Spatially Resolved Wind Tunnel Wake Measurements at High Angles of Attack and High Reynolds Numbers Using a Laser-Based Velocimeter

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North American Wind Energy Academy 2015 Symposium

June 11, 2015

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Outline

- Background
- Motivation
- Cross-correlation Doppler global velocimetry
- “Optical wake rake” configuration
- Results
- Conclusions
- Future development

Acknowledgements

GE Power & Water

- Program managers Jon Luedke and Christian Carroll

Background

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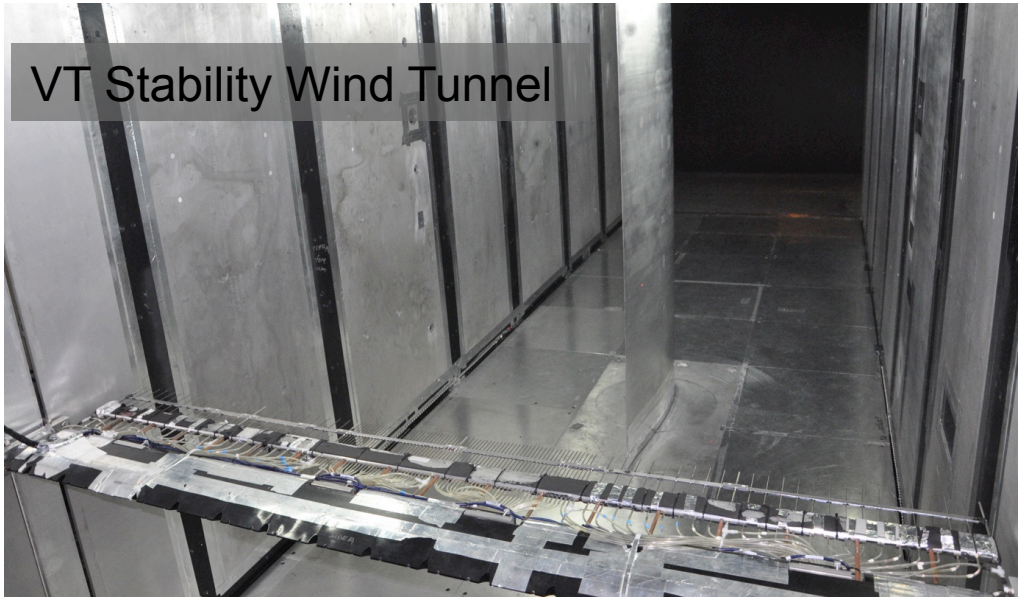
"Drag rakes" have been extensively studied and employed in large scale facilities

Some examples in wind energy:

- Timmer and van Rooji[1]: Delft Univ. Low-Speed Wind Tunnel
- Cerretelli et al.[2]: Univ. of Stuttgart Laminar Wind Tunnel
- Joseph[3]: Virginia Tech Stability Wind Tunnel



[1]Timmer WA, van Rooij RPJOM. Some aspects of high angle-of-attack flow on airfoils for wind turbine application. Delft University Wind Energy Research Institute 2001.
[2]Cerretelli C, Gharaibah E, Toplack G, Gupta A, Wuerz W, "Unsteady Separation Control for Wind Turbine Applications at Full Scale Reynolds Number," *47th AIAA Aerospace Sciences Meeting including The New Horizons Forum and Aerospace Exposition.* AIAA, Reston, Virigina, AIAA 2009-380
[3]Joseph LA. Transition Detection for Low Speed Wind Tunnel Testing Using Infrared Thermography. MS Thesis, Virginia Tech 2014.

