

REINHOLD ENVIRONMENTAL Ltd.



2017 NO_x-Combustion-CCR Round Table Presentation

February 27 & 28, 2017, in Cleveland, OH / Hosted by FirstEnergy

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Optimization of Boiler Emissions & Heat Rate

Reinhold Environmental NO_x – Combustion – CCR
Round Table

Cleveland, OH

February, 2017

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Outline

- Introduction
- Testing
- Modeling
- Case Study
- Conclusion

Introduction

- ❑ Optimizing boiler emissions and heat rate
 - ❑ MATS compliance
 - ❑ Reduced operating costs
 - ❑ Reduced maintenance costs

Introduction

- Many systems to consider for optimization
 - Primary air
 - Coal flow
 - Secondary air
 - Overfire air

- Additional items not covered
 - Inleakage
 - CEMS accuracy
 - Turbines
 - Compressors

Systems to Consider

- Primary air

- Mill to mill split

- Pipe to pipe split

- Coal flow

- Pipe to pipe split

- Fineness

- Secondary air

- Proper flow split

- Uniformity of flow at the burner

- Overfire air

- Proper flow split

Evaluation Tools

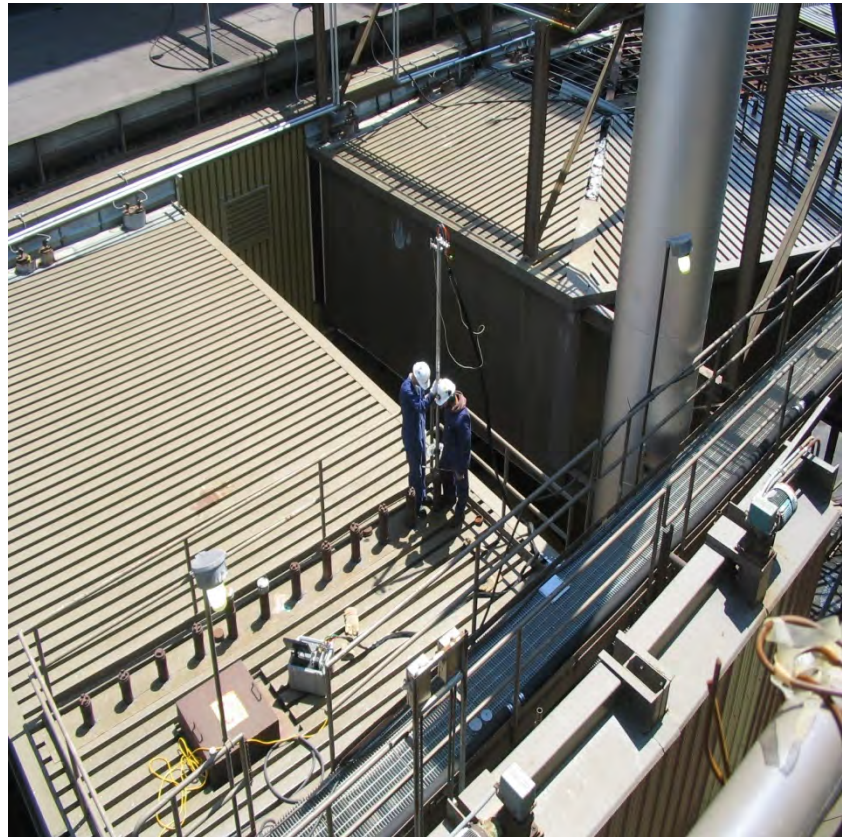
- Flow element
 - Pitot array
 - Airfoil
 - Venturi
 - Microwave
- Periodic testing
- Modeling
- Observation
- Trial and error

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- Testing
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Flow Testing Focus

- ❑ Performance
 - ❑ Flow uniformity
 - ❑ Flow element calibration
 - ❑ Air/coal flow rates
 - ❑ Emissions / species
 - ❑ Temperature



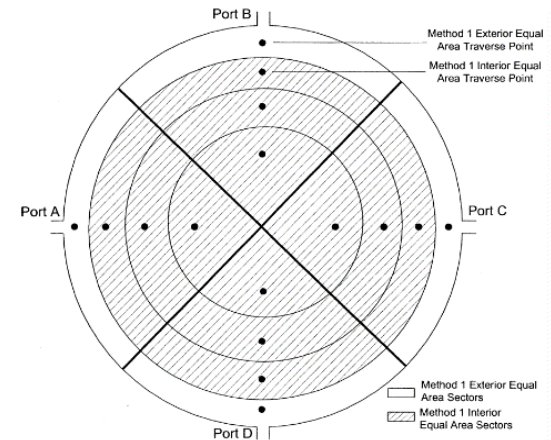
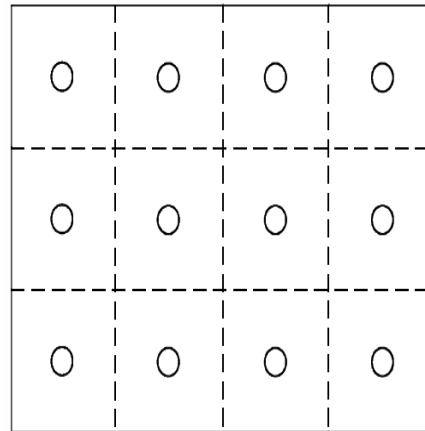
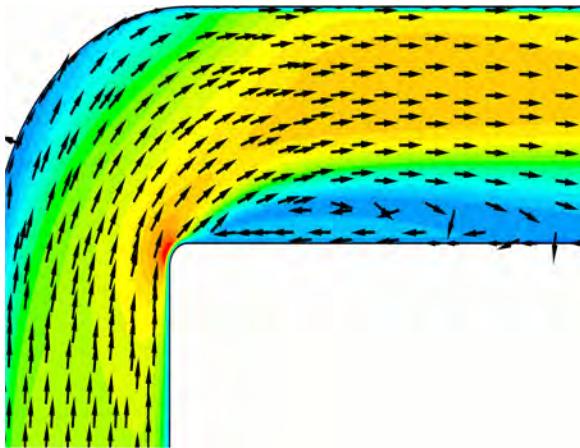
Flow Testing Focus

