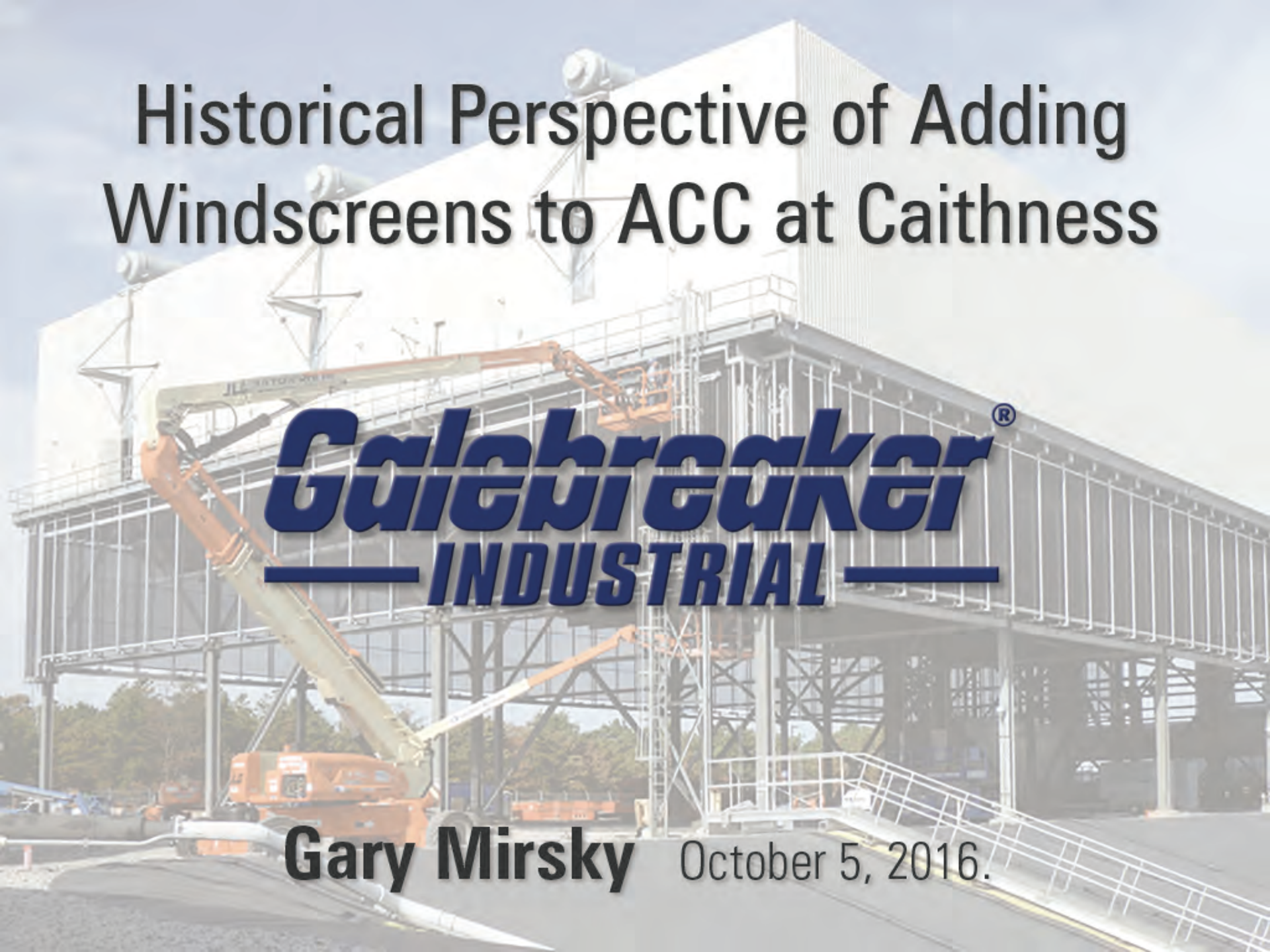
Historical Perspective of Adding Windscreens to ACC at Caithness



Gary Mirsky October 5, 2016.

Fan Blade, Vibration & Motor Trip Problems

Outline

- Caithness Aerial View
- Highlights of Literature Search
- Several CFD Analysis
- Plan Layout of Caithness ACC
- Data Suggesting Wind Related Issues
- Testing After Windscreen Installation
- Instrument Deployment
- Normalization of Airflow
- Videos of Wind Tunnel Tests

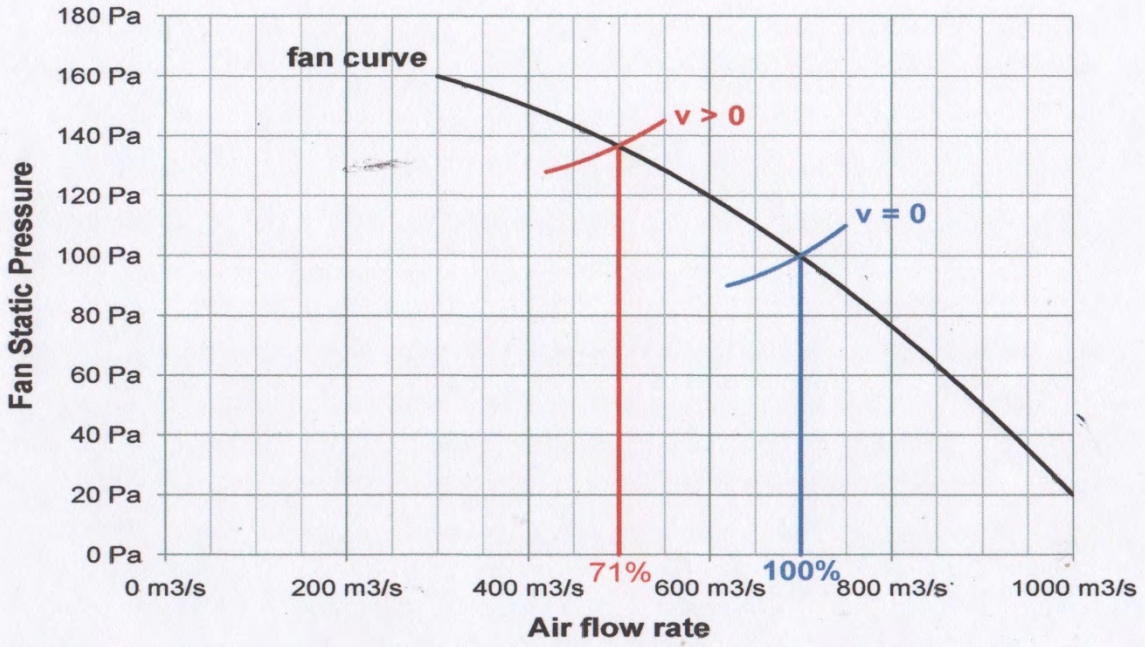
Caithness Aerial View

Highlights of Literature Search

1. Impact of Wind on Performance – Debacker/GEA
2. Innovative Concepts to Mitigate Wind Effects – Wyndrum/SPX
3. CFD Analysis by Mortensen/SPX
4. CFD Analysis by Galebreaker
5. Volumetric Effectiveness Kroger/van Royen of Stellenbosch University
6. Wind Effects on ACC's Maulbetsch/DiFilippo

GEA Wind Effects on Airflow

Aerodynamic impact of wind on fan operation



If v_{wind} increases → static pressure increases → reduced air flow

GEA Performance Improvements Using Wind Screens

ACC performance improvement using wind screens

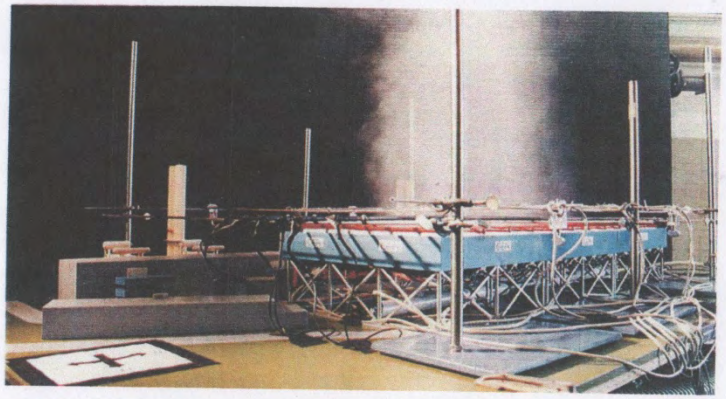
Case study: up to 30% ACC performance loss for 30 mph wind

