

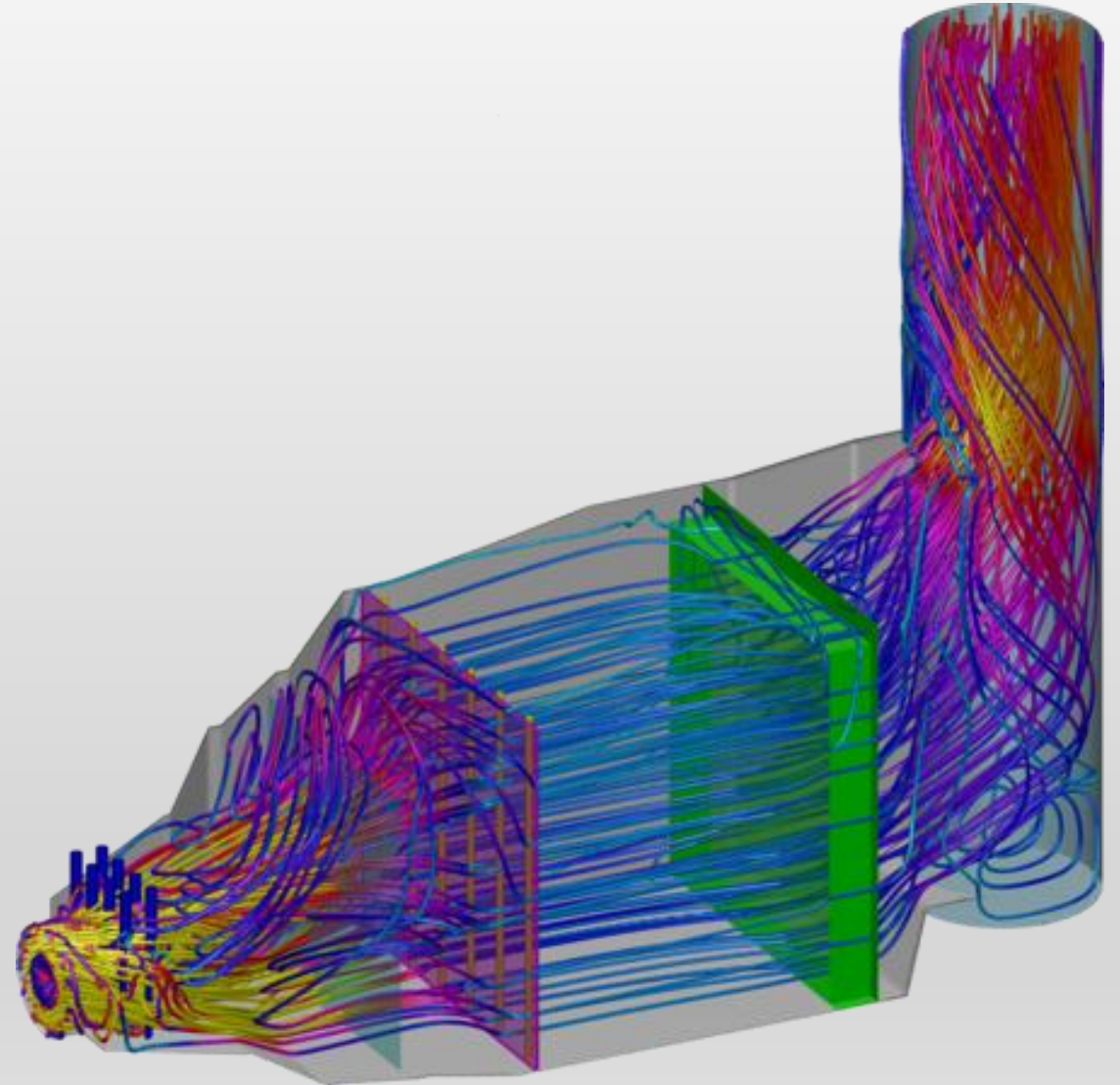
FLOW MODELING FOR AERODERIVATIVE POWER PLANT PERFORMANCE OPTIMIZATION

Matt Gentry, P.E.
Airflow Sciences Corporation

WTUI 2025
Long Beach, CA
April 1, 2025

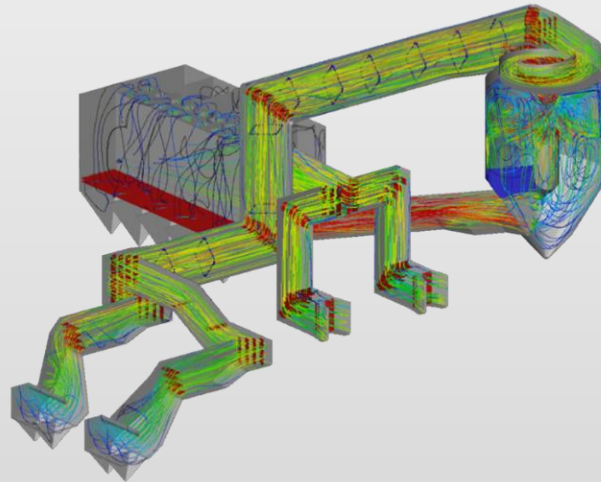
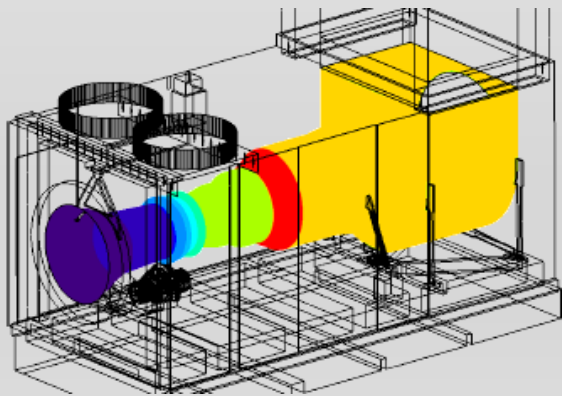
AGENDA

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



AIRFLOW SCIENCES CORPORATION

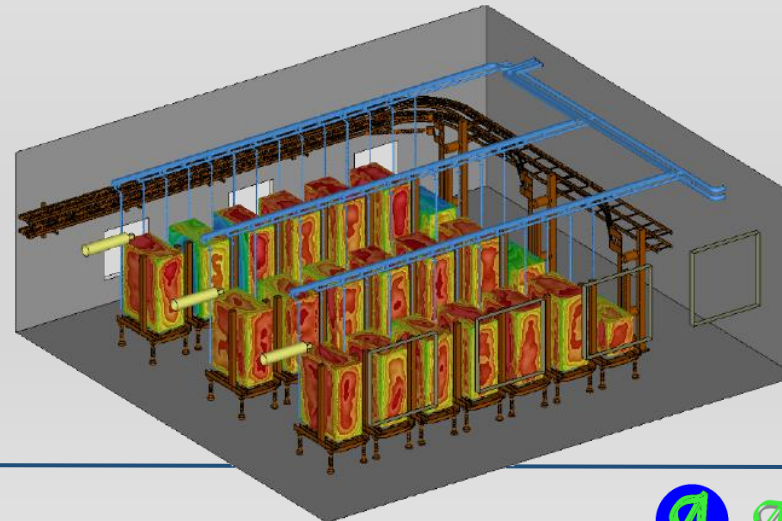
- Providing engineering services to industry since 1975
- Specialize in developing cost-effective solutions to problems involving
 - Fluid flow
 - Heat transfer
 - Particulate transport
 - Chemical reaction
 - Aerodynamics



Airflow Sciences Corporation
fifty years of delivering trusted flow solutions

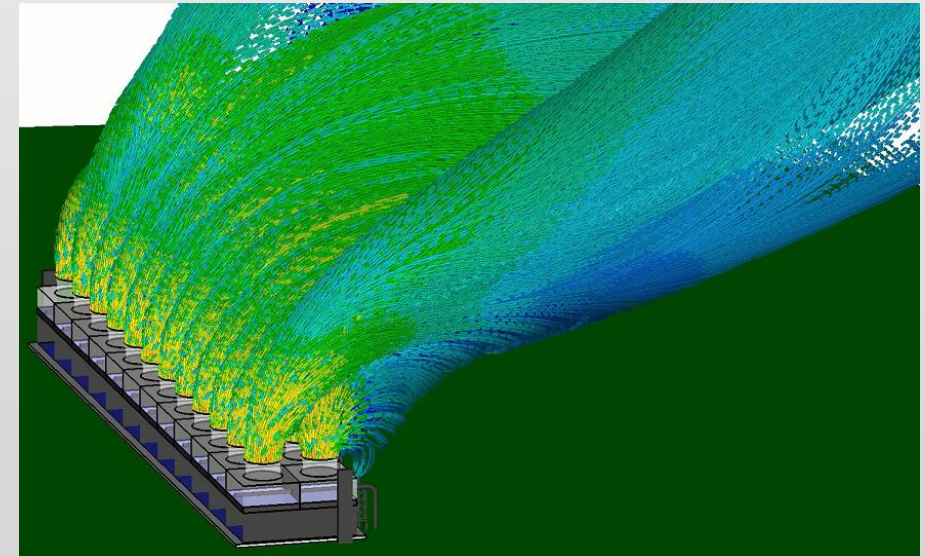
AIRFLOW SCIENCES CORPORATION

- Flow Modeling Services – CFD, Physical
- Field Testing – SCR tuning, boiler/duct/stack testing
- CFD Software - Azore®
- Portable and Online Test Equipment
- ASC has experience in a wide variety of industries:
 - Power and Steam Generation
 - Metals Processing
 - Food Processing
 - Biotech
 - HVAC
 - Consumer Products



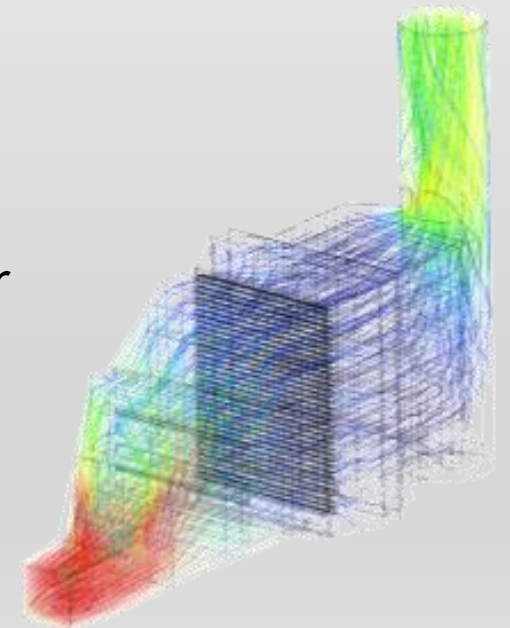
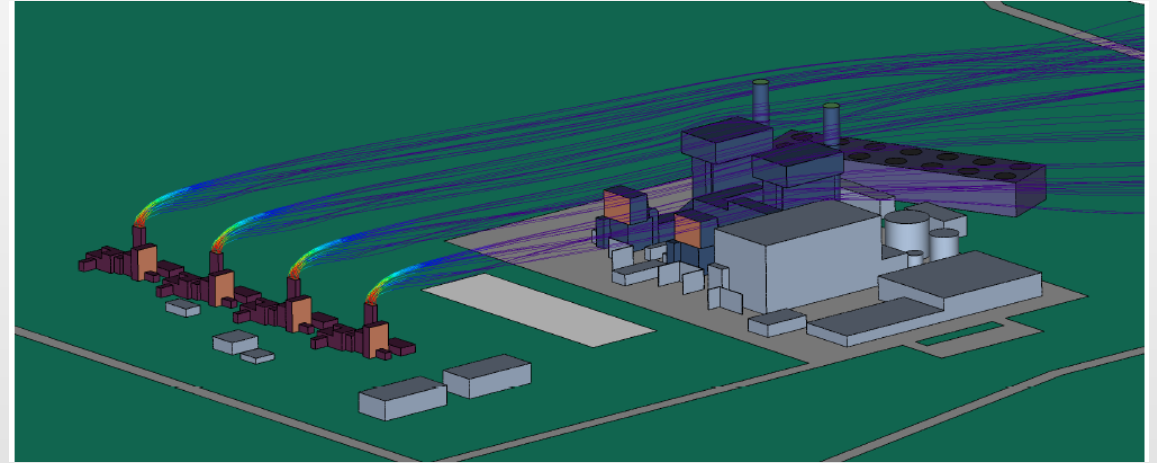
WHY PERFORM FLOW MODELING?

- Verify initial design of new equipment (required for most large capital projects)
- Conduct troubleshooting/optimization of existing equipment
 - Velocity
 - Heat transfer
 - Emissions
 - Flow-induced vibration
- 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



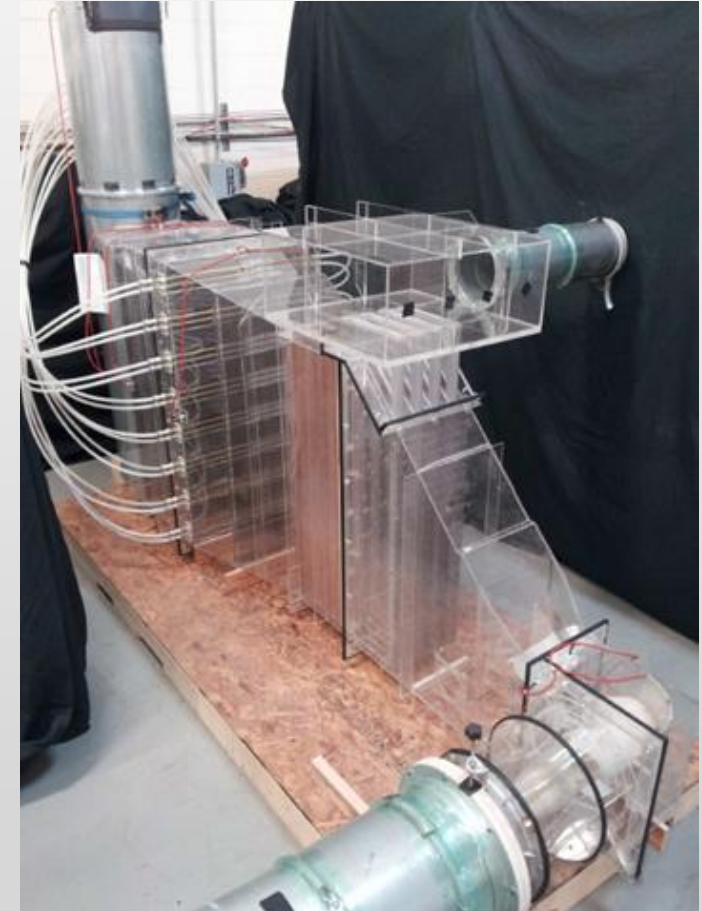
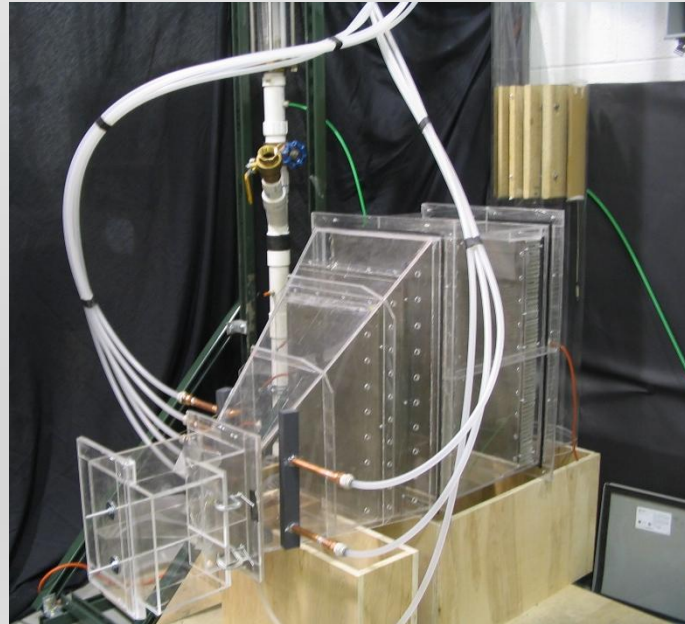
COMPUTATIONAL FLUID DYNAMICS (CFD)