Motivation

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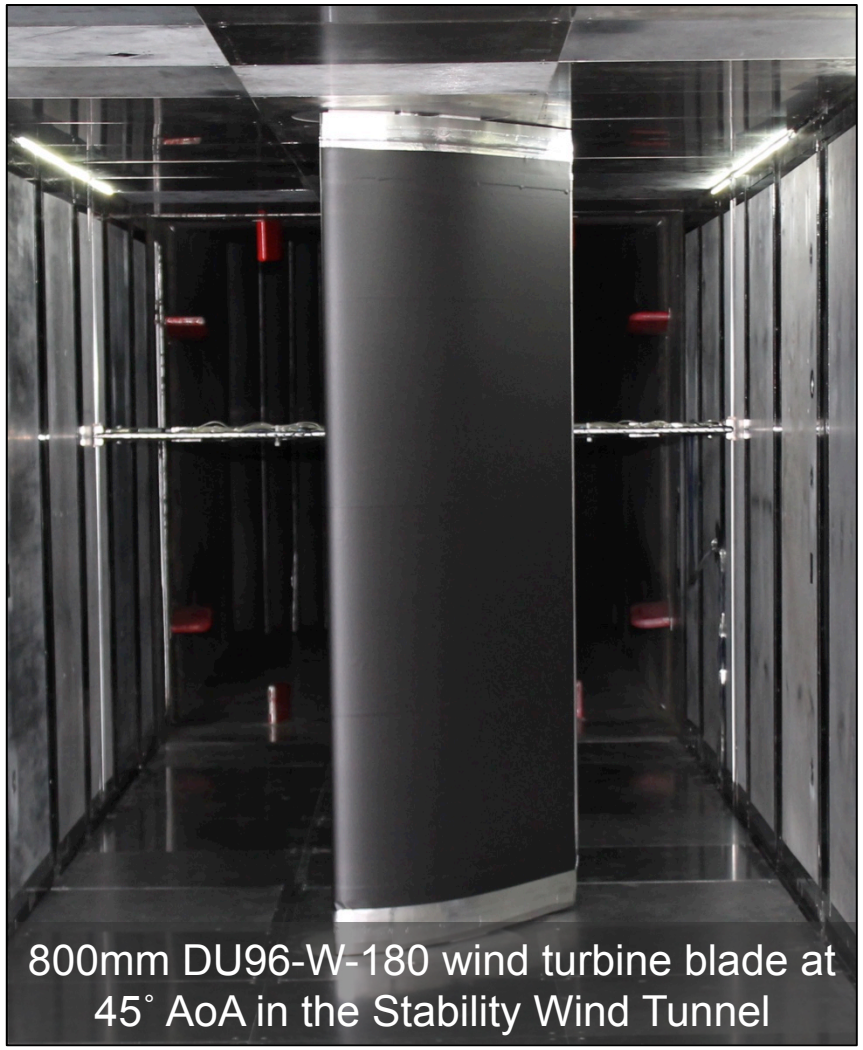
- Buffeting and large scale vortices become a physical concern at stalled conditions
- Doppler global velocimetry is well-suited to large facilities
  - Direct sensing of Doppler shift- no need to resolve individual particles
  - Can accommodate low levels of scattered light intensity
  - PIV not practical in this configuration: would require very high power lasers