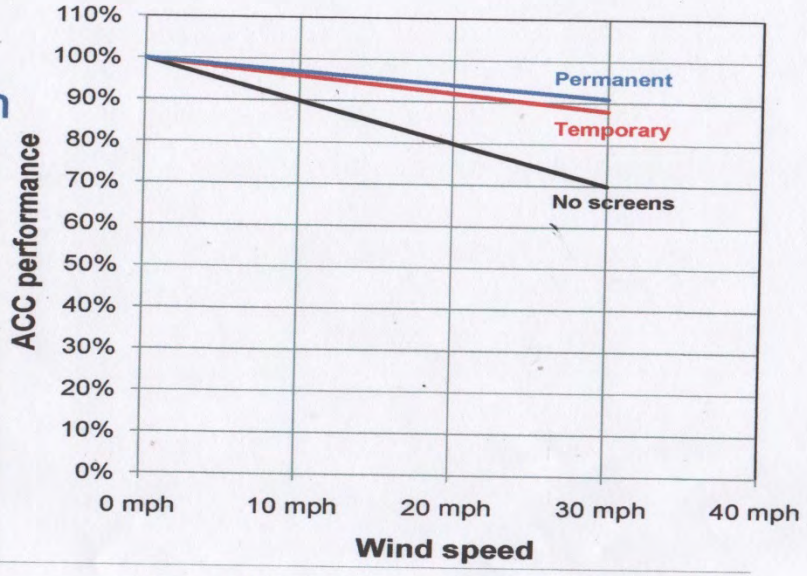
Various configurations of screens tested at different locations under ACC

→ The best temporary solution resulted in significant mitigation

Finally Permanent screen:

- additional modifications
- ACC perf. > 90% @ 30 mph





GEA Performance Improvements Using Wind Screens

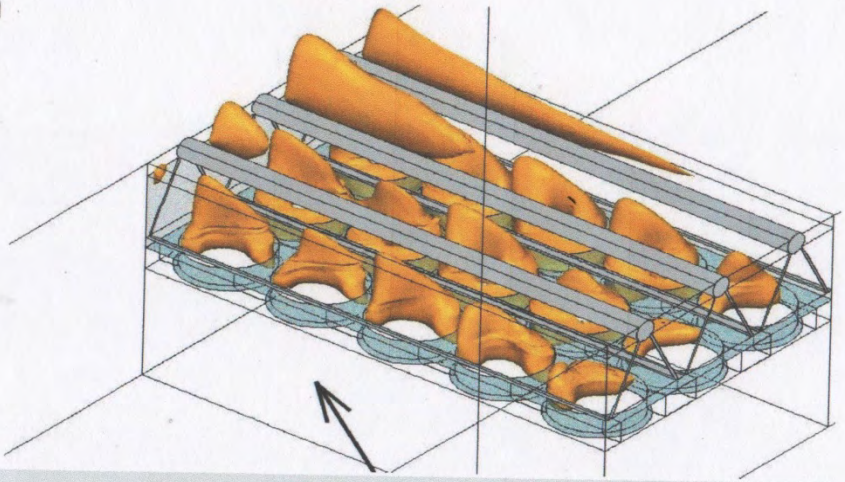
- Increased Wind Speed Increases Static Resistance to Airflow
- Airflow into Fans can Reduce by as much as 30% for Wind Speeds of 30 MPH
- Wind Screens can Reduce Performance Loss to a Level that is Equal to 90% of Optimal Design Condition

Wyndrum/SPX - Wind Effects on Performance

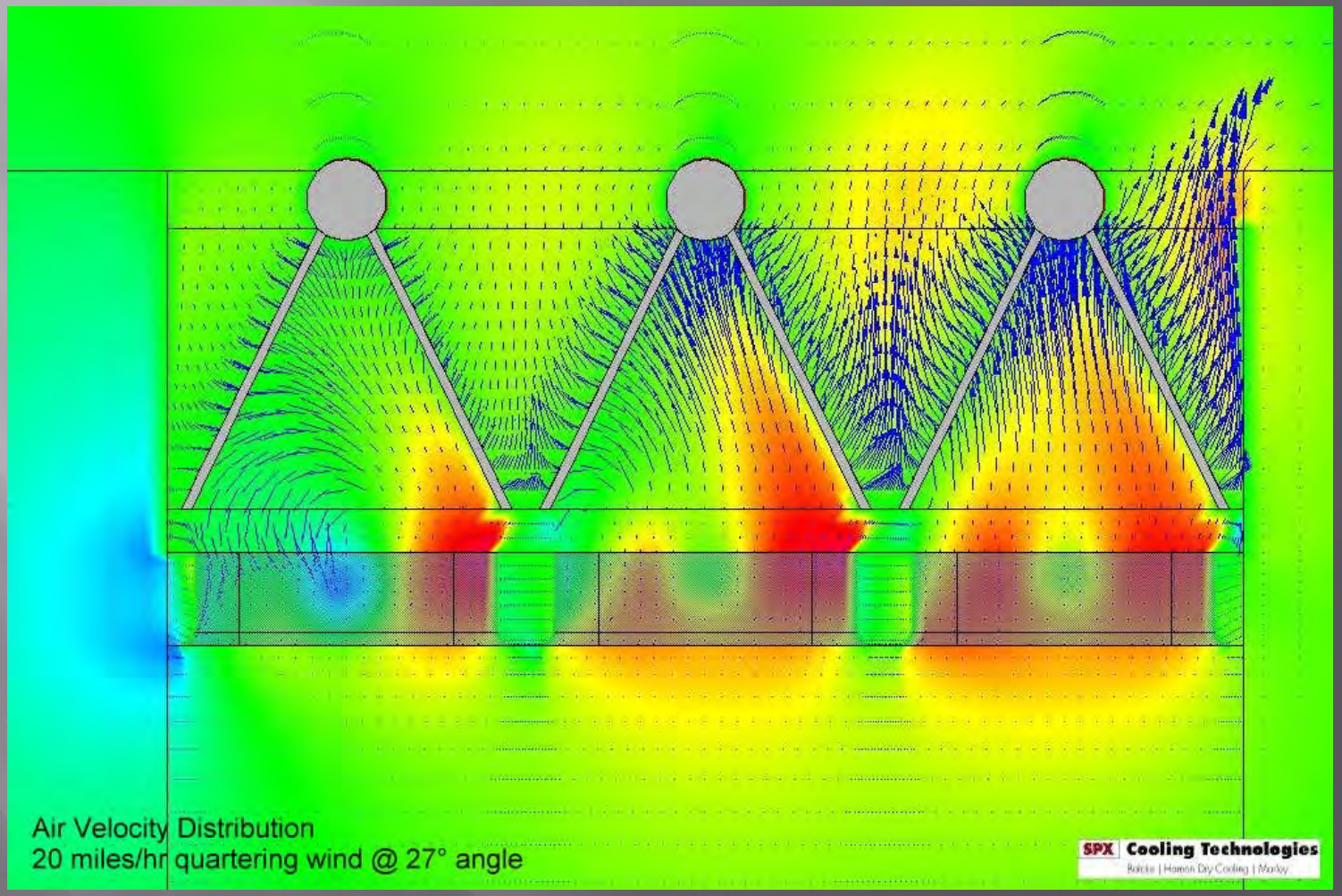
Innovative Solution

SPX

- CFD SIMULATION RESULTS
  - Without Wind Mitigation Features / 9m/s Quartering Wind
  - 15% to 20% Reduction in Airflow
  - 0.5 to 0.7"Hg Backpressure Increase
  - 5 to 7 MWe STG Reduction
  - $ Notable Generation Loss



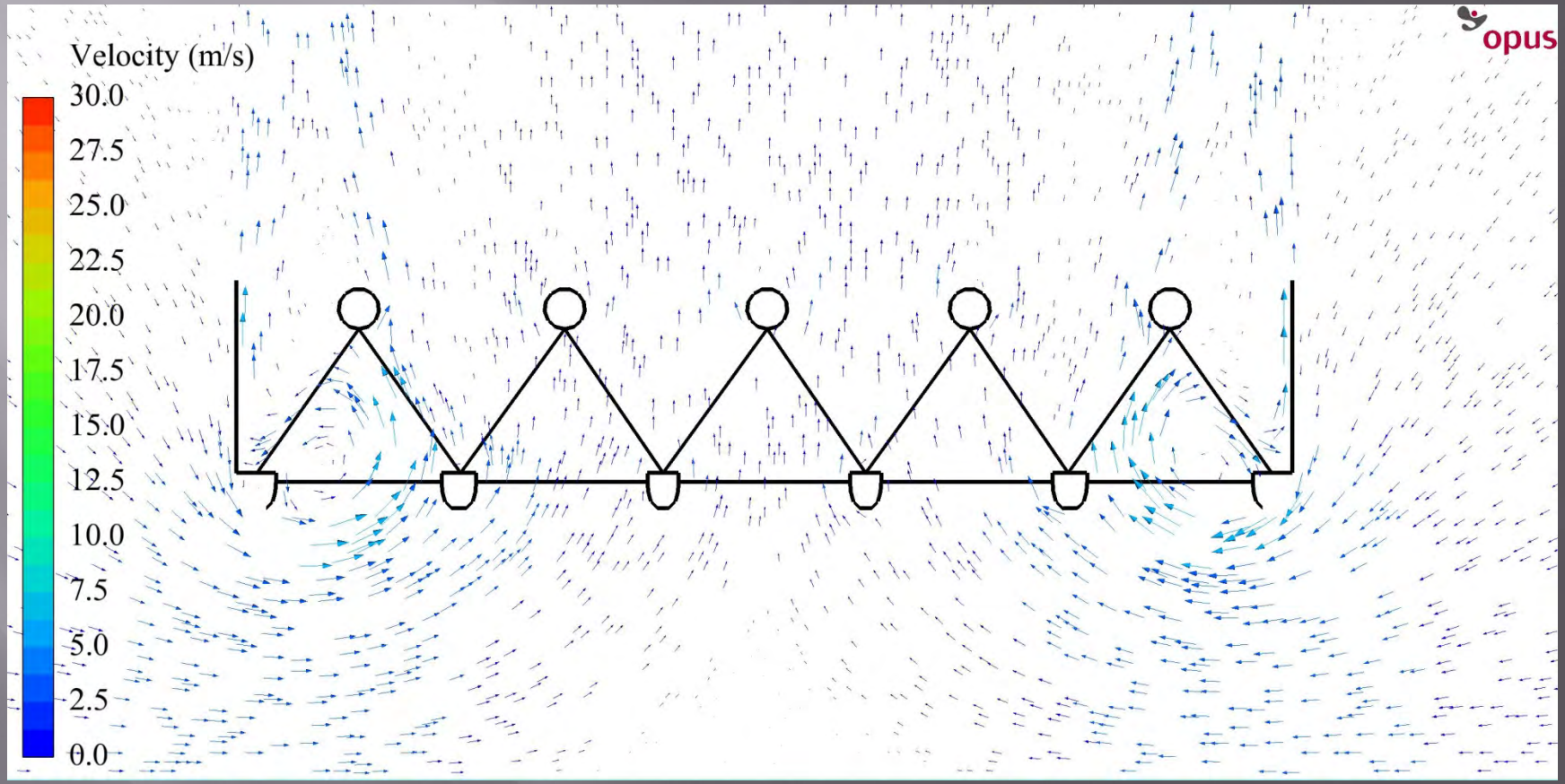
CFD Analysis of ACC Operating with Wind by K. Mortensen



