SAND2015-10159C

Turbulent Eddies in a Compressible Jet in Crossflow Measured using Pulse-Burst PIV

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Albuquerque, NM

68th Annual Meeting of the
American Physical Society, Division of Fluid Dynamics
November 22-24, 2015
Boston, MA

National Nuclear Security Administration

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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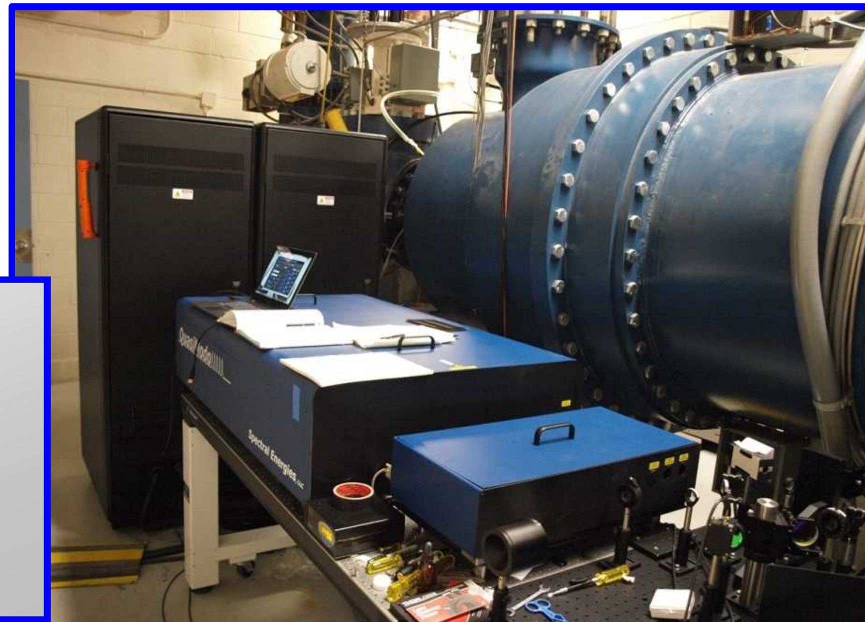
Time-Resolved PIV with a Pulse-Burst Laser

Current TR-PIV capability isn't enough for a high-speed wind tunnel.

- **Faster repetition rates for briefer time scales.**
- **Higher energy required.**
  - **Scatter light off smaller particles**
  - **Expand laser sheet for larger field of view**

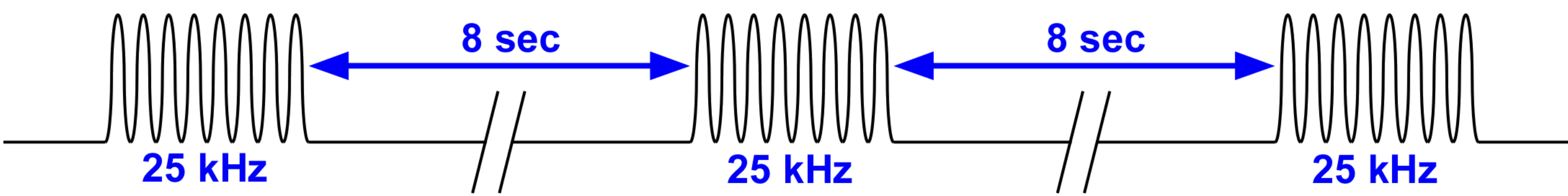
A pulse-burst laser allows high energy and high repetition rates.

But a very low duty cycle.

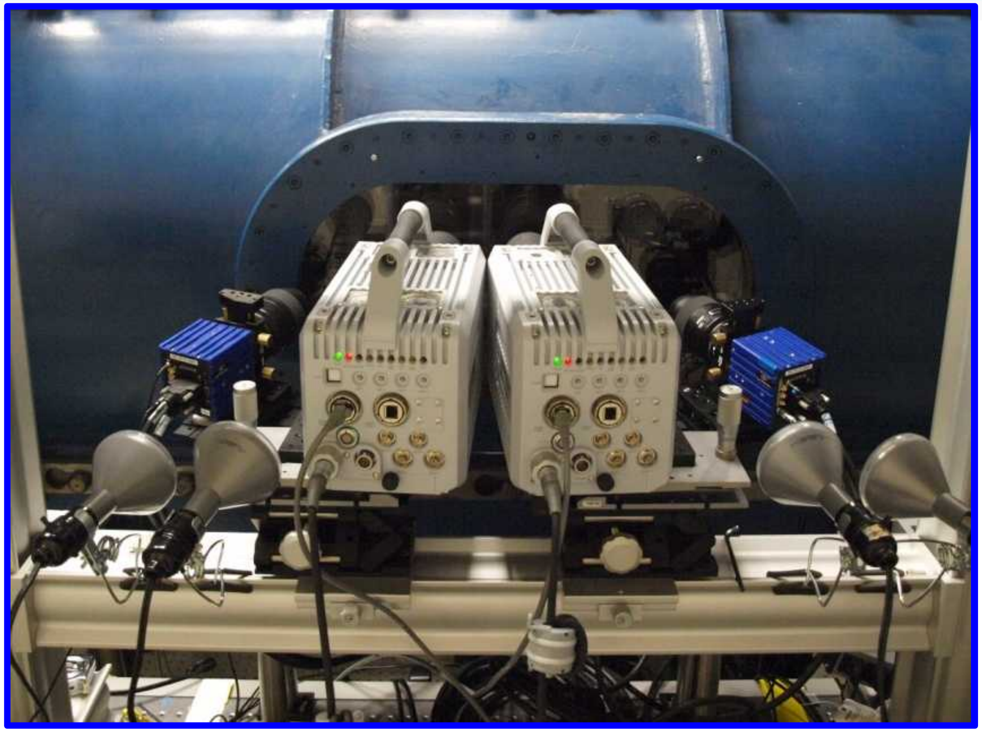


Pulse-Burst Laser:

- **Manufactured by Spectral Energies, LLC**
- **Bursts of pulses for 10.2 ms**
- **Up to 500 kHz of pulse pairs, 20-500 mJ**
- **But only one burst every 8 sec**



High-Speed Cameras



High-Speed Cameras
- Photron SA-X2
- Two side-by-side for wider field of view
- Two-component PIV

Camera Orientation
- Cameras canted at 5° due to large size of camera body.
- Max error in streamwise component is < 2%.

