CFD and Physical Flow Modeling

Improving Plant Performance, Maintenance, & Emissions

KCPL / WPCA Technical Seminar
June 5, 2018

Robert Mudry, P.E.
Airflow Sciences Corporation

Airflow Sciences Corporation

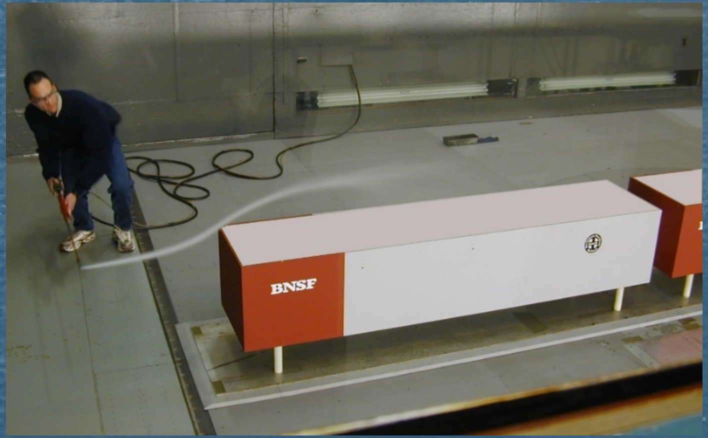
Agenda

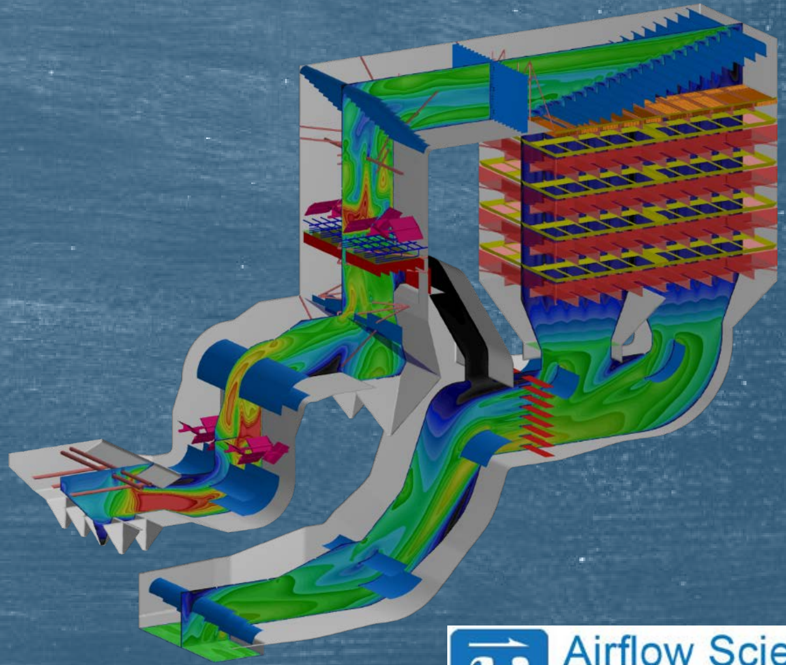
- Introduction
- Methodology
  - Computational Fluid Dynamics (CFD)
  - Physical Modeling
- Plant Applications
  - Boiler / Furnace
  - SCR
  - ESP/FF
  - DSI/ACI
  - FGD
  - Ducts
  - Stacks

Airflow Sciences Corporation

Airflow Sciences Corporation

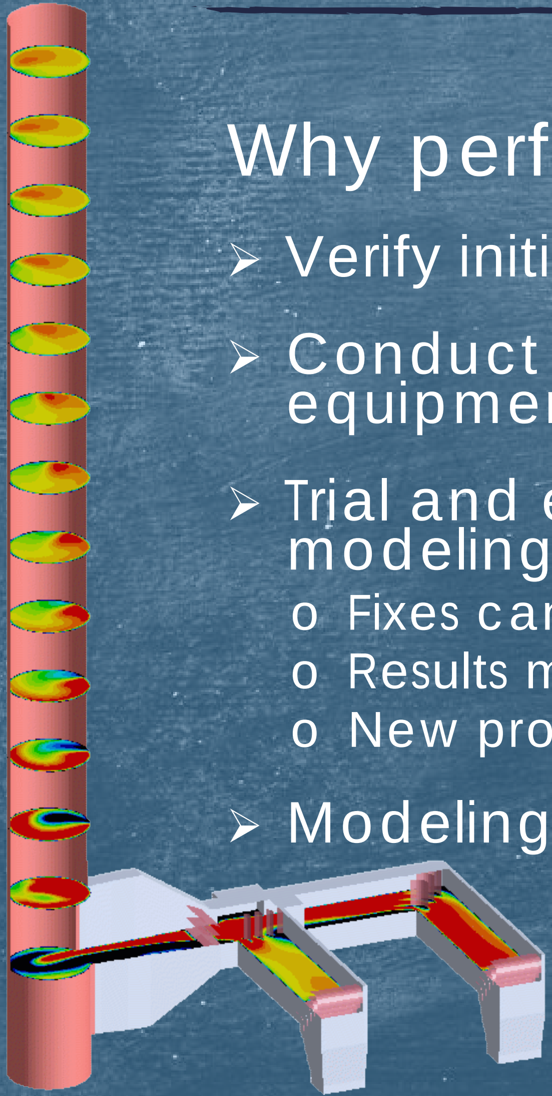
- Providing engineering and field testing since 1975
- Specialize in developing cost-effective solutions to problems involving:
  - Fluid Flow
  - Heat Transfer
  - Particulate Transport
  - Chemical Reaction
  - Aerodynamics





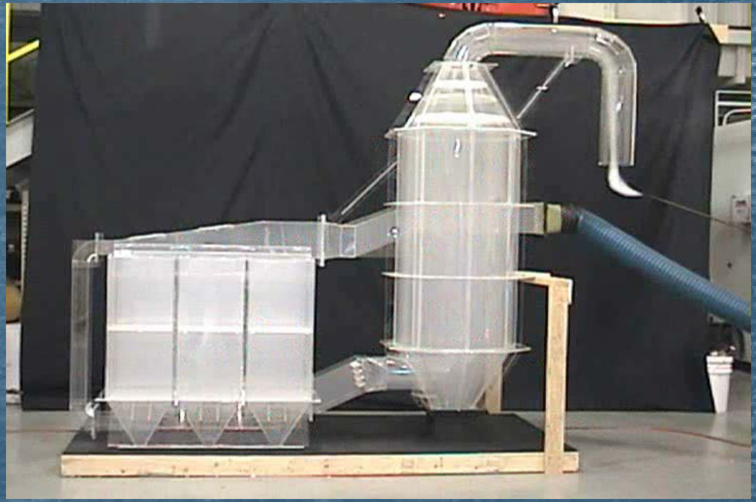
Airflow Sciences Corporation

Flow Modeling



Why perform flow modeling?

- Verify initial design of new equipment
- Conduct troubleshooting/optimization of existing equipment
- Trial and error design optimization without modeling can work, but…
  - o Fixes can be costly
  - o Results may not be as expected
  - o New problems could develop
- Modeling can save time and $$ in the long run



Airflow Sciences Corporation

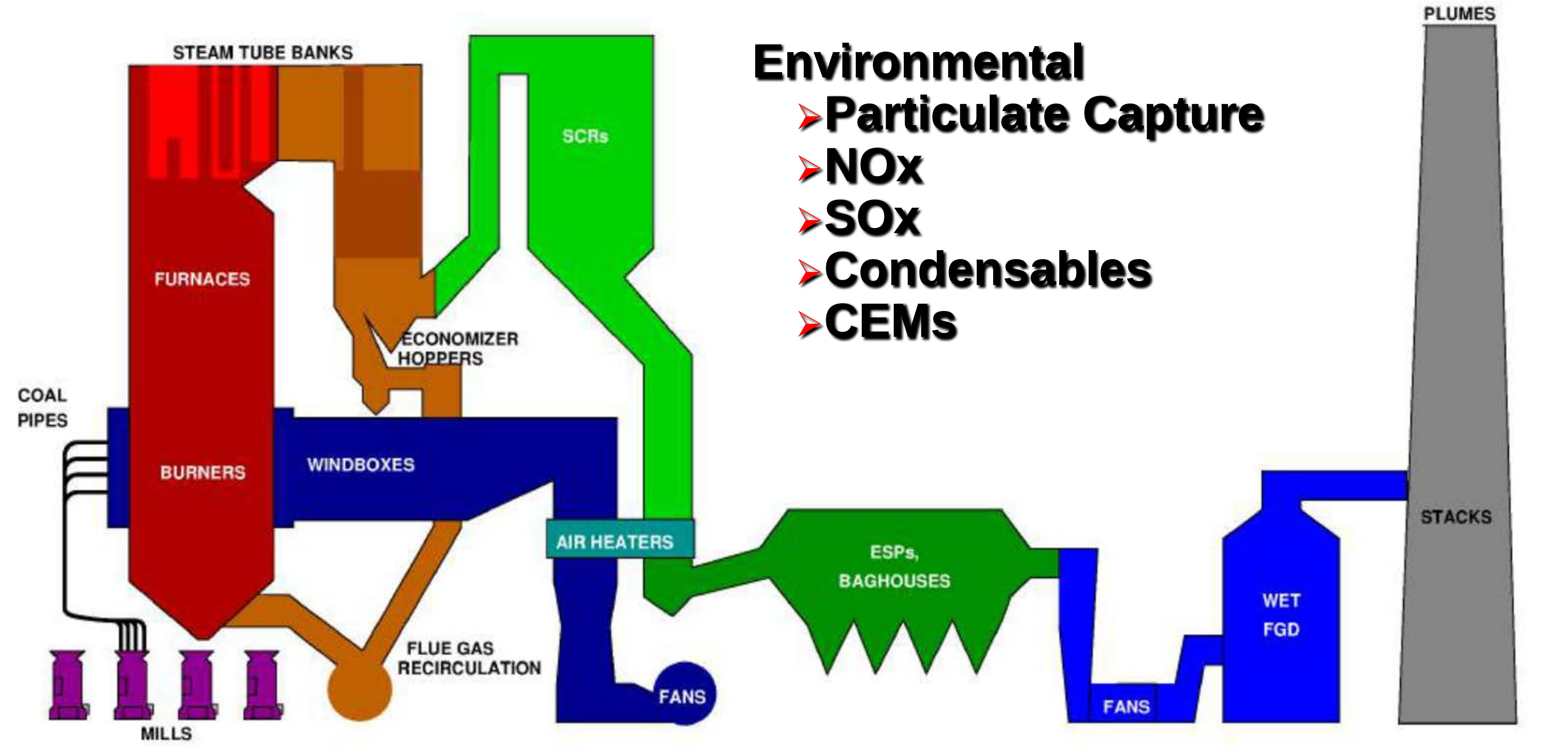
Industry Need

- Flow and heat transfer issues can be found from the fan to the stack, and beyond

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

Environmental
- Particulate Capture
- NOx
- SOx
- Condensables
- CEMs

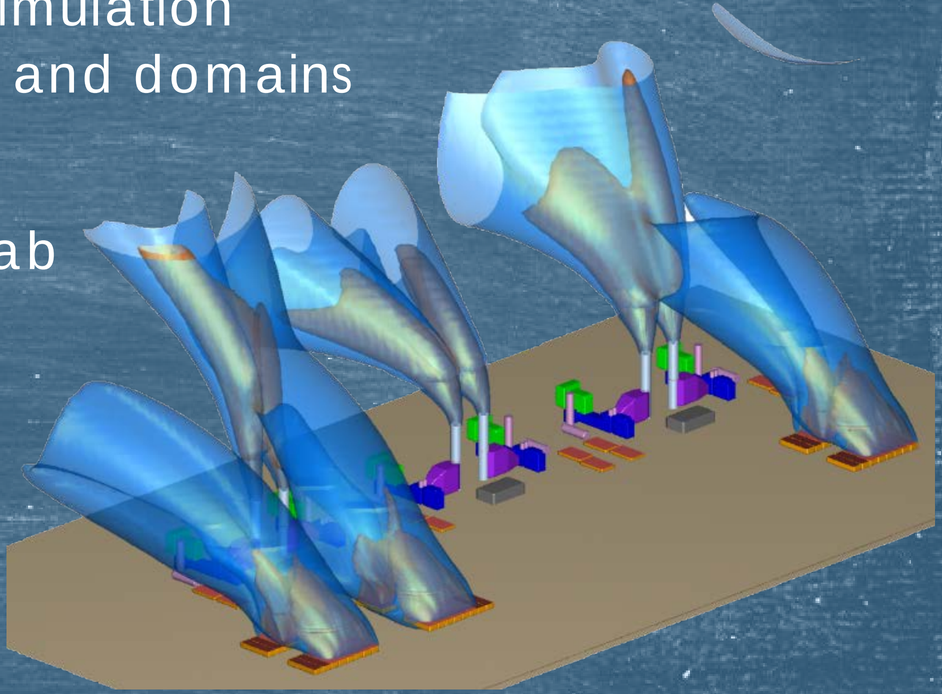
Maintenance
- Fouling
- Pluggage
- Erosion
- Corrosion
- Vibration