- Numerical simulation of flow
- Utilize high speed computers and sophisticated software
- Calculate flow properties
 - Velocity, temperature, pressure
 - Chemical species, combustion
 - Particle behavior
 - Steady state or transient flows
- Azore and Fluent software accuracy has been proven for a wide range of industrial applications



PHYSICAL FLOW MODELING

- Popular in the electric power generation industry
- Laboratory representation of geometry
 - Typical scale between 1:8 and 1:16
 - “Cold Flow” modeling
- Velocity and/or species concentration data collected



FLOW TESTING

- Performance
 - Flow uniformity, mixing
 - Temperature mixing / heat transfer
 - Turbine outlet profile
- O&M Costs
 - Pressure drop
 - Tube bank fouling
 - Ammonia consumption
- Maintenance
 - Catalyst Pluggage
 - Vibration



GT POWER PLANT DESIGN CONSIDERATIONS

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



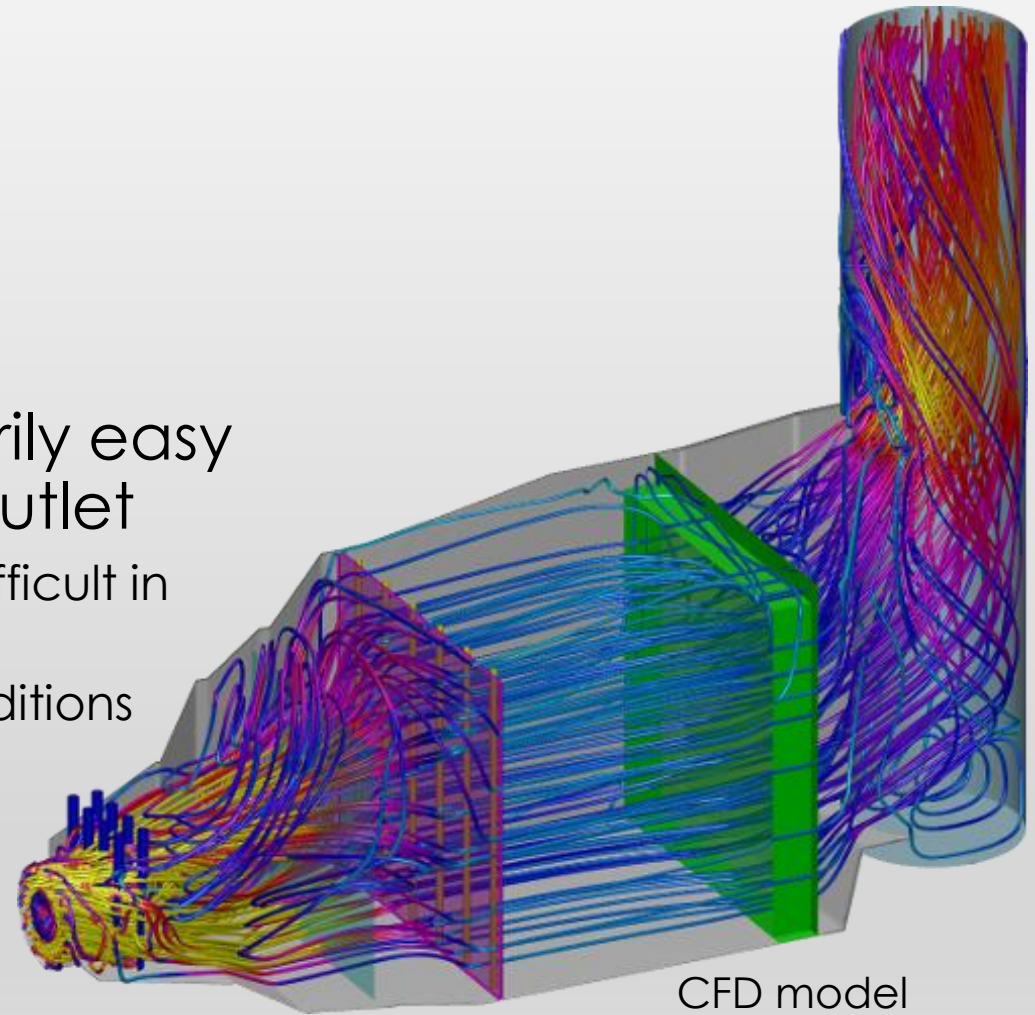
GT POWER PLANT DESIGN CONSIDERATIONS

- Velocity Profile
- Temperature
- Ammonia/NOx Ratio
- Pressure Drop
- External Flow Considerations
- Performance optimization involves a balance of competing goals
- Larger engines are making flow control more challenging
 - Turbine outlet flow patterns vary with load
 - Simple cycles require large mass flow of tempering air



GT POWER PLANT DESIGN CONSIDERATIONS

- Gas Velocity Profile Uniformity
 - CO/NOx/Dual Action Catalyst
 - Ammonia Injection Grid (AIG)
 - Tube banks
 - Stack CEMs
- Obtaining uniform velocity is not necessarily easy due to swirling, turbulent flow at turbine outlet
 - Representing the turbine discharge velocity is very difficult in physical models
 - CFD modeling more advantageous to replicate conditions
- Requires intricate design of flow devices
 - Baffles
 - Straighteners
 - Perforated plates

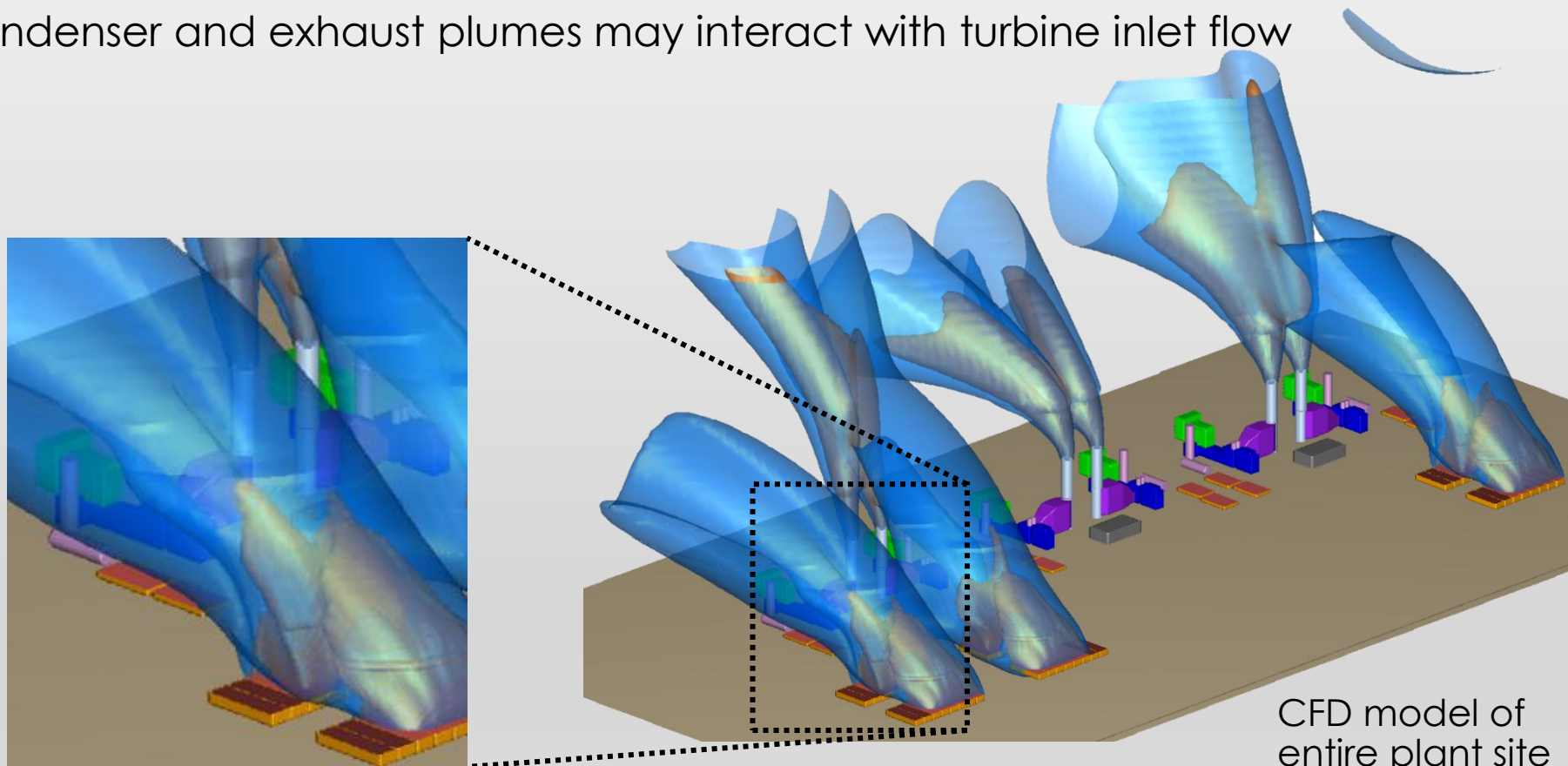


CFD model
Flow streamlines

GT POWER PLANT DESIGN CONSIDERATIONS

- Turbine Inlet Conditions

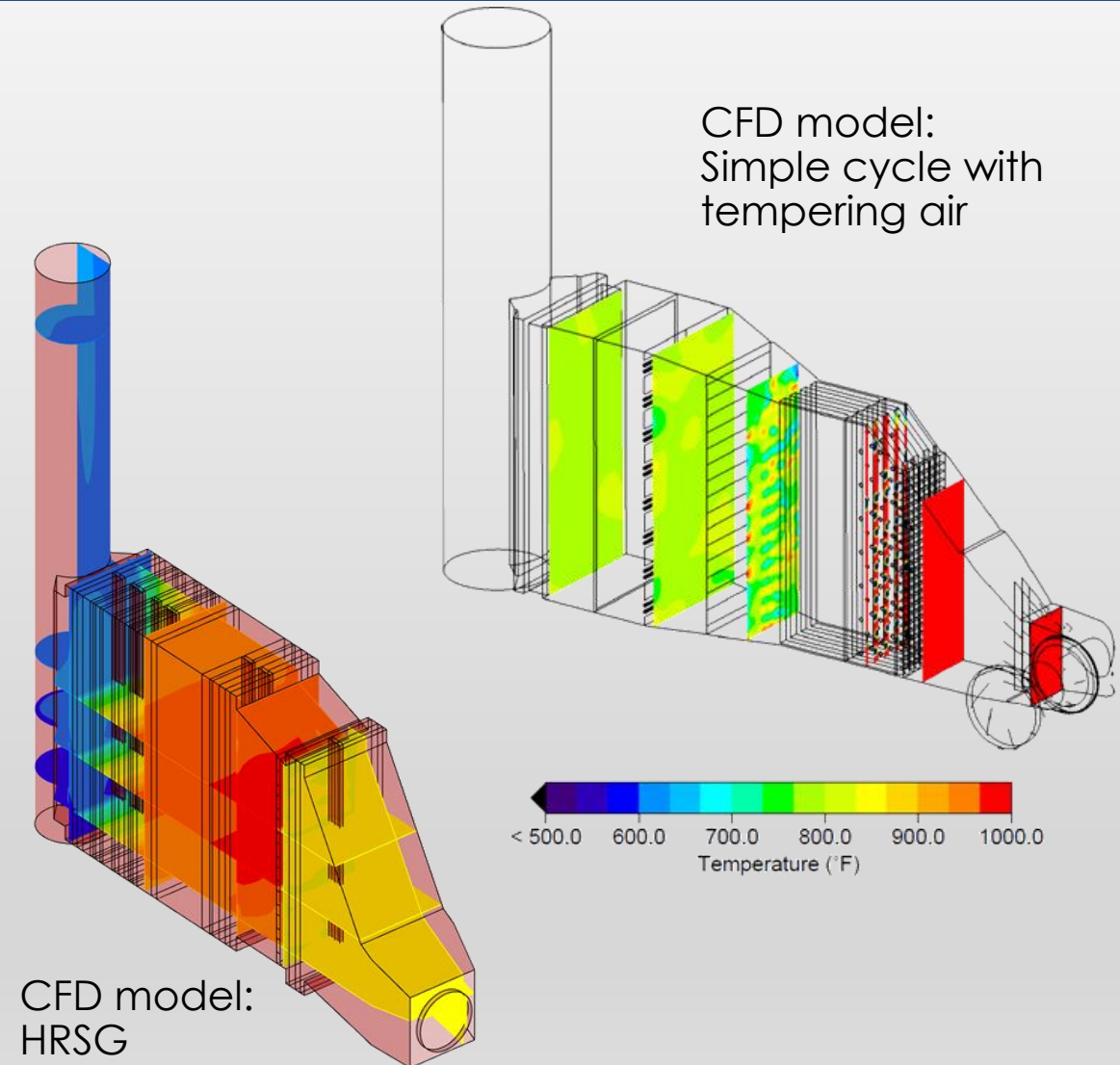
- Plant layout can affect turbine inlet conditions
- Condenser and exhaust plumes may interact with turbine inlet flow



