National Aeronautics and Space Administration

Fundamental Aeronautics Program

Subsonic Rotary Wing Project

PIV Measurements of Full-Scale UH-60A Tip Vortices

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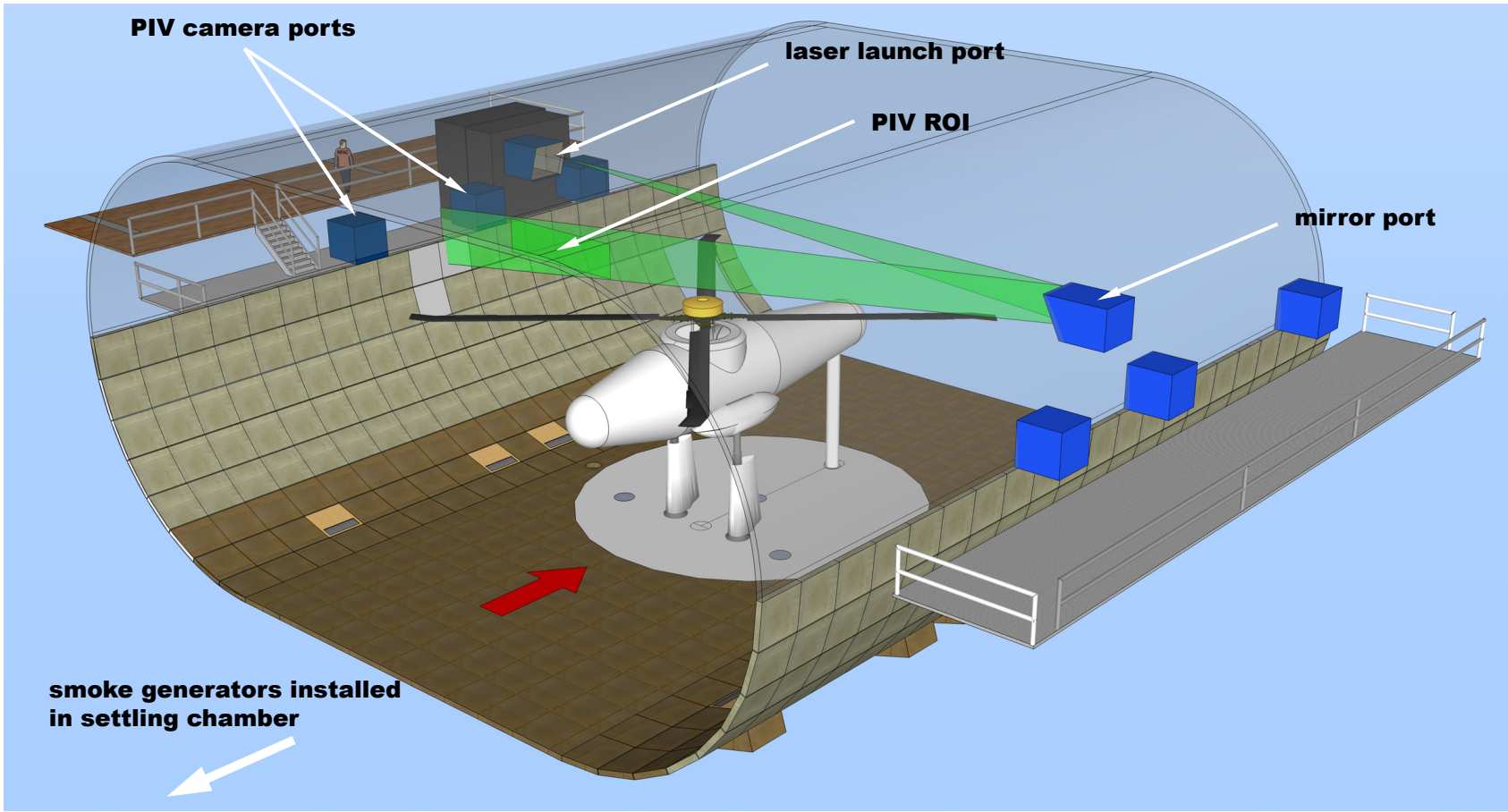
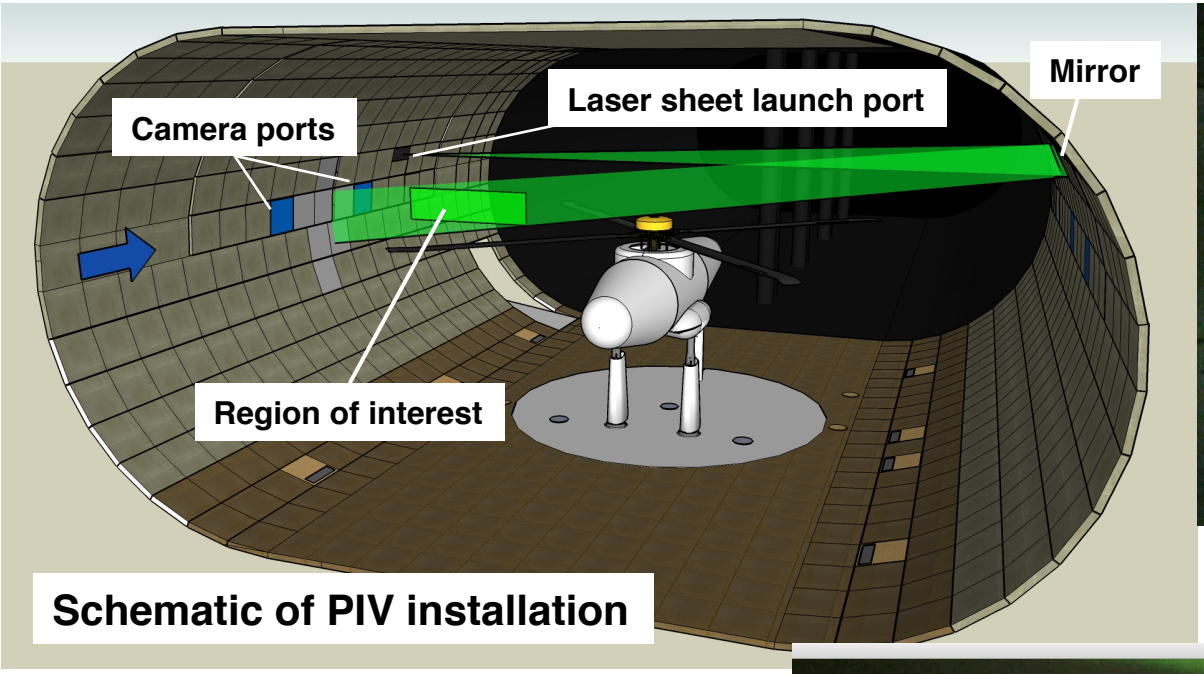
Outline