Airflow Sciences Corporation

Methodology

- Computational Fluid Dynamics (CFD) modeling
  - Virtual representation of flow system via simulation
  - Quantitative results with complex physics and domains
- Physical Flow Modeling
  - Scale representation of flow system in a lab
  - Quantitative and qualitative results

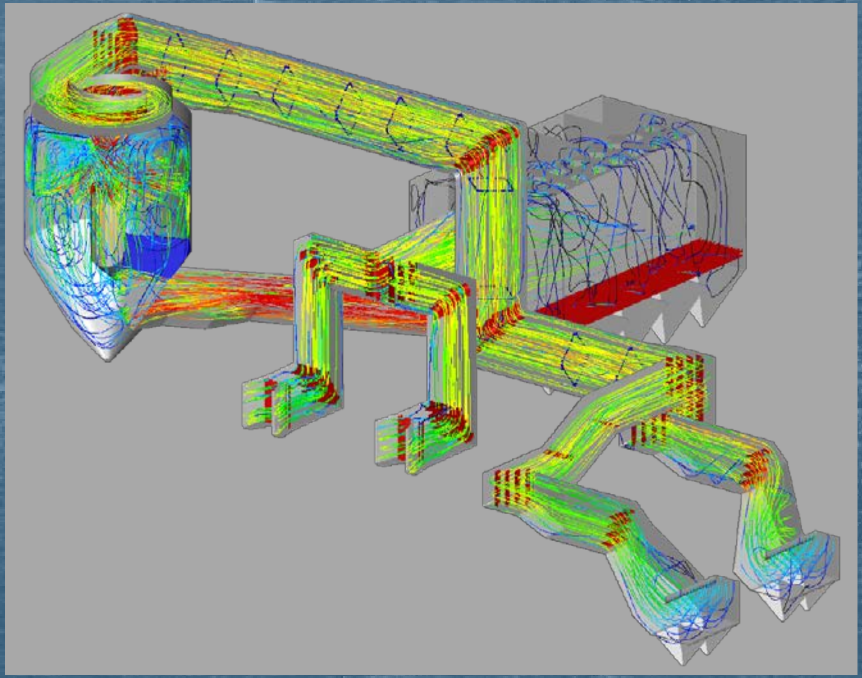


- Field Testing plays a role in modeling

Airflow Sciences Corporation

Computational Fluid Dynamics (CFD)

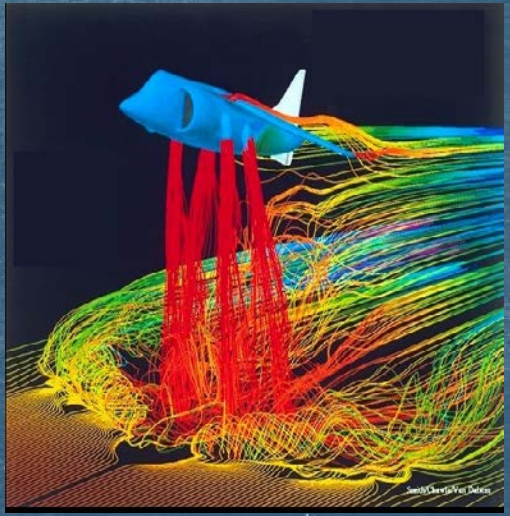
- Numerical simulation of flow
- Utilize high speed computers and sophisticated software
  - Azore
  - Fluent
- Calculate flow properties
  - Velocity
  - Pressure
  - Temperature
  - Chemical species
  - Particle streamlines
- Steady state or transient analysis

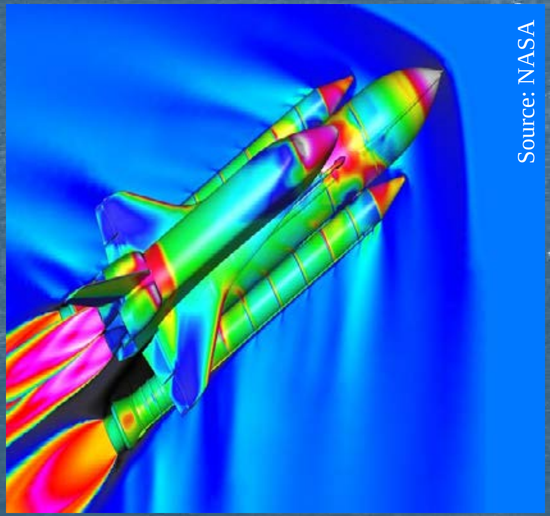


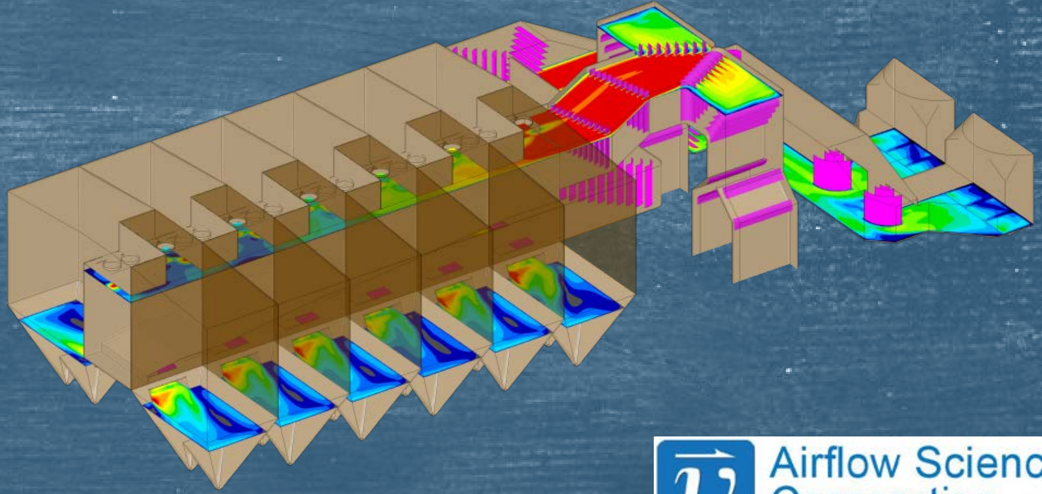
Airflow Sciences Corporation

CFD History

- Developed in the aerospace industry c. 1970 (with the advent of “high speed” computers)
- Applied to industrial equipment for 40+ years
- Underlying principle is to solve the first-principles equations governing fluid flow behavior



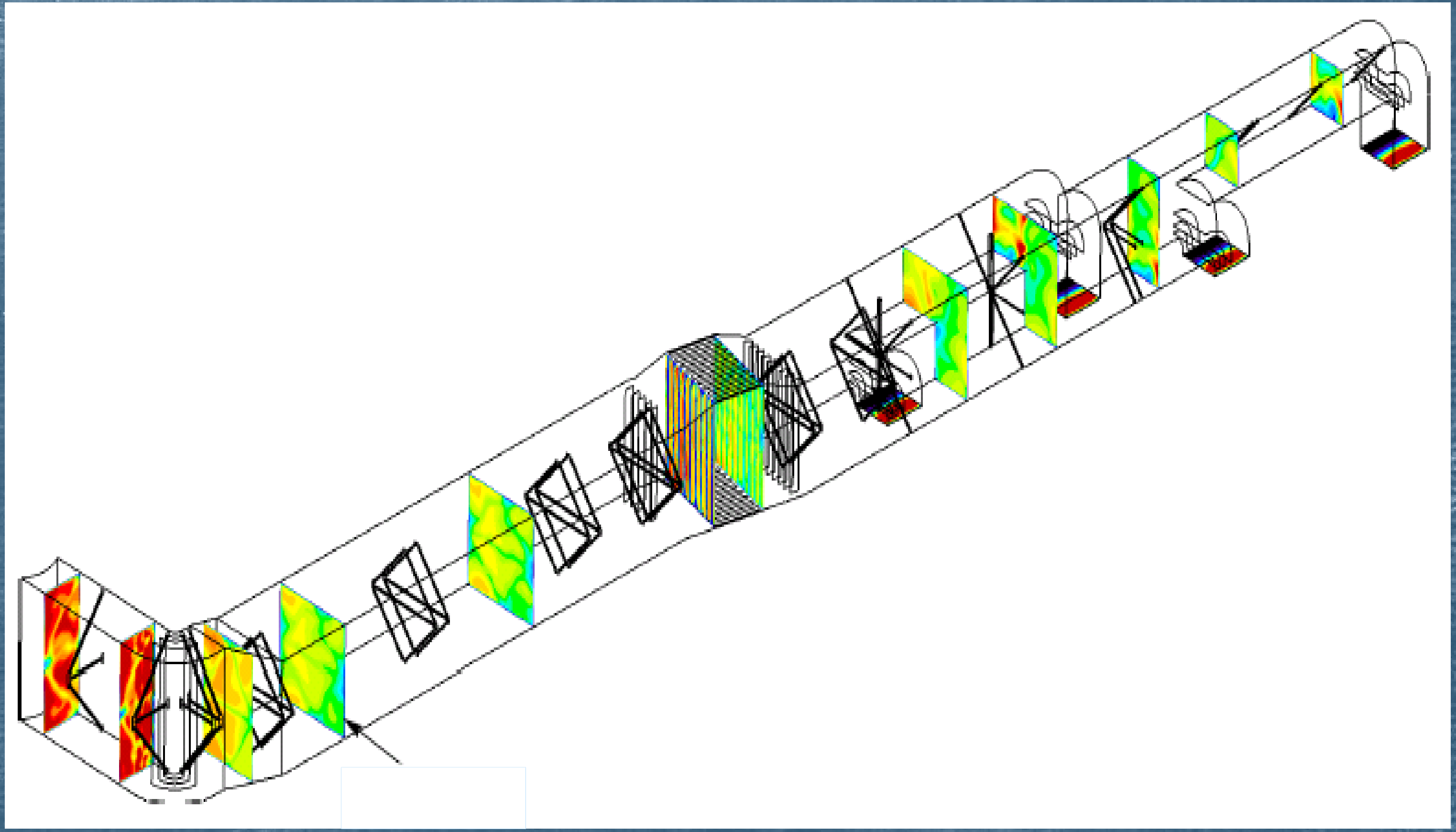




Airflow Sciences Corporation

CFD Methodology

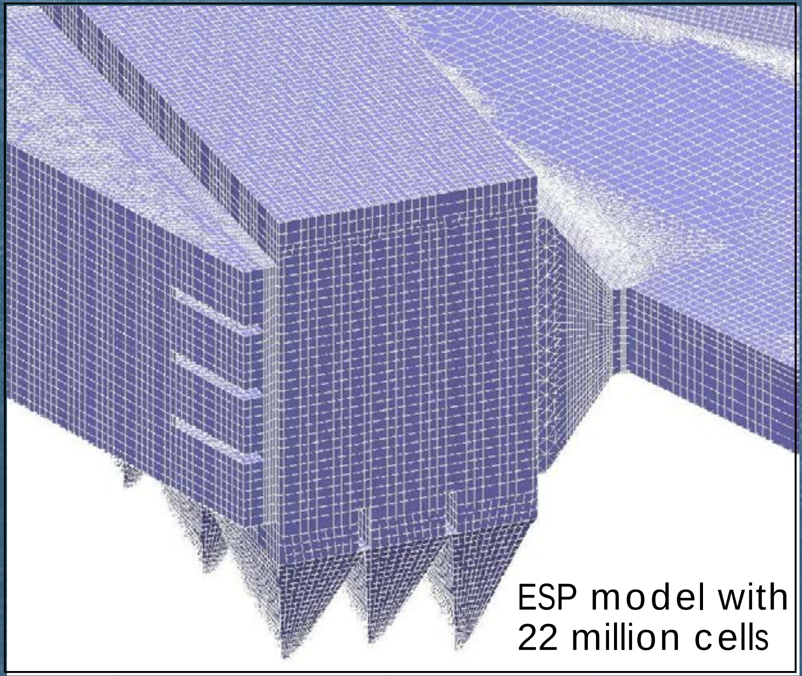
1. Set up
   - Geometry (3D CAD)
   - Computational mesh
   - Boundary conditions
2. Solve
3. Analyze
   - Contour plots
   - Flow statistics and integrations
   - Particle/species tracking

