

Can PIV Measure a Full-Scale Wind Turbine?

Steven Beresh



Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Why do we want PIV?

Capture instantaneous velocity images to resolve coherent turbulent structures in the wind turbine wake region.

Impact:

- Enable the validation of research codes and design tools used to optimize wind plant performance.
- Complement existing measurement capabilities such as lidar and radar.

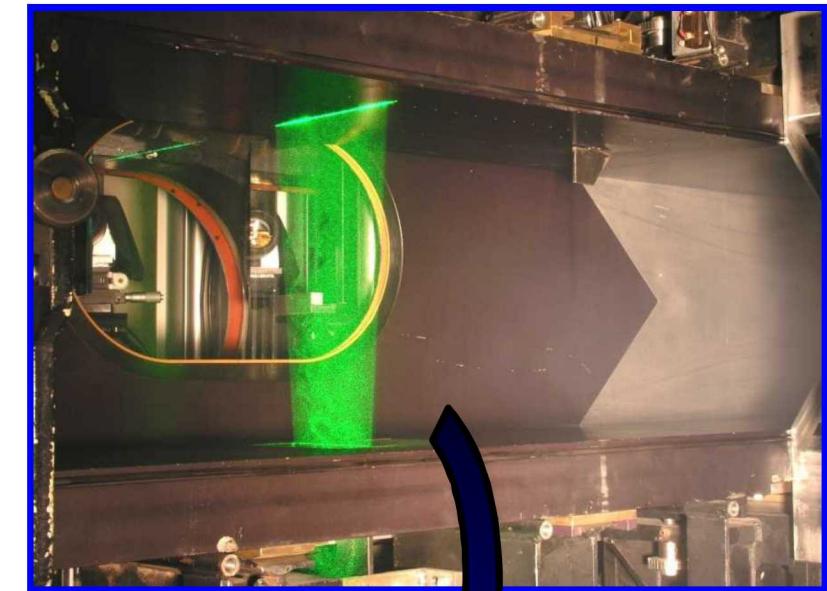
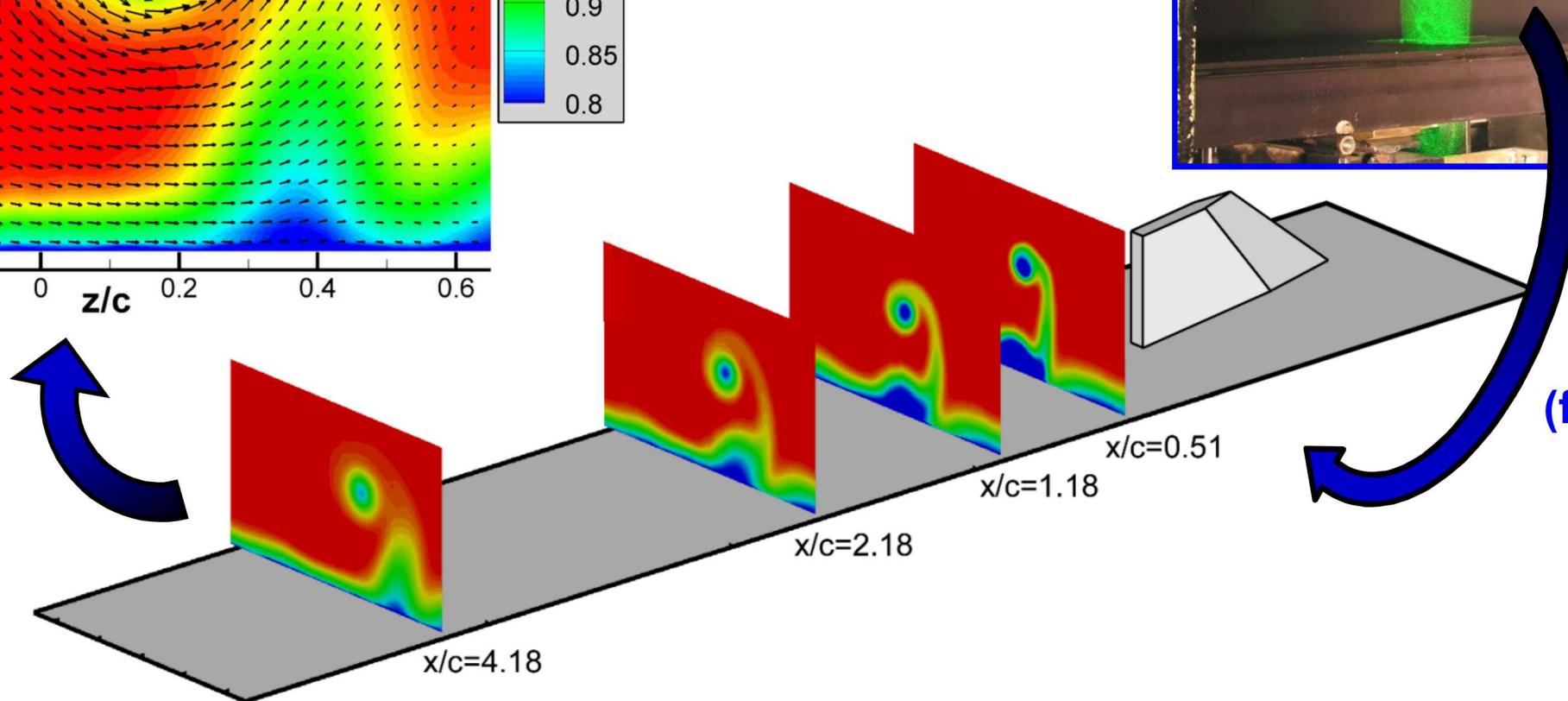
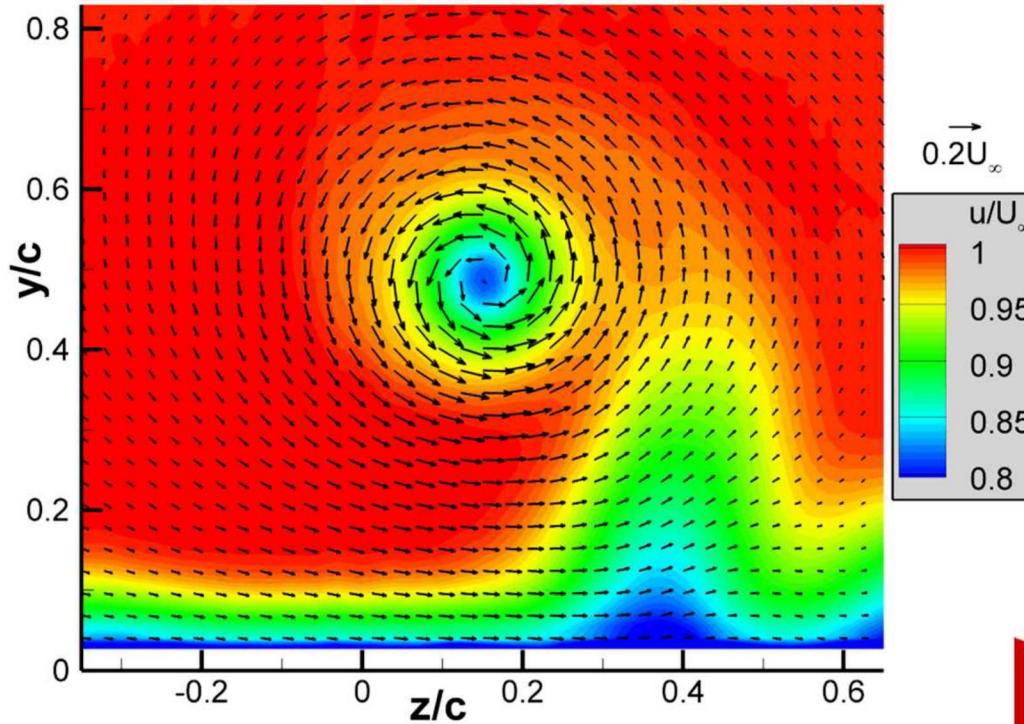
What can PIV offer that LIDAR cannot?