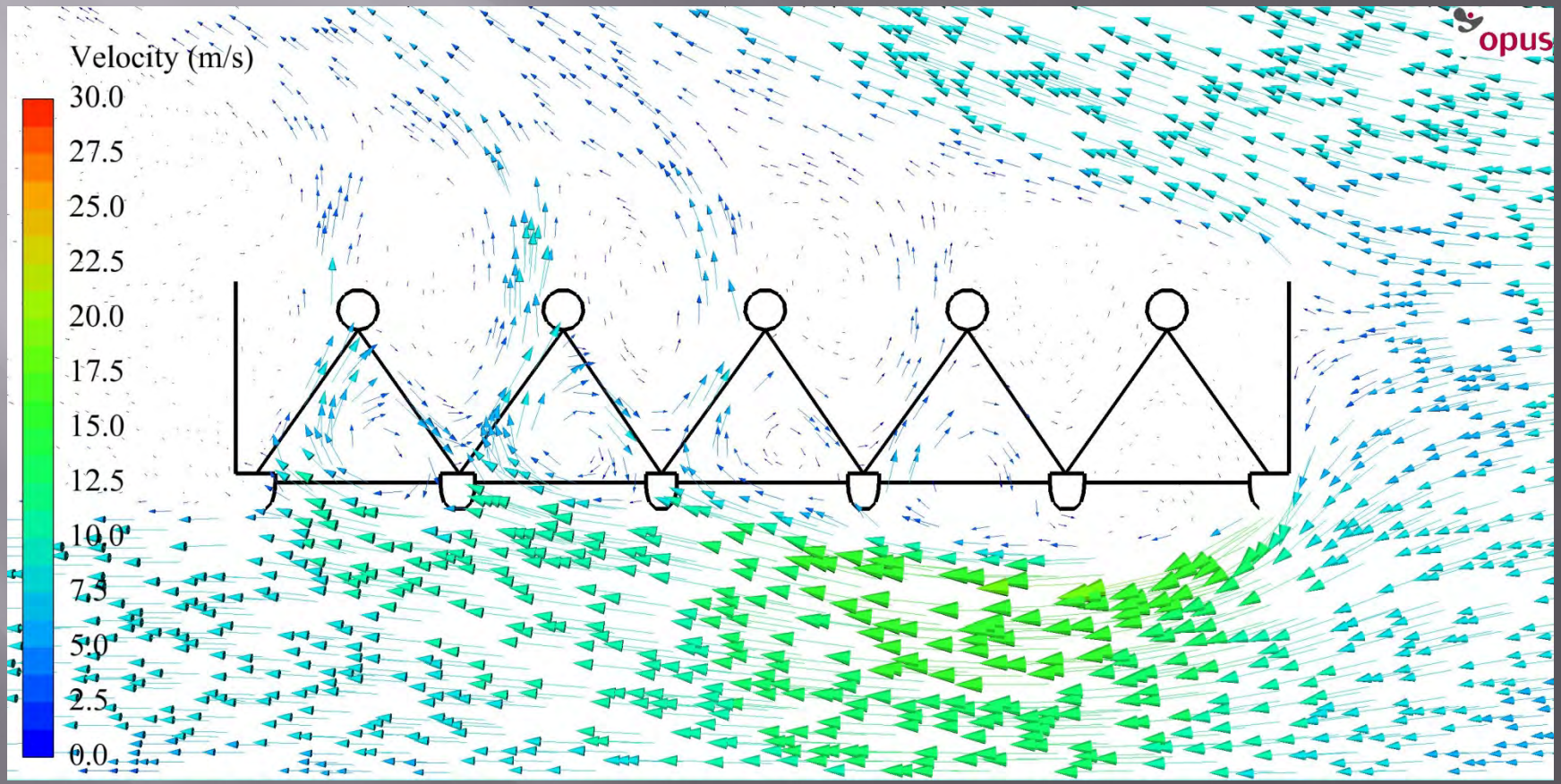
CFD Analysis of ACC Operating with Wind

- CFD Modeling Demonstrates the Airflow Conditions Inside the ACC
- There is a High Pressure Region Created on the Windward Side
- High Air Velocity is Created on the Leeward Side of the Fans
- Down Flow or Fan Stall Occurs on the Windward Side of the Windward Fans

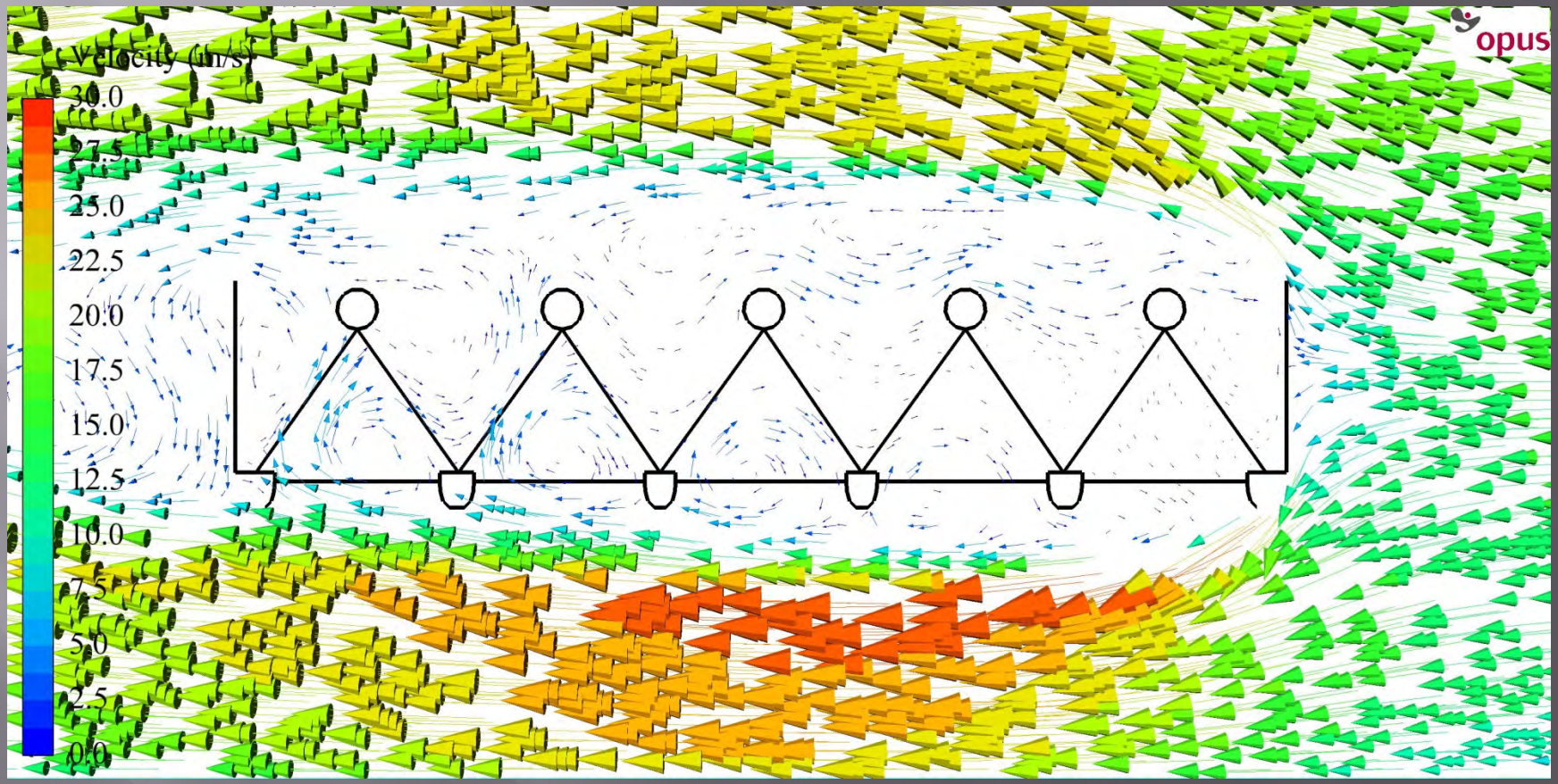
Velocity Vectors at 0 M/S Galebreaker CFD Analysis



