Wind Effects

Caithness Windscreen Study

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Gettysburg, PA

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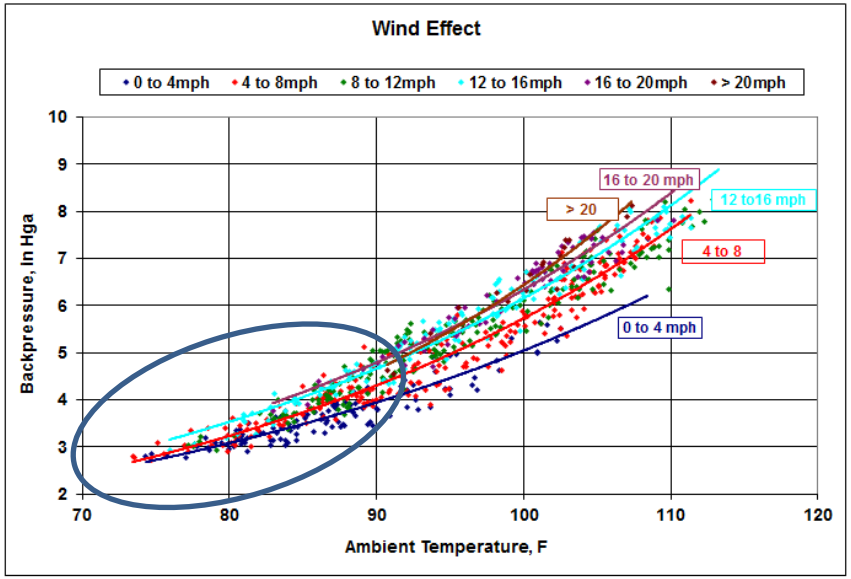
The Two Minute Story

What We Knew



- Wind can cause problems
  - Thermal performance
  - Fan damage
- Wind barriers can help
  - Analysis
  - Data/experience
  - Belief

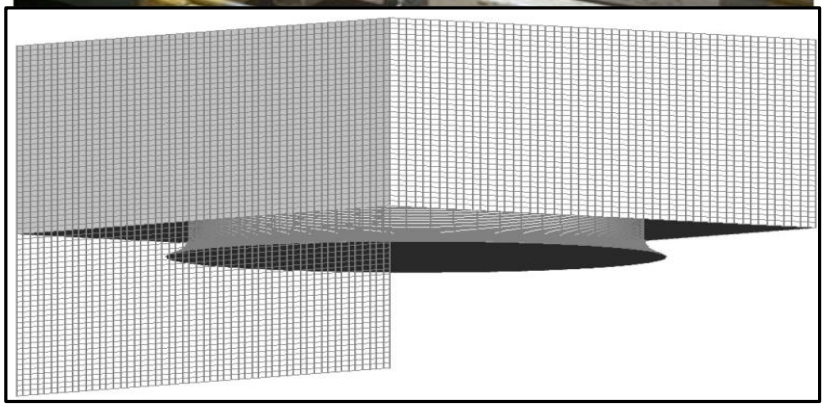
The Two Minute Story

What We Didn't Know

- **How to quantify**
  - **Performance benefit**
  - **Fan protection**
- **Basis for**
  - **Screen choice**
  - **Arrangement**
  - **Location**

The Two Minute Story

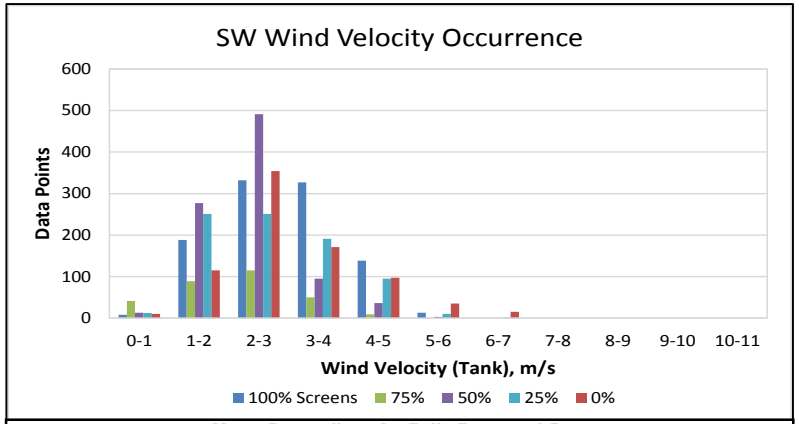
The Plan

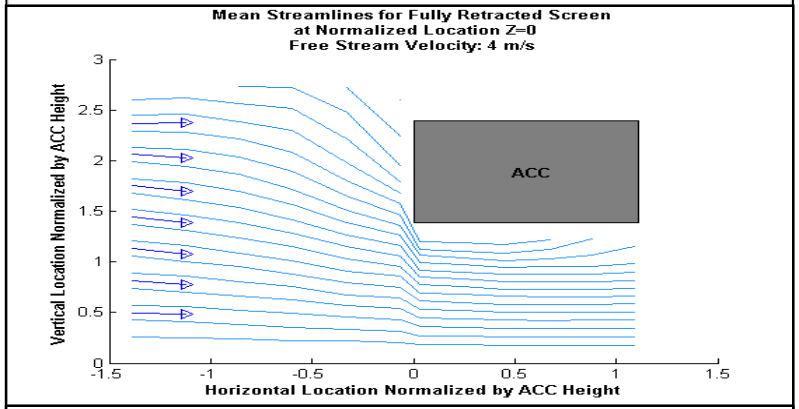


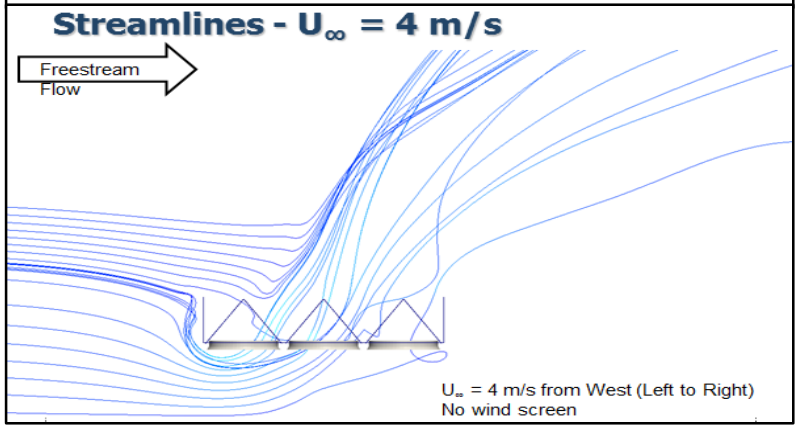
- **Integrated study**
  - **Field test of ACC**
  - **Wind tunnel modeling**
  - **CFD modeling**
- **Procedure**
  - **Validate models with field data**
  - **Extend range of results in wind tunnel**
  - **Generalize/predict new situations with CFD**

The Two Minute Story

The Outcome







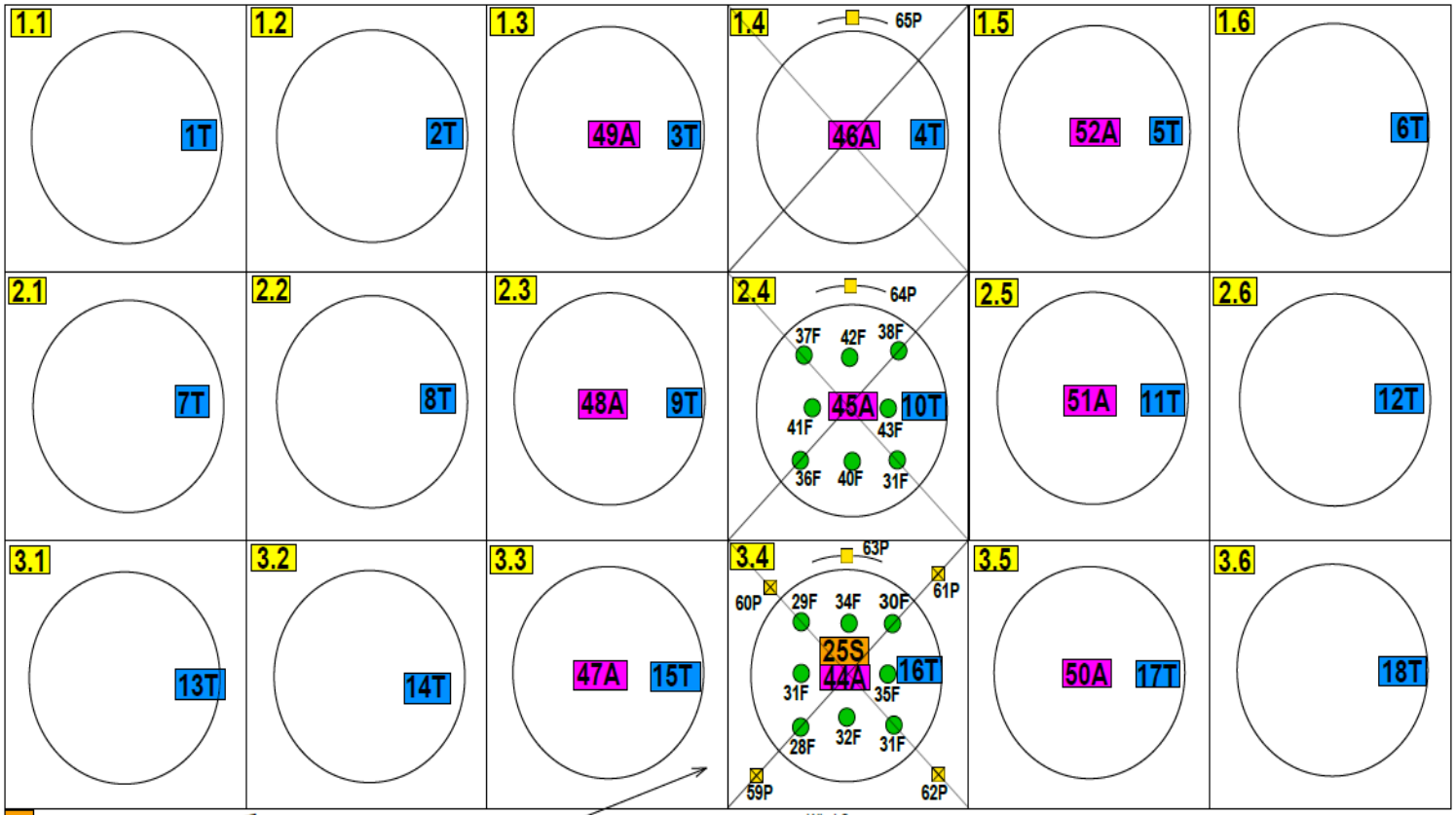
- **Field test results**
  - LOTS of data
  - Little +/- on thermal performance
  - Significant reduction in dynamic blade loading
- **Wind tunnel**
  - Good simulation
  - Quantitative agreement
  - Useful visualization
- **CFD**
  - Some insights
  - Quantitatively unsuccessful
  - Generalization goal unmet

Study Team

- J. Maulbetsch, M. DiFilippo—Co-PIs
- UC Davis---Wind Tunnel
  - Bruce White, Ryan Parker, Rachael Larson
- Senta Engineering---CFD model
  - Case VanDam, Ray Chow
- Howden---Fan vendor; Field test set up
  - Sander Venema, Harry Olthof, Desmond de Haan, Paul Nelissen
- Caithness---Host site; Test operations
  - Bill Wareham, Kevin Collins, Tim German
- Galebreaker---Windscreen vendor
  - Simon Melhuish, Andrew Gardner, Gary Mirsky, Jamie Wilde
- California Energy Commission
  - Joe O'Hagan, Lillian Mirviss

Field Tests—Caithness
18 cell ACC; retractable screens

Position Sensors Caithness



T = Temperature Probe (1-19)
D = Wind Direction (22, 23)
A = Wind Speed (20, 21),
Amps (44-52)
F = Flow Sensor (28-42)
L = Load Cell (53-58)
P = Pressure (59-65)
S = Position, Fan Blade Location (24, 25),
Screen (26)

Data Used for Comparisons

- July & August, 2014---All fans full
- Cells 3.4 and 2.4 (behind 3.4)
- Plot against wind speed (at tank)
- Sorted by
  - wind directions—NW, W, SW, S, SE (at tank)
    - Average all from 180° +/- 45° (Howden)
    - Nominal +/- 11.5° (JSM/MND)
  - Screen positions—0, 25, 50, 75, 100%

Caithness project

Results

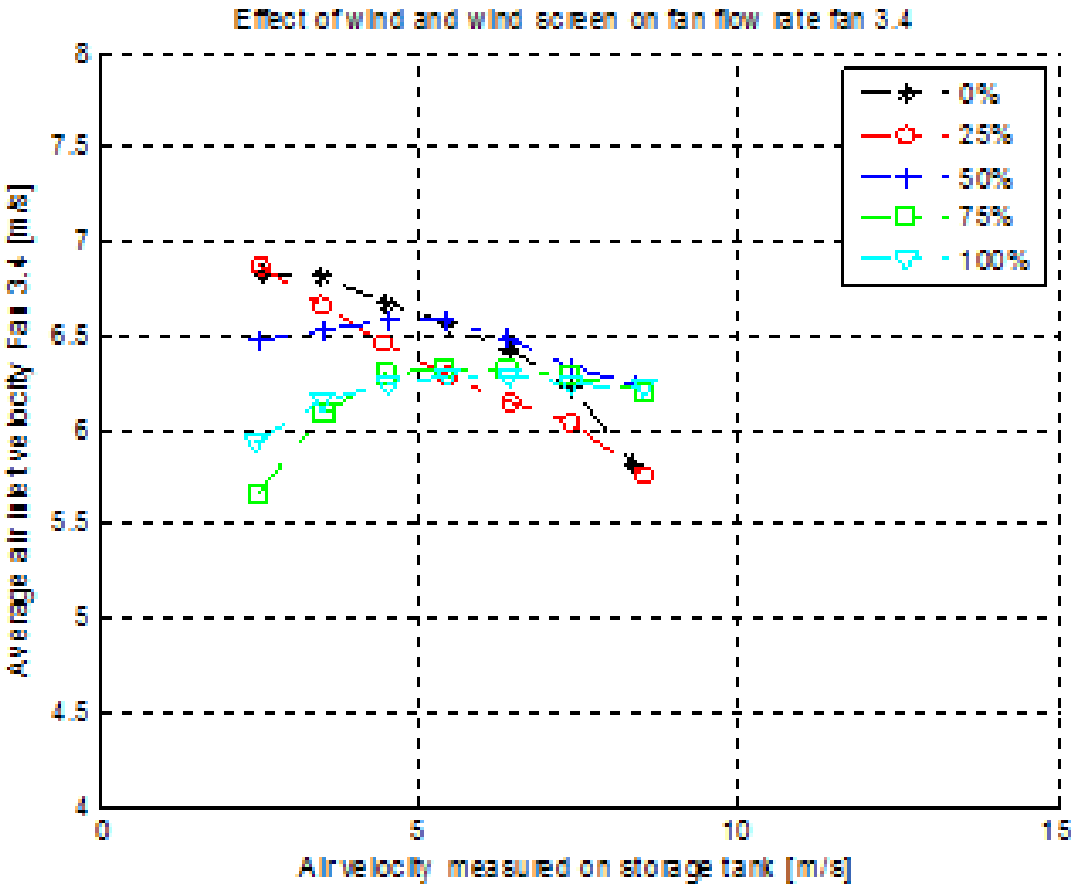
Average air inlet velocity fan 3.4

Positive effect screen at higher wind speeds

Negative effect screen at lower wind speeds

Break even at ±7 m/s wind speed

50% screen deployment gives best results (up to a wind velocity of 8 m/s)

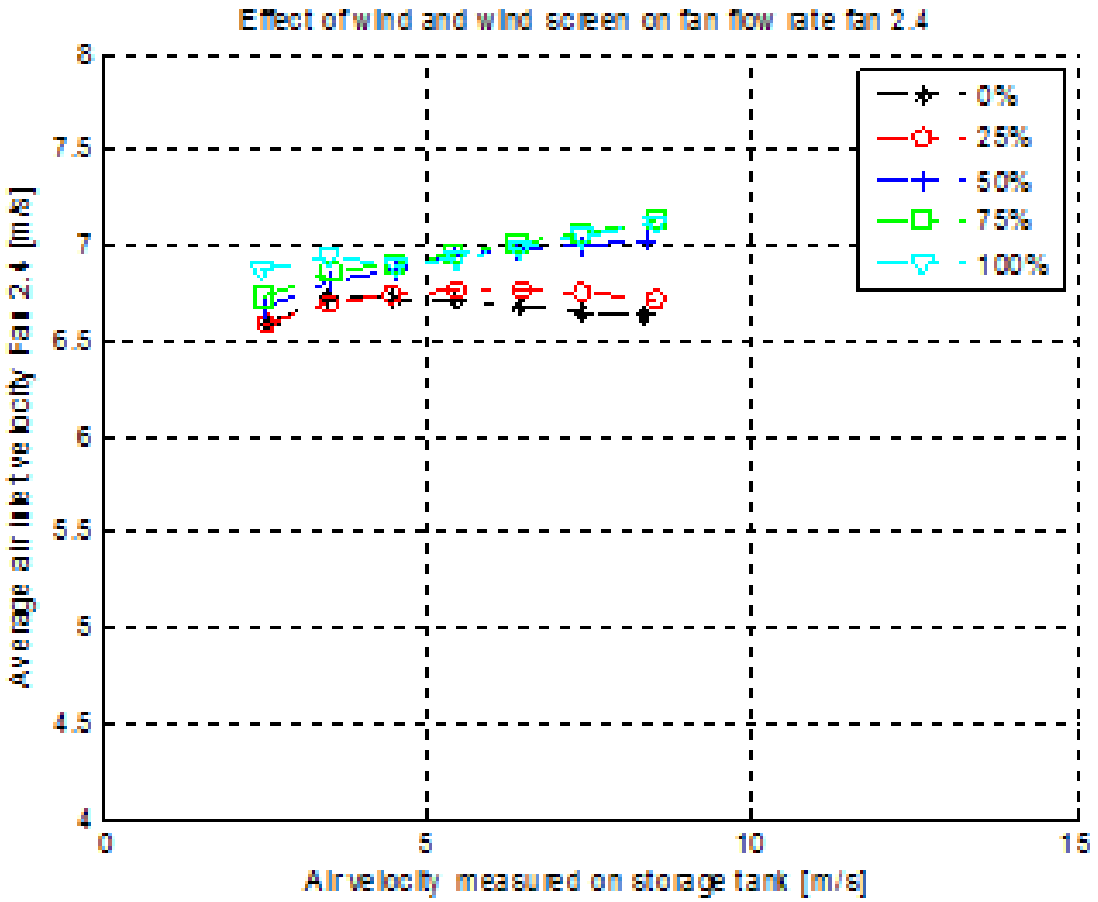


Caithness project

Results

Average air inlet velocity fan 2.4

Positive effect screen at all wind speeds



Caithness project

Results

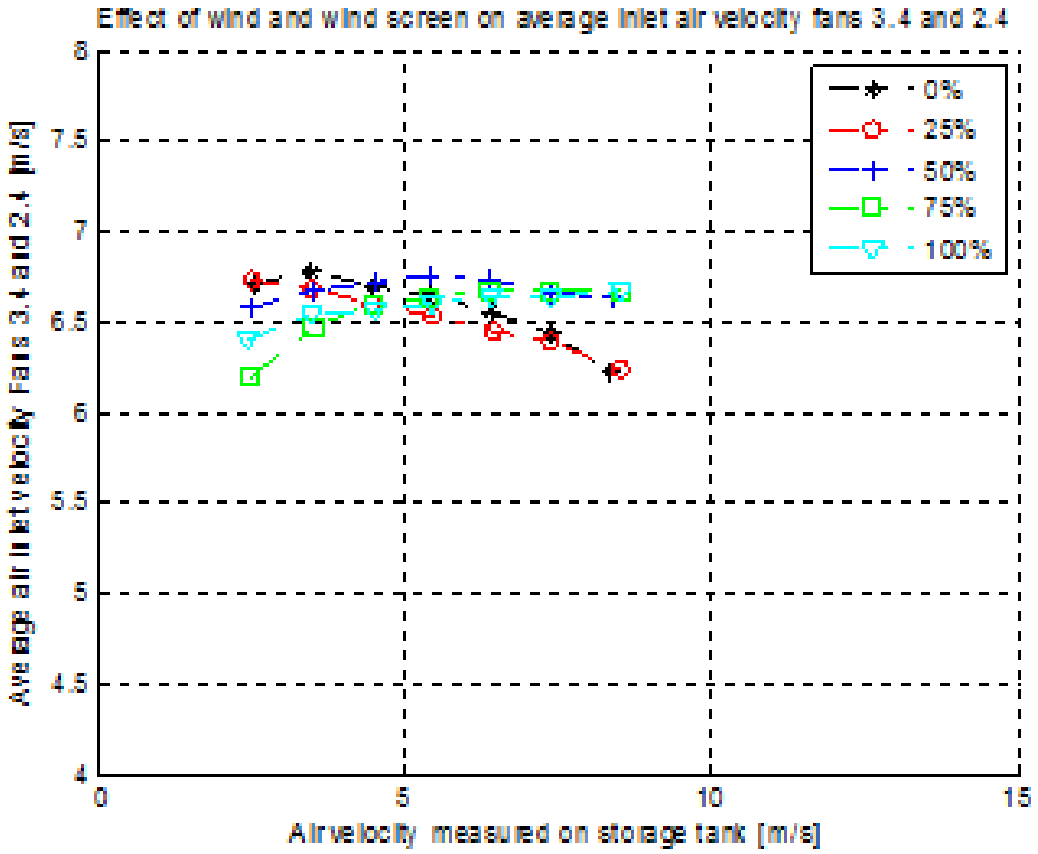
Average air inlet velocity fan 2.4 and 3.4