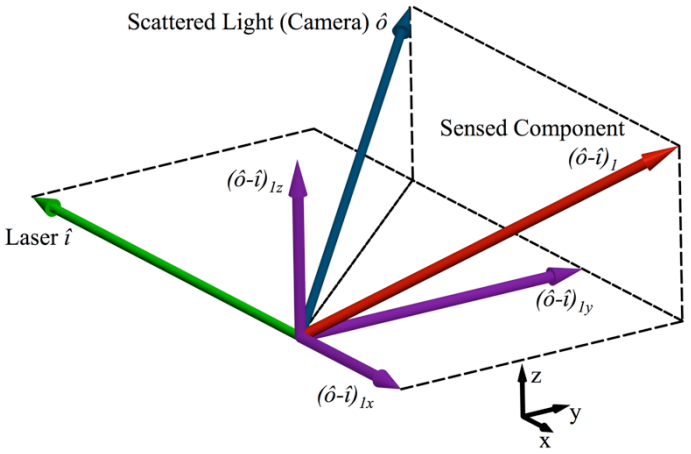


800mm DU96-W-180 wind turbine blade at 45˚ AoA in the Stability Wind Tunnel

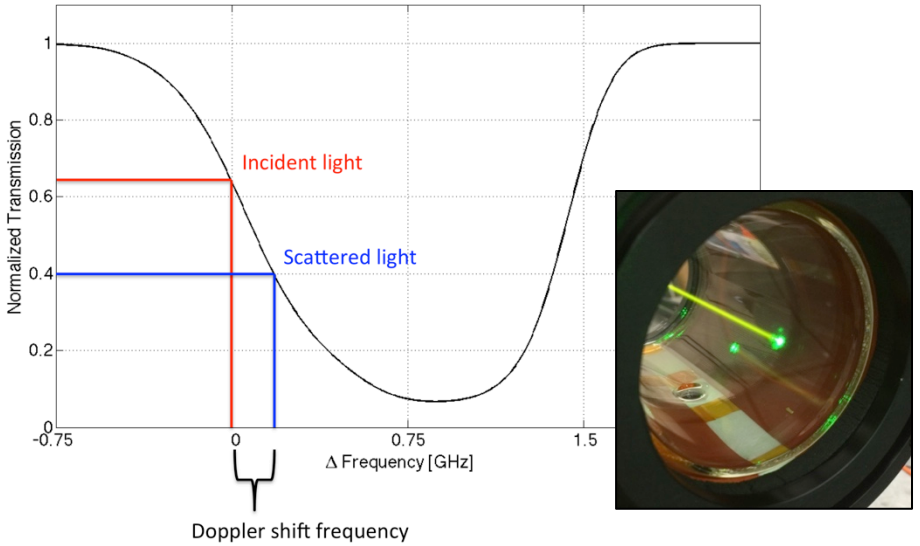
Doppler Global Velocimetry (DGV)

- Light scattered off particles is **Doppler shifted** in frequency

$$\nu = \frac{(\hat{o} - \hat{i}) \cdot \vec{V}}{\lambda}$$



- Doppler shift measured by converting light intensity to frequency via a **vapor absorption cell**



Cross-correlation DGV (CC-DGV)

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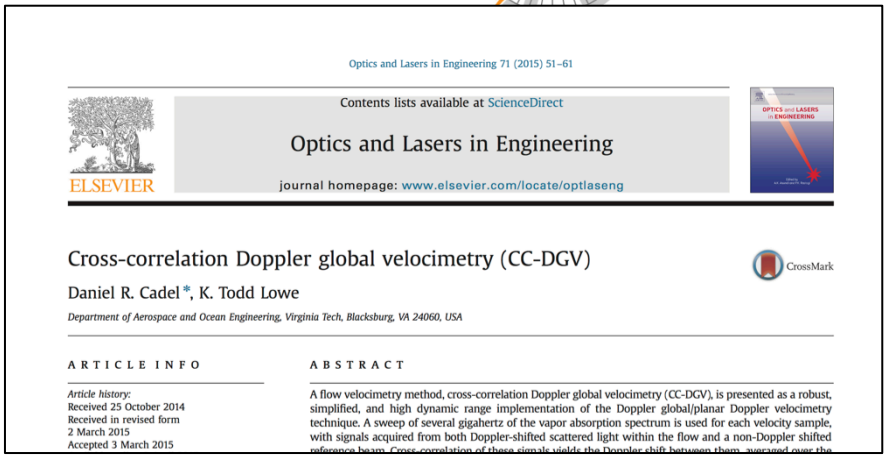
- Mean velocity measurement
- Laser frequency swept through several GHz
- Cross-correlate incident light signal and scattered light signal



Optics and Lasers in Engineering 71 (2015) 51–61

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

Cross-correlation Doppler global velocimetry (CC-DGV)