Velocity Vectors @ 5 M/S Galebreaker CFD Analysis



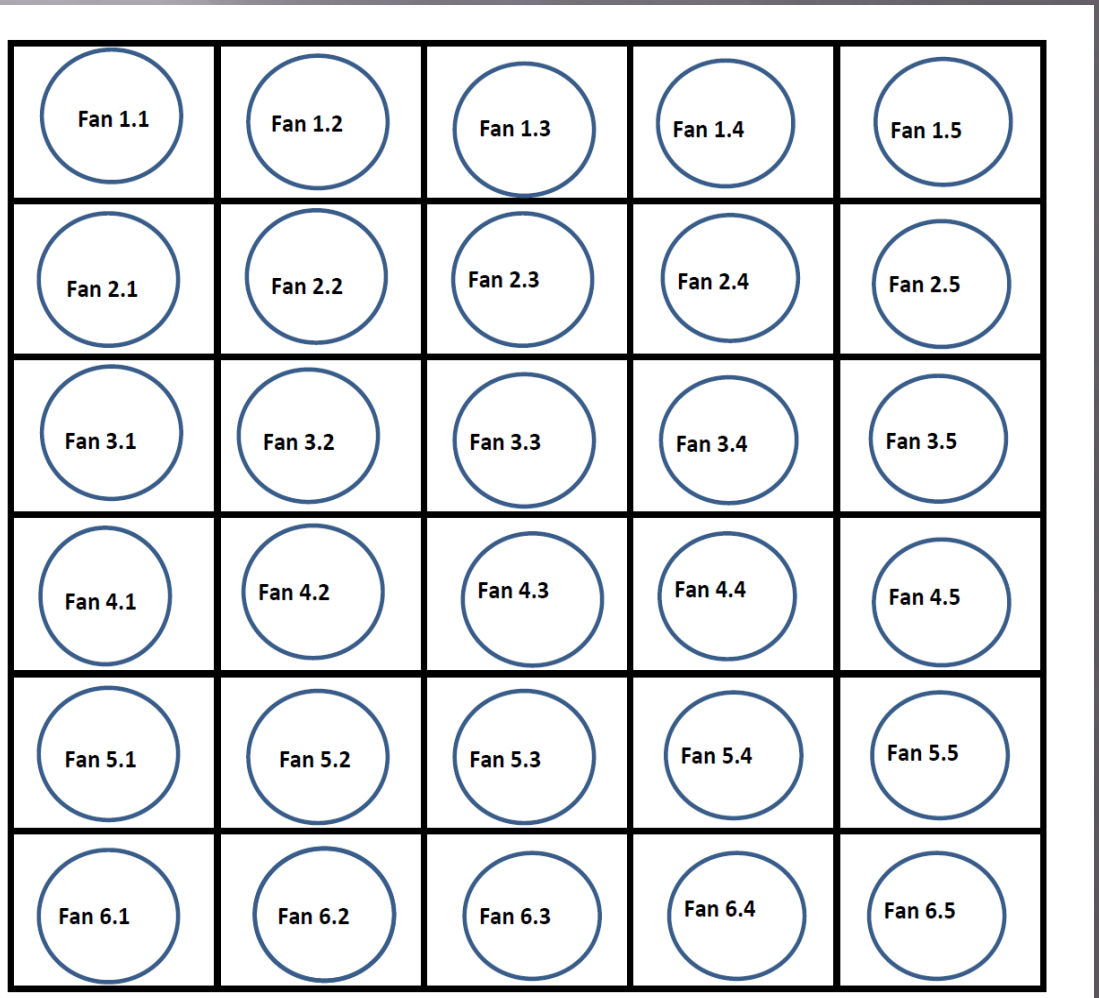
Velocity Vectors @ 10 M/S Galebreaker CFD Analysis



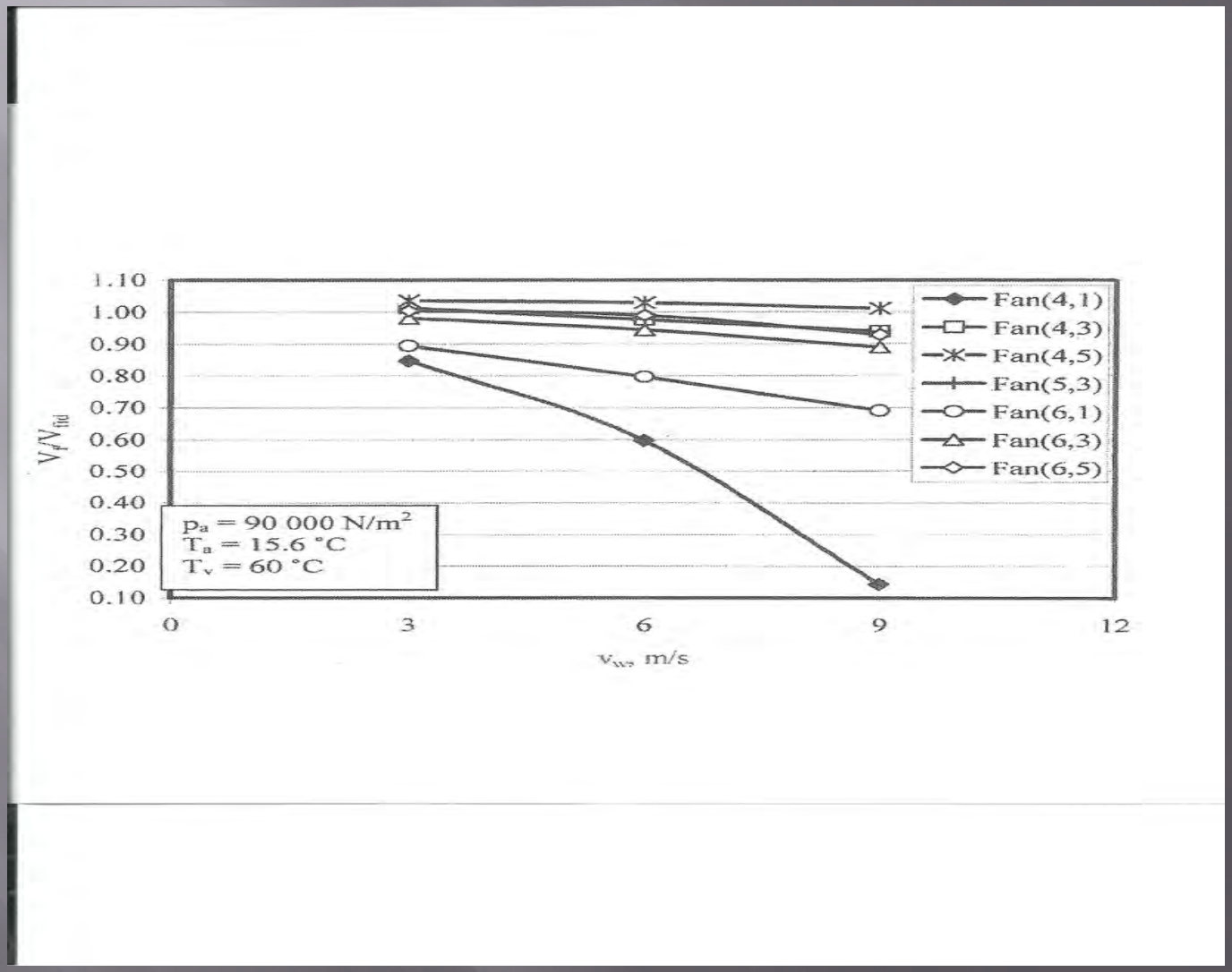
CFD Analysis

- Wind Impinges of the Windward Side Wind Wall
- Velocity Vectors Flow Down and Under the Fans Creating Vortexes and Turbulent Conditions
- This Creates Fan Stall and Uneven Loading on the Fan Blades