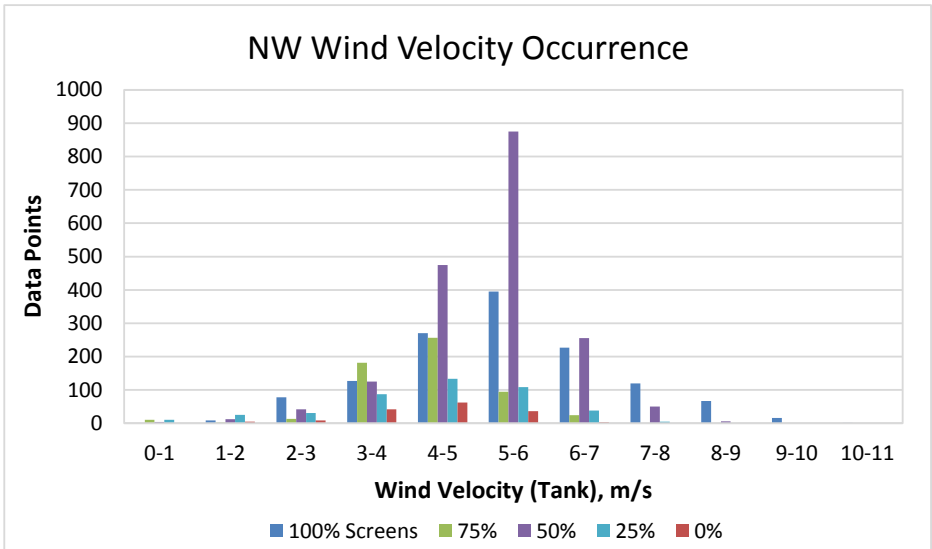
Positive effect screen at higher wind speeds

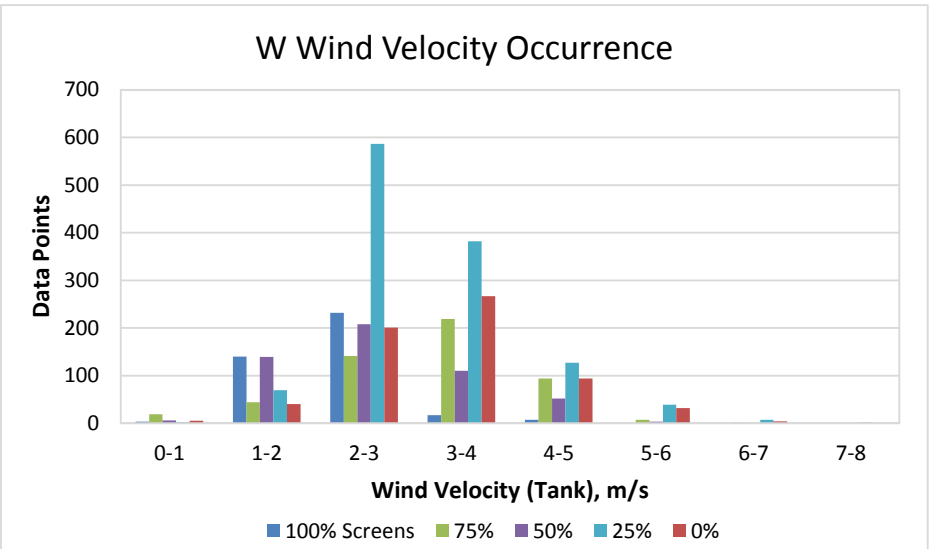
Negative effect screen at lower wind speeds

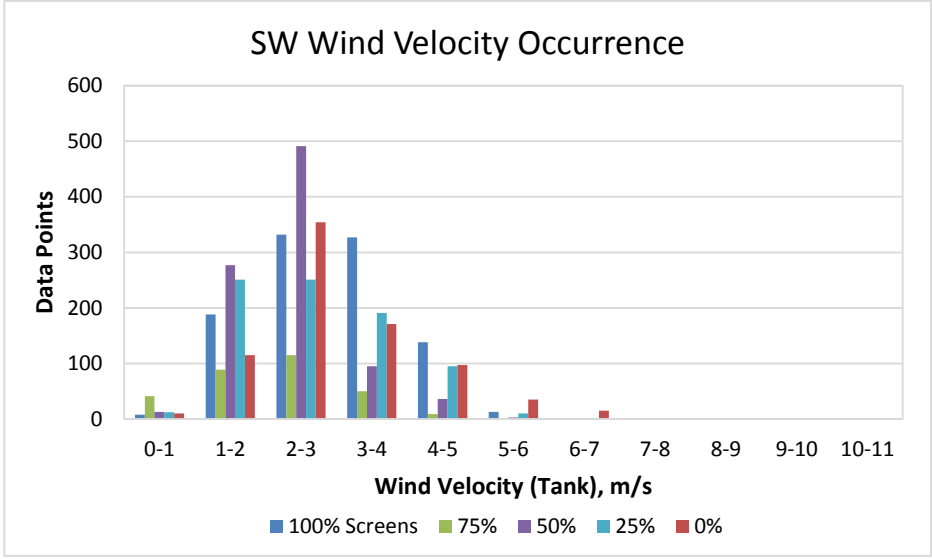
Break even at ±4 m/s wind speed

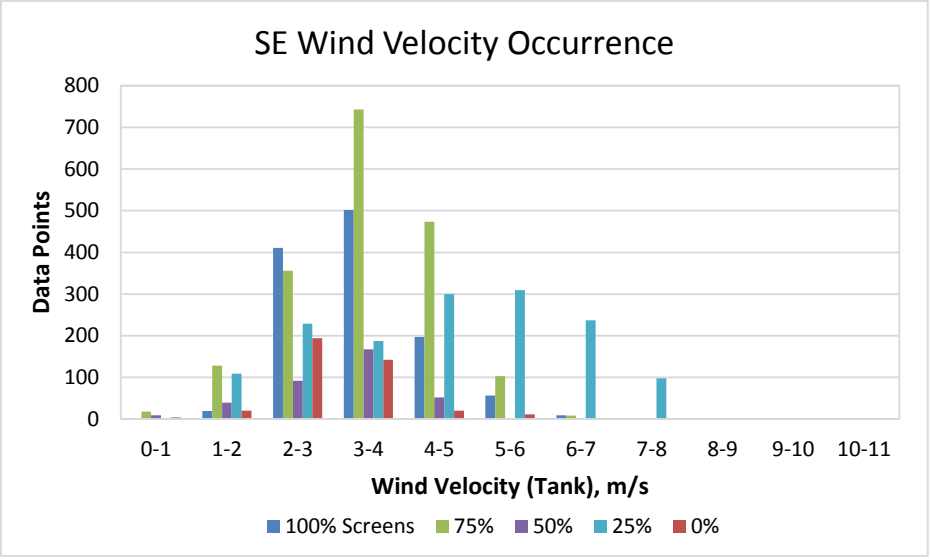
50% screen deployment again gives best results (up to a wind velocity of 8 m/s)

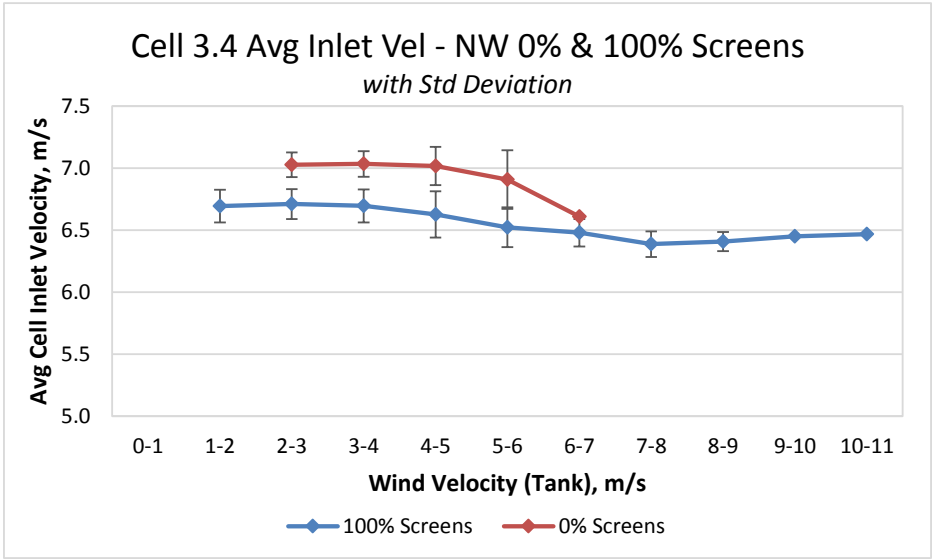


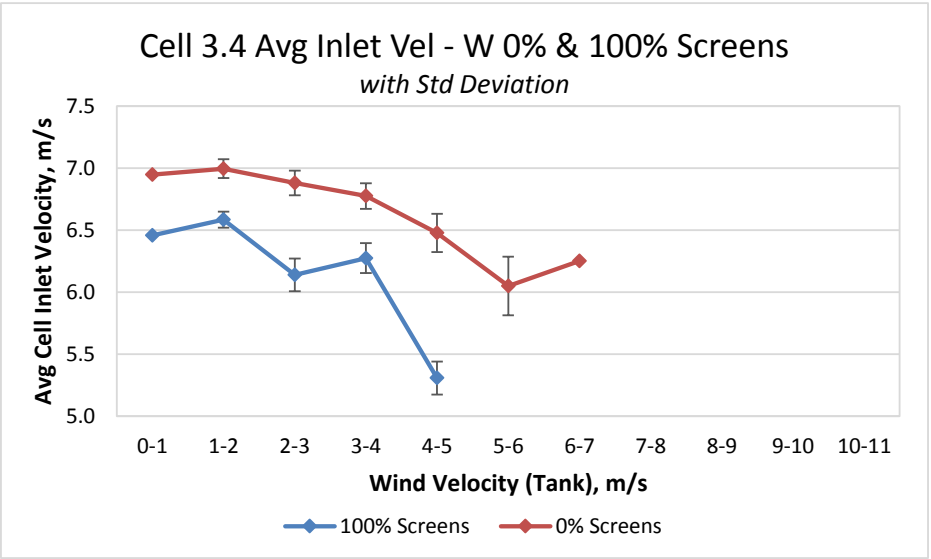

NW Wind Velocity Occurrence
Data Points
1000
900
800
700
600
500
400
300
200
100
0
0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
Wind Velocity (Tank), m/s
100% Screens
75%
50%
25%
0%

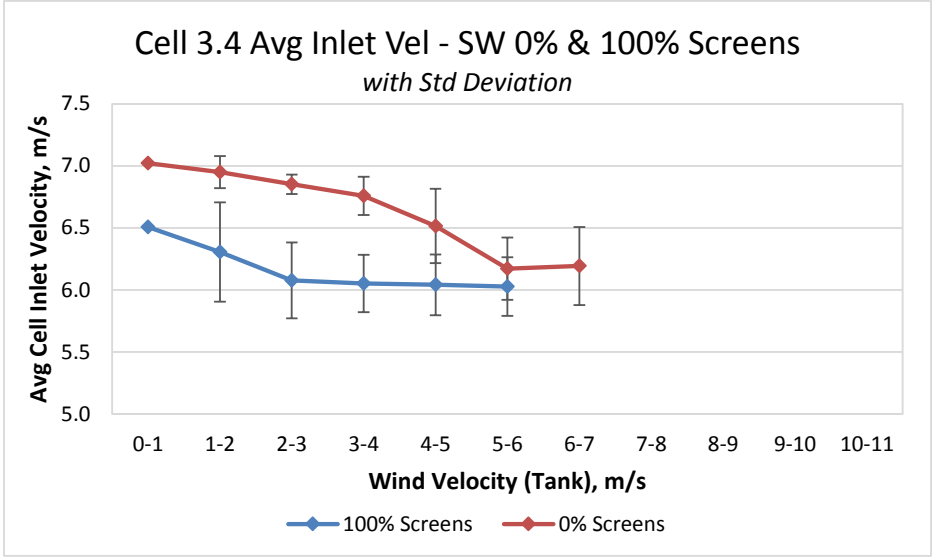

W Wind Velocity Occurrence
Data Points
700
600
500
400
300
200
100
0
0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
Wind Velocity (Tank), m/s
100% Screens
75%
50%
25%
0%

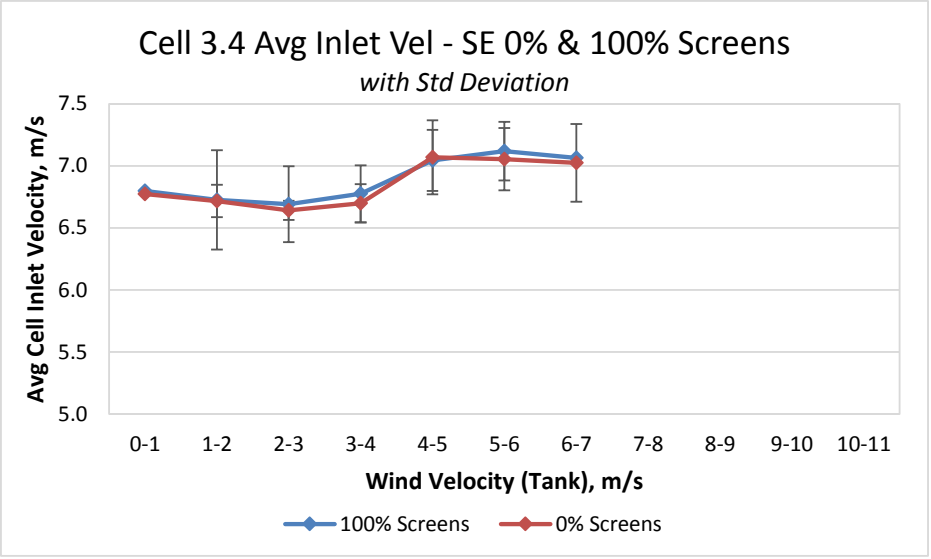

SW Wind Velocity Occurrence
Data Points
600
500
400
300
200
100
0
0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
Wind Velocity (Tank), m/s
100% Screens
75%
50%
25%
0%


SE Wind Velocity Occurrence
Data Points
800
700
600
500
400
300
200
100
0
0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
Wind Velocity (Tank), m/s
100% Screens
75%
50%
25%
0%


Cell 3.4 Avg Inlet Vel - NW 0% & 100% Screens
with Std Deviation
Avg Cell Inlet Velocity, m/s
7.5
7.0
6.5
6.0
5.5
5.0
0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
Wind Velocity (Tank), m/s
100% Screens
0% Screens


Cell 3.4 Avg Inlet Vel - W 0% & 100% Screens
with Std Deviation
Avg Cell Inlet Velocity, m/s
7.5
7.0
6.5
6.0
5.5
5.0
0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
Wind Velocity (Tank), m/s
100% Screens
0% Screens


Cell 3.4 Avg Inlet Vel - SW 0% & 100% Screens
with Std Deviation
Avg Cell Inlet Velocity, m/s
7.5
7.0
6.5
6.0
5.5
5.0
0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
Wind Velocity (Tank), m/s
100% Screens
0% Screens