Present experiments:
- 50 kHz framing rate
- 640 × 384 pixels
- Frame straddle pulse pairs

Present laser settings:
- 25 kHz of pulse pairs
- Δt = 2.00 μs
- 2.5 ms burst, 175 mJ/pulse

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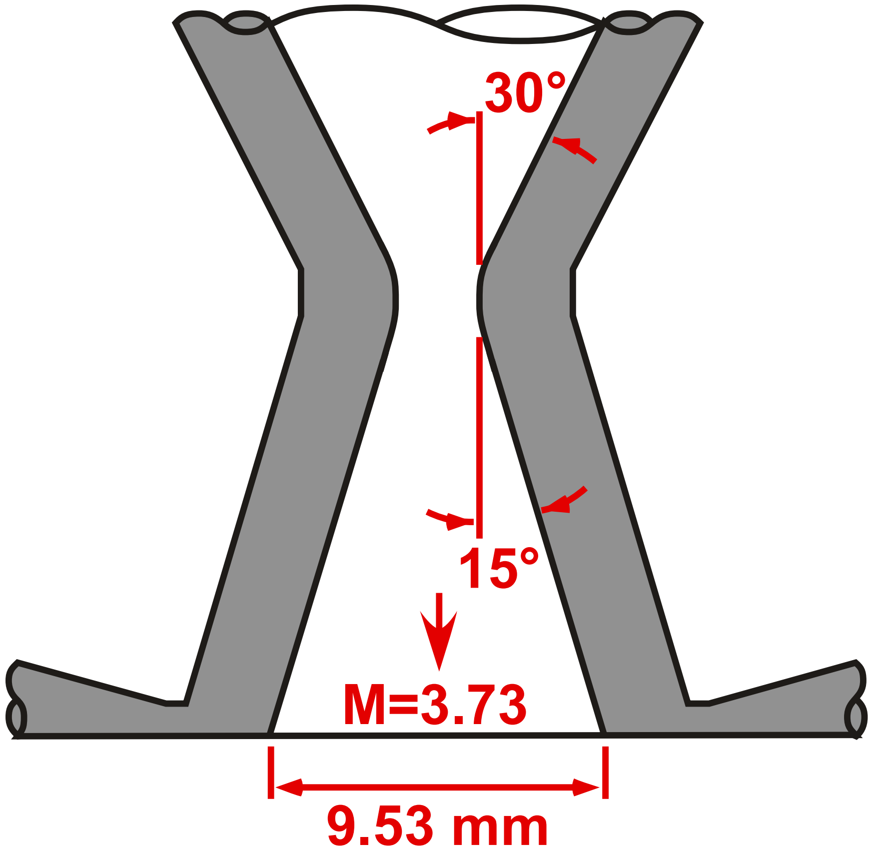
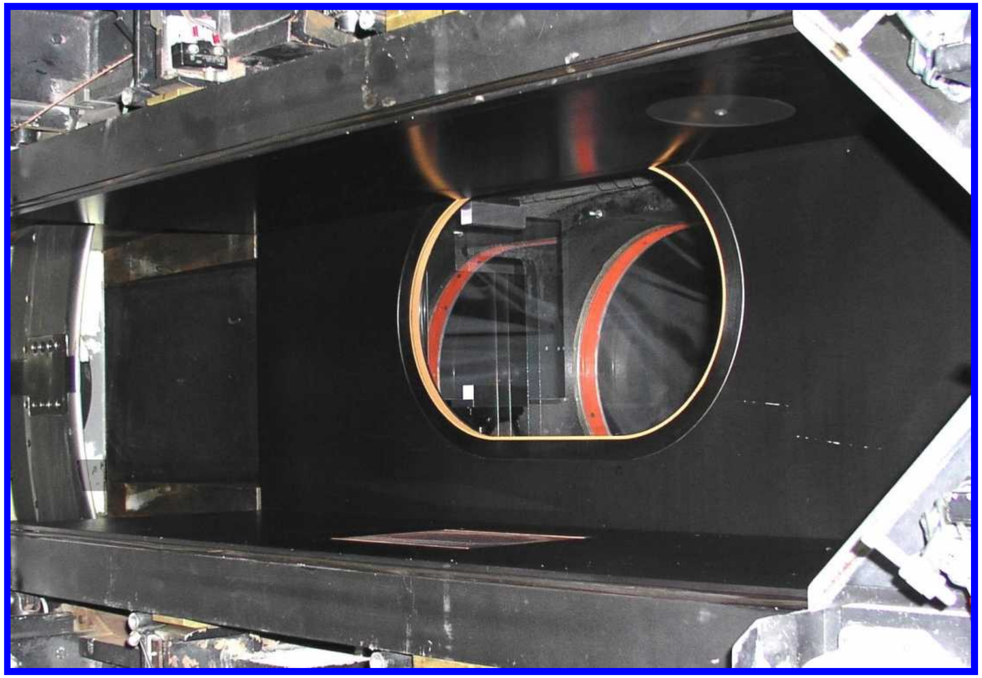
Our First Test Application