GT POWER PLANT DESIGN CONSIDERATIONS

- 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
 - Catalysts have min and max allowable temperatures for optimized performance and to minimize damage
 - Can be challenging if significant amount of tempering air
 - Temperature is not necessarily uniform exiting the turbine



GT POWER PLANT DESIGN CONSIDERATIONS

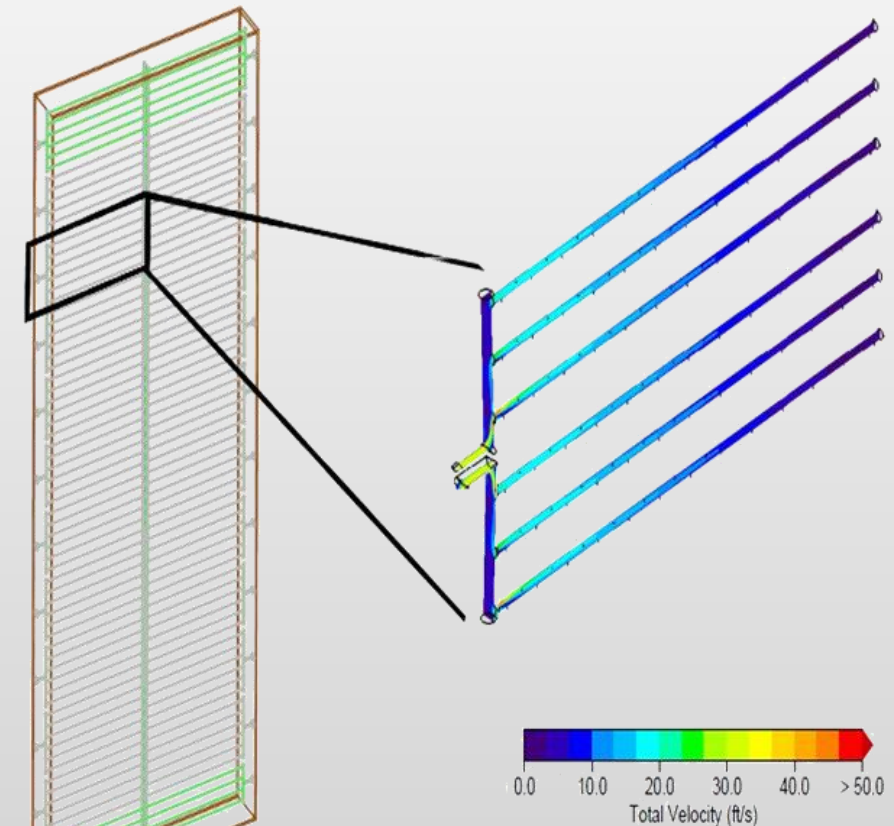
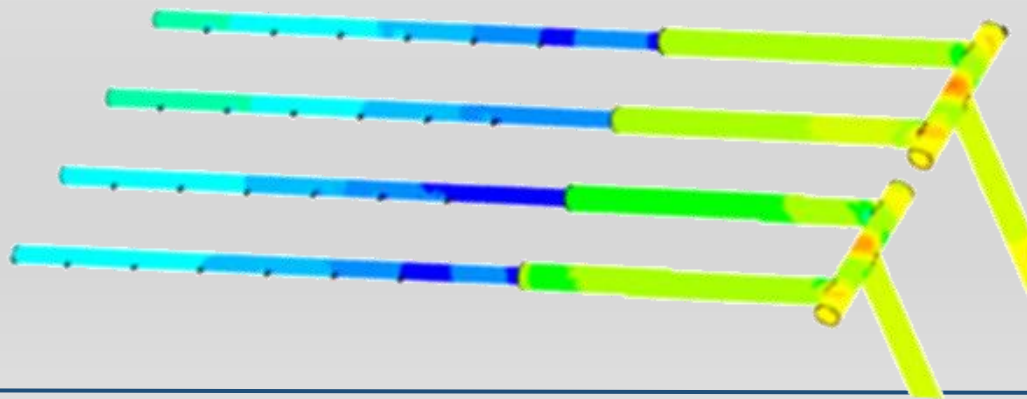
- Ammonia Injection
 - The key factor in deNOx performance and ammonia slip
 - Goal is uniform concentration (ammonia-to-NOx ratio) at SCR catalyst
 - General target is 5% RMS or better
 - Optimization requires balance of competing goals
 - Velocity profile at AIG
 - Uniform injection from AIG nozzles
 - 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

GT POWER PLANT DESIGN CONSIDERATIONS

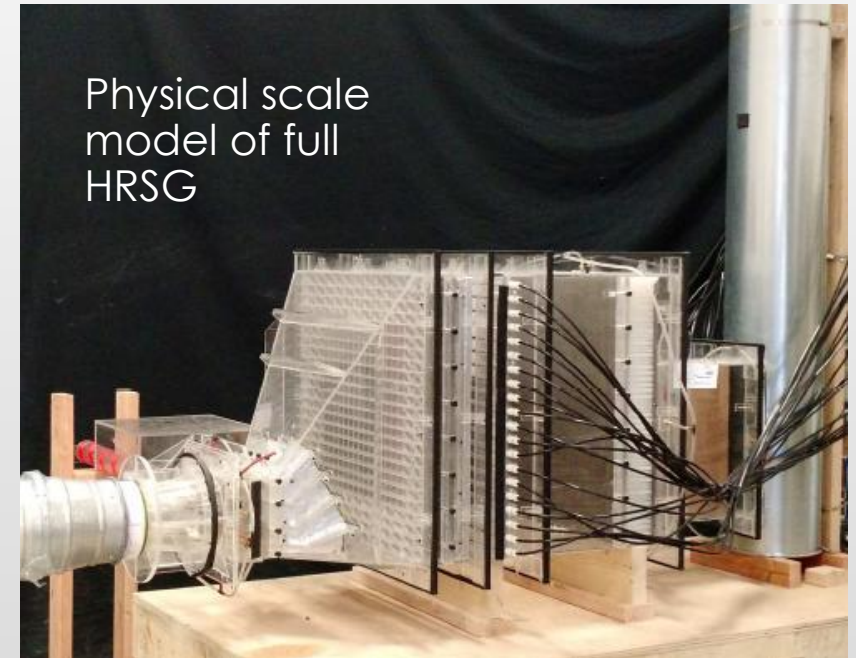
- Conventional Ammonia Injection Grid
 - General goal is to inject equal ammonia from each nozzle to within 2% or better
 - Correct sizing of header ID, lance ID, and nozzle diameters is important
 - Need to consider heat transfer from gas side to the internal pipe flow; this can influence the balance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



Detailed CFD model of AIG header and lances

GT POWER PLANT DESIGN CONSIDERATIONS

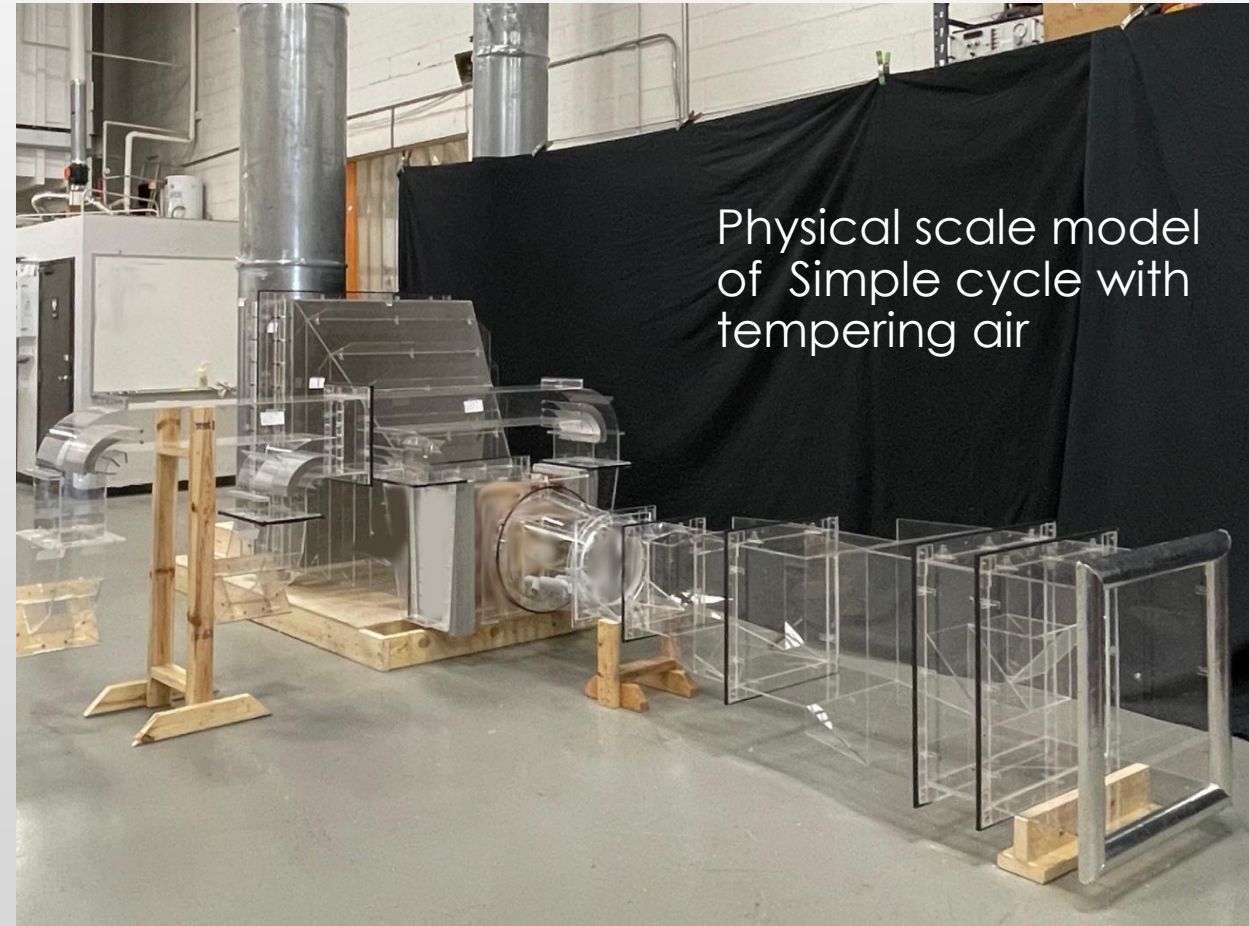
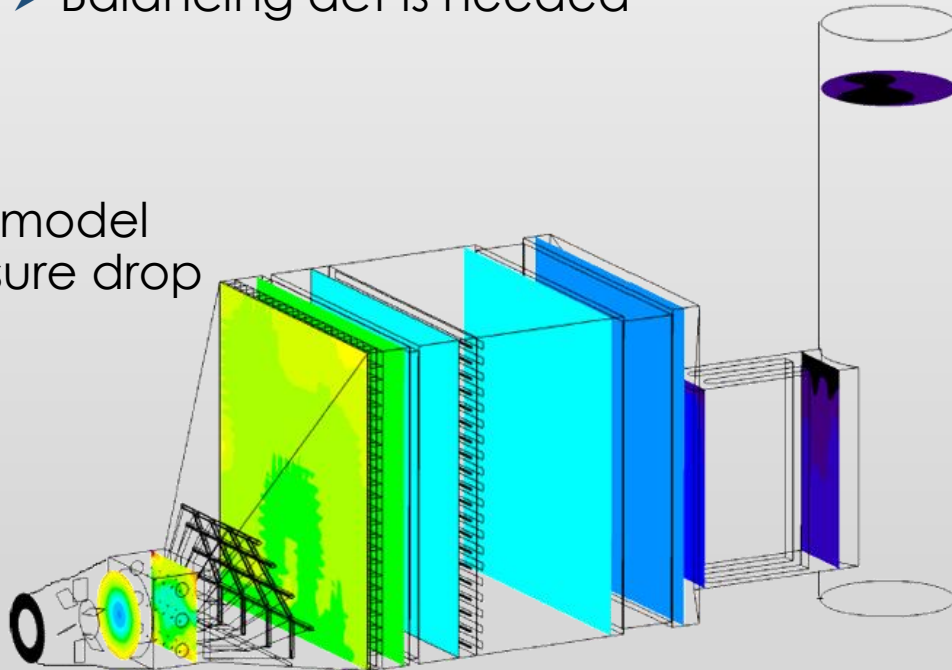
- Ammonia Distribution at SCR Inlet
 - Old goal <10% RMS
 - Modern goal <5% RMS (or better)
 - Tighter uniformity goals related to more stringent NOx regulations plus potential for hydrogen firing
- AIG Design
 - Need to ensure sufficient number of lances/nozzles to cover the cross-section
 - Depends on residence time to catalyst and turbulence
 - Additional mixing may be required
 - Static mixer after AIG
 - Turbulence generators integrated with AIG
- CFD and Physical modeling complement each other to develop optimal design



GT POWER PLANT DESIGN CONSIDERATIONS

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

CFD model
pressure drop



Physical scale model
of Simple cycle with
tempering air

FIELD TESTING AND INSPECTIONS

- AIG tuning
 - Perform periodically to optimize NOx removal
- Inspections
 - Gaps in catalyst seals can lead to NOx bypass
- Velocity testing
 - EPA Method 2F using 3D pitot probe
 - Standard or water-cooled probe depending on location
 - High quality velocity data is critical for flow modeling projects



