FLOW MODELING AS A TOOL FOR HRSG PERFORMANCE OPTIMIZATION

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HRSG Users Group
Houston, TX
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Airflow Sciences Corporation

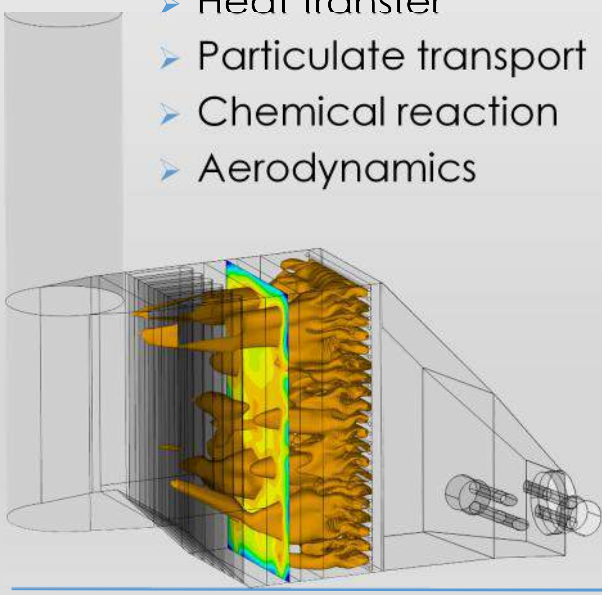
Azore® Software

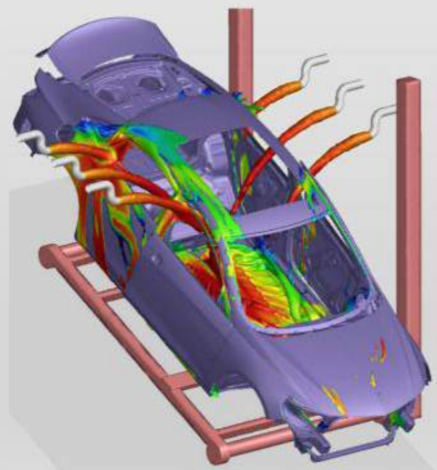
AGENDA

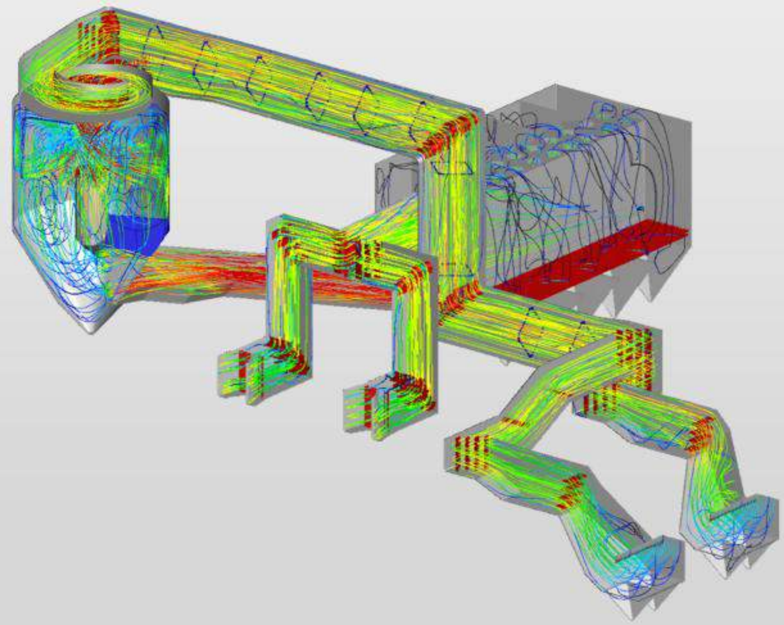
- Introduction
- Methodology
  - CFD Modeling
  - Physical Flow Modeling
  - Field Testing
- Gas Turbine Plant Design Objectives
  - Flow
  - Temperature
  - Ammonia
  - Pressure Drop
- Operating Plant Optimization
  - AIG Tuning
  - O&M
  - Troubleshooting
- CFD Case Studies
- Conclusions

AIRFLOW SCIENCES CORPORATION

- Providing engineering services to industry since 1975
- Specialize in developing cost-effective solutions to problems involving
  - Fluid flow
  - Heat transfer
  - Particulate transport
  - Chemical reaction
  - Aerodynamics

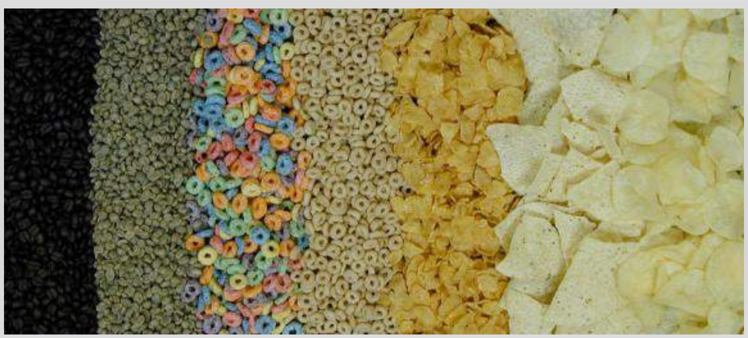


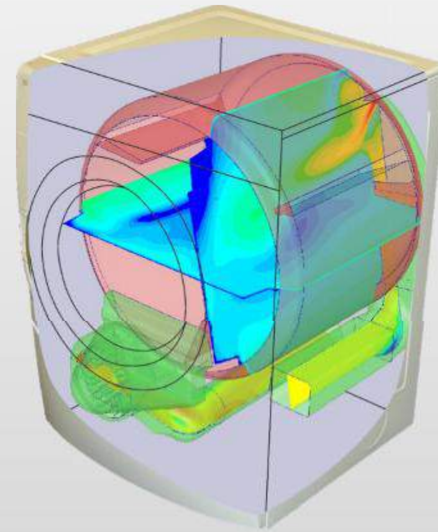


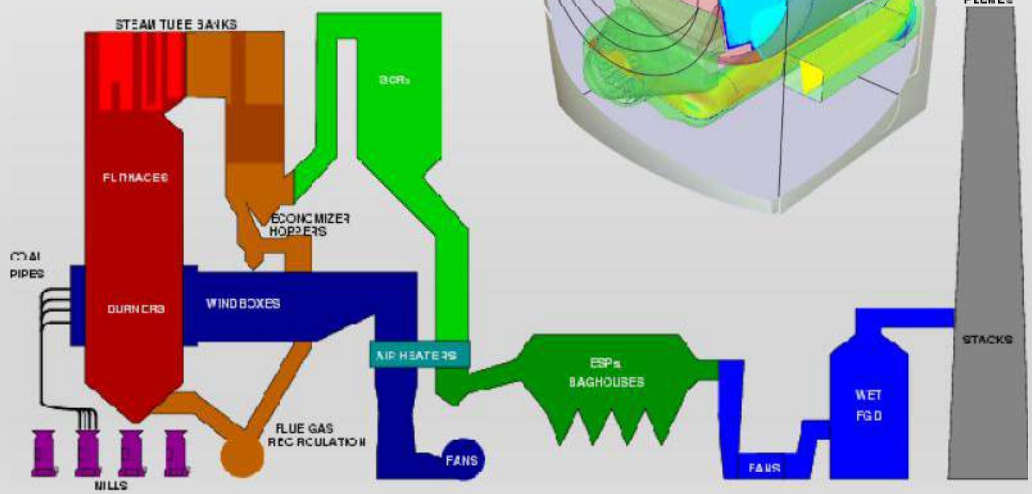


AIRFLOW SCIENCES CORPORATION

- Providing engineering services to industry since 1975
- ASC has experience in a wide variety of industries:
  - Power and Steam Generation
  - Metals Processing
  - Food Processing
  - Building Materials
  - Biotech
  - Consumer Products