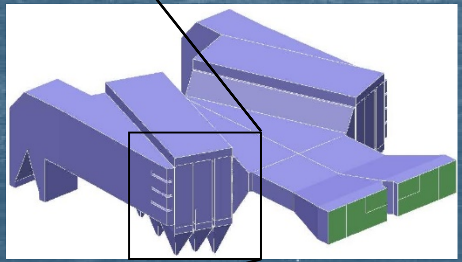


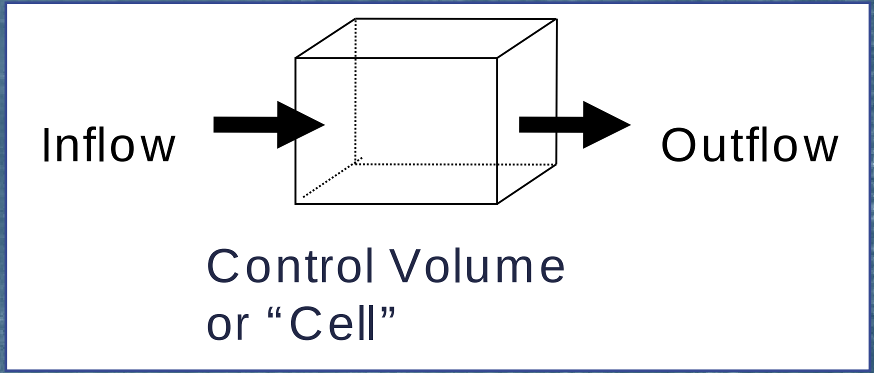
Airflow Sciences Corporation

CFD Mesh

- 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



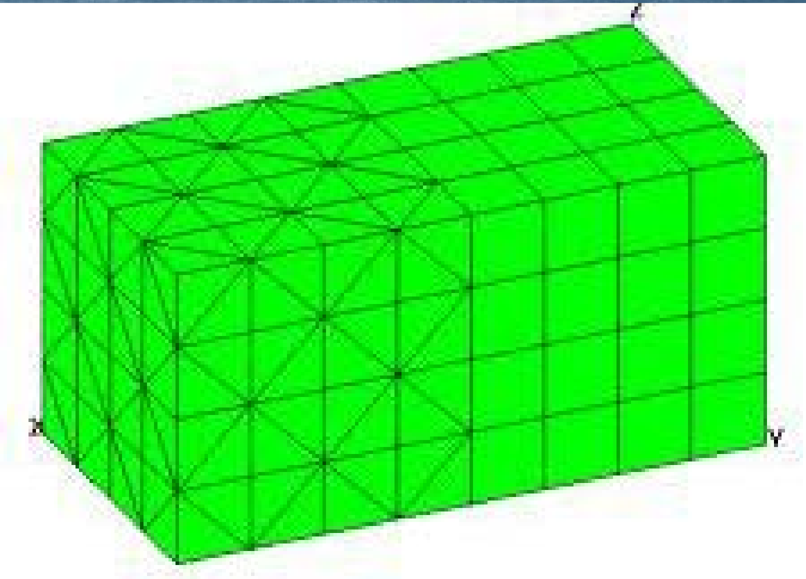




Airflow Sciences Corporation

CFD Mesh Quality

- Important mesh properties
  - Number of cells
  - Length scale of cells
  - Distribution of cells
  - Shape/topology of cells
  - Flow alignment

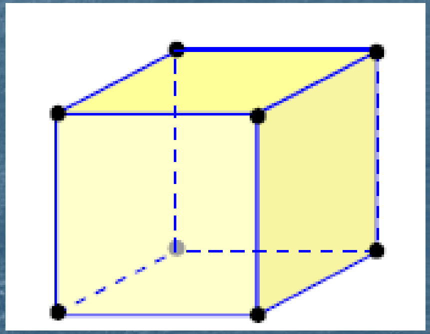


- Why?
  - Finer resolution = more accurate results
  - Numerical calculation scheme accuracy is influenced by cell arrangement

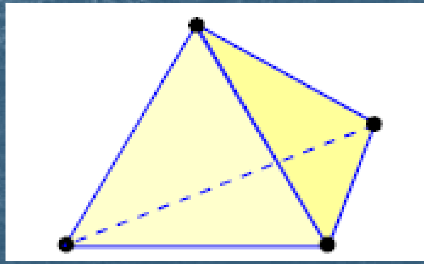
Airflow Sciences Corporation

CFD Mesh Quality – Cell Topology

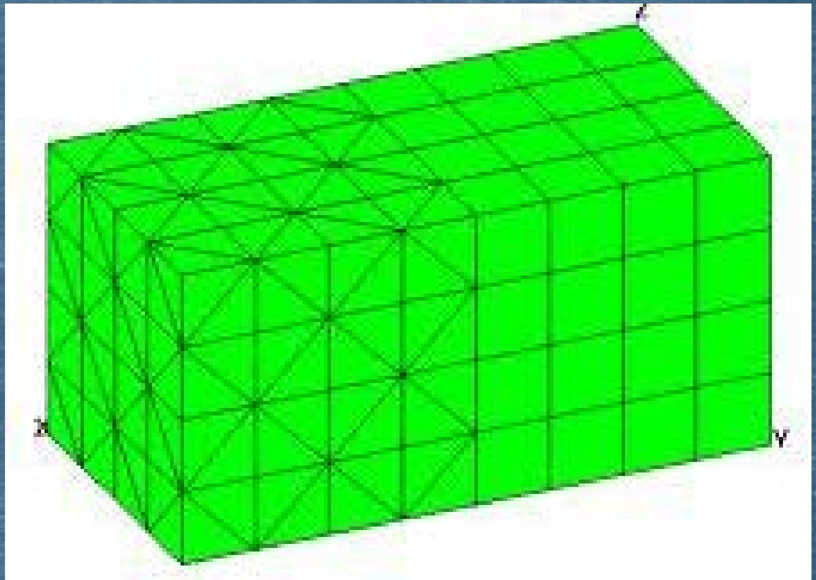
- Not all CFD cells are created equal
  - 5 million Hex cells = 30 million Tet cells
  - Hex cells maintain better flow alignment



Hexahedral cell
(6 faces)



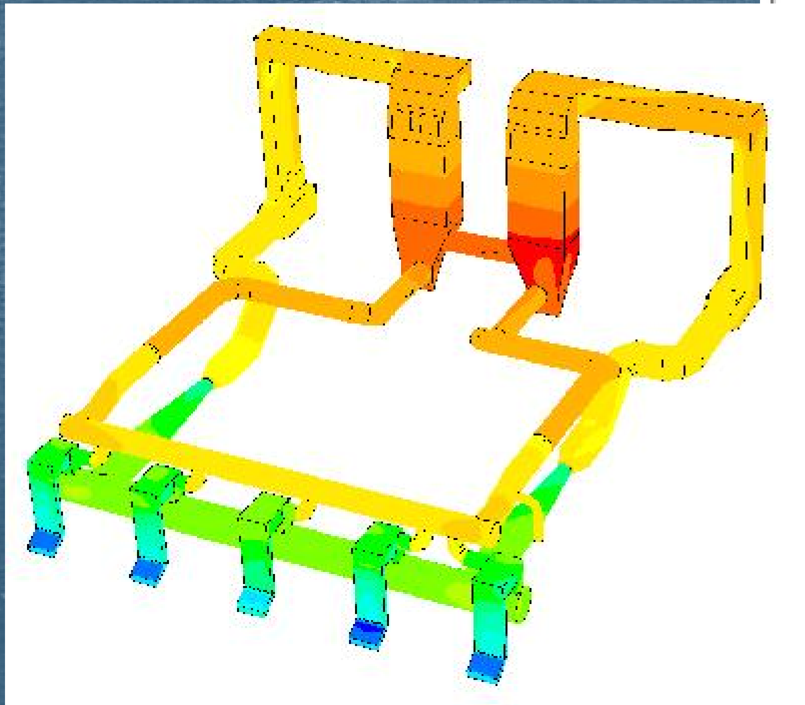
Tetrahedral cell
(4 faces)



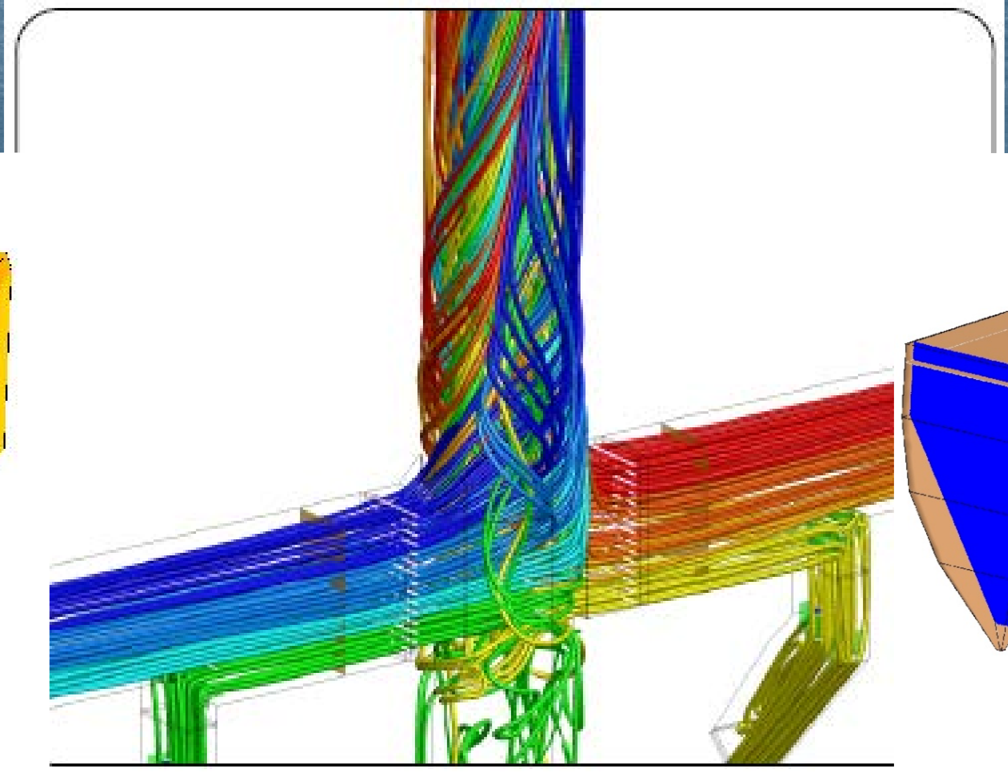
6 Tet cells fit into 1 Hex cell
of the same length scale

Airflow Sciences Corporation

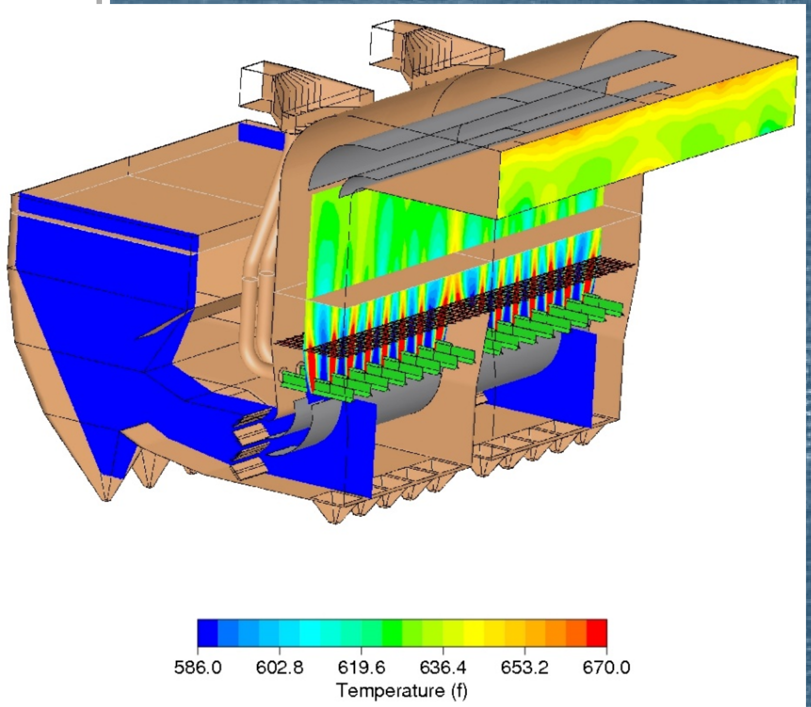
CFD Results – Examples



Surface Contours



Flow Streamlines



Cutting Planes

Airflow Sciences Corporation

CFD Flow Animations

Airflow Sciences Corporation

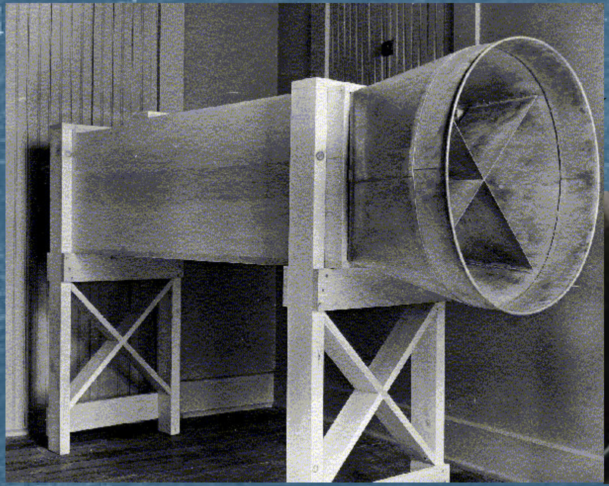
Physical Flow Modeling

- Laboratory representation of geometry
- Can be scaled or full size
- Ambient or controlled temperatures
- Visualize flow with smoke
- Simulate particle drop-out & re-entrainment
- Measure flow properties
  - Velocity (Hot wire or pitot)
  - Pressure (Pitot-static probe w/ manometer)
  - Tracer gas (Gas analyzer)