3DDAS



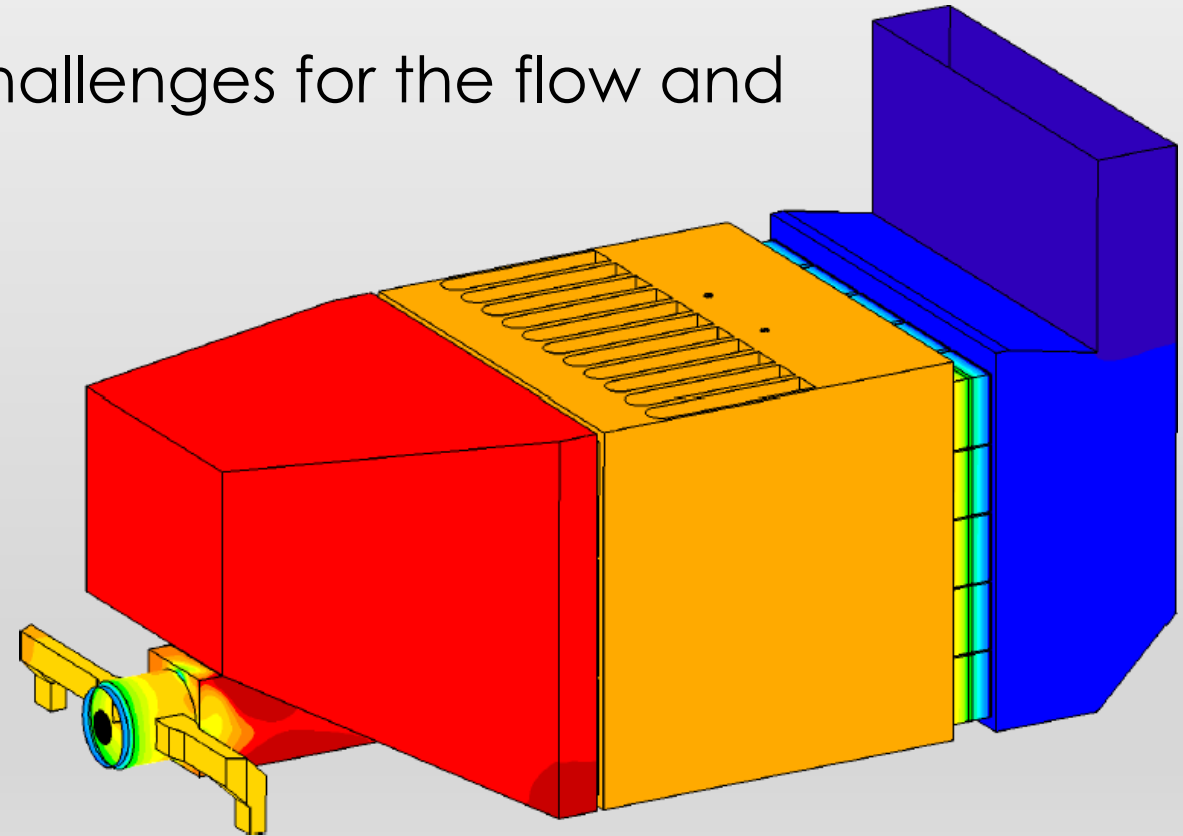
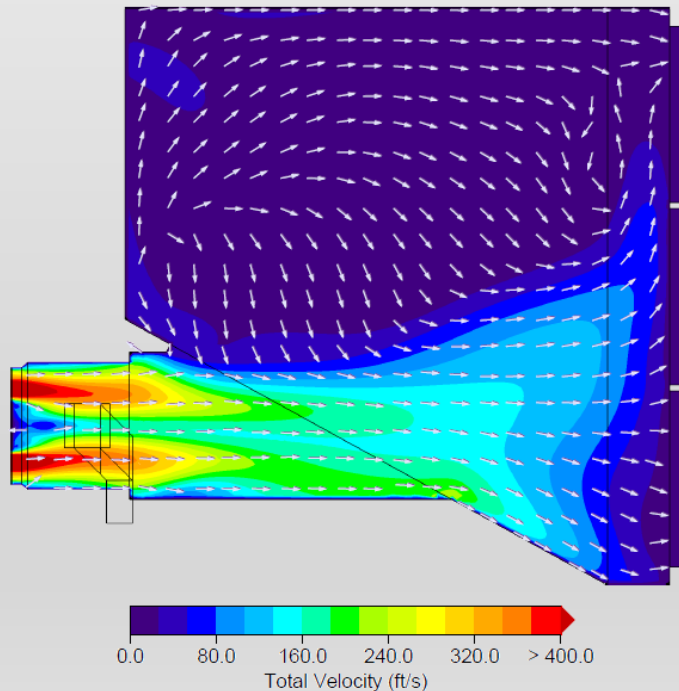
GT outlet flow measurement

GT CFD MODELING CONSIDERATIONS

- Inlet boundary conditions are critical to any modeling effort
 - GT outlet profiles can vary considerably across operating conditions. Push your GT supplier to provide as detailed a data set as possible.
 - When GT outlet data is lacking, or off-condition data are not available, work to ensure that any designs are sufficiently robust.
- Give consideration to the turbulence model used for CFD analysis
 - K-epsilon:
 - The most widely used and validated turbulence model, heavily used for industrial and environmental flow applications.
 - Well-suited for duct flows, with large flow areas.
 - Ideal for GT power plant applications.
 - K-omega SST:
 - A blended turbulence model, which uses K-epsilon relationships in areas away from solid surfaces and then blends to using K-omega near solid surfaces.
 - Requires great attention to detail in meshing the boundary layer. Ideal for models of the turbine itself, with the very narrow passages between turbine blades. The mesh constraints are not practical for full-scale duct models, and K-omega SST models tend to be unstable.

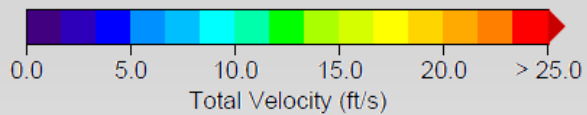
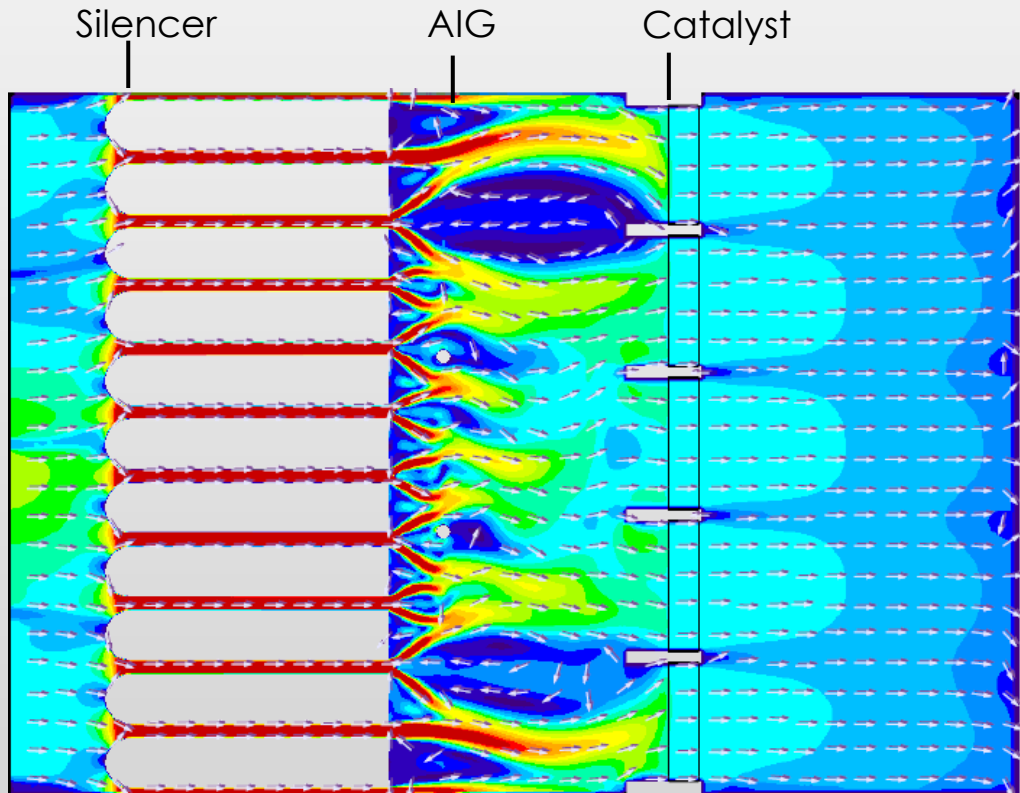
CASE STUDY – FLOW DISTRIBUTION

- Simple cycle unit – 54MW – LM6000 Turbine, with tempering air
- Plant designed for a larger turbine, but was retrofit with an LM 6000.
- The resulting inlet geometry posed challenges for the flow and ammonia distributions downstream.

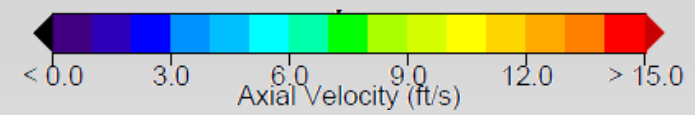
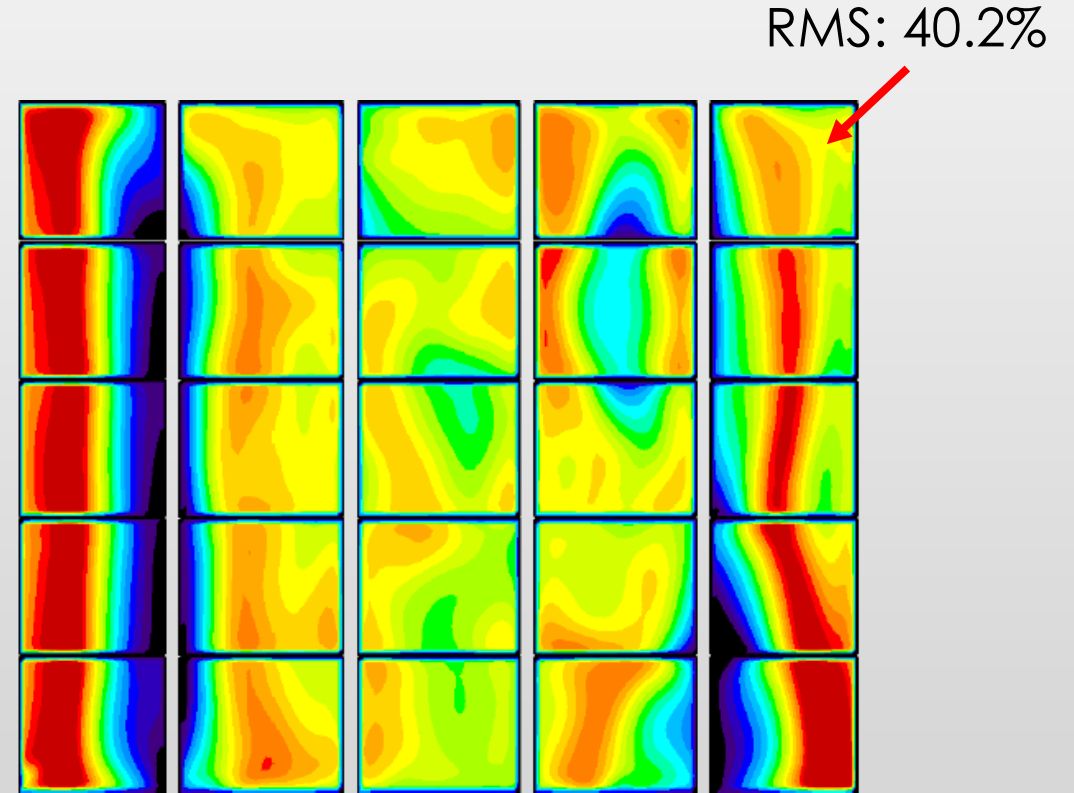


CASE STUDY – FLOW DISTRIBUTION

- Baseline: Poor velocity uniformity at the AIG, resulting in inadequate mixing



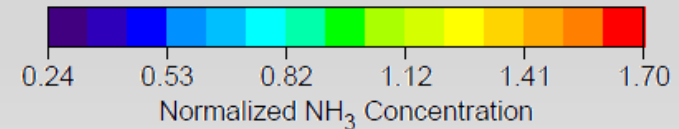
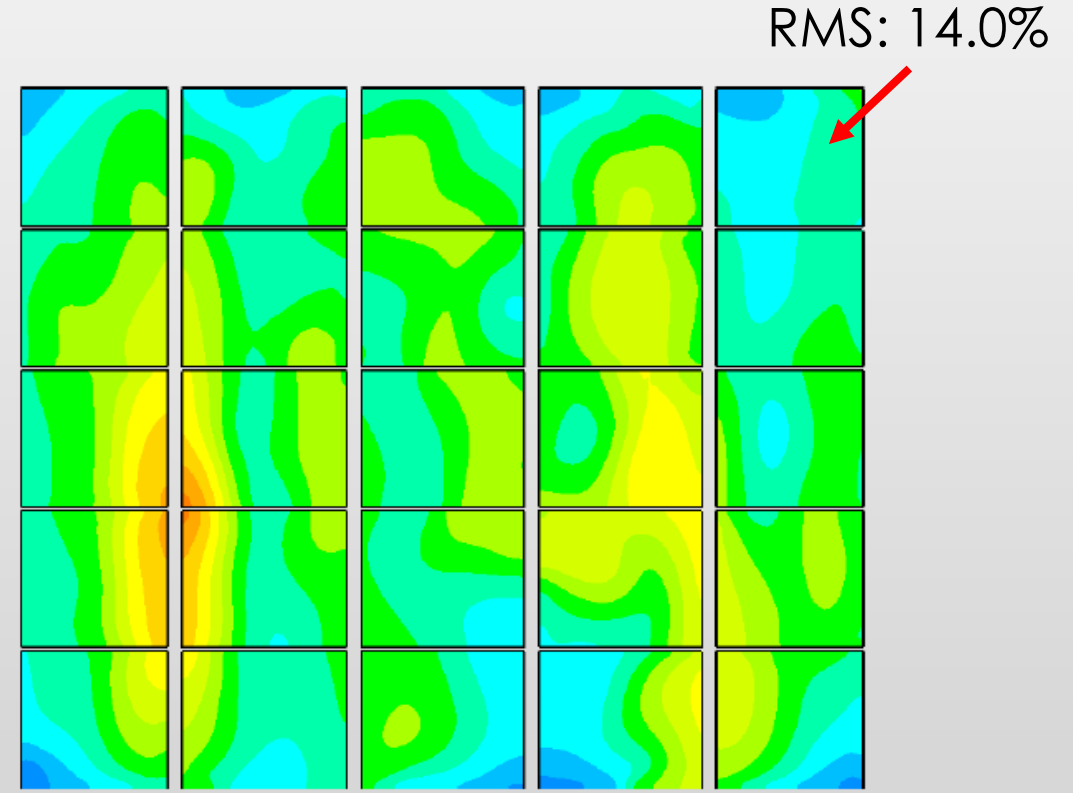
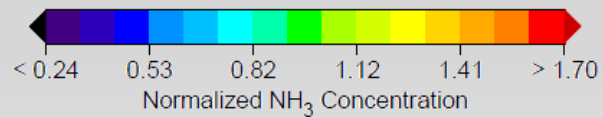
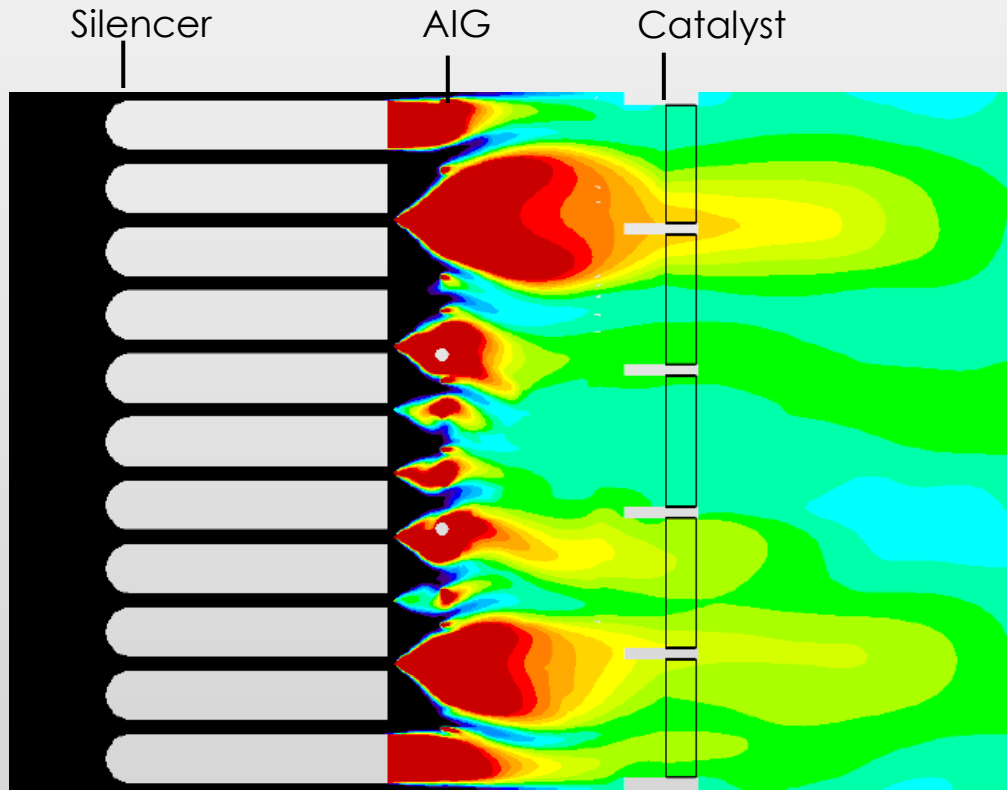
Velocity - Plan View



