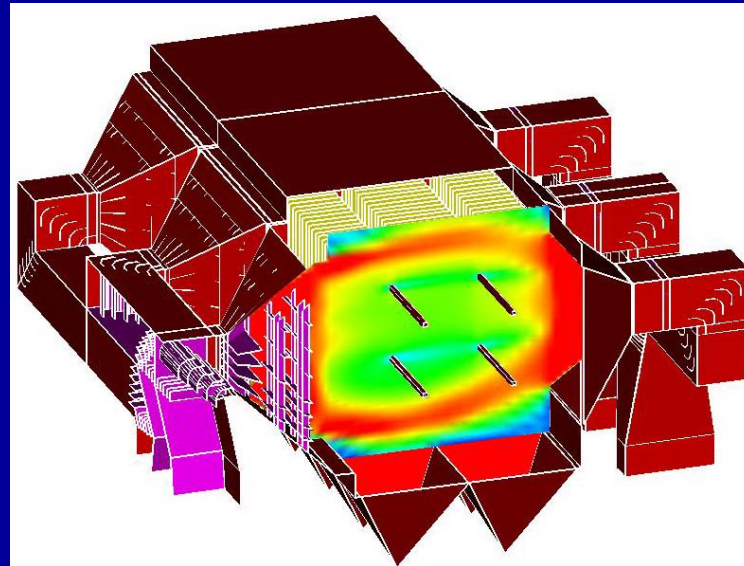
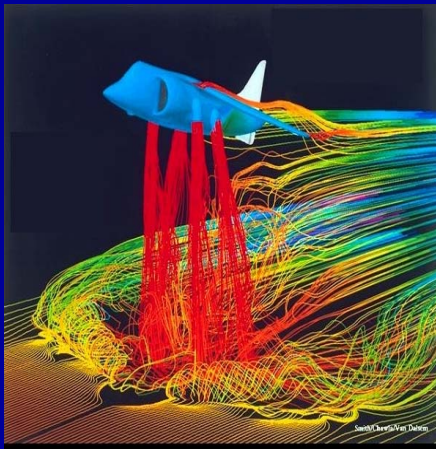
Flow Modeling – Computational Fluid Dynamics (CFD)