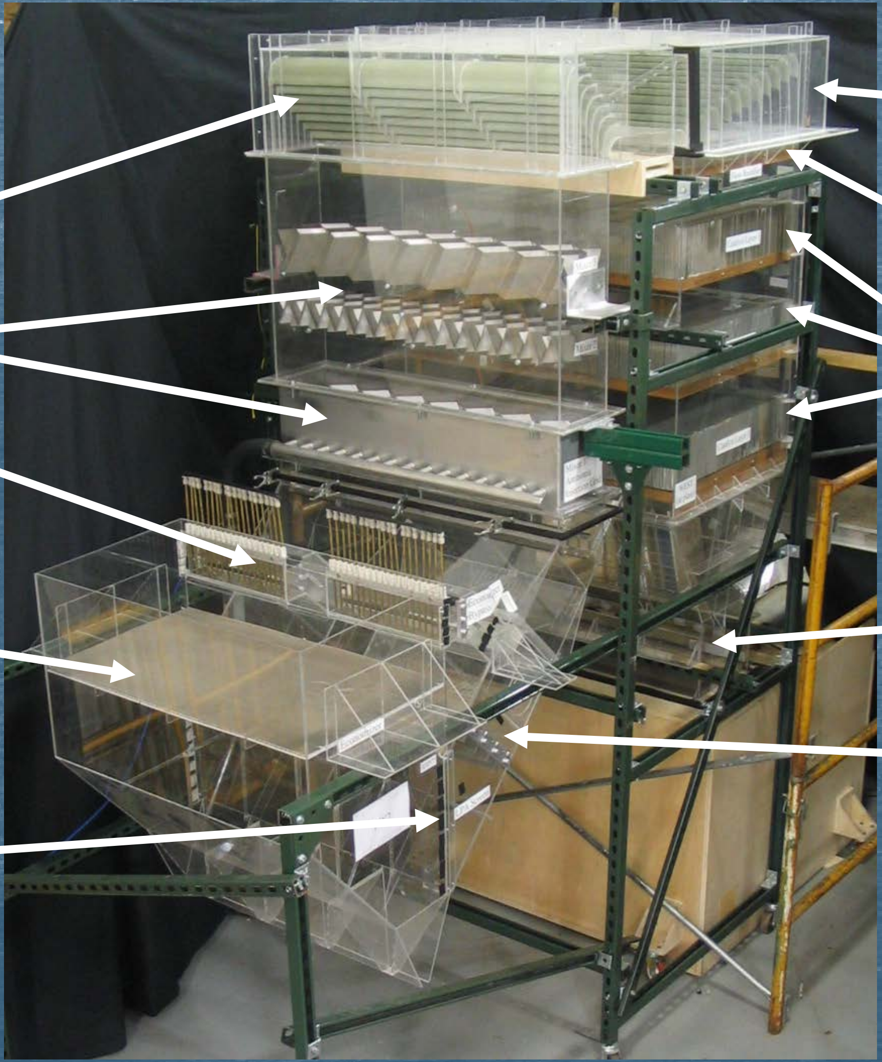
Airflow Sciences Corporation

Physical Modeling History

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



Physical Model – Typical 1/12 Scale SCR



Turning vanes
AIG w/static mixers
Economizer bypass
Economizer outlet
LPA screen

Vanes
Rectifier
Catalyst layers
Air heater
Dampers

Airflow Sciences Corporation

Physical Model Methodology

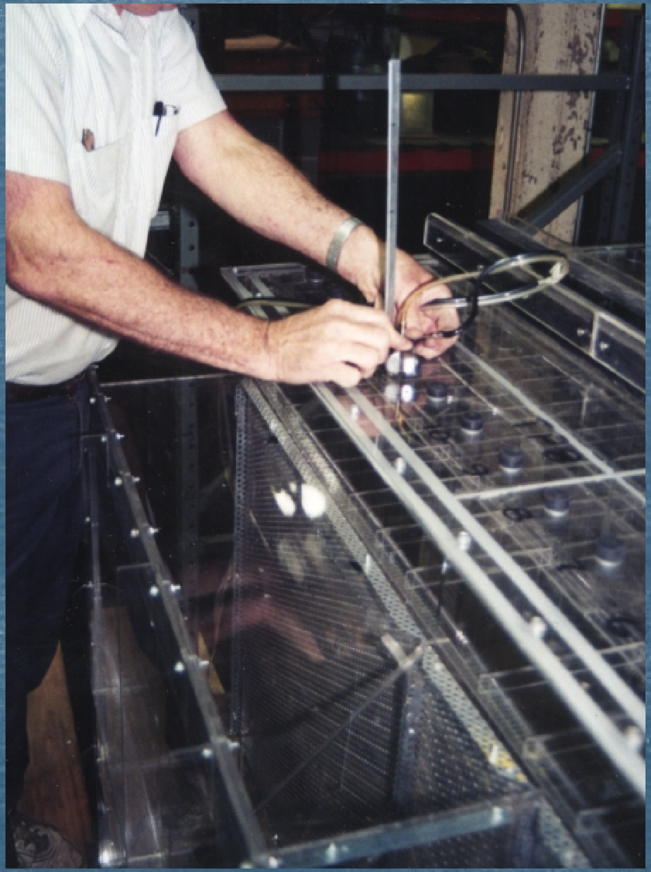
- Key criterion is to generate “similarity” between the scale model and the real-world object
  - Geometric similarity
    - Accurate scale representation of geometry
    - Inclusion of all influencing geometry elements
    - Selection of scale can be important
  - Fluid dynamic similarity
    - Precise Reynolds number (Re) matching as close as possible
    - General practice is to match full scale velocity but ensure that Re remains in the turbulent regime throughout the model

$$Re = \frac{\rho \upsilon D h}{\mu}$$

Airflow Sciences Corporation

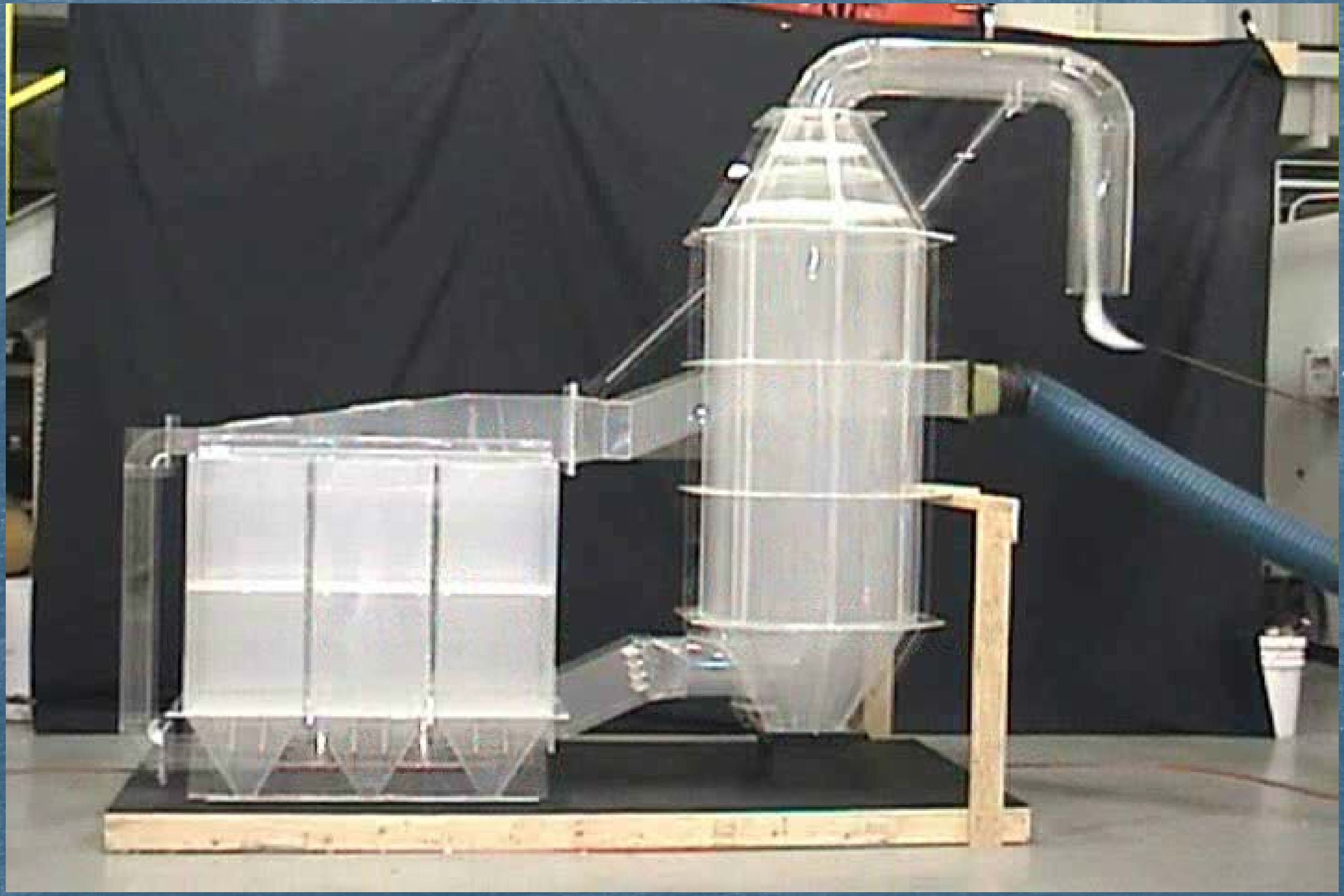
Physical Model Methodology

1. Set up
   - Fabricate(from CAD)
   - Boundary conditions
   - Similarity calculations
2. Test
3. Analyze
   - Contour plots
   - Flow statistics and integrations
   - Flow visualization



Airflow Sciences Corporation

Physical Model Smoke Flow



Flow Modeling Pros and Cons

- Physical Modeling - Pros
  - Proven technique
  - Can “touch and feel” model
  - Complex flow simulations and solutions
  - Species distribution modeling using tracer gas
  - Ash drop-out and re-entrainment
  - Flow visualization
- Physical Modeling - Cons
  - Design iterations can be time consuming (no parallelization)
  - Thermal mixing difficult
  - Limited number of measurement points
  - Harder to simulate complex physics (chemical reactions, density variations, particulate drag/aerodynamics)
  - Model storage can take up significant space

Airflow Sciences Corporation

Flow Modeling Pros and Cons

- CFD Modeling - Pros
  - Iterations can be done in parallel
  - Detailed representation of flow and mixing patterns
  - Data available at millions of traverse points
  - Output can be customized to maximize information
  - Can track particulate in flight
  - Model stored on computer or CD/DVD
- CFD Modeling - Cons
  - Model is virtual, can't "touch and feel"
  - Accuracy of results relies on mesh quality and resolution
  - Particulate drop-out/re-entrainment capability is limited
  - Species distribution modeling requires detailed (dense) mesh
  - Some physics and geometries are difficult to resolve in mesh