- O&M costs
 - Pressure drop
 - Chemical costs (NH₃)
 - Sorbent costs
 - Erosion
 - Corrosion
 - Slagging



Velocity, Temperature, & Pressure

- ❑ Applications – PA, SA, OFA, AH, fans, APC equipment, stacks, etc...
- ❑ EPA Method 1 - Test port quantity and location of traverse points



Velocity, Temperature, & Pressure

- ❑ EPA Method 2 - Velocity with S-type pitot probe



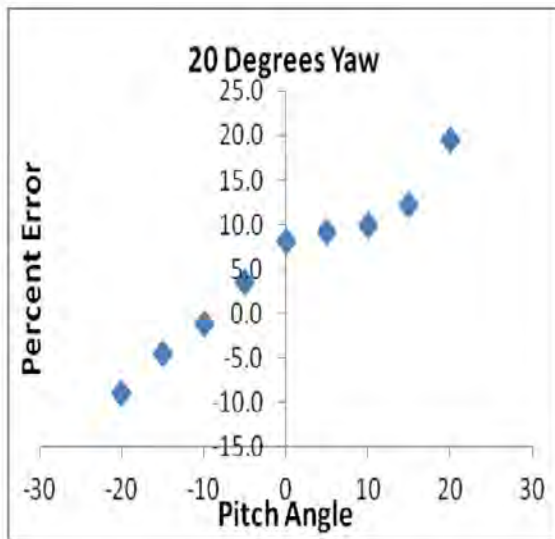
Velocity, Temperature, & Pressure

- ❑ EPA Method 2F - Velocity with 3D pitot probe

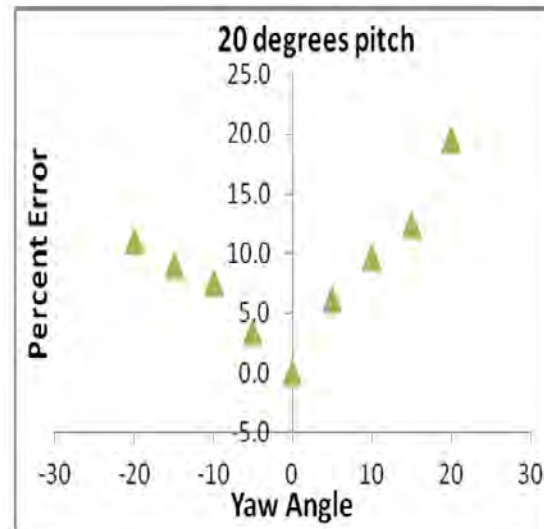


Velocity, Temperature, & Pressure

- ❑ Method 2F vs Method 2, why should I care?
 - ❑ Flow misalignment with probe means the velocity measurement is biased
 - ❑ Has direct impact on measured flow rate



Percent error at 20° yaw

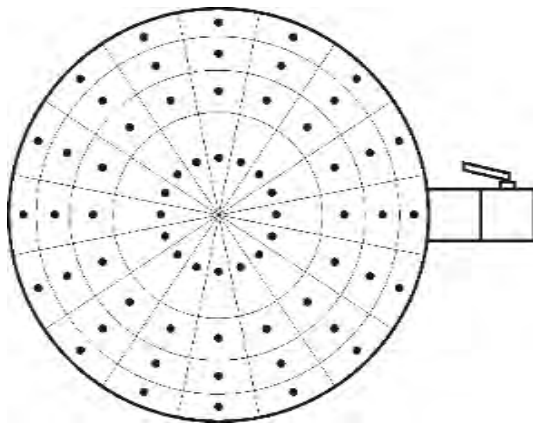


Percent error at 20° pitch



Coal Sampling

- ❑ Coal pipe testing
 - ❑ Velocity with Dirty Air Probe
 - ❑ Isokinetic sampling via ISO9931 or ASME style probes



Gas Sampling

- ❑ Evaluate emissions profile at boiler exit
- ❑ Evaluate leakage across the air heater
- ❑ Evaluate conditions in the boiler (H₂O cooled probe)



QAQC

- Is this test data any good?
 - Equipment calibration
 - Leak checks
 - Spatial considerations
 - Operator influence
 - Repeatability