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



CFD – Background

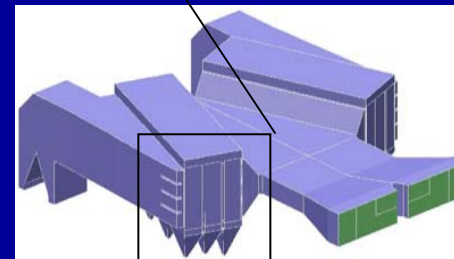
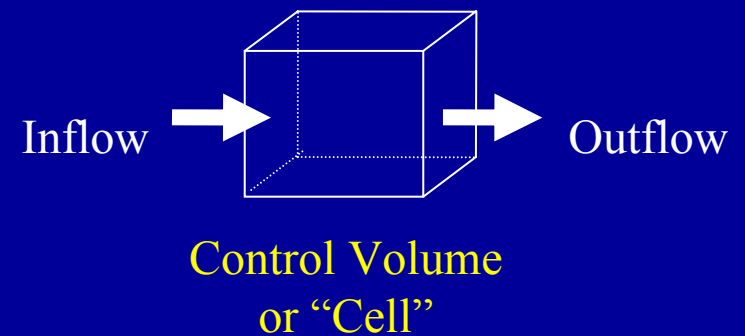
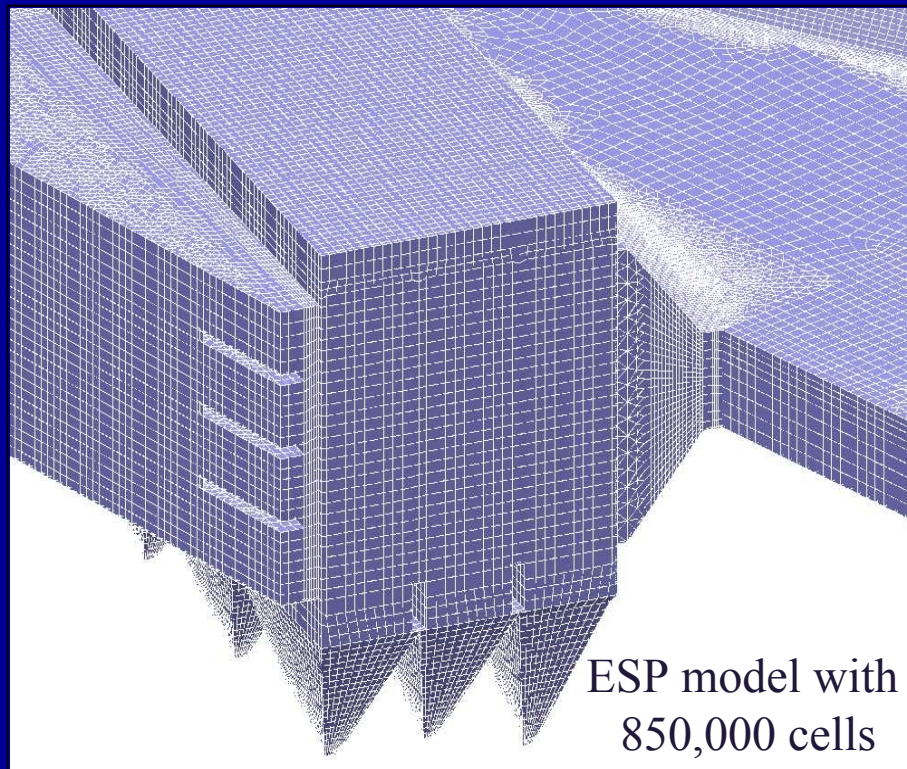
- ❖ Developed in the aerospace industry c.1970 (with the advent of “high speed” computers)
- ❖ Applied to ESPs for 15+ years
- ❖ Underlying principle is to solve the first-principles equations governing fluid flow behavior using a computer



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



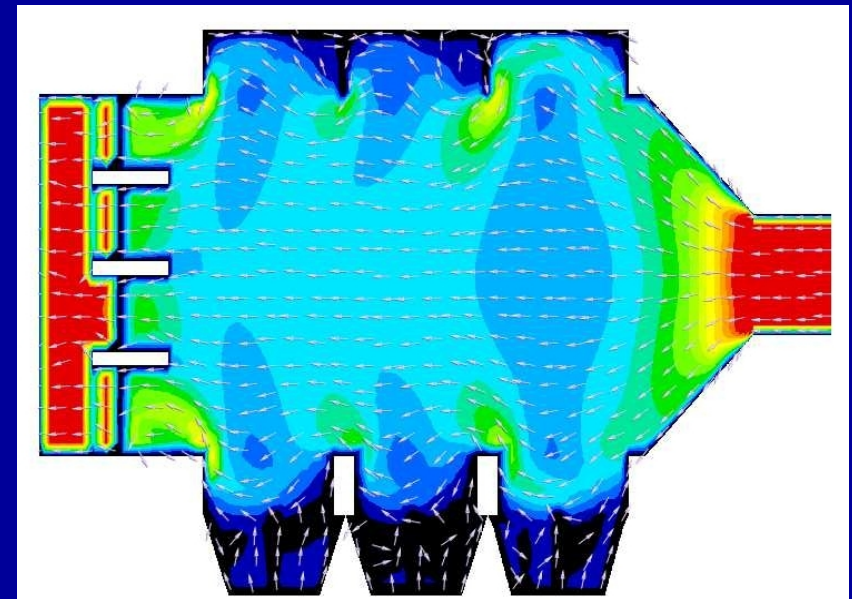
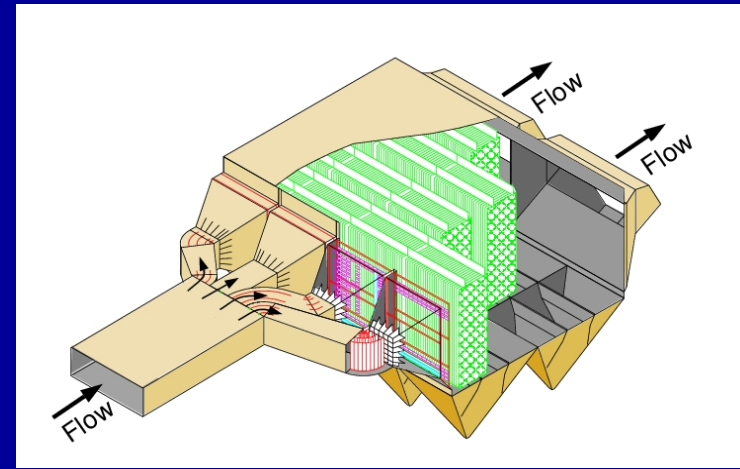
CFD – Simulation Parameters