- Description of experiment
  - Installation
  - PIV Measurements
  - Test conditions
- Status of data processing
- Preliminary results
- Plans

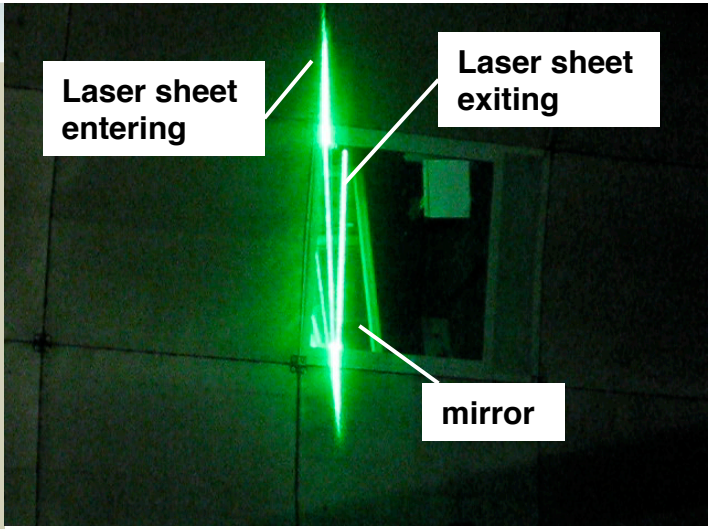
Sketch of PIV System Installation



Ref.: Wadcock, A. J., Yamauchi, G. K., Solis, E., and Pete, A. E., "PIV Measurements in the Wake of a Full-Scale Rotor in Forward Flight," AIAA paper 2011-370, 29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 2011.

