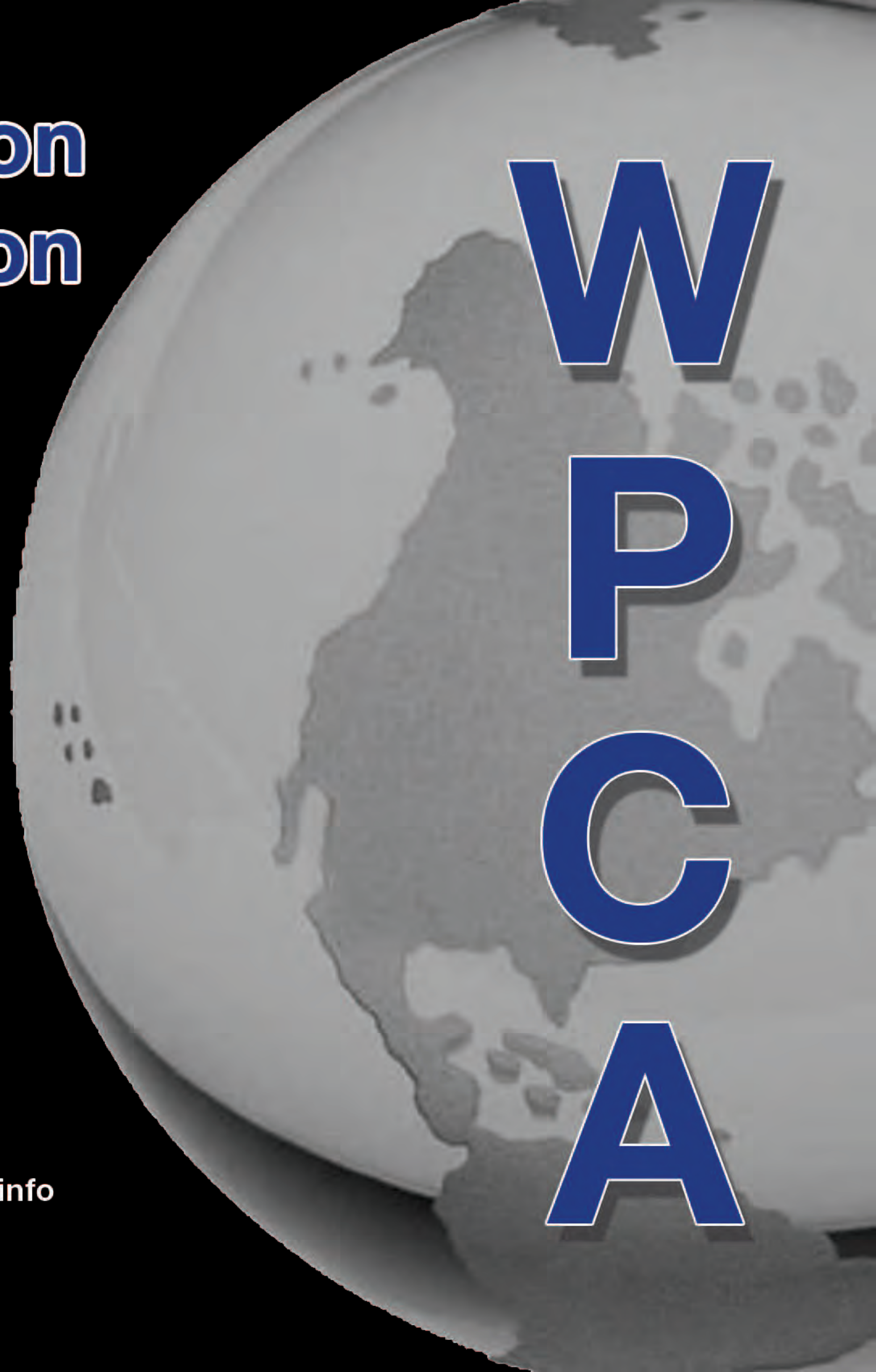
Worldwide Pollution Control Association

Ameren Seminar

August 19–20, 2008

Effingham, IL



WPCA

Vist our website at www.wpca.info

Understanding Gas Flow to Improve ESP Performance

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WPCA / Ameren Seminar
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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 Bremo 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_2O

About Your Speaker

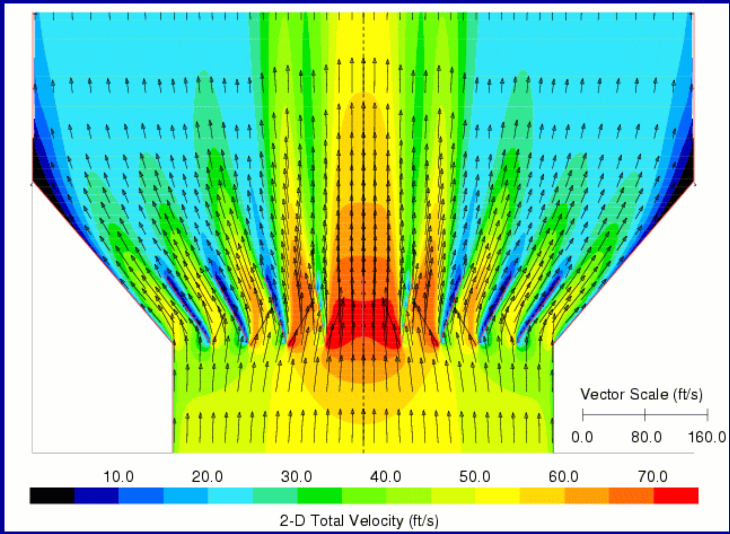
- BSE, MSE Aerospace Engineering – University of Michigan
- 19 years as fluid dynamics consultant to industry
- Involved in 500+ testing/modeling projects
- Institute of Clean Air Companies (ICAC) member
- WPCA Director and Treasurer
- Author of 10 power industry technical papers
- Registered Professional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