QAQC

Airflow Sciences Corporation Rectangular 3-D Duct Traverse Project: AEN Site: ABC Power - XYZ Power Plant Task: Unit 1 SA Airfoil Calibration Location: Duct 1 Condition: Test 1 Full Load Personnel: mrg, rms Date: Friday, 6/8/2016				3DDAS019, Calibrated: 05/31/2016 3-D Probe v.4.9.r13 Start Time: 6:04 PM End Time: 7:45 PM																																											
Duct Width [ft]: 9.58 Duct Depth [ft]: 4.50 Number of Test Ports: 5 Number of Test Points per Port: 15 Dry Gas Molecular Weight [g/mol]: 28.967 Water Vapor Volume Fraction, Bws [-]: 0 Spec. Gas Constant [(ft-lbf)/(slug-R)]: 1716.2				Last Leak Check: 06/08/16 04:57 PM Decay Time [s]: 15 Start P [IWC]: 25.92 End P [IWC]: 25.90																																											
Test Data Summary Total Wet Gas Mass Flow Rate [lbm/hr]: 321.579 Total Wet Gas Vol. Flow Rate, Qsw [WSCFH]: 4,277.960 Total Dry Gas Vol. Flow Rate, Qsd [DSCFH]: 4,277.960				Probe Used 3D046 Rsl0: 1.5 Probe Calibration Date: 6/6/2016																																											
Axial Velocity [ft/s]: Temperature [°F]: Wet Gas Density [lbm/ft³]: Static Pressure [IWC]: Total Pressure [IWC]: Barometric Pressure [°Hg at 32°F]:				Pressure Transducer Zero Readings (in IWC) <table border="1"> <thead> <tr> <th></th> <th>P1-P2 (low)</th> <th>P1-P2 (high)</th> <th>P2-P3</th> <th>P4-P5 (low)</th> <th>P4-P5 (high)</th> <th>P1-Pbar</th> <th>Time</th> </tr> </thead> <tbody> <tr> <td>PRE</td> <td>0.000</td> <td>0.003</td> <td>-0.002</td> <td>0.000</td> <td>-0.001</td> <td>-0.09</td> <td>5:44 PM</td> </tr> <tr> <td>POST</td> <td>0.000</td> <td>-0.001</td> <td>-0.004</td> <td>0.000</td> <td>-0.003</td> <td>-0.13</td> <td>7:47 PM</td> </tr> <tr> <td>SN</td> <td>D11200258</td> <td>60125963</td> <td>D11200019</td> <td>60125980</td> <td>D11200021</td> <td>1854974</td> <td></td> </tr> <tr> <td>RANGE</td> <td>0.0->1.0</td> <td>0.0->10.0</td> <td>-2.5->2.5</td> <td>-0.5->0.5</td> <td>-2.5->2.5</td> <td>-69.2->69.2</td> <td></td> </tr> </tbody> </table>					P1-P2 (low)	P1-P2 (high)	P2-P3	P4-P5 (low)	P4-P5 (high)	P1-Pbar	Time	PRE	0.000	0.003	-0.002	0.000	-0.001	-0.09	5:44 PM	POST	0.000	-0.001	-0.004	0.000	-0.003	-0.13	7:47 PM	SN	D11200258	60125963	D11200019	60125980	D11200021	1854974		RANGE	0.0->1.0	0.0->10.0	-2.5->2.5	-0.5->0.5	-2.5->2.5	-69.2->69.2	
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Min Max Avg 0.0 113.4 58.8 649.1 655.0 651.5 0.0351 0.0353 0.0352 5.84 6.88 6.22 5.93 7.48 6.69 29.05 29.07 29.06				NOTES: 1. All averages are number averages, not flow weighted averages 2. Calculation of total mass flow rate (lbm/hr) is based on individual areas for each traverse point; these areas are not necessarily equal 3. Calculation of wet and dry volumetric flow rate (SCFH) is based on the number-average axial velocity (per EPA Method 2F) and hence assumes equal areas regardless of test port spacing																																											
Traverse Data MEASURED VALUES				CALCULATED VALUES																																											
Port	Point	Port Spacing [ft]	Withdrawal Distance [ft]	Time (Local)	Area [ft²]	Patm [°Hg at 32°F]	P1-P2 [IWC]	P2-P3 [IWC]	P4-P5 [IWC]	P1-Pbar (Total P Gage) [IWC]	Temp [°F]	Yaw Null Angle [°]	Yaw Angle [°]	F1 [-]	Pitch Angle [°]	F2 [-]	Dynam P [IWC]	Static P [IWC]	Wet Gas Density [lbm/ft³]	Total Velocity [ft/s]	Vaxial [ft/s]	Vpitch [ft/s]	Vyaw [ft/s]	Mass Flow [lbm/hr]	Wet Vol Flow [WACFH]	Wet Vol Flow [WSCFH]																					
1	1	0.96	0.15	6:04 PM	0.58	29.07	0.454	0.004	-0.114	6.78	649.1	15.2	13.7	-0.252	-16.6	1.137	0.587	6.19	0.0353	74.6	69.4	-21.4	17.0	5,072	143,693	67,448																					
1	2	0.96	0.45	6:04 PM	0.58	29.07	0.715	0.007	-0.045	7.21	649.4	8.9	7.4	-0.062	-2.1	1.104	0.871	6.34	0.0353	90.9	90.0	-3.3	11.7	6,580	186,385	87,496																					
1	3	0.96	0.75	6:04 PM	0.58	29.07	0.790	-0.028	0.055	7.30	650.0	8.6	7.1	0.069	8.8	1.088	0.935	6.37	0.0353	94.2	92.4	14.4	11.5	6,747	191,227	89,726																					
1	4	0.96	1.05	6:05 PM	0.58	29.07	0.362	-0.014	-0.093	6.80	649.2	5.1	3.6	-0.256	-16.9	1.138	0.469	6.33	0.0353	66.7	63.7	-19.4	4.0	4,652	131,758	61,860																					
1	5	0.96	1.35	6:06 PM	0.58	29.07	0.690	0.026	-0.038	7.03	649.1	5.0	3.5	-0.055	-1.5	1.103	0.839	6.19	0.0353	89.2	89.0	-2.3	5.4	6,502	184,200	86,460																					
1	6	0.96	1.65	6:07 PM	0.58	29.07	0.573	-0.026	-0.012	7.09	649.3	8.1	6.6	-0.022	1.3	1.098	0.691	6.40	0.0353	80.9	80.4	1.8	9.3	5,874	166,353	78,112																					