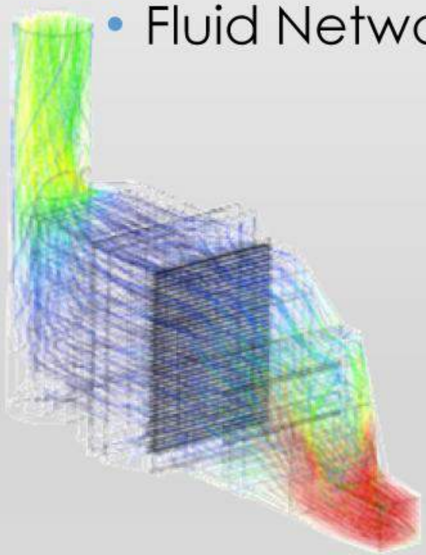


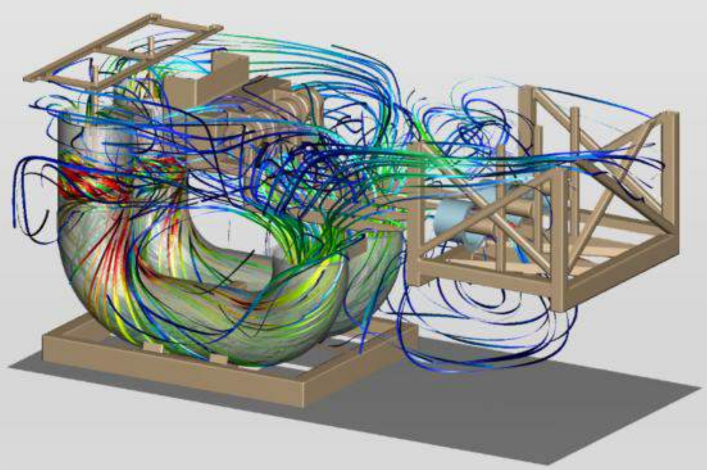
FLOW MODELING

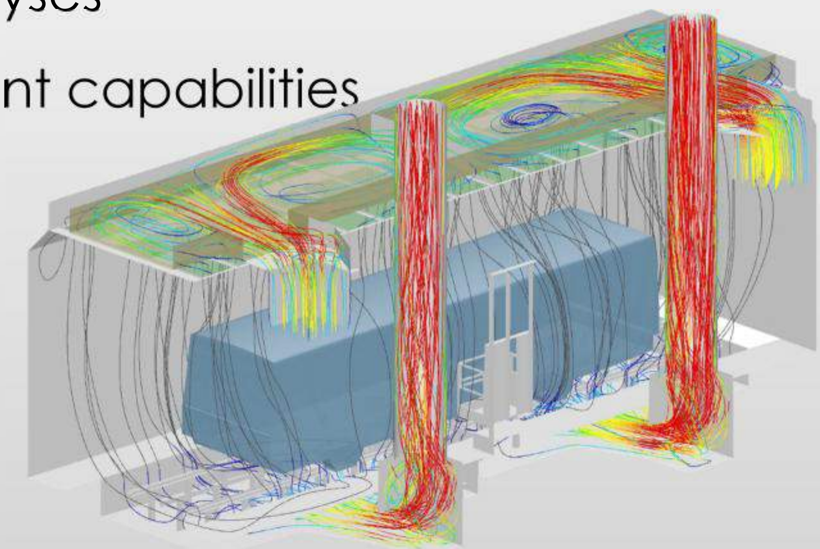
- Why perform flow modeling?
- Verify initial design of new equipment (required for most air pollution control applications)
- Conduct troubleshooting/optimization of existing equipment
- Trial and error design optimization without modeling can work, but…
  - Fixes can be costly
  - Results may not be as expected
  - New problems could develop
- Modeling can save time and $$ in the long run

COMPUTATIONAL FLUID DYNAMICS

- Azore® used for most CFD analyses
- ANSYS-Fluent used for balance of CFD analyses
- Many UDFs written by ASC to augment Fluent capabilities
- Fluid Network Modeling (in-house)

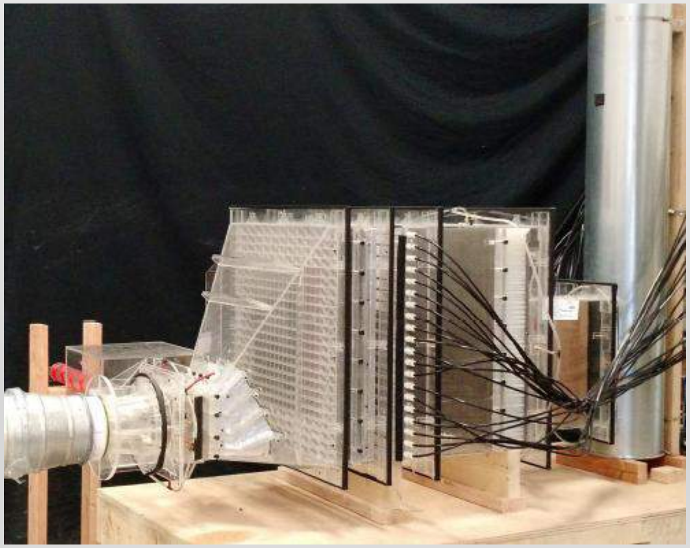






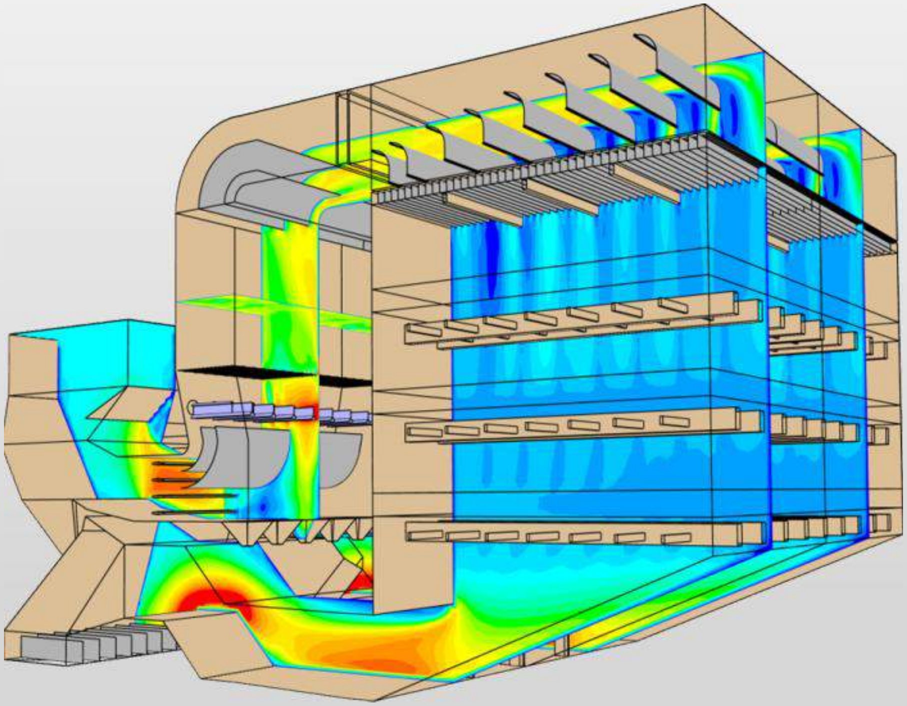
PHYSICAL FLOW MODELING

- Popular in the electric power generation industry
- Scale model constructed of large equipment
- Velocity and/or species concentration data collected



PHYSICAL FLOW MODELING

- Often combined with CFD for faster turnaround.