Velocity - End View, Catalyst Face

CASE STUDY – FLOW DISTRIBUTION

- Baseline: Recirculating flow negatively impacts the SCR ammonia uniformity

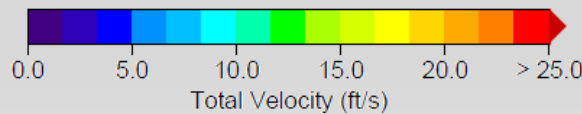
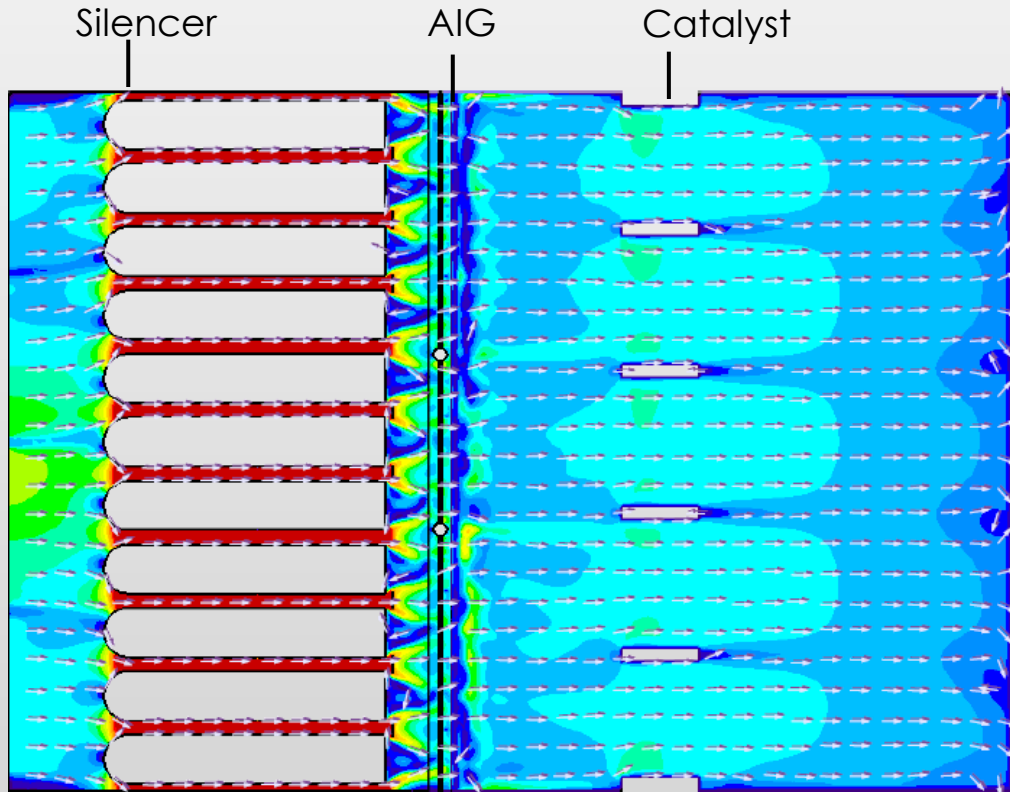


CASE STUDY – FLOW DISTRIBUTION

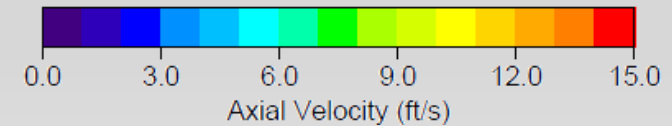
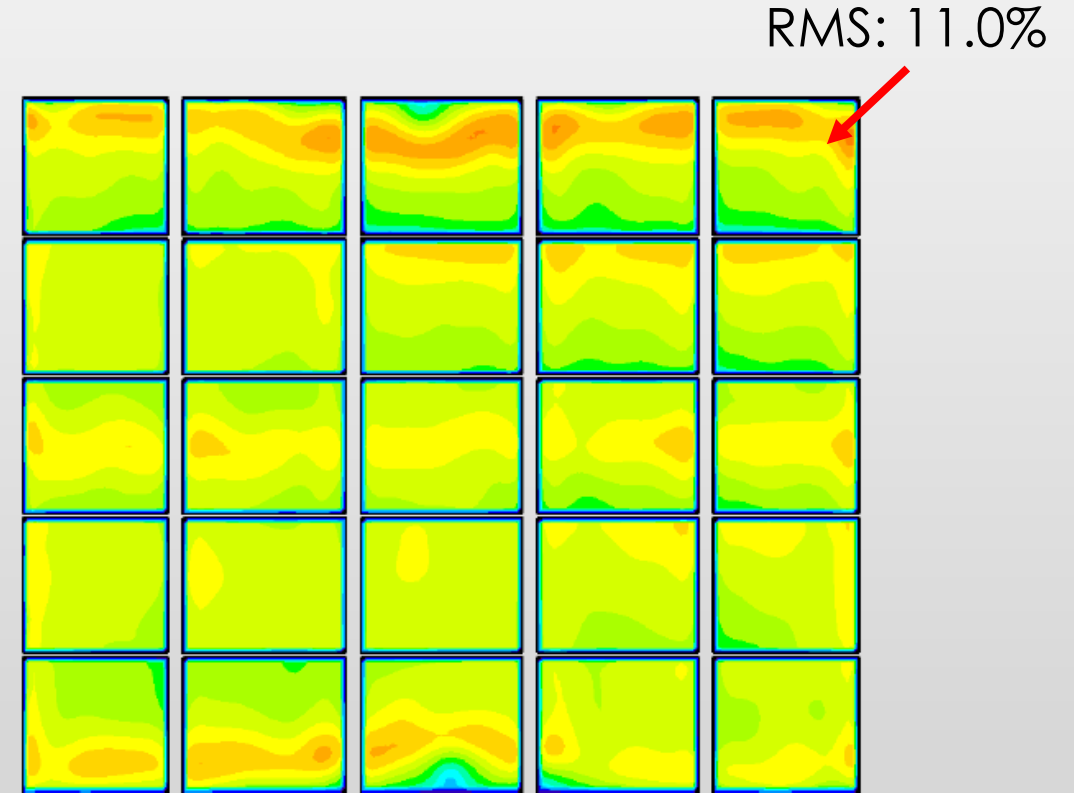
- Numerous design changes were investigated during the CFD analysis.
- Perforated plates were implemented downstream of the duct silencer, to improve the velocity uniformity at the AIG.
- A dense grid of mixing baffles was recommended at the AIG, to promote improved mixing. (Client goal was 10% RMS at the catalyst face).
- As seen on the following slides, the modifications were successful, significantly improving both the velocity and ammonia distribution at the catalyst inlet.

CASE STUDY – FLOW DISTRIBUTION

- Final Design: Both velocity and ammonia uniformity improved significantly



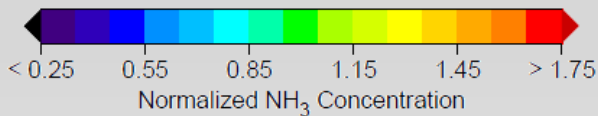
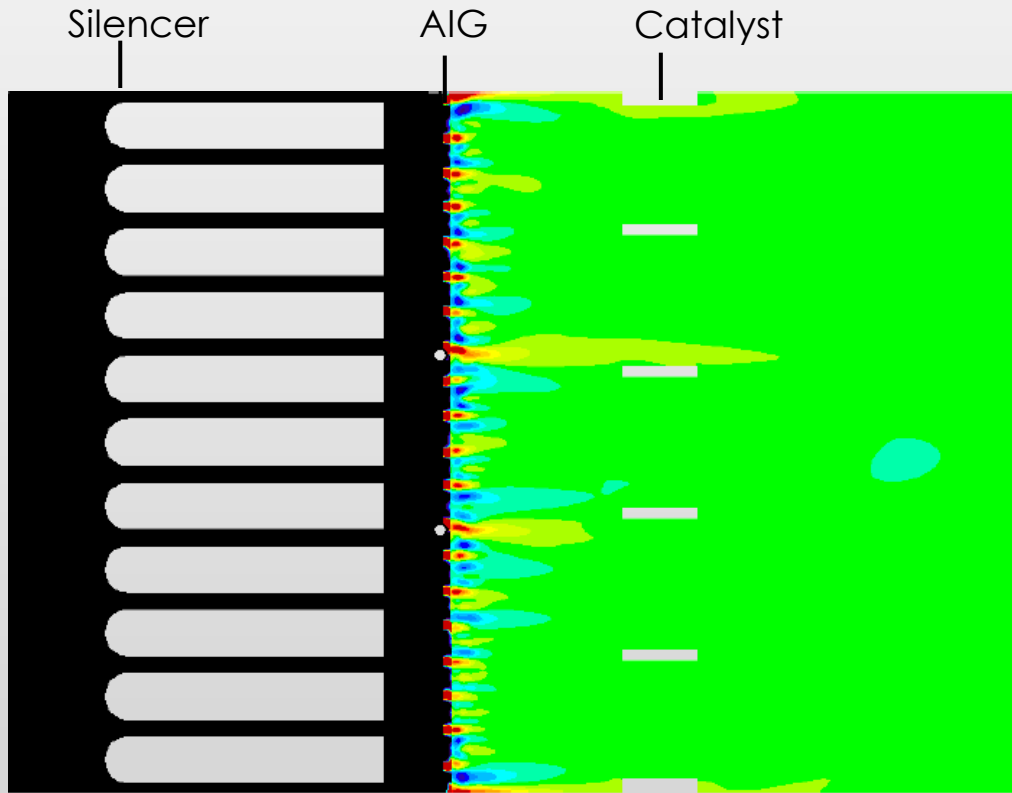
Velocity - Plan View



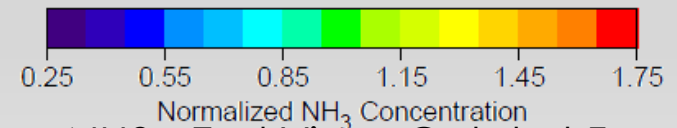
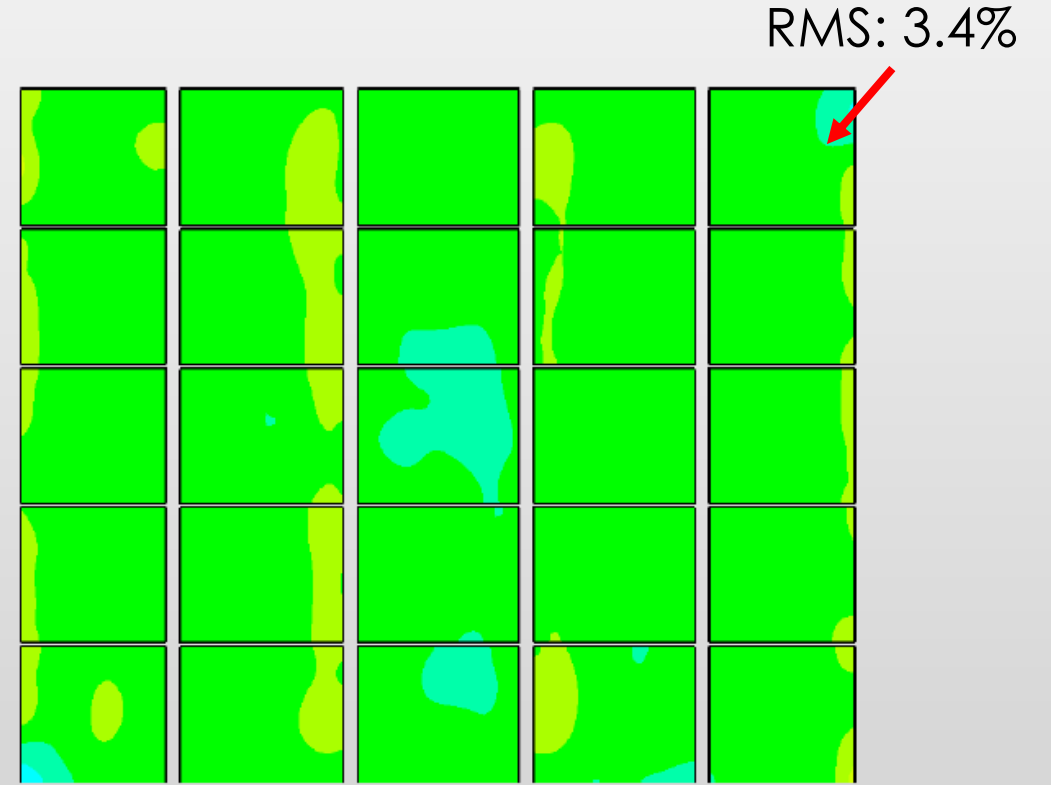
Velocity - End View, Catalyst Face