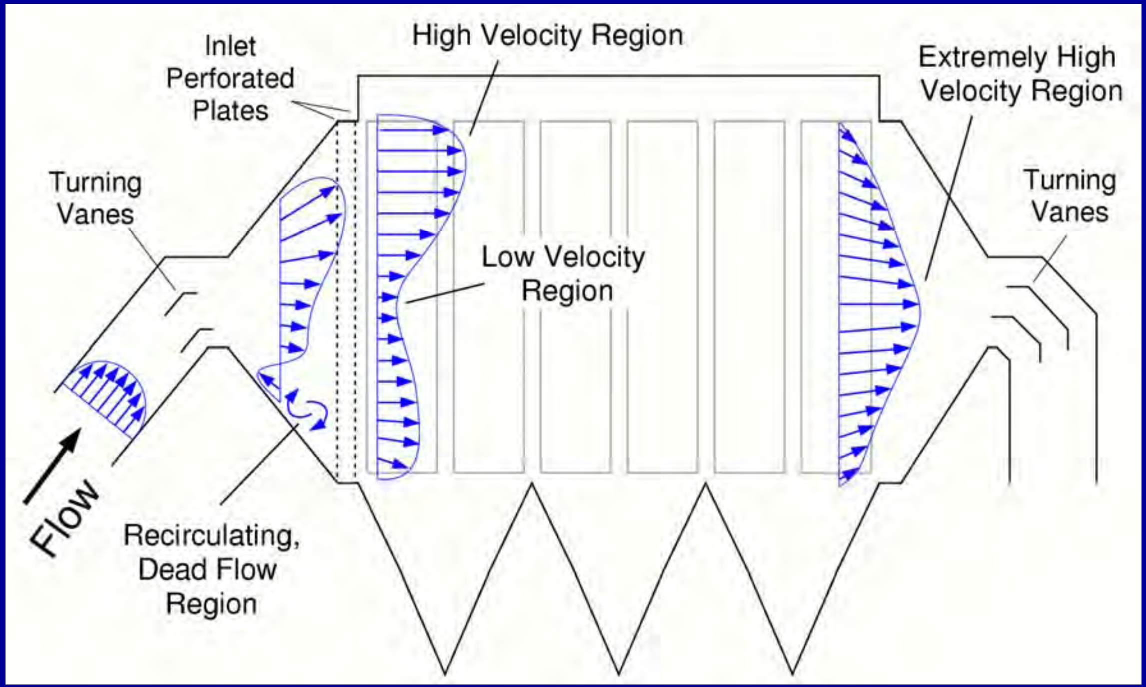
Gas Velocity Distribution – Ductwork

- 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 ≤ 1.15 * V_{avg}
99% of velocities ≤ 1.40 * V_{avg}
Other: % RMS Deviation ≤ 15% of V_{avg}

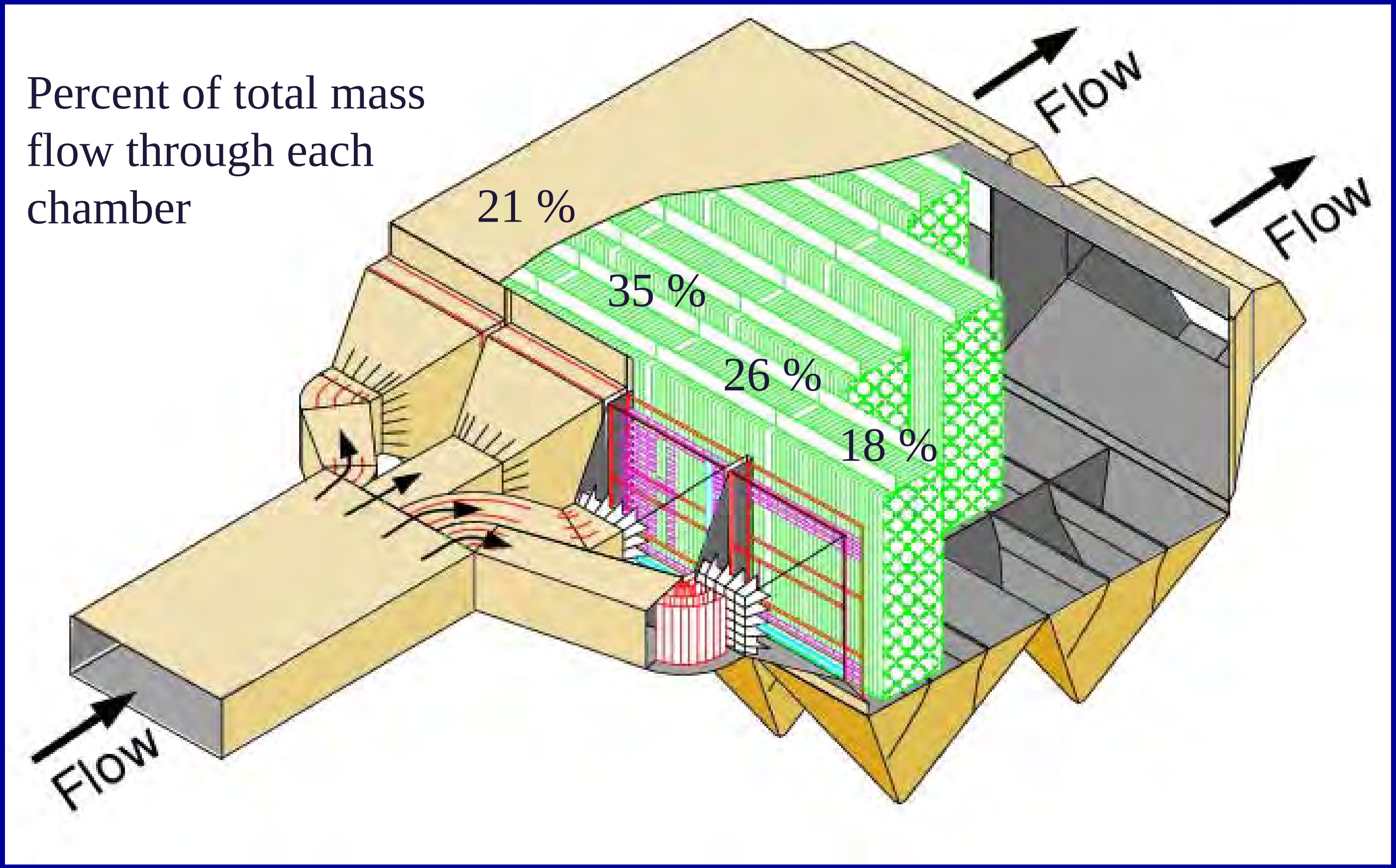
Gas Velocity Distribution – Collection Region

- Flow Control Methods
  - Vanes, baffles
  - Flow straighteners
  - Perforated plates