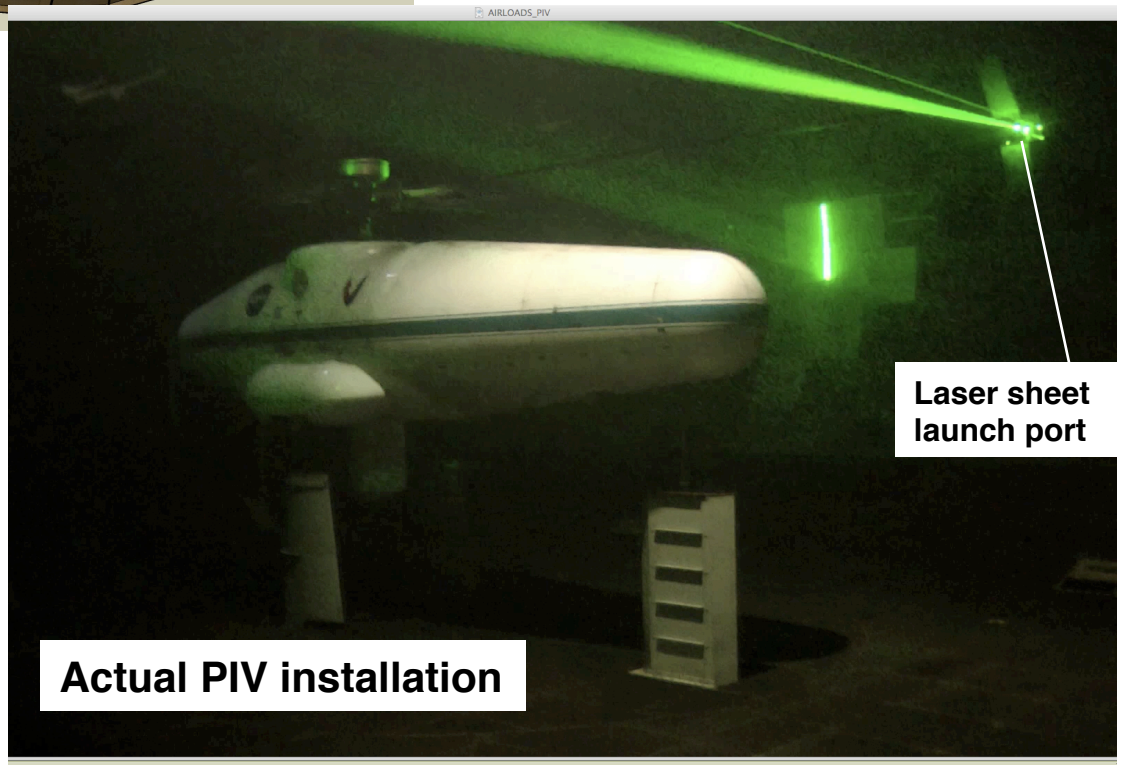


Schematic of PIV installation



System Components

- Two TSI 11 Mp cameras with 120 mm lens
- Spectra-Physics PIV laser, ~260 mJ per pulse@ 532 nm
- Four MDG seeders emitting 0.75 micron particles
- Remotely-controlled (2 axes) mirror (36 in x 12 in, H x W)
- 4-ft x 8-ft dual plane calibration plate
- Software
  - INSIGHT 3G™ (TSI, Inc.)
  - proVISION™ (IDT, Inc.)



Actual PIV installation

PIV Measurements

- 3D velocity field in a stationary cross-flow plane
  - Location: approximately 90 degree rotor blade azimuth
  - Coverage: outer 50% of the rotor radius
  - Field of View: approximately 3.5 ft-high by 14 ft-wide

- From the velocity field, we will extract
  - Blade tip vortex position and trajectory in laser sheet
  - Blade trailed wake position and trajectory in laser sheet
  - Tip vortex core size
  - Vortex strength and vortex structure

PIV Test Conditions

NFAC Run No.	Rotor Shaft Angle (deg)	Tip Mach Number	Advance Ratio	C_T/σ	Azimuth delay (deg)
73	0	0.65	0.15	0.08	5, 15, 30, 45, 60,75, 95, 135, 185, 225, 275, 315
75	4	0.65	0.15	0.08	5, 15, 30, 45, 60, 75, 95, 135, 185, 225, 275, 315
78*	-4.82	0.638	0.303	0.087	5, 15, 30, 45, 60, 75, 95
81	0	0.65	0.24	0.07, 0.09	5
81	0	0.65	0.24	0.11	5, 15, 30, 45, 60, 75, 95, 185, 275
83	0	0.65	0.15	0.07, 0.09, 0.11, 0.12	15
83	-6.9	0.65	0.35	0.08	5, 10, 15, 20, 30, 45, 60, 75, 95, 185, 275