Airflow Sciences Corporation

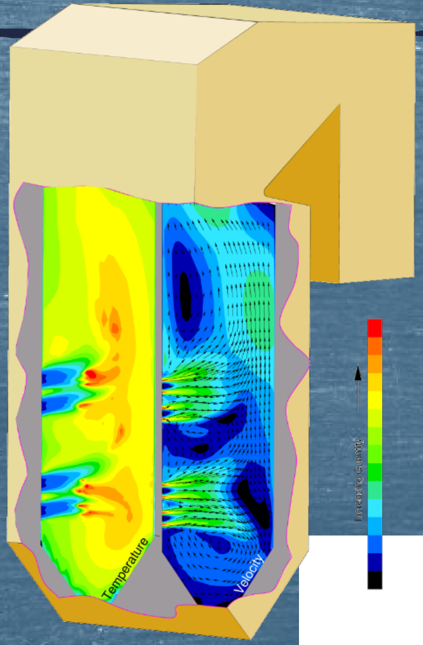
Model Accuracy

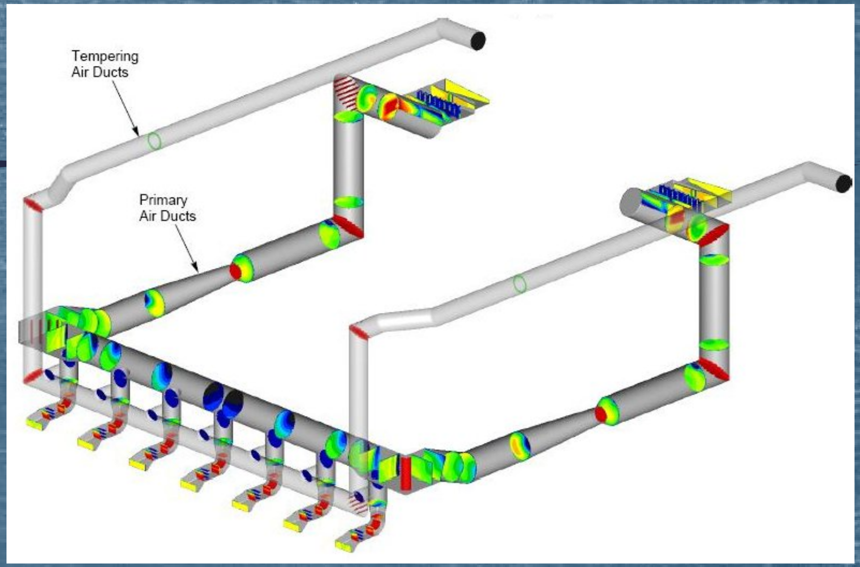
- Do physical and CFD models match field test data?
  - Where data is available, models match well
  - Rely on industry experience and whether performance goals are met
- Do physical and CFD models match each other?
  - For velocity and pressure drop predictions, correlation is quite good
  - For NH_3 and other gas species, correlation has improved steadily over time
    - Better CFD meshes (mesh quality and resolution of detailed features)
    - Faster computers (allowing larger CFD meshes)

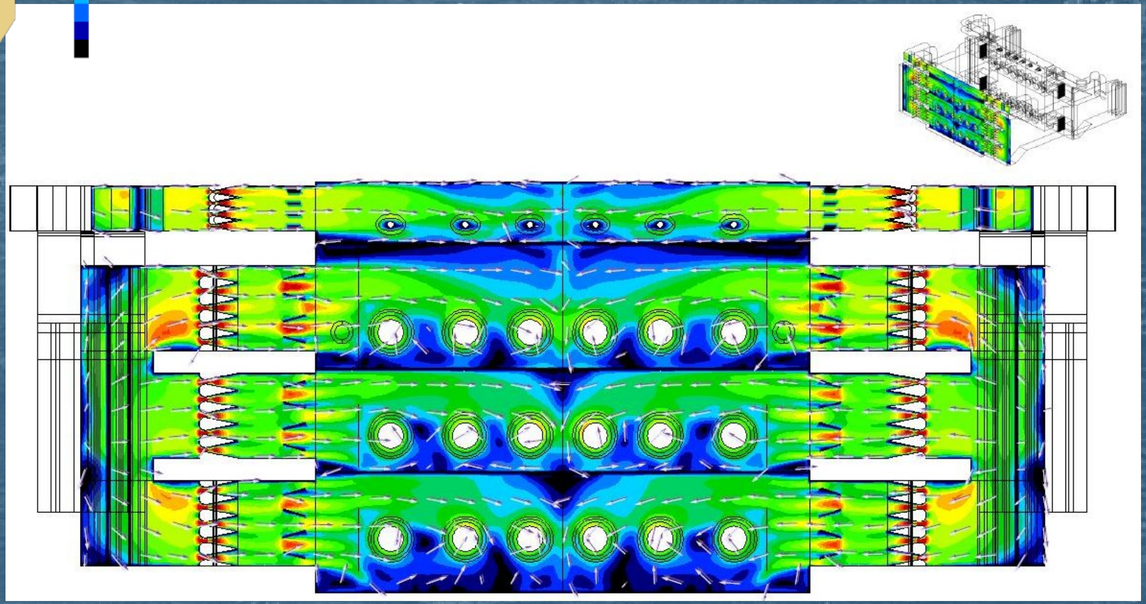
Airflow Sciences Corporation

Applications: Boiler / Furnace

- PA / SA
- Windbox balance
- Furnace combustion
- Heat transfer
- Erosion / corrosion