QAQC

AIRFLOW SCIENCES CORPORATION Advanced Coal Flow Measurement Coal Pipe Traverse Results				Software Version 6.0.34 Pressure Transducer Cal Date: 01/13/2015 Flow Meter Cal Date: 01/13/2015 Gas Molecular Weight (g/mol): 28.97 Atmospheric Pressure ("Hg): 25.57			
Backwoods Power Plant Unit 2 Coal Pipe Testing Wednesday, August 12, 2015 14:56:04 - 15:17:39							
Test Number: 1.0		Mill: A		Pipe: 4		Conducted By: jde	
Pipe Diameter (inches): 14.75		Number of Test Ports: 2		Number of Traverse Points/Port: 13		Sample Time Per Point (s): 15.00	
Total Sample Time (s): 390.50		Dirty Air Probe Used: DA005		Probe Nozzle Area (in ²): 0.077		ACFM SN: 0014	
Velocity (ft/s): 80.6 120.3 102.5		Temperature (F): 144.0 145.4 144.7		Static Pressure (IwC): 2.27 4.04 3.30		Total Pressure (IwC): 3.68 6.43 5.14	
Percent Isokinetic: 98.9 100.8 99.9		Coal LID Correction Factor (-): 1.000		Total Air Mass Flow (lbm/hr) 24,799		Coal Sample Weight (g): 168.5	
				Total Coal Mass Flow (lbm/hr) 7,629		Air/Coal Ratio: 3.25	

Air Velocity Profiles

Measured Values										Calculated Values								
Port	Point	Probe Withdrawal (in)	Air Temp (deg F)	Probe Delta P (IwC)	Probe Rel P (IwC rel)	Coal Samp Wt (g)	Coal Samp Time (s)	Air Probe Cal Fac (-)	Air Probe Cp (-)	Air Dyn P (IwC)	Air Static P (IwC rel)	Air Total P (IwC rel)	Air Density (lbm/ft ³)	Air Velocity (ft/sec)	Air Mass Flow (lbm/hr)	Coal Mass Flow (lbm/hr)	Extraction Percent Isokinetic	Air/Coal Ratio (-)
1	1	-7.09	144.5	2.280	2.01	NA	NA	0.903	-0.580	2.059	3.21	5.26	0.05685	110.3	1,027	NA	98.9	NA
1	2	-6.47	144.2	2.292	2.33	NA	NA	0.903	-0.580	2.070	3.53	5.60	0.05673	110.5	1,030	NA	100.2	NA
1	3	-5.79	144.5	1.922	1.77	NA	NA	0.904	-0.580	1.736	2.78	4.51	0.05658	101.4	942	NA	100.6	NA
1	4	-5.01	144.6	1.557	1.45	NA	NA	0.906	-0.580	1.411	2.27	3.68	0.05649	91.4	849	NA	100.7	NA
1	5	-4.09	144.5	2.085	2.46	NA	NA	0.903	-0.580	1.883	3.56	5.44	0.05670	105.4	982	NA	99.4	NA
1	6	-2.89	144.6	2.154	2.25	NA	NA	0.903	-0.580	1.945	3.38	5.33	0.05666	107.2	998	NA	99.6	NA

Test Plan

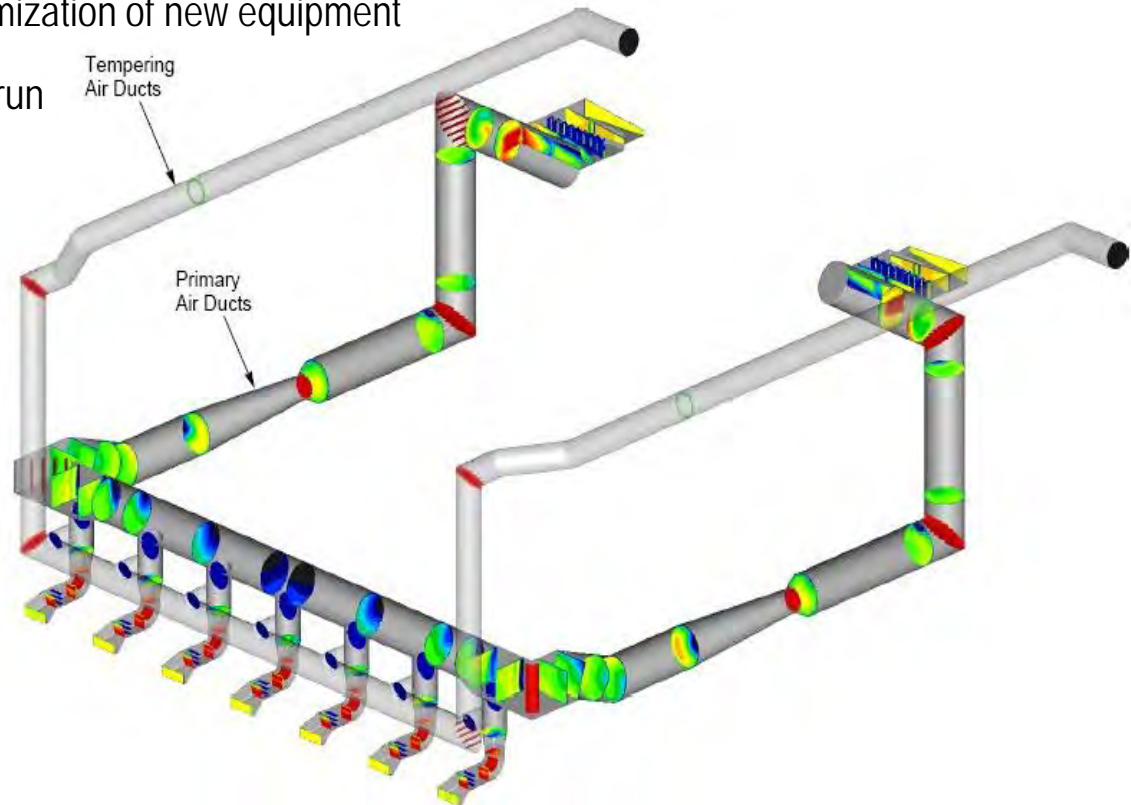
- Items to consider
 - How many loads to test
 - What does your DCS support
 - How do you typically operate
 - What control authority do you have