Supersonic Jet in Transonic Crossflow
installed in Sandia's Trisonic Wind Tunnel



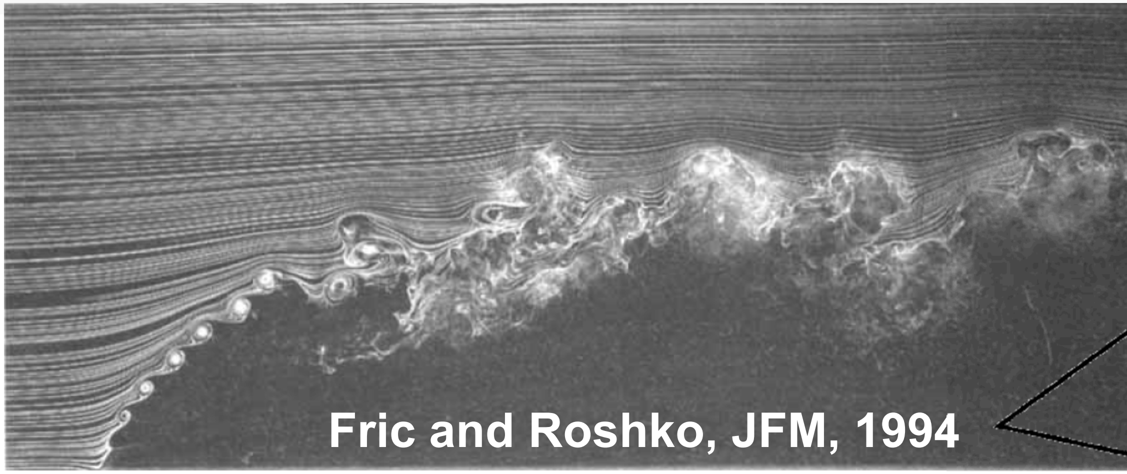
Freestream at Mach 0.8 and J=8.1



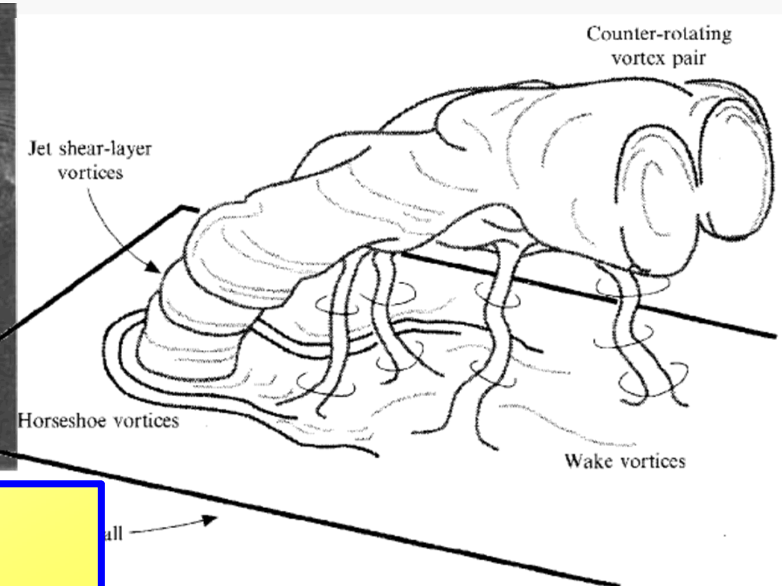
Jet Nozzle Installation

- Mounts on top wall of TWT
- View the far-field of the interaction

Why is Pulse-Burst PIV Important to this Flow?



Fric and Roshko, JFM, 1994

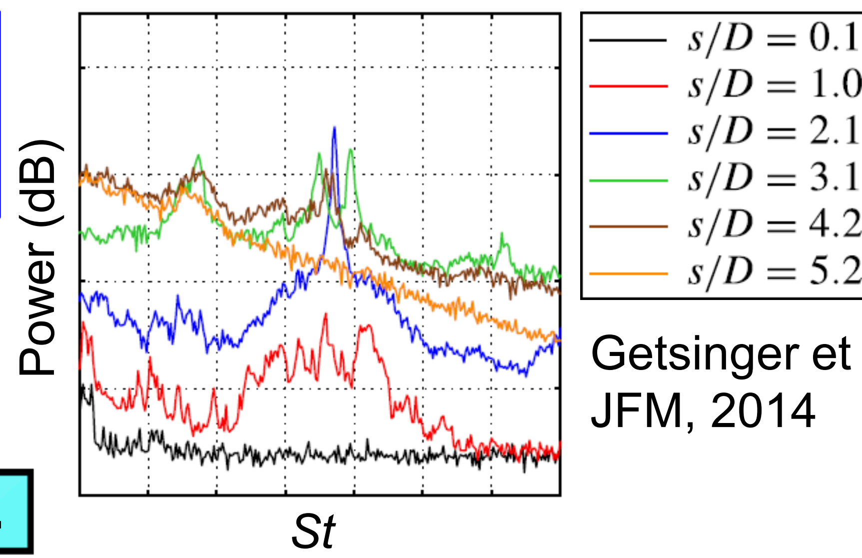


Shear layer vortices are important to the CVP development in the near-field.

But of secondary importance in the far-field.

The Kelvin-Helmholtz instability frequency is visible in the near-field.

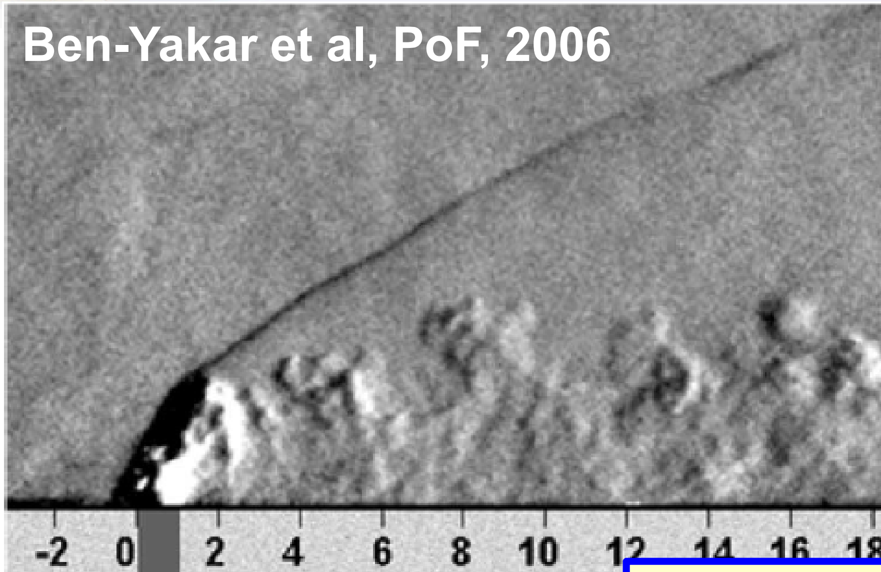
It decays in the far-field.

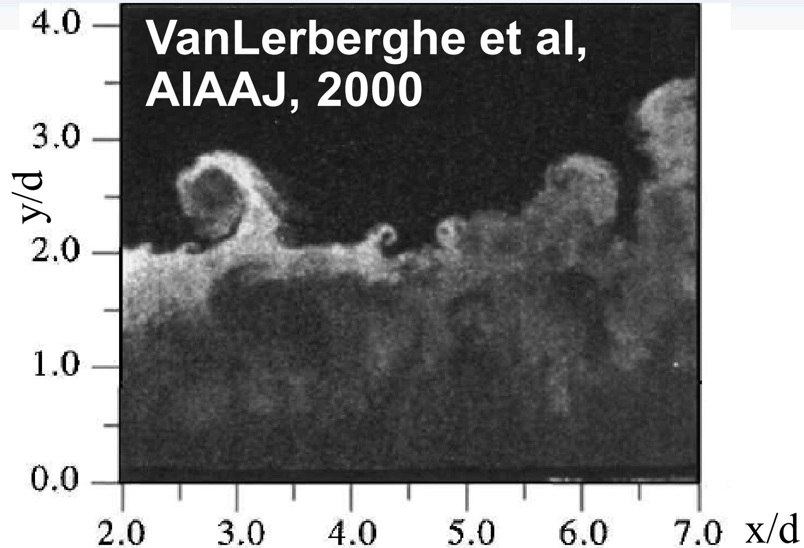


Getsinger et al, JFM, 2014

But this is based on low-speed flows.