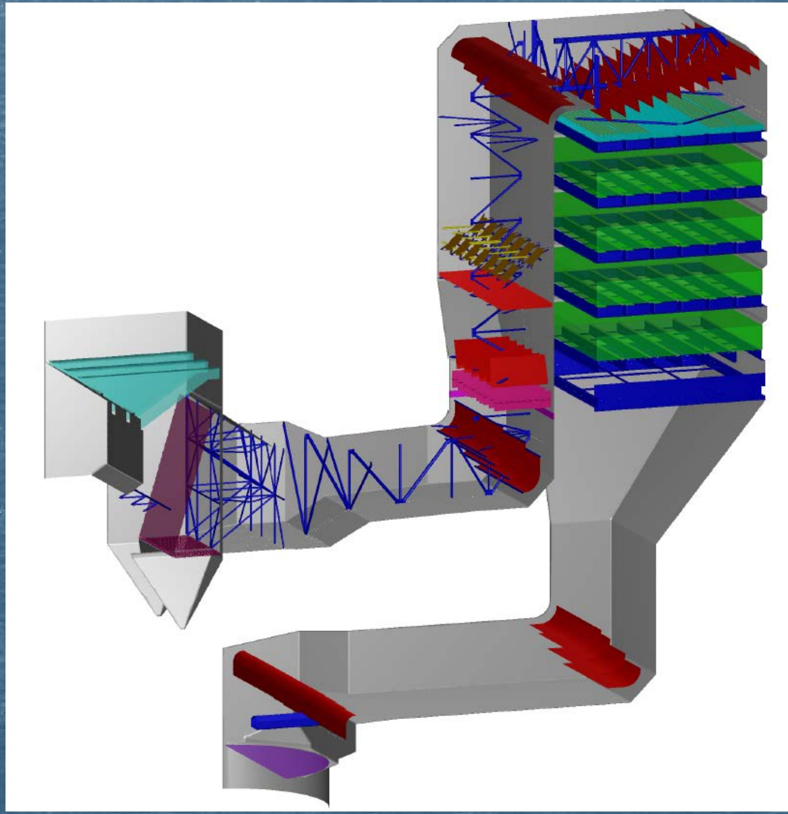




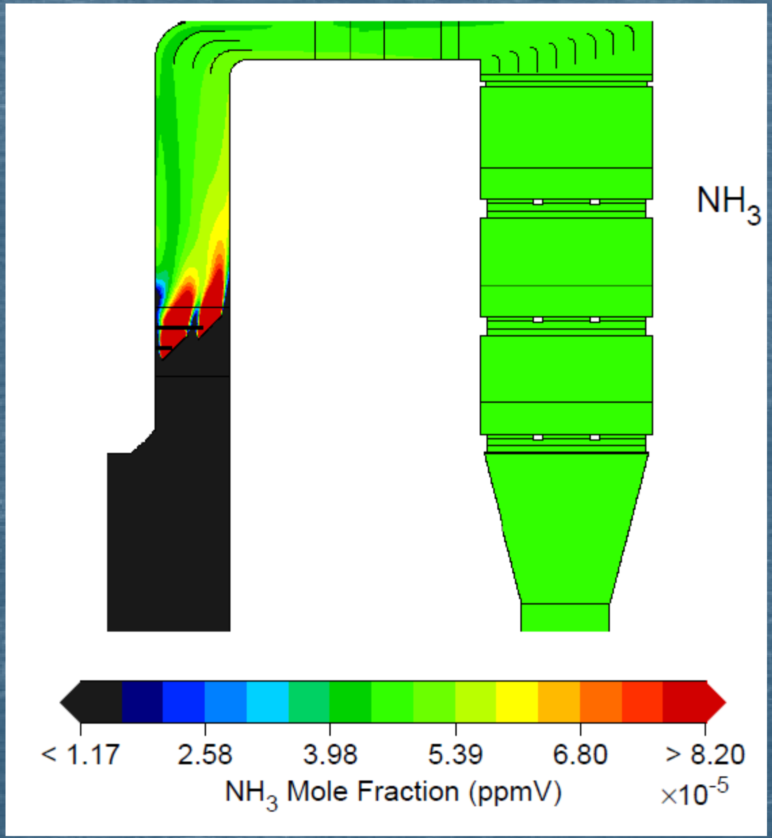


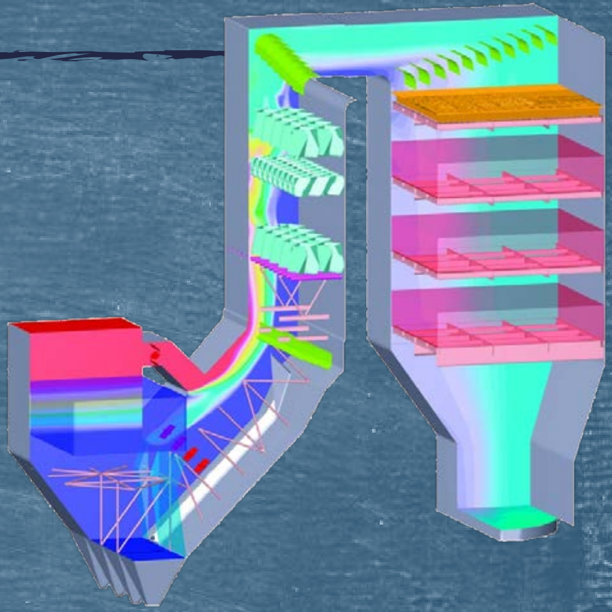
Applications: SCR

- Flow distribution
- Thermal mixing
- Ammonia mixing
- Ash deposition

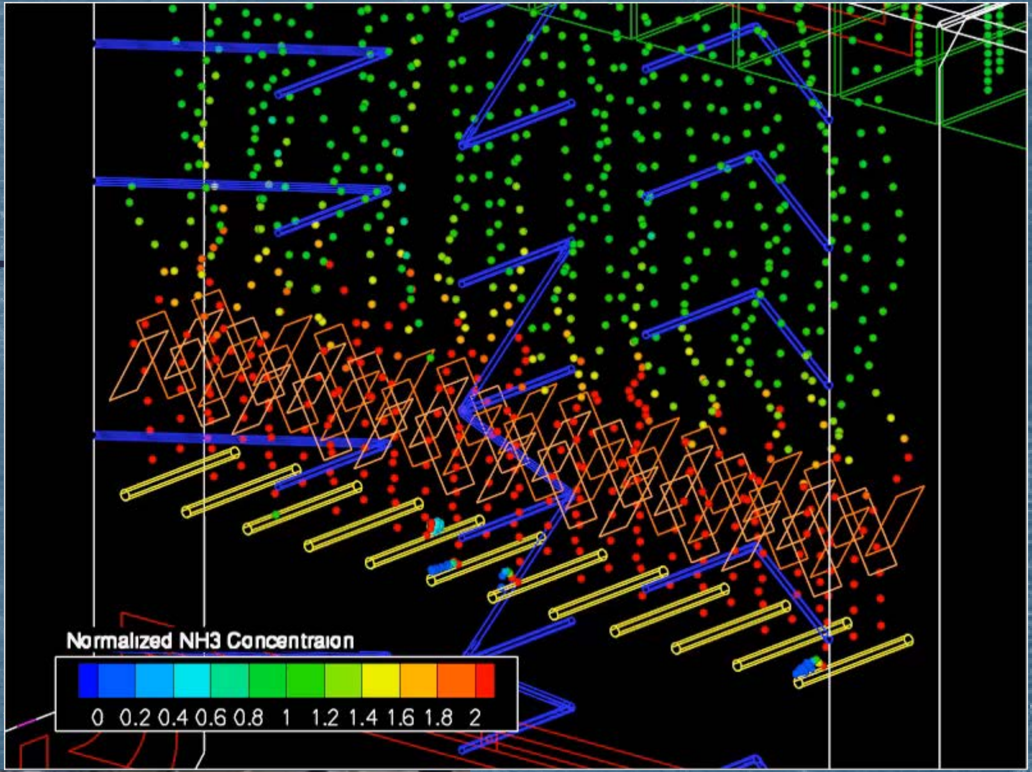


Applications: SCR



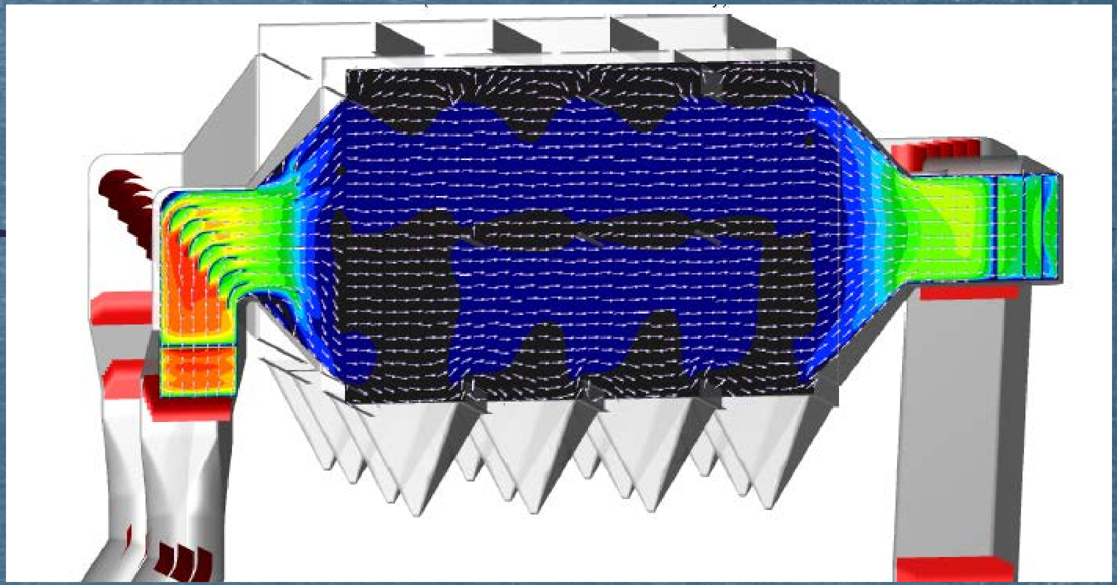


Applications: SCR

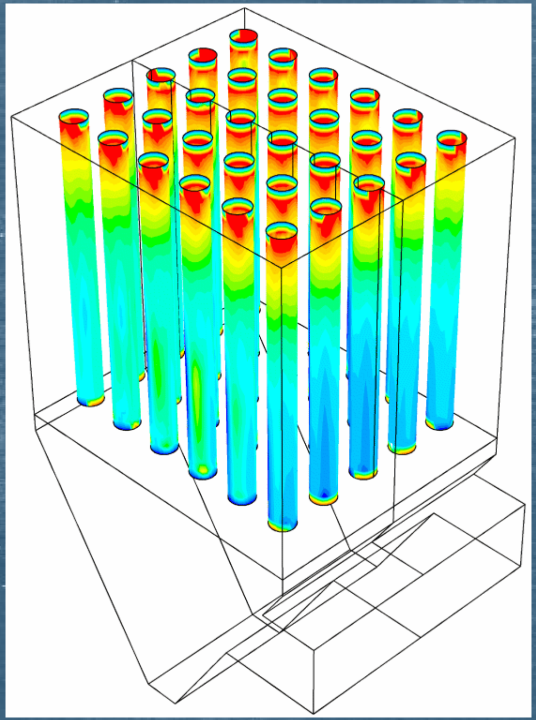


Airflow Sciences Corporation

Applications: ESP / FF



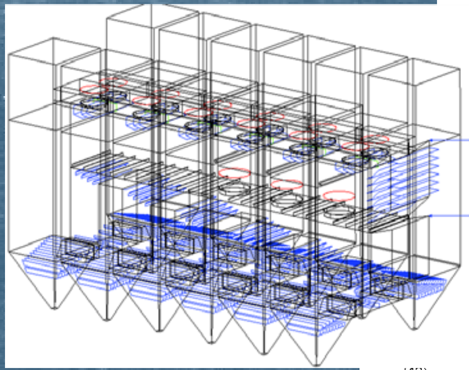
- Flow distribution
- Flow balance
- Pressure loss
- Thermal mixing
- Sorbent injection
- Ash deposition

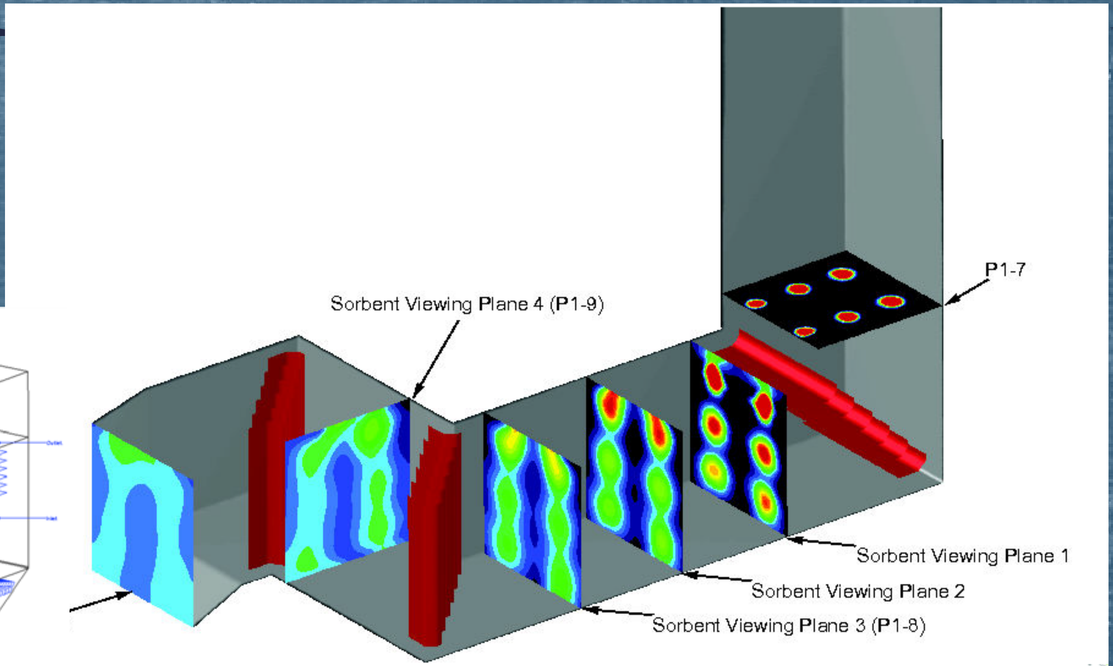


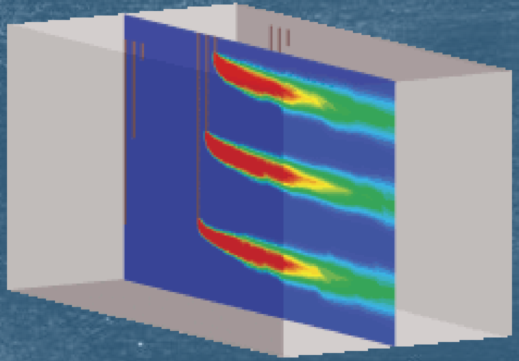
Airflow Sciences Corporation

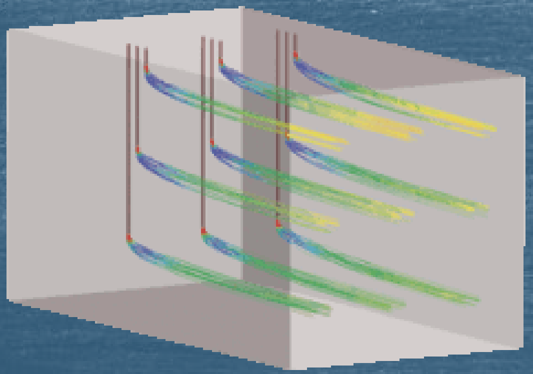
Applications: Sorbent Injection

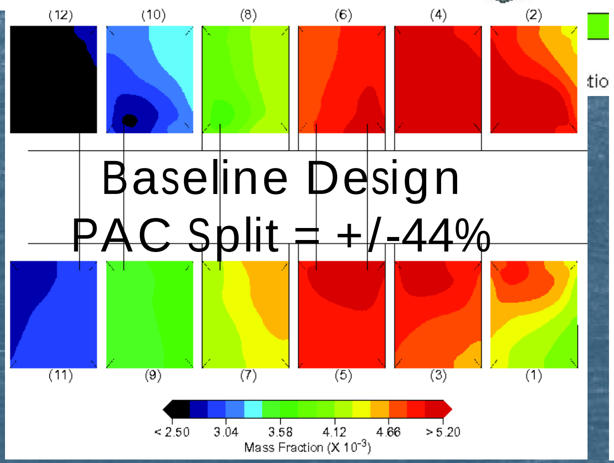
- ACI / DSI
- Lance placement / optimization
- Residence time
- Static mixing

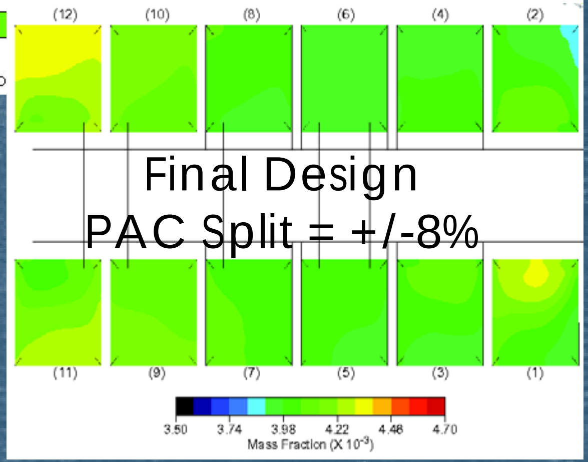






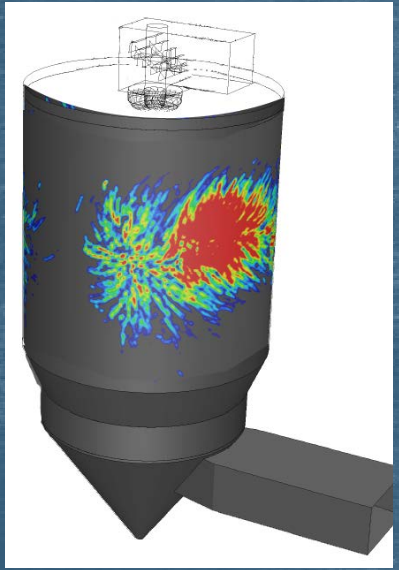


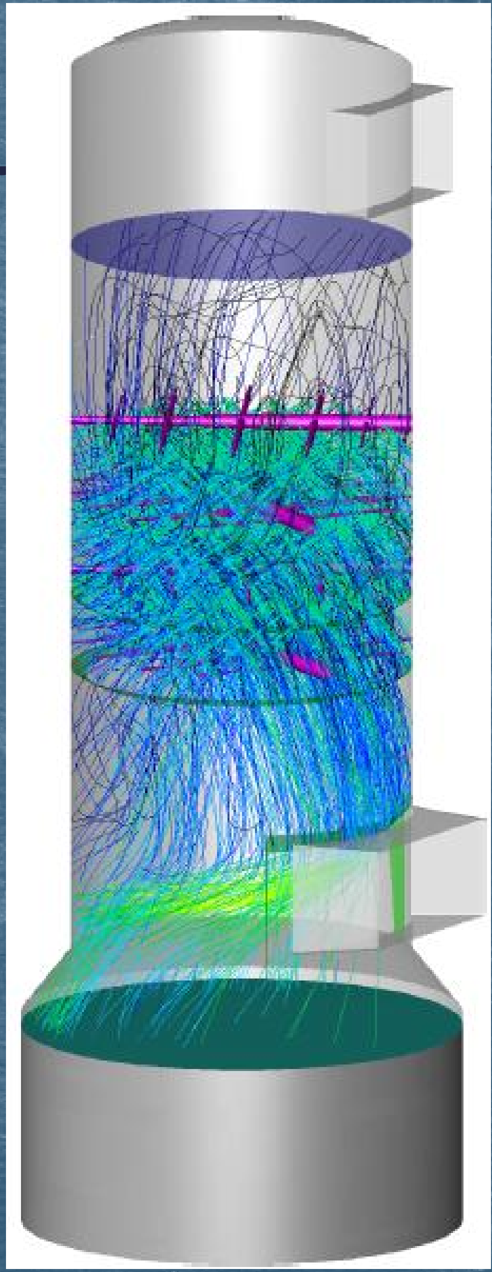




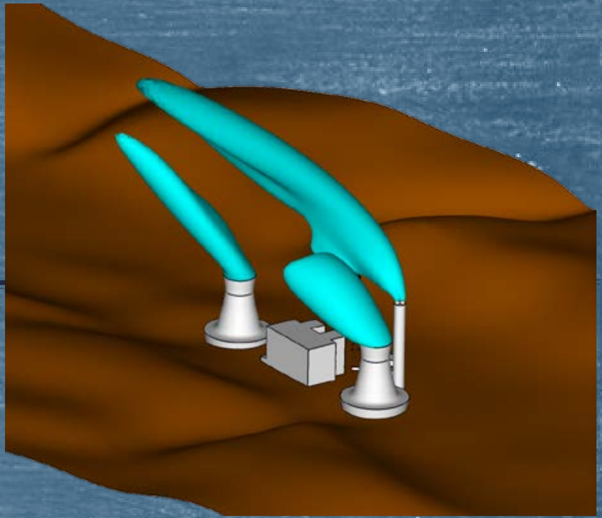
Applications: FGD

- Flow and droplet distribution
- Spray pullback into inlet duct
- Solids deposition

