Reinhold Environmental Ltd.

2008 NOx-Combustion Round Table & Expo Presentation

February 4-5, 2008 in Richmond, VA

Graduated Straightening Grid Technology

Fluid Dynamics Analyses of SCR Reactor Hood Arrangements

2008 NO_x-Combustion PCUG Roundtable

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Agenda

- Review the current state of SCR fluid dynamics design
- Review the development of alternative technology
- Review results from recent projects
- Feedback and discussion

SCR Design

Selective Catalytic Reduction (SCR) is a process whereby Nitrogen Oxides (NO_x) are converted into N_2 and H_2O with the aid of a ceramic catalyst

- NH_3 is added to flue gas and reacts with NO_x in catalyst pores at temperatures between 450 and 840 F

$$\begin{aligned} 4NO + 4NH_3 + O_2 &\rightarrow\ 4N_2 + 6H_2O \\ 2NO_2 + 4NH_3 + 2O_2 &\rightarrow\ 3N_2 + 6H_2O \\ 2NO_3 + 4NH_3 + O_2 &\rightarrow\ 3N2 + 6H_2O \end{aligned}$$

- With proper design reduction can be as high as 95%

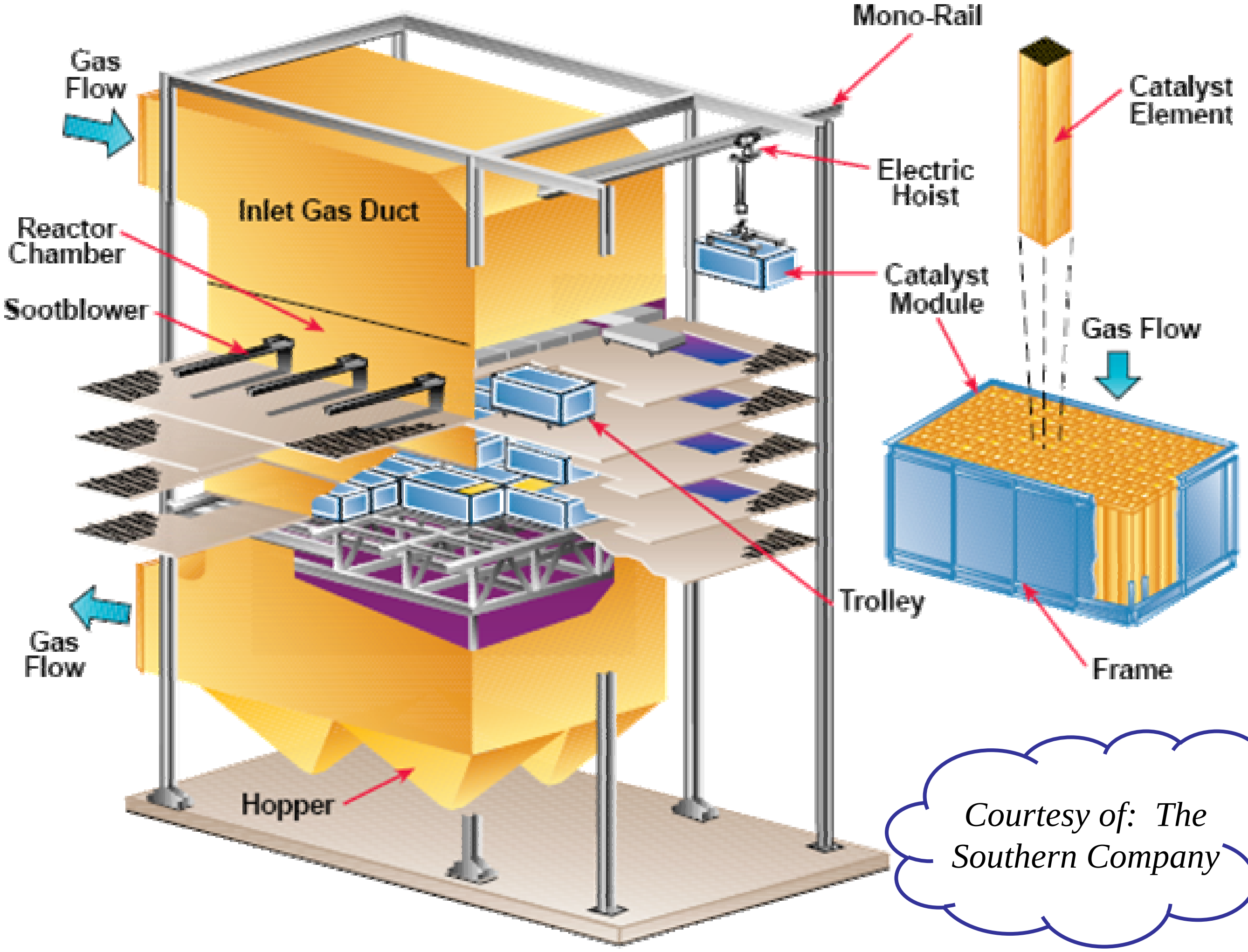
SCR Design

Fluid dynamics are critical to successful SCR operation

- Velocity and NH_3/NO_x uniformity critical factors;
  - Higher NO_x reduction
  - Lower NH_3 slip
  - Less risk of erosion
  - Less risk of pluggage
  - Less draft pressure loss
- Standard design criteria;
  - All velocity measurements at the inlet to the first layer of catalyst within 15% of the average velocity
  - Less stringent; velocity distribution with normalized standard deviation of 15%

SCR Design

Reactors are oriented vertically to reduce the risk of pluggage and are larger than standard ductwork to prevent erosion