Gas Flow Balance

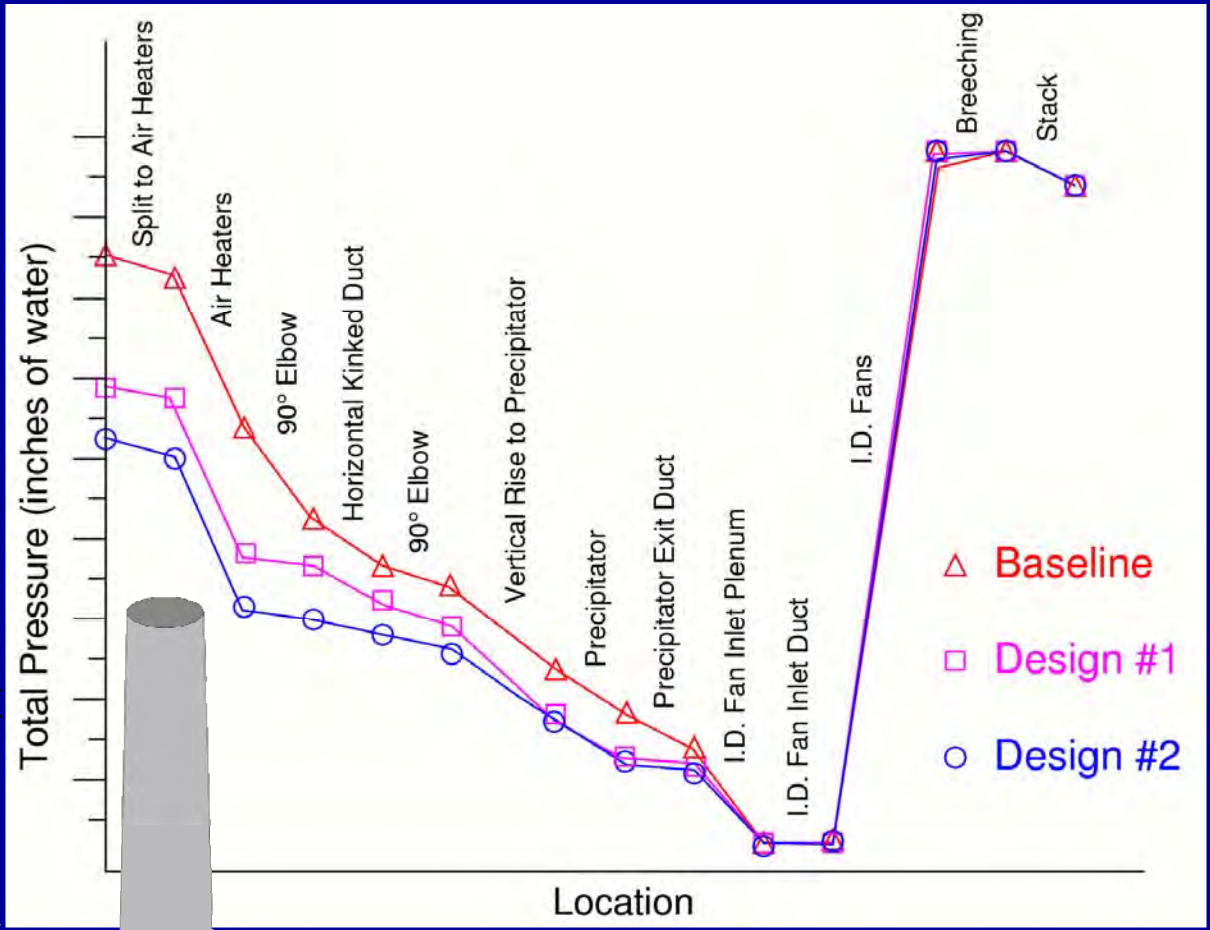
- Industry Standards
- Control Methods

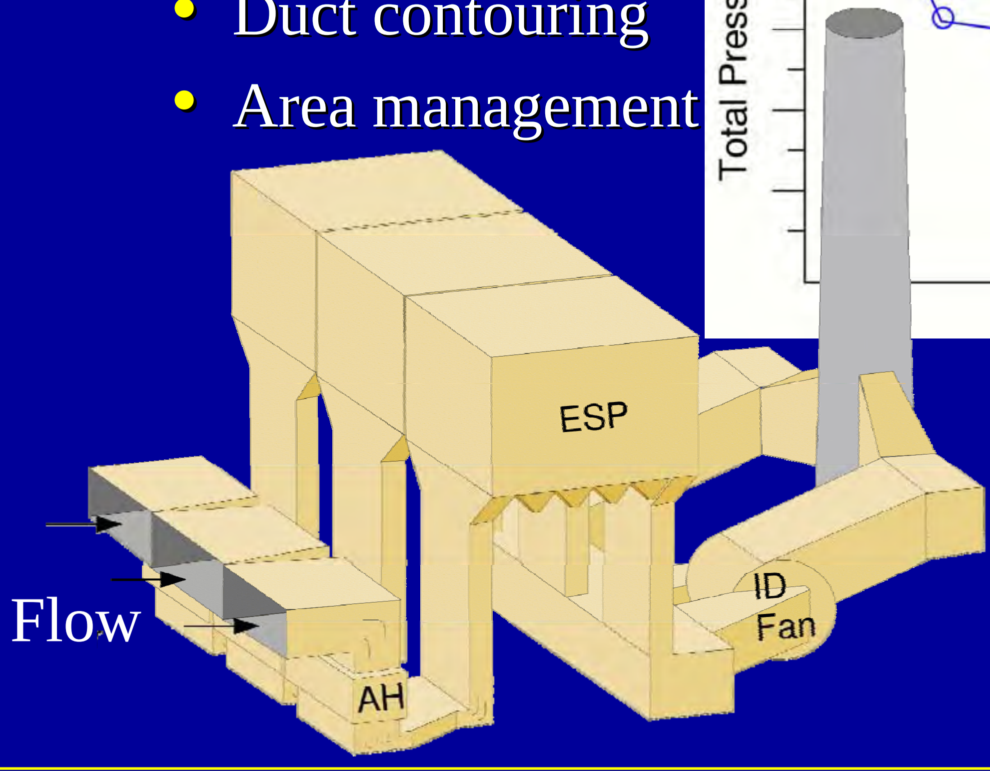
ICAC: Flow within each chamber to be within ±10% of its theoretical share