Cell 3.4 Avg Inlet Vel - SE 0% & 100% Screens
with Std Deviation
Avg Cell Inlet Velocity, m/s
7.5
7.0
6.5
6.0
5.5
5.0
0-1
1-2
2-3
3-4
4-5
5-6
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8-9
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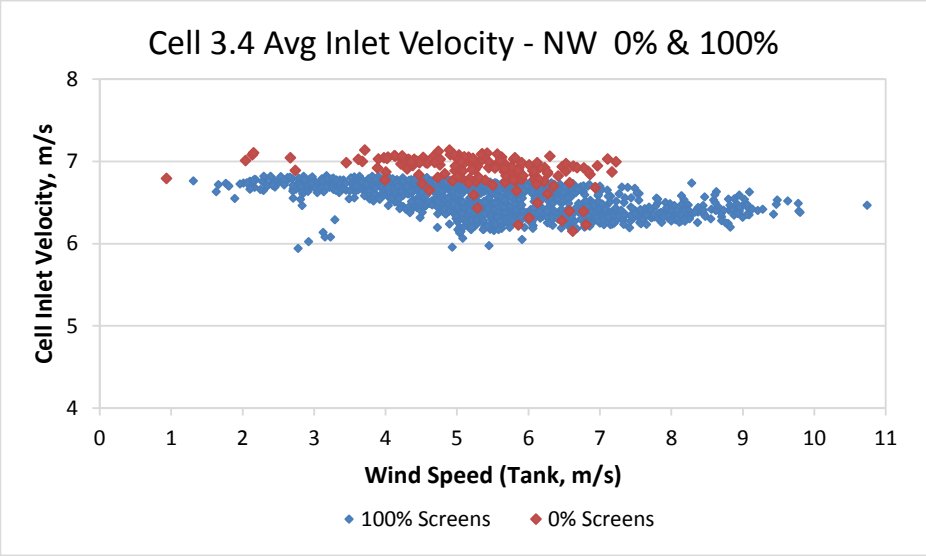
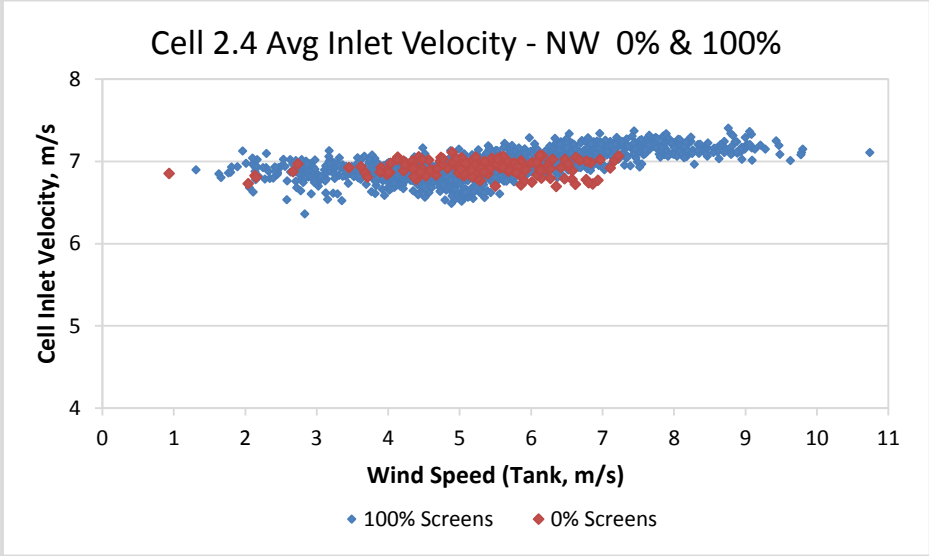
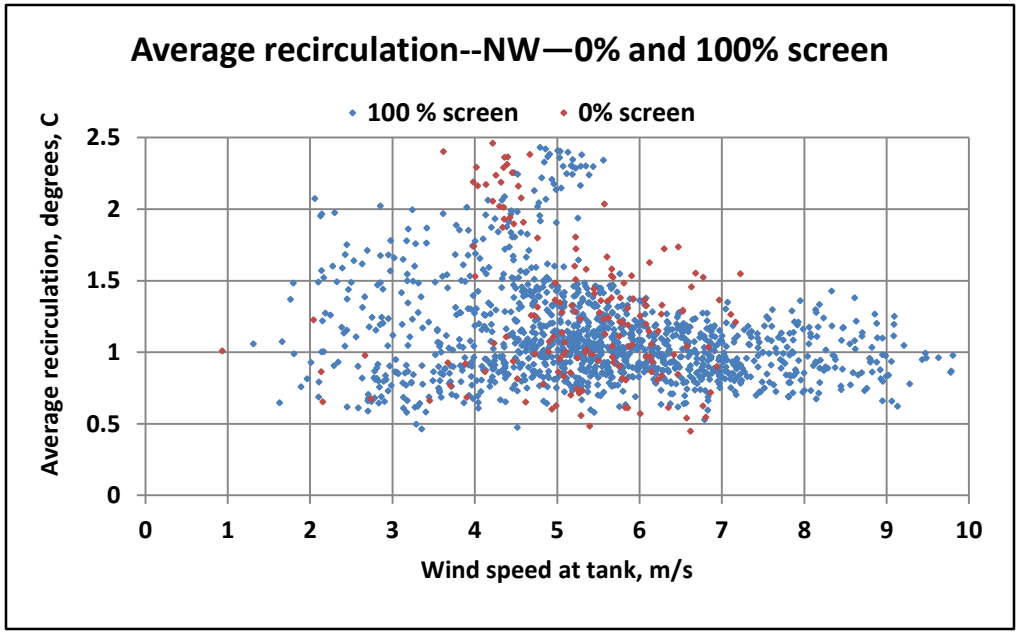
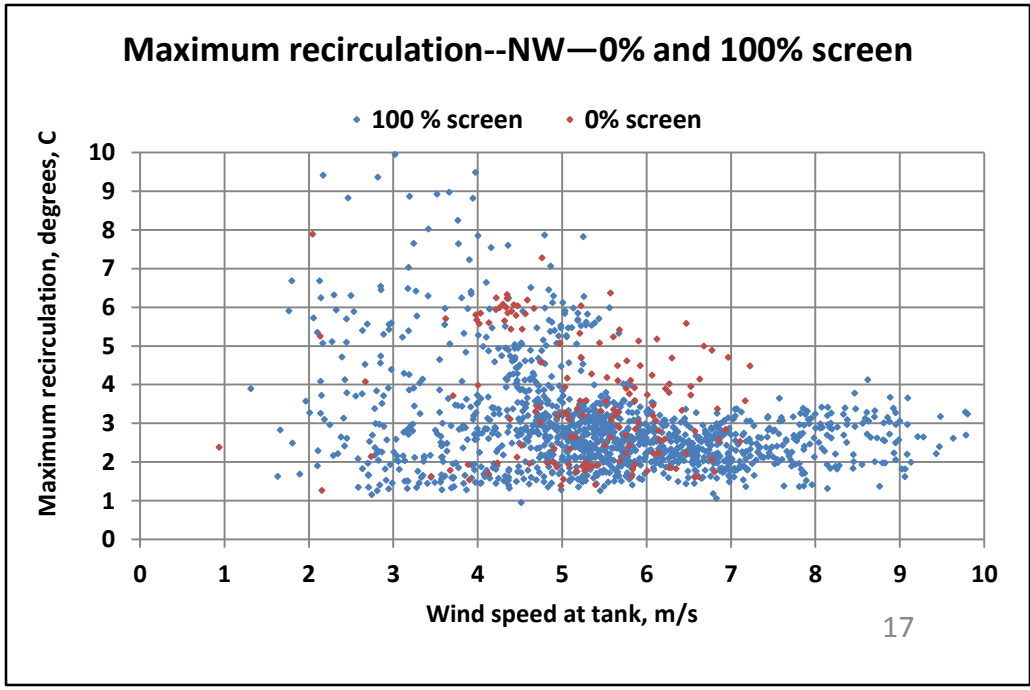
10-11
Wind Velocity (Tank), m/s
100% Screens
0% Screens


Cell 3.4 Avg Inlet Velocity - NW 0% & 100%
Cell Inlet Velocity, m/s
8
7
6
5
4
0
1
2
3
4
5
6
7
8
9
10
11
Wind Speed (Tank, m/s)
100% Screens
0% Screens

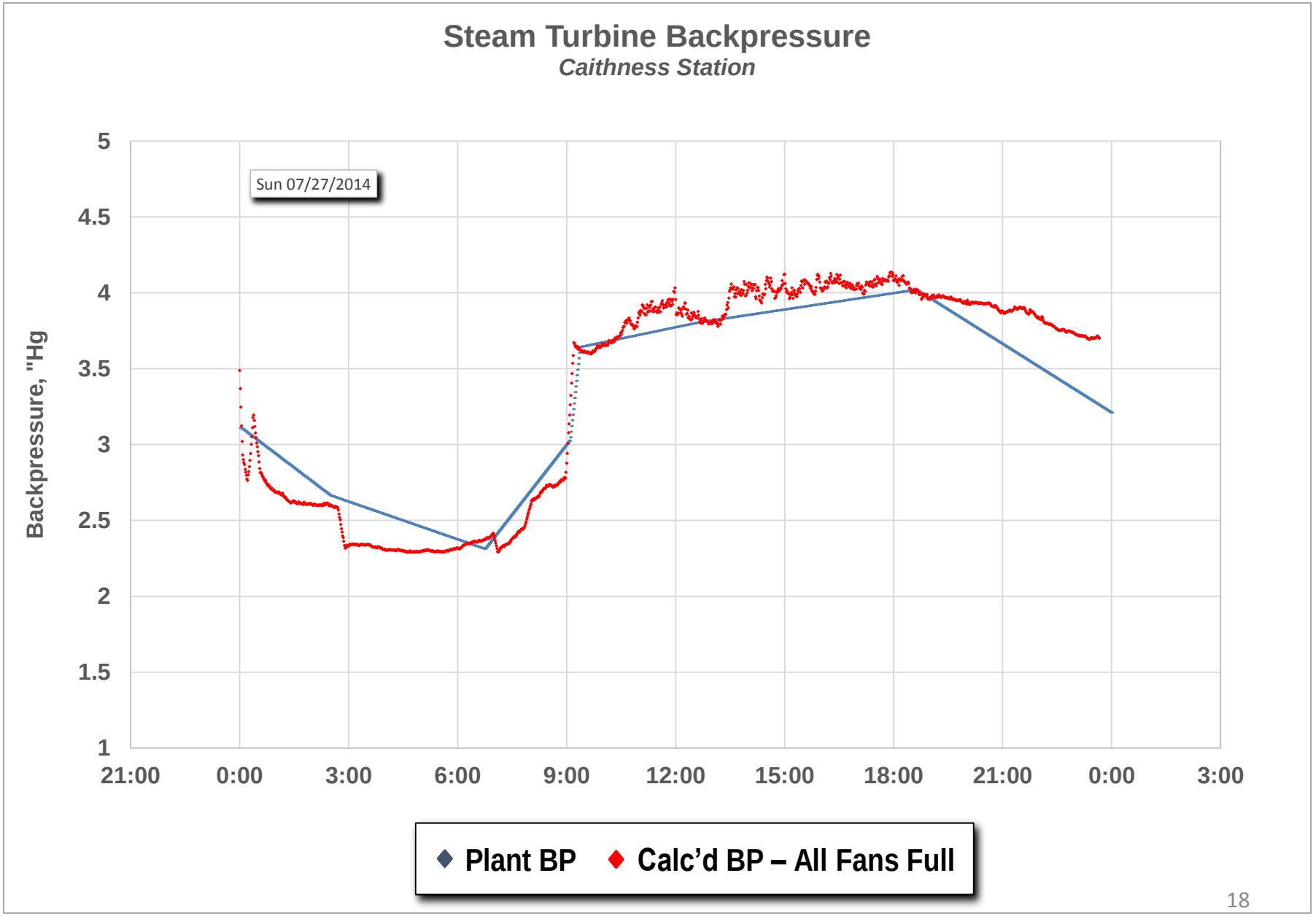

Cell 2.4 Avg Inlet Velocity - NW 0% & 100%
Cell Inlet Velocity, m/s
8
7
6
5
4
0
1
2
3
4
5
6
7
8
9
10
11
Wind Speed (Tank, m/s)
100% Screens
0% Screens