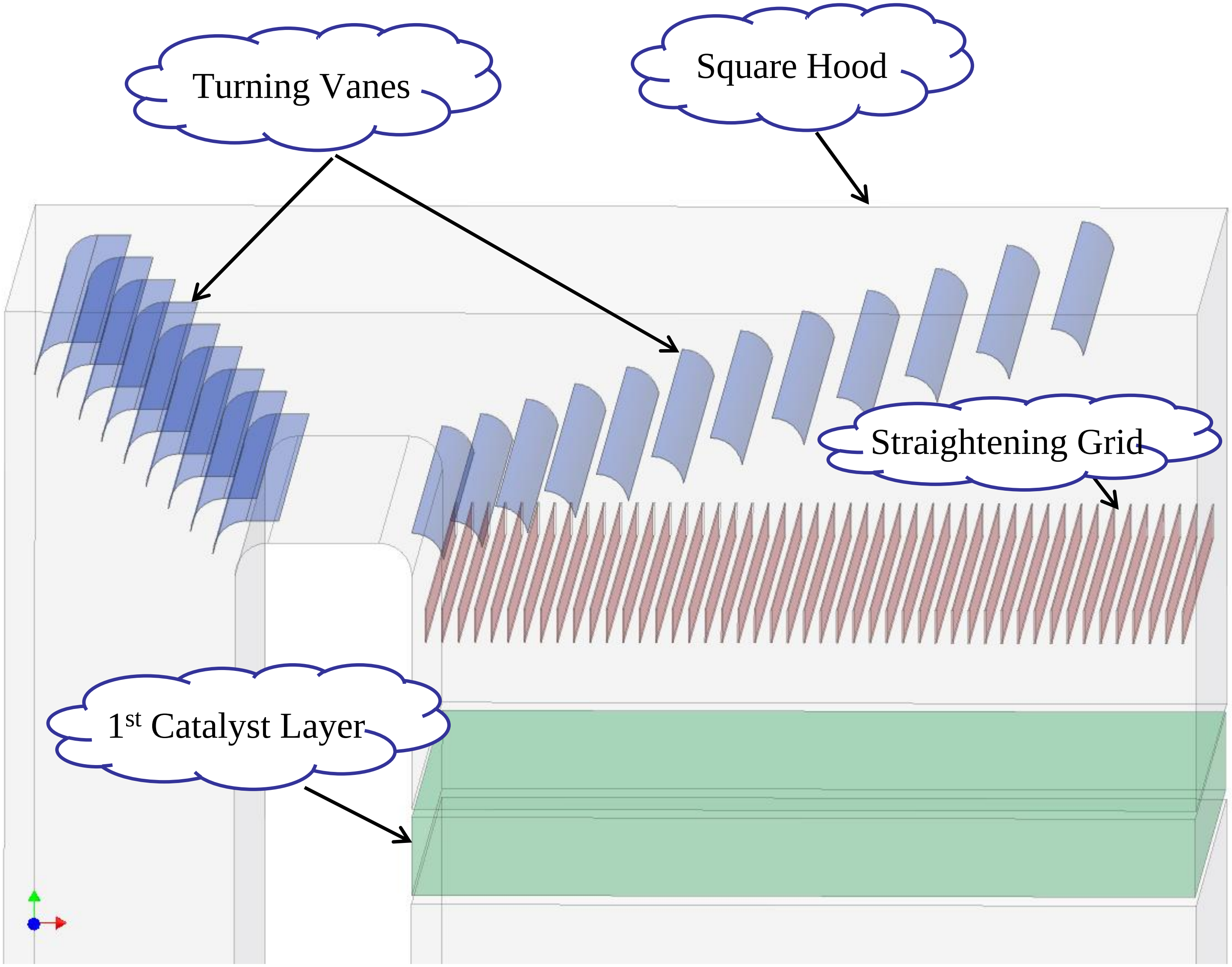
Courtesy of: The Southern Company

SCR Design

There are two standard arrangements which we will call

- Standard Design A
- Standard Design B

SCR Design: Standard Design A


Turning Vanes

Square Hood

Straightening Grid

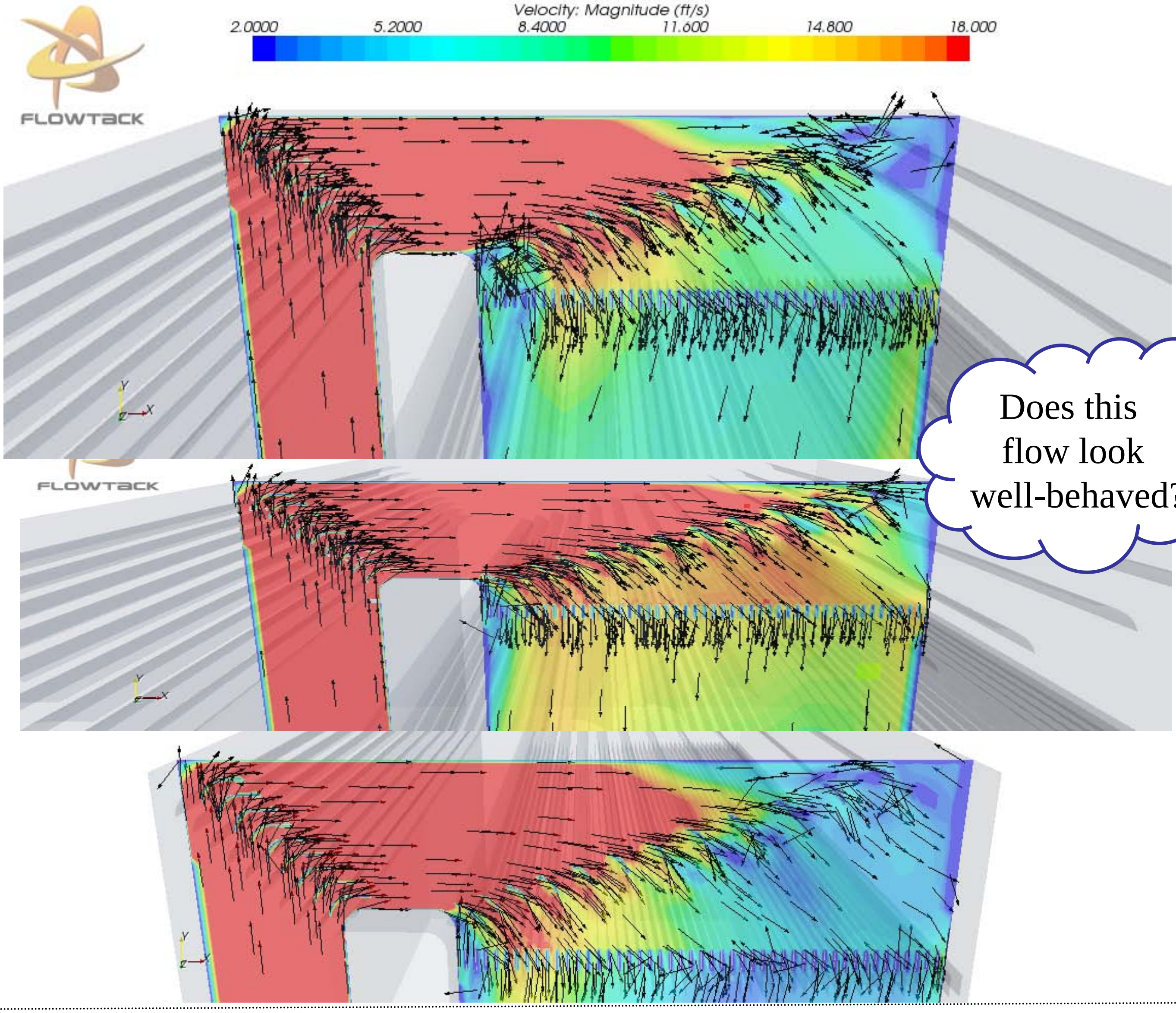
1st Catalyst Layer

Design A Fluid Dynamics

Operational problems due to fluid dynamics of Design A

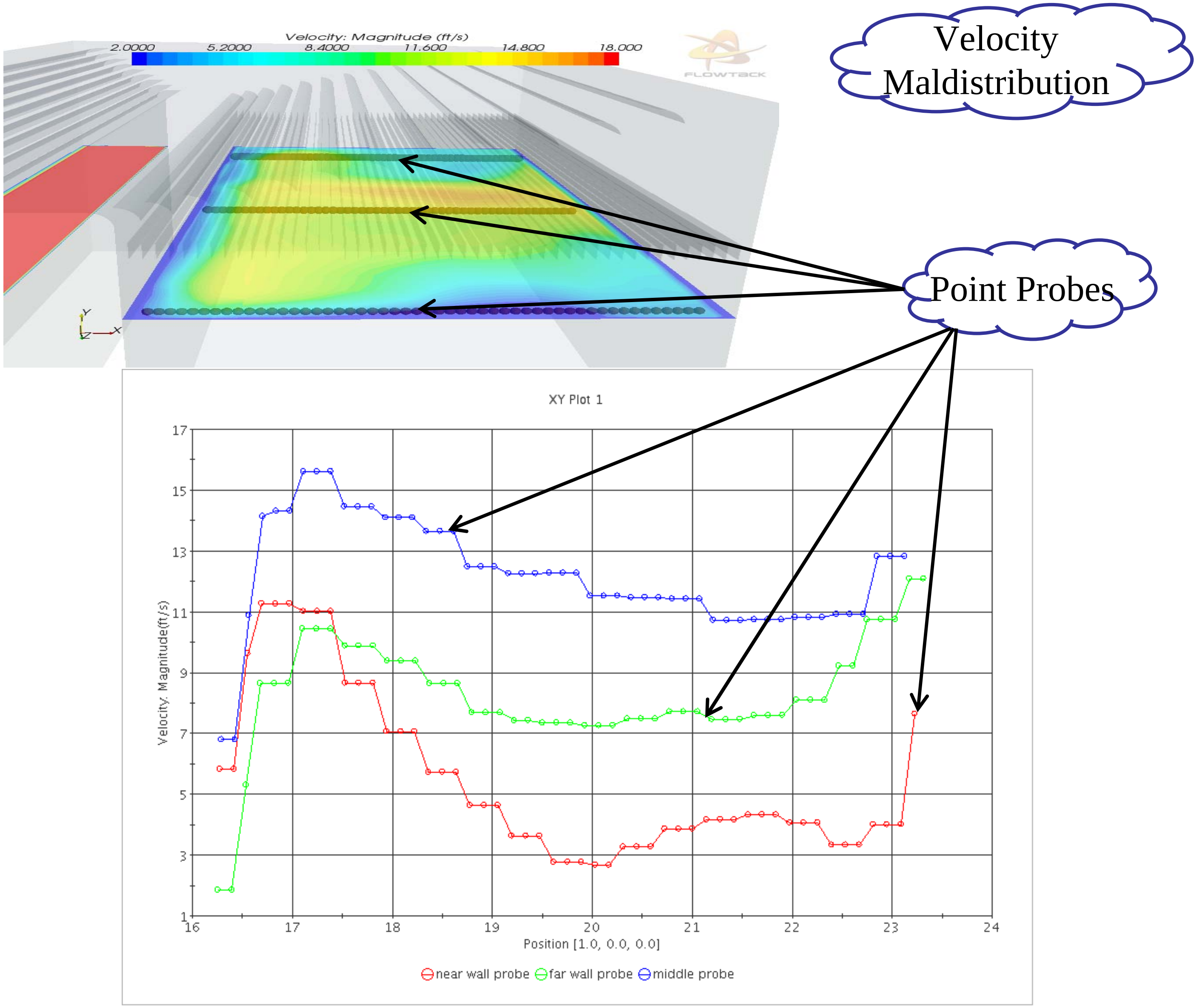
- Velocity distribution requirements difficult, sometimes impossible, to achieve (NO_x , NH_3 and erosion concerns)
- Fly ash on turning vanes tends to “slough off” and pile up on catalyst (catalyst plugging concern)
- Tendency for low velocities on inside corner (catalyst plugging, NO_x concerns)
- Angled flow into catalyst (erosion concern)