Pressure Drop

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

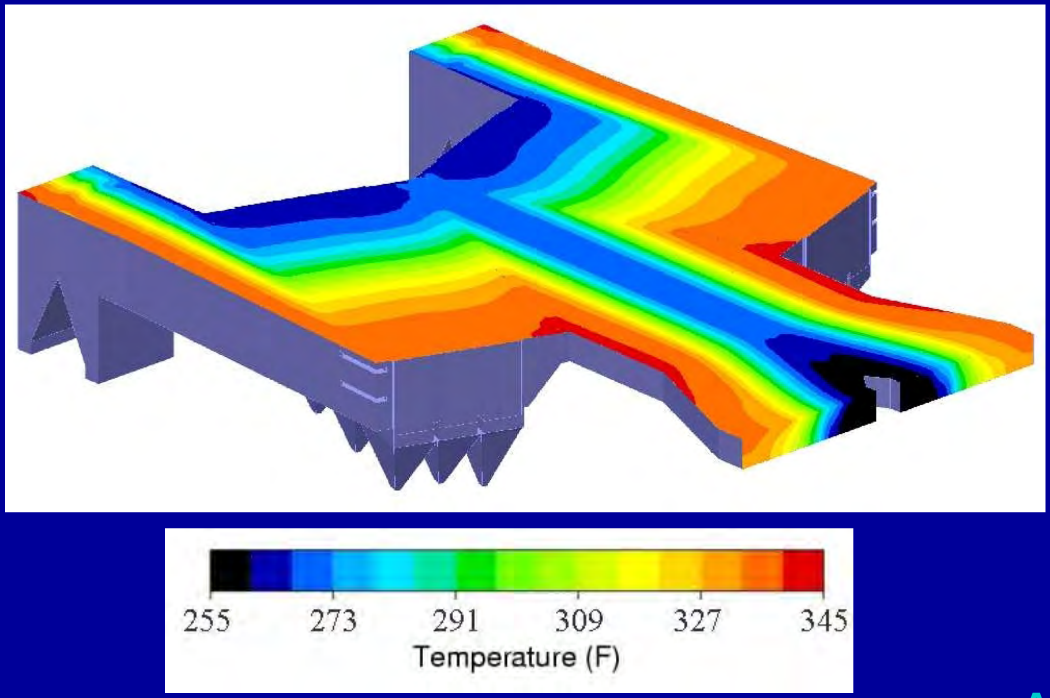


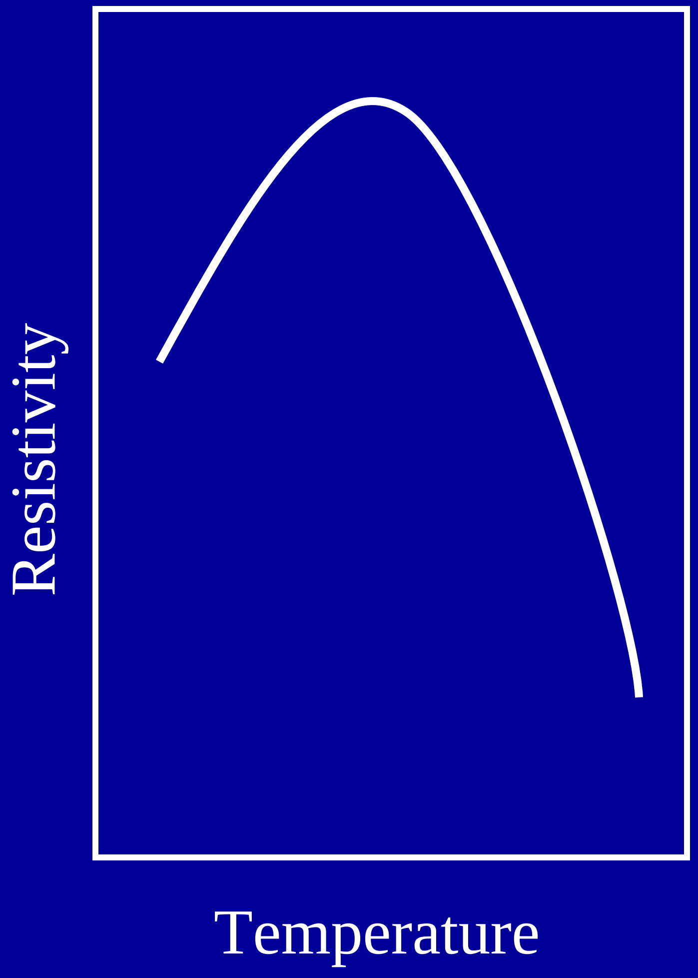


Ductwork redesign saves
2.1 inches H_2O over baseline

Gas Temperature

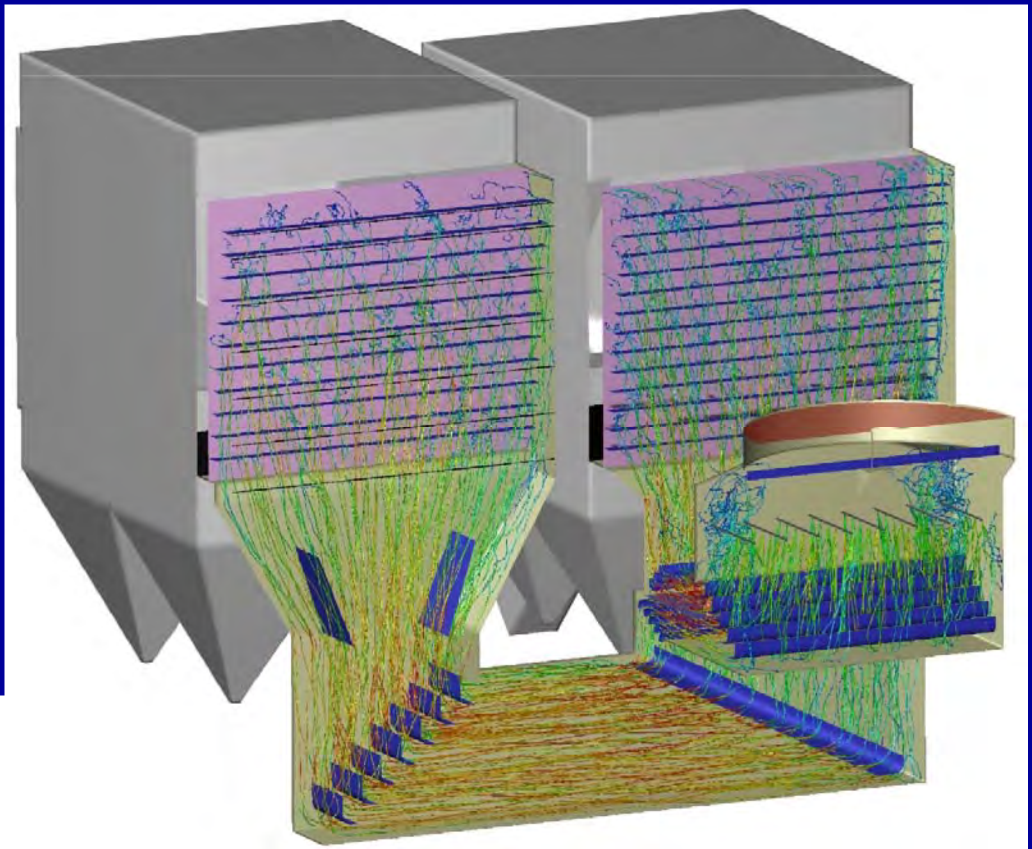
- Average temperature
- Temperature stratification
- Inleakage