Recirculation---Effect of wind direction and screen position

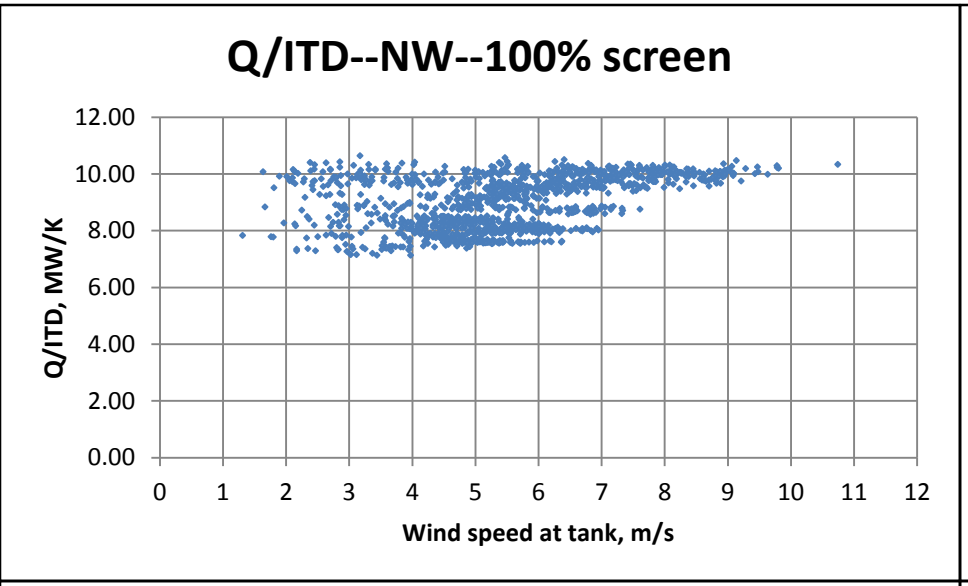


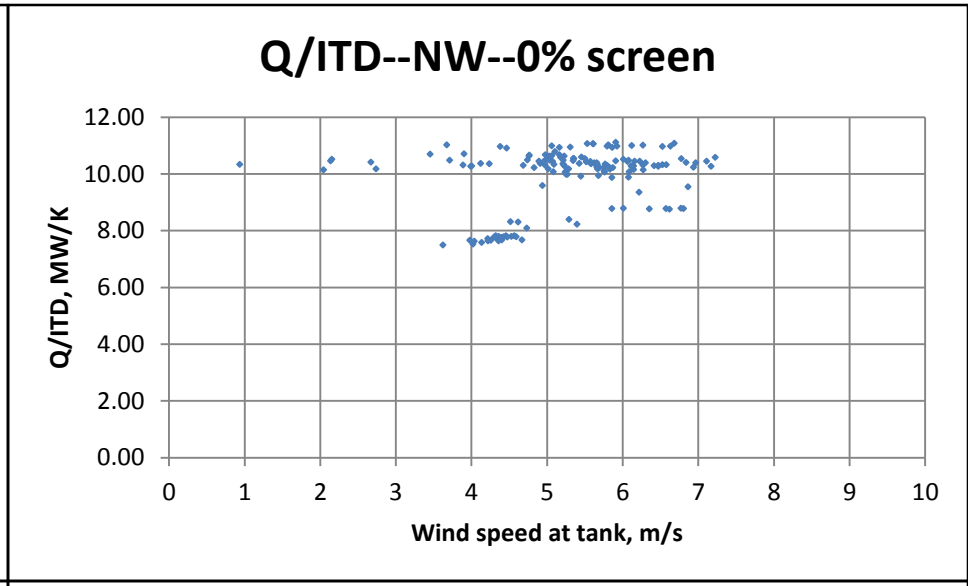


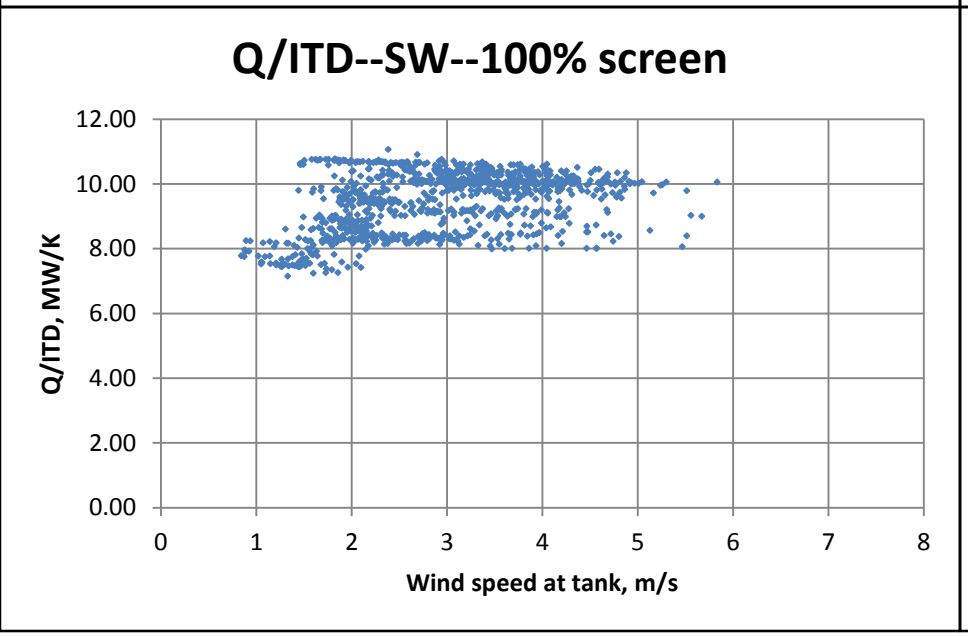
Comparison to performance curves

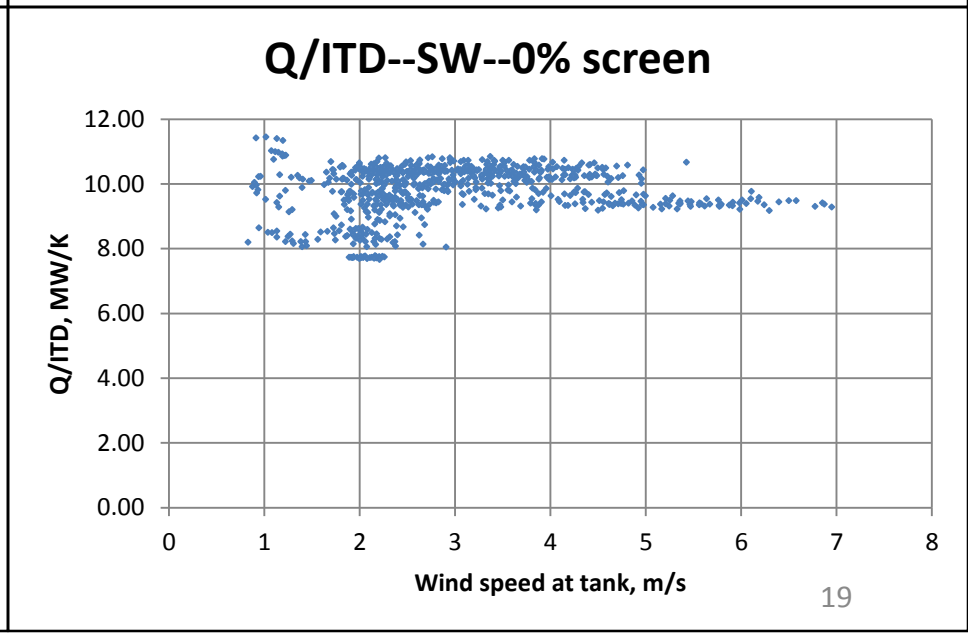


Thermal performance
Effect of wind direction and screen position

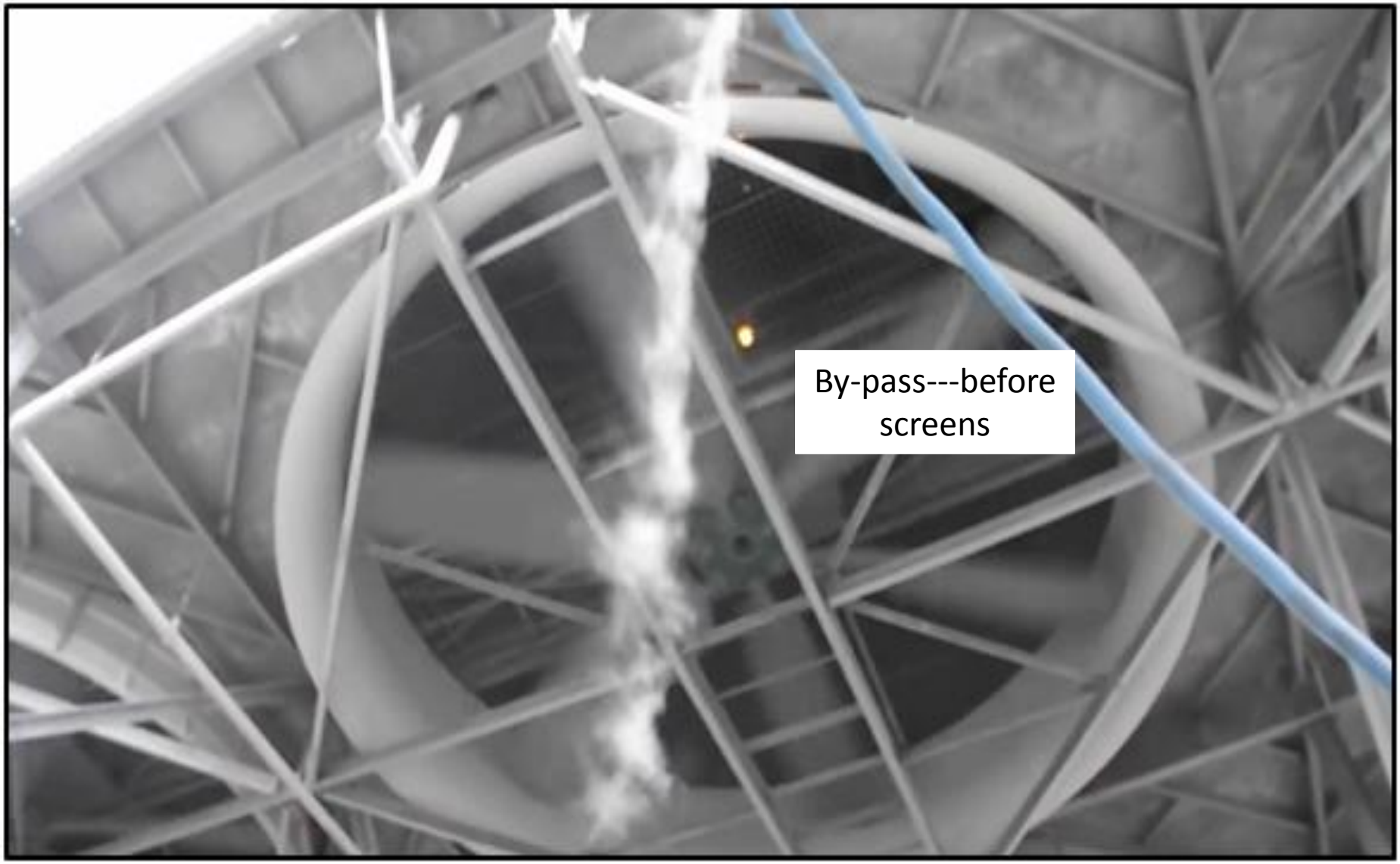








Blade Dynamics & Non-Uniform Inlet



Dynamic Blade Loading Measurements

For all 6 load cells the average variation in output over this 10 second period was determined (This is a measure for dynamic loading)

Top

Raw data from load cell

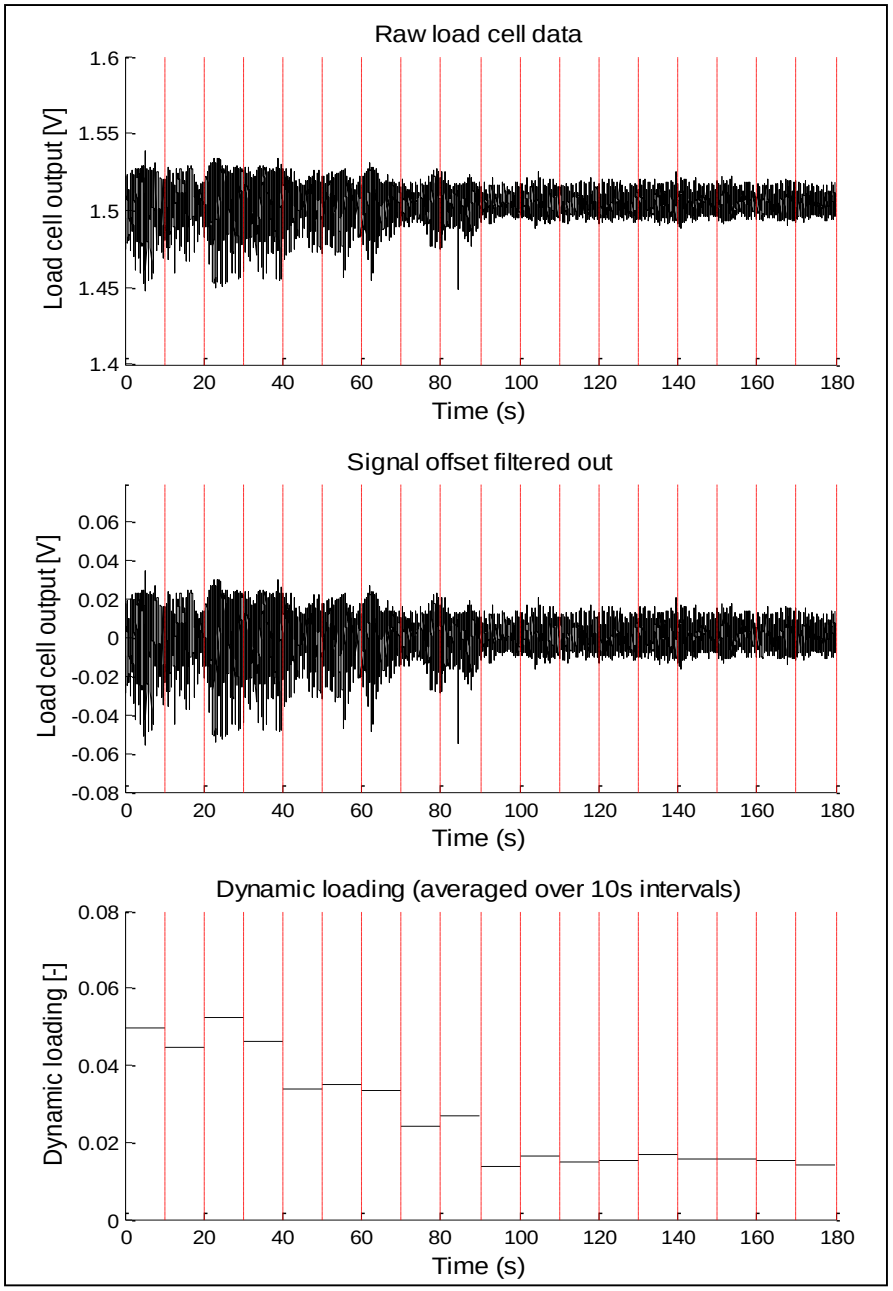
Middle

Static load filtered out

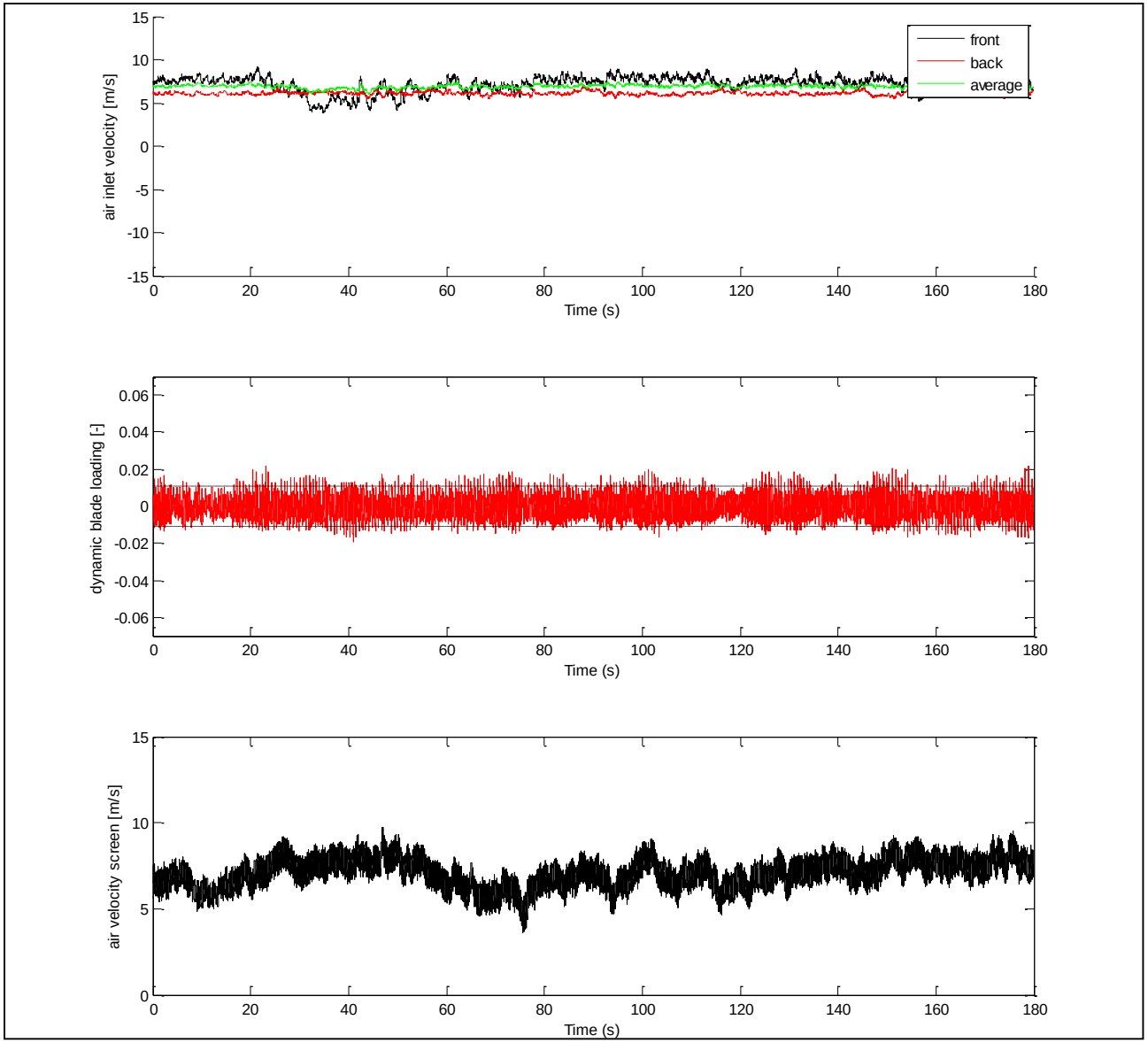
Leaving dynamic component of blade loading

Bottom

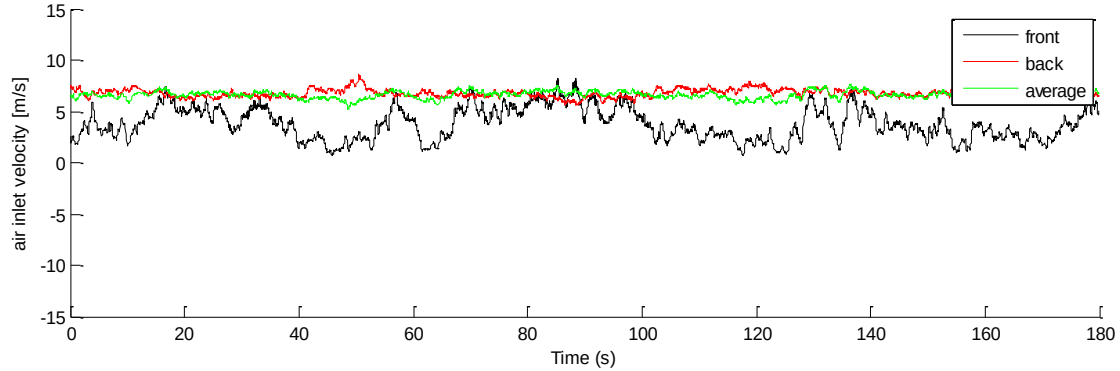
Dynamic blade loading averaged over 10 second intervals