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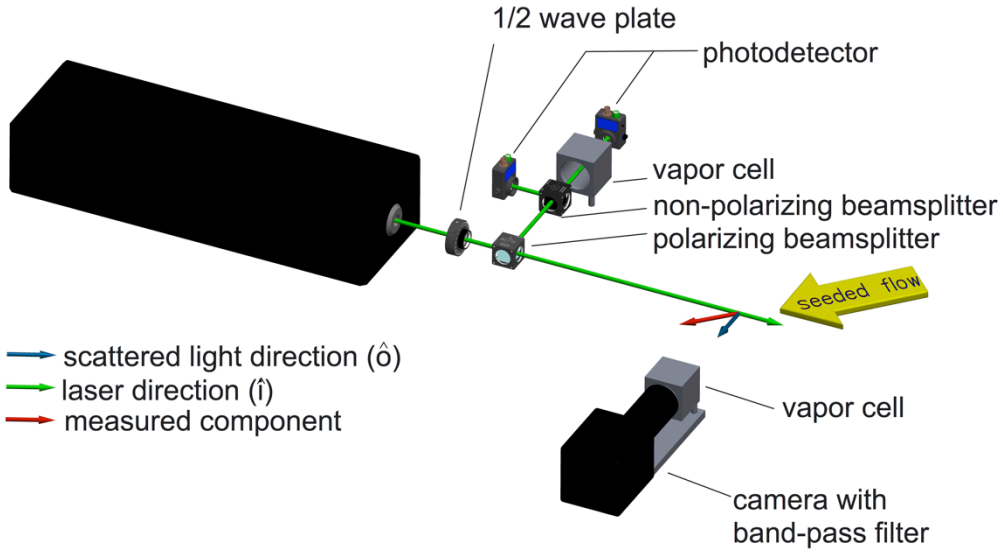
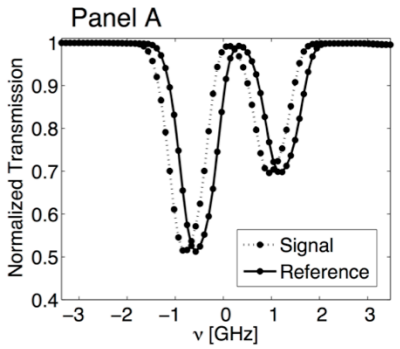
ARTICLE INFO

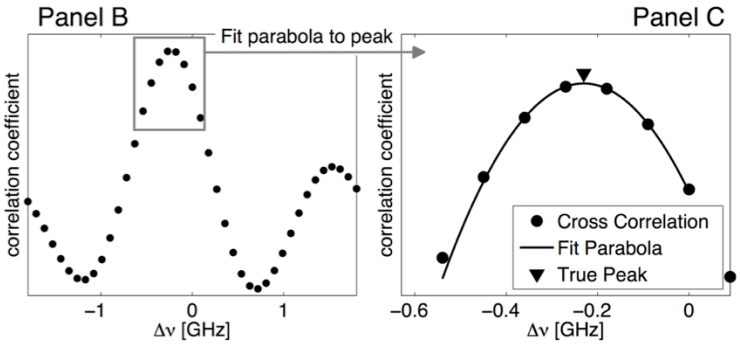
Article history:
Received 25 October 2014
Received in revised form
2 March 2015
Accepted 3 March 2015

ABSTRACT

A flow velocimetry method, cross-correlation Doppler global velocimetry (CC-DGV), is presented as a robust, simplified, and high dynamic range implementation of the Doppler global/planar Doppler velocimetry technique. A sweep of several gigahertz of the vapor absorption spectrum is used for each velocity sample, with signals acquired from both Doppler-shifted scattered light within the flow and a non-Doppler shifted