FIELD TESTING

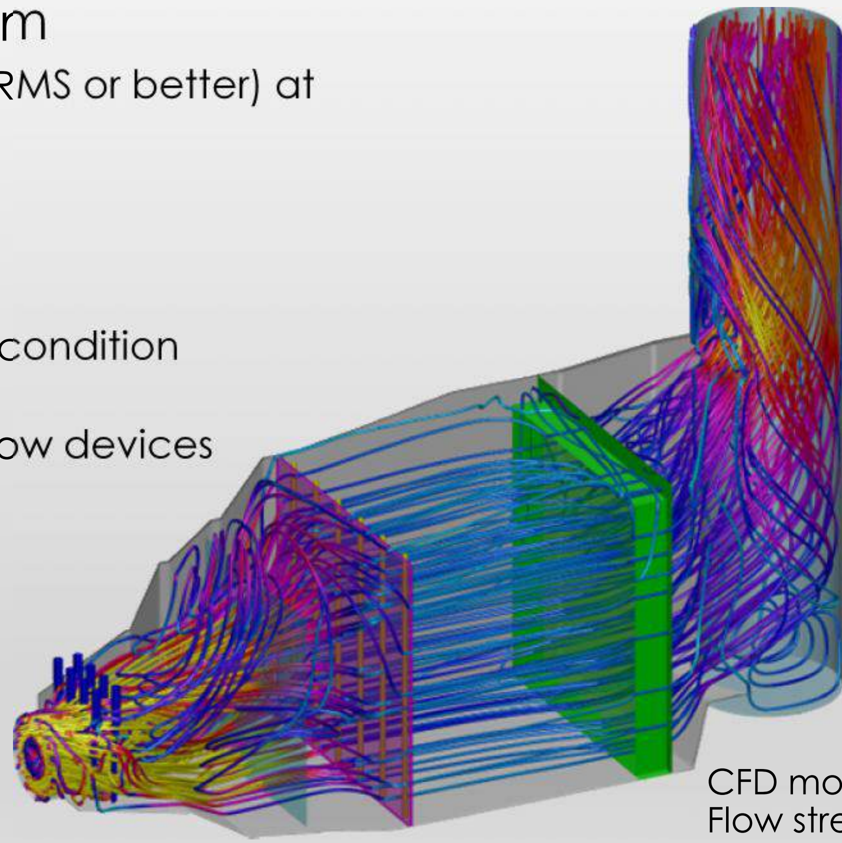
- Performance
  - Flow uniformity, mixing
  - Combustion optimization
- O&M Costs
  - Pressure drop
  - Ammonia costs
- Maintenance
  - Erosion / corrosion
  - Pluggage
  - Vibration
- Compliance
  - Stack testing
  - CEMS calibration

HRSG DESIGN CONSIDERATIONS

- General Design Considerations
  - Gas turbine plants come in many sizes and flavors
    - Simple cycle
    - HRSG / Combined cycle
    - With / without catalyst
    - With / without tempering air
    - With / without duct burner
    - Footprint
    - Site arrangement
  - Performance optimization involves careful balance of competing goals
    - Power / steam output
    - Emissions
    - Pressure drop
    - Ammonia consumption
    - O&M costs

DESIGN OBJECTIVES

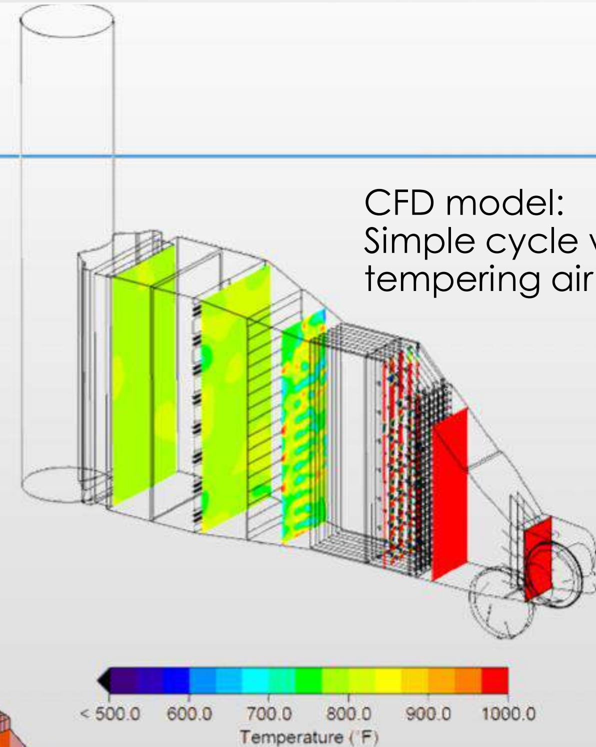
- Gas Flow Through System
  - Uniform velocity profile (15% RMS or better) at
    - CO/NOx/Dual Action Catalyst
    - AIG
    - Tube banks
    - Stack CEMs
  - Not easy given that the inlet condition resembles a tornado
  - Requires intricate design of flow devices
    - Baffles
    - Straighteners
    - Perforated plates
    - AIG



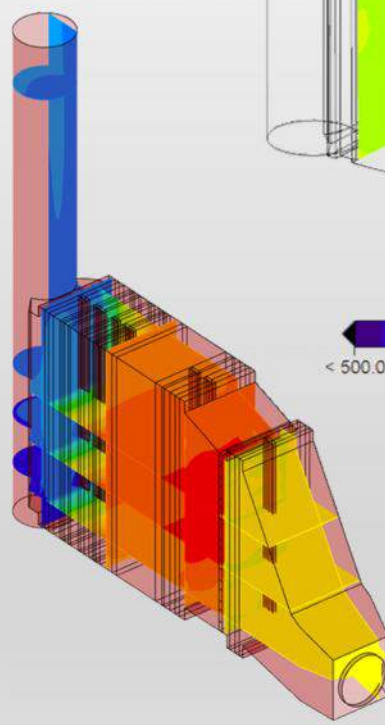
CFD model
Flow streamlines

DESIGN OBJECTIVES

- Gas Temperature
  - Heat transfer to tube banks is very important
    - Performance
    - Tube life
  - Duct burner can influence thermal performance
  - Uniformity at catalyst (CO, NOx) affects performance
    - Typical goal +/-50 F
    - Can be challenging if significant amount of tempering air
    - Temperature is not necessarily uniform exiting the turbine