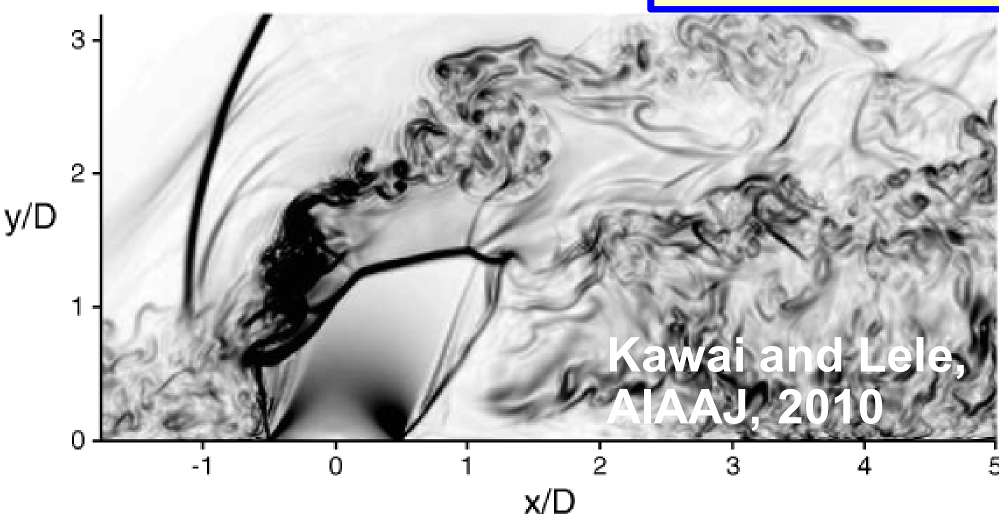
Why is Pulse-Burst PIV Important to this Flow?





In compressible flows, large shear-layer eddies appear more persistent downstream.

They are as prominent as the CVP.



This may be due to unsteadiness of the jet exit shock structure.

Unclear whether periodicity may exist.

Can we use our pulse-burst PIV data to answer these questions?

Field of View

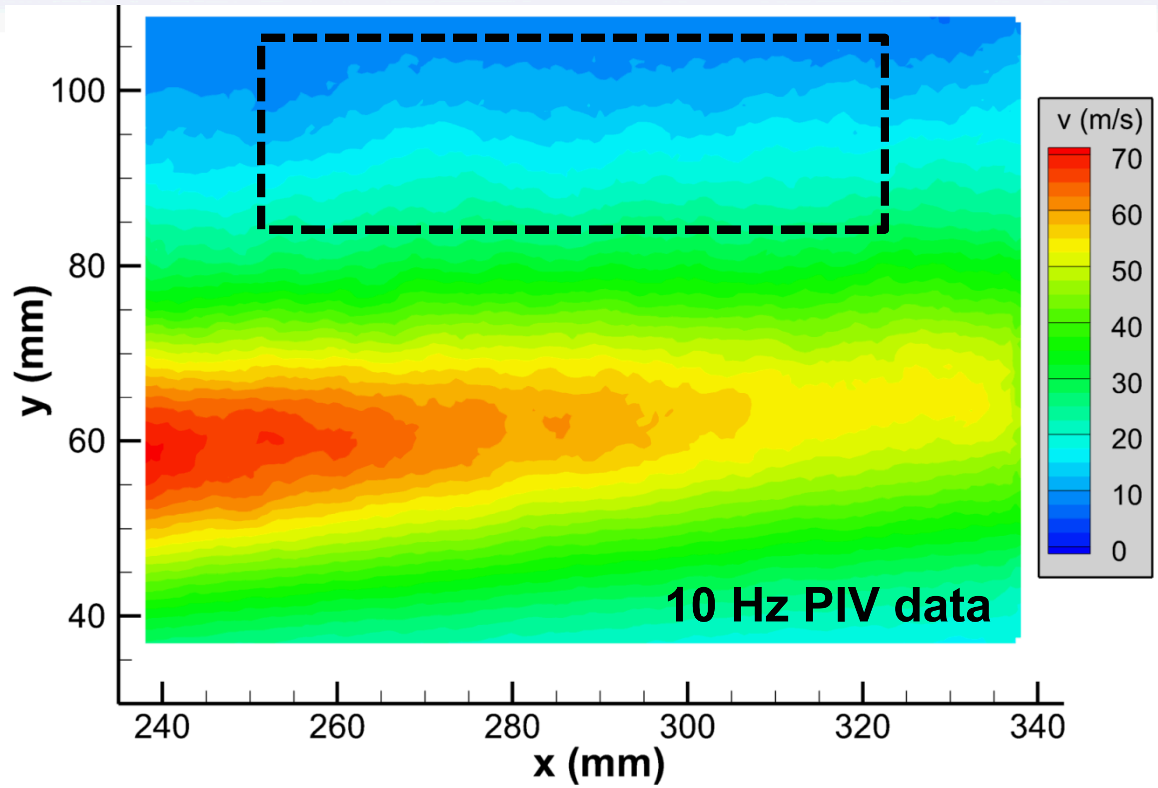
Combined field of view:

Image turbulent eddies at the outward mixing layer.

Today's data at J=8.1

Far from jet core and sparser turbulent eddies.

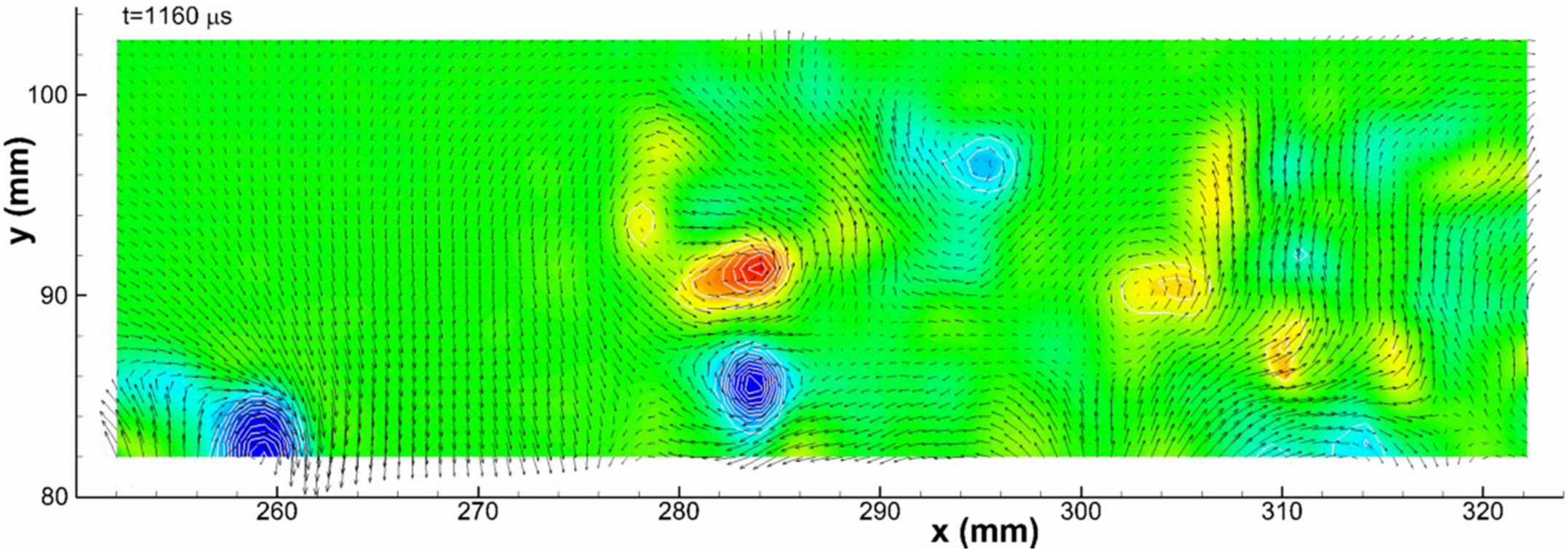
Makes data more visually interpretable.