- Full-field measurements with tighter spatial resolution.
- Vortical structures shed by turbine blades.

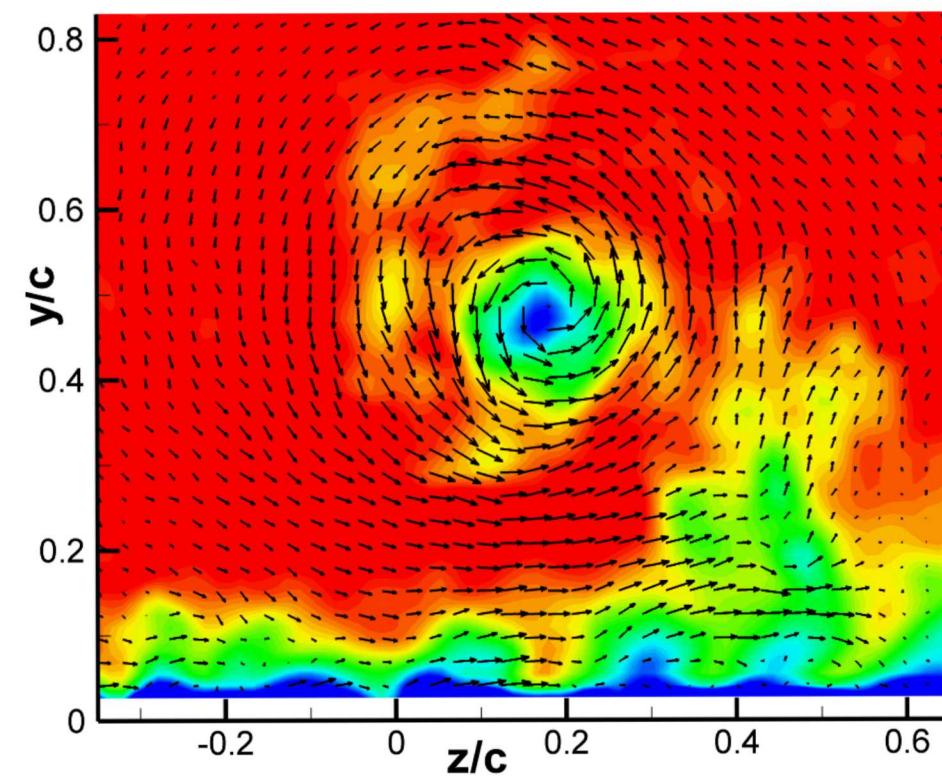
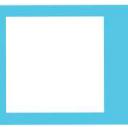
Previous effort using Doppler Global Velocimetry established some key capabilities...

...but instantaneous measurement accuracy was a problem.

Sandia is a world leader in the use of Particle Image Velocimetry (PIV) in high-speed wind tunnels.



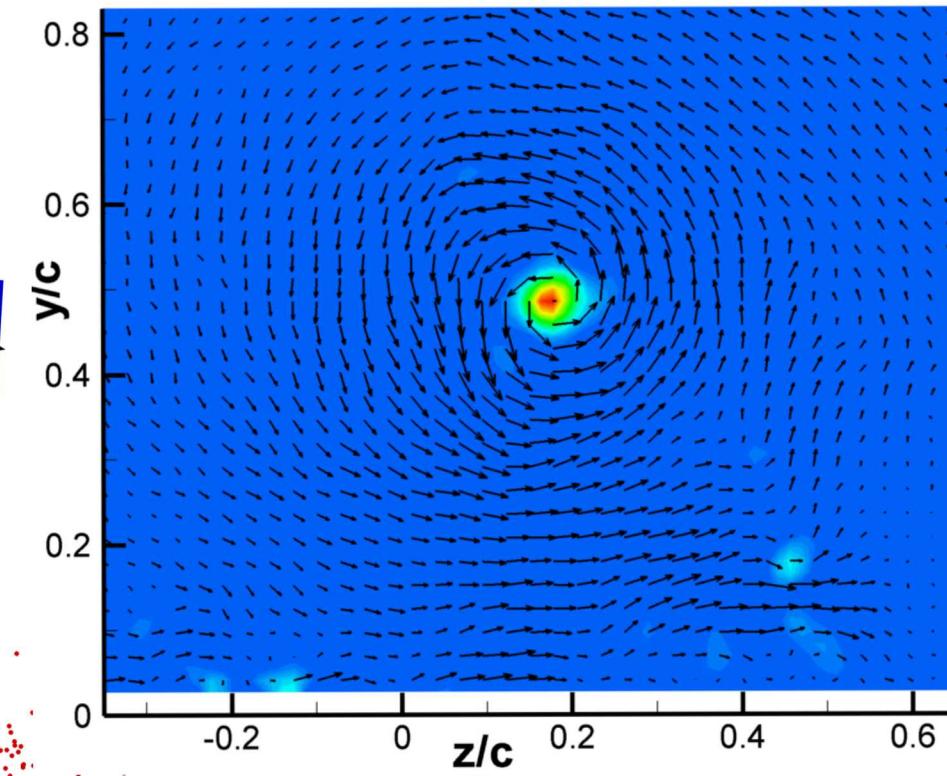
Instantaneous Turbulence



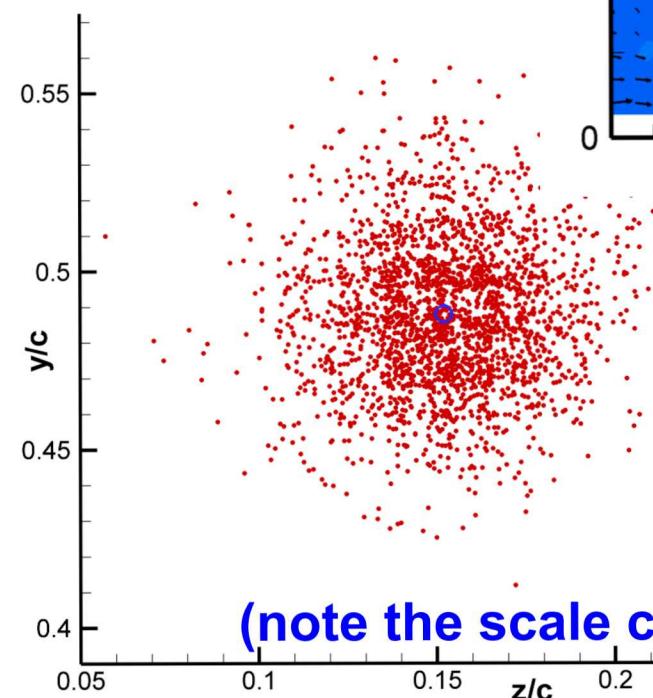
Take each individual vector field...



compute the swirling strength...



and locate the peak for each sample.