Design A Fluid Dynamics



Does this flow look well-behaved?

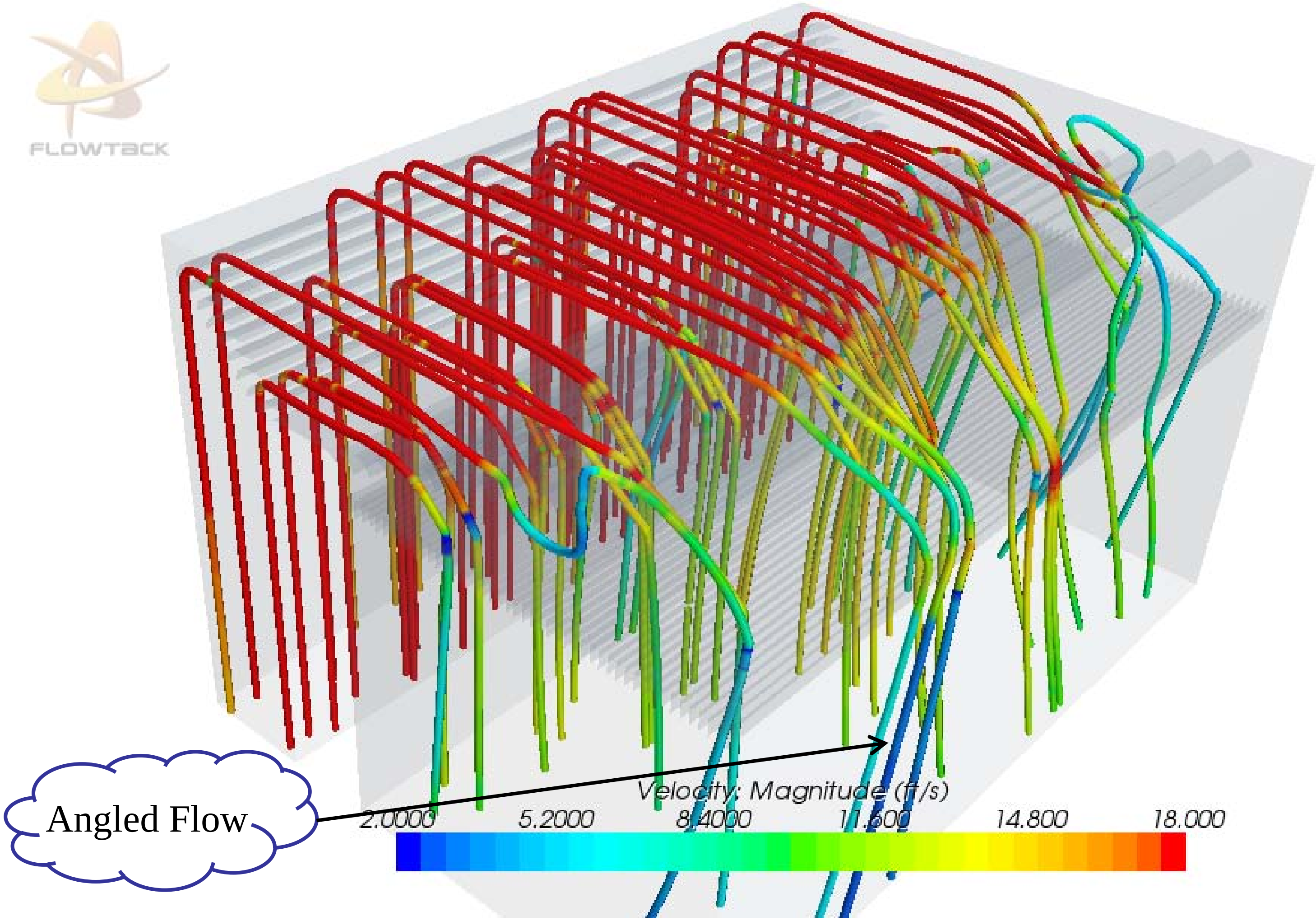
Design A Fluid Dynamics



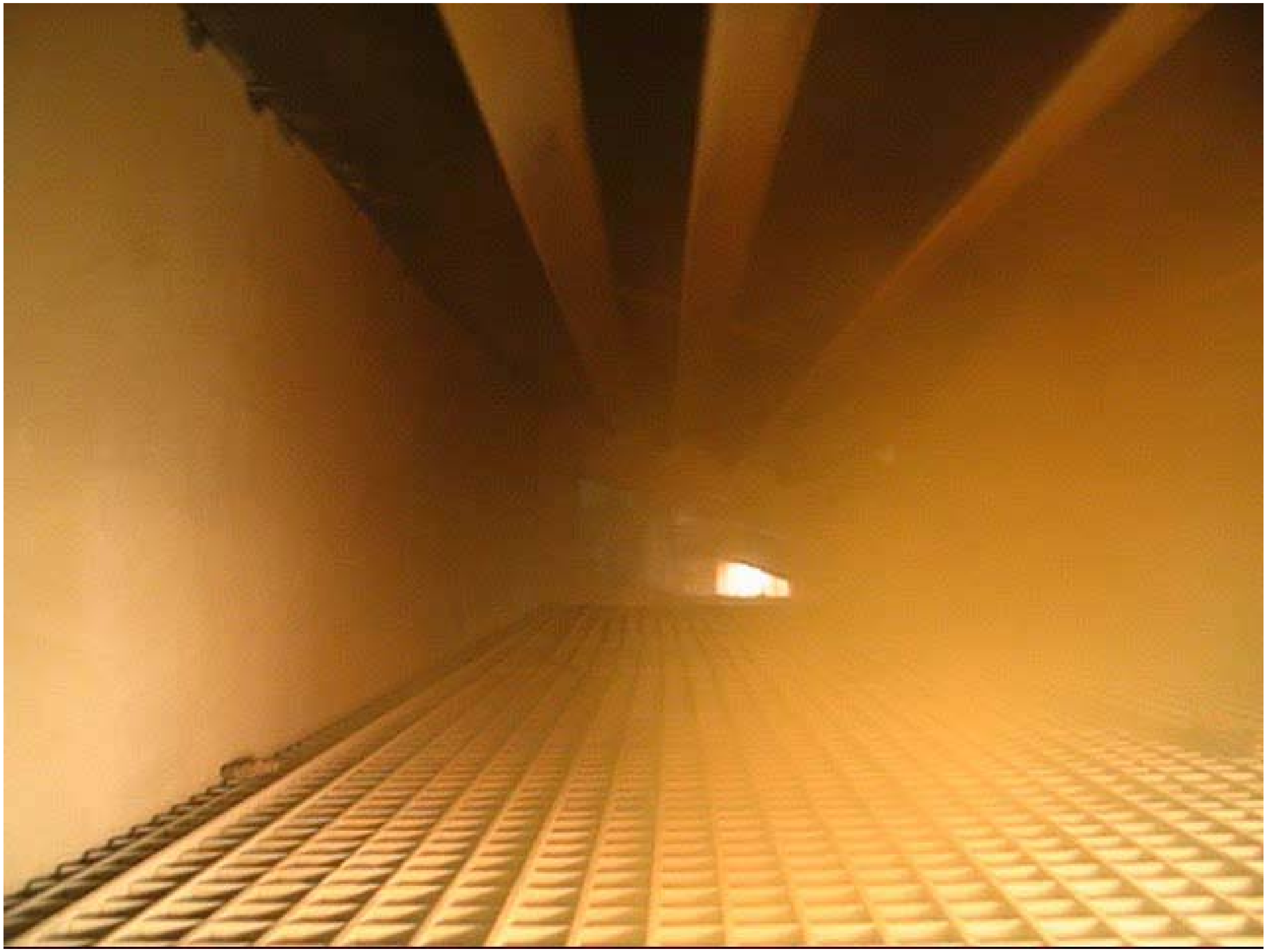
Velocity Maldistribution

Point Probes

Design A Fluid Dynamics



Design A Fluid Dynamics



Design A Fluid Dynamics

Design A Fluid Dynamics

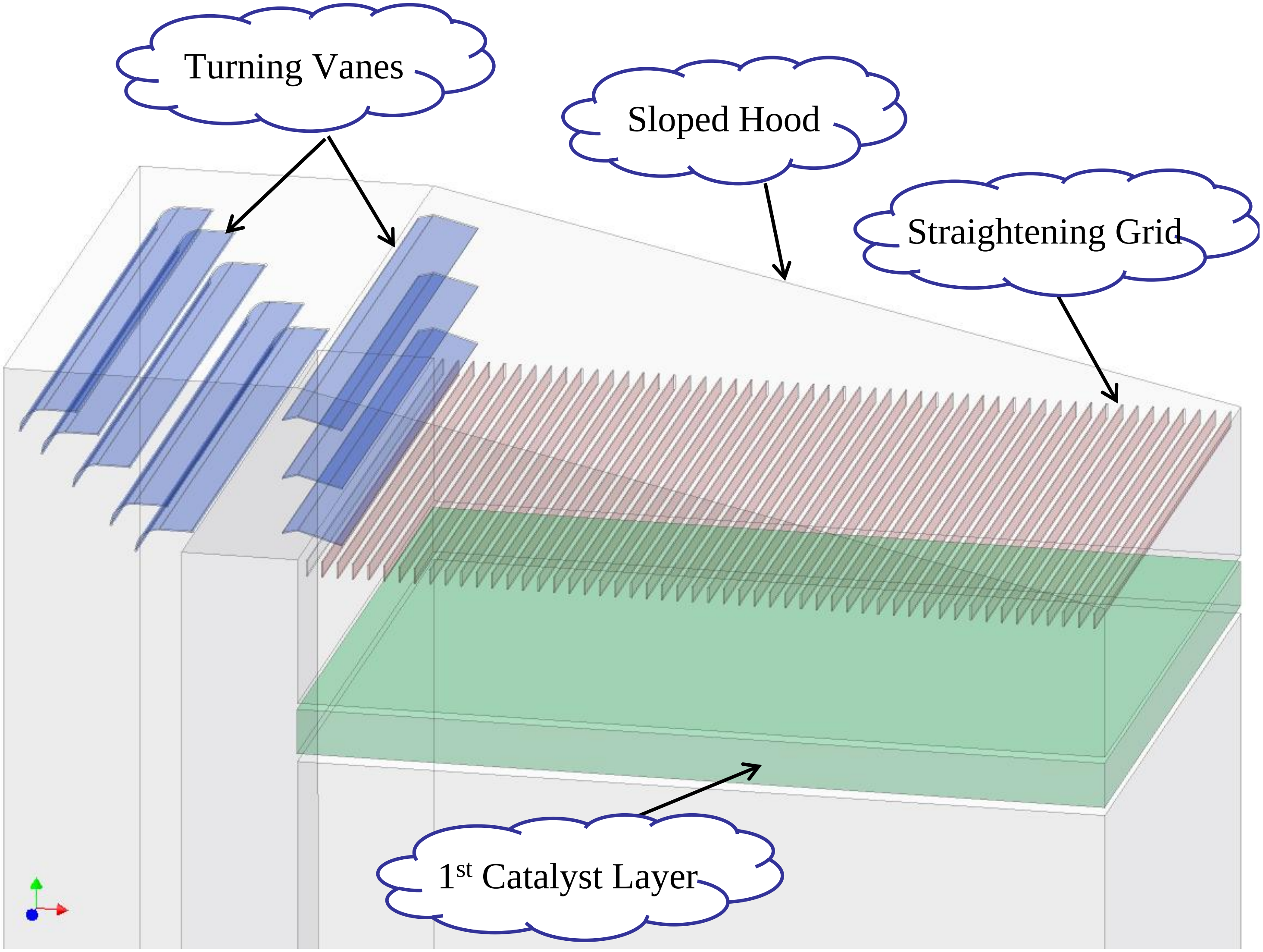
Velocity magnitudes

Criteria	+/- 5%	+/-10%	+/-15%	+/-20%	RMSE
Goal		***85%***	***100%***		
Unit A	26%	52%	75%	89%	13.8
Unit B	23%	47%	66%	80%	15.2
Unit C	18%	39%	47%	75%	17.1

Velocity angles

Criteria	+/- 5 °	+/- 10 °	+/- 15°	+/- 20 °	Avg.
Goal			***100%***		
Unit A	**6%**	**32%**	**68%**	**83%**	13.8 °
Unit B	**15%**	**45%**	**68%**	**80%**	14.1 °
Unit C	**7%**	**41%**	**61%**	**80%**	15.1°