Outline

- Introduction
- Testing
- Modeling
- Case Study
- Conclusion

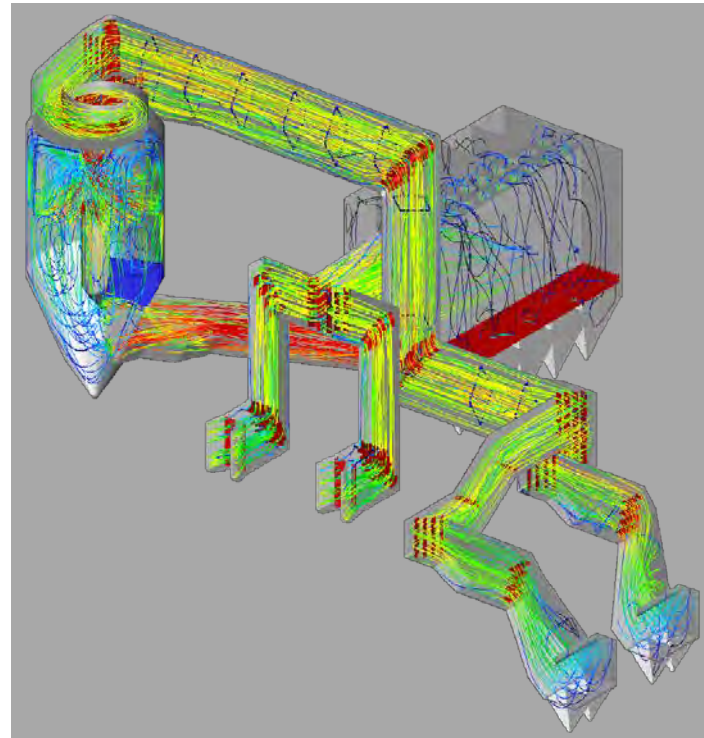
Flow Modeling

- ❑ Why perform flow modeling?
 - ❑ Verify design of new equipment
 - ❑ Conduct troubleshooting / optimization of new equipment
 - ❑ Save time and \$\$\$ in the long run



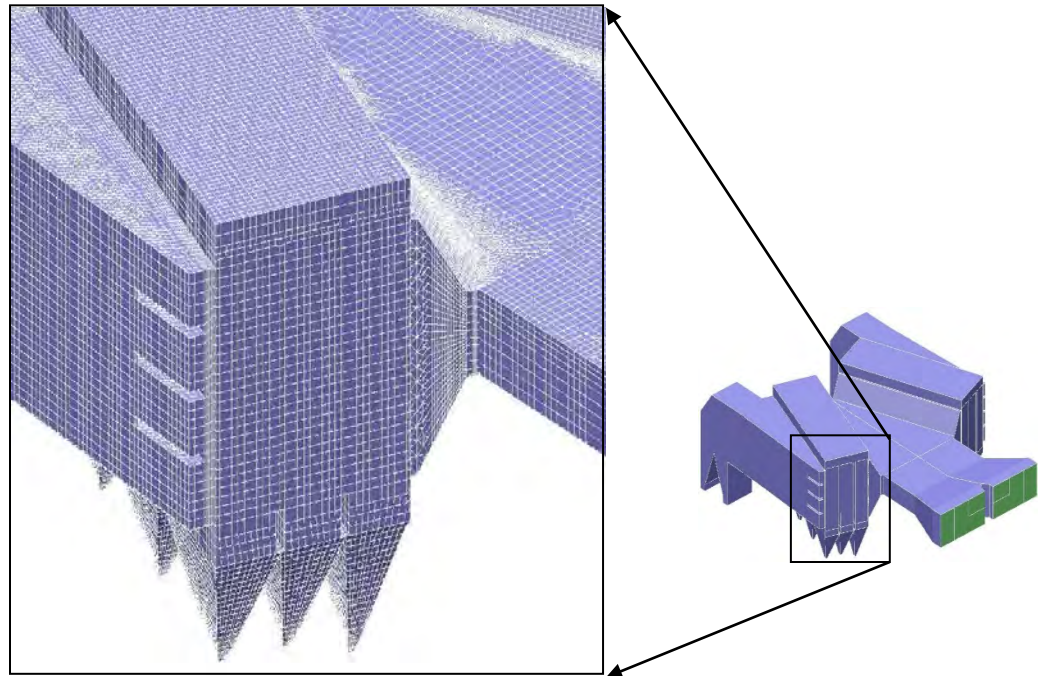
Computational Fluid Dynamics (CFD)