***Corresponds to flight test counter 8424**

Status of Data Processing

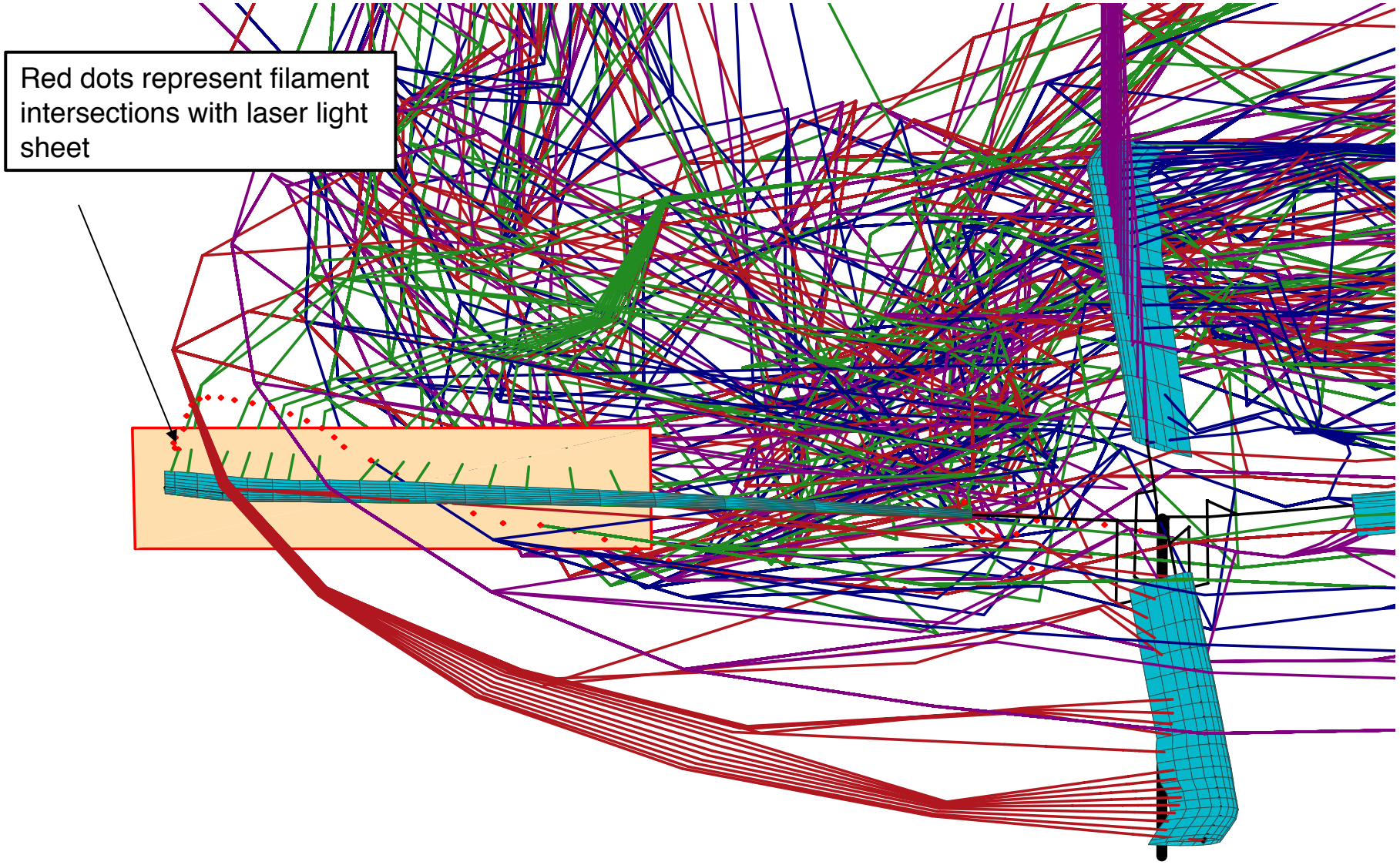
• Processed images (using LaVision DaVis software) from Run 73 correcting for laser sheet movement

• Extracted vortices from each instantaneous velocity field
  -If a vortex is within approximately 10 core diameters of another vortex, then both vortices are extracted in the same sub-region
  -Two-three vortices are typically extracted per field

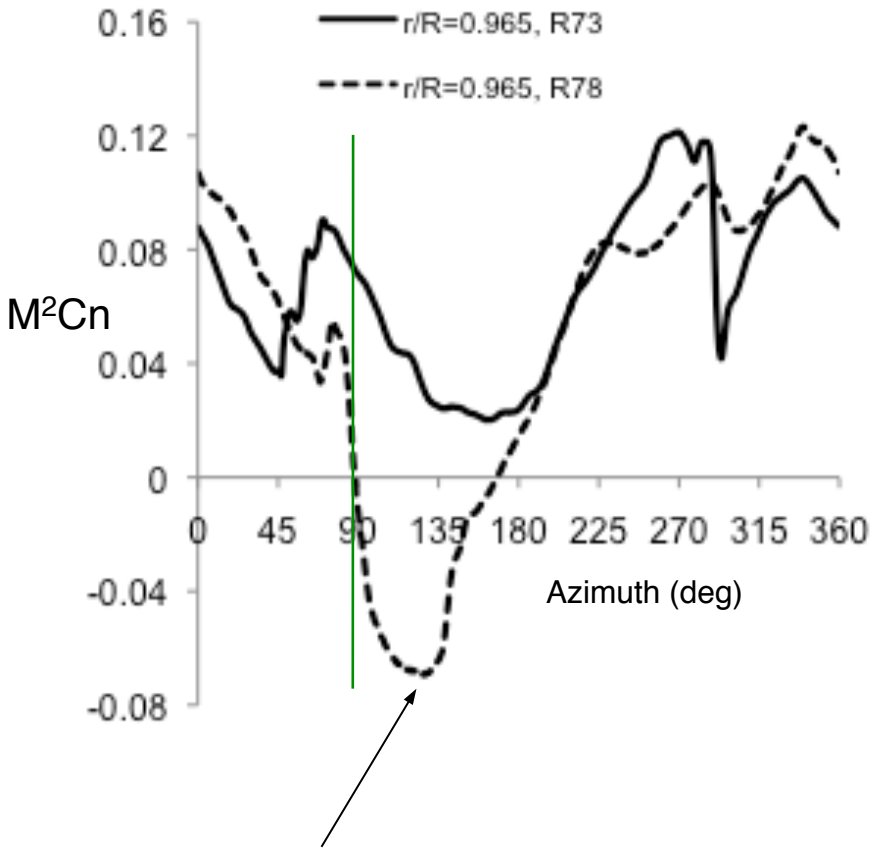
• Used the method developed by Ramasamy (2011) and Bhagwat (2011) to determine vortex characteristics (location, core size, circulation, and filament angles relative to laser sheet)
  - planar fit of instantaneous velocity field to an assumed vortex model
  - typically, one or two vortices are simultaneously modeled
  - shear layer is currently not modeled