SCR Design: Standard Design B

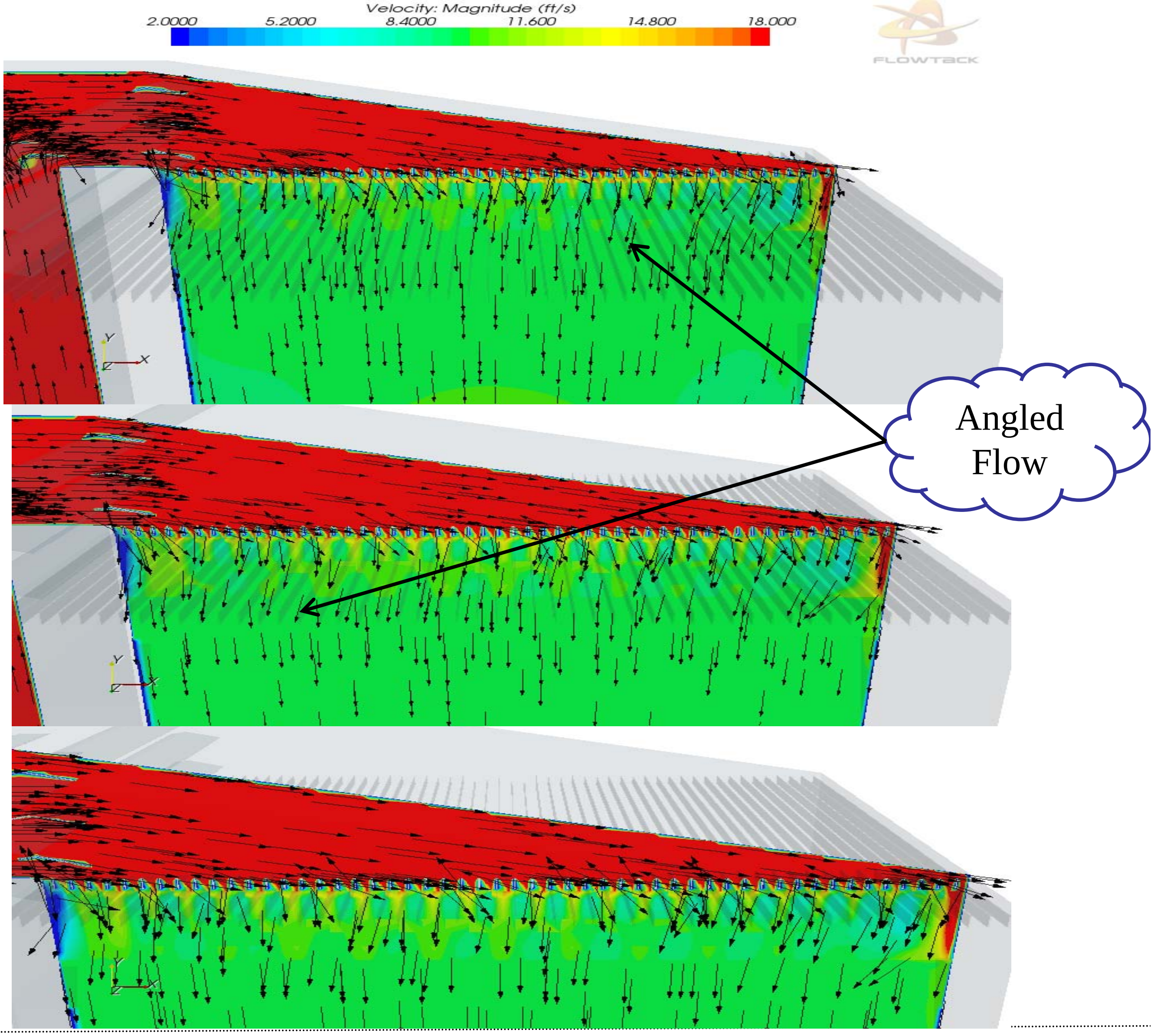


Design B Fluid Dynamics

Operational problems due to fluid dynamics of Design B

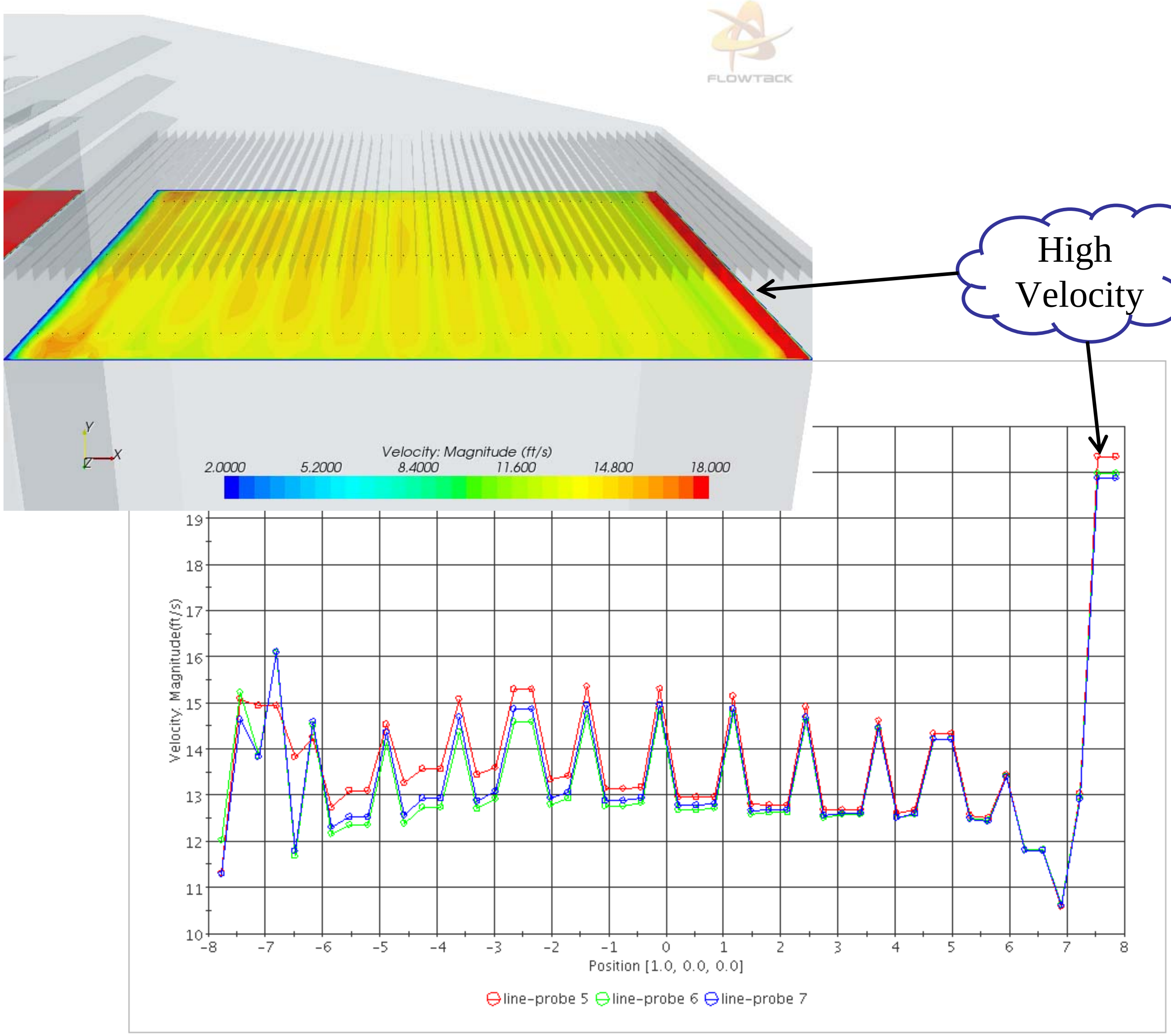
- Velocity distribution requirements difficult, sometimes impossible, to achieve (NO_x , NH_3 and erosion concerns)
- High ash load to rear of reactor due to poor momentum distribution (catalyst plugging concern)
- Tendency for high velocities on rear of reactor(erosion concern)
- Angled flow into catalyst (erosion concern)