- ❑ Numerical simulation of flow
- ❑ Utilize high speed computers and sophisticated software
- ❑ Calculate flow properties
 - ❑ Velocity
 - ❑ Temperature
 - ❑ Pressure
 - ❑ Chemical Species
 - ❑ Particle streamlines



CFD Methodology

- ❑ Set up
 - ❑ Geometry (3D CAD)
 - ❑ Computational mesh
 - ❑ Boundary conditions
- ❑ Solve
- ❑ Analyze
 - ❑ Contour plots
 - ❑ Flow statistics and integrations



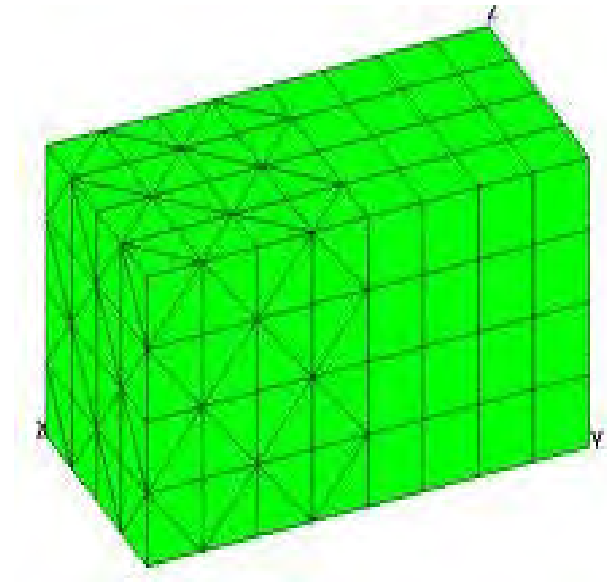
CFD Mesh Quality

Important mesh properties

- Number of cells
- Length scale of cells
- Shape / topology of cells
- Flow alignment

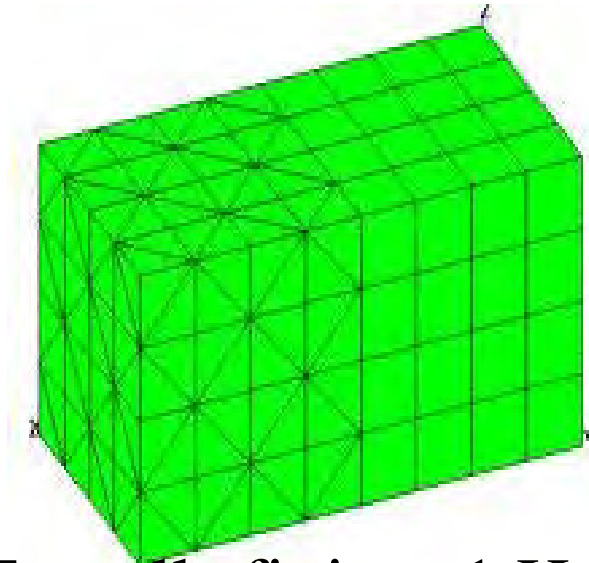
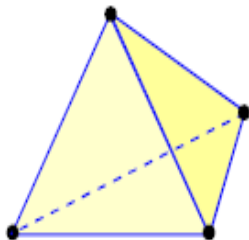
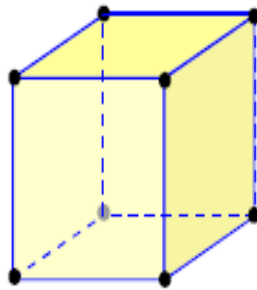
Why?

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



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



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

Physical Flow Modeling

- ❑ Laboratory representation of geometry
- ❑ Typical scale between 1:8 and 1:16
- ❑ “Cold flow” modeling
- ❑ Visualize flow with smoke
- ❑ Measure flow properties
 - ❑ Velocity (hot wire or pitot)
 - ❑ Pressure (pitot-static probe w/ manometer)
 - ❑ Tracer gas (gas analyzer)