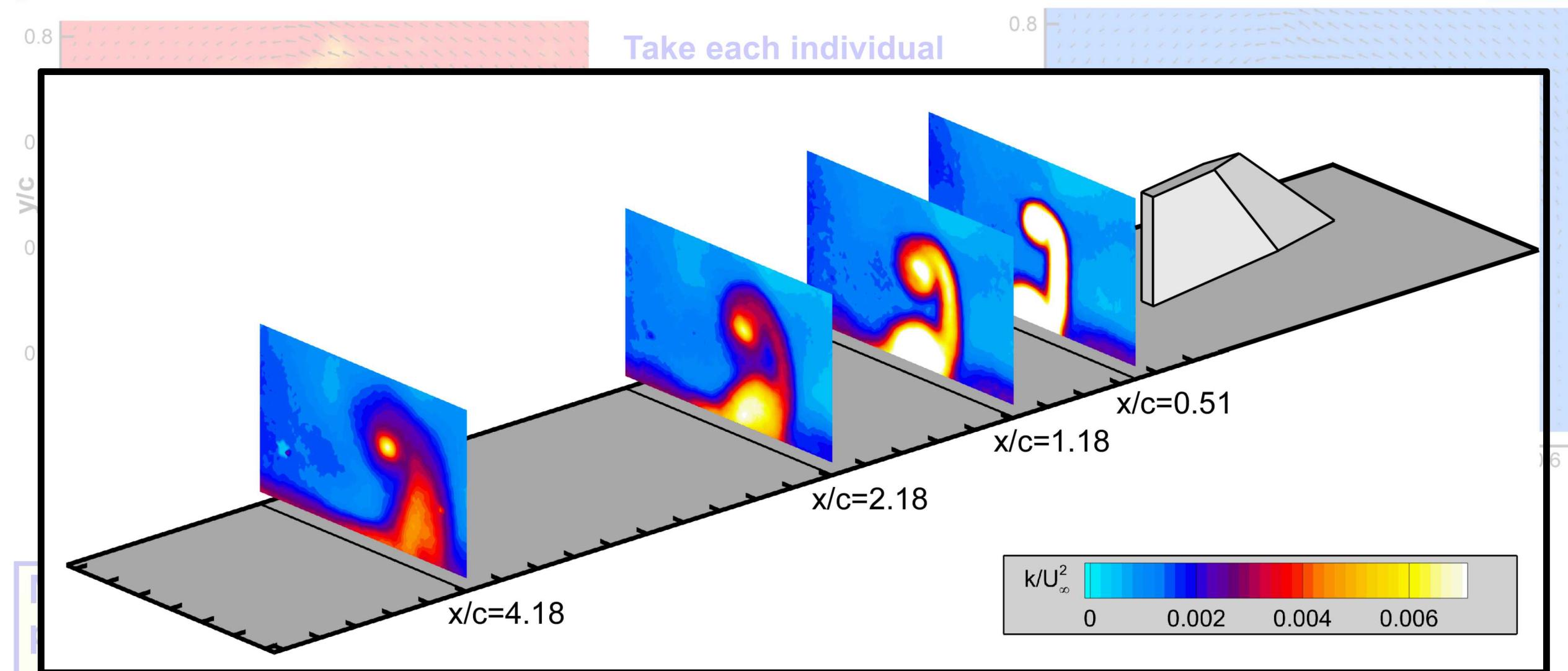


(note the scale change)

Meander is a known vortex phenomenon in wind tunnels.

- This is a means of quantifying it from PIV.