Design B Fluid Dynamics



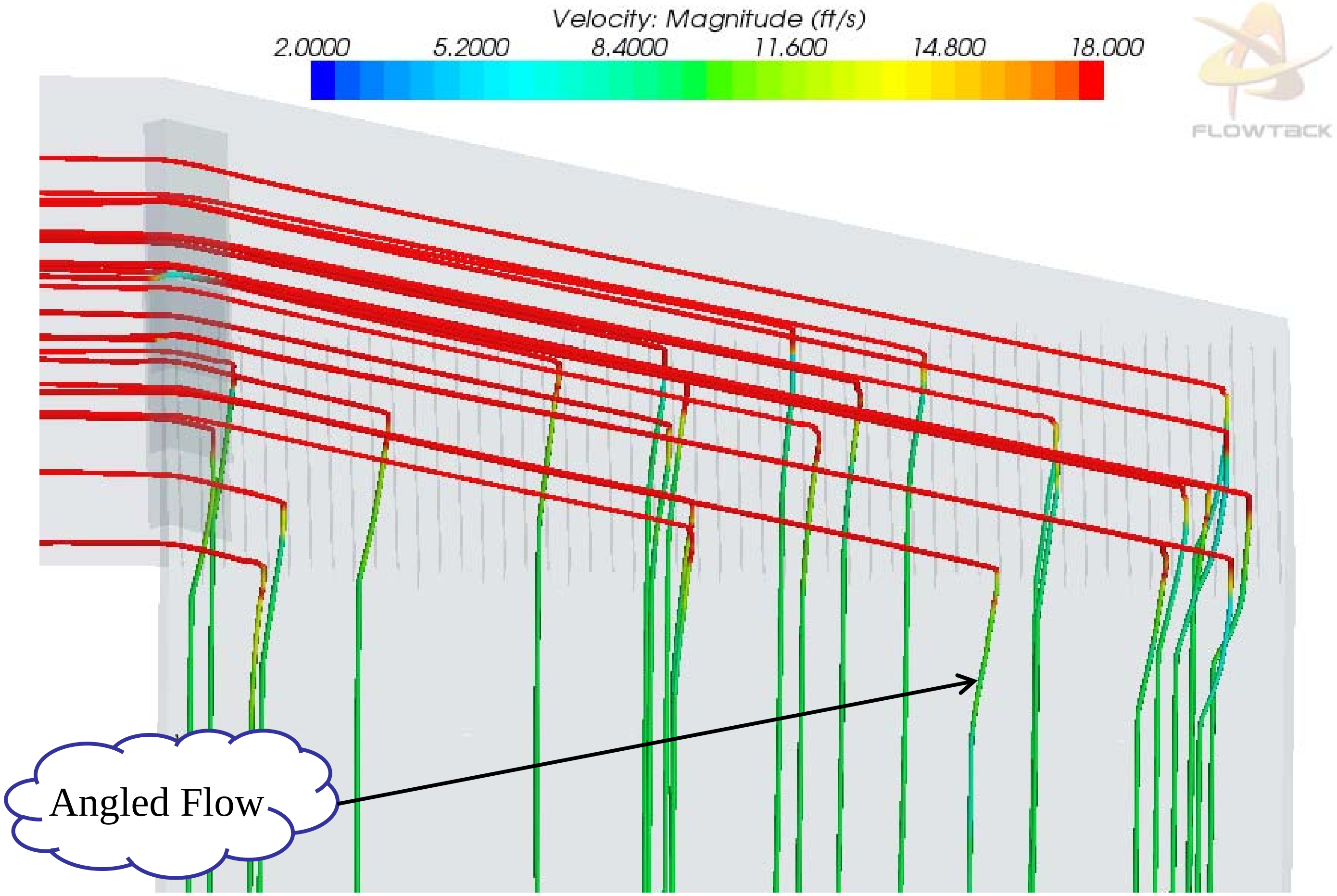
Angled Flow

Design B Fluid Dynamics



High Velocity

Design A Fluid Dynamics



Angled Flow

Design B Fluid Dynamics

Design B Fluid Dynamics

Velocity magnitudes

Criteria	+/- 5%	+/-10%	+/-15%	+/-20%	RMSE
Goal		***85%***	***100%***		
Unit A	33%	81%	95%	96%	12.1
Unit B*	74%	88%	96%	100%	5.4

Velocity angles

Criteria	+/- 5 °	+/- 10 °	+/- 15°	+/- 20 °	Avg.
Goal			***100%***		
Unit A	**19%**	**61%**	**89%**	**96%**	7.2 °
Unit B*	**47%**	**69%**	**85%**	**100%**	5.8°

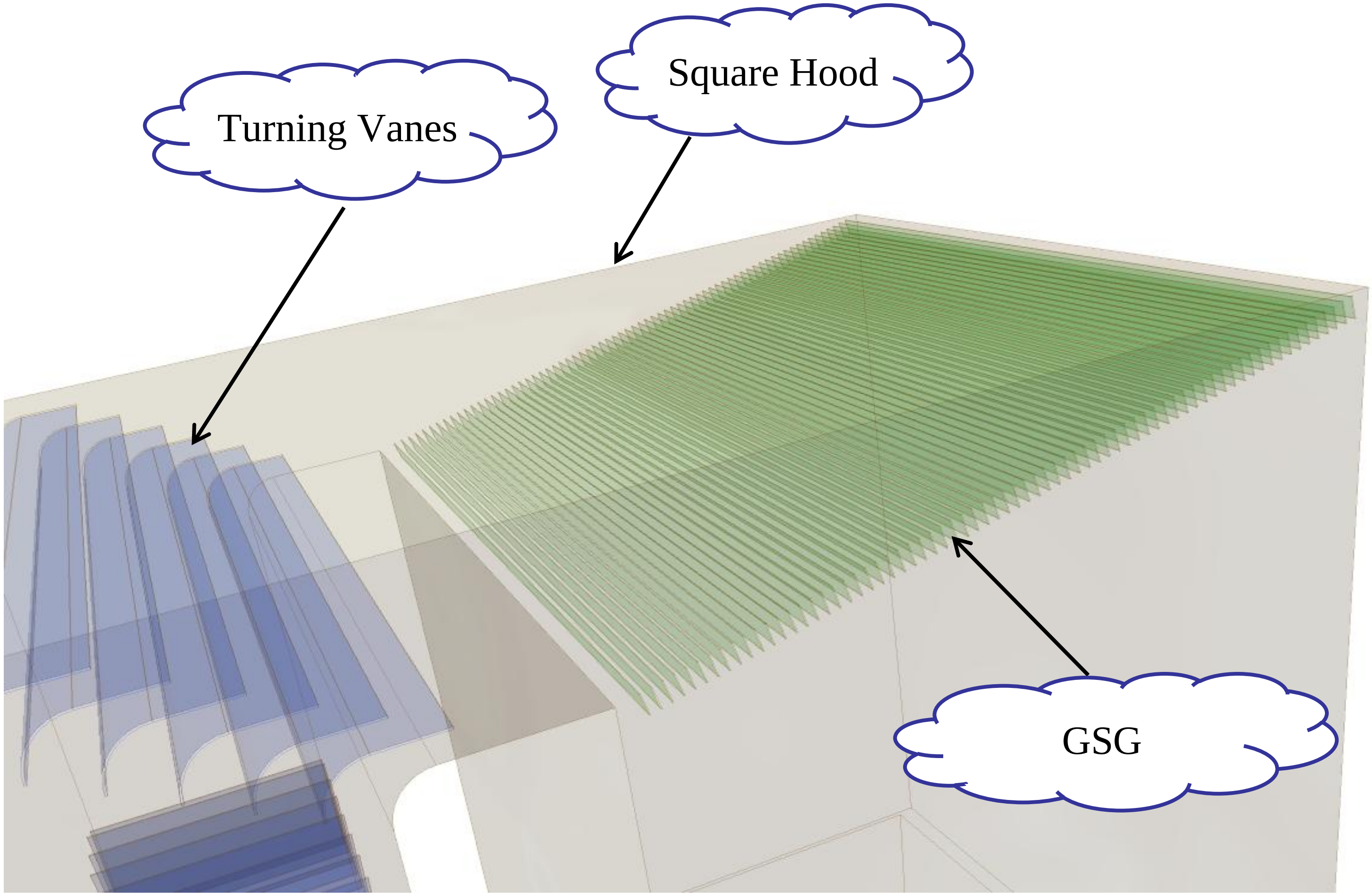
* No Reactor Hood Trusses Modeled in Unit B

Alternative Developments

The fluid dynamics analyses outlined above begs the question of a better standard designs

- A modified arrangement was sought in R&D
- Now the preferred solution in-house
- Has been implemented in five projects thus far
- A square hood arrangement coupled with a device known as the Graduated Straightening Grid (GSG) results in significantly better fluid dynamics performance than either of the two traditional arrangements

