



Fundamental Aeronautics Program

Subsonic Rotary Wing Project

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

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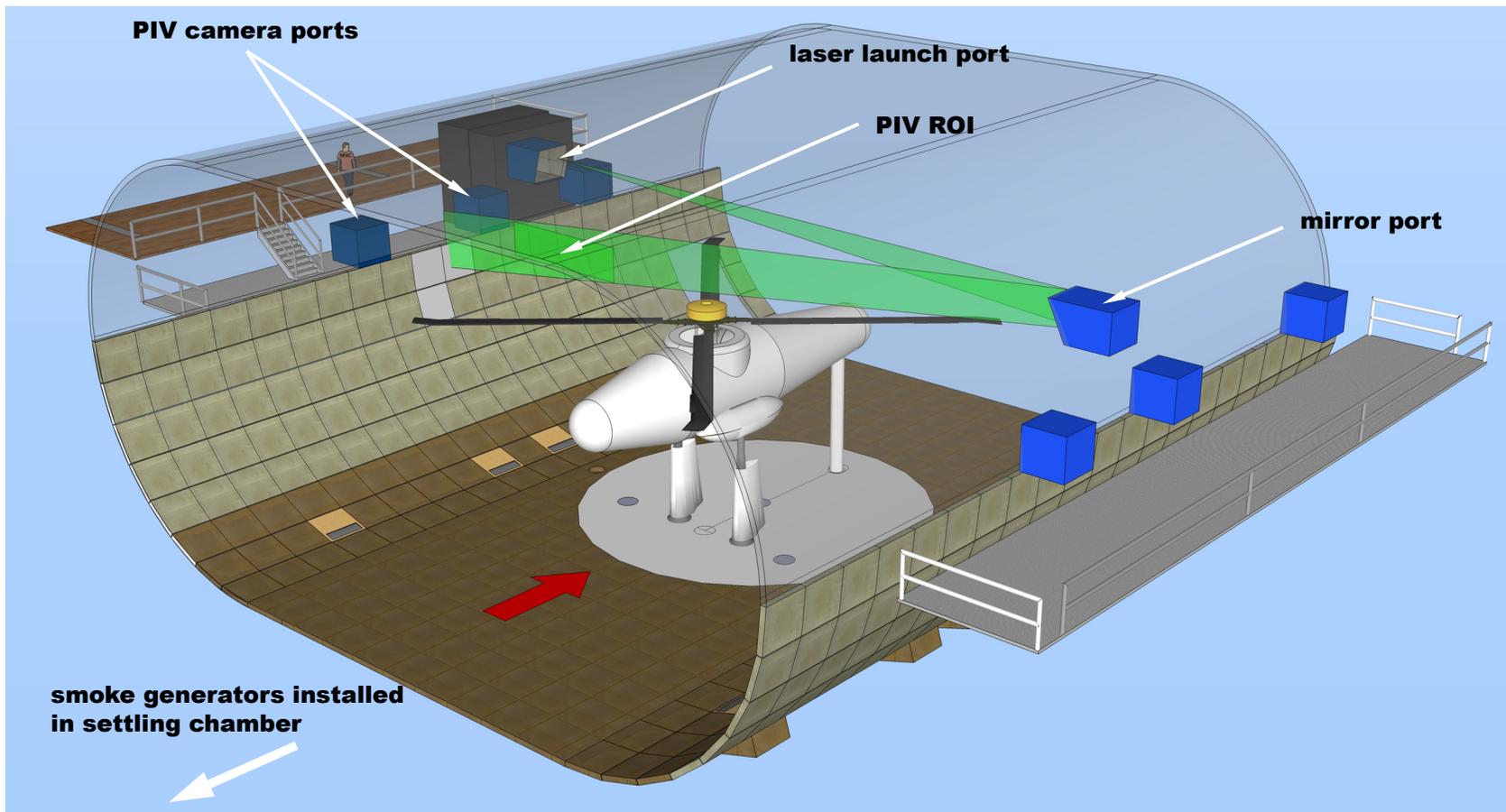
Outline