Volumetric Effectiveness Analysis Using CFD by D. Kroger and J. Van Royen



Volumetric Effectiveness



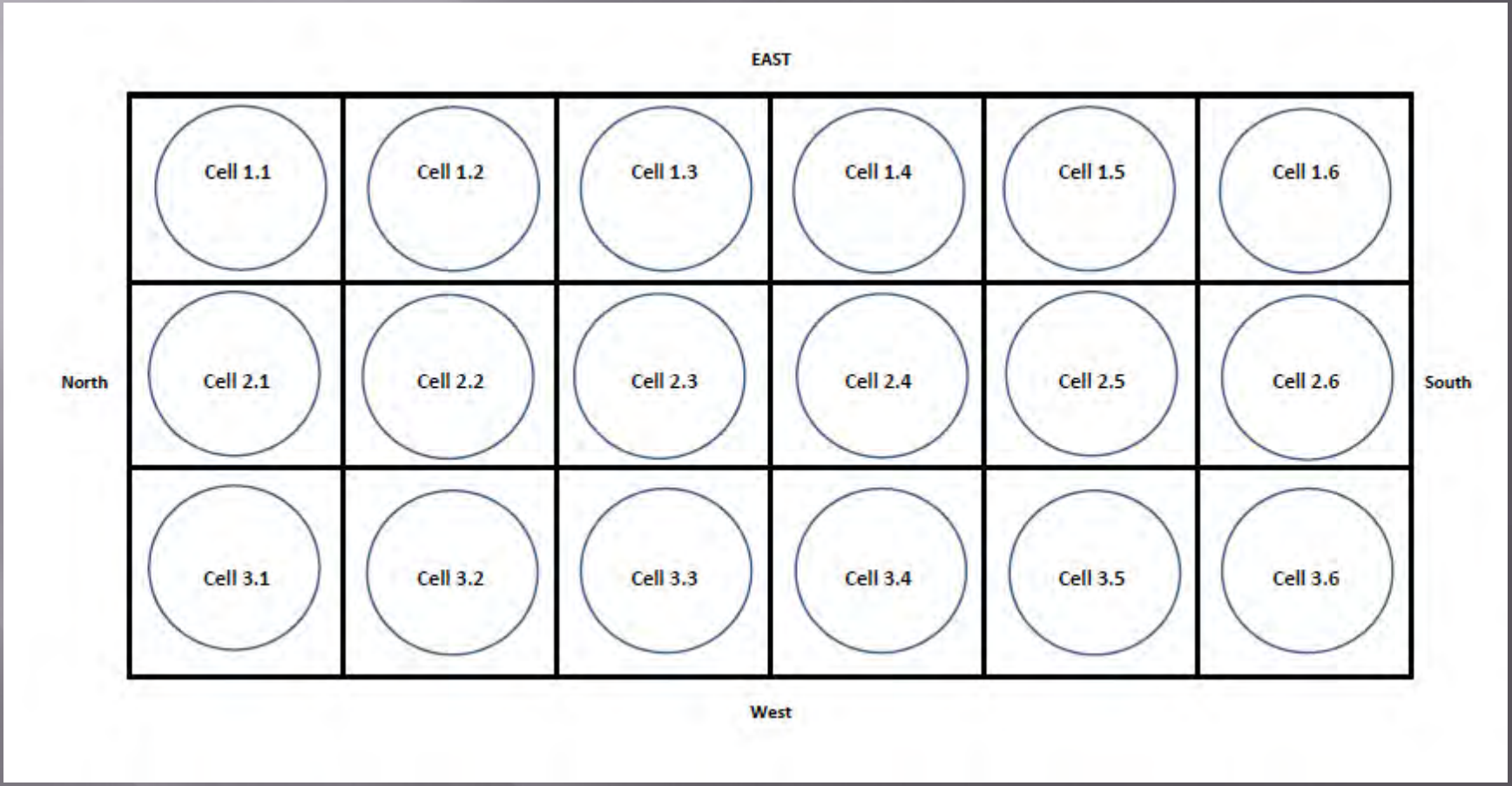
Volumetric Effectiveness

- Kroger and van Royen Analyzed and Quantified Wind Effects on a Large ACC
- Their Analysis Demonstrates Significant Reduction in Airflow on the Windward Fans
- The Center Fan, 4.1, on the Windward Street is Most Effected
- The Corner Fan and Those In Between are also Effected
- The Fans on the Leeward Side Will Produce Equal or Slightly Better Than Their Original Design

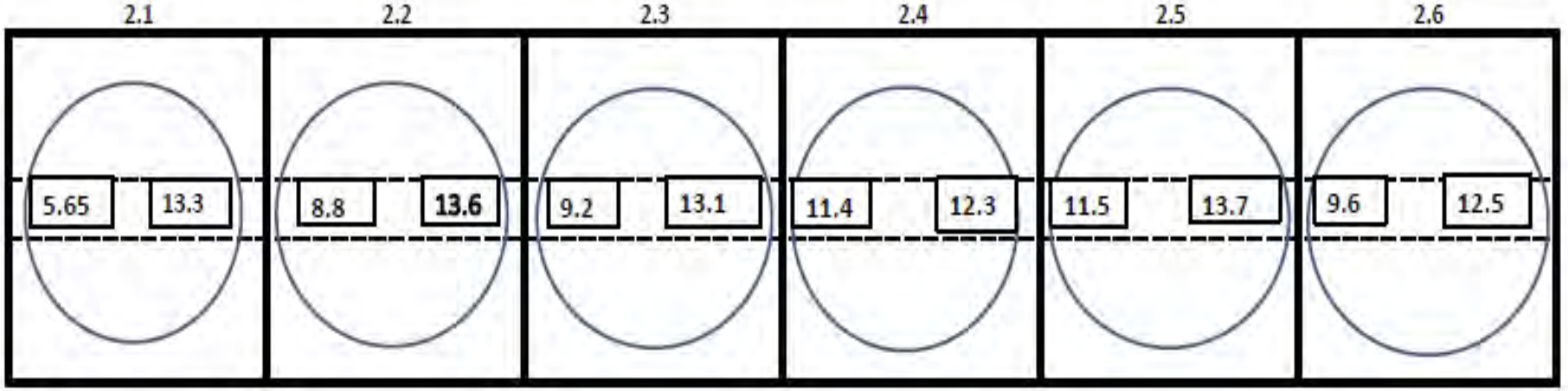
Early Testing at Caithness

1. Four Sets of Testing at Caithness
2. Joint Efforts by EPC, ACC Supplier, & Fan Supplier
3. Air velocity
4. Static Pressure
5. Vibration
6. Blade Stress
7. Smoke Testing

ACC Layout and Cell Numbering System at Caithness



Data Suggesting Wind Related Issues



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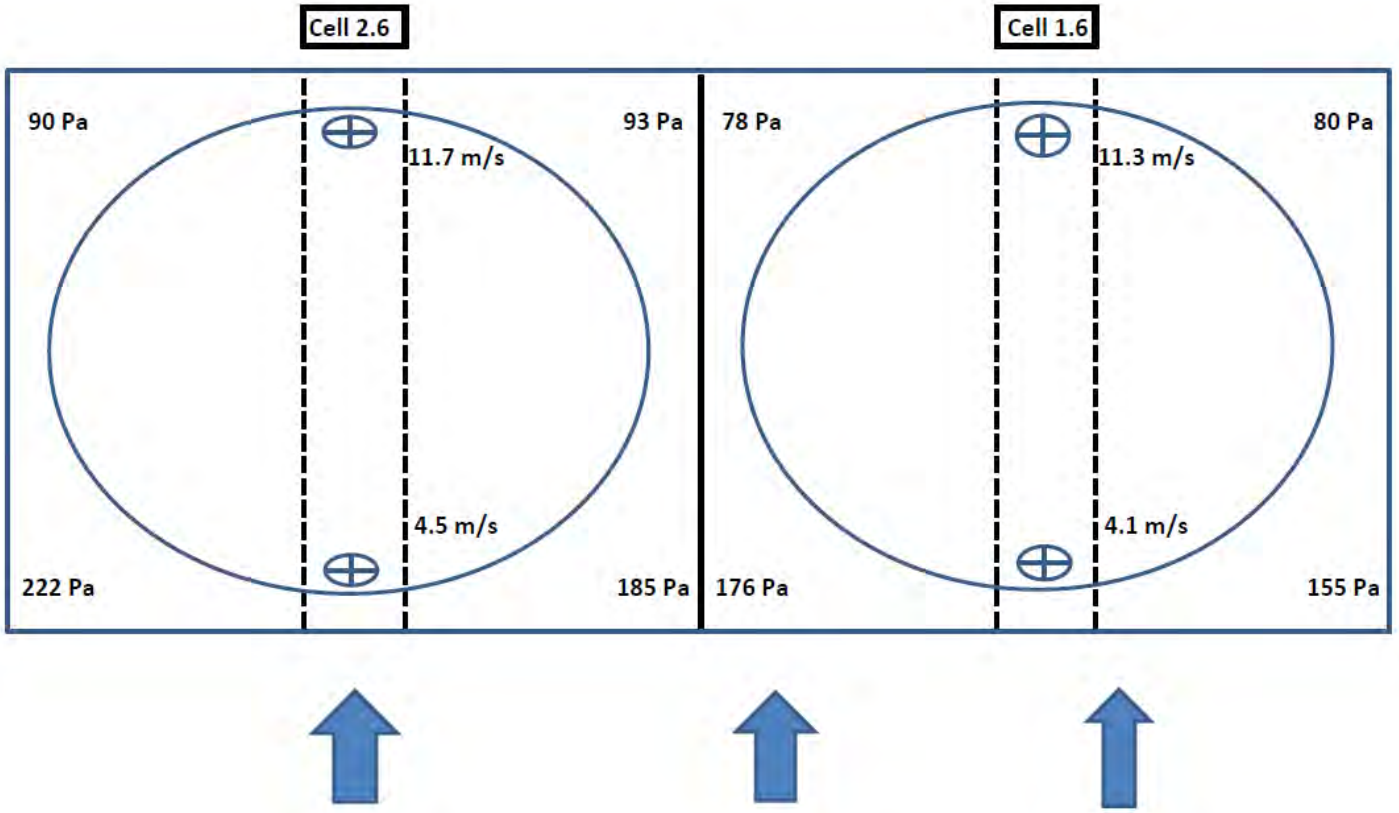