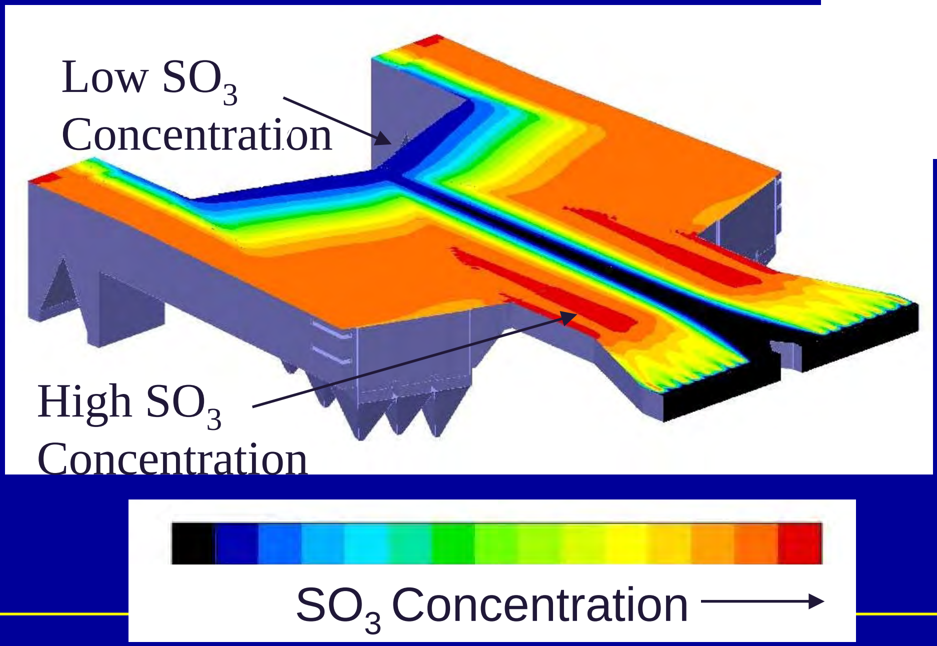


Injection Systems

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



Activated Carbon Injection – Particle Tracking

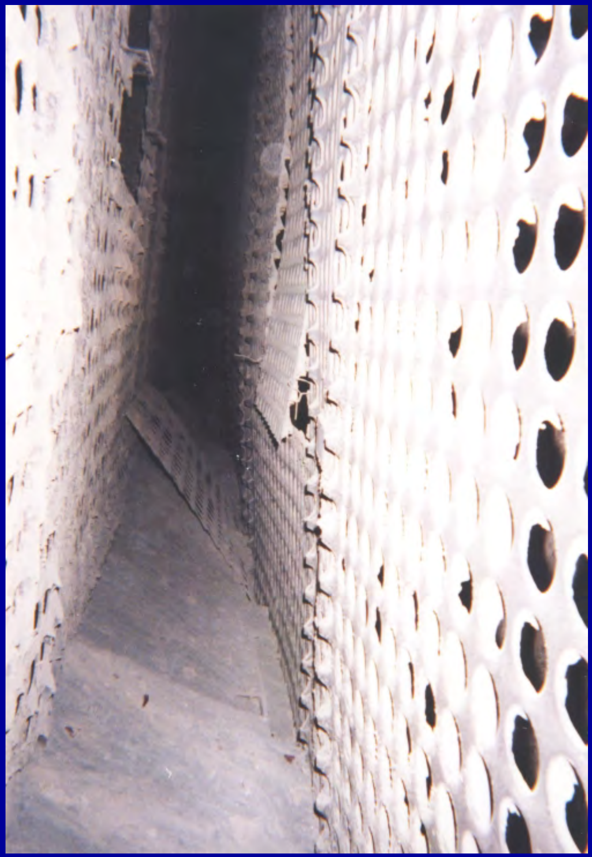


Outline

- 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

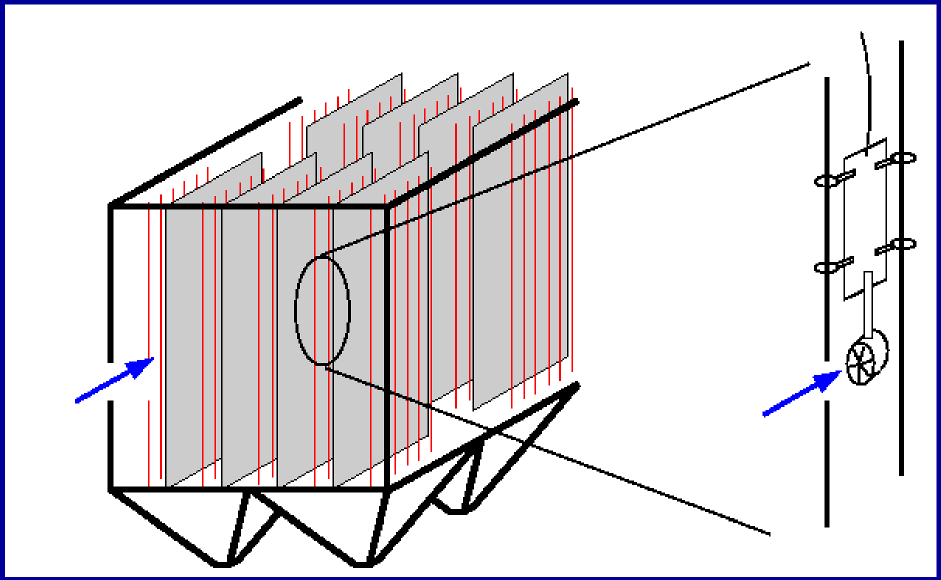


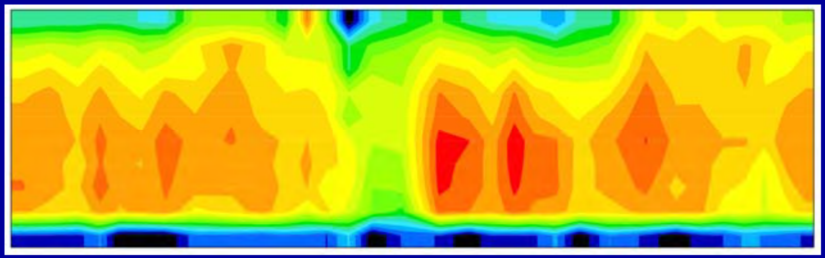
Field Testing – Ductwork

- 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





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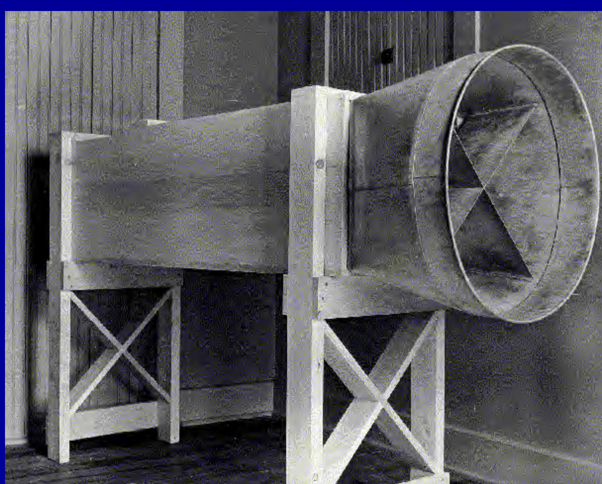
- Introduction
- ESP Fluid Flow Basics