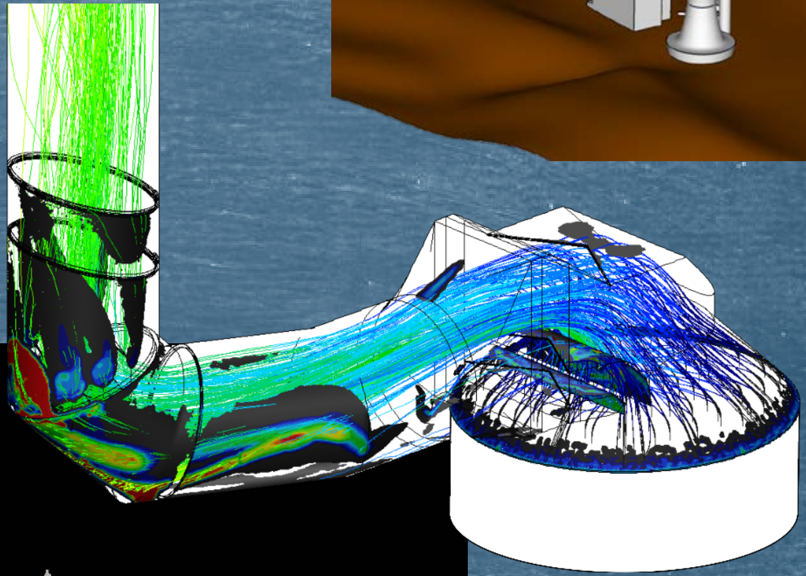


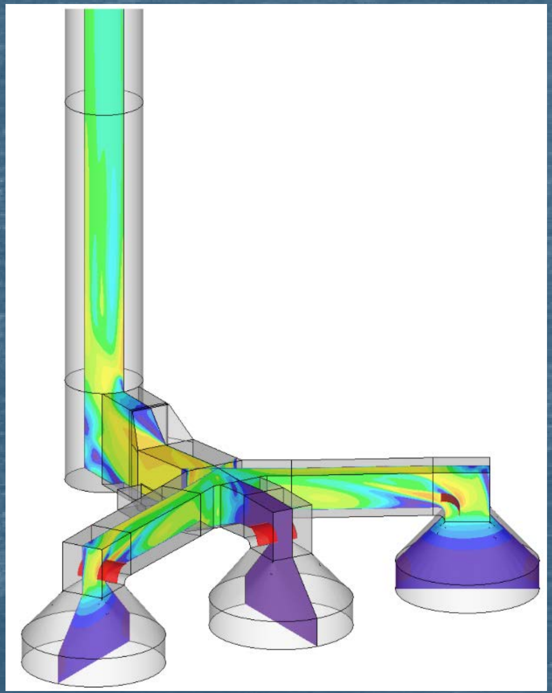


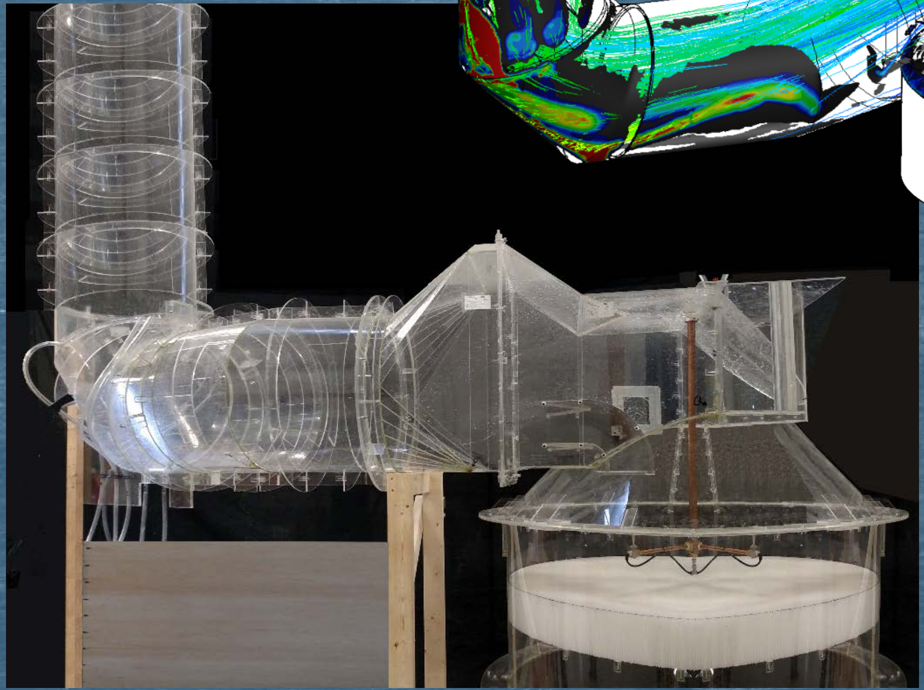
Applications: Stacks



- Flow distribution at CEMS plane
- Liquid collection
- Plume / droplet fallout



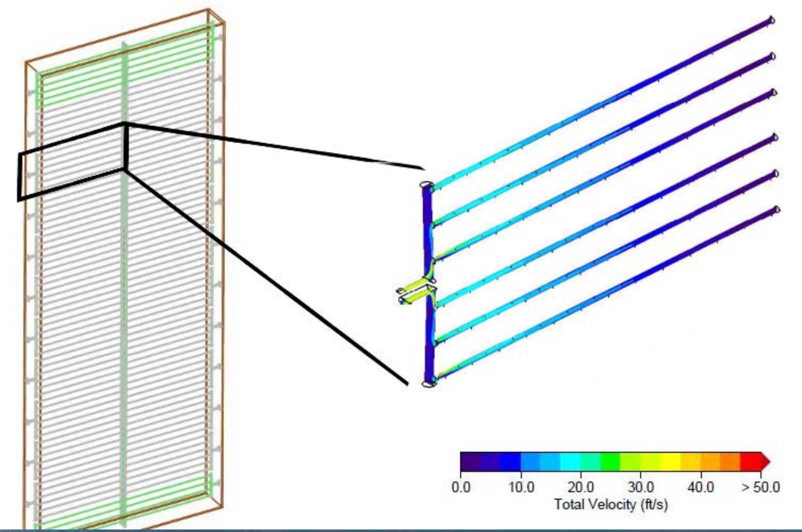


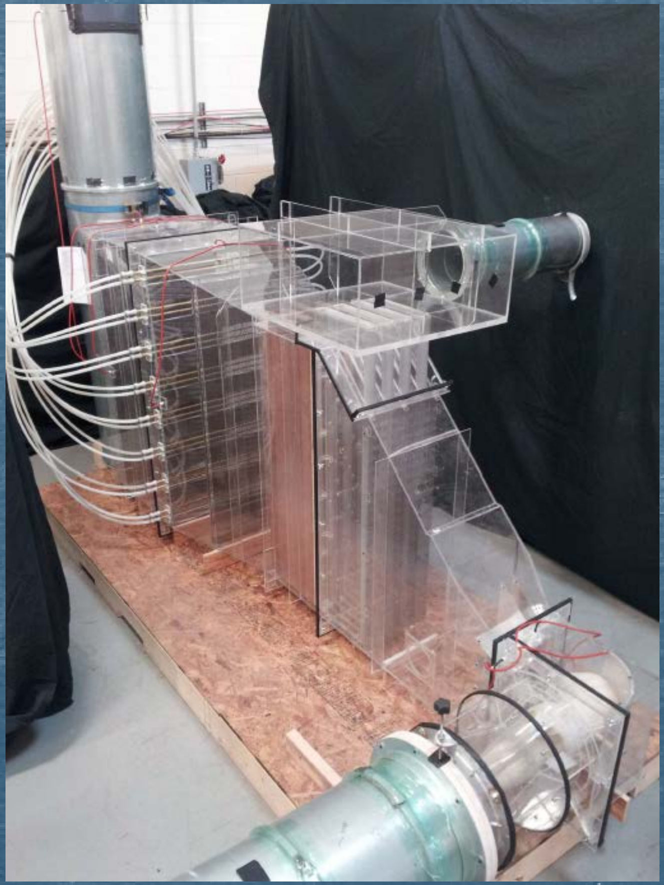


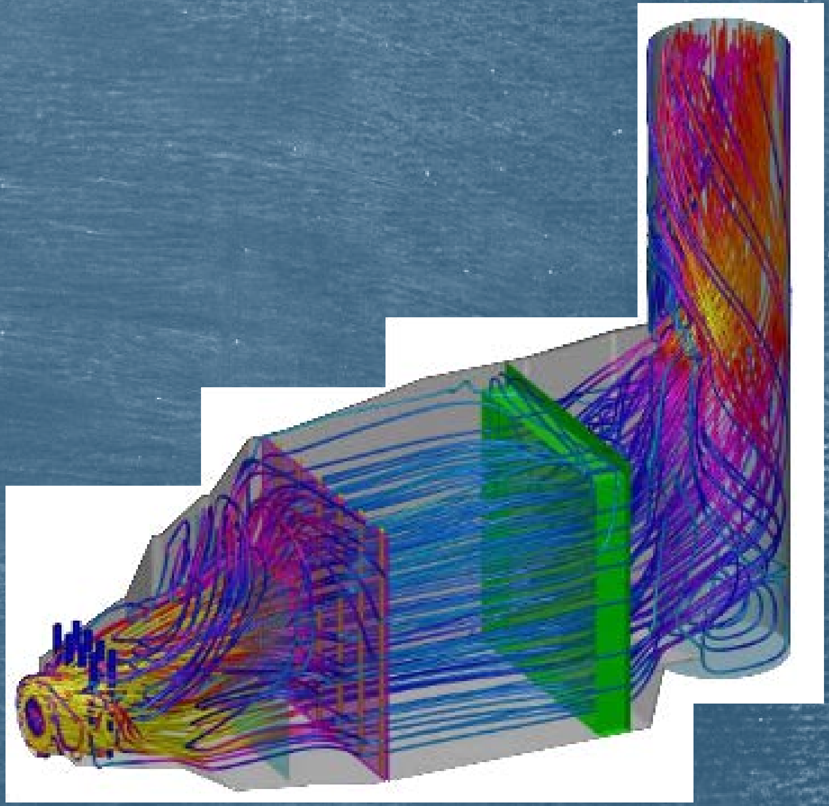
Airflow Sciences Corporation

HRSG and Simple Cycle – Flow Optimization

- Flow distribution
- Ammonia injection
- Pressure loss
- Thermal mixing







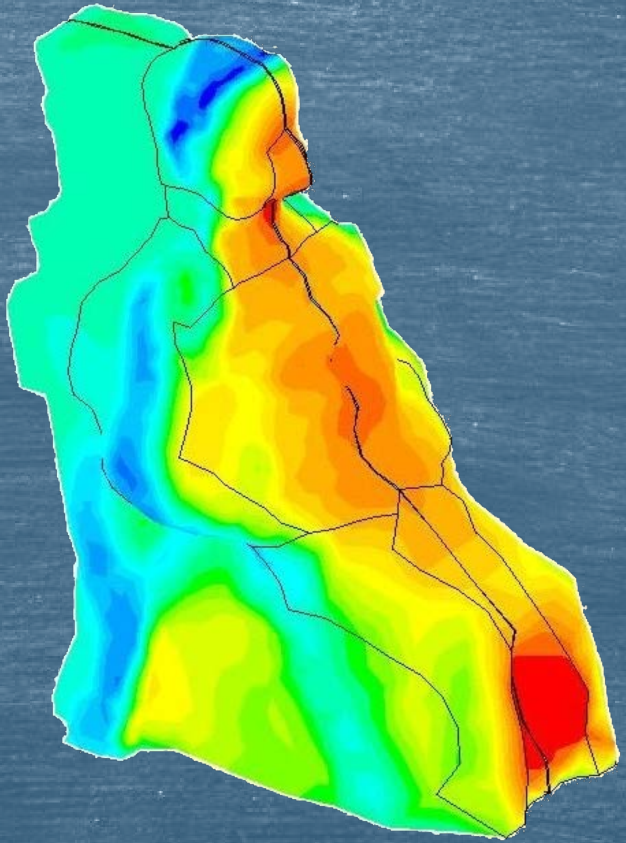
Airflow Sciences Corporation

Field Testing Support of Modeling

- Inlet conditions
- Correlation data
- Methods
  - 3-D Velocity Testing
  - Pressure loss
  - Particulate
  - Gas species concentration

Other Industries – Aerospace

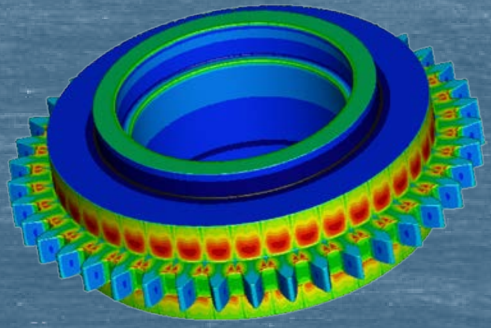
- Spacecraft
- Aircraft
- Missiles
- Engines