Physical Model Methodology

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

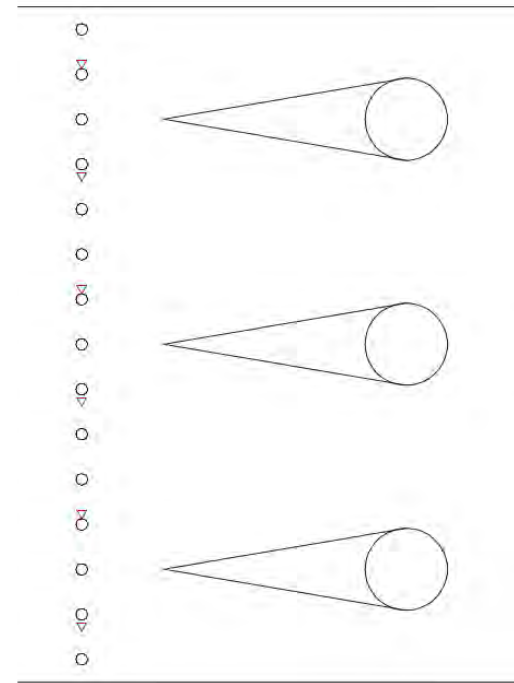


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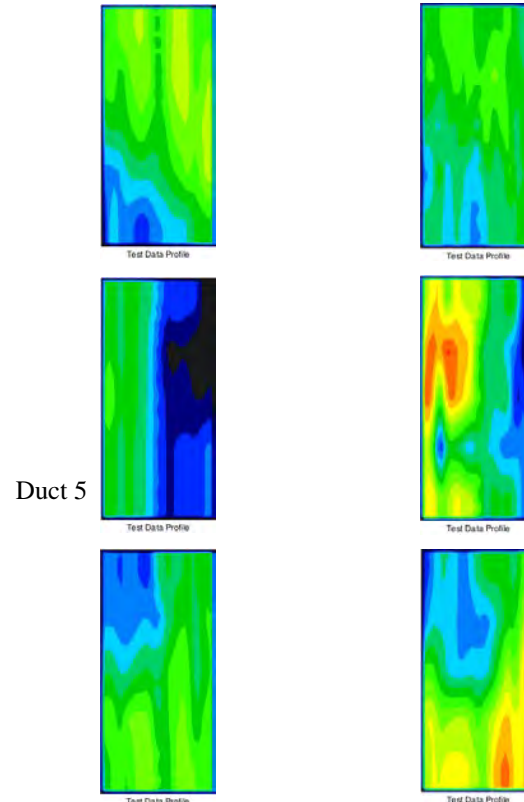
Case Study – Calibration Testing

- ❑ Utility replaced pitot array with airfoils in their SA ducts
- ❑ Initial calibration performed at 6 points per port with S-type probe
- ❑ Given geometry, appropriate number of points is 15 and angular flows are expected



Case Study – Calibration Testing

- ❑ Calibration testing performed at 6 ducts with airfoils at two loads
- ❑ DCS allows for a single K factor for each airfoil
- ❑ K factor generally constant across loads except Duct 5
- ❑ Duct 5 dampers constantly fluctuating, causing unit de-stabilization

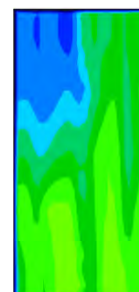
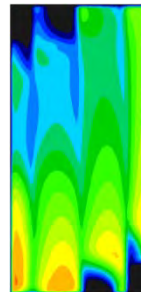
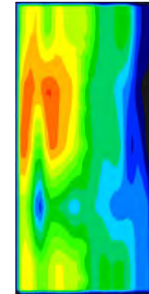
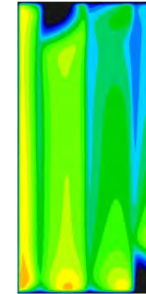
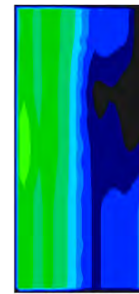
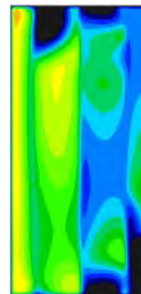
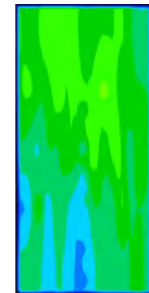
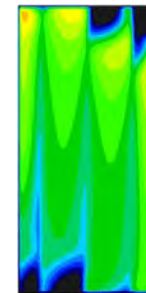
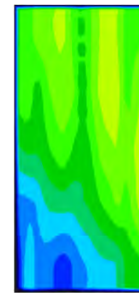
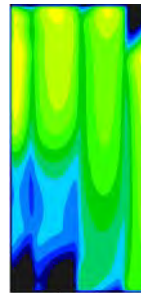


Case Study – CFD Modeling

- CFD model commissioned
 - Improve flow uniformity
 - Improve flow split to each winbox compartment
- Baseline model created to compare with test data

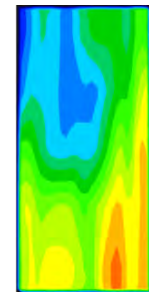
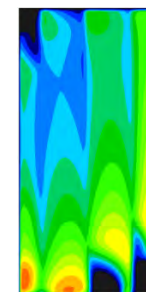
Case Study – CFD Modeling