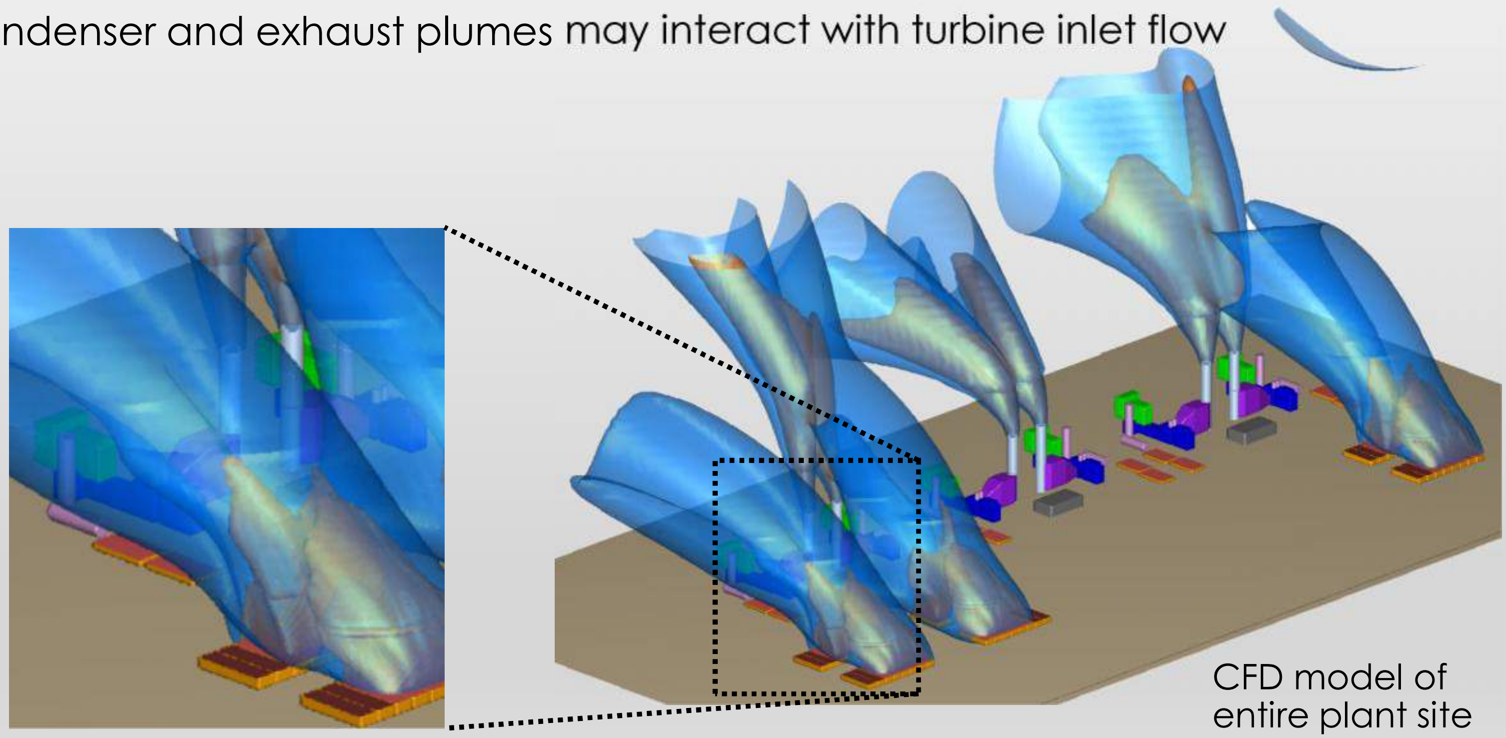
CFD model:
Simple cycle with tempering air



CFD model:
HRSG

DESIGN OBJECTIVES

- Turbine Inlet Conditions
  - Plant layout can affect turbine inlet conditions
  - Condenser and exhaust plumes may interact with turbine inlet flow



CFD model of
entire plant site

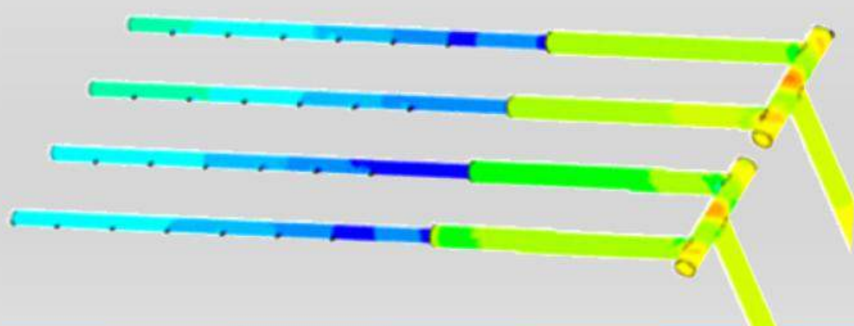
DESIGN OBJECTIVES

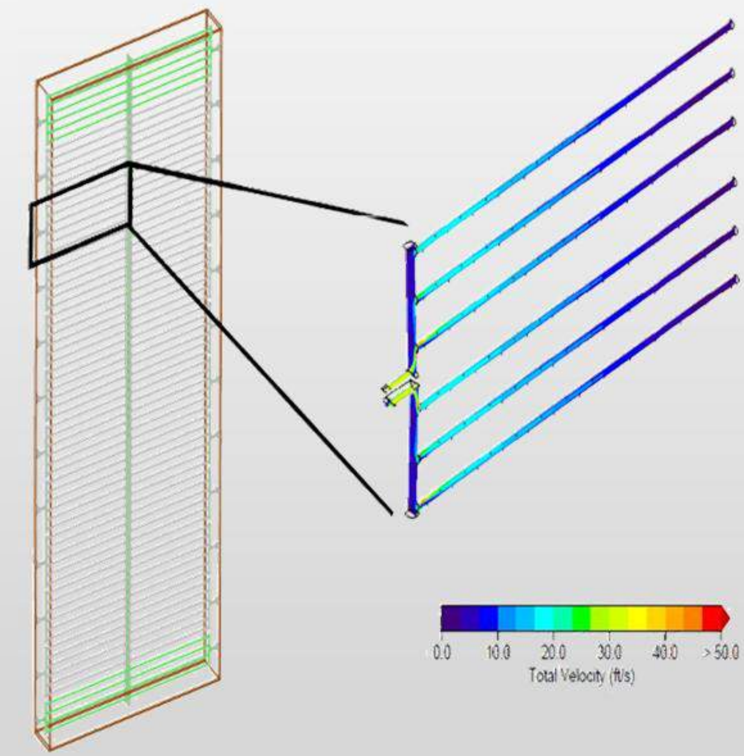
- Ammonia Injection
  - The key factor in deNOx performance and ammonia slip
  - Goal is uniform concentration (ammonia-to-NOx ratio) at SCR catalyst
  - General target is 5% RMS or better
  - Optimization requires balance of competing goals
    - Velocity profile at AIG
    - Uniform injection from AIG nozzles
    - Mixing effectiveness
    - Turbulence
    - Pressure drop
  - AIG design is not straight-forward
    - Residence time for mixing is limited
    - Temperature heat up can affect distribution
    - Updated design practices have led to advances
    - Older systems likely have room for improvement

AIG piping

DESIGN OBJECTIVES

- Conventional Ammonia Injection Grid
  - General goal is to inject equal ammonia from each nozzle to within 2% or better
  - Correct sizing of header ID, lance ID, and nozzle diameters is important
  - Need to consider heat transfer from gas side to the internal pipe flow; this can influence the balance between nozzles <u>significantly</u>
  - The presence of tuning valves cannot always fix a poor AIG header/lance design

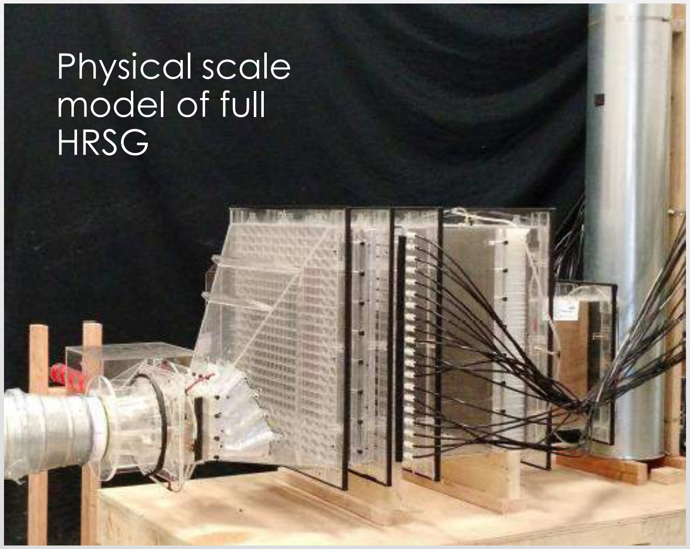




Detailed CFD model of AIG header and lances

DESIGN OBJECTIVES

- Ammonia Distribution at SCR
  - Need to ensure sufficient number of lances/nozzles to cover the cross section
  - Depends on residence time to catalyst and turbulence intensity
  - Additional mixing may be required depending on geometry details
    - Static mixer after AIG
    - Turbulence generators integrated with AIG
  - Determined through modeling, validated via testing