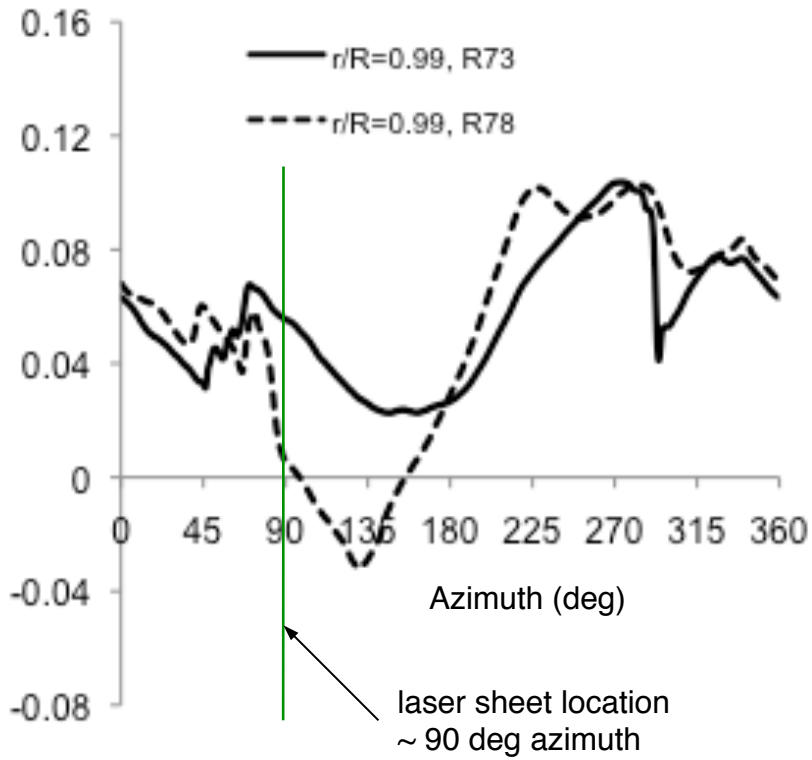
• Compared vortex location and circulation with CAMRAD II calculations