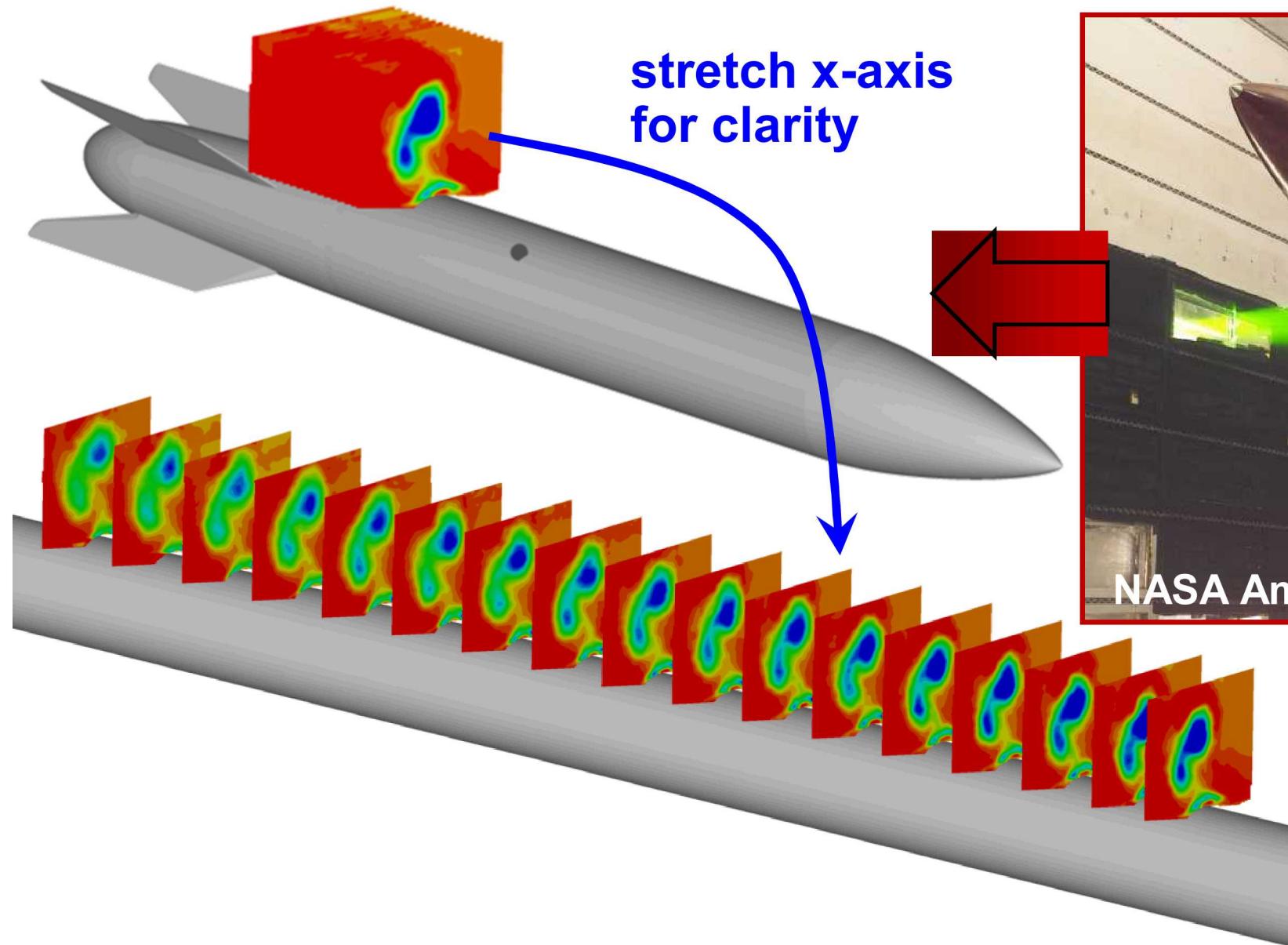
Instantaneous Turbulence



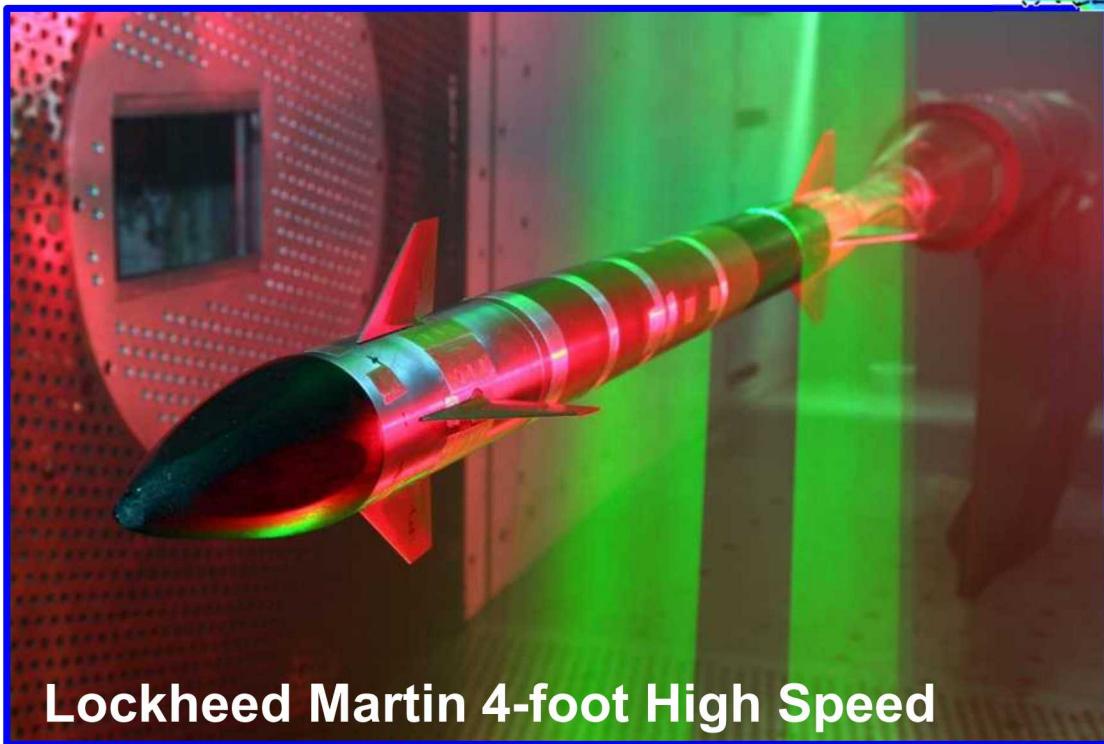
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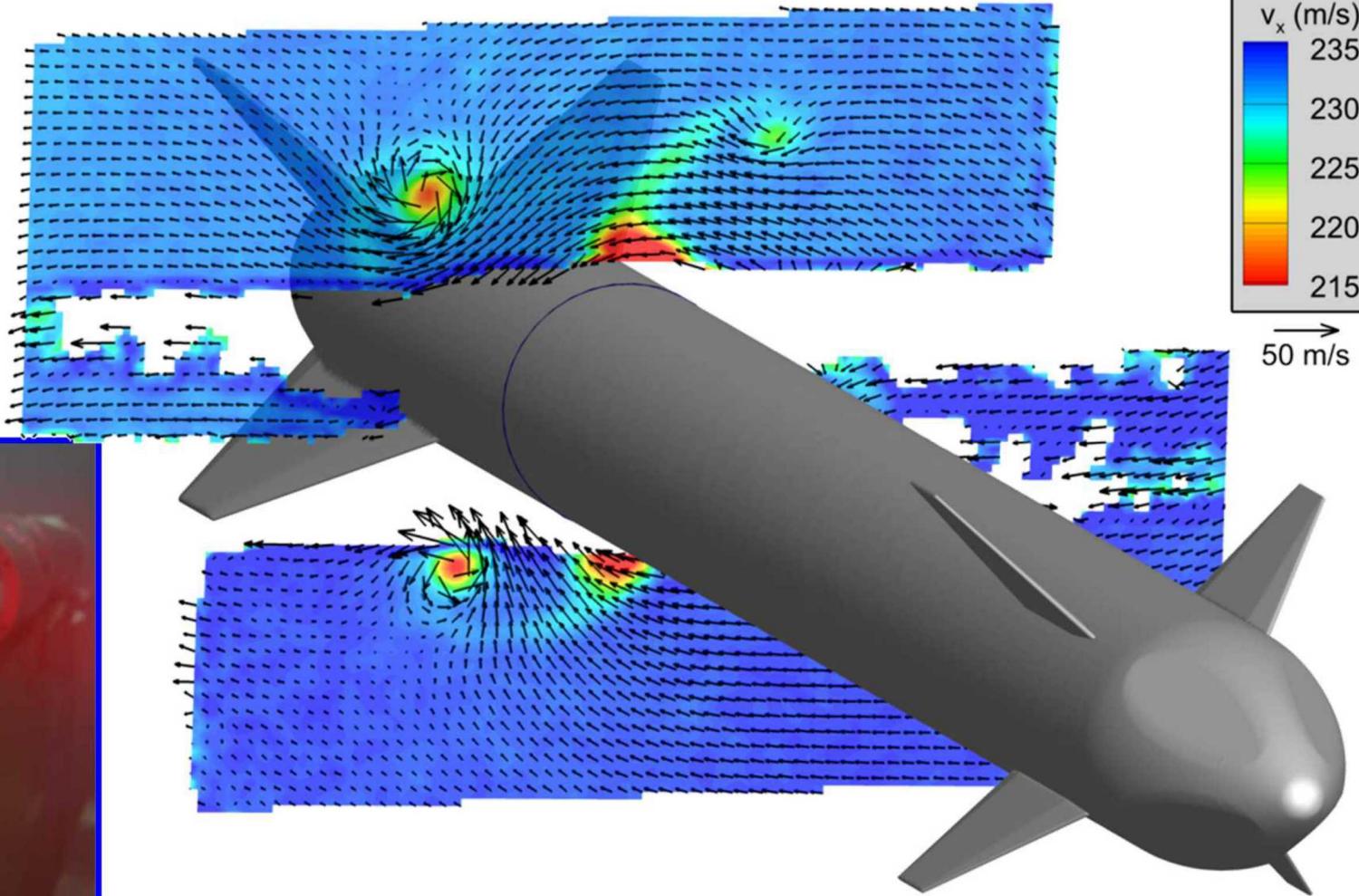
And we have successfully fielded PIV in large-scale production wind tunnels.