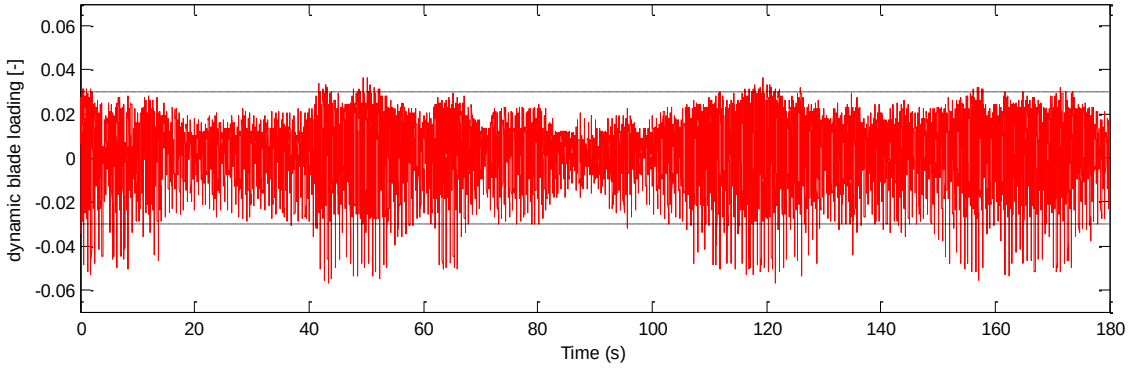


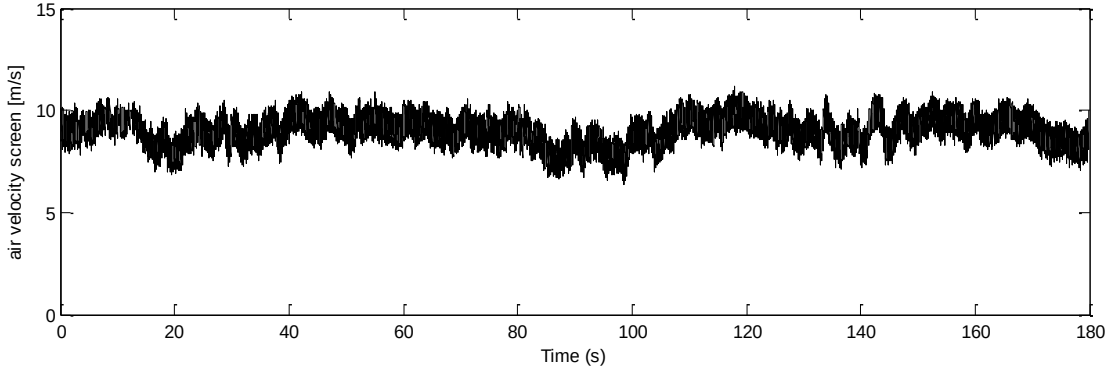
Uniform inlet flow



Non-uniform inlet flow







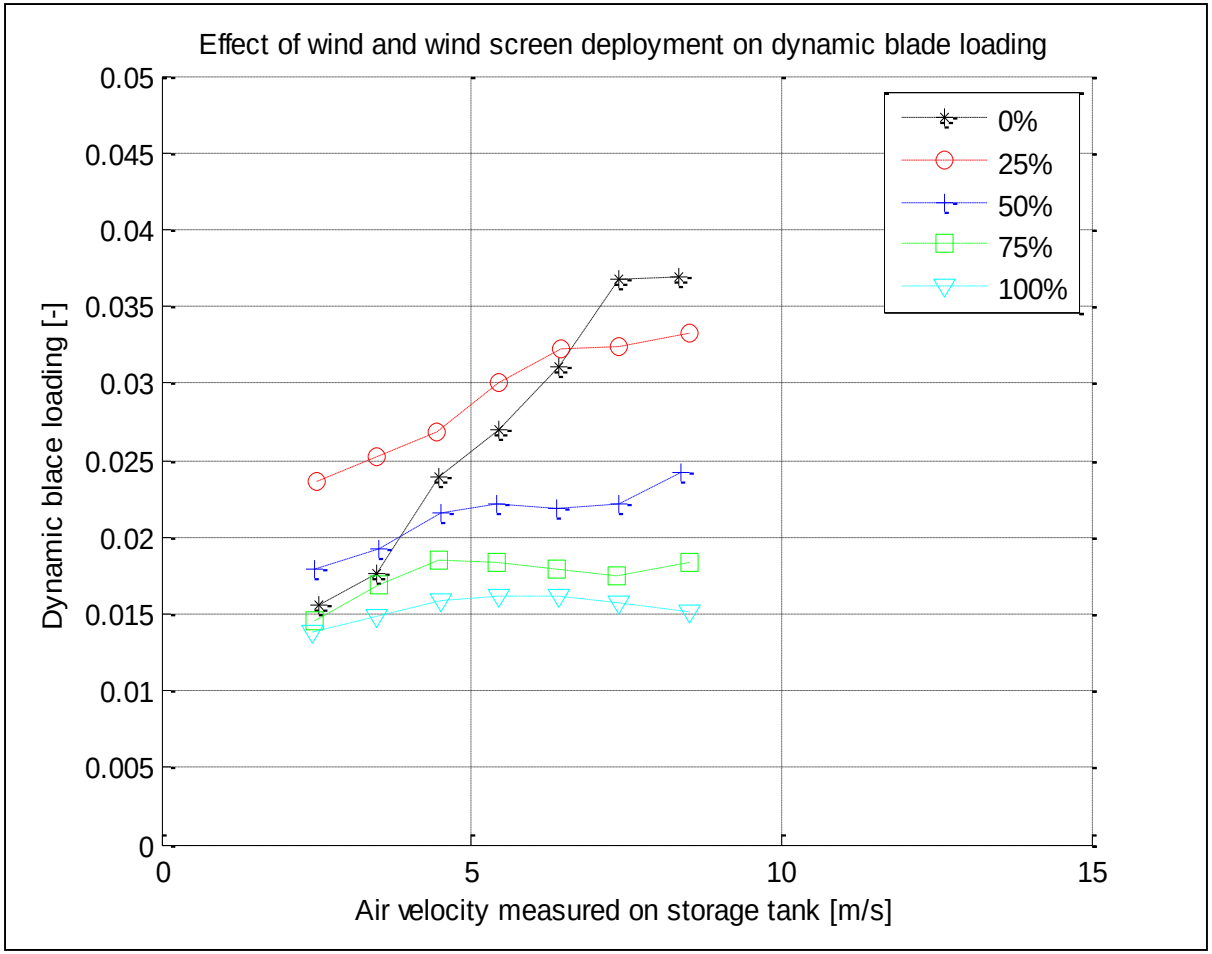
Effect of screen deployment

Dynamic blade loading fan 3.4

Increase at higher wind speeds

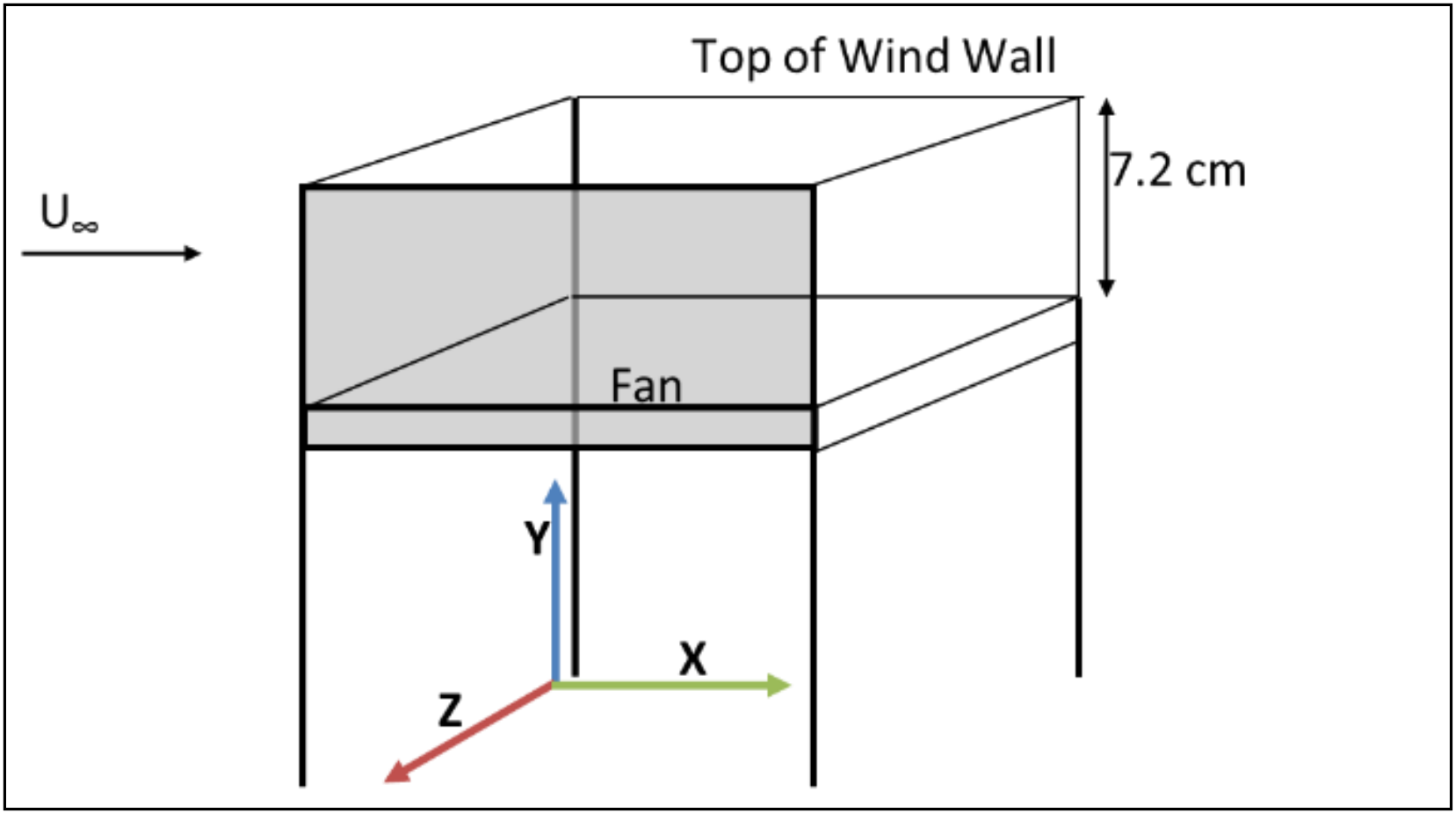
Significant influence wind screen

Screen deployment reduced dynamic blade load by a factor 2-3

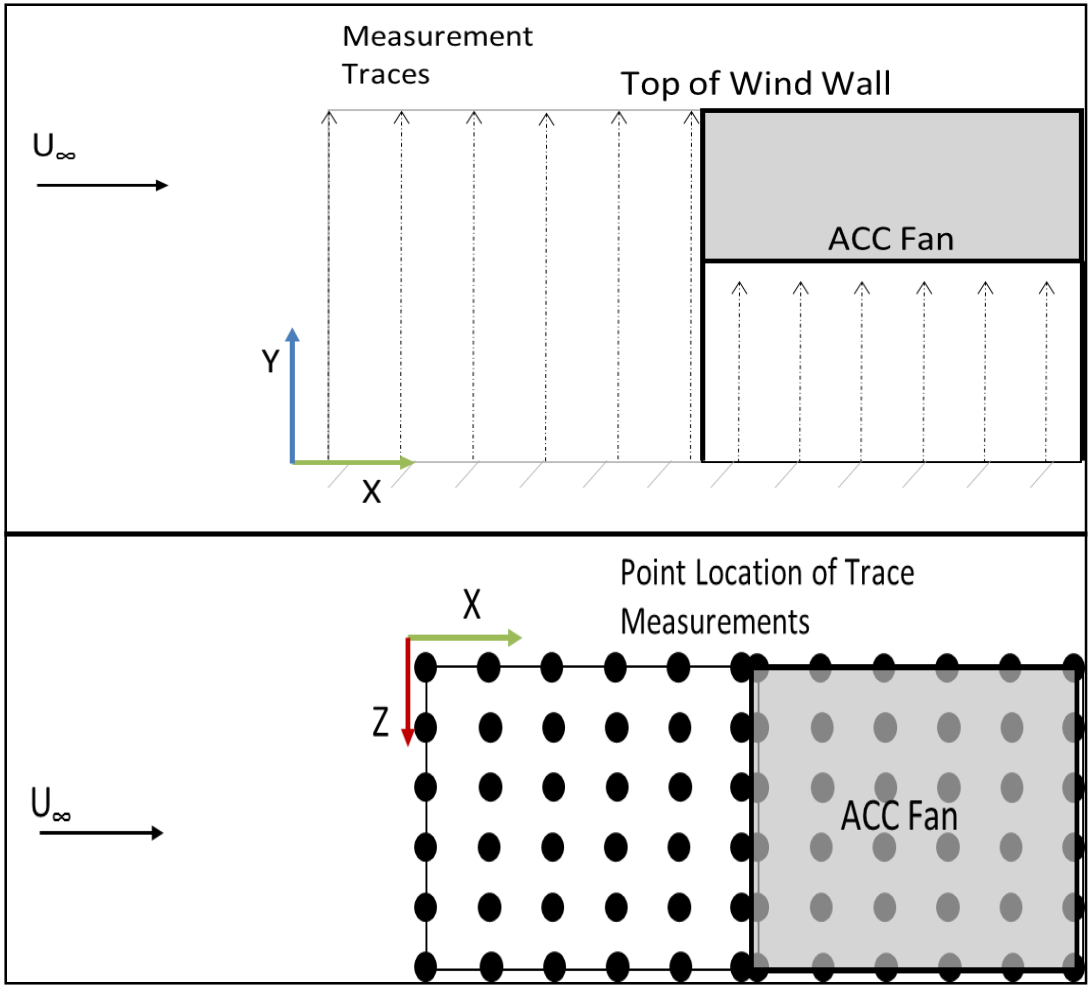


Wind Tunnel Modeling

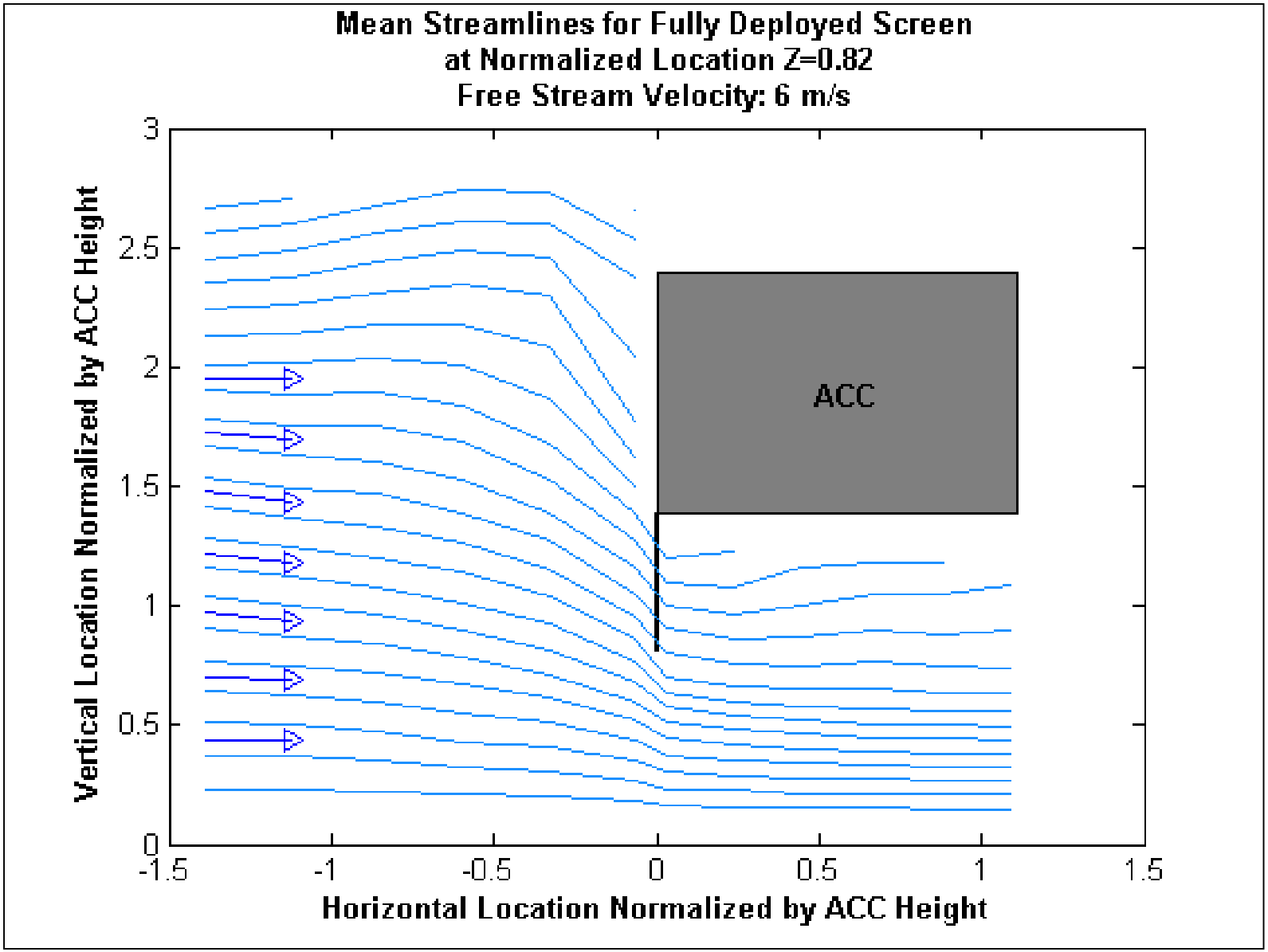
Skeleton Schematic of Cell 3.4



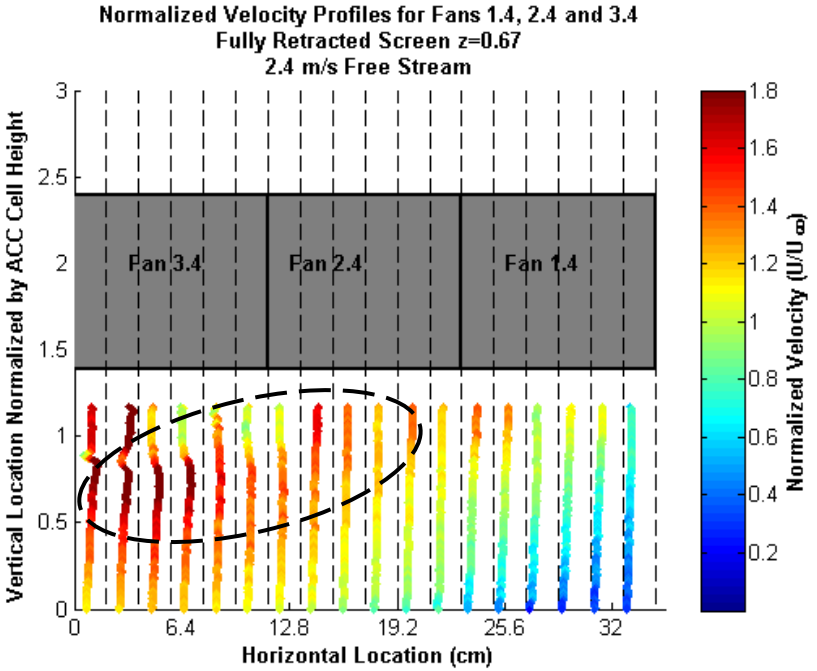
Measurement Locations

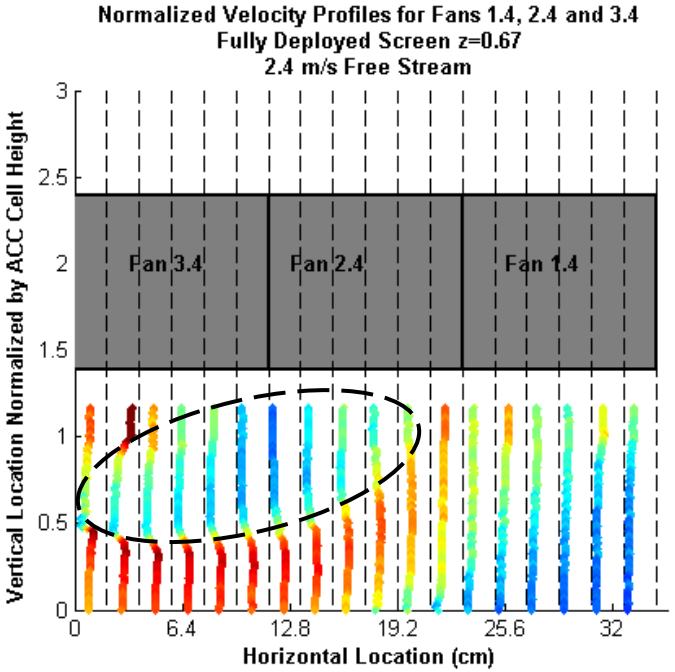


Streamline tracing

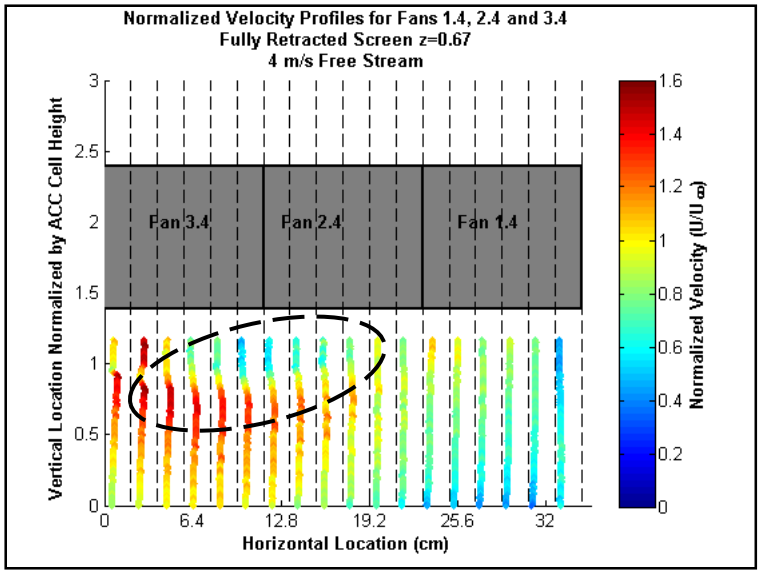


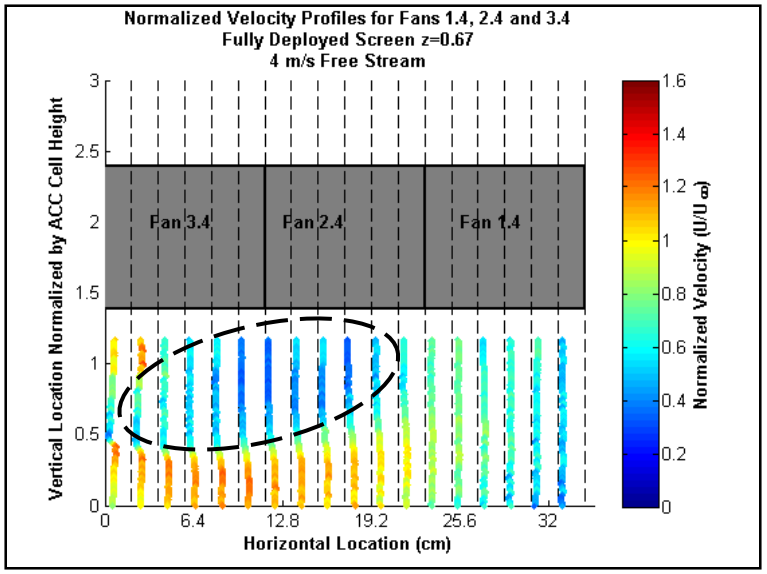
Velocity Profiles
Free Stream 2.4 m/s (6.0 m/s Full Scale)



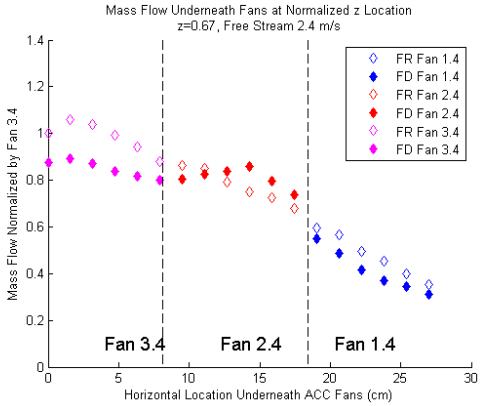


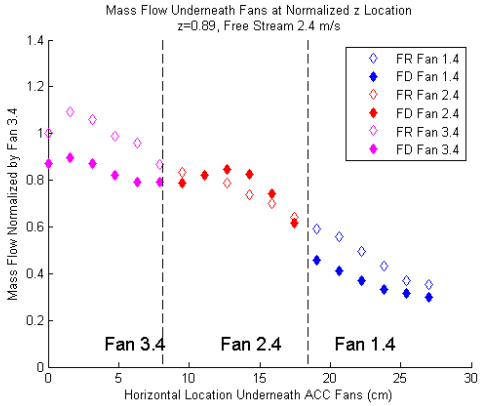
Velocity Profiles
Free Stream 4.0 m/s (9 m/s Full Scale)