CASE STUDY – FLOW DISTRIBUTION

- Final Design: Both velocity and ammonia uniformity improved significantly



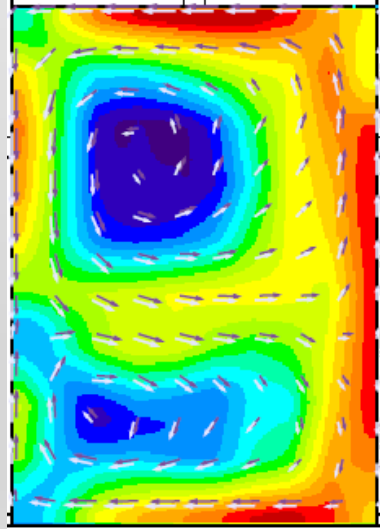
NH3 - Plan View



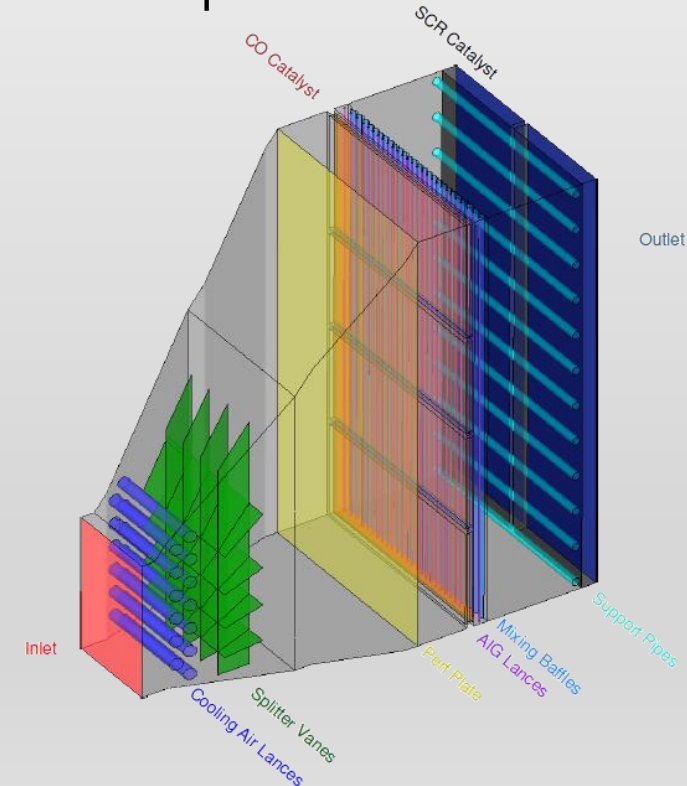
NH3 - End View, Catalyst Face

CASE STUDY – CO CATALYST OPTIMIZATION

- Simple cycle unit – 105MW – LMS100 Turbine, with tempering air
- Unit suspected of poor flow distribution at the CO catalyst.
- Poor ammonia-to-NOx ratio at the SCR catalyst was also suspected.
- CFD flow modeling was requested.

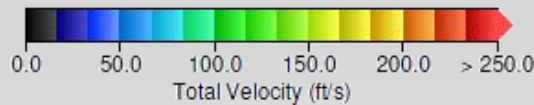
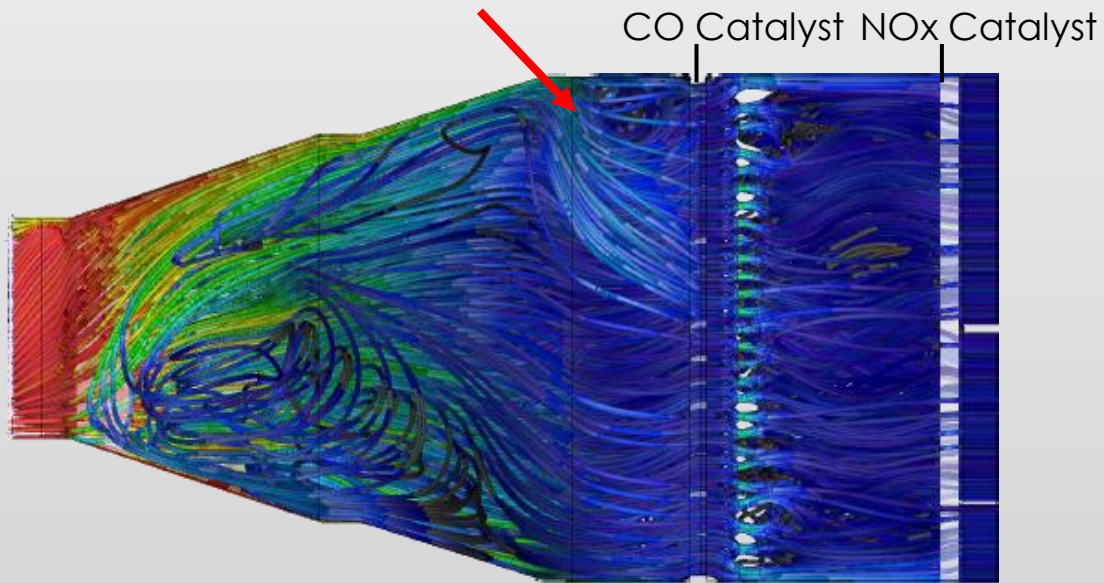


Model Inlet – Swirling LMS100 Exhaust Flow

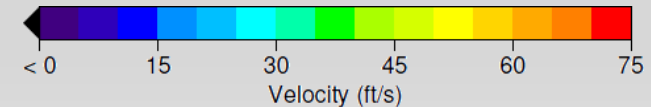
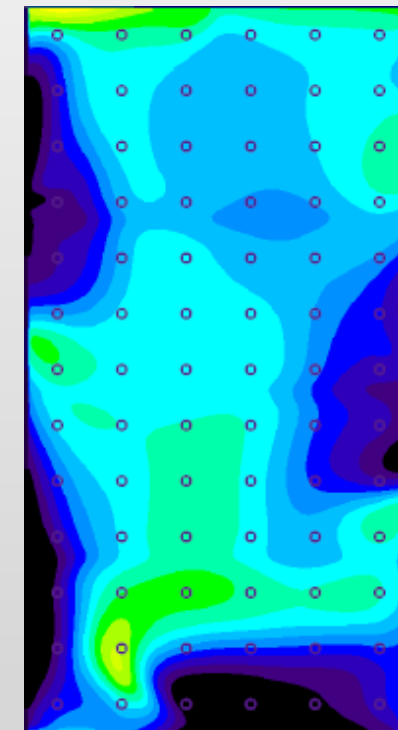


CASE STUDY – CO CATALYST OPTIMIZATION

- Baseline modeling confirms poor velocity distribution at the CO catalyst.
- Flow slides along the existing perf plate and has significant angularity upstream of the catalyst.



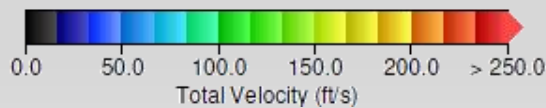
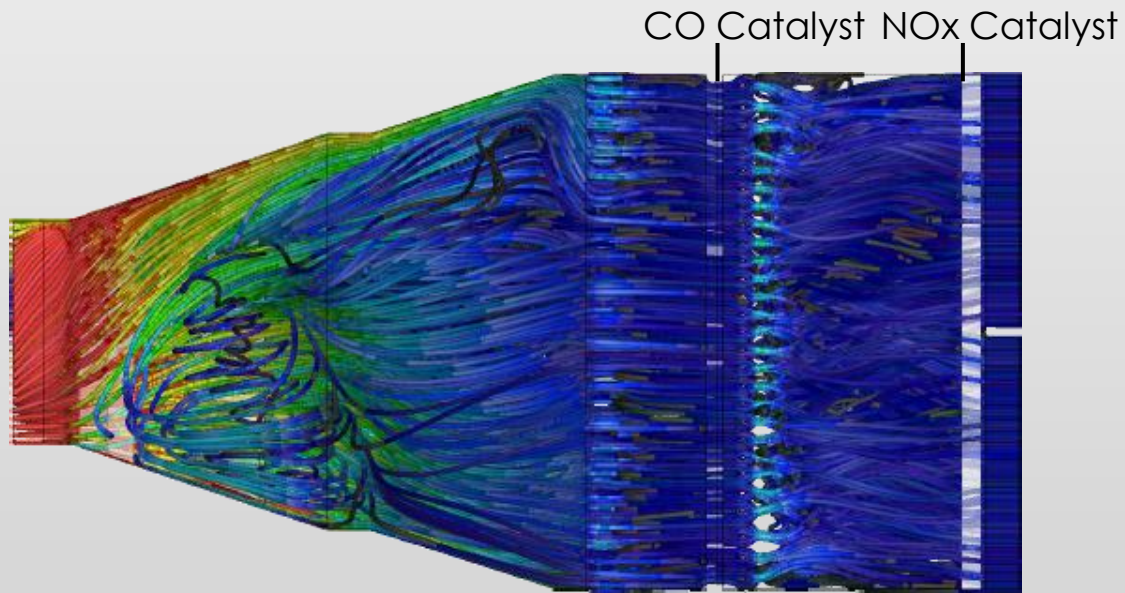
Velocity - Plan View



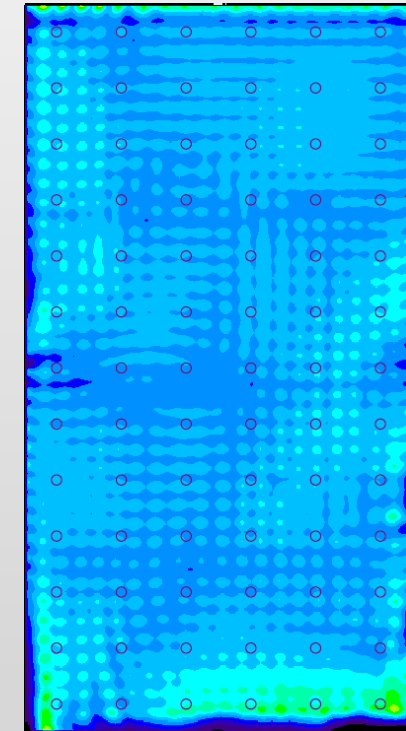
Velocity - End View - Upstream CO Catalyst

CASE STUDY – CO CATALYST OPTIMIZATION

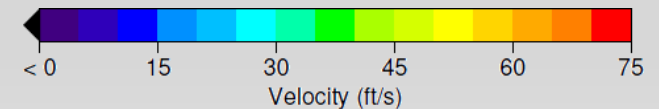
- Egg-crate flow straightener added for the design.
- Velocity upstream of the catalyst significantly improved, with no increase in back pressure.



Velocity - Plan View



RMS: 14.7%



Velocity – End View – Upstream CO Catalyst

CASE STUDY – AIG OPTIMIZATION

- HRSG unit – 2x240MW
- Since plant startup in 2000, the HRSGs have experienced high gas pressure drop in the next to last tube bundle before the exhaust gas leaves the HRSG through the stack. The cause of the high pressure drop was due to ammonium salts building up within the tube bundle caused by high local ammonia slip.
- The HRSGs were cleaned annually utilizing costly ice blasting, but the pressure drop quickly increased after cleaning, from 2.1 IWC pressure drop in clean condition to often greater than 6.8 IWC.

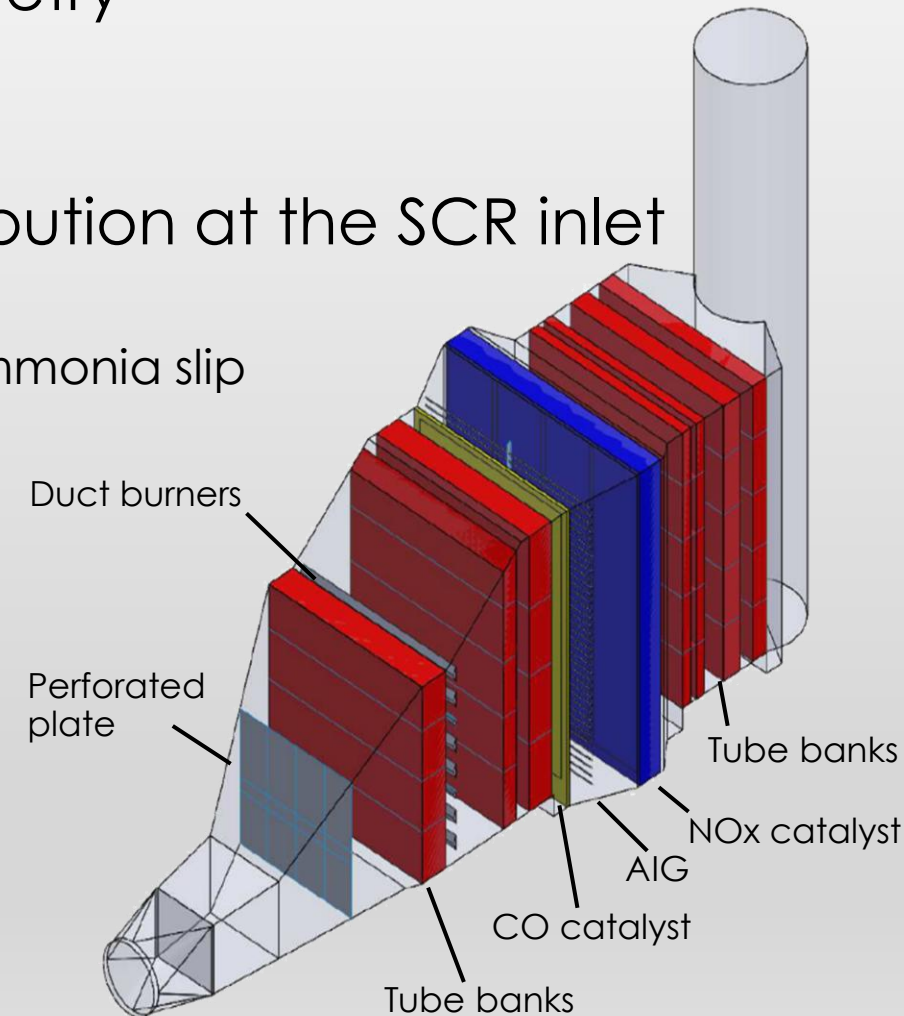


CASE STUDY – AIG OPTIMIZATION

- The HRSG was thought to have “typical” geometry
- So why did it have performance issues?
- Initial field testing showed poor ammonia distribution at the SCR inlet
 - Goal was <10% RMS; data indicated >20% RMS
 - The plant struggled balancing de-NO_x performance and ammonia slip
 - Could not tune the AIG to improve performance