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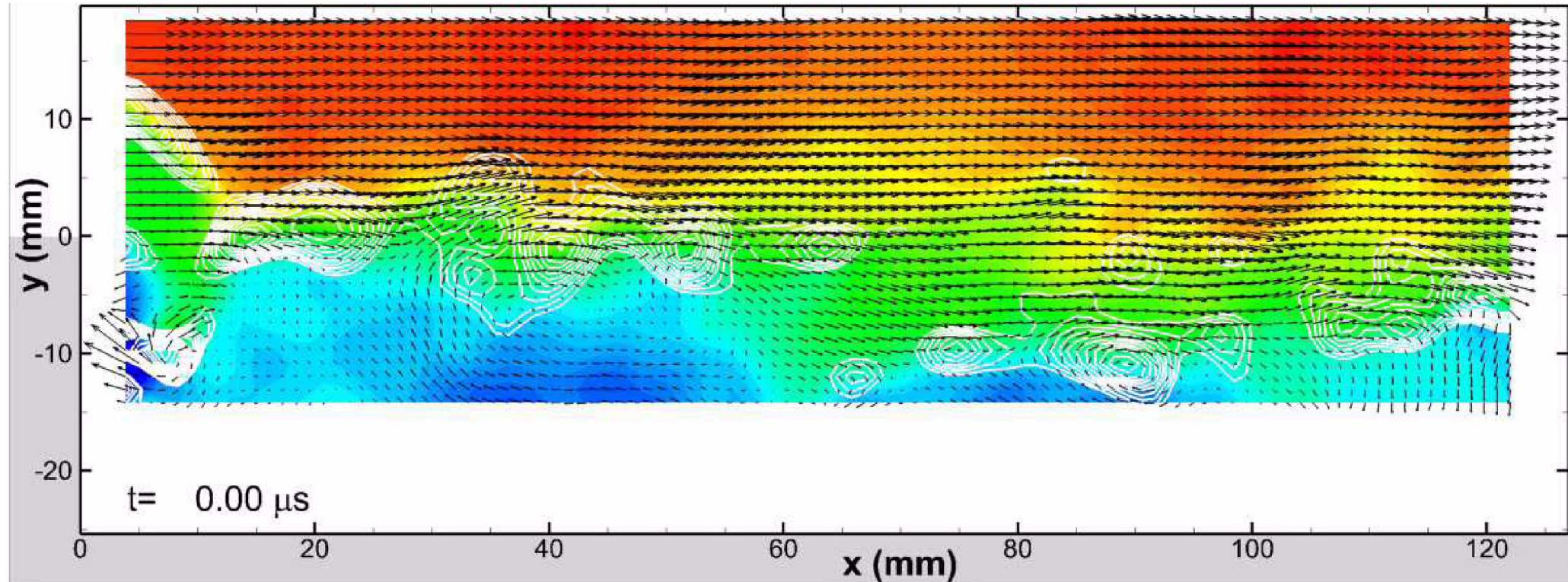
Lockheed Martin 4-foot High Speed



v_x (m/s)
235
230
225
220
215

50 m/s

New technologies allow us to acquire PIV movies in high-speed flows.

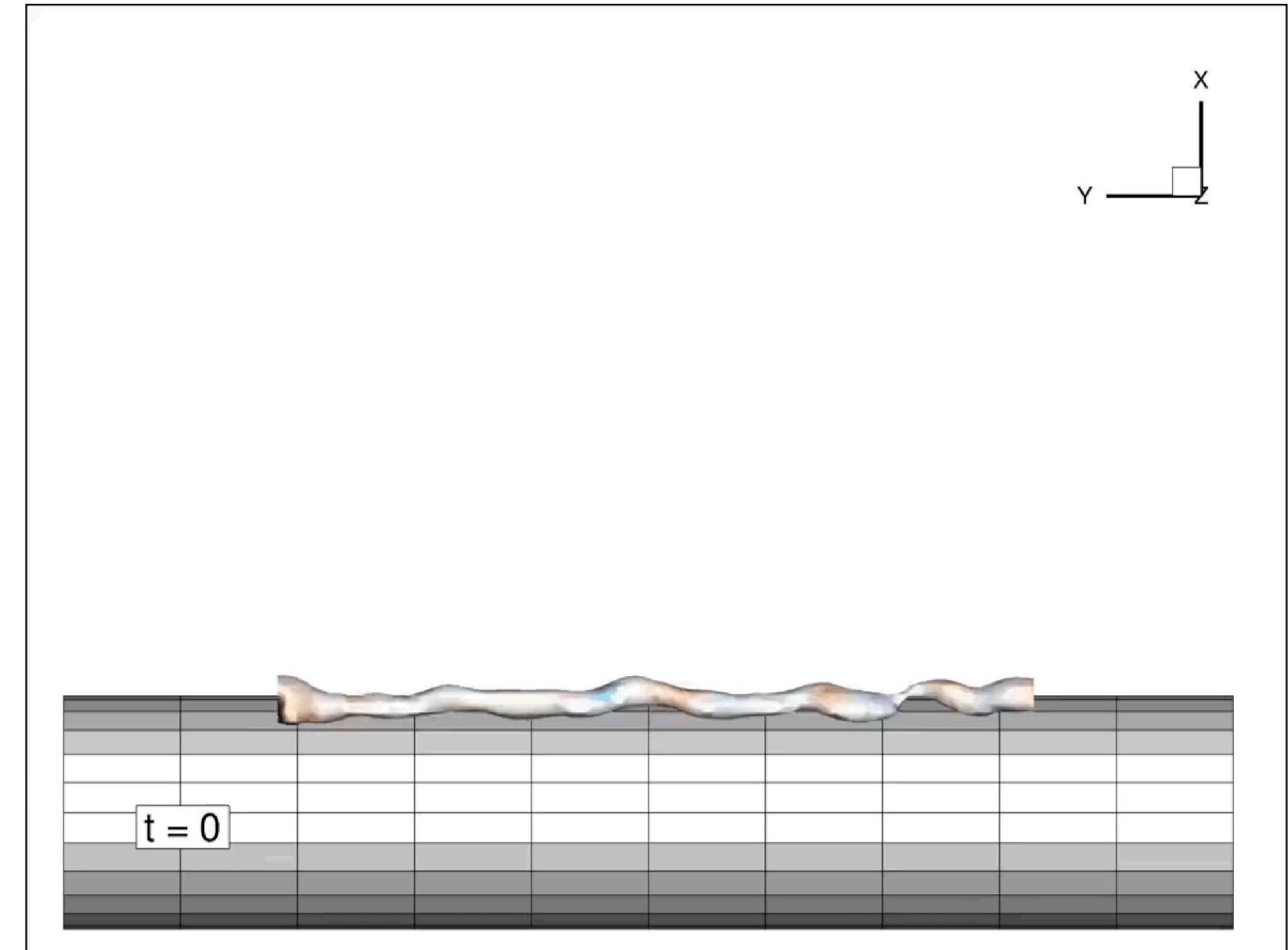


Example: Mach 0.8 flow of the shear layer over a cavity.

Each velocity vector is a quantitative measurement and a signal in time, complete with estimated uncertainty.