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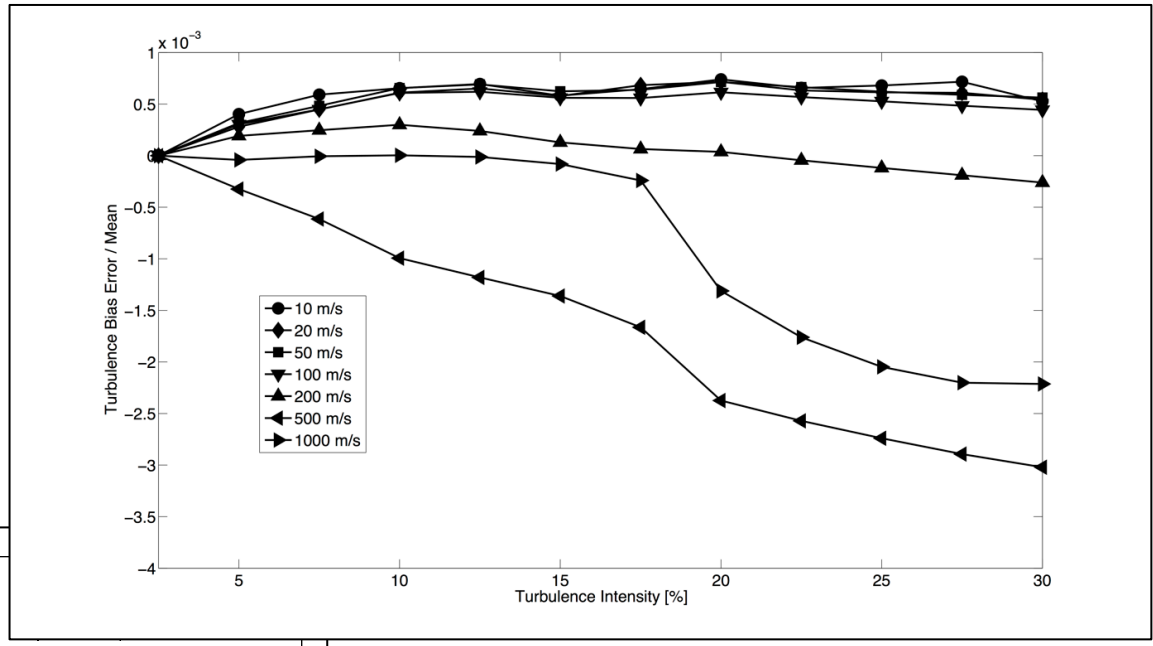
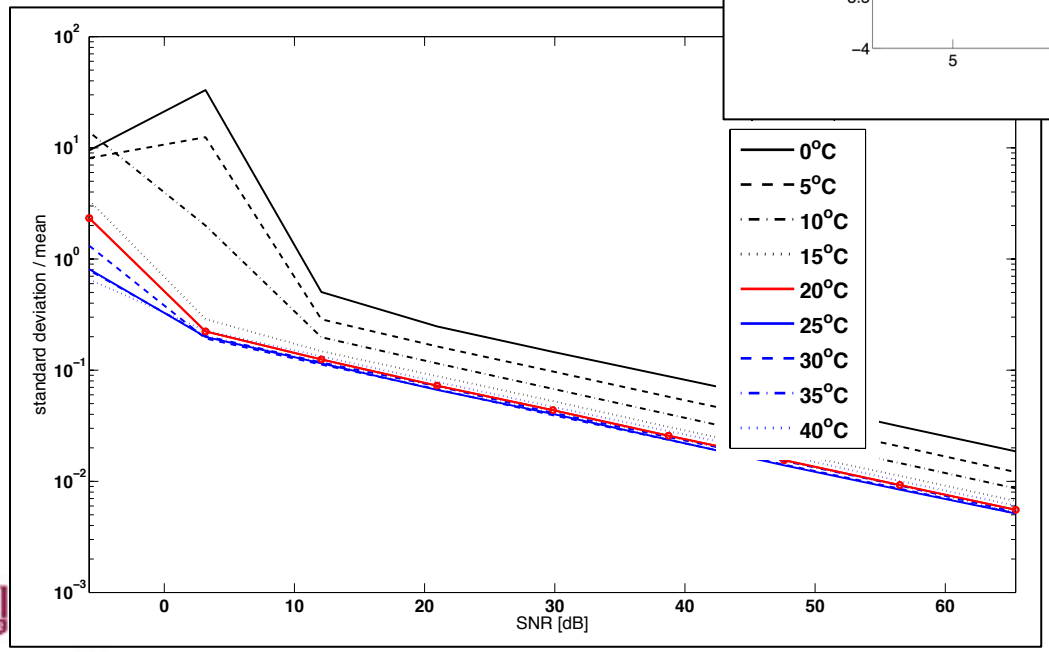
CC-DGV Sensitivities