AIG lance detail

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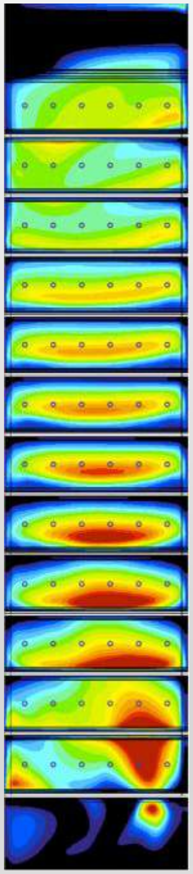
DESIGN OBJECTIVES

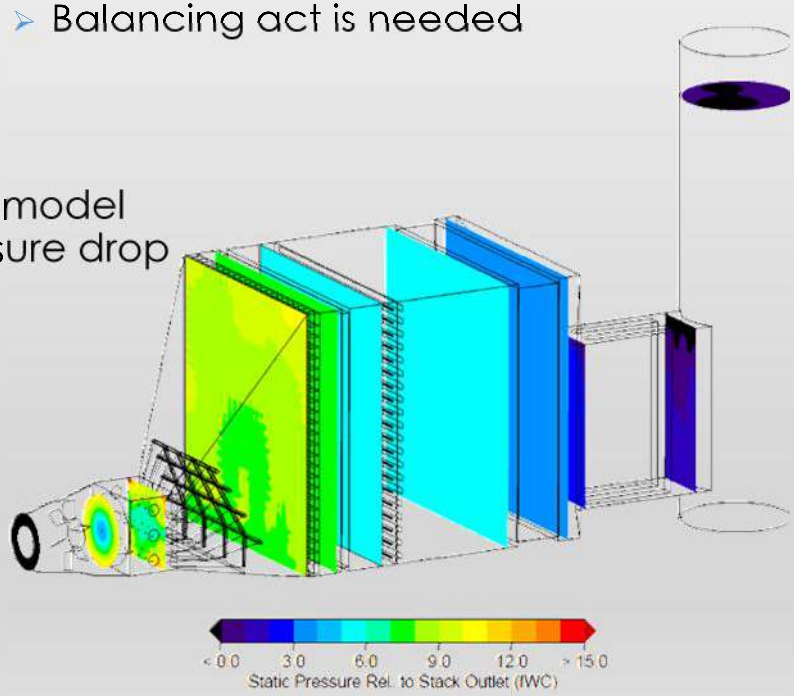
- Optimize Thermal Performance/Reduce Tube Failure
  - Poor flow/temperature uniformity can have detrimental effects on tubebank thermal performance.
  - Stratified or overly turbulent flow can lead to structural failures.
  - Optimizing the velocity uniformity into the tubebank can have significant positive effects.

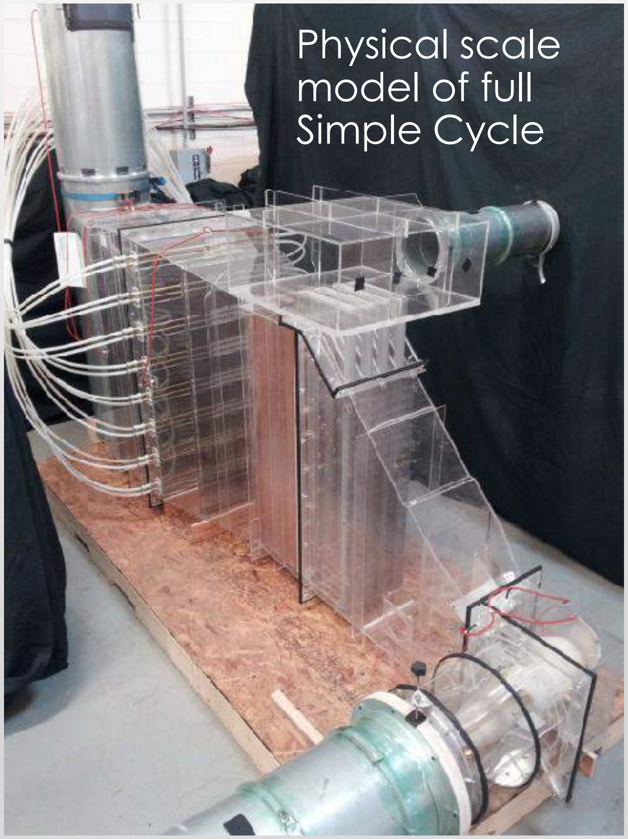


DESIGN OBJECTIVES

- Pressure Drop
  - Minimize
  - This goal competes with all the other goals
  - Balancing act is needed

CFD model
pressure drop





GAS TURBINE OPTIMIZATION

- AIG tuning
  - Perform periodically
  - If possible install fixed gas sampling grid
- Inspections
  - Gaps in catalyst seals can lead to NOx bypass

Gap in SCR catalyst seal

AIG tuning for SCR

GAS TURBINE TROUBLESHOOTING

- Velocity testing
  - EPA Method 2F using 3D pitot probe
  - Standard or water-cooled probe depending on location

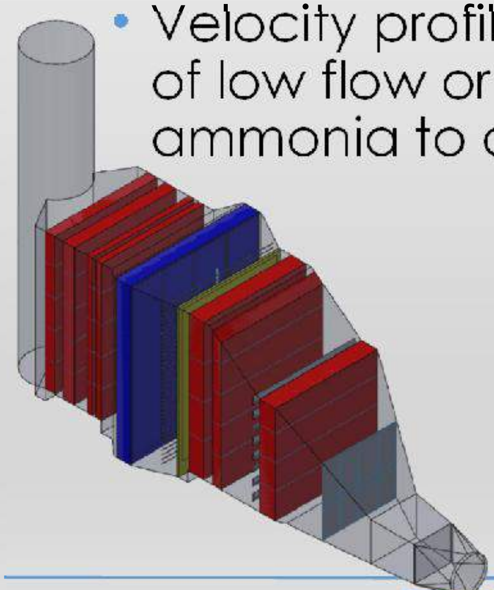
Turbine outlet flow profiling
(water cooled 3D probe)