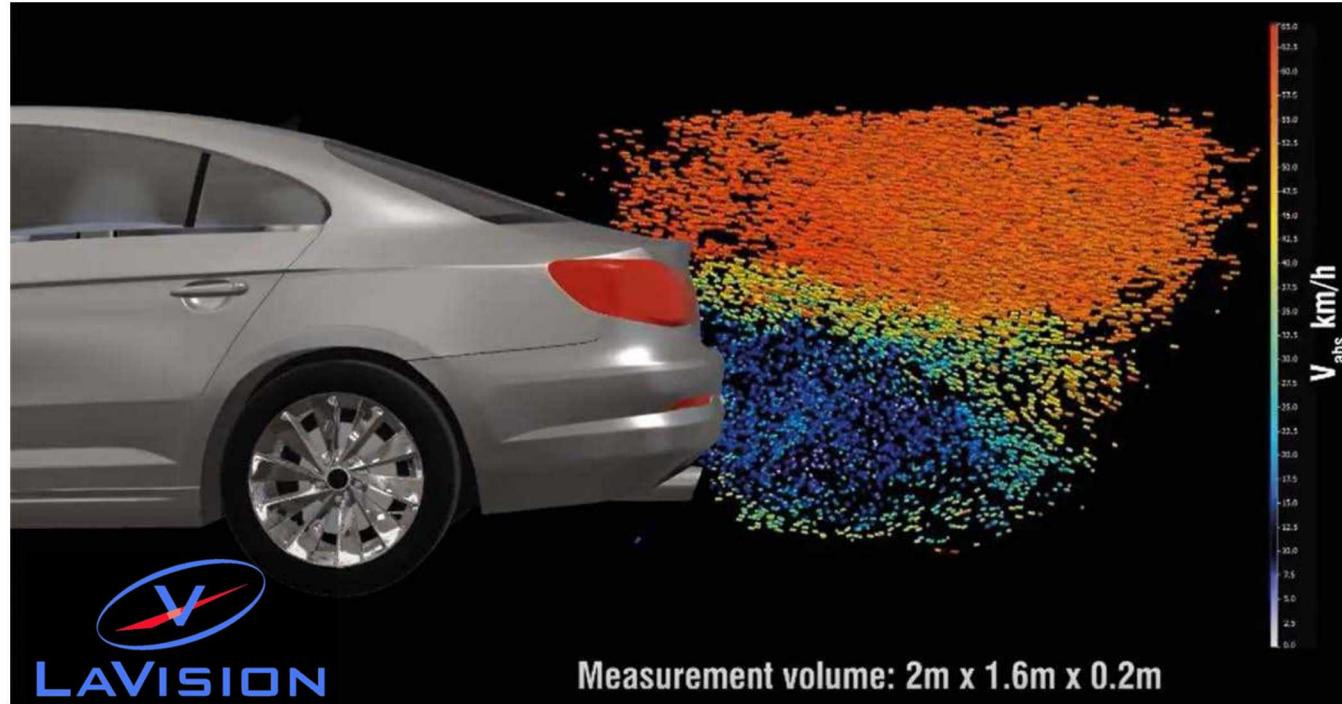
A large part of what makes wind tunnel testing modern is the advanced measurement capability now possible.

And we can make three-dimensional measurements.



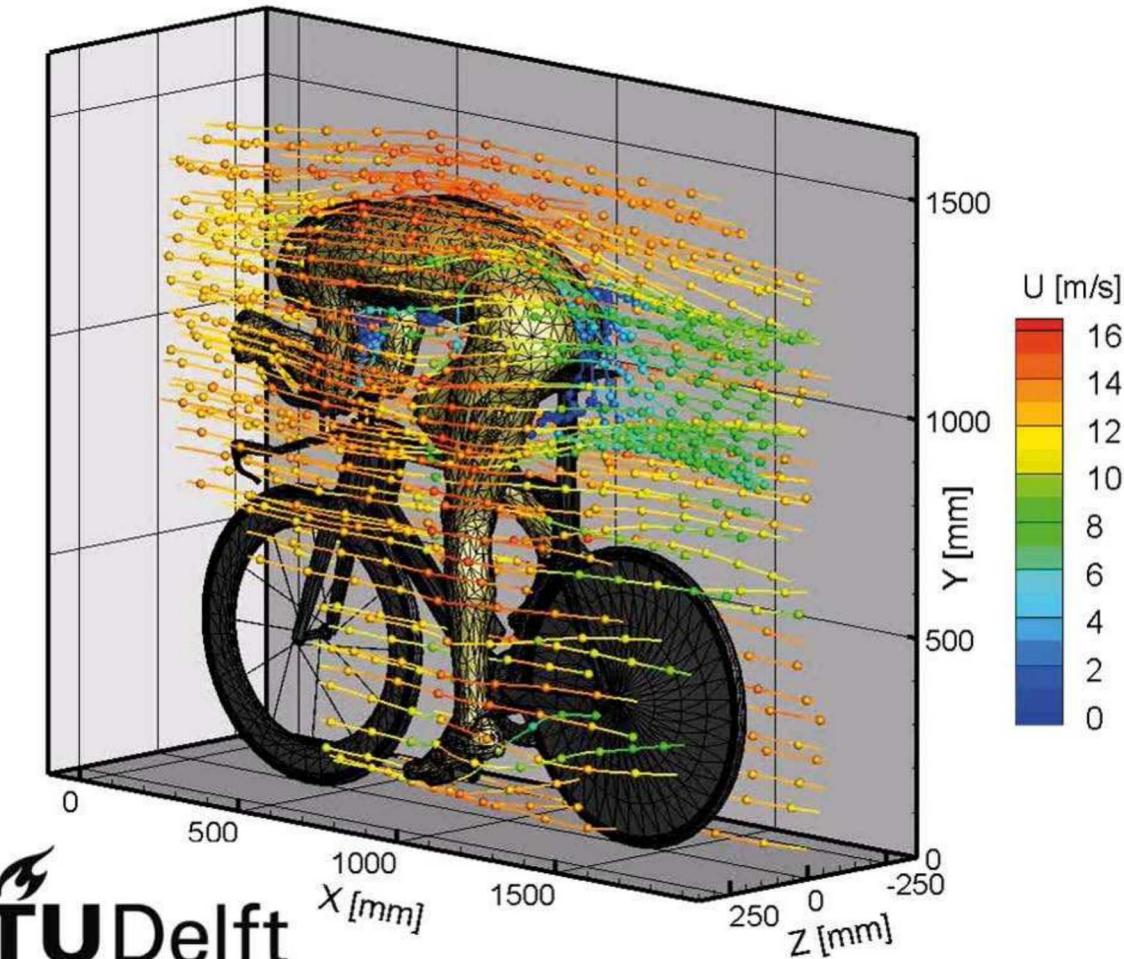
**Tomographic PIV of the
wake of a cylinder in
impulsively-started flow.**