- Turbulence causes small bias error since absorption lines are non-linear





- Low effect from vapor cell temperature mismatch

Optical Wake Rake (OWR) concept

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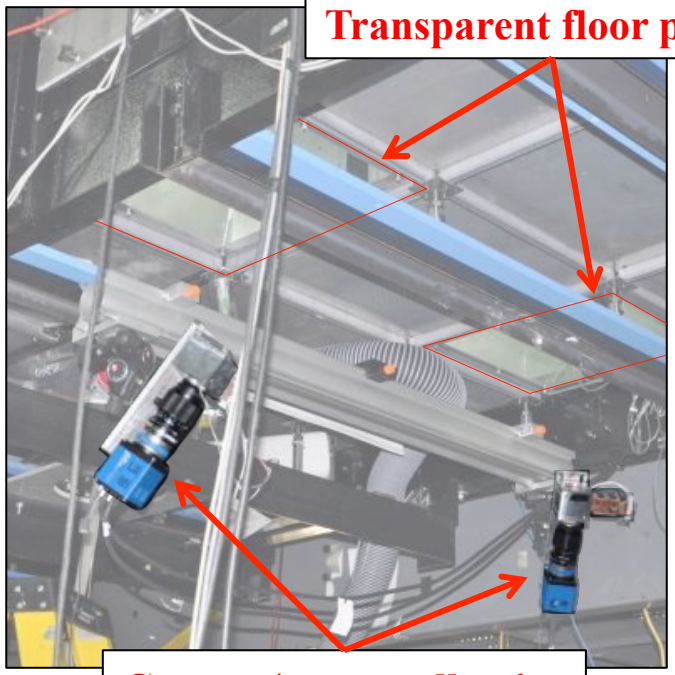
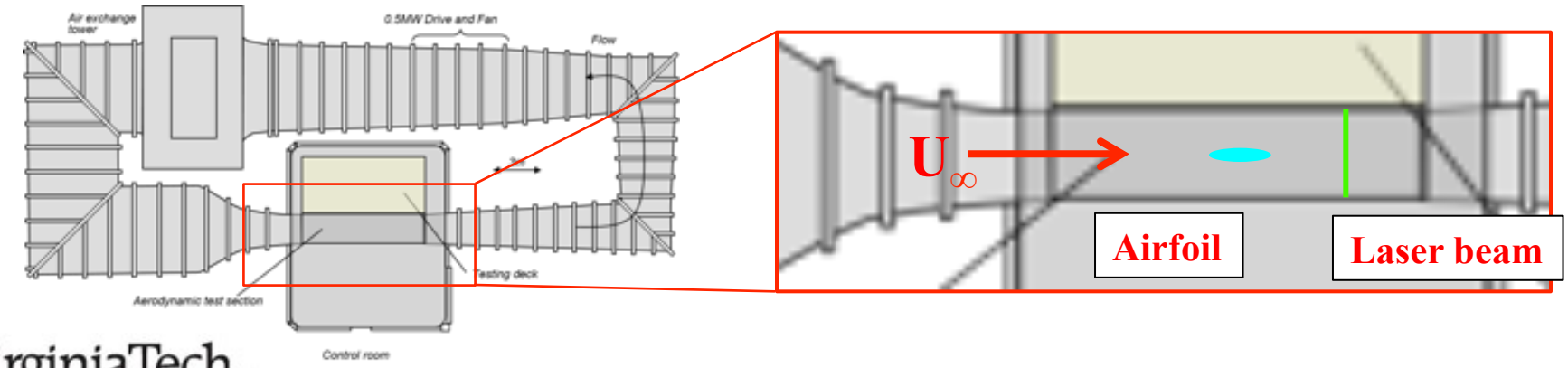
CC-DGV replaces traditional pneumatic drag rake measurements at stalled conditions

- A laser beam replaces pneumatic rake
- Cameras placed outside the tunnel
- CC-DGV: high spatial resolution velocities along beam trajectory
- Velocity profile can be integrated to yield drag