SCR Design: GSG Arrangement



Turning Vanes

Square Hood

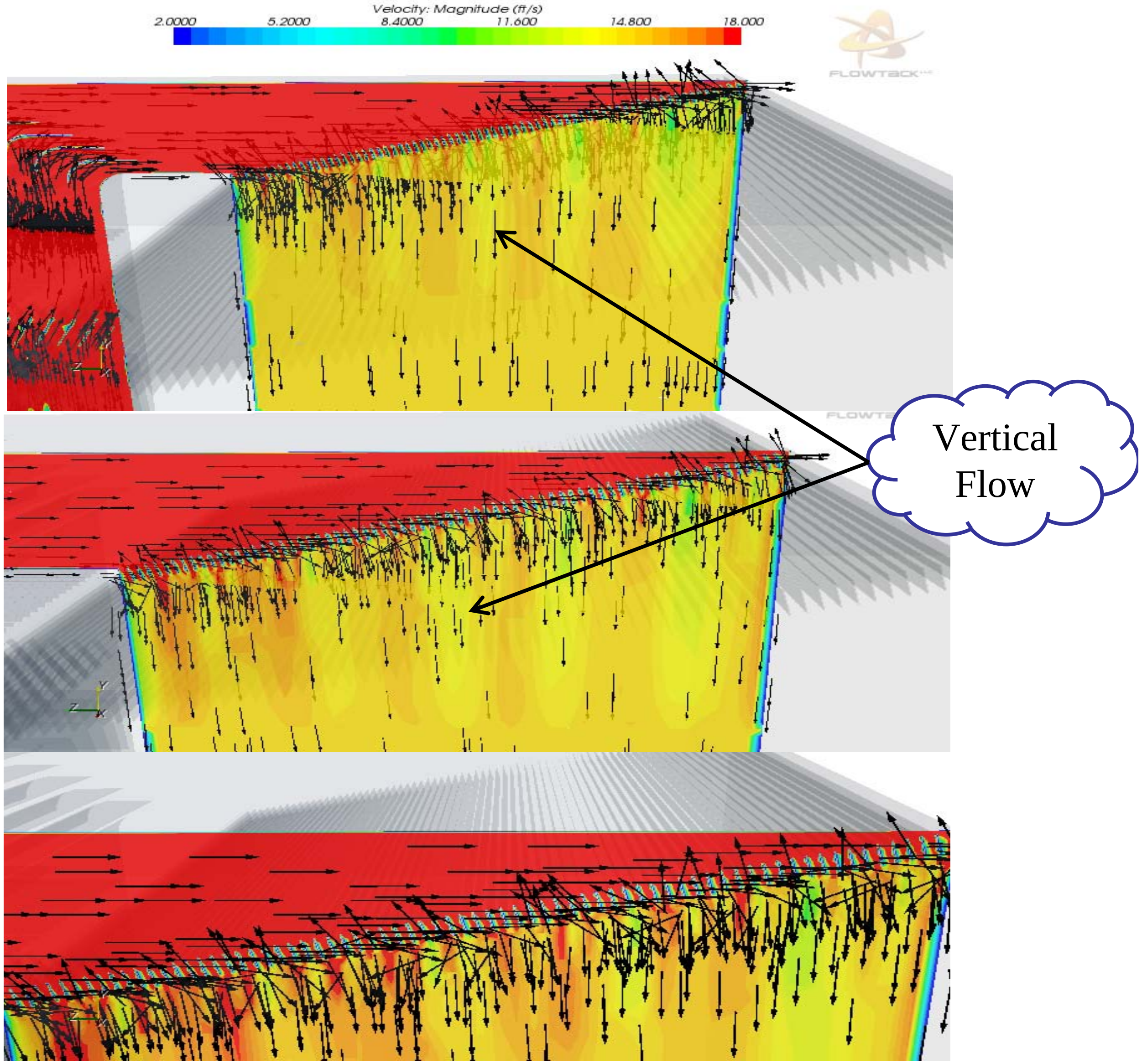
GSG

GSG Fluid Dynamics

Operational enhancements due to fluid dynamics

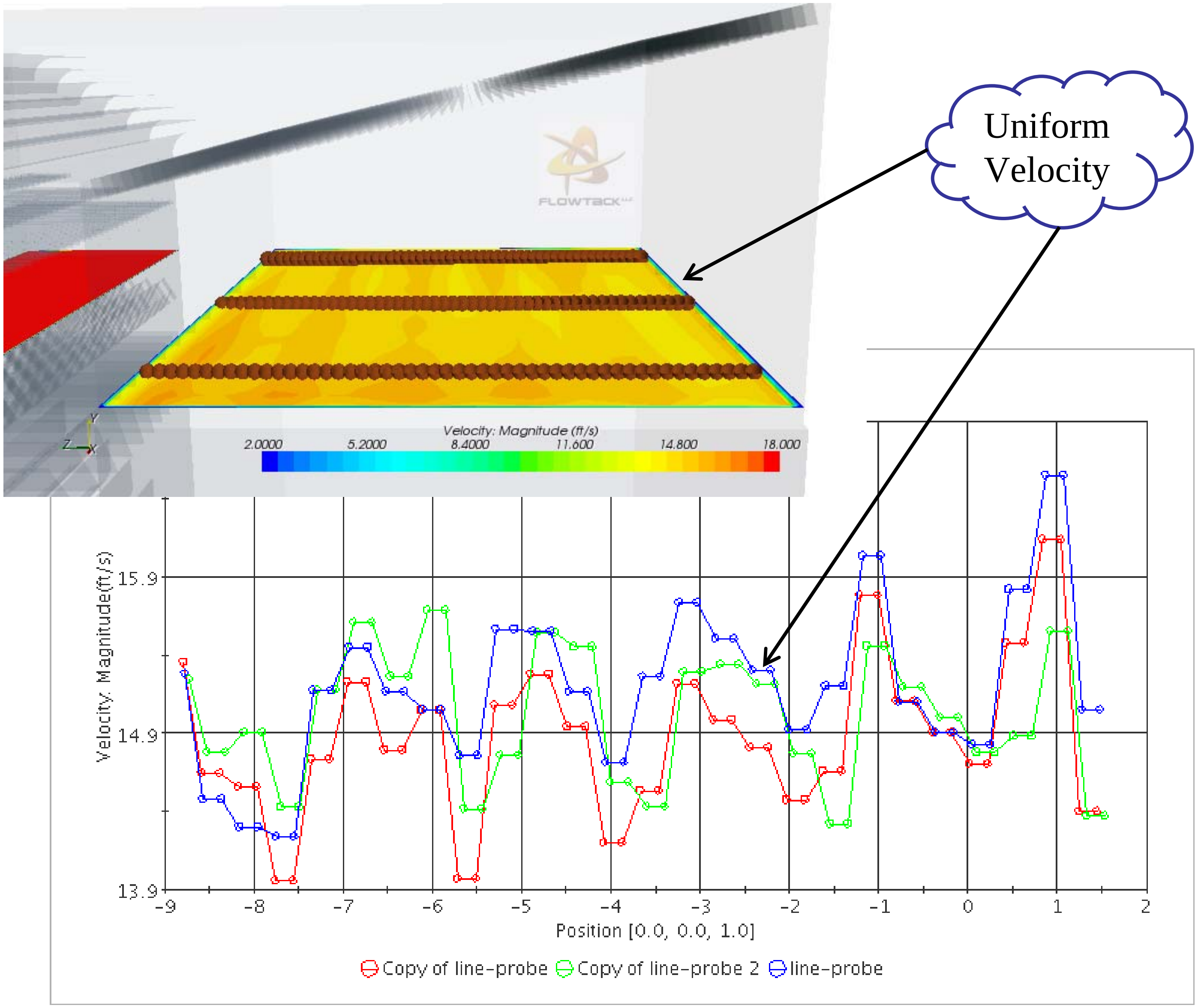
- Best possible velocity and ash distributions (highest possible NO_x removal with minimal NH_3 slip and no erosion concerns)
- No horizontal faces for flyash accumulation and sloughing (no pluggage concern)
- Almost perfectly vertical flow into catalyst (no erosion concern)