Other Large-Scale Examples

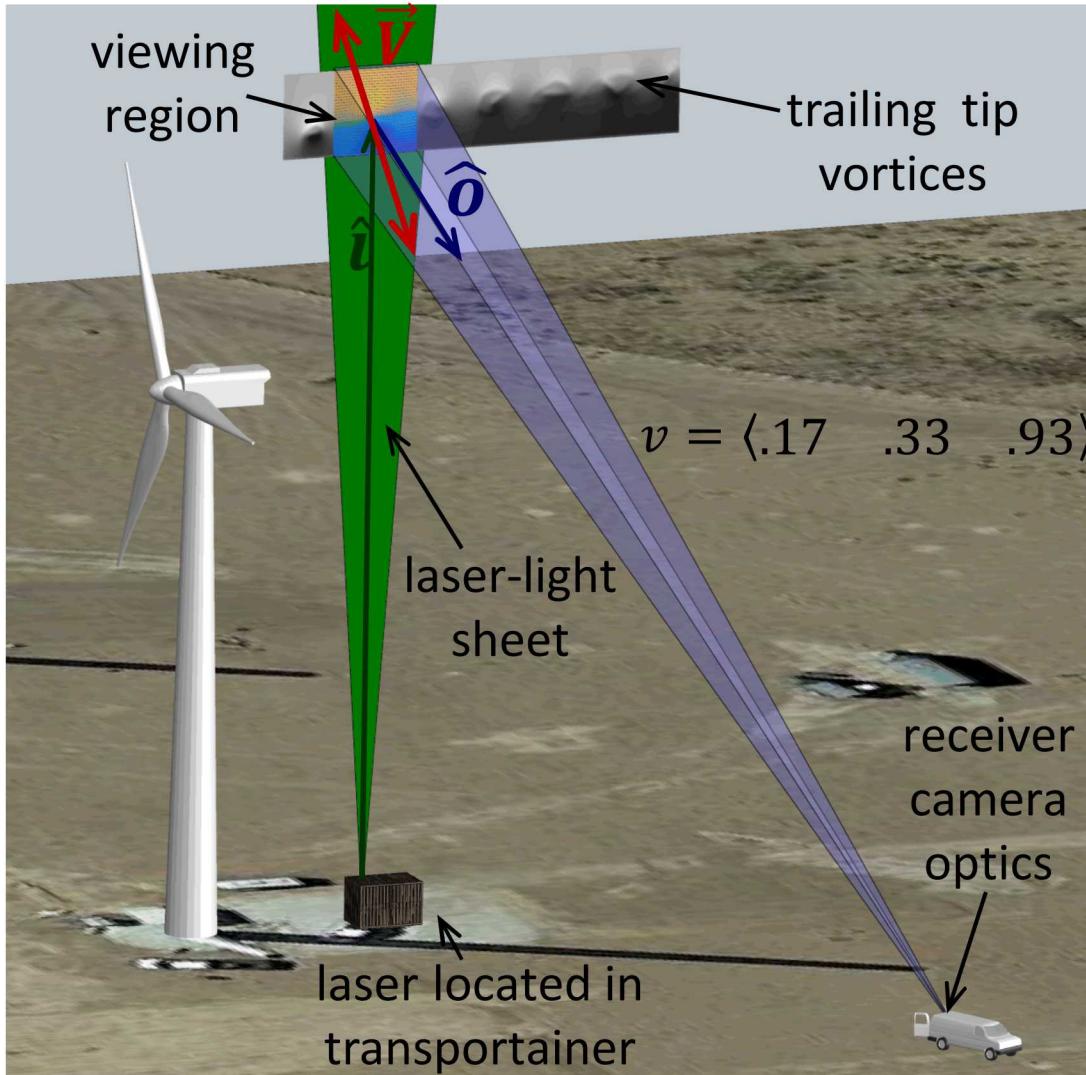


We have established capability at about the 2-meter scale.

- Can we increase to 10's of meters?



Sandia Wake Imaging System (SWIS)



Doppler Global Velocimetry

- Successfully imaged wake vortices

We can leverage some of the techniques developed here.

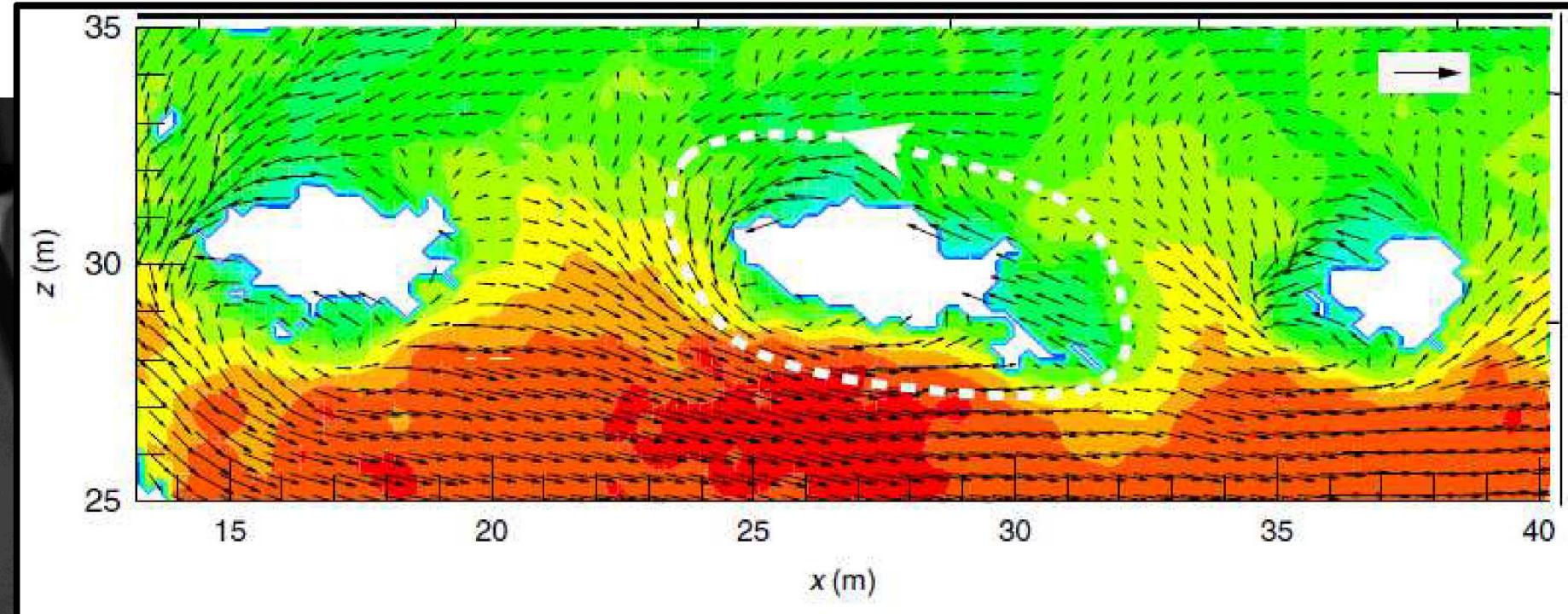
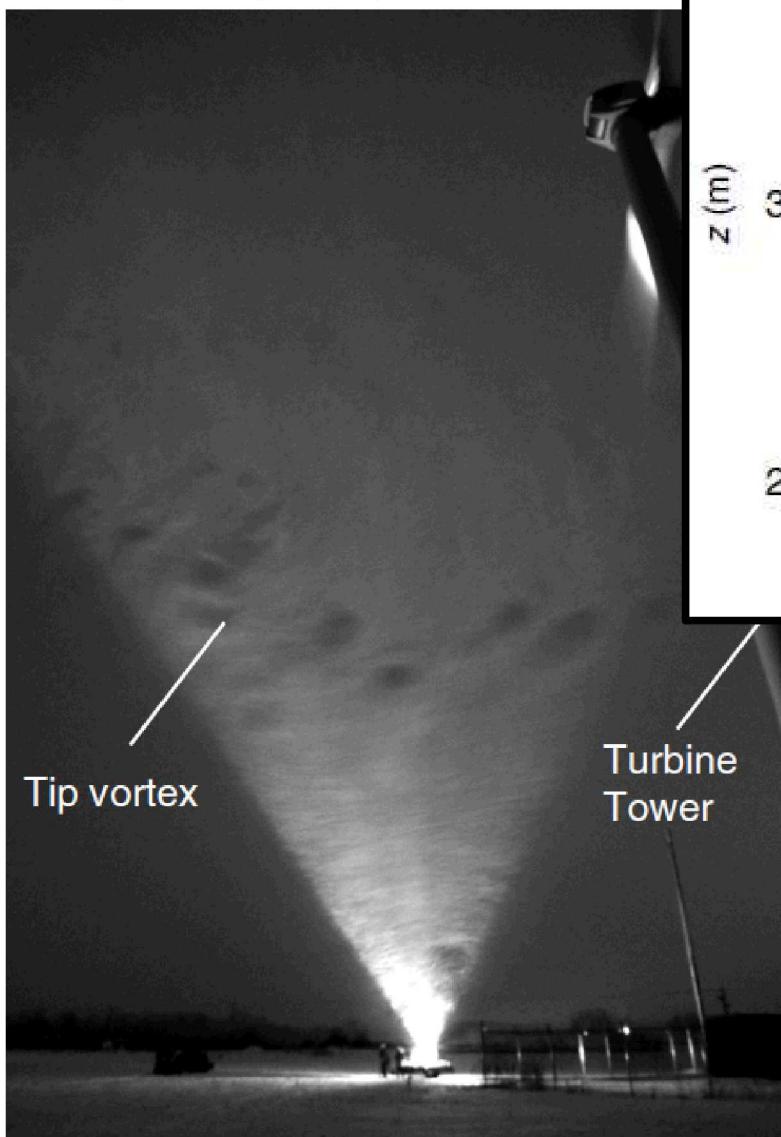
PIV offers some advantages:

- Improved accuracy.
- Better for instantaneous measurements.
- Simpler equipment more robust for use in the field.
- No target required for camera alignment.

The Minnesota “Snow PIV” Experiment



Hong et al (2013)



**A clear success...
...but the seeding is inadequate.**

This shows it can be done!
**• But can we make it more robust
and accurate?**

Controlled Seeding for Large Scales

Helium-Filled Soap Bubbles

- Millimeter-size for strong scattering
- Neutrally buoyant
- Low mass for fast response
- Lifetime of minutes
- Commercially available



Embedded in an airfoil
to minimize disturbances.

Can we build arrays of these
in the field?



Lighting

We don't need a laser for PIV.

- Searchlights or spot lights are readily available for a few \$100 to \$1000.
- Designed for outdoor use in rugged conditions.
- Additional optics could collimate better into a sheet.
- Gang a few together.
- Lots of affordable options that could be repurposed.

LED's have been used for PIV on large scales.

- We'd be raising the game but there's precedent to draw upon.
- Probably not as bright as Halogen or Xenon lights.



A plan to get started

I foresee two major challenges:

Seeding towers that don't disturb the inflow.

- Large arrays of helium-filled soap bubbles are needed for PIV.
- How do we build towers to do this without altering the flow?
- Not a PIV-specific problem.
- Is there experience in the wind turbine community to help solve this?

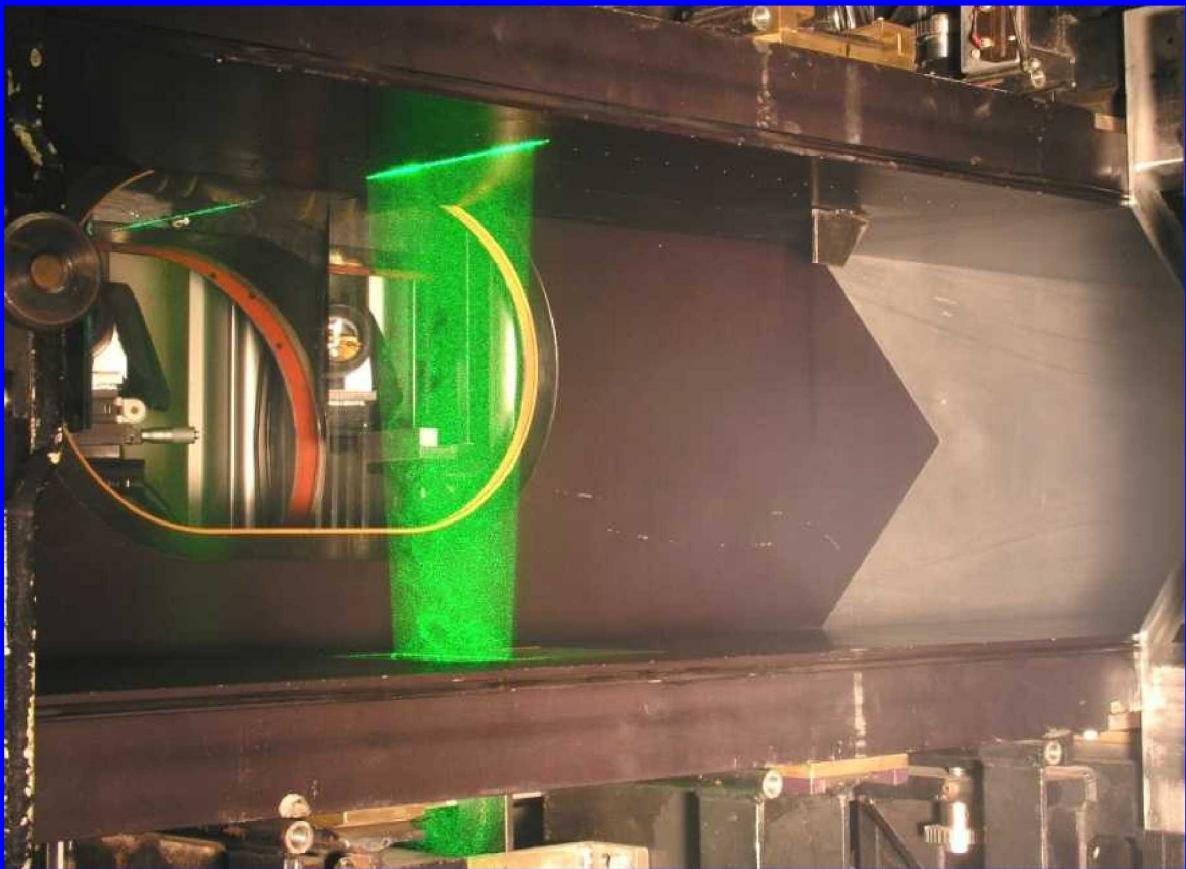
Lighting for PIV that can be separated from background.

- Lighting will be broadband and not filterable from background illumination.
- Initially we will need to operate at night.
 - This is still valuable.
 - Even nighttime operation may have background contamination.
- Ideally, we would like to operate at any time in any atmospheric condition.

We can begin working these problems in Sandia's backyard.

Then transport to the field for wind turbine measurements.

The technology is ready for PIV on wind turbine scales!



**Using wind tunnel experience
to enable field success!**