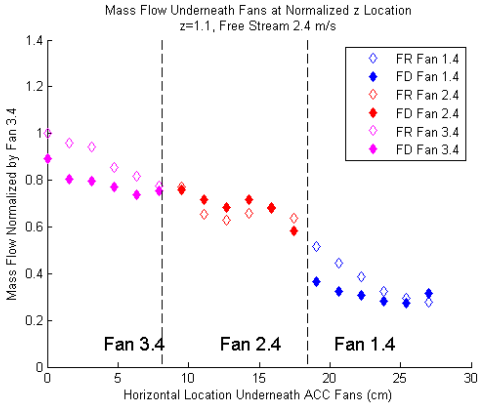


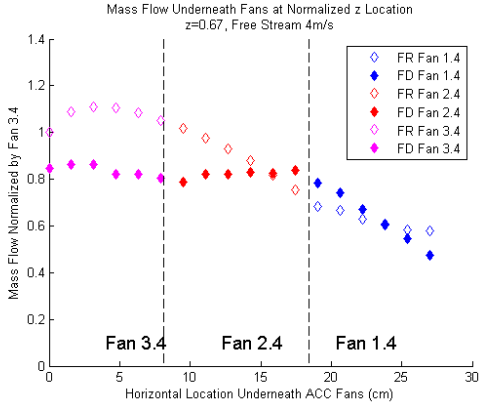


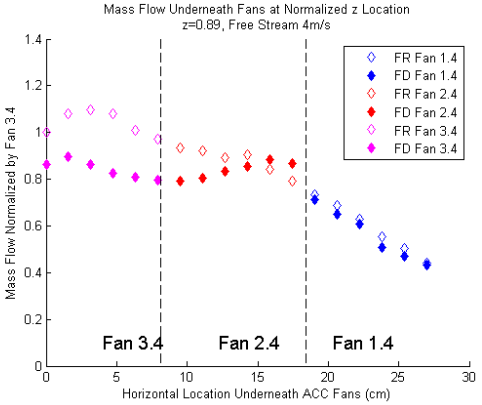
Total Average Horizontal Mass Flow

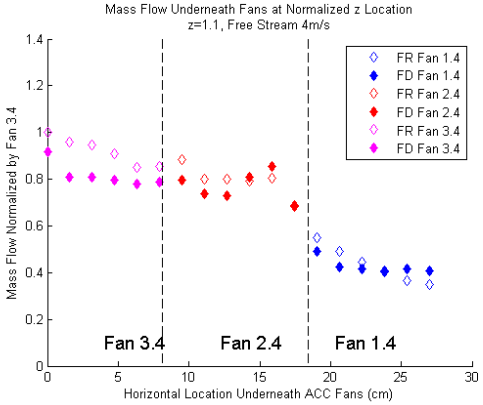




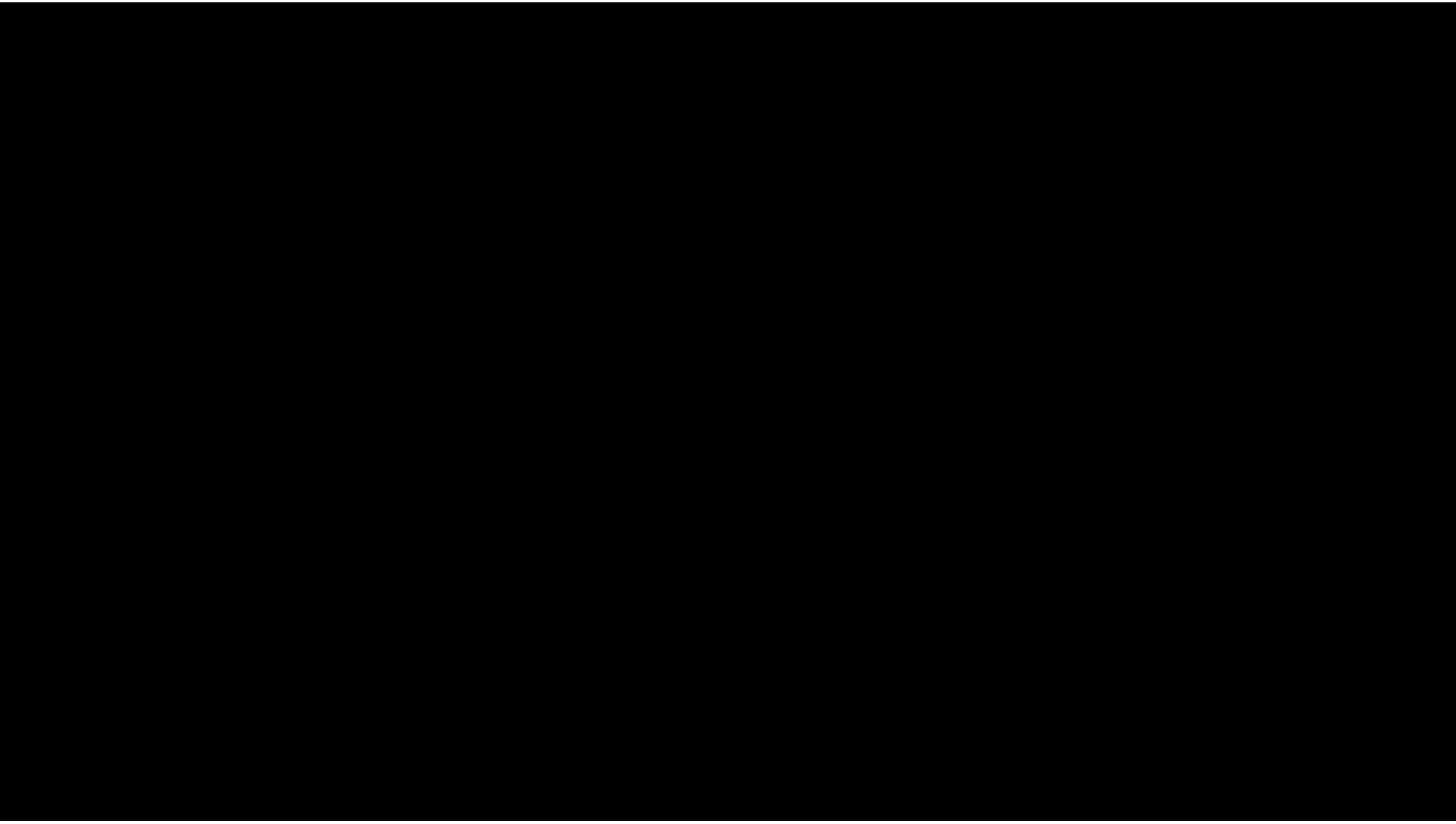








Smoke Visualization



CFD---What worked/What didn't?

Simple cases

- **Case 1:**
  - **Uniform inlet flow**
  - **Nearly still air (.3 m/s; ~ .7 mph)**
  - **No screens**

- **Case 2:**
  - **Uniform inlet flow**
  - **No screens**
  - **Moderate wind (3 & 6 m/s; ~ 7 & 14 mph)**

Still Air vs. Crosswind

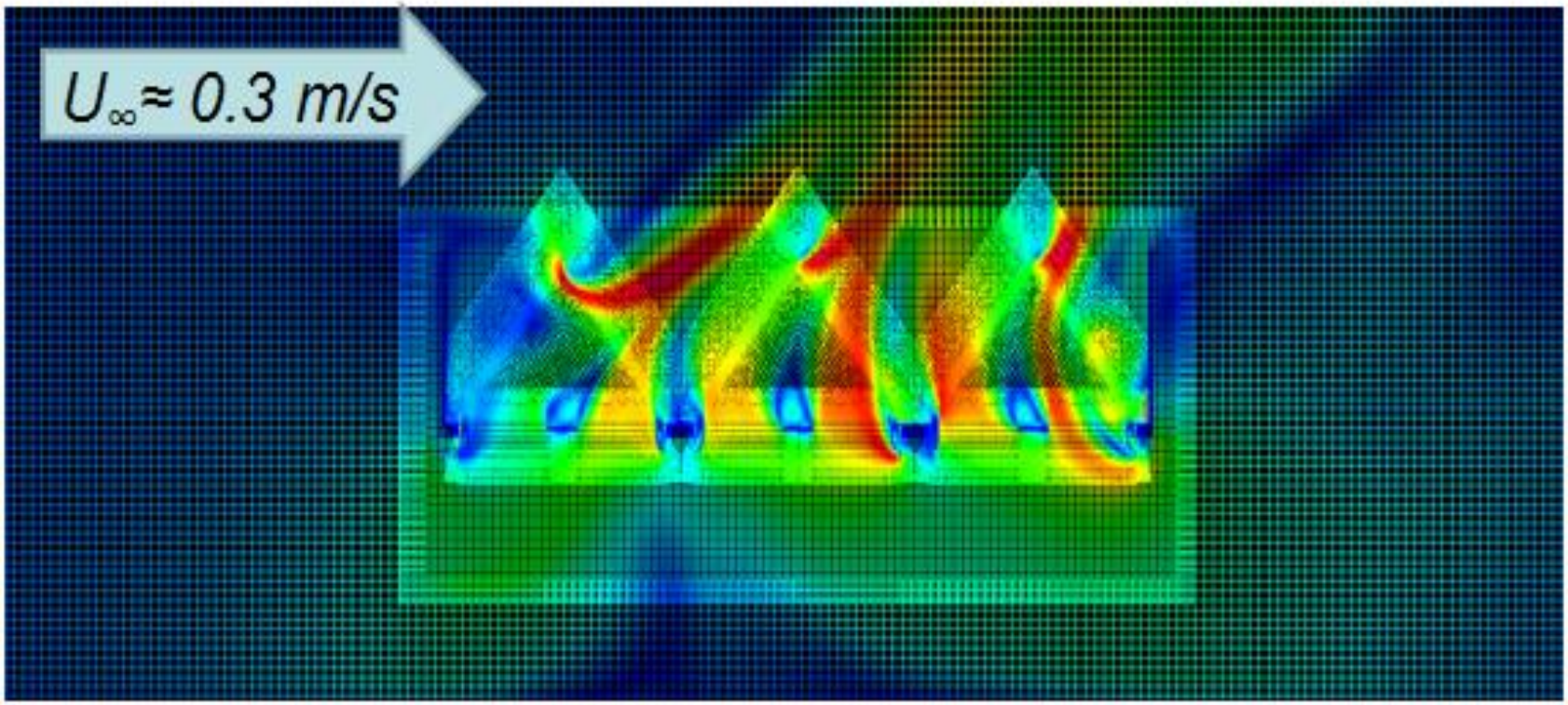
U_∞ (m/s)	Screen PDC	Tot Fan Press (Pa)	Fan	m_{dot}* -	m_{dot} (kg/sec)	Vol_{dot} (m^3/sec)	V_{fan} **(m/s)**
0.3	0	110.0	1,4	20.3	788	643	7.62
			2,4	23.6	914	746	8.85
			3,4	19.3	748	610	**7.24**
			3,6	21.9	848	692	8.20

U_∞ (m/s)	Screen PDC	Tot Fan Press (Pa)	DP_{AFrame} (Pa)	Fan	m_{dot}* -	m_{dot} (kg/sec)	Vol_{dot} (m^3/sec)	V_{fan} (m/s)	V_{exp_avg} (m/s)
3	0	110.0	78.0	1,4	20.2	782	638	7.56	-
				2,4	17.2	665	543	**6.43**	**6.78**
				3,4	3.2	123	100	**1.19**	**6.83**
3	1.1	110.0	78.0	1,4	15.6	604	493	5.85	-
				2,4	18.8	730	596	7.07	-
				3,4	5.3	206	169	**2.00**	-
6	0	110.0	78.0	1,4	16.6	644	526	6.23	-
				2,4	16.4	637	520	**6.16**	**6.34**
				3,4	4.8	187	152	**1.81**	**5.87**
6	1.1	110.0	78.0	1,4	14.1	545	445	5.28	-
				2,4	17.5	679	554	**6.57**	**6.41**
				3,4	5.2	203	166	**1.96**	**5.04**

Qualitative Understanding

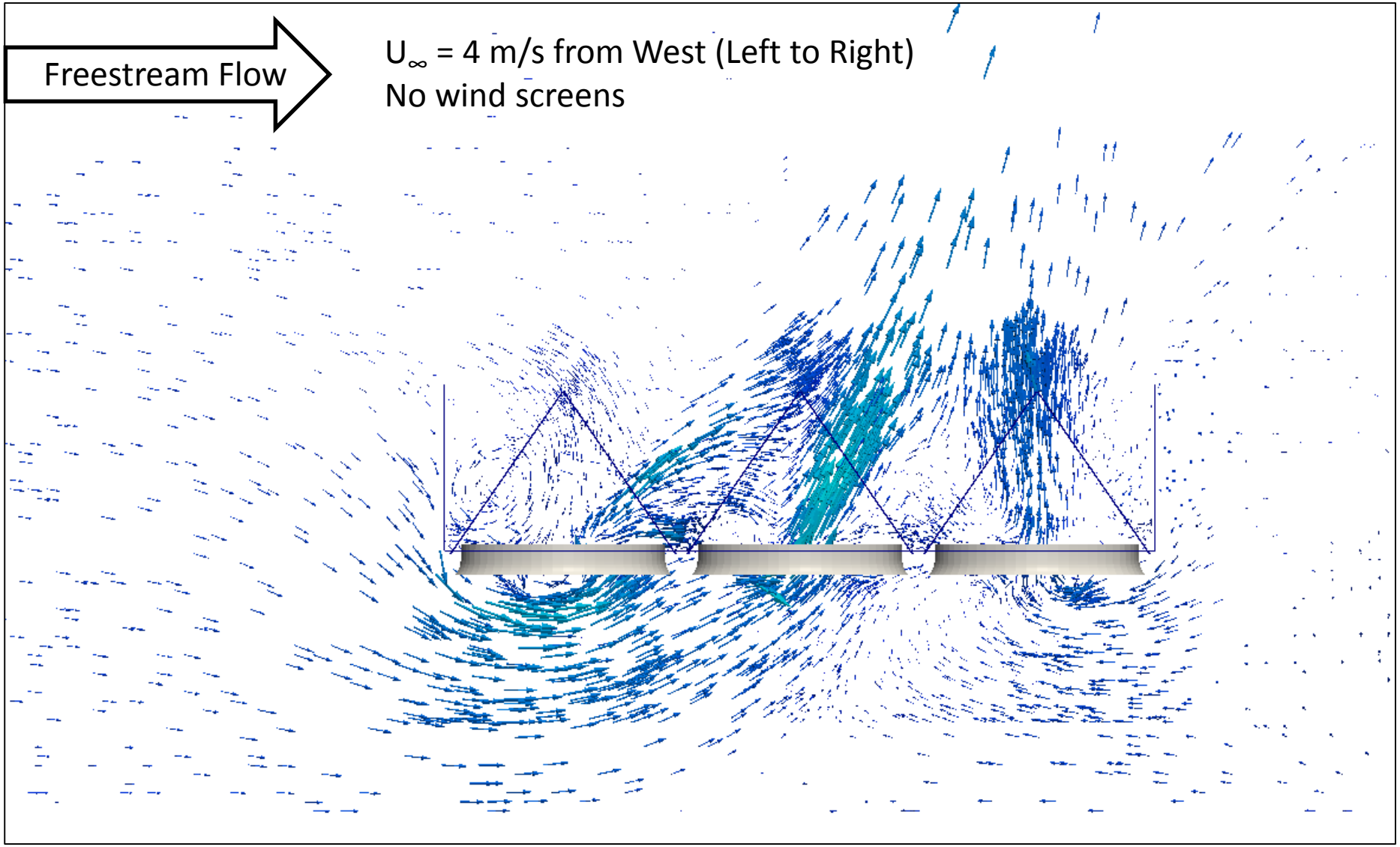
- **Physical picture**
  - **Streamlines**
  - **Velocity vectors**

Low Cross-Flow – Total Velocity Mag

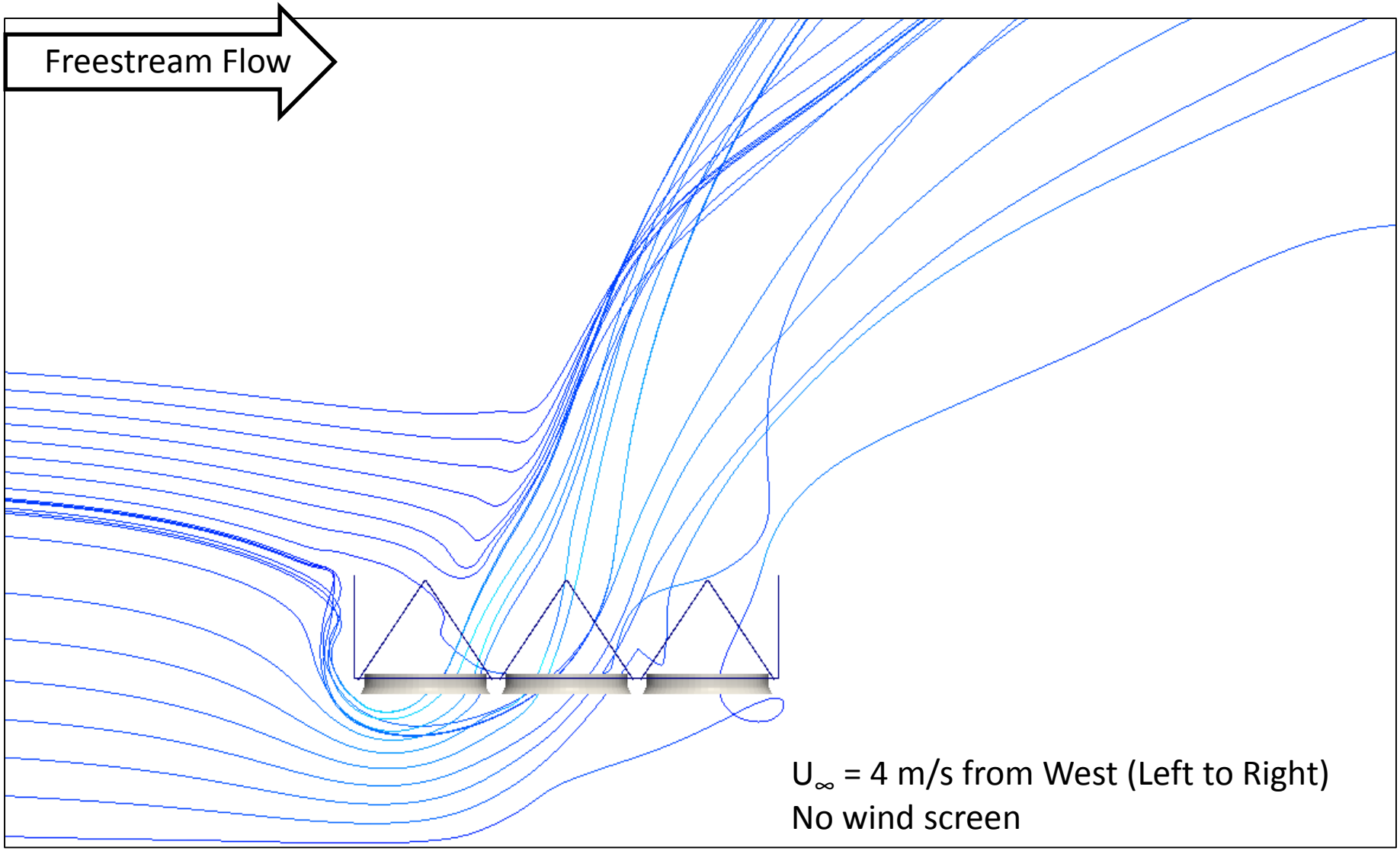


$V_{fan3,4}$ = **7.24 m/s** $V_{fan2,4}$ = **8.85 m/s** $V_{fan1,4}$ = **7.62 m/s**