jet exit

A Sample Pulse-Burst PIV Movie

This is a 2.5 ms movie with 63 vector fields acquired at 25 kHz.



(920)

Velocity fluctuations are shown.

Final pass uses 24 × 24 pixel interrogation windows.

Counter-rotating eddies convect past, typically in pairs.

- **About 8-10 mm separating eddies in a pair**
- **About 20-30 mm separating pairs**

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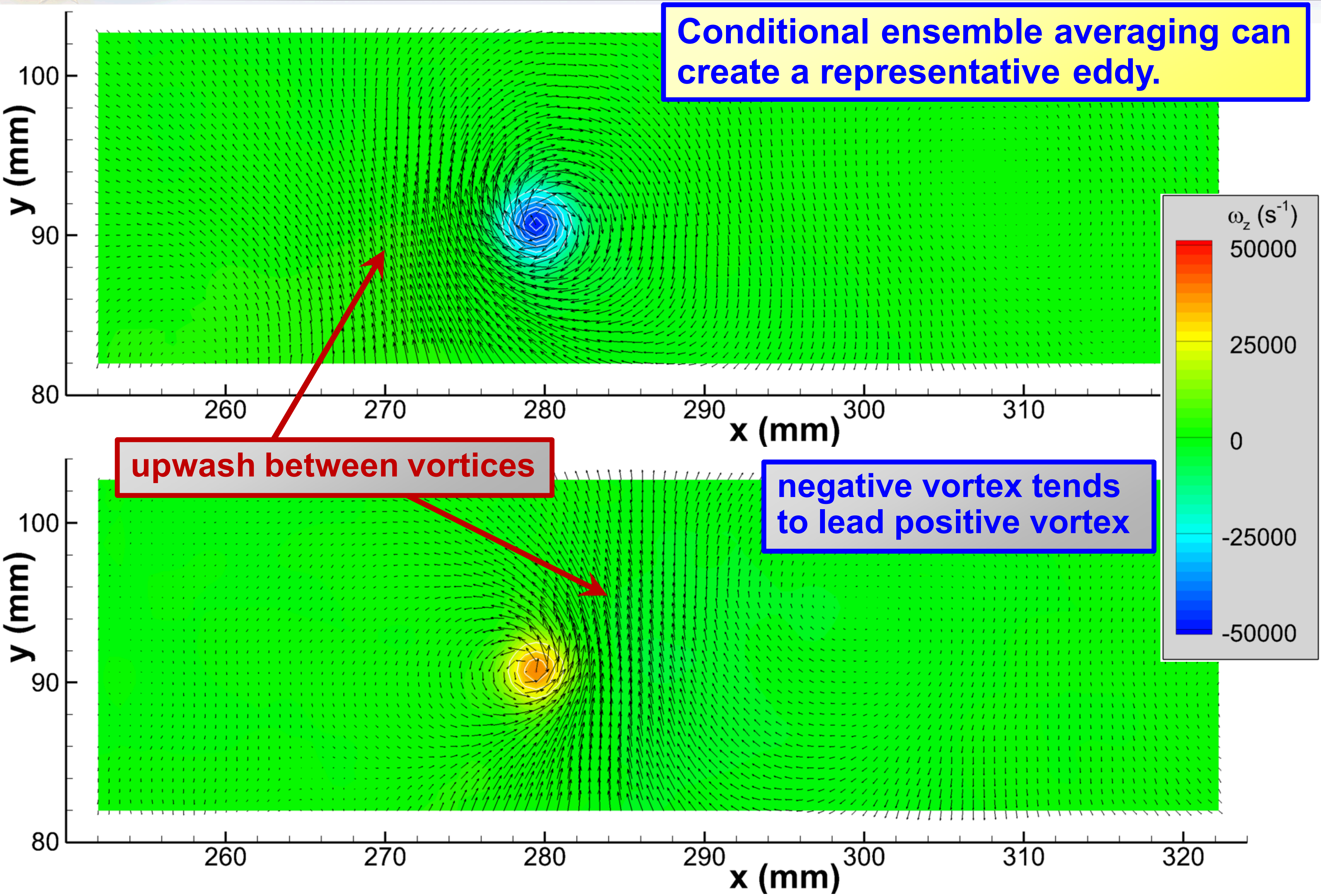
Eddies tend to occur in counter-rotating pairs.