GSG Fluid Dynamics



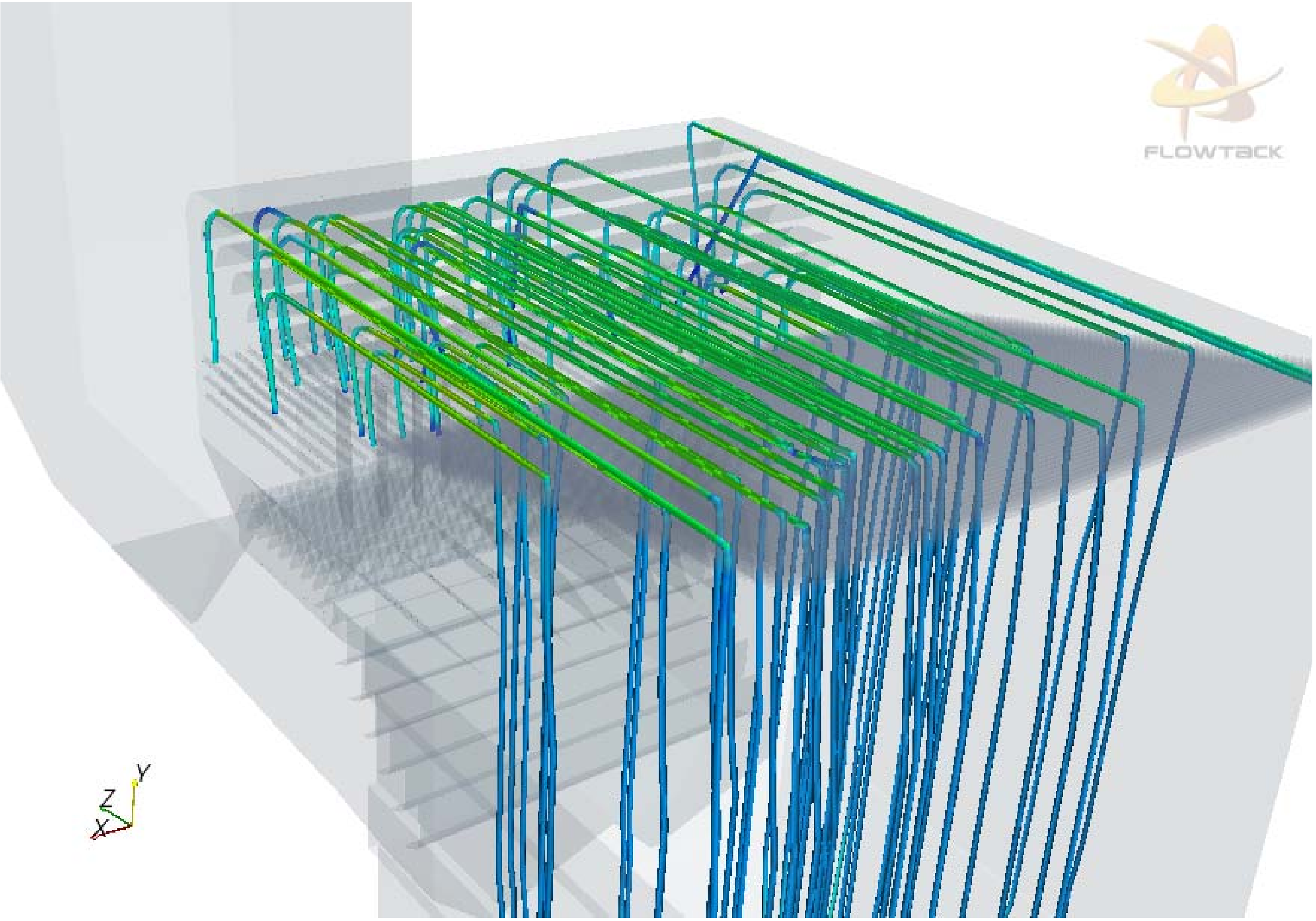
Vertical Flow

GSG Fluid Dynamics



Uniform Velocity

Design A Fluid Dynamics



Design B Fluid Dynamics

Design B Fluid Dynamics

Velocity magnitudes

Criteria	+/- 5%	+/-10%	+/-15%	+/-20%	RMSE
Goal		***85%***	***100%***		
Unit A*	57%	89%	100%	100%	6.0
Unit B*	61%	75%	87%	100%	8.6
Unit 3**	64%	95%	100%	100%	5.4
Unit 4**	69%	97%	100%	100%	4.9
Unit 5 ^{NT}	68%	87%	100%	100%	3.9
Unit 5 ^{T}	48%	67%	85%	93%	11.6

* Internal Trusses

** External Trusses

^{NT} No Trusses Included

^{T} Trusses and Monorails Included

Design B Fluid Dynamics

Velocity angles

Criteria	+/- 5	+/-10	+/-15	+/-20	Average
Goal			***100%***		
Unit A*	60%	97%	100%	100%	5.0
Unit B*	61%	95%	100%	100%	5.1
Unit 3**	69%	100%	100%	100%	4.3
Unit 4**	73%	100%	100%	100%	4.1
Unit 5 ^{NT}	70%	100%	100%	100%	4.0
Unit 5 ^{T}	45%	84%	97%	100%	7.6

* Internal Trusses

** External Trusses

^{NT} No Trusses Included

^{T} Trusses and Monorail Included

Installation

The GSG is in either the final design or the constuction phase on all five units

Installation

Other

Applications

- All new units
- Existing units with operational problems
- Existing units where higher NO_x removal is desired

Other Advantages

- Lower total weight than either traditional arrangement
- Allows for reduction in height of reactor without the need for straightening grid and less space between crossover and 1st layer
- No horizontal surfaces for ash to buildup upon
- Improved flow distributions allow design limitations (average velocity) to be pushed (smaller reactors)

Development and Use

Development and validation of CFD NO_x removal tool in 2008

- To be used in model studies of switch from traditional to GSG arrangements; when higher NO_x removal becomes financially justifiable for existing plants

Domestic and Overseas patents have been applied for

- Contracting a relatively low cost flow model study for SCR design with FlowTack, LLC will include authorized usage of the GSG design
- Others wishing to implement the GSG design will be required to pay a licensing fee

Conclusions

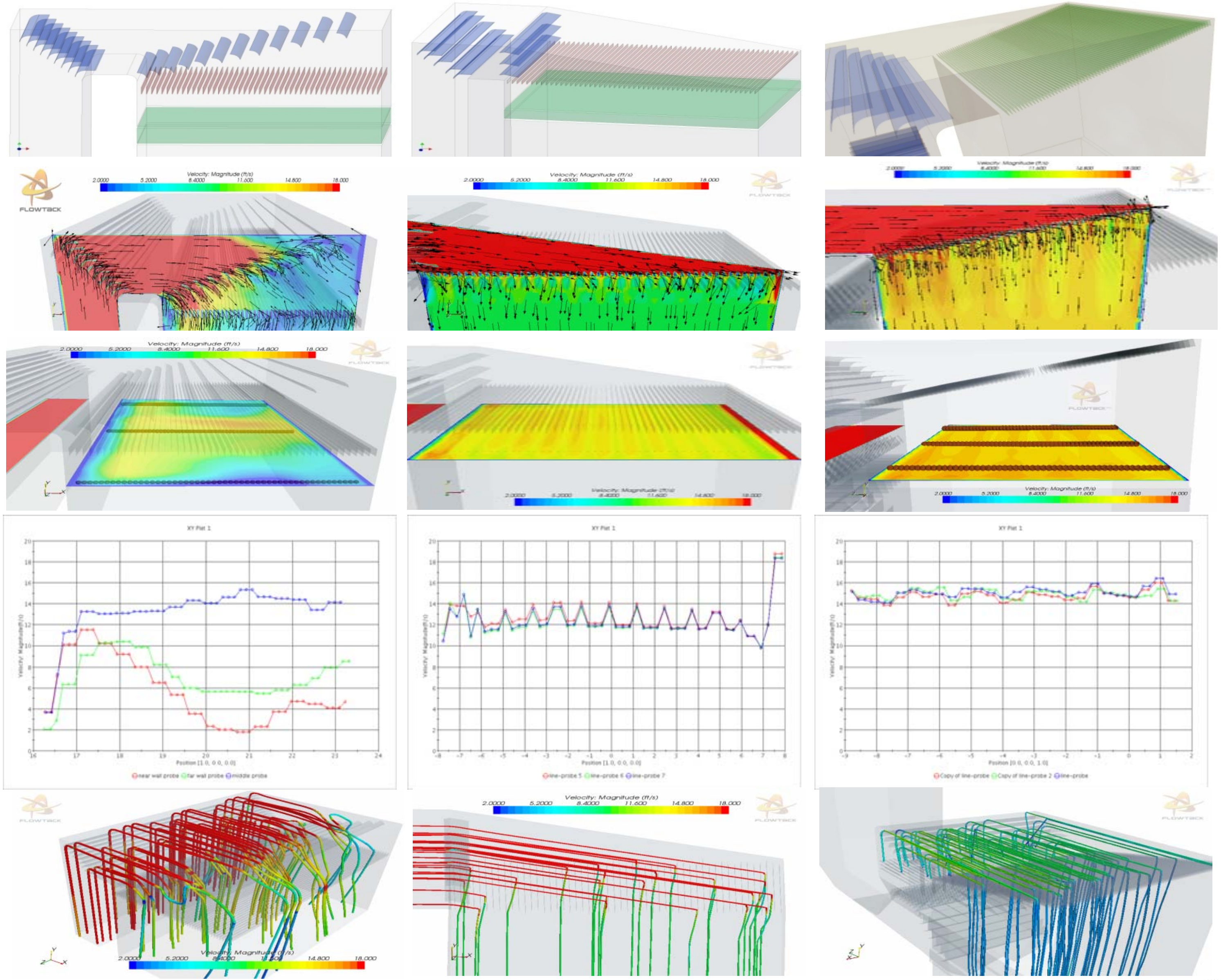
Fluid dynamics analyses of traditional SCR arrangements identified the following

- Less-than-ideal velocity distributions likely
- Uneven and detrimental flyash characteristics
- Angled flow

An alternative arrangement was developed that provided

- Homogenous velocity distributions
- Good flyash characteristics
- Vertical flow

Side-by-Side


FLOWTACK
Velocity: Magnitude (ft/s)
2.0000
5.2000
8.4000
11.600
14.800
18.000
XY Plot 1
Velocity: Magnitude(ft/s)
Position [1.0, 0.0, 0.0]
near wall probe
far wall probe
middle probe
line-probe 5
line-probe 6
line-probe 7
Position [0.0, 0.0, 1.0]
Copy of line-probe
Copy of line-probe 2
line-probe