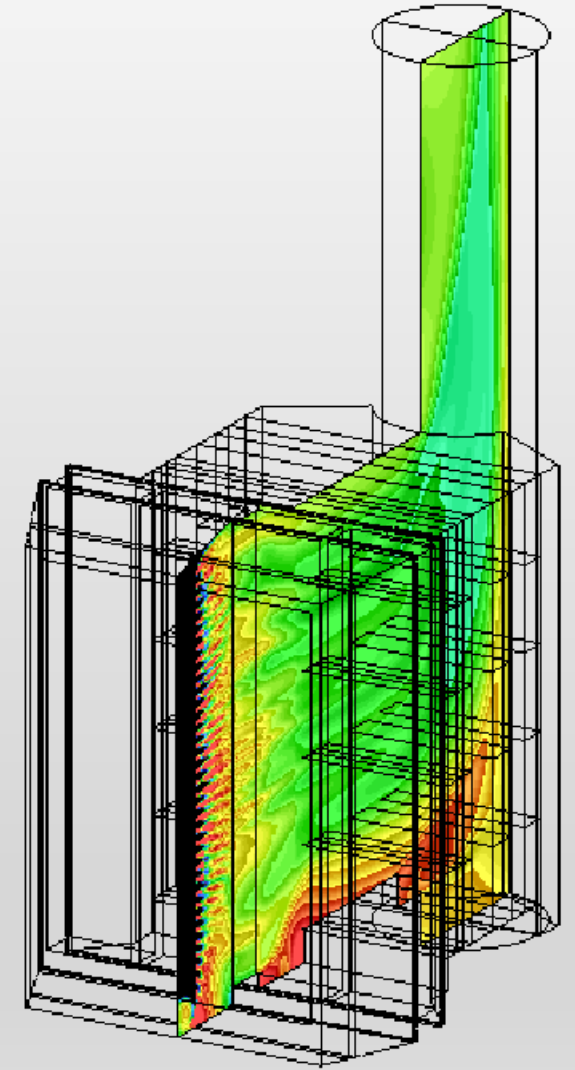
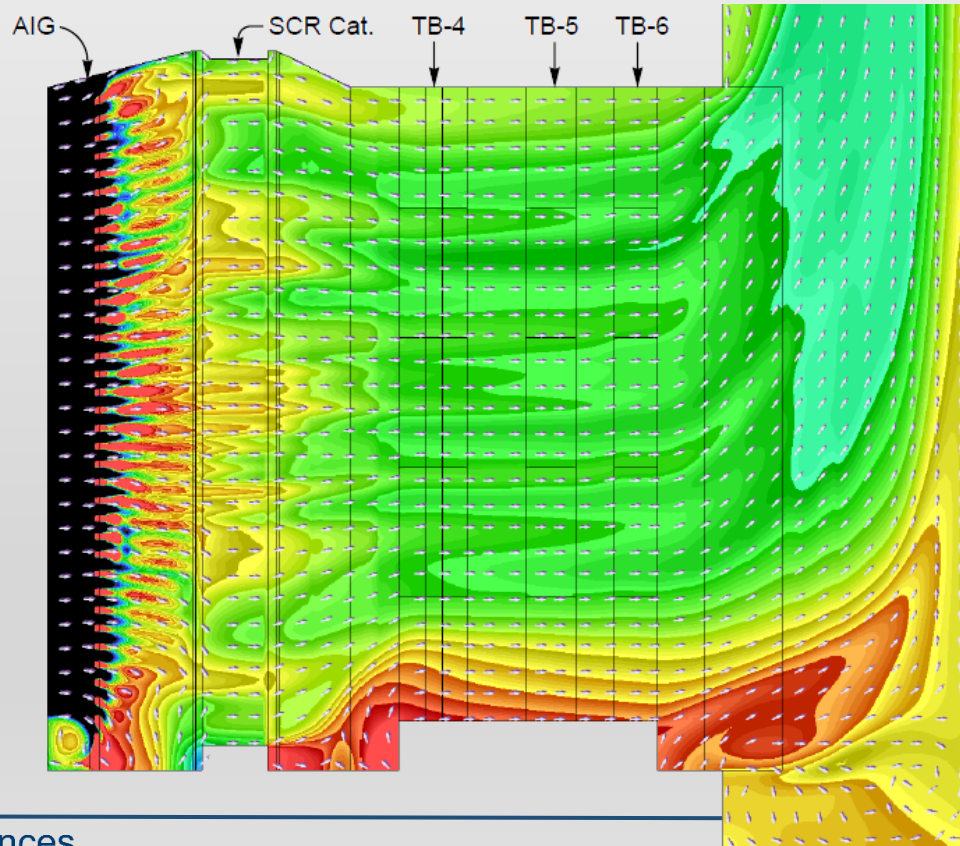


Fouled tubes



CASE STUDY – AIG OPTIMIZATION

- Baseline CFD modeling showed two problems with the ammonia injection grid
 - Localized mixing from each lance / nozzle was insufficient due to low turbulence level exiting CO catalyst

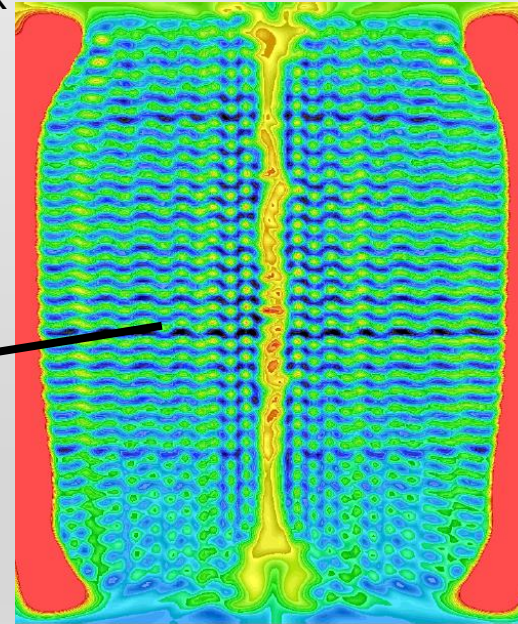


CASE STUDY – AIG OPTIMIZATION

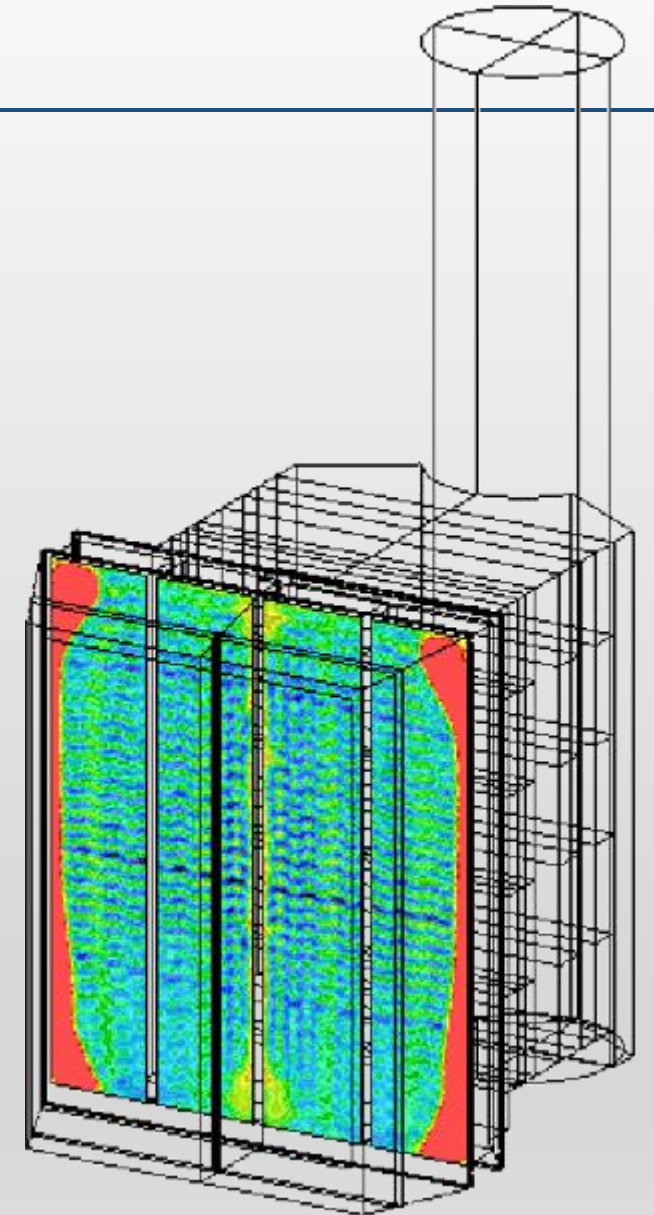
- Baseline CFD modeling showed two problems with the ammonia injection grid
 - Localized mixing from each lance / nozzle was insufficient due to low turbulence level exiting CO catalyst
 - Perimeter flow control was poor, resulting in very high ammonia along walls and through the SCR



Bulk of SCR
Inlet Area
25% RMS

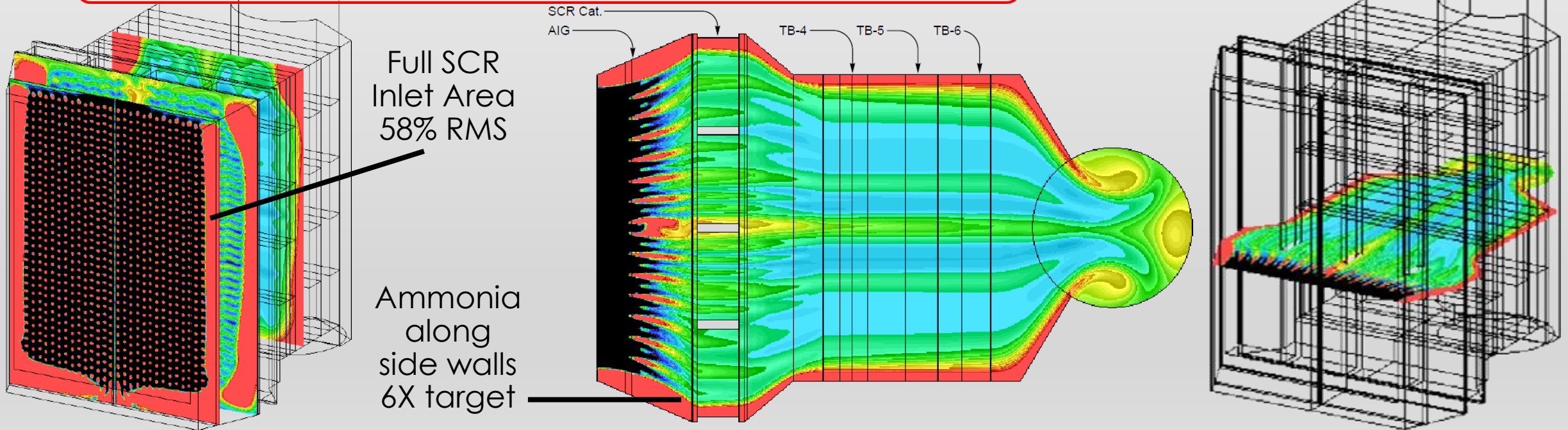


< 0.50 0.70 0.90 1.10 1.30 > 1.50
Normalized Ammonia Concentration



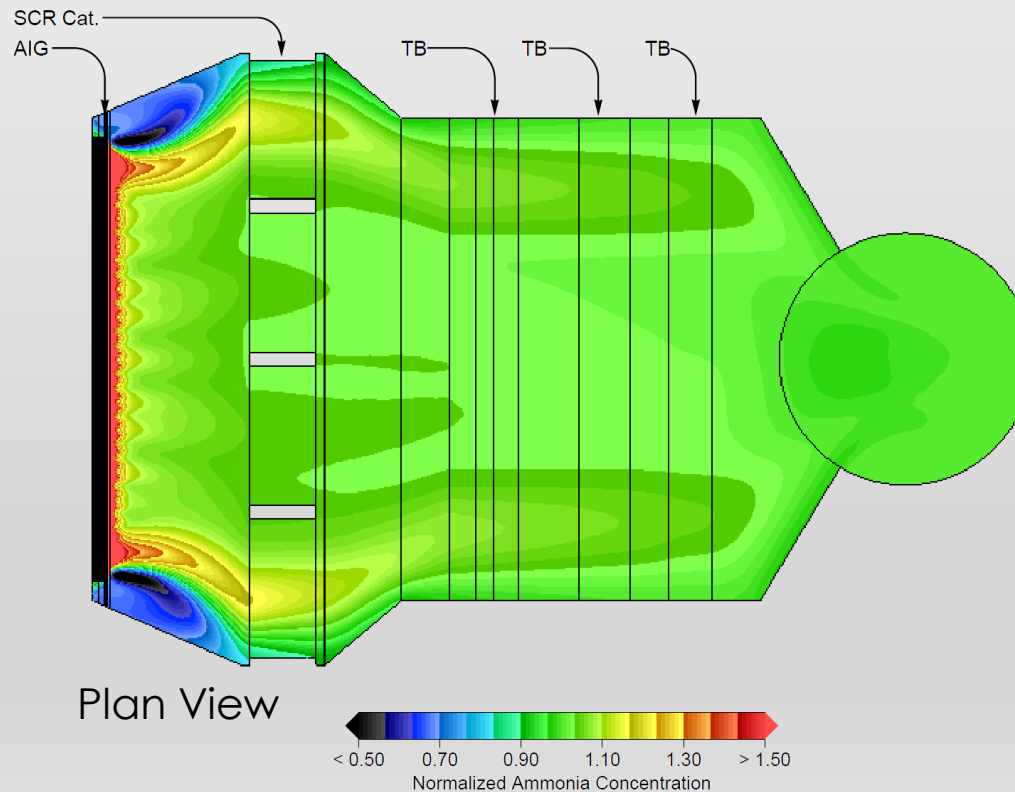
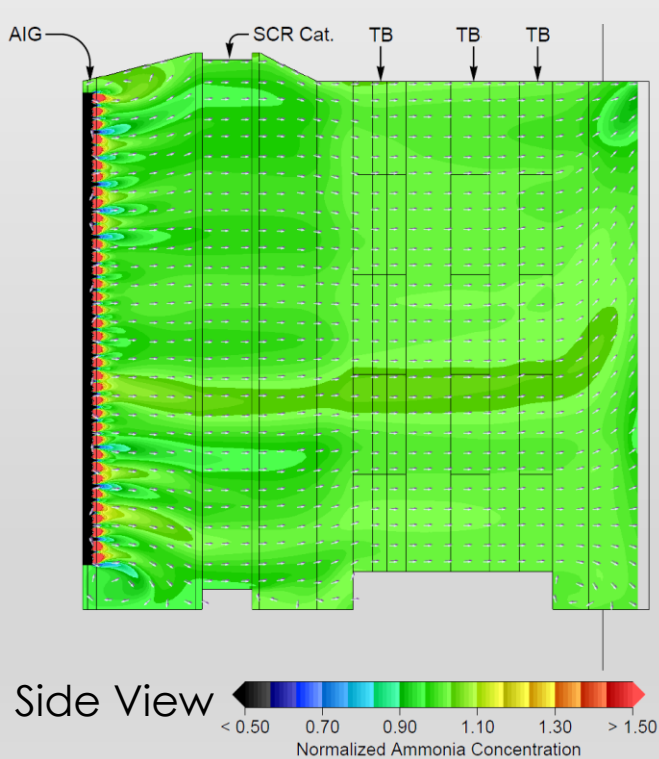
CASE STUDY – AIG OPTIMIZATION