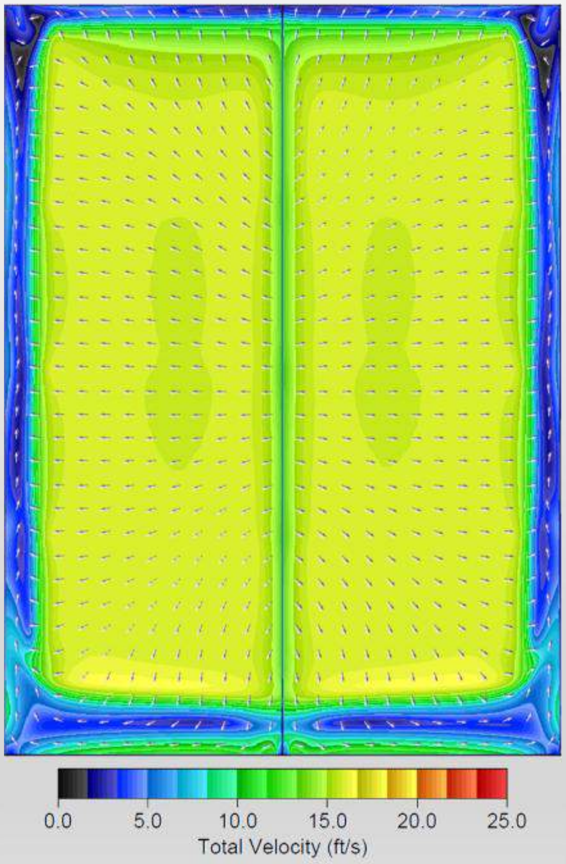
AIG inlet flow measurement

3DDAS test system

CASE STUDY – AIG OPTIMIZATION

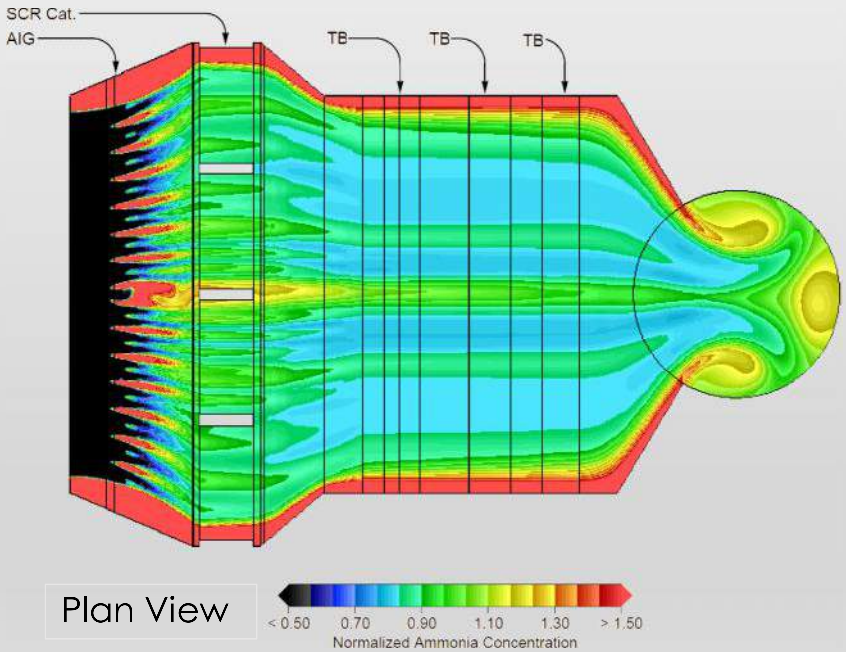
- HRSG unit – 501F Turbine
- Utility struggling with very poor ammonia distribution at the SCR catalyst and high ammonia slip.
- Velocity profile at the AIG indicates large areas of low flow or recirculation, which would allow ammonia to accumulate.

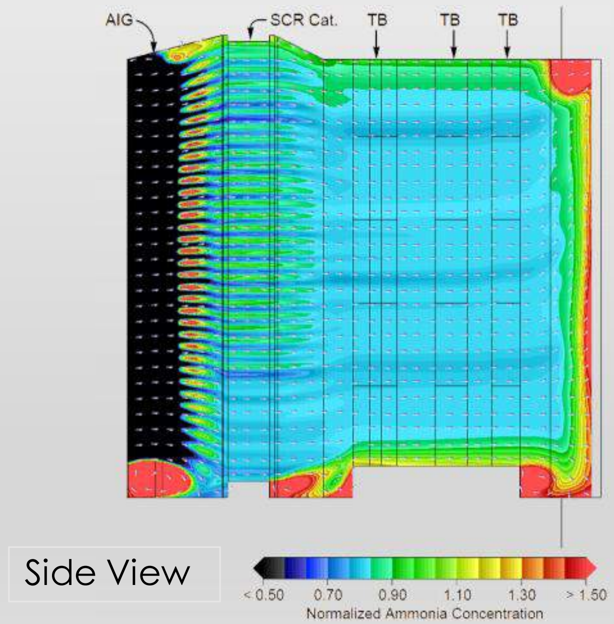


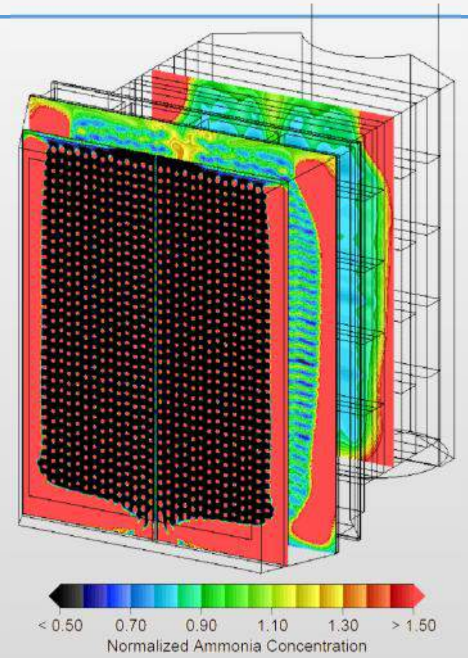


CASE STUDY – AIG OPTIMIZATION

- CFD model indicates very high ammonia concentrations near the walls of the unit.
- Ammonia RMS of 59% at the SCR catalyst face.

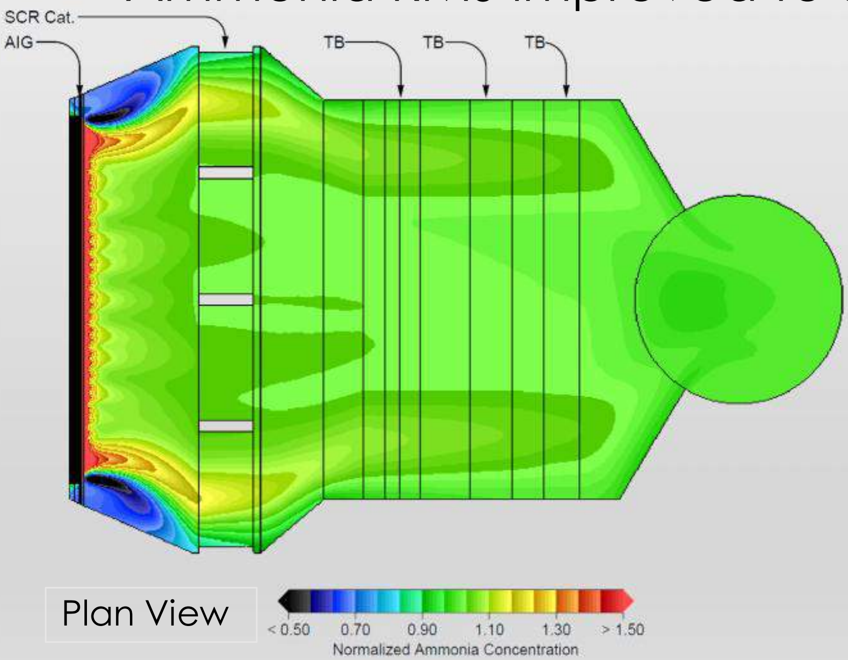




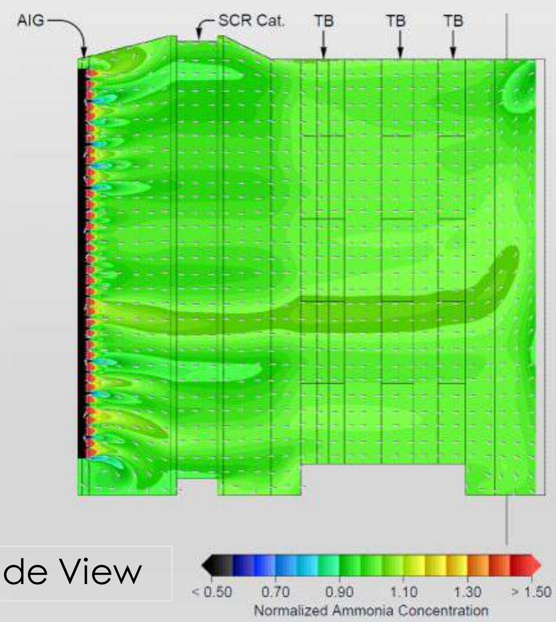


CASE STUDY – AIG OPTIMIZATION

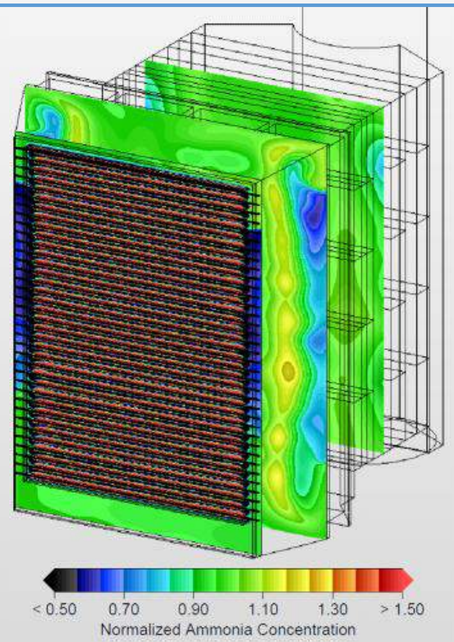
- AIG modifications/baffling added to improve mixing an distribution.
- Ammonia RMS improved to 8% at the catalyst face.