Velocity Vectors



Streamlines - U_∞ = 4 m/s



Qualitative Understanding

- **Upstream complexity**
  - **Inlet boundary layer**
  - **Upstream obstructions—trees and buildings**
  - **Horizontal ledge at bottom of windwall**

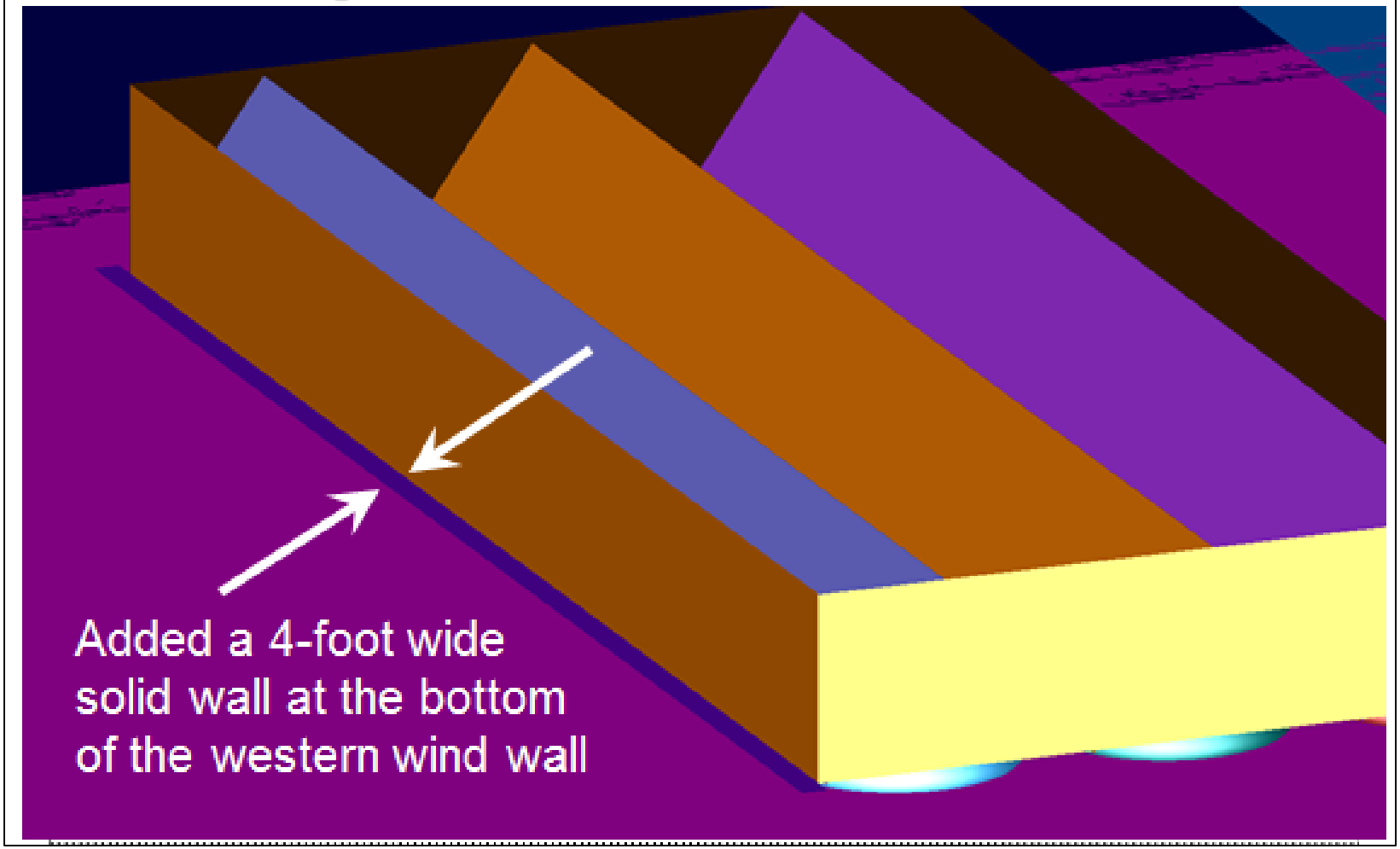
Field Tests—Caithness
18 cell ACC; retractable screens

Inflow Trees/Buildings

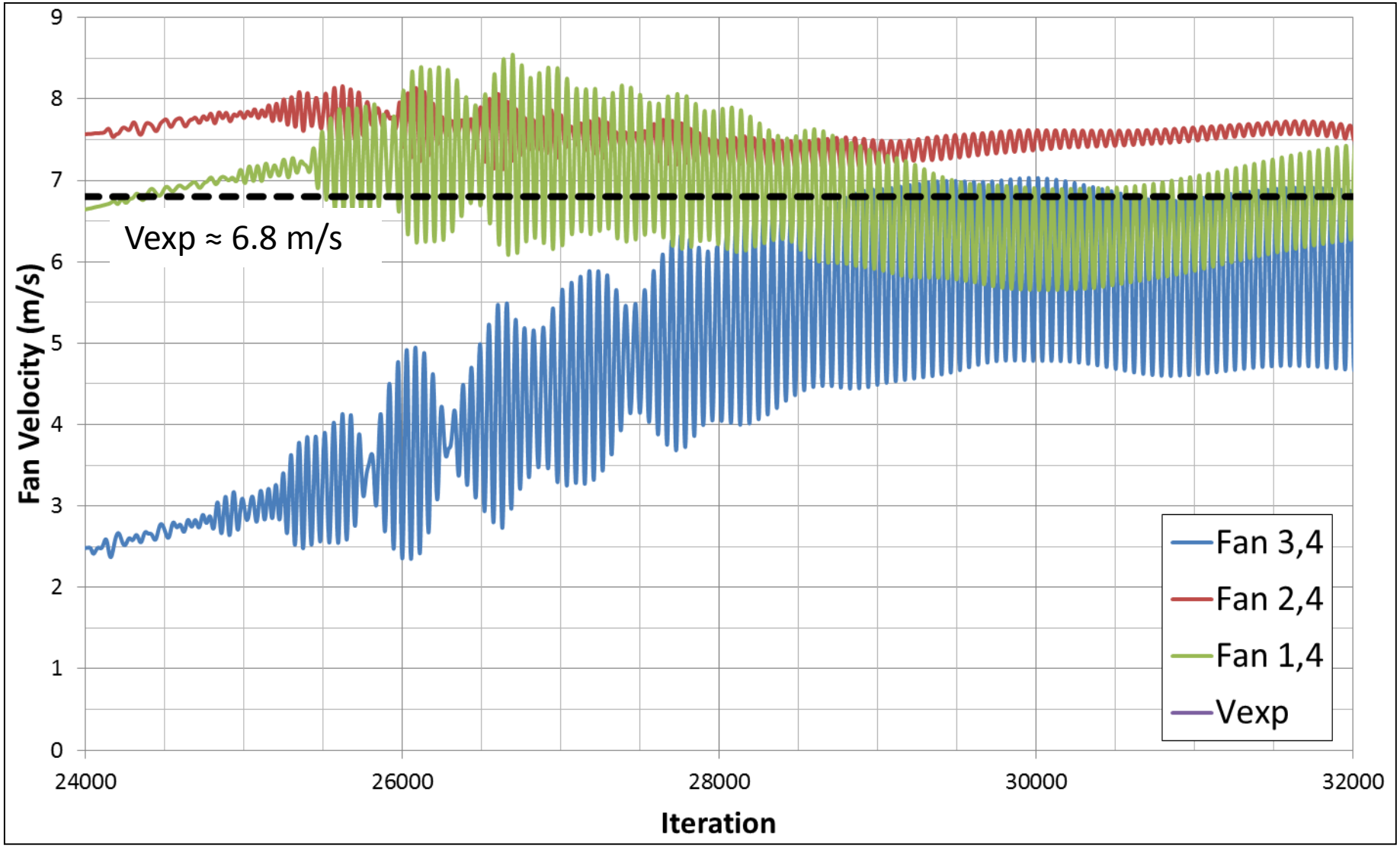
Case	U_∞ (m/s)	Screen PDC	Tot Fan Press (Pa)	DP_{AFrame} (Pa)	Fan	m_{dot}* -	m_{dot} (kg/sec)	Vol_{dot} (m^3/sec)	V_{fan} (m/s)	V_{exp_avg} (m/s)
No Trees	3	0	110.0	78.0	1,4	20.2	782	638	7.56	-
w/ BL					2,4	17.2	665	543	6.43	6.78
					3,4	3.2	123	100	**1.19**	**6.83**
Trees	3	0	110.0	78.0	1,4	17.1	661.1	539.7	6.40	-
w/ BL					2,4	18.4	713.2	582.2	6.90	6.78
					3,4	5.2	200.4	163.6	**1.94**	**6.83**

- Various tree/building configurations and heights examined
- All increased flow rate through fan 3,4, but not sufficiently

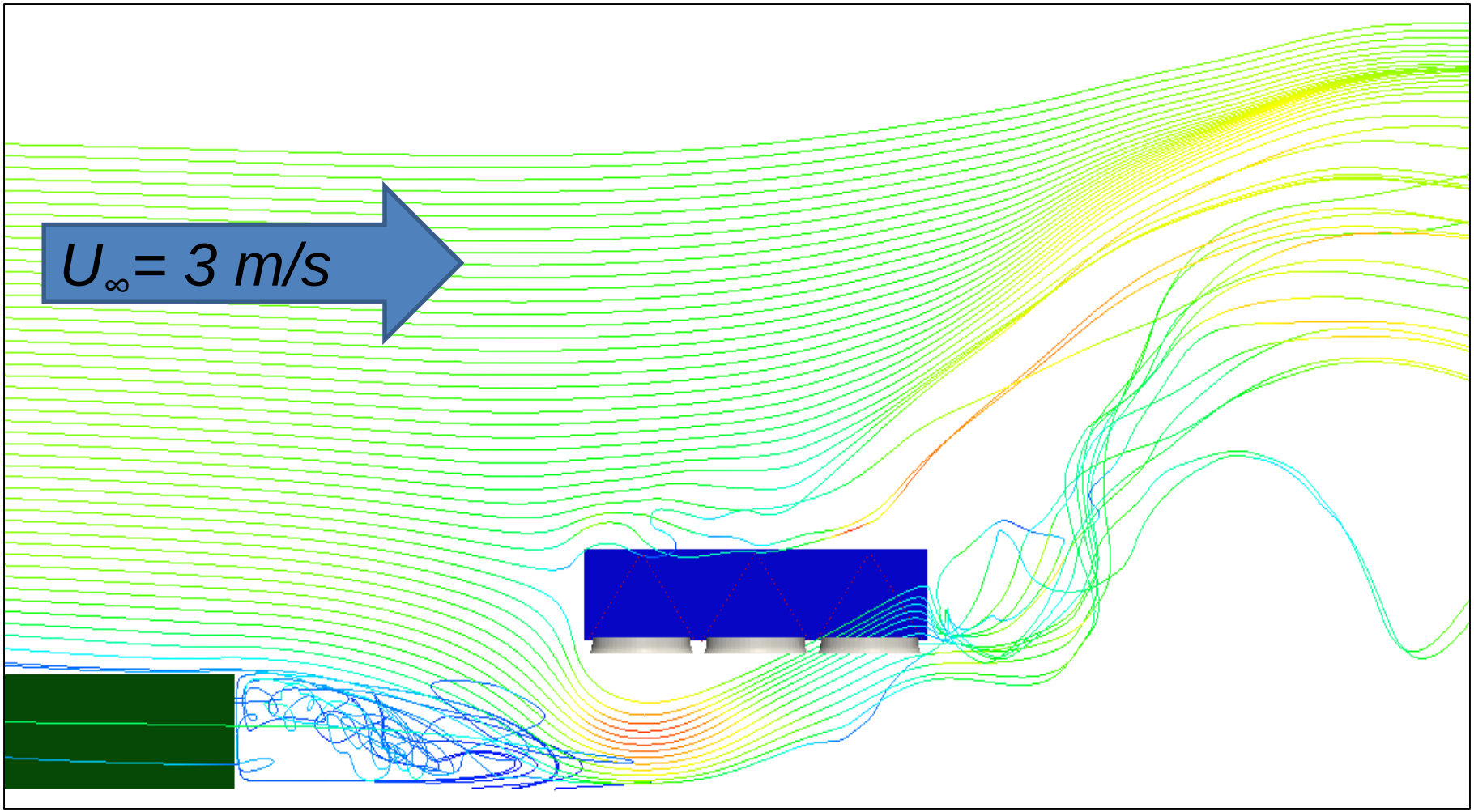
Walkway


Added a 4-foot wide
solid wall at the bottom
of the western wind wall

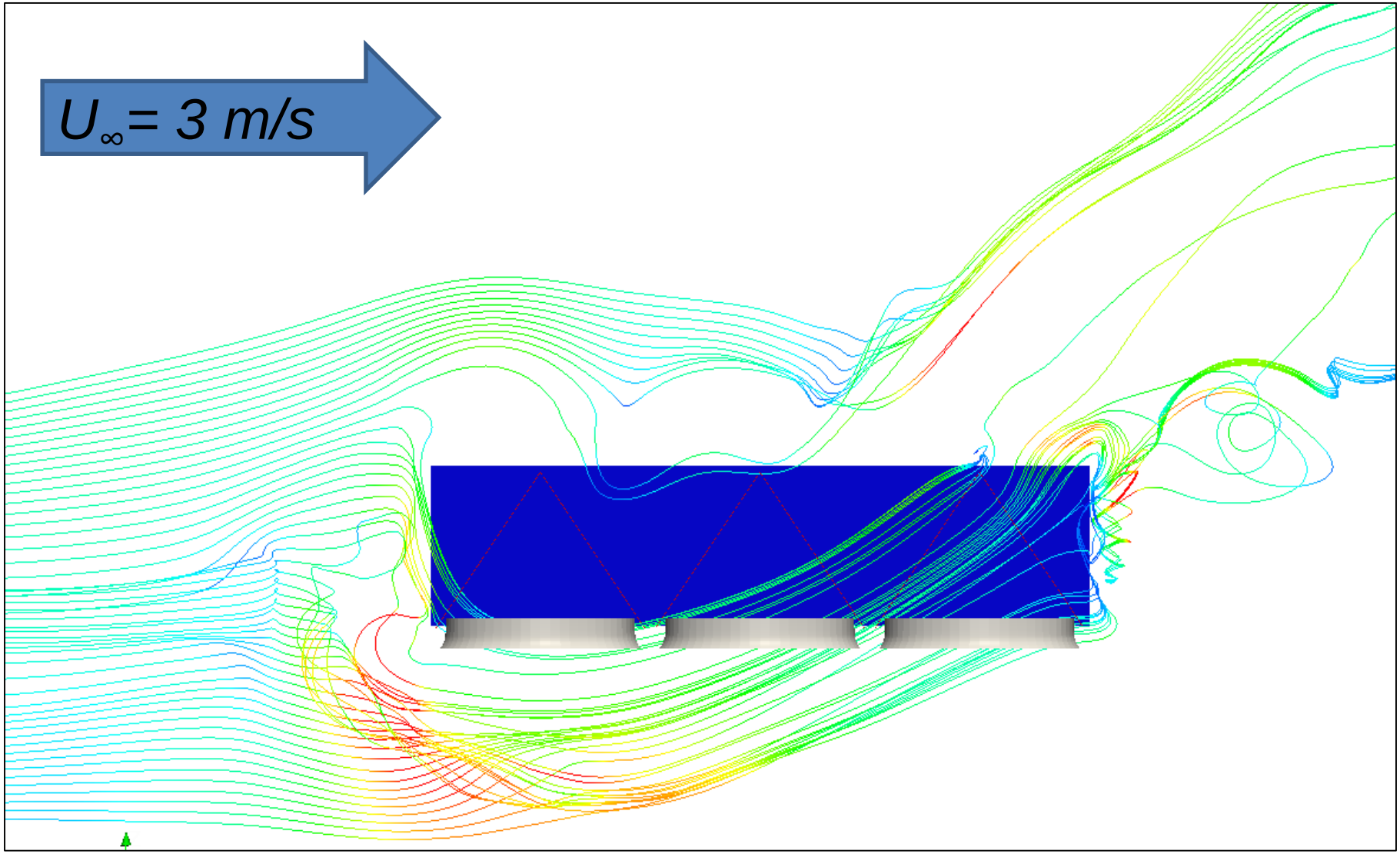
Ledge/Walkway – U_∞=3 m/s



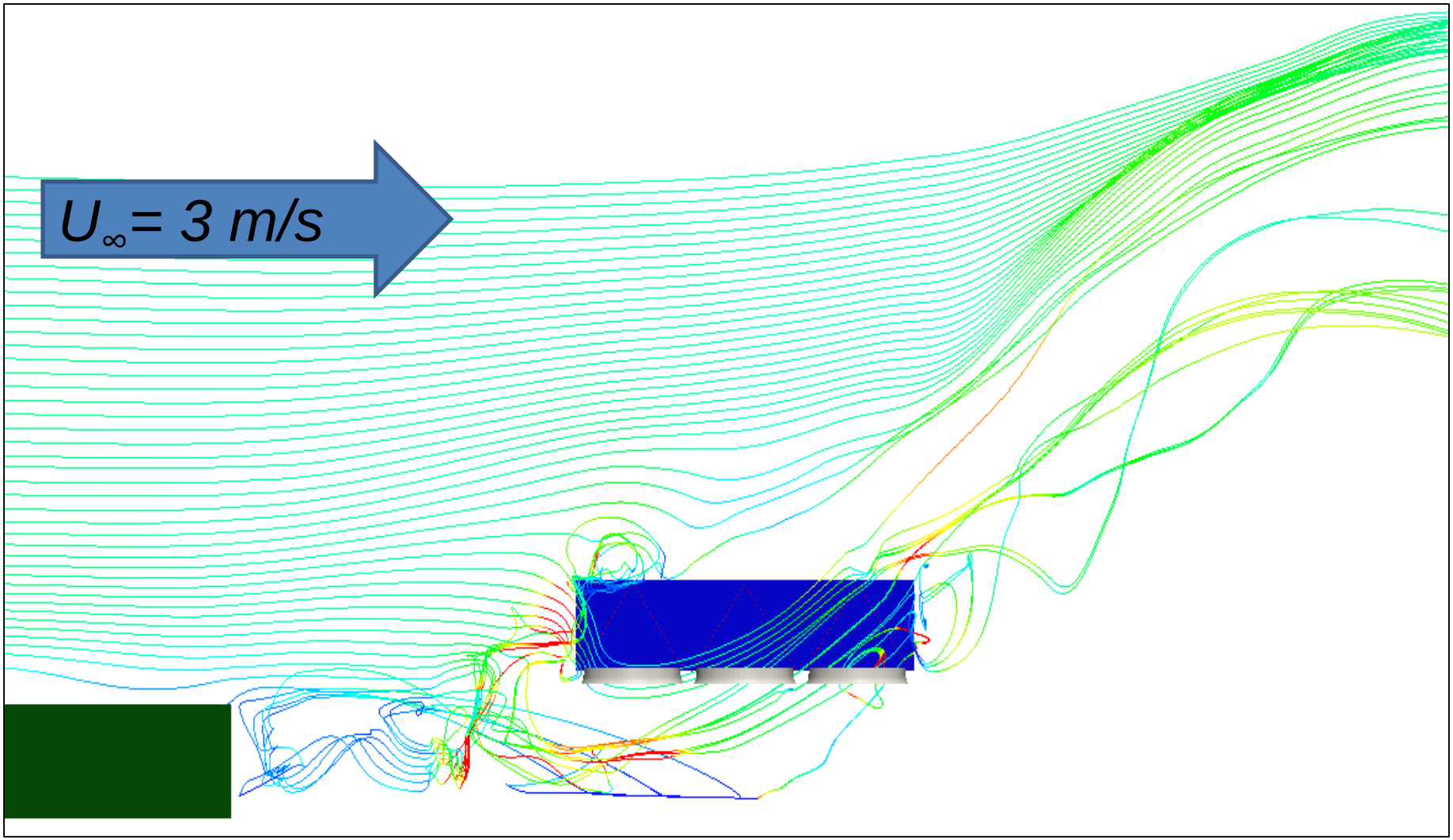
Without Walkway w/ Trees



With Ledge/Walkway and w/o Trees



With Ledge/Walkway and Trees



Summary

Field tests:

- **Reduce loading on blades**
- **Improve fan inlet uniformity**
- **May enhance performance**

Wind tunnel modeling

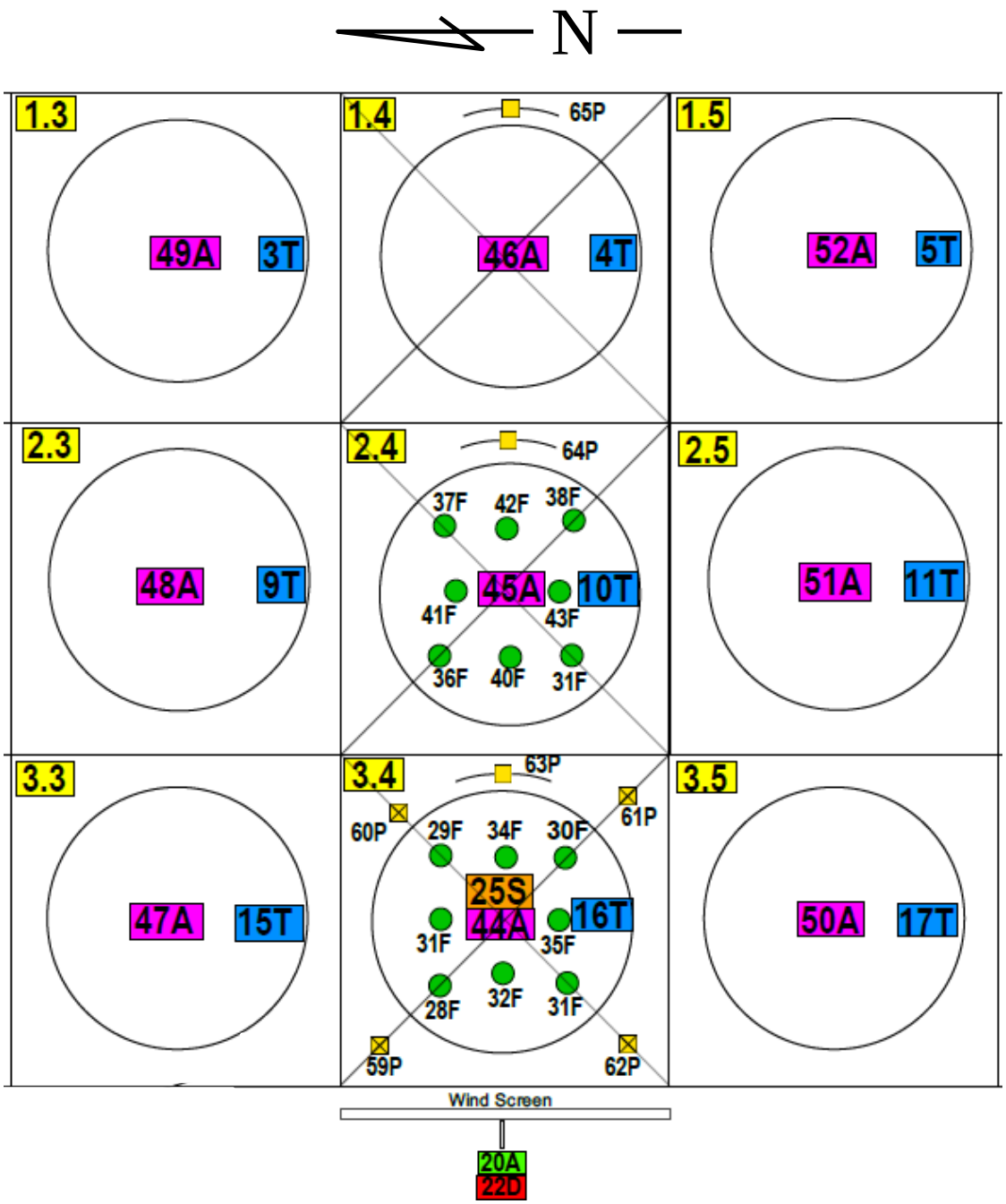
- **Good correspondence to field**
- **Can explore alternatives**
- **Provide physical feel**

CFD

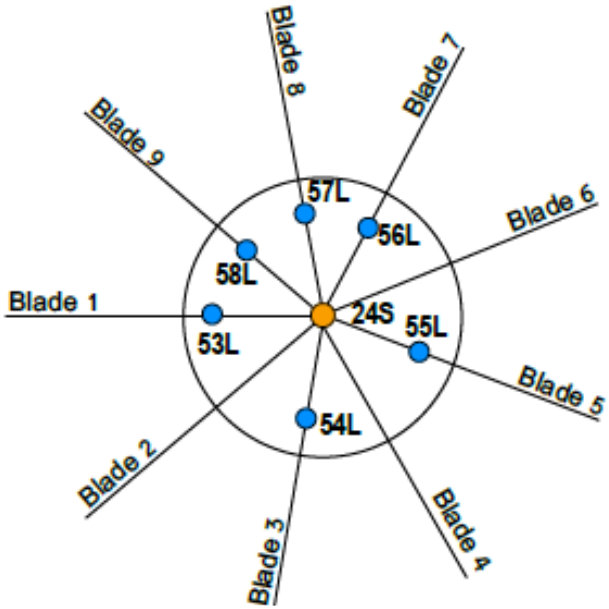
- **Very detailed representation**
- **Can explore wide range of cases**
- **Quantitative results not achieved**

Windscreens coming into common use

Plant Name	Country	Utility	Location	ACC Vendor	Date	Screen type	New or Retrofit
Big Horn	US	NV Power	NV	SPX (Hamon)	2003	Perimeter	New
Maalaea, HI	US	HECO	HI	SPX	2005	One bay in	Retrofit
Gateway	US	PG & E	CA	SPX	2008	One bay in	New
Caithness	US	Caithness LLC	NJ	GEA	2012	Retractable	Retrofit
Ivanpah Solar	US	NextEra	CA	SPX	2012	One bay in	New
El Dorado	US	SDG&E	NV	GEA	2002	Cruciform	Retrofit
WyGen	US	Pacificorp	WY	GEA	2002	Cruciform	Retrofit
Deer Creek	US	Basin Electric	ND	SPX	2010	One bay in	New
Tracy	US	GWF Energy	CA	SPX	2012	One bay in	New
Comanche III	US	Xcel Energy	CO	GEA	2013	Perimeter	Retrofit
Long Beach	US	LADWP	CA	GEA	2014	Perimeter	Retrofit
Mystic #8	US	Excelon	MA	SPX	2014	Perimeter	Retrofit
Scattergood #3	US	LADWP	CA	Holtec	2015	Perimeter	New
North Bay	Canada	Atlantic Power	Ontario	GEA	2014	Perimeter	Retrofit
North Battleford	Canada	Nortland Power	Saskatchewan	GEA	2014	Perimeter	Retrofit
San Luis de la Paz	Mexico	AEP	San Luis de la Paz	SPX	2014	Perimeter	New
Kings Lynn	UK	Centrica	Norfolk	SPX	1998	Cruciform	Retrofit
Kings Lynn	UK	Centrica	Norfolk	SPX	2011	Retractable	Retrofit
Peterborough	UK	Centrica	Cambridgeshire	GEA	1999	Perimeter	Retrofit
Barry	UK	Centrica	Glamorgan	GEA	2001	One bay in	Retrofit
Coryton	UK	Intergen	Essex	GEA	2004	Perimeter	Retrofit
Spalding	UK	Intergen	Lincolnshire	GEA	2007	Perimeter	Retrofit
Sutton Bridge	UK	Macquarie Group	Lincolnshire	SPX	2008	Perimeter	Retrofit
Enfield	UK	Enfield Energy Centre	London	SPX	2010	Perimeter	Retrofit
Langage	UK	Centrica	Devon	SPX	2010	One bay in	New
Stevens Croft	UK	E.ON	Cumbria	GEA	2011	Perimeter	Retrofit
Western Biomass Energy	UK	RWE	South Wales	GEA	2013	Perimeter	Retrofit
Dordecht	Netherlands	South Holland Power	Dordecht	SPX	2012	Perimeter	Retrofit
Wijster	Netherlands	Attero	Wijster	SPX	2006	Perimeter	Retrofit
Catalagzi	Turkey	EUAS	Catalagzi	GEA	2012	Cruciform	New
Denizli	Turkey	RWE/EUAS	Denizli	SPX	2012	One bay in	New
Hsin Tao	Taiwan	Hsin Tao Power Corp	Taiwan	SPX	2003	One bay in	Retrofit
Kuo Kuang	Taiwan	CPC	Taiwan	GEA	2009	Perimeter	Retrofit
Star Buck	Taiwan	Starbuck Power Corp	Taiwan	SPX	2012	One bay in	Retrofit
Thiva	Greece	GDF Suez	Thiva	SPX	2008	One bay in	New
Fengzhen	China	China Huaneng Group	Fengzhen	SPX	2006	One bay in	Retrofit



T = Temperature Probe (1-19)
D = Wind Direction (22, 23)
A = Wind Speed (20, 21),
Amps (44-52)
F = Flow Sensor (28-42)
L = Load Cell (53-58)
P = Pressure (59-65)
S = Position, Fan Blade Location (24, 25)
Screen (26)



Fan 3.4 Load Cells

Caithness project

Data used for analysis

Howden

Filtered data divided into 7 subsets based on wind speed

2 < v < 3

3 < v < 4

4 < v < 5

5 < v < 6

6 < v < 7

7 < v < 8

v > 8

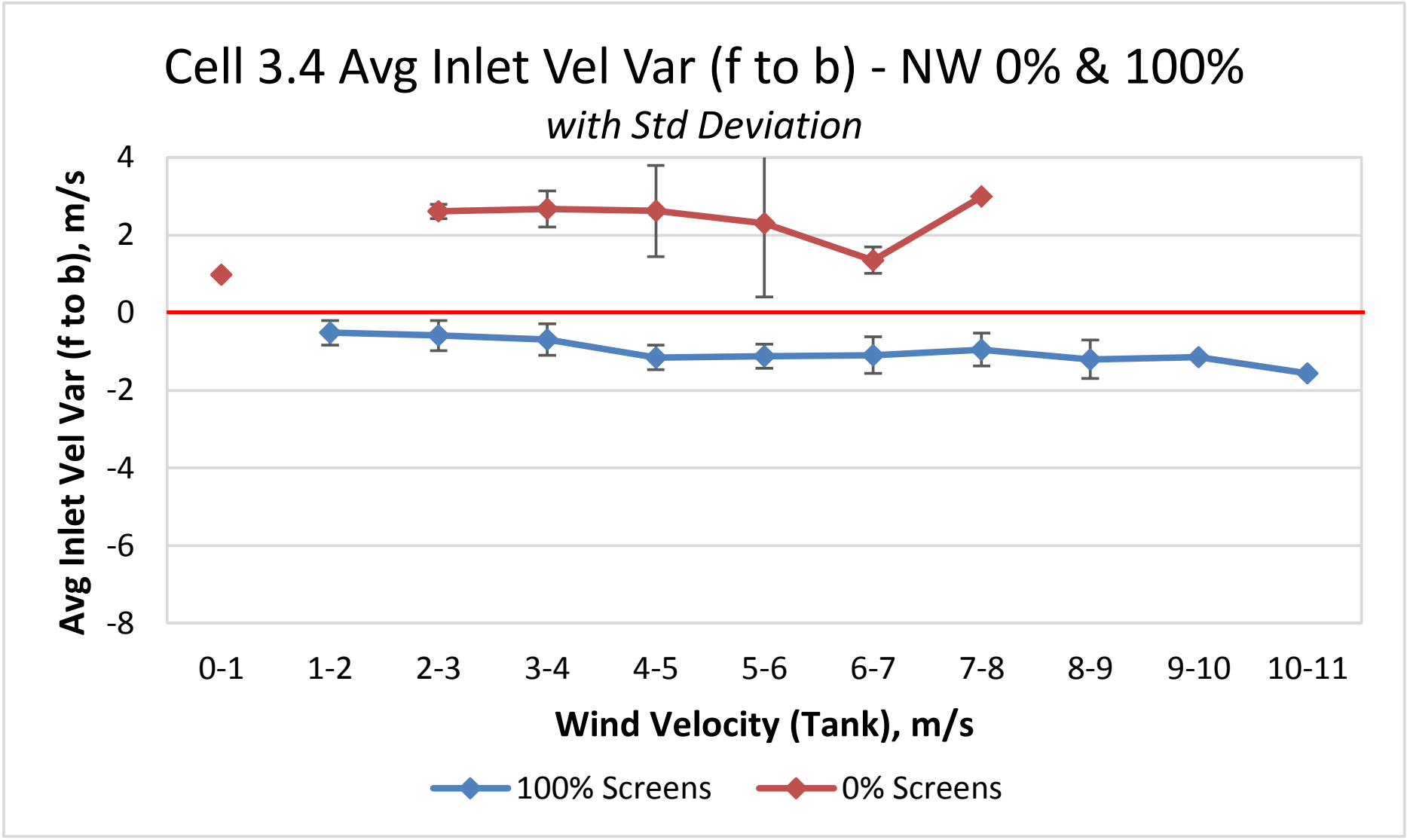
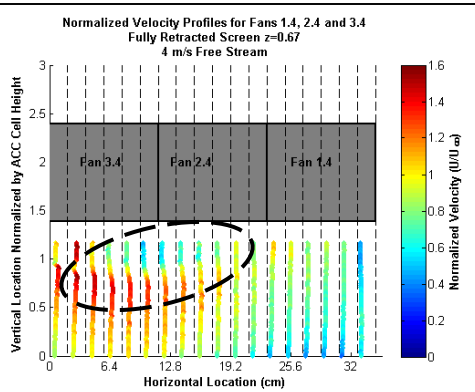
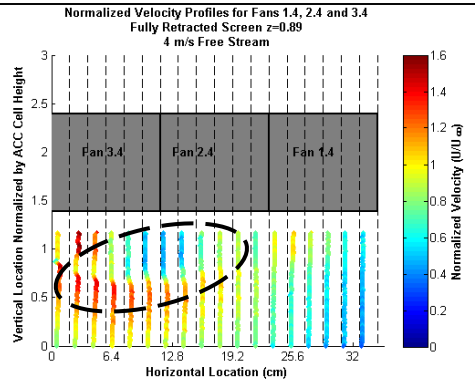
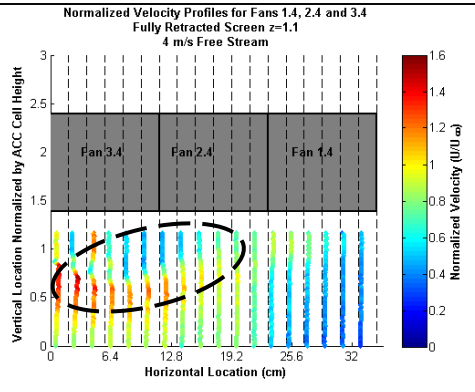
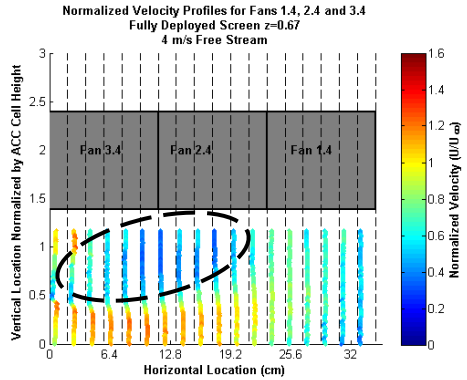
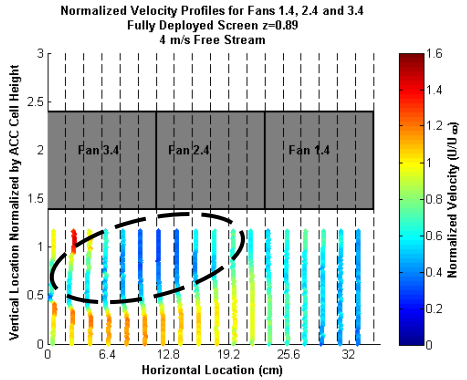
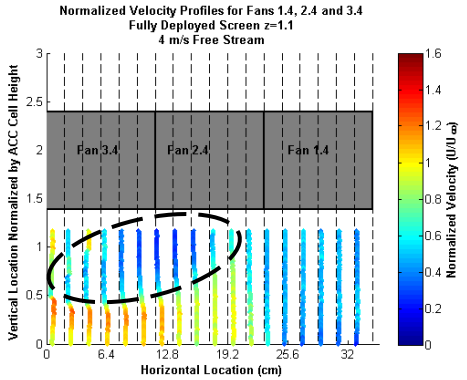
Resulting size of data subsets

	Screen position				
Air velocity [m/s]	0%	25%	50%	75%	100%
2 < v < 3	*3994*	*7980*	*7670*	*3048*	*11312*
3 < v < 4	*5915*	*6279*	*5581*	*3205*	*7876*
4< v < 5	*3182*	*4475*	*9031*	*3727*	*6405*
5 < v < 6	*1786*	*2427*	*6199*	*2332*	*4610*
6 < v < 7	*629*	*1135*	*1588*	*649*	*1884*
7< v < 8	*153*	*407*	*269*	*103*	*542*
v >8	*25*	*131*	*41*	*9*	*146*

Screen Position	Cell 3.4 NW Data Points	Cell 3.4 W Data Points	Cell 3.4 SW Data Points	Cell 3.4 SE Data Points	Cell 2.4 NW Data Points
100%	1,305	399	1,006	1,195	1,305
75%	580	525	304	1,830	580
50%	1,844	518	915	359	1,844
25%	439	1,214	811	1,533	439
0%	159	647	797	393	159
Total	4,330	3,303	3,833	5,310	4,330

Caithness—With screens

Non-Uniform Inlet Velocity



Velocity Profiles
Free Stream 4.0 m/s (9 m/s Full Scale)