- Baseline model demonstrated excellent agreement with test data



CFD

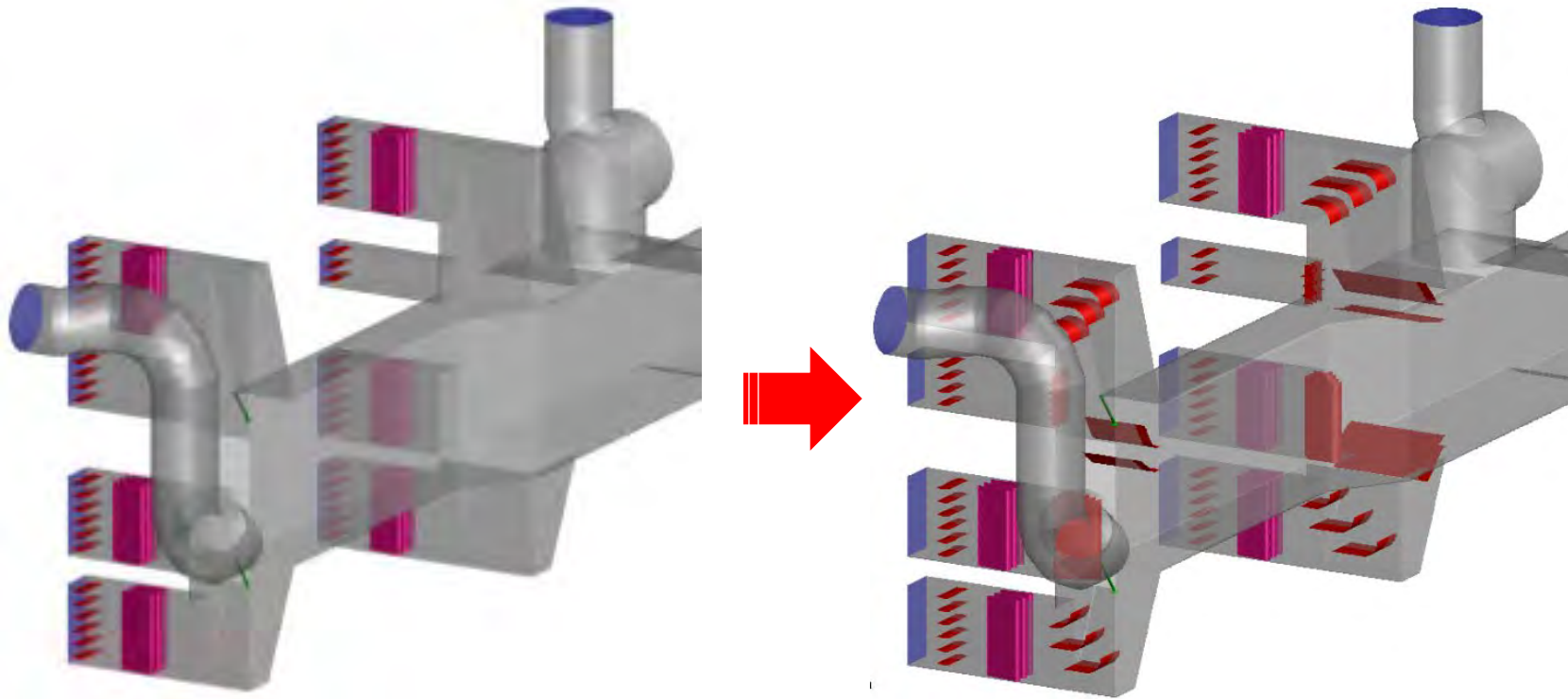
Test
Data



CFD

Test
Data

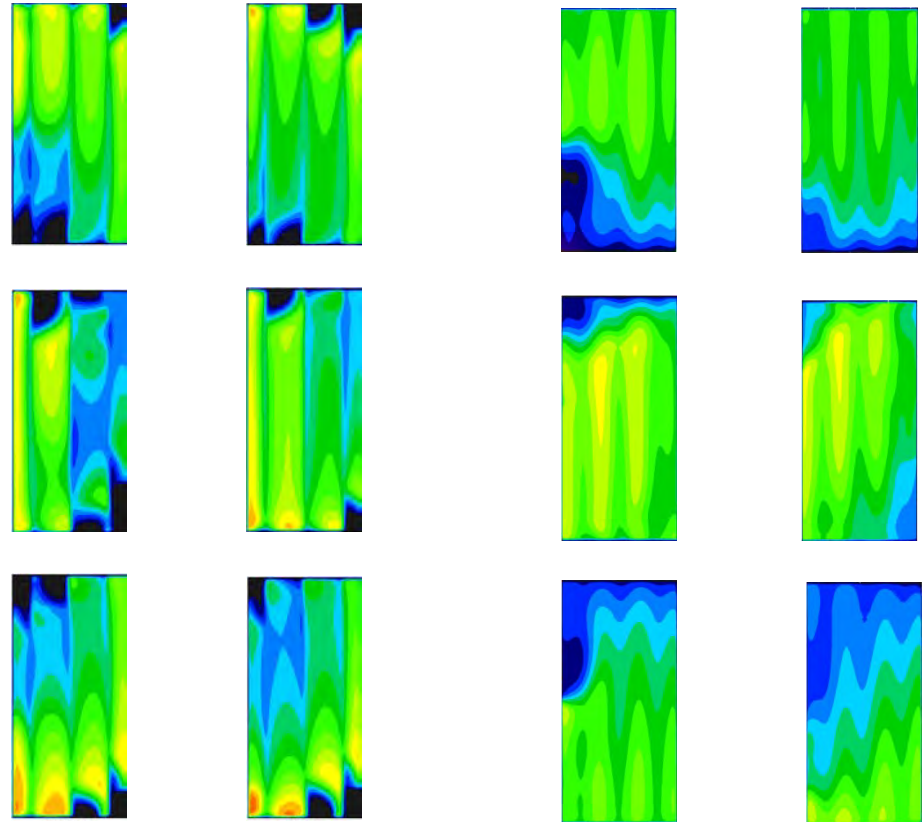
Case Study – Design Modifications



New vanes in duct and at
compartment inlets

Case Study – Design Results

- ❑ Improved flow uniformity, particularly side-to-side
- ❑ Eliminated “run away dampers” in duct five
- ❑ Improved flow split between ducts, ultimately saving pressure by reducing damper influence



Baseline

Design

Outline

- Introduction
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Conclusion

- Numerous systems affect emissions and heat rate
- Tools for improvement include modeling and testing
- Regardless of approach, care must be taken to ensure a positive result

Modeling

- Realistic boundary conditions
- Quality mesh
- Does it match reality?

Testing

- Use the right equipment for the job
- QAQC

Questions?

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