- Baseline CFD modeling showed two problems with the ammonia injection grid
 - Localized mixing from each lance / nozzle was insufficient due to low turbulence level exiting CO catalyst
 - Perimeter flow control was poor, resulting in very high ammonia along walls and through the SCR



CASE STUDY – AIG OPTIMIZATION

- Solution: Redesign the AIG
 - Improve local mixing in the center / Control the flow at the perimeter
 - New AIG lances with integrated mixing baffle
 - Proper design of flow baffling at CO catalyst and AIG



Final Design:
Ammonia RMS
improved to 5.8% at
the catalyst face

CASE STUDY – AIG OPTIMIZATION

- After modifications:
 - Plant performance improved significantly on both units
 - Small increase in pressure drop due to the new baffles (0.25 IWC), but pressure drop held steady over the next 6 months, indicating that the ammonia salt buildup on the tubes was not occurring
 - Ammonia consumption was reduced by 15-25% depending on load
- Plant feedback, January 2024 (6.5 years after modifications)

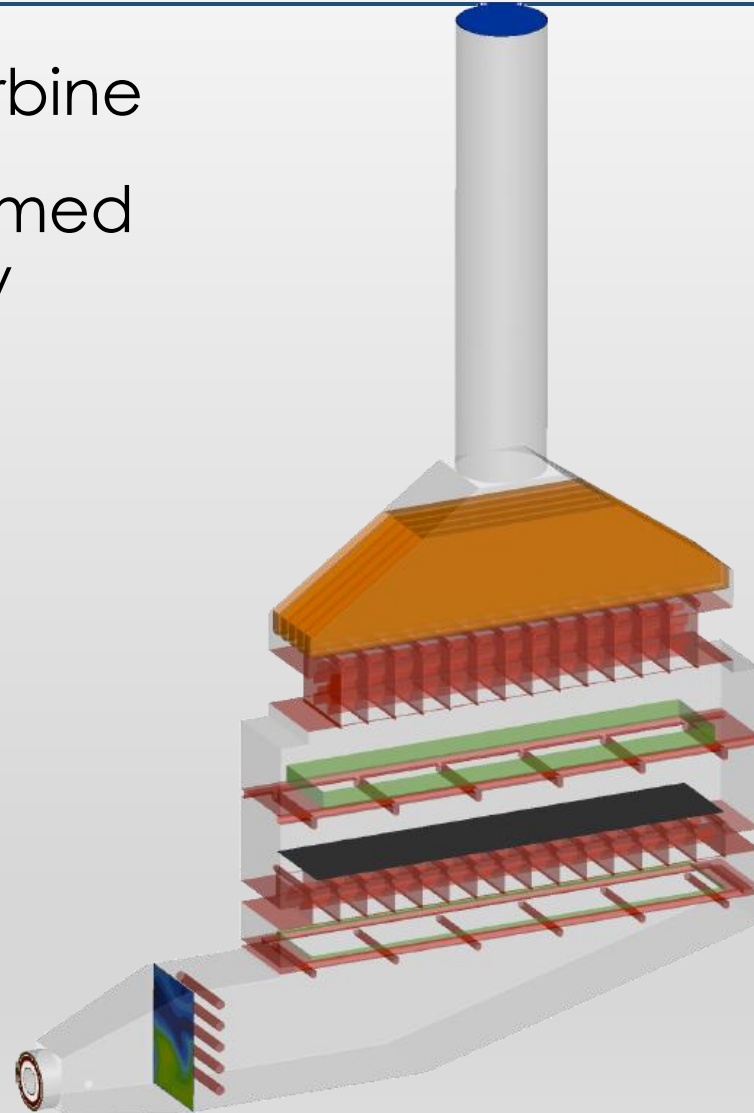
We did see an immediate decrease in aqueous ammonia usage (~20%), improved NOx control, and a reduced rate of ammonia salt deposition on the HRSG tube surfaces over time. The bulk of salt deposition also appears to have shifted further back in the HRSG from Module 5 to Module 6. As you know, the reduced salt deposition directly affects heat rate, but there hasn't been any reason for us to quantify the correlation. Since the project was completed, we have only cleaned the HRSGs once, and there was minimal debris recovered. In our opinion, the project was a huge success.

Take care,

XXX (plant engineer name withheld upon request)

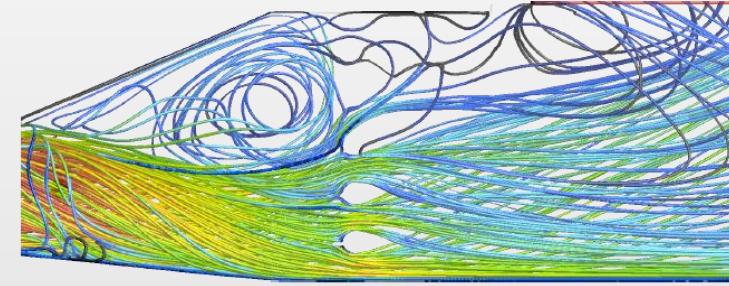
CASE STUDY – THERMAL OPTIMIZATION

- OTSG Unit – 71 MW – LM6000 Turbine
- Pre-installation modeling performed to optimize unit design and flow control devices.

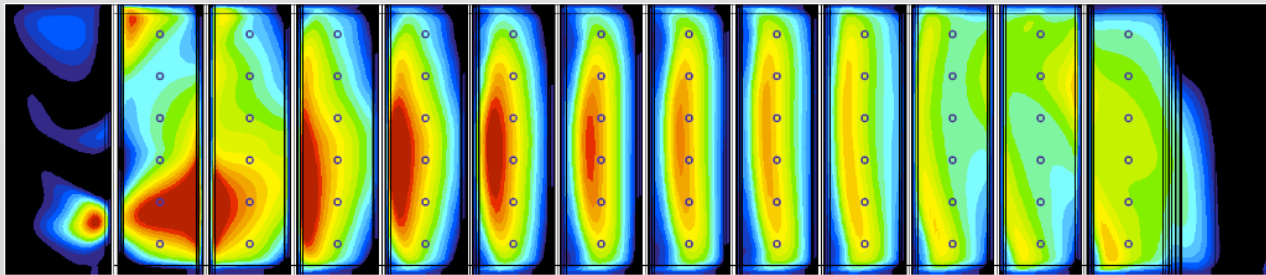


CASE STUDY – THERMAL OPTIMIZATION

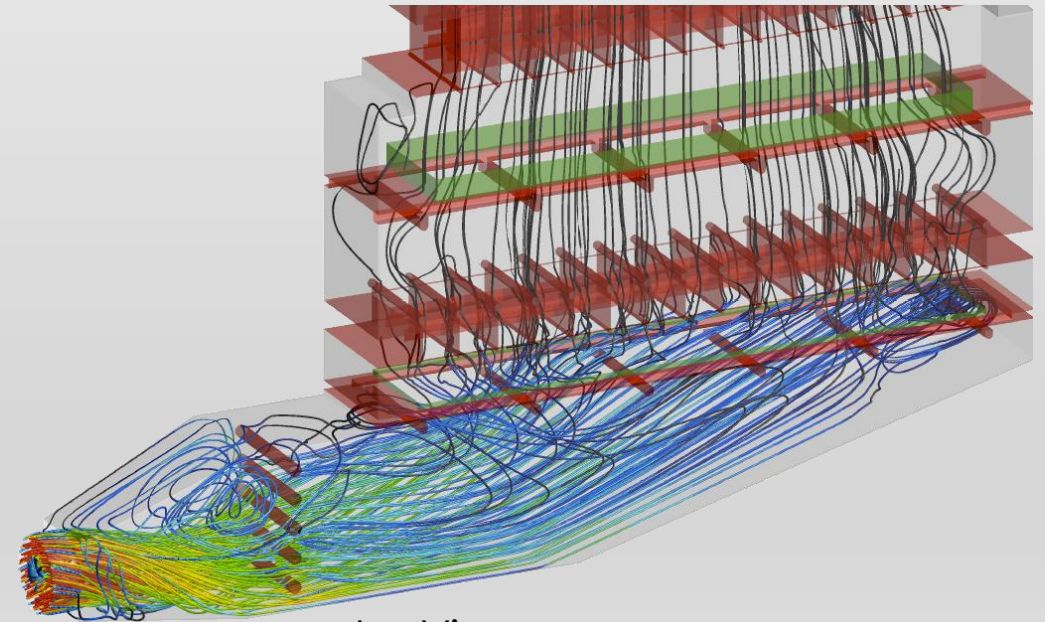
- Baseline results, with no flow control devices, show a large recirculation zone and poor velocity uniformity at the tubebank.
- Velocity RMS at the tubebank = 25%



Side View



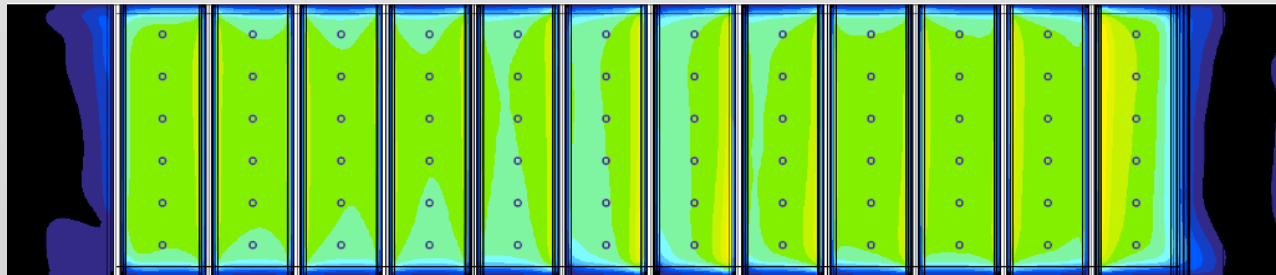
Plan View – Tubebank Inlet Velocity



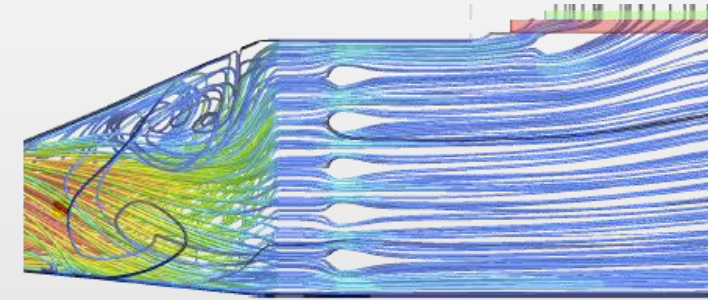
Iso View

CASE STUDY – THERMAL OPTIMIZATION

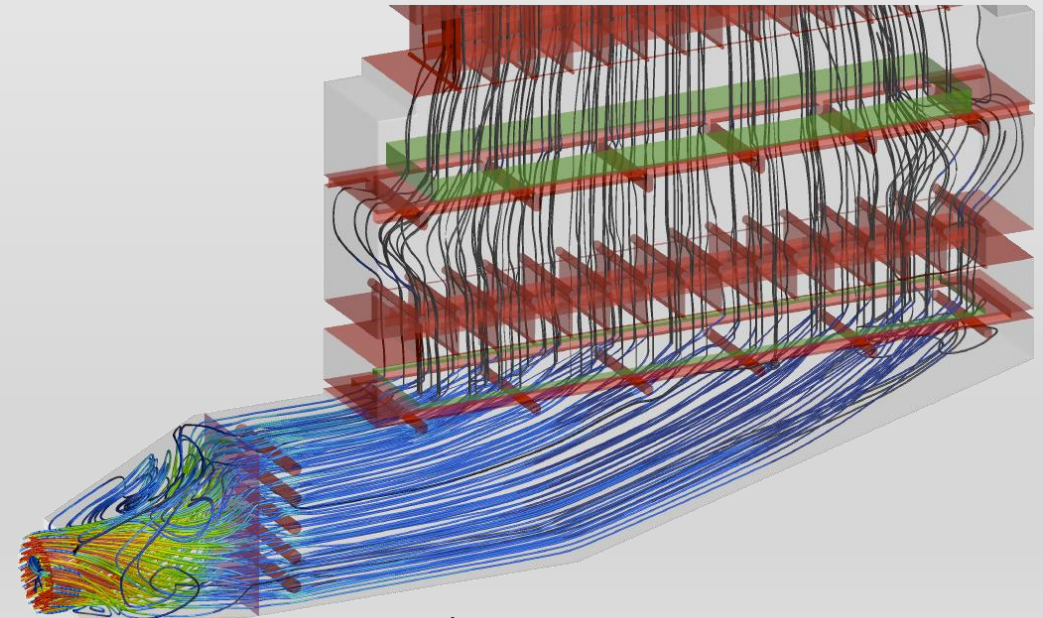
- Perforated plate set added to provide more uniform side-to-side velocity distribution.
- Velocity RMS at the tubebank reduced to 4%.
- Improvements made to the design prior to installation, saving headaches.



Plan View – Tubebank Inlet Velocity



Side View



Iso View

CONCLUSIONS

- There are many parameters that affect GT power plant performance
- Need optimized design for flow, temperature, ammonia, NOx, and pressure drop
 - CFD modeling
 - Scale physical modeling
 - Field testing
- Many flow-related parameters are inter-related
 - Ammonia non-uniformity can cause DP and heat rate issues
 - Poor velocity distribution can result in skewed heat transfer at tube banks
 - Tube bank, catalyst and AIG seals/baffles seem “simple” but if not designed/maintained can have significant negative impact
 - Bigger engines require a new look at goals, margin vs. goals, and goals over the load range

CONTACT INFORMATION

Matt Gentry, P.E.

Airflow Sciences Corporation

Engineering Manager

734-525-0300 x211

MGentry@AirflowSciences.com

www.AirflowSciences.com

www.AzoreCFD.com



 Airflow Sciences Corporation
fifty years of delivering trusted flow solutions