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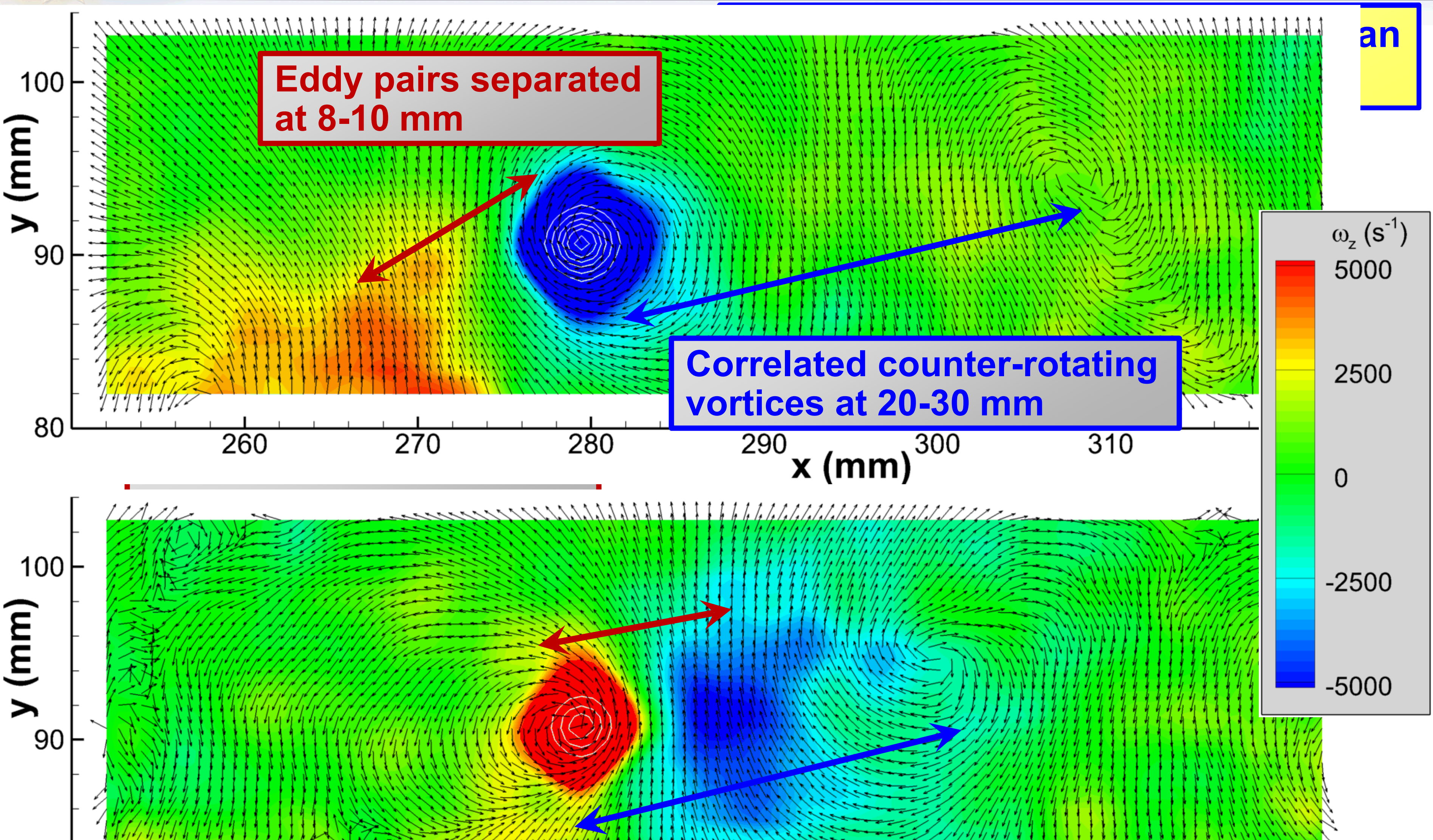
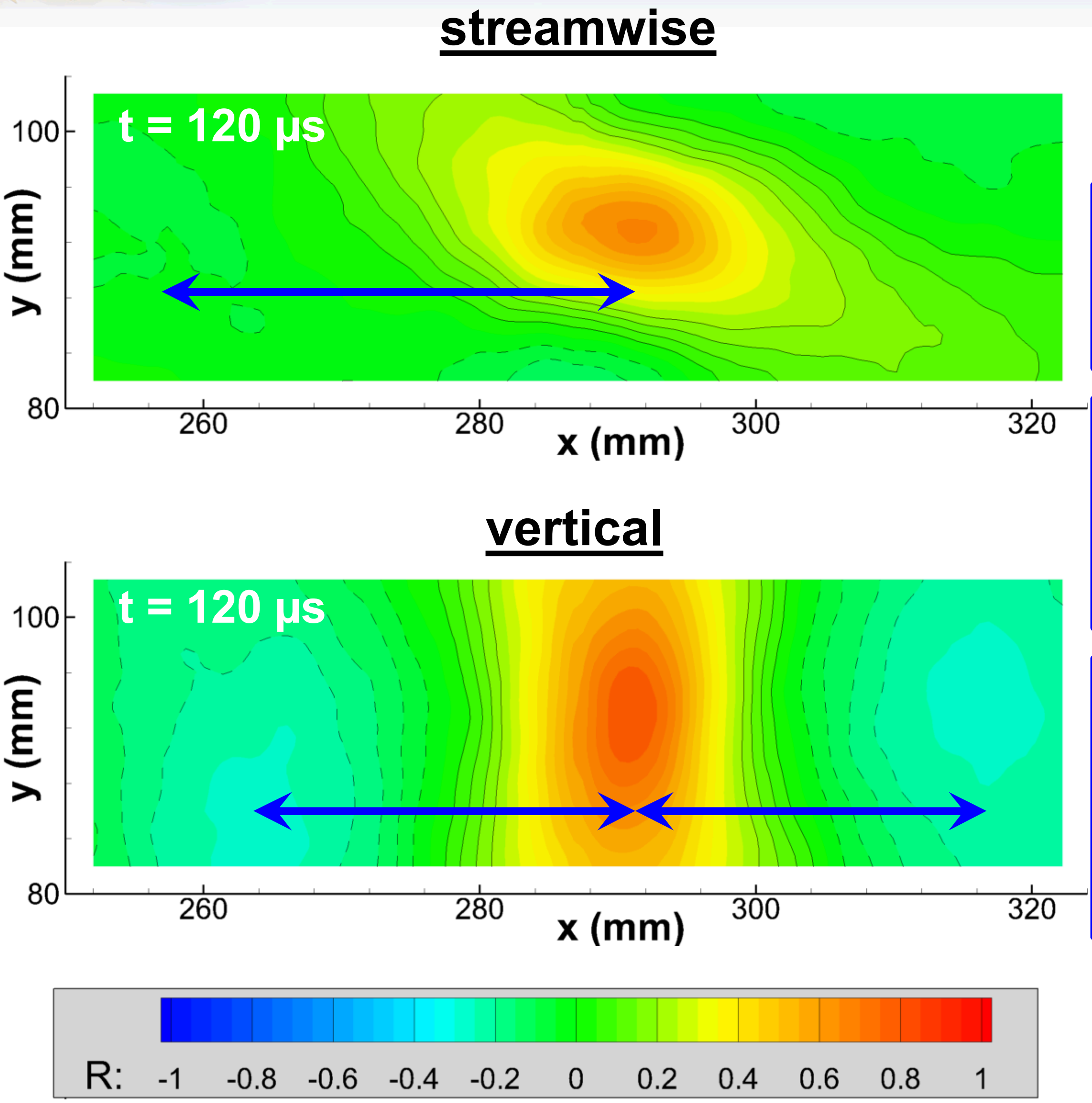


Therefore: Turbulent eddies tend to occur in pairs.
These pairs tend to convect at repeatable spacings.

Cross-Correlations of Time-Resolved Velocity



Anti-correlations at 20-30 mm.

- Shows repeatable spacing of eddies.