Plan View



Side View



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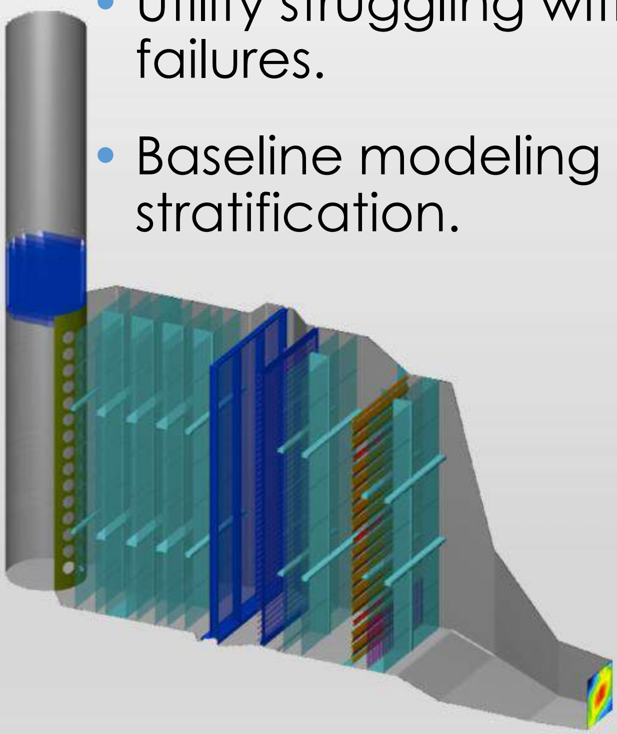
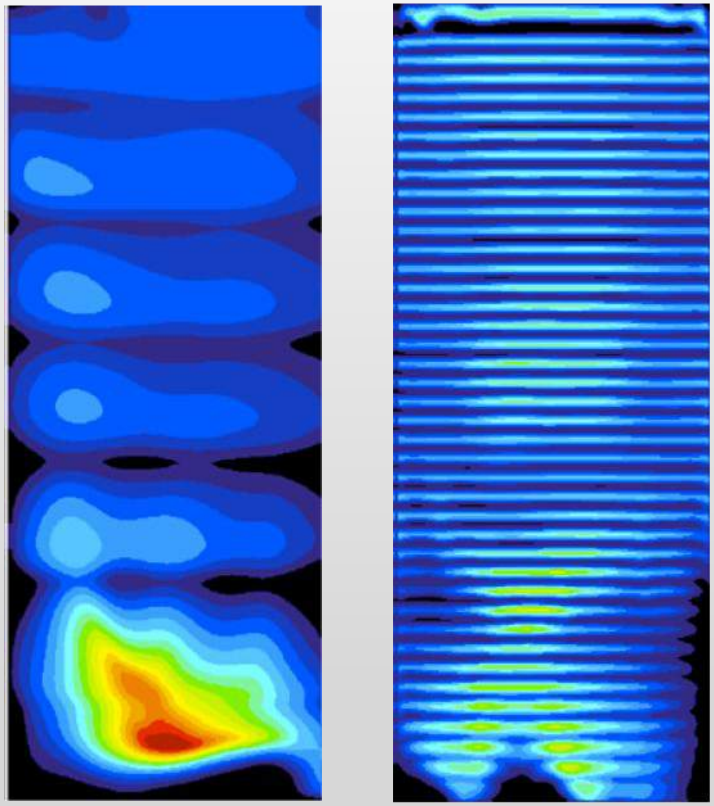
CASE STUDY – TUBEBANK FORCE REDUCTION

- HRSG Unit – 7FA Turbine
- Utility struggling with thermal performance and tube failures.
- Baseline modeling indicates significant velocity stratification.



CASE STUDY – TUBEBANK FORCE REDUCTION

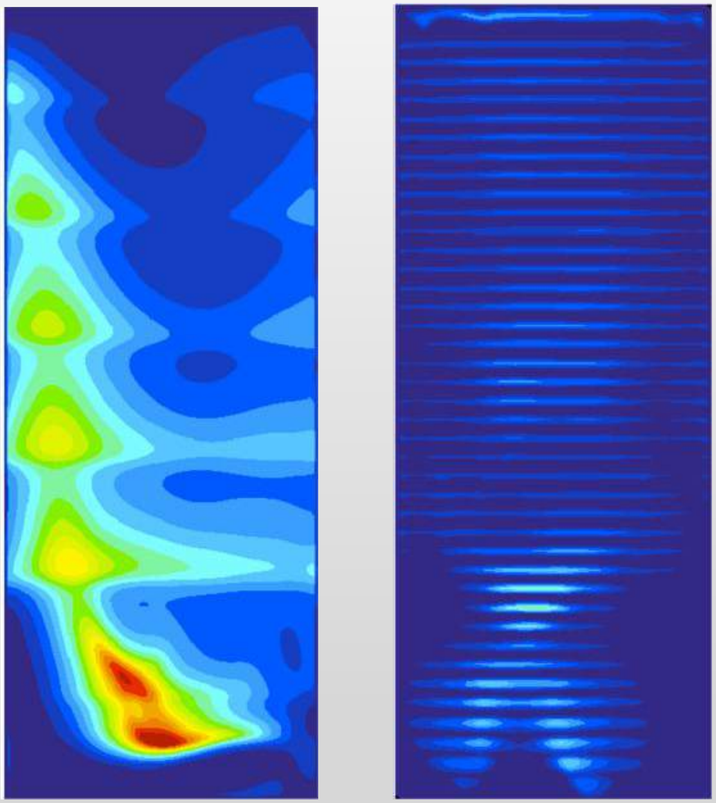
- Turning vane sets and upstream perf plate were optimized, resulting in much improved velocity uniformity.



Baseline Design
Axial Velocity

CASE STUDY – TUBEBANK FORCE REDUCTION

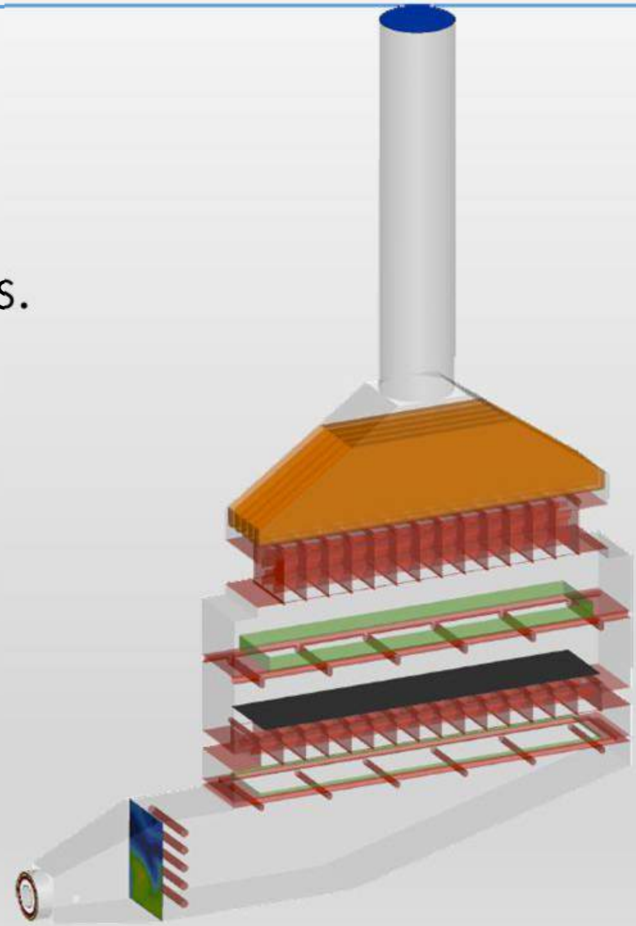
- Aerodynamic forces on the lower tubes reduced significantly.
- Improved mass flow distribution contributed to improved thermal performance as well.