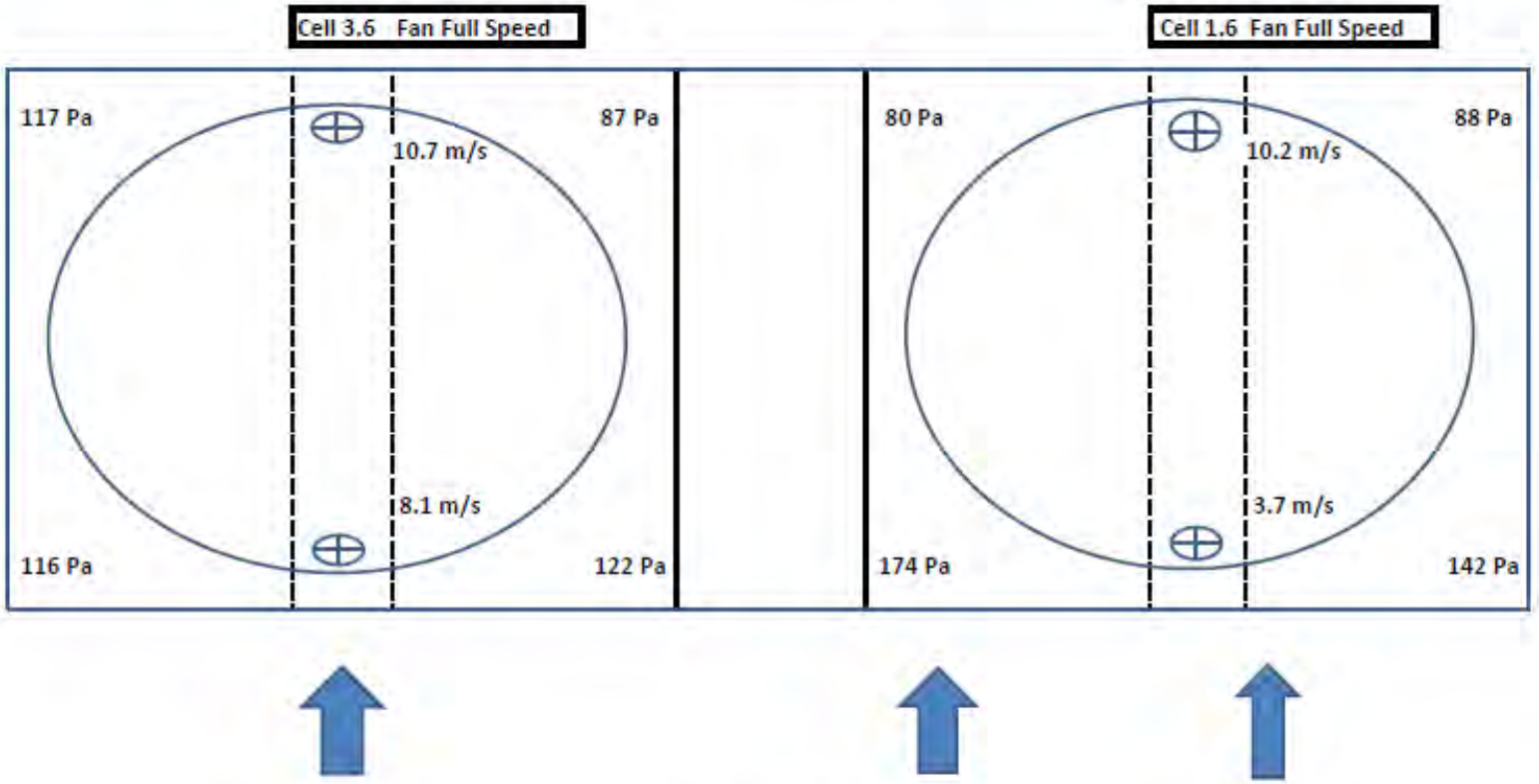
Early Testing

- Early tests measured air velocity measured on the motor bridge with hand held anemometers
- Testing conducted when wind was from the north consistently indicated lower air velocity on the windward side as compared to the leeward side
- Testing when the wind was from the south indicated similar results but also demonstrated high static pressure readings on the windward side

Testing Confirming Wind Screen Benefits with Temporary Screens

Galebreaker temporary wind screens on unit 3.6

Testing Confirming Wind Screen Benefit



Temporary Screens Added

- Two temporary screens were installed.
- The air velocity on cell 3.6 with the screens was normalized
- The measured static pressure was also normalized when compared to cell 1.6 that had no screen

Testing Post Installation of Motorized Wind Screens and 9 Bladed Fans

Motorized Wind Screen 100% Deployed

Motorized Windscreen in 0% Deployed Position

Instrumentation Orientation Cell 3.4

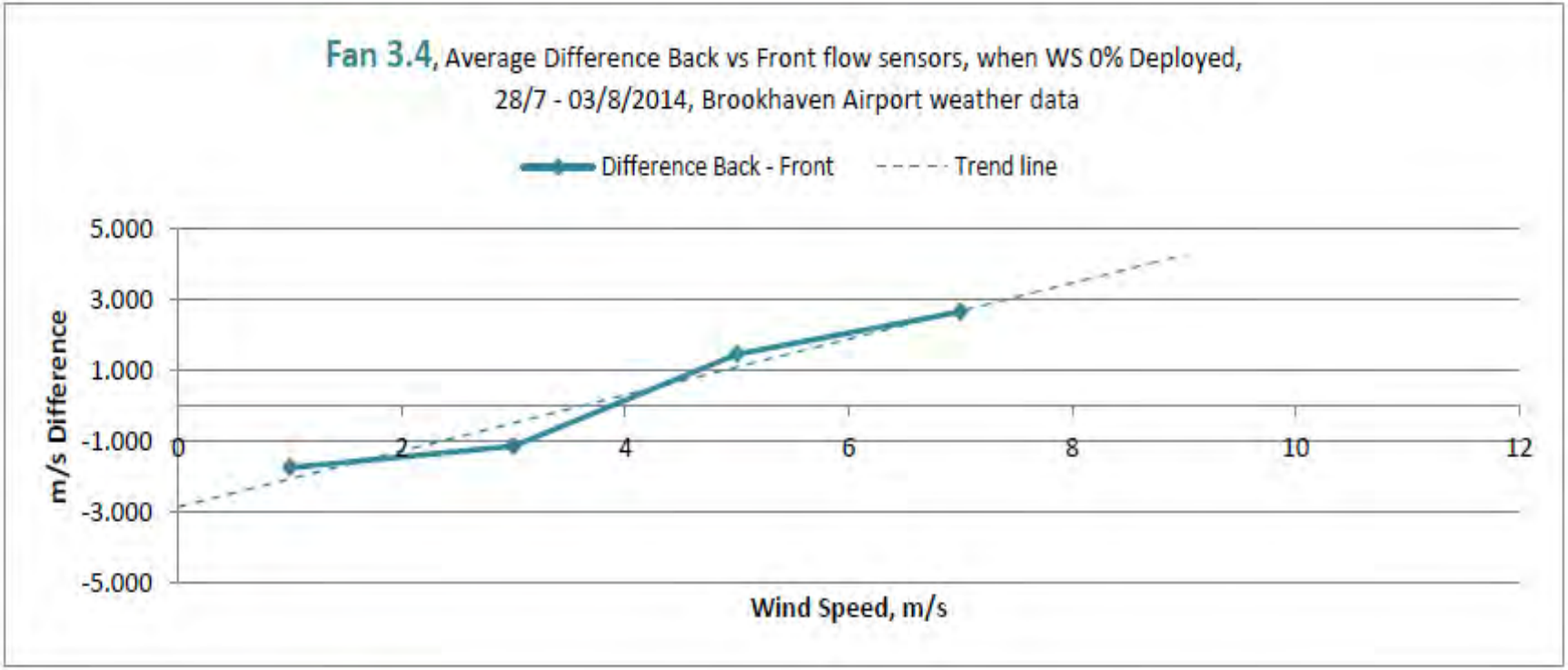
Test Instrument Configuration

- Instruments were deployed on cells 3.4 and 2.4
- Measurements were taken continually over an 18 month period
- Measurements of air velocity, static pressure, air temperature, amps and stress