No sign of paired eddies at 8-10 mm.

- Due to distributed azimuthal orientation.

Strongest anti-correlation is only 0.25.

- Suggests repeatable spacing is inconsistent or may vary in position.

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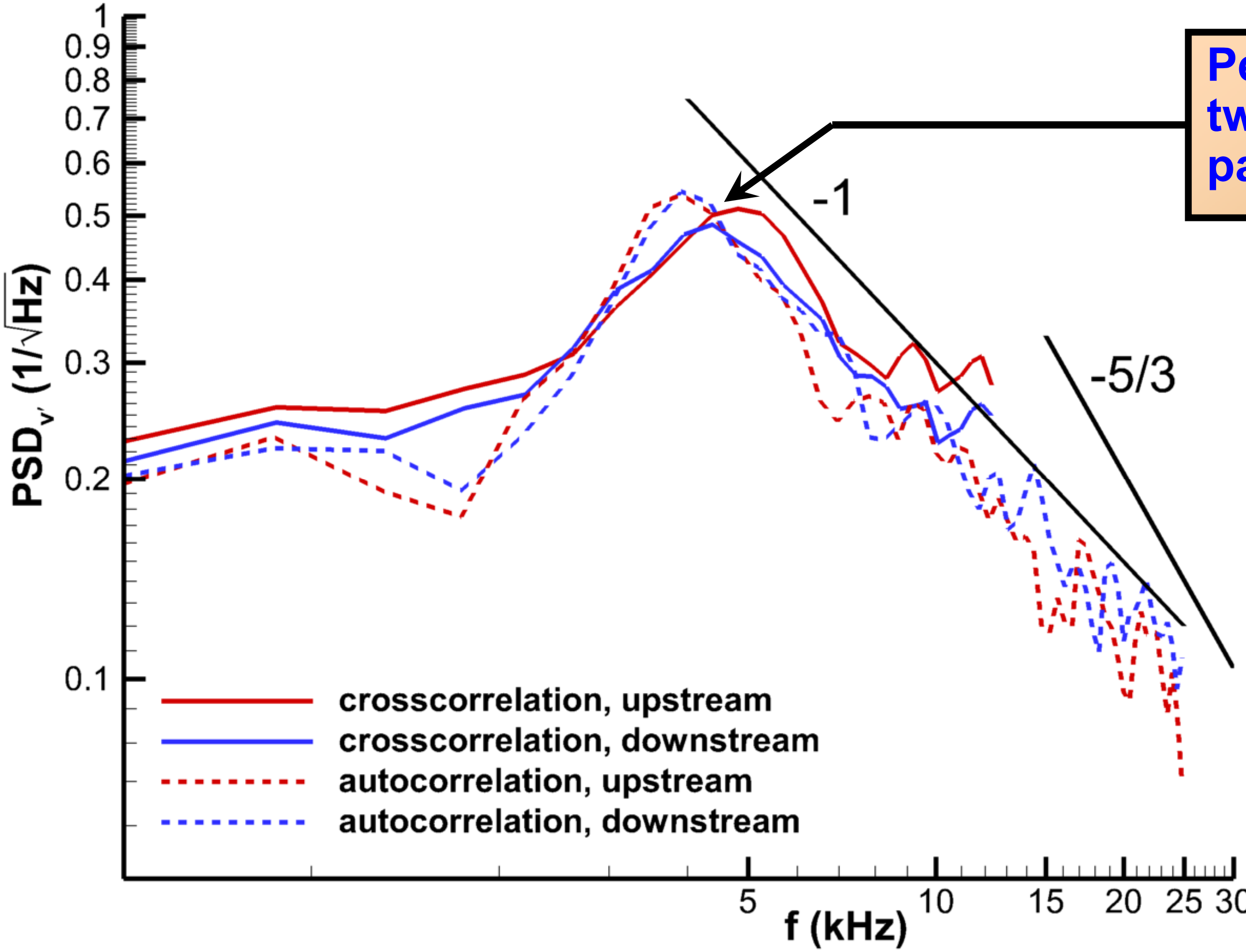
What else can we do with Pulse-Burst PIV?

Compute power spectra from the time signal of each vector.



Peak corresponds to about twice the spacing of eddy pairs.

Inertial subrange should show -5/3 slope.

- Does not begin until about 20-30 kHz.

But we do see an apparent "-1" power law.

- Historically elusive and controversial for velocity fields.
- Or is it a measurement artifact?

Assembled from 53 bursts of 25 kHz data, 25 bursts of 50 kHz data.

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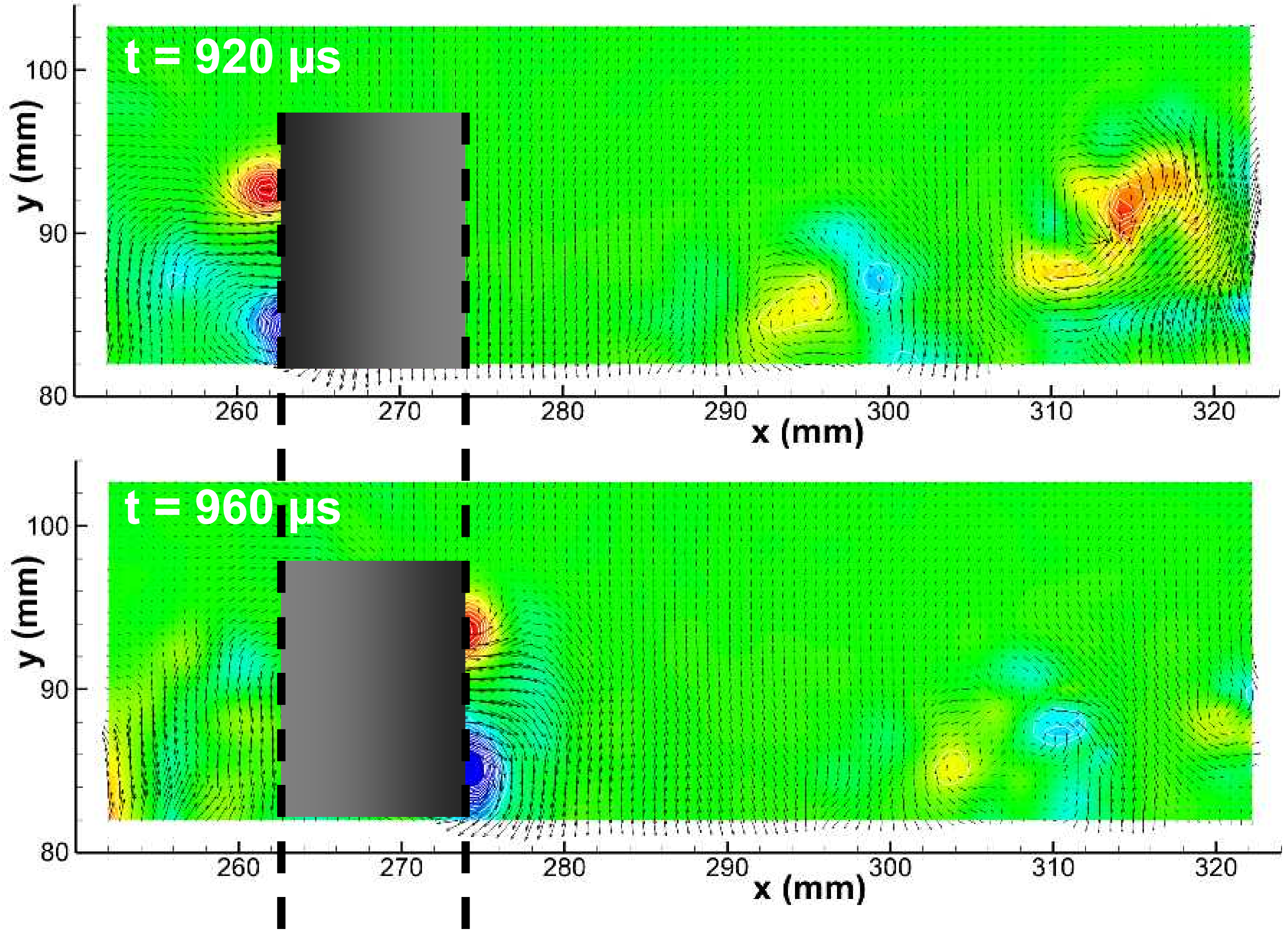
Velocity Supersampling