❖ 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



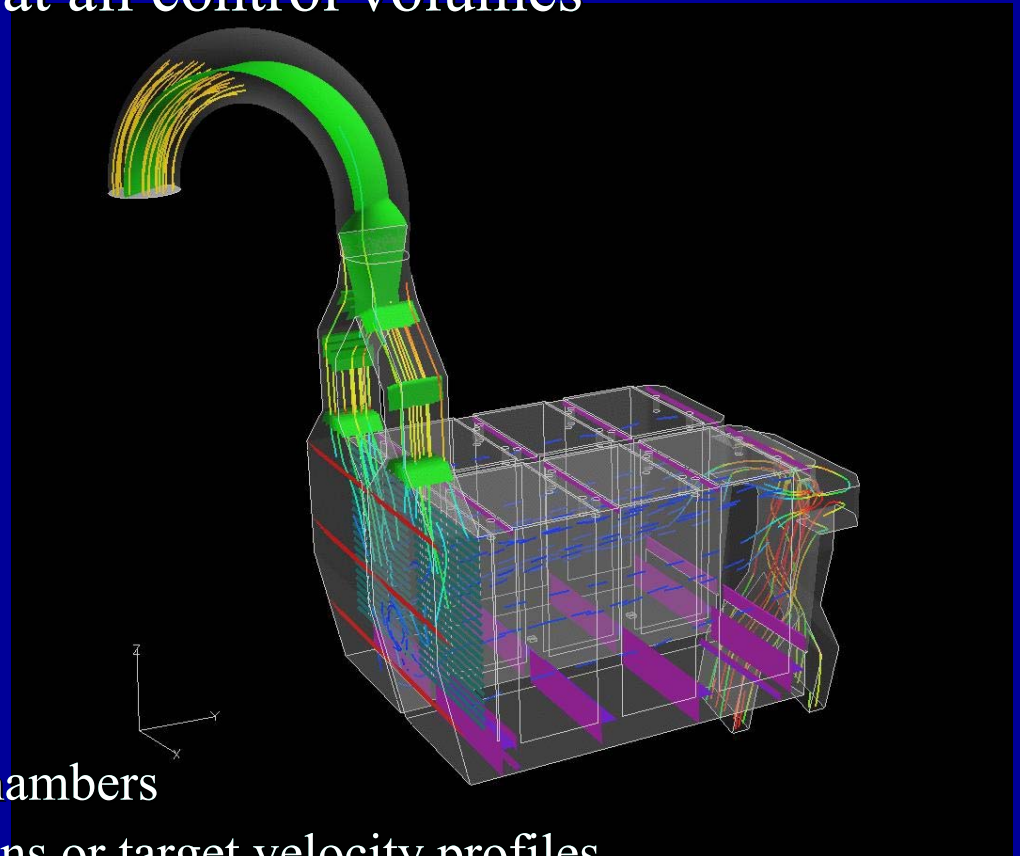
CFD – Results Analysis

❖ 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:
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