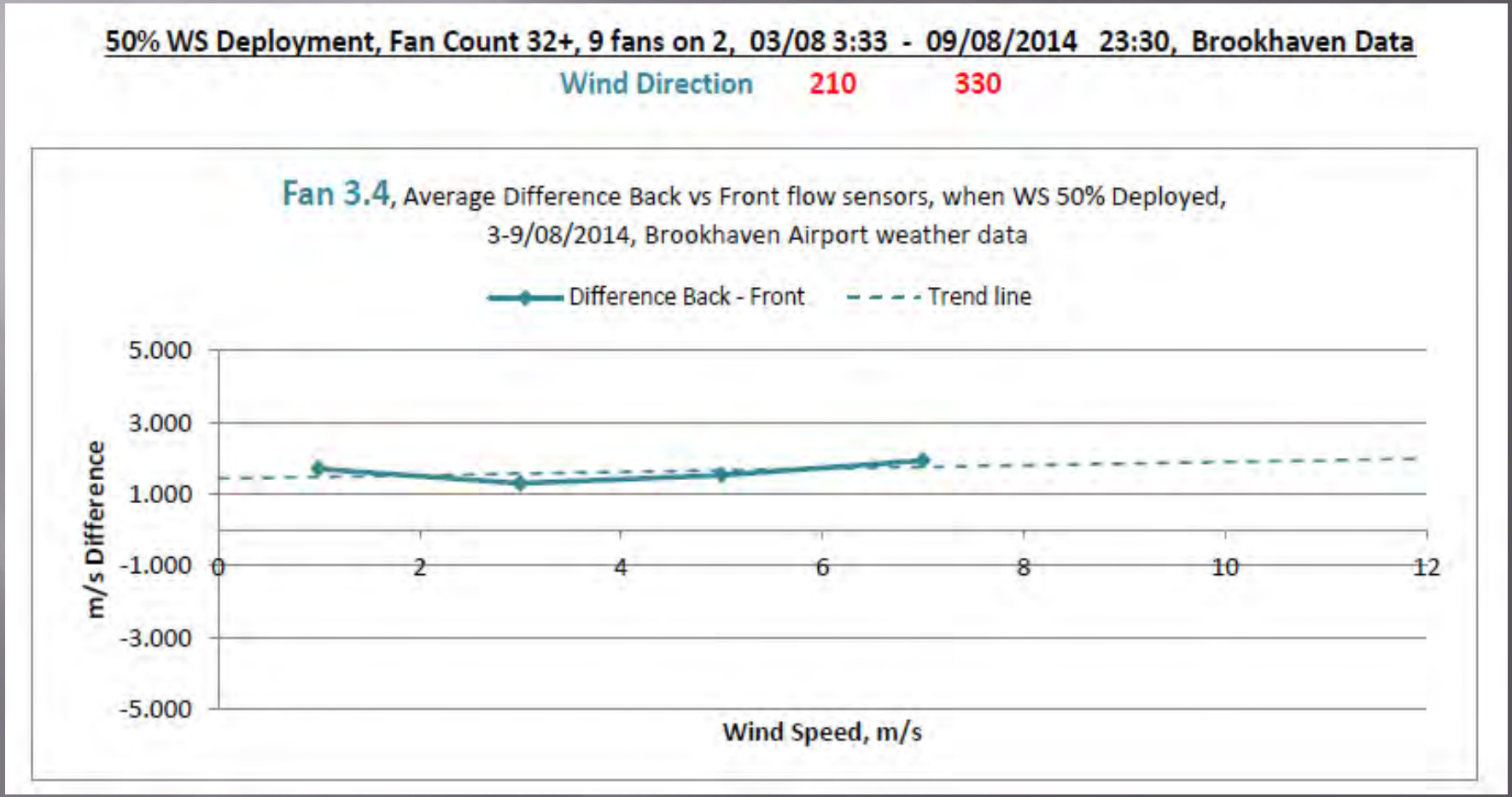
Effects of Windscreen Deployment

0% WS Deployment, Fan Count 32+, 9 fans on 2, 28/7 9:39 - 03/8/2014 3:30, Brookhaven Data