CAMRAD II tip vortex trajectory calculations for Run 73



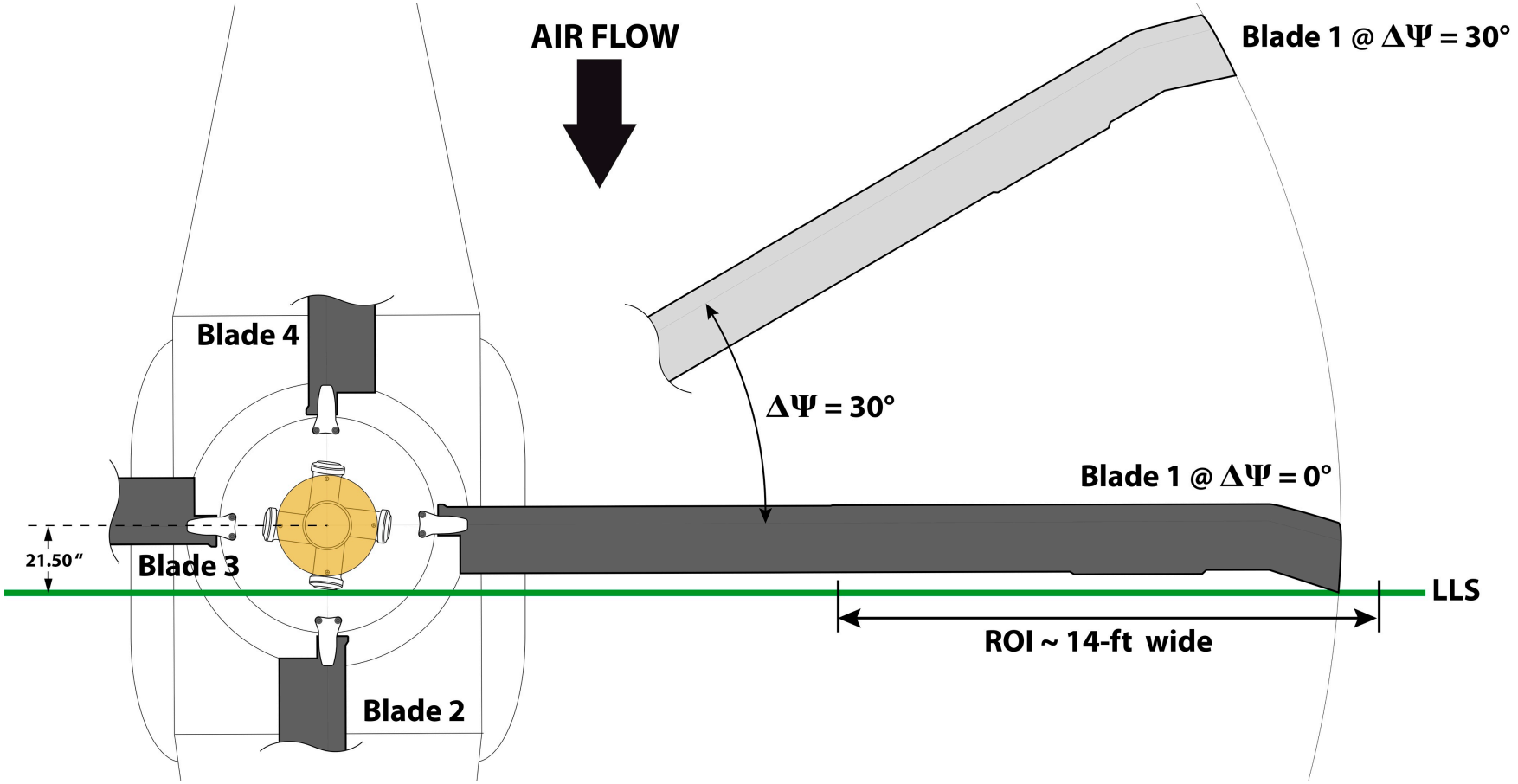
Runs 73 and 78: Blade loading





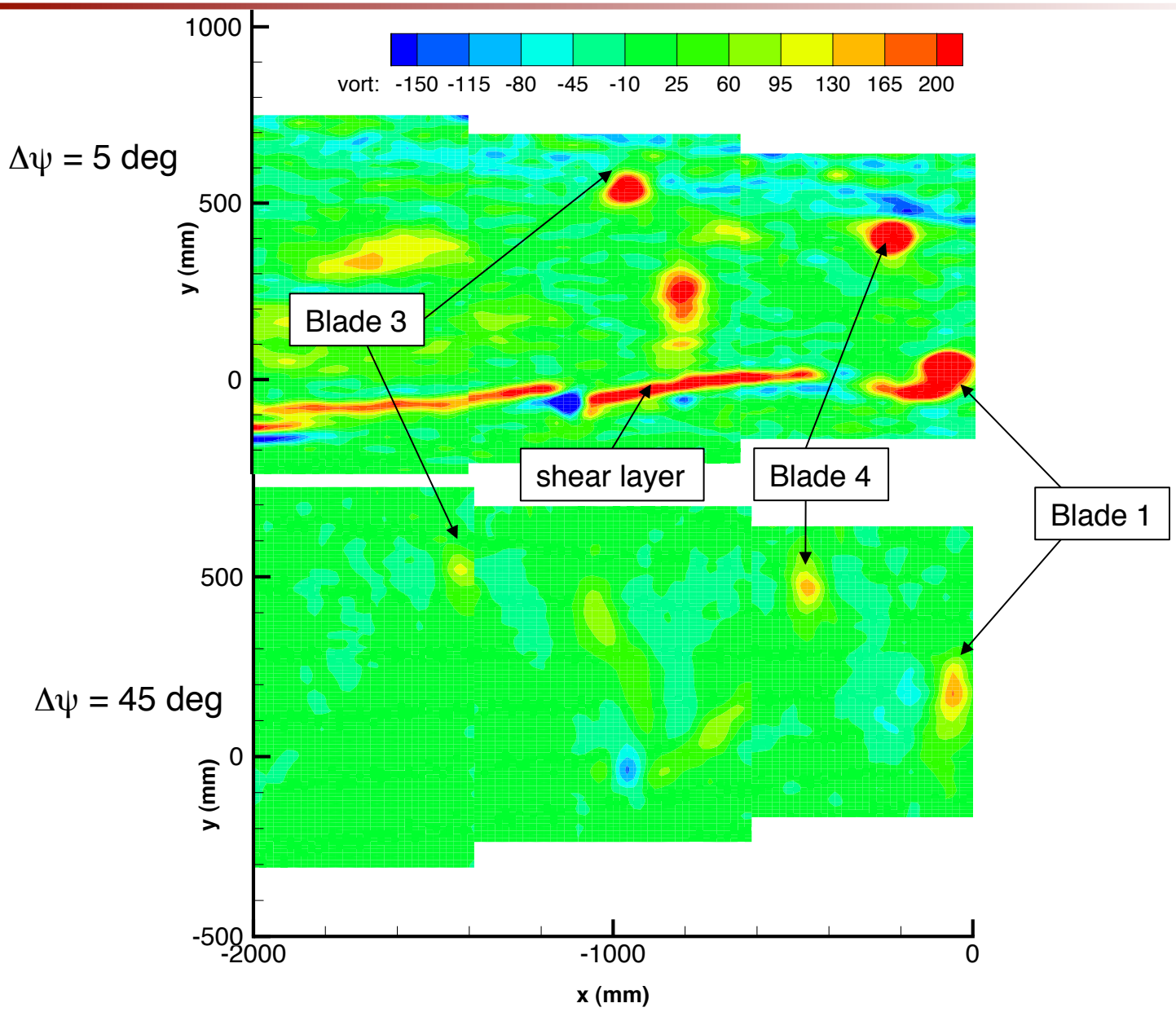
Negative loading at blade tip for Run 78 will generate tip vortices of opposite sign compared to Run 73