Baseline Design
Aerodynamic Forces

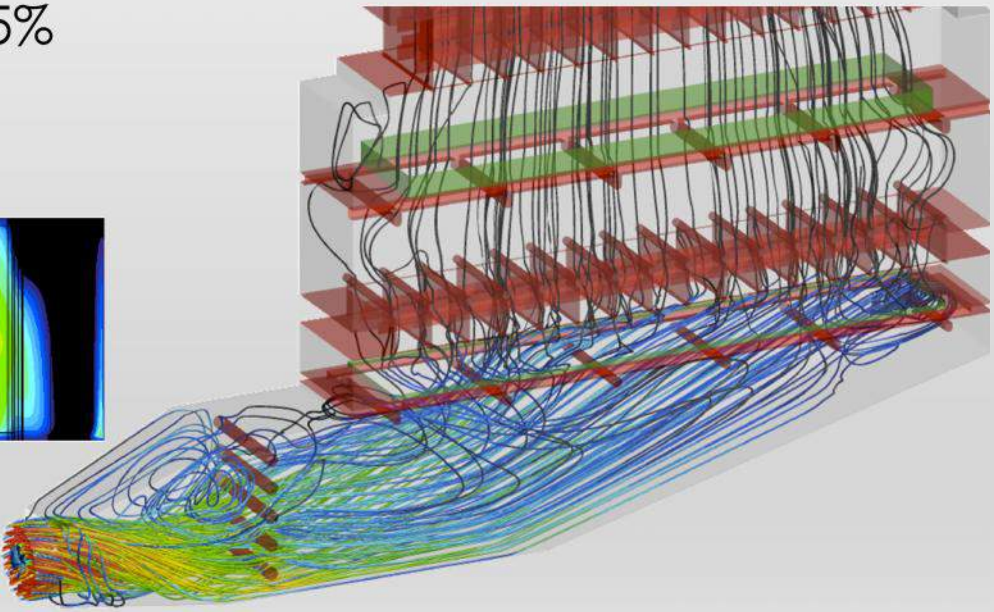
CASE STUDY – THERMAL OPTIMIZATION

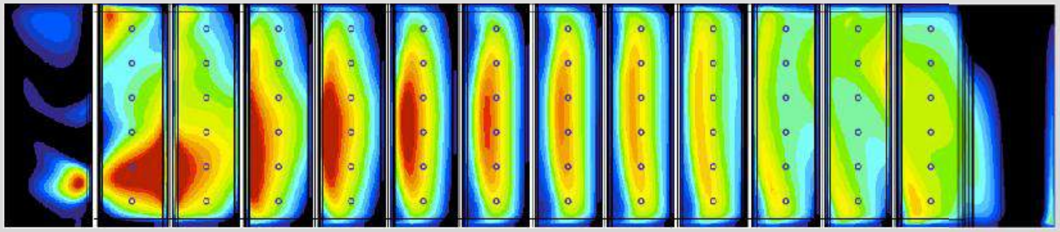
- OTSG Unit – LM6000 Turbine
- Pre-installation modeling performed to optimize unit design and flow control devices.



CASE STUDY – THERMAL OPTIMIZATION

- Baseline results, with no flow control devices, show a large recirculation zone and poor velocity uniformity at the tubebank.
- Velocity RMS at the tubebank = 25%

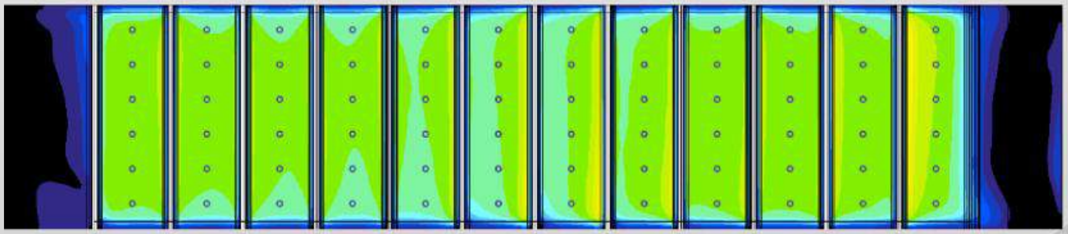




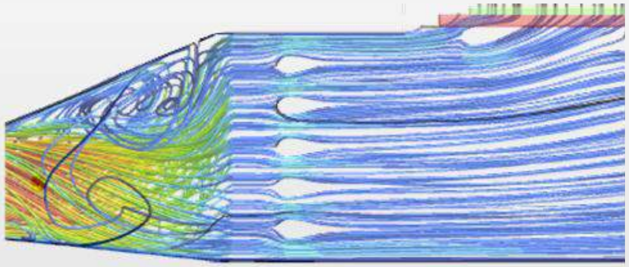
Plan View – Tubebank Inlet Velocity

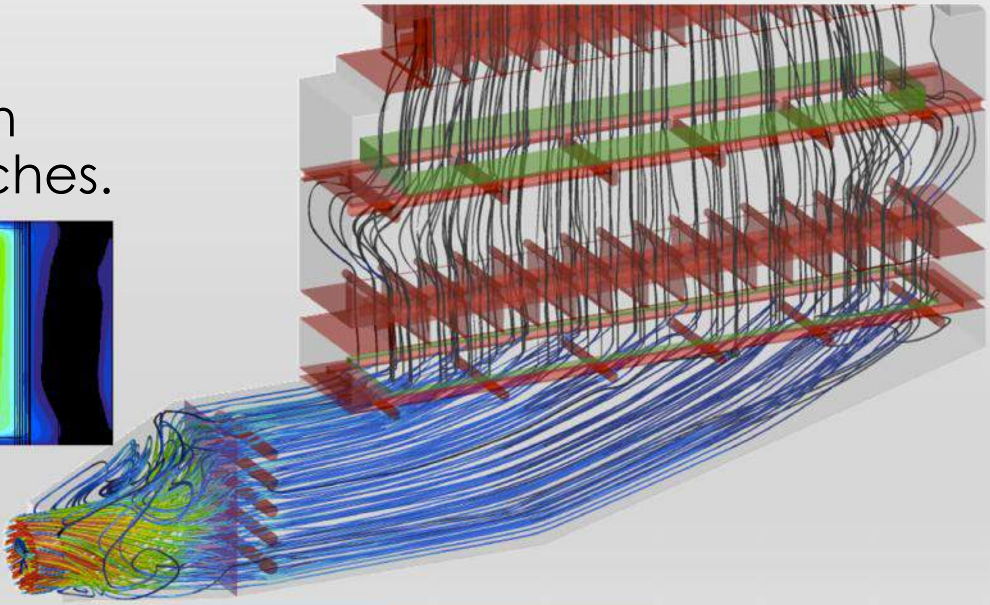
CASE STUDY – THERMAL OPTIMIZATION

- Perforated plate set added to provide more uniform side-to-side velocity distribution.
- Velocity RMS at the tubebank reduced to 4%.
- Improvements made to the design prior to installation, saving headaches.



Plan View – Tubebank Inlet Velocity





CONCLUSIONS

- There are many parameters that affect HRSG performance
- Need optimized design for flow, temperature, ammonia, and pressure drop
  - CFD modeling
  - Scale physical modeling
- Good O&M practices
  - AIG tuning should be done regularly
  - Inspect and maintain AIG, SCR, and seals

CONTACT INFORMATION

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