- Assessing Flow Characteristics
- ESP Flow Modeling
  - Physical Models
  - Computational Fluid Dynamics (CFD) Models
- Movies and Animations
- Questions

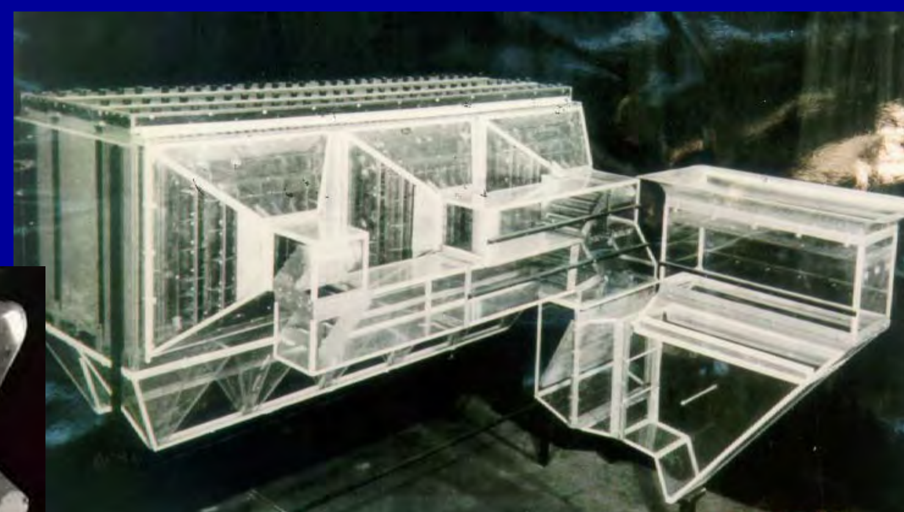
ESP Modeling – Physical Models

- 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

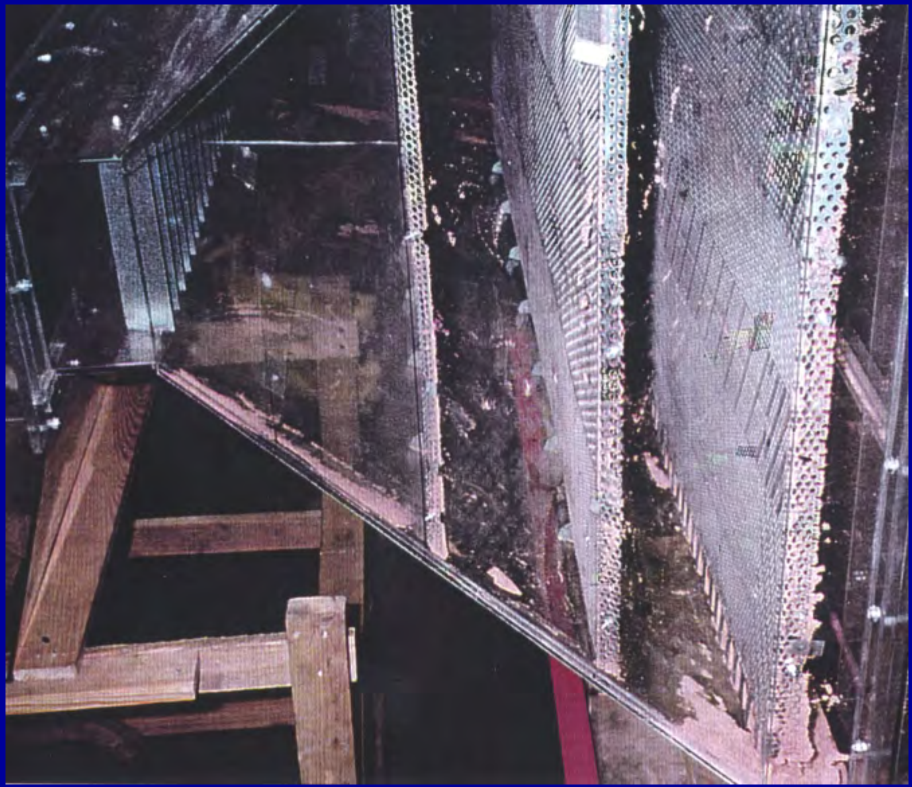
$$Re = \frac{\rho \, v \, D_h}{\mu}$$

Physical Models – Simulation Parameters

- ESP geometry
  - 1/8th to 1/16th scale representation
  - Include features >4" in size
- Flow conditions
  - Scaled <u>air</u> 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