Blade Position for PIV Measurements



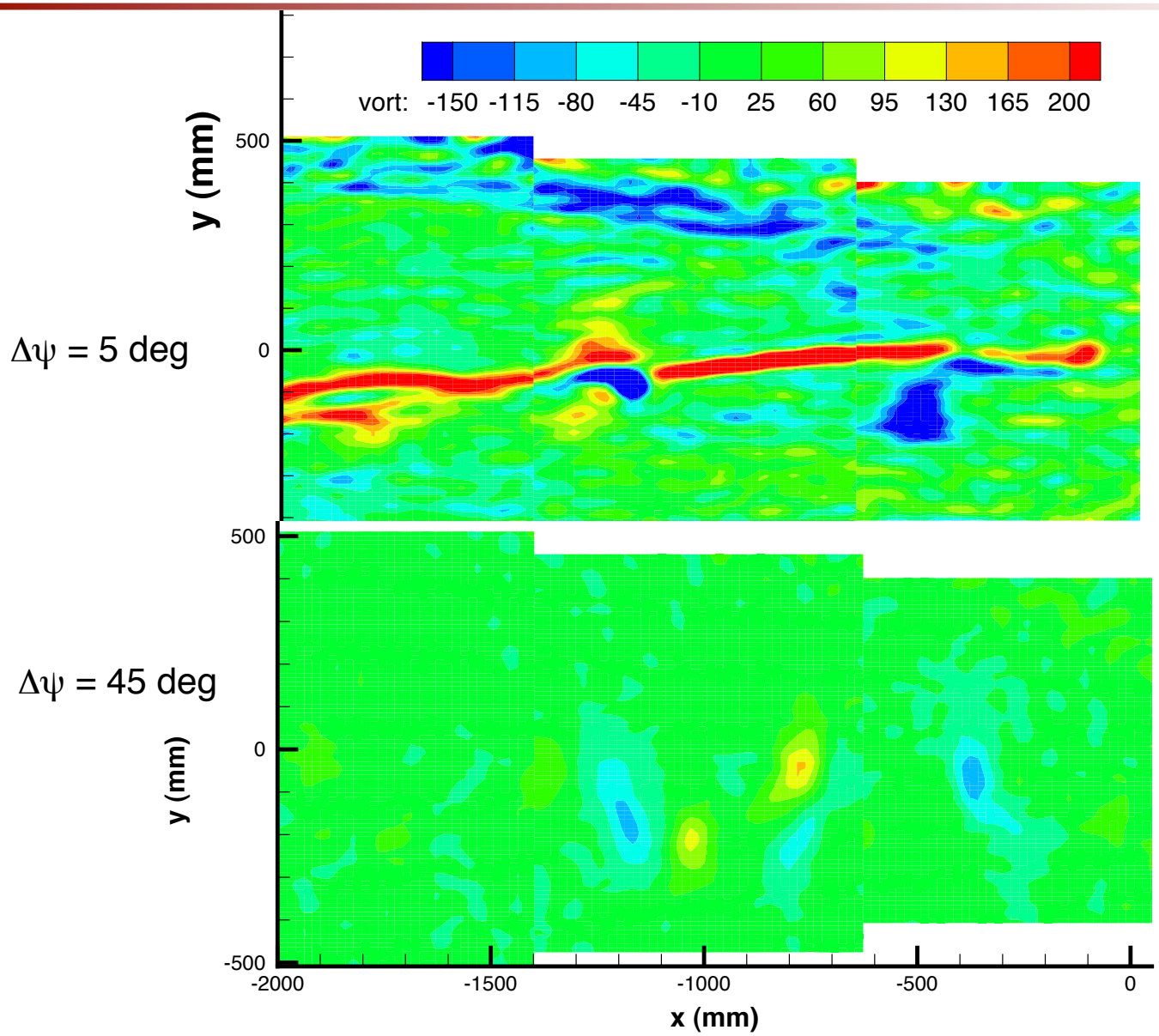
Preliminary Results: Vorticity Field for Run 73