OWR Configuration

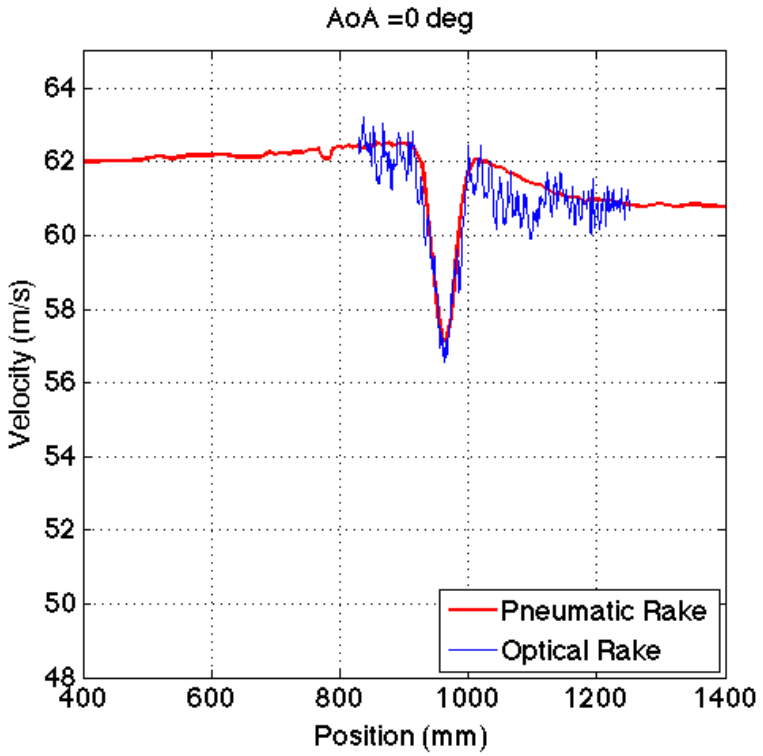
- Virginia Tech Stability Wind Tunnel in aerodynamic configuration
- Three camera/vapor cell pairs: three components of velocity
- Probe beam is spanwise traversable
- LaVision Davis camera calibration capability into CC-DGV processing
  - Spatial mapping and image registration

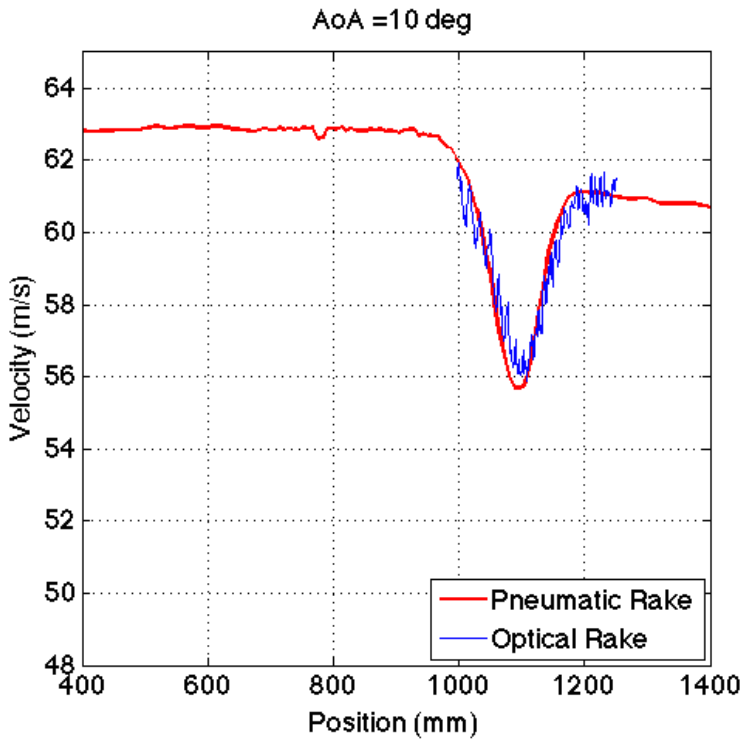




Results: Re = 3 Million

- System validation performed at low angles of attack, pneumatic rake for comparator data
- Self-calibration technique to determine velocities
- Single camera with highest u-component sensitivity used





Conclusions

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- Non-intrusive, spatially resolved velocity profiles were obtained using cross-correlation Doppler global velocimetry
- Measurements possible at any Reynolds number and angle of attack regime attainable in a given facility
- Difficulties in application mainly arose from seeding uniformity and optical access

Future Development

- Increase field of view to enable drag integration
- Remote focusing and traversing capabilities for cameras
- Develop robust seeding technique to minimize drift of scattered light intensity
- Simplified optical arrangement (sidewall cameras)

Questions?

Supplemental Slides

SWT Camera Calibration

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