Use the supersampling algorithm of Scarano and Moore (2012).

"Pour space into time"

Between successive velocity fields, the flow convects by 16 vector spacings.

Use local convection velocity and Taylor's hypothesis to convert the intervening 15 vectors from space to time.



Follow the local streamlines

Interpolate into new intervening vector fields

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Velocity Supersampling Power Spectrum

This will extend the power spectrum to much higher frequencies.

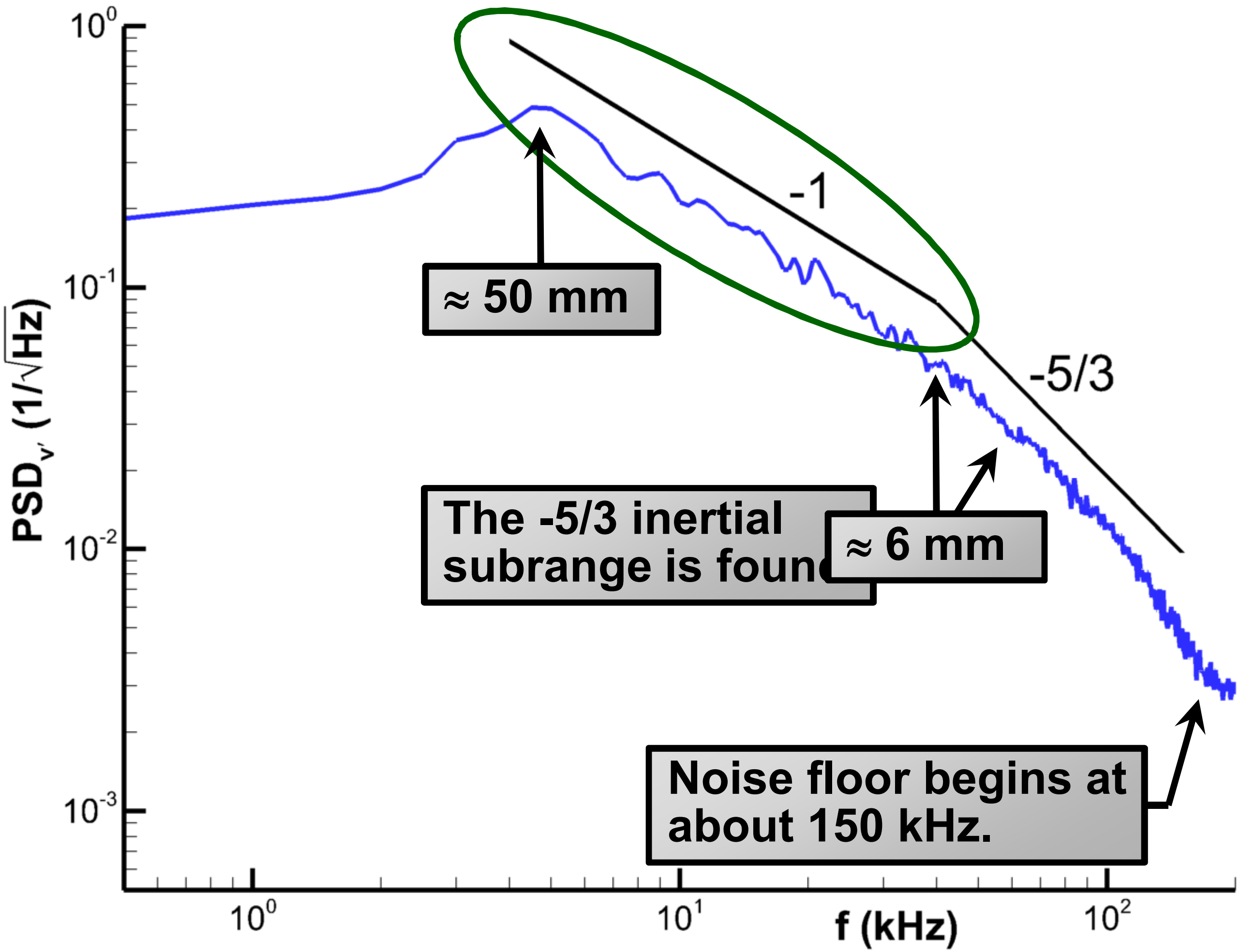
The -1 region is substantiated.

- **Lasts for one full decade.**
- **Any remaining aliasing or denoising effects ≥ 100 kHz.**

Scales of the -1 regime:

- **Pope predicts inertial subrange starts at Λ/6 = 40 kHz ≈ 6 mm.**
- **PIV spatial resolution is about 1 mm.**

Corresponds to the dominant turbulent eddies measured by PIV.



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What's next in the wind tunnel?

Data up to Mach 2.5.

- **Started working on this last summer.**

Add more cameras!

- **Boost the framing rate without sacrificing spatial resolution.**

Application to other flowfields:

- **Transonic cavity, hemisphere wake, supersonic boundary layer.**

Pulse-burst lasers make TR-PIV feasible for high-speed flows.

- ***This is the first application of Pulse-Burst PIV to a ground test facility.***

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