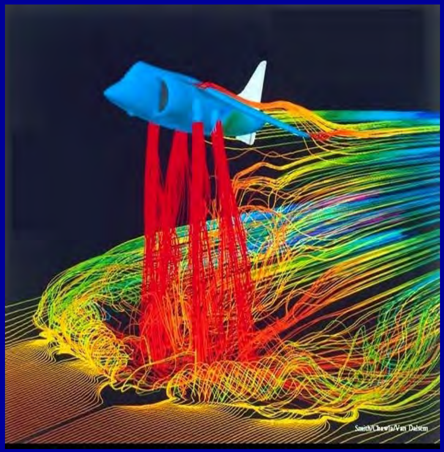


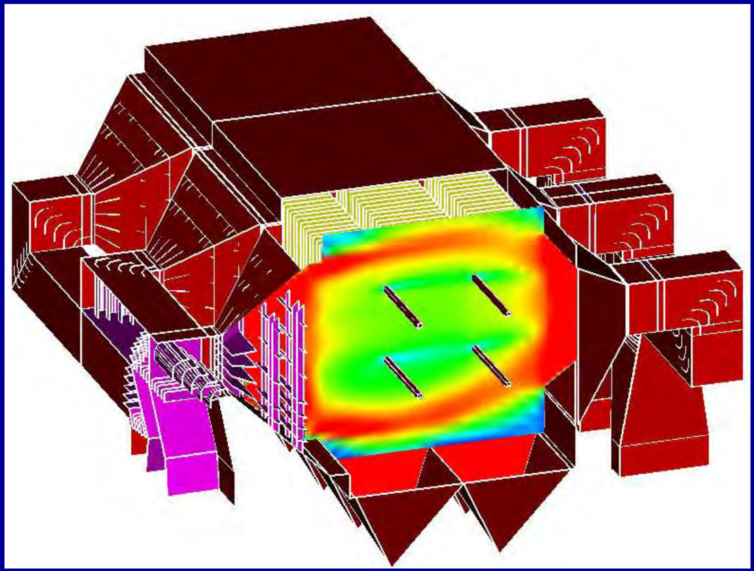
Flow Modeling – Computational Fluid Dynamics (CFD)

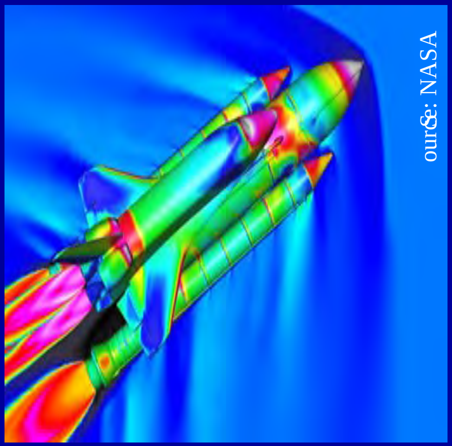
- Background
- Theory
- Simulation Parameters (how the model is set up)
- Results Analysis (what you get from the model)

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







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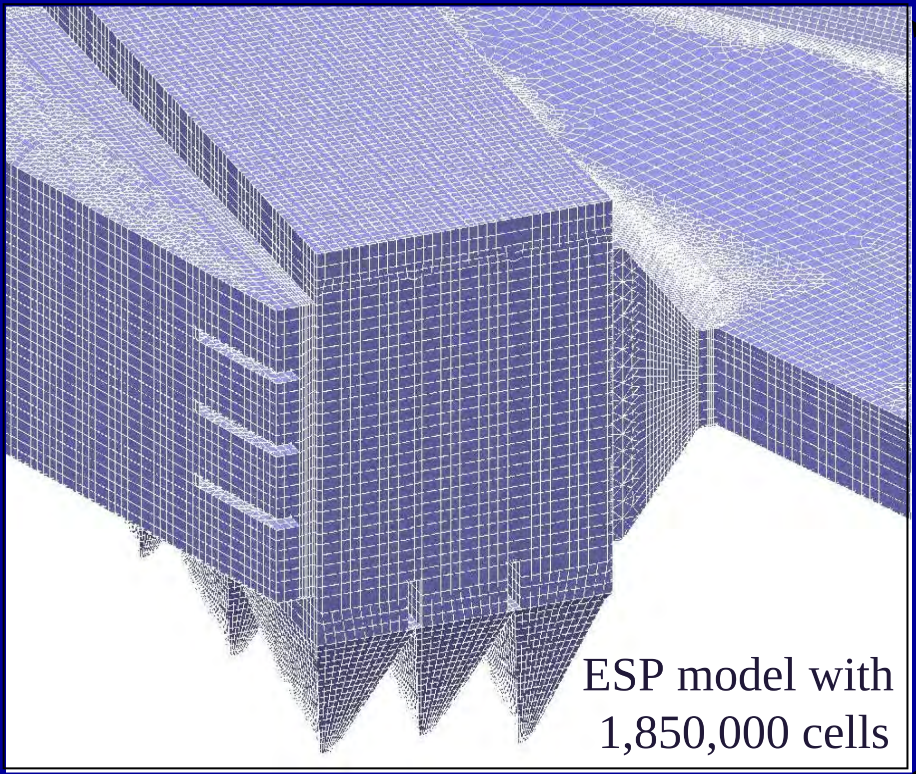
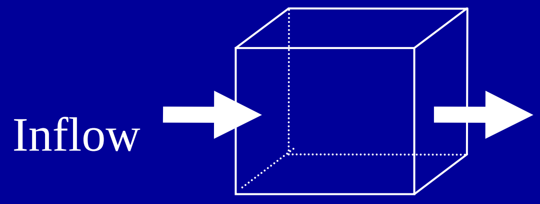
CFD – Theory