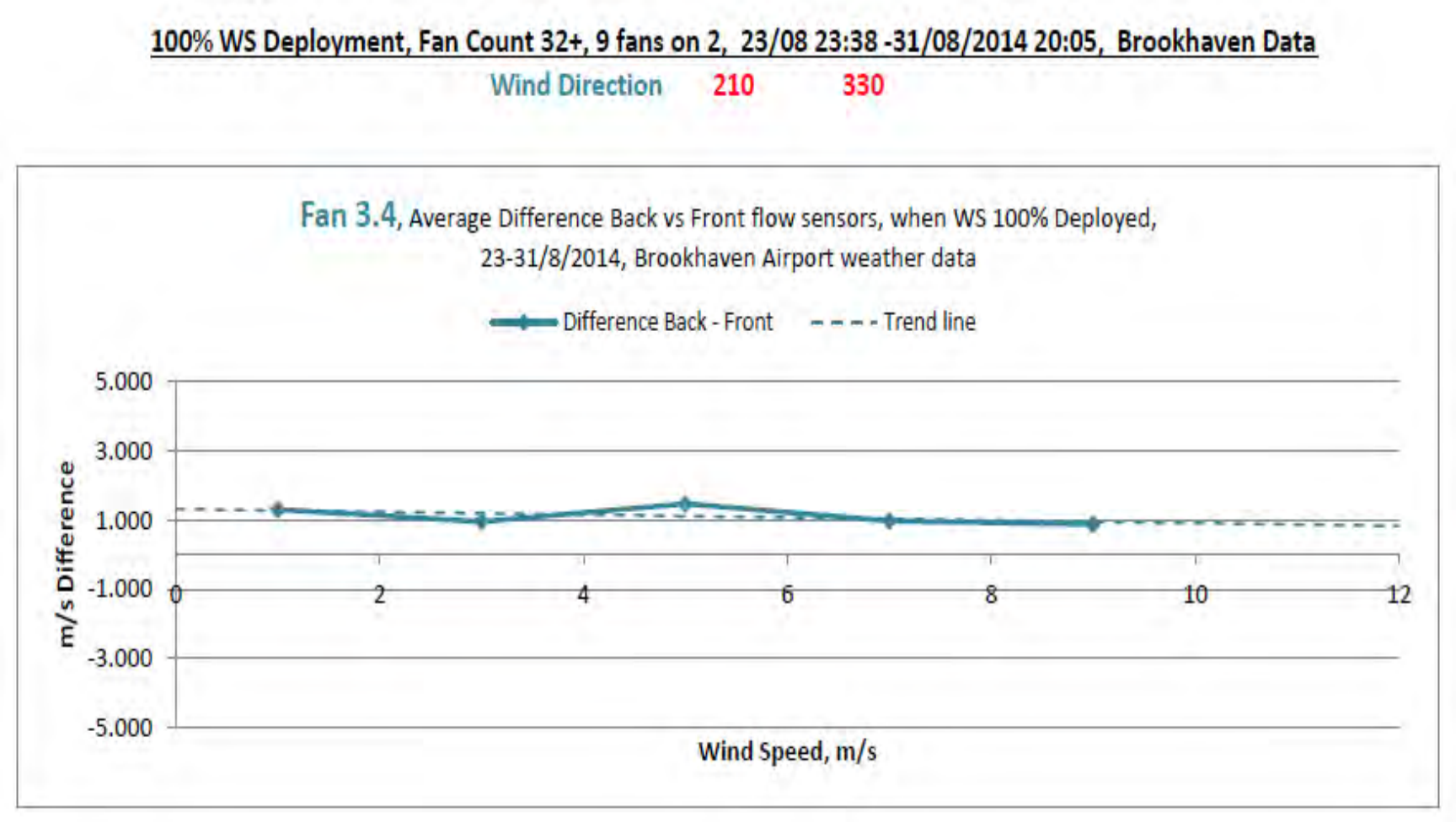
Wind Direction 210 330



Effects of Windscreen Deployment



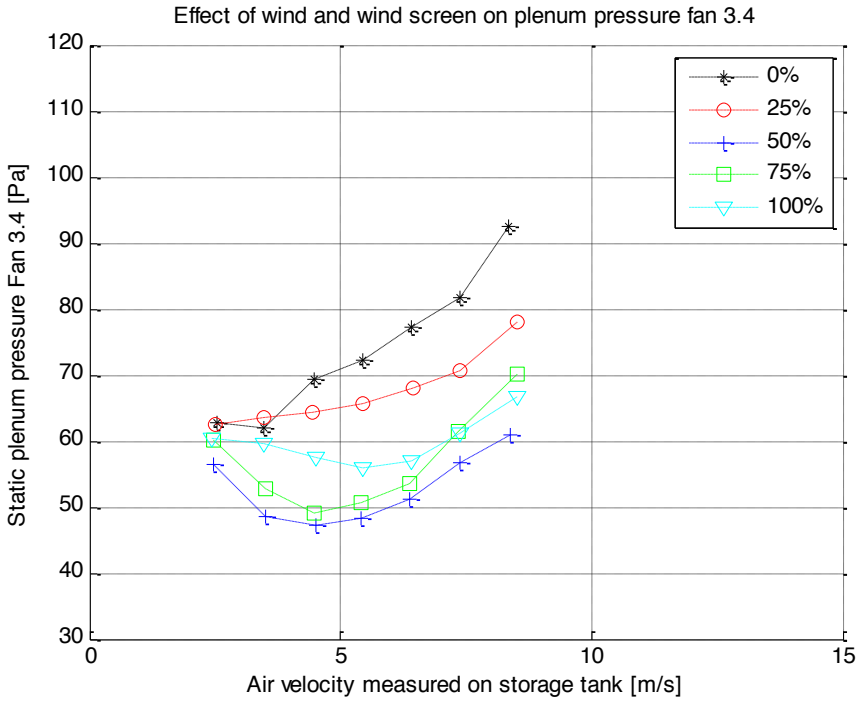
Effects of Windscreen Deployment



Static plenum pressure fan 3.4

Strong increase at higher wind speeds

Significant influence wind screen

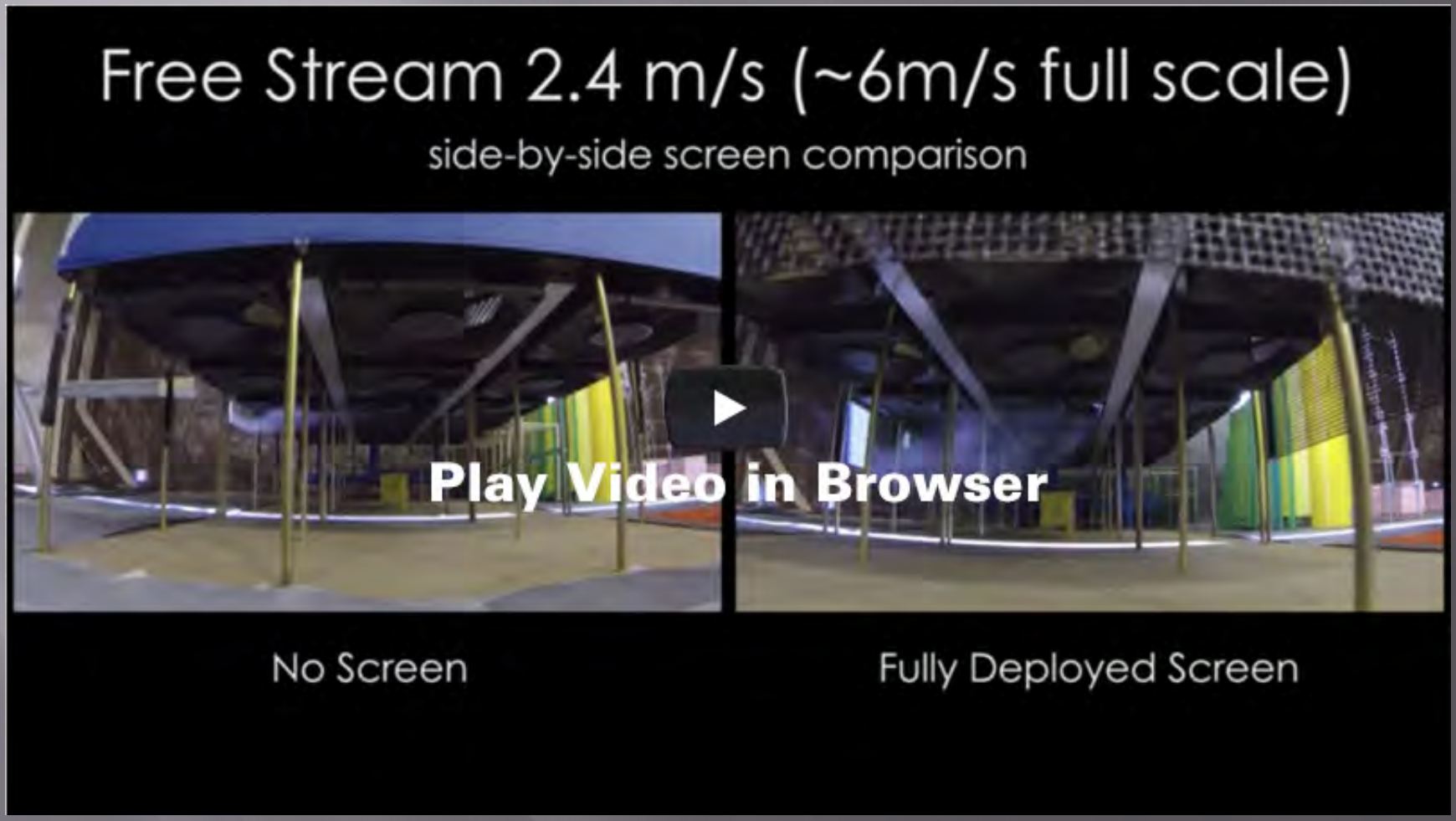


UC Davis Wind Tunnel Testing

- Modeled Caithness ACC 3 x6
- Wind Screens cover half the inlet height
- Compared No Screens, Perimeter Screens, and Perimeter plus Cruciform
- For the videos press play arrow and give it a few seconds, 20, to load and play.

UC Davis Wind Tunnel – No Screen Horizontal Wind Speed 9 m/s

UC Davis Wind Tunnel
6 m/s Wind - Side x Side Comp



Perimeter Screen with Wall or Hi Density Screen at Base

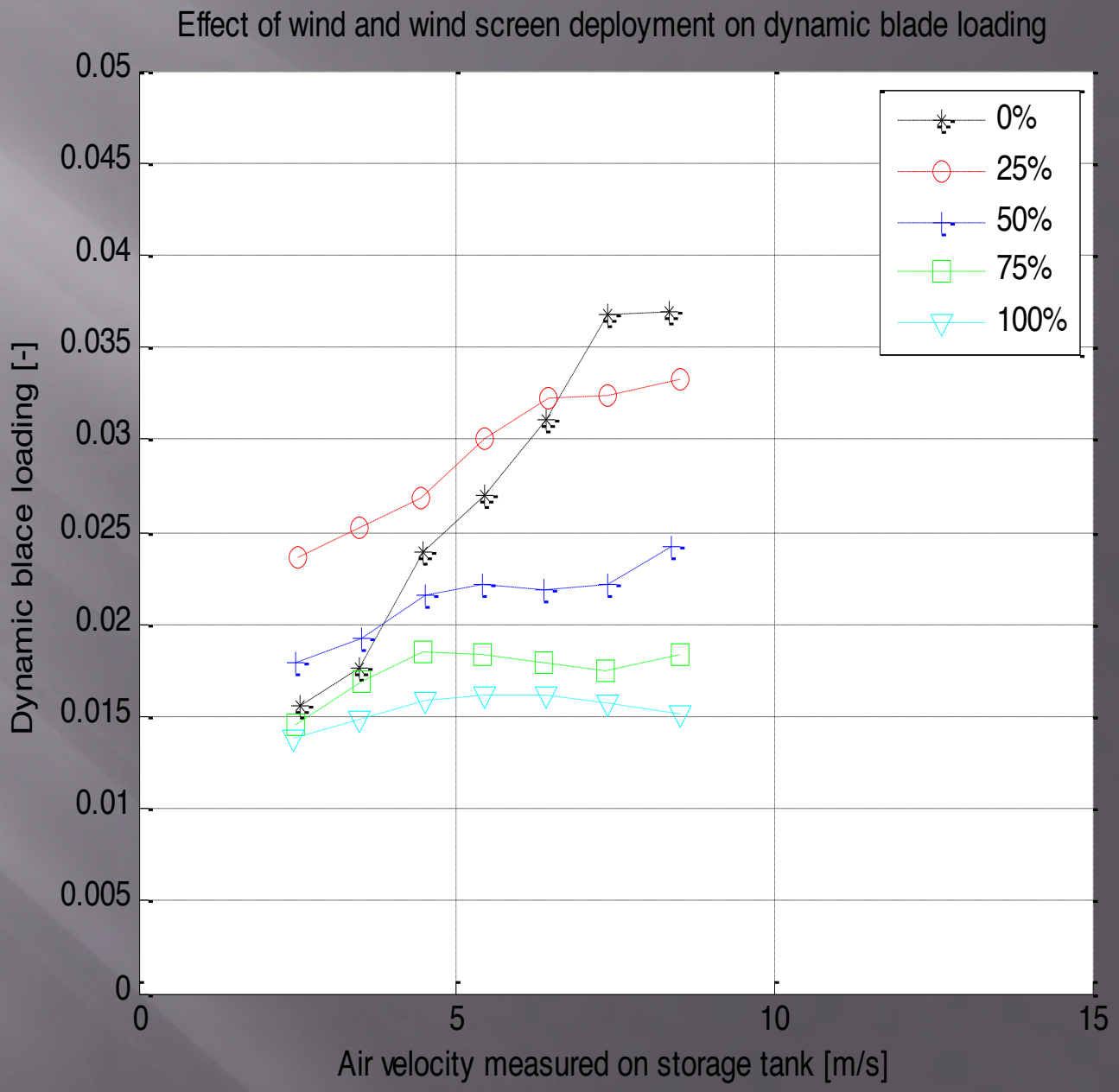
Dynamic Blade Loading Fan 3.4

Loading Increases at Higher Wind Speeds

Significant Influence of Wind Screen

Screen Deployment Reduces Loading

Fully Deployed Dynamic Blade Load Reduced by a Factor 2-3



Conclusions

1. Difference in Back vs. Front Air Velocity was Normalized with Screens
2. Dynamic Blade Loading Considerably Reduced
3. Longer Fan Blade Life Projected
4. Measured Static Pressure Differences Reduced Indicating Airflow Increase
5. For Complete Analysis, see Report by John Maulbetsch on the California Energy Commission website