C_T/σ = 0.080, μ = 0.150, α_{shaft} = 0 deg, Mtip = 0.6 (view looking upstream)



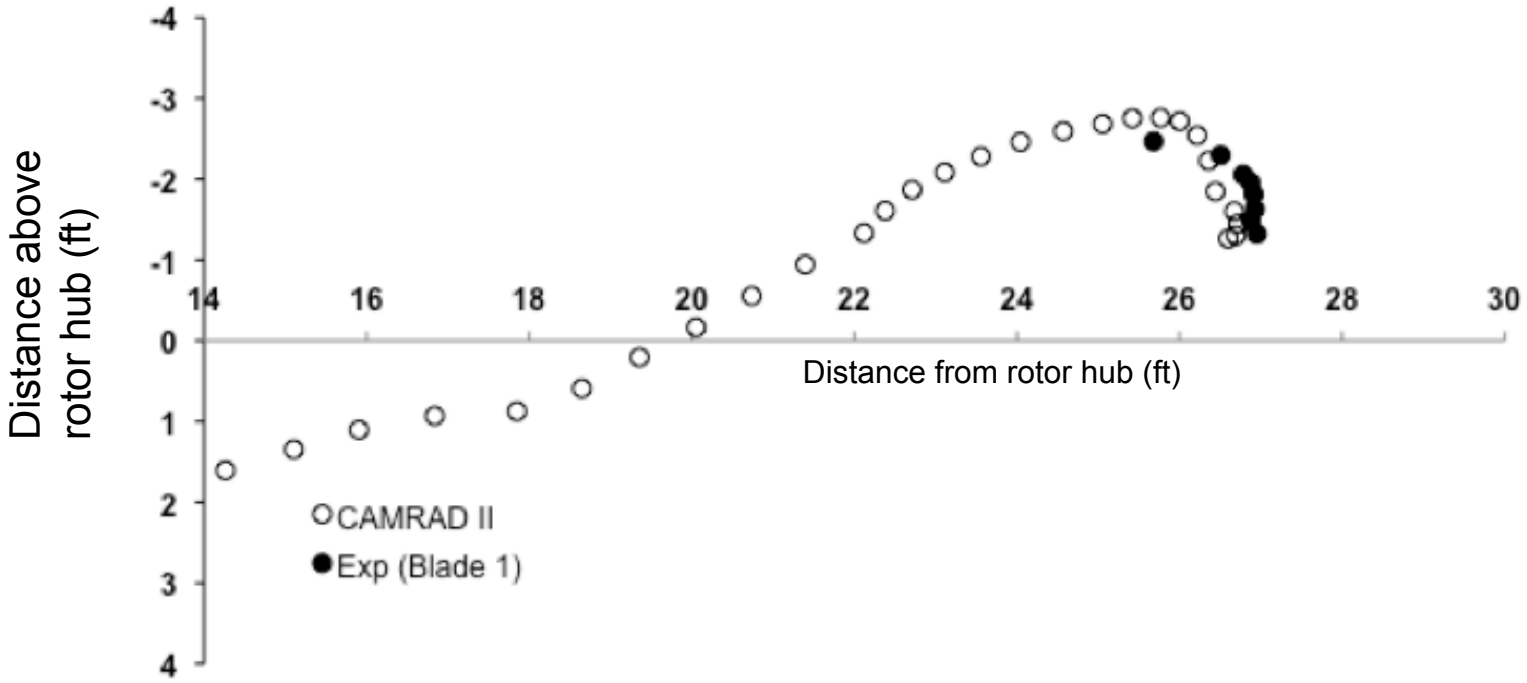
Preliminary Results: Vorticity Field for Run 78

$C_T/\sigma = 0.087$, $\mu = 0.303$, $\alpha_{shaft} = -4.82$ deg, Mtip = 0.638 (view looking upstream)



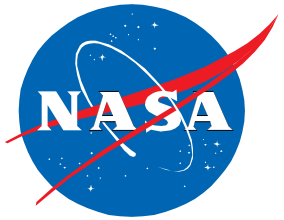
Preliminary Results: Comparison of predicted and measured vortex trajectory

Run 73: $C_T/\sigma = 0.080$, $\mu = 0.150$, $\alpha_{shaft} = 0$ deg, Mtip = 0.65, $\Delta\psi = 30$ deg



Plans

- Process images from remaining test conditions
- Automate a method for extracting sub-regions from overall velocity field
- Expand planar fit analysis to include model of shear layer and convection velocity gradient
- Evaluate other vortex models for planar fit analysis
- Study mutual interference of multiple vortices
- Compare results with CFD simulations
- Present paper: “Wind Tunnel Measurements of Full-Scale UH-60A Rotor Tip Vortices,” G. Yamauchi, A. Wadcock, W. Johnson, and M. Ramasamy, AHS 68th Annual Forum, Ft. Worth, TX, May 1-3, 2012.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