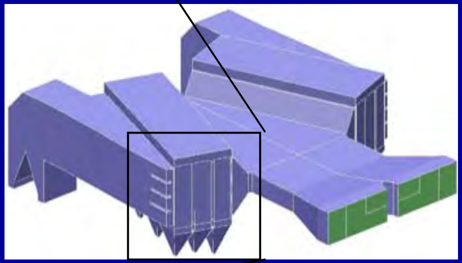
- Control Volume Approach
  - Divide the flow domain into distinct control volumes
  - Solve the Navier-Stokes equations (Conservation of Mass, Momentum, Energy) in each control volume



ESP model with 1,850,000 cells

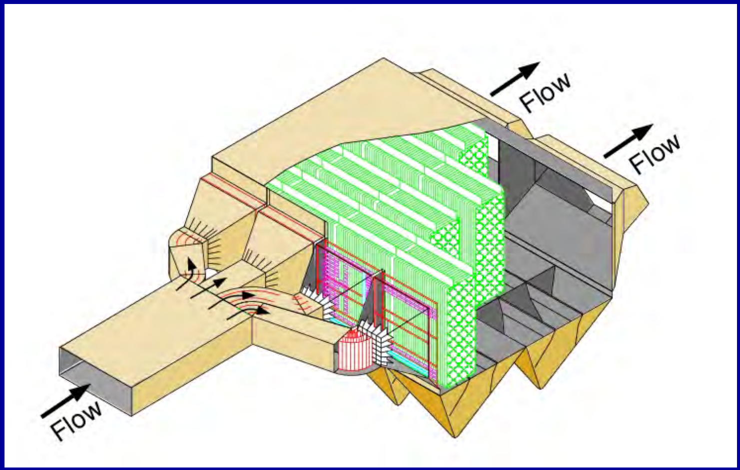


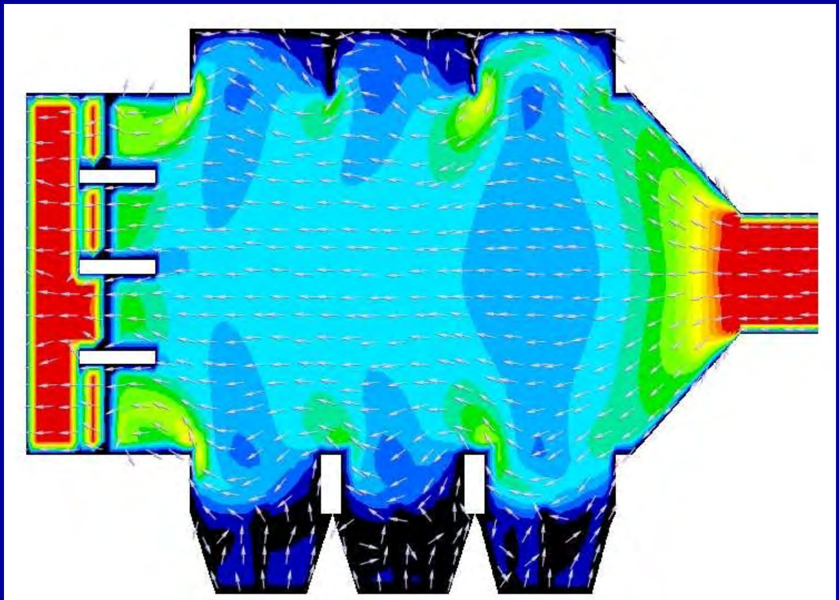
Control Volume
or “Cell”



CFD – Simulation Parameters

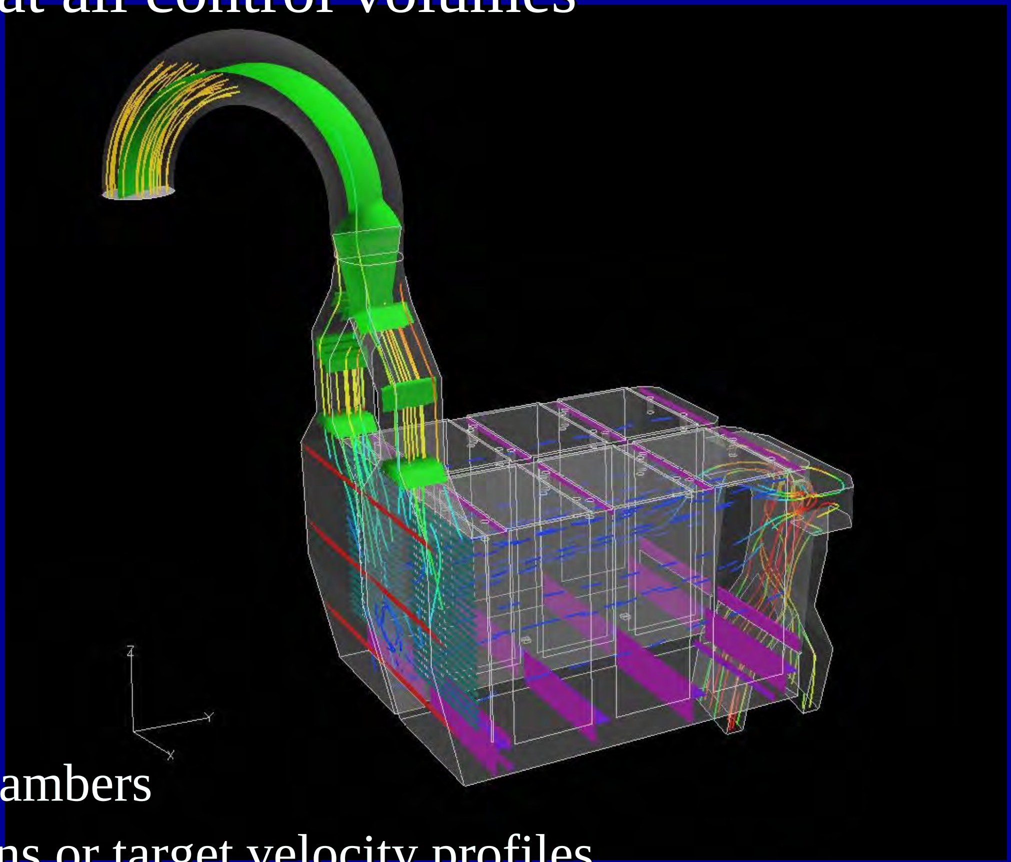
- ESP geometry
  - Full scale representation
  - Include features >4” in size, more detail if possible
- Flow conditions
  - Full scale gas flow rate
  - Reproduce velocity profile at model inlet
  - Reproduce temperature profile at model inlet
  - Simulated chemical injection
  - Simulated particle 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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