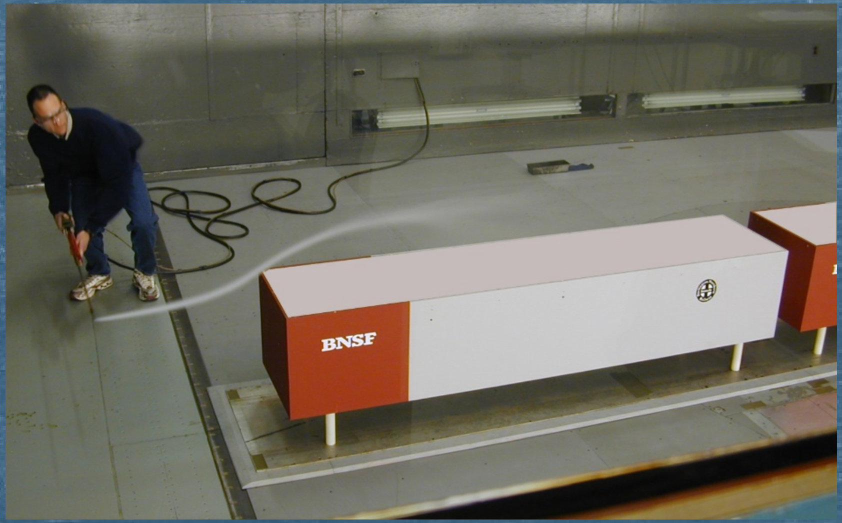


Airflow Sciences Corporation

Other Industries – Transportation

- Aerodynamics
- HVAC, cooling systems
- Engine components

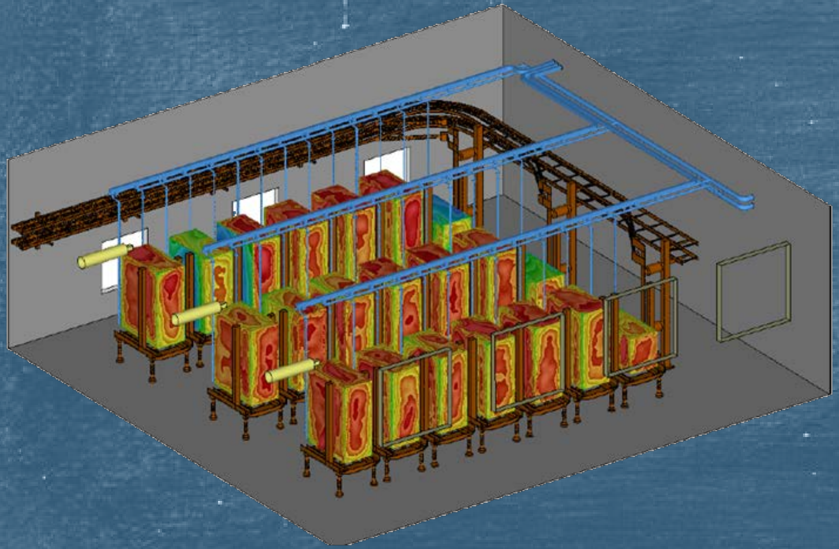


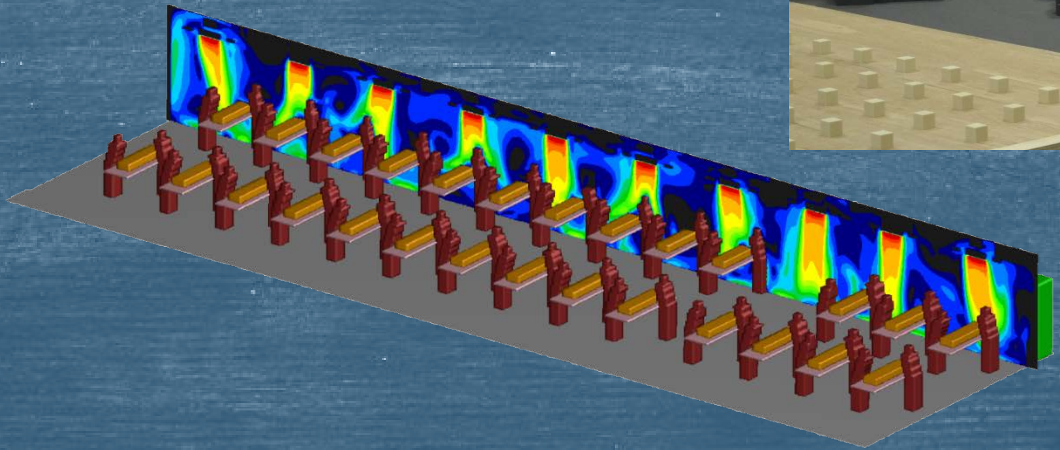


Airflow Sciences Corporation

Other Industries – Architectural

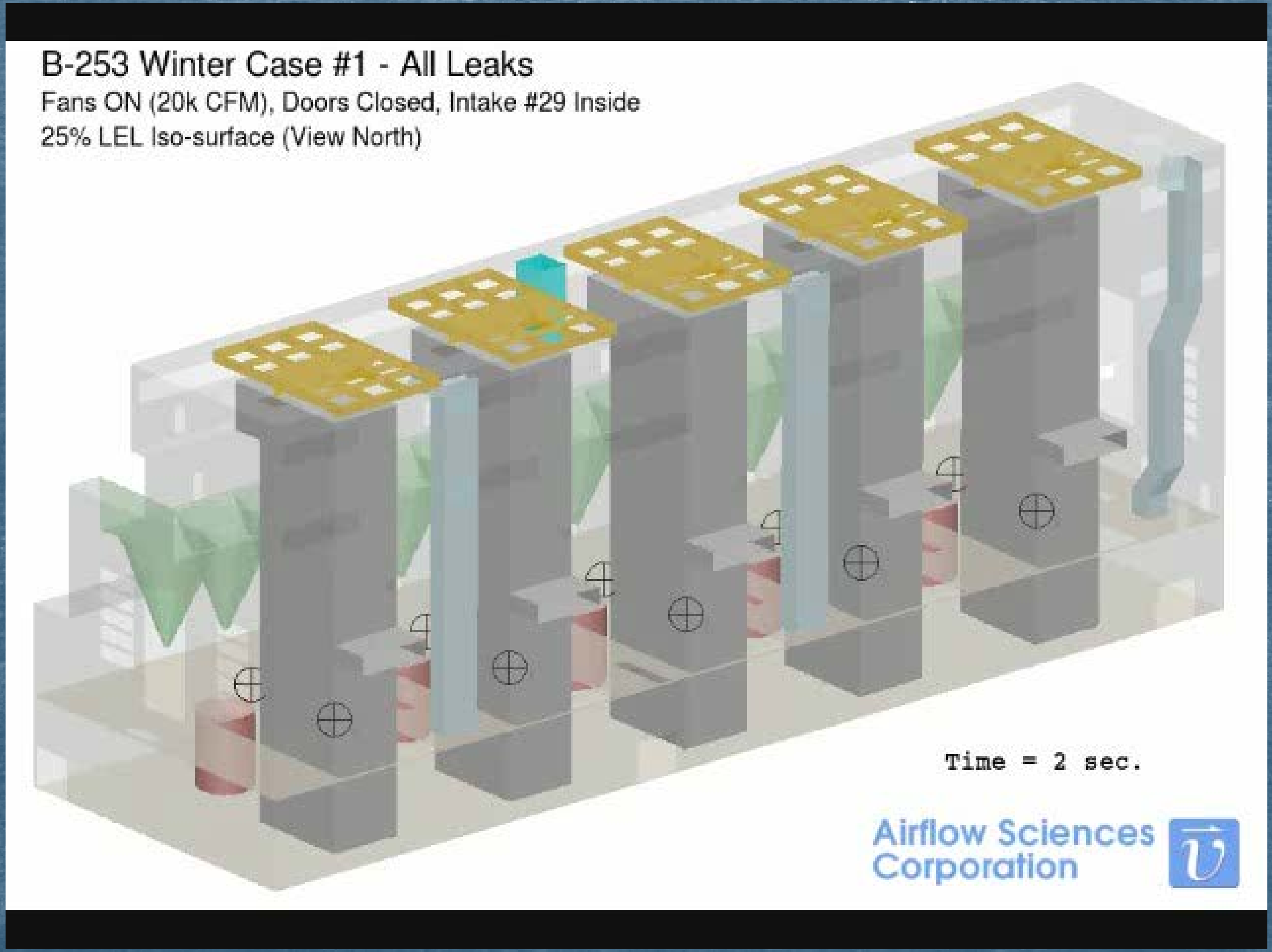
- HVAC
- Plume Dispersion
- Contamination





Airflow Sciences Corporation

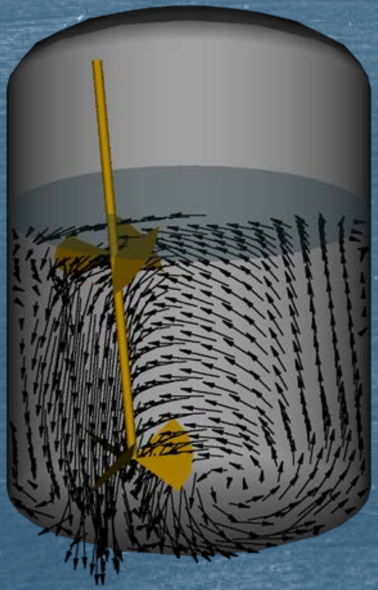
Other Industries – Architectural

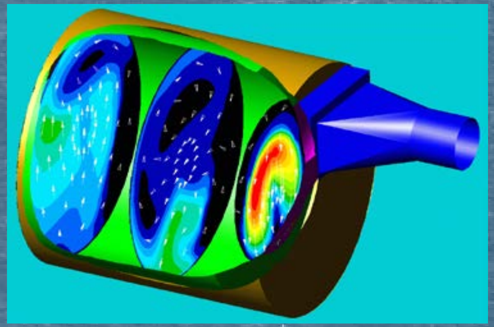


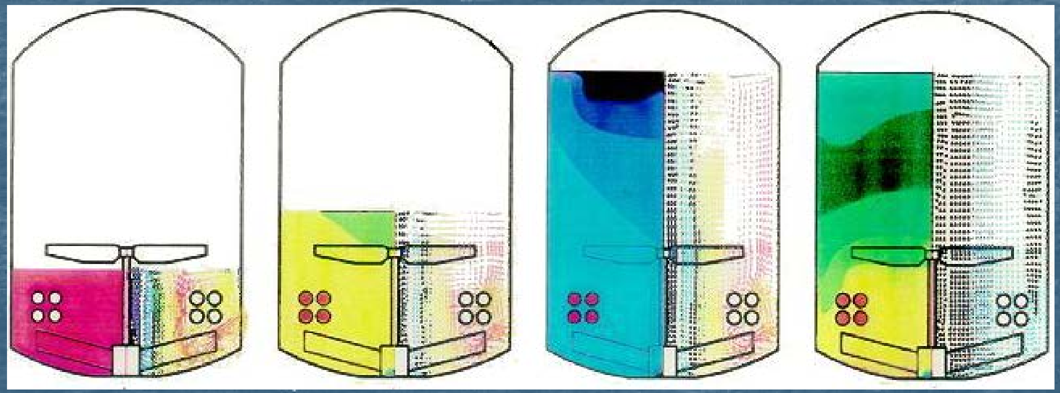
Airflow Sciences Corporation

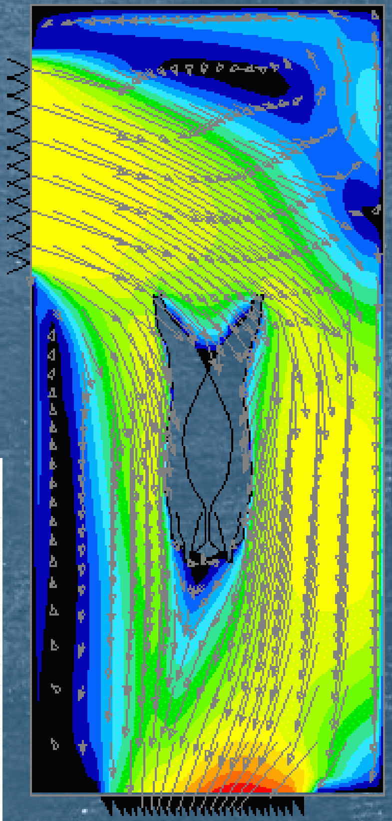
Other Industries – Food Processing

- Baking
- Toasting
- Roasting
- Drying
- Frying
- Chilling
- Coating
- Mixing









Airflow Sciences Corporation

Conclusions

- Gas flow patterns have a significant impact on the performance of many industrial components
- Analysis and design tools include field testing and flow modeling
- CFD and physical modeling are applied to a wide range of equipment and processes

Questions / Discussion

- Contact info:

Robert Mudry, P.E.

734-525-0300

rmudry@airflowsciences.com

Airflow Sciences Corporation