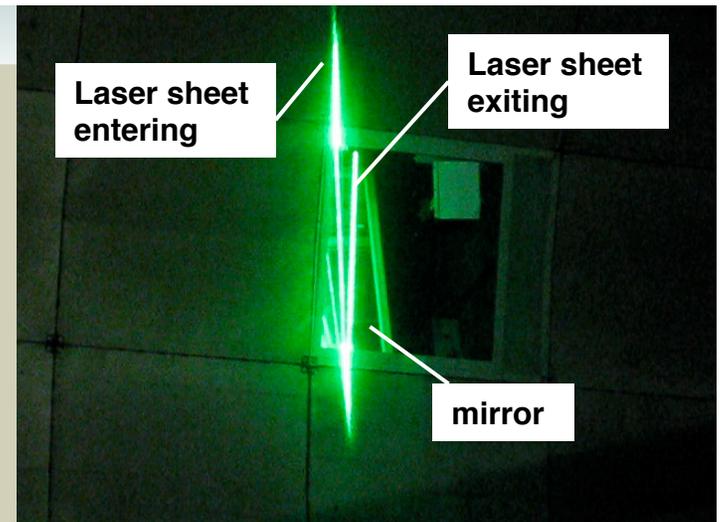
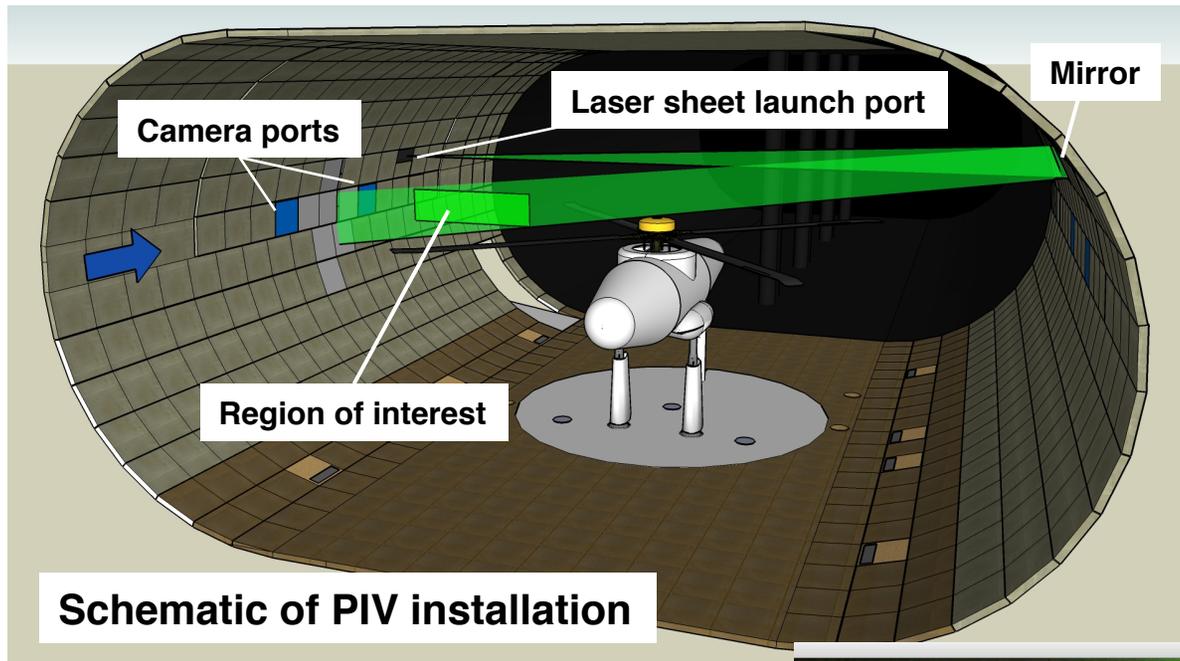
- Description of experiment
 - Installation
 - PIV Measurements
 - Test conditions
- Status of data processing
- Preliminary results
- Plans



Sketch of PIV System Installation

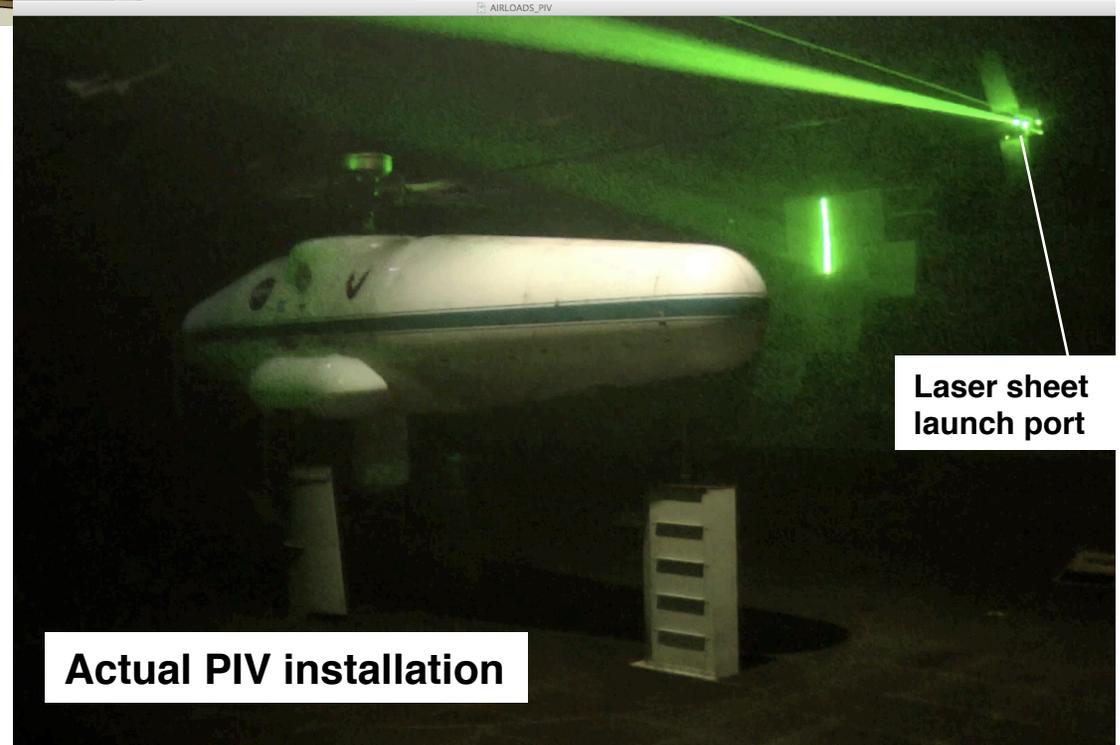


Ref.: Wadcock, A. J., Yamauchi, G. K., Solis, E., and Pete, A. E., "PIV Measurements in the Wake of a Full-Scale Rotor in Forward Flight," AIAA paper 2011-370, 29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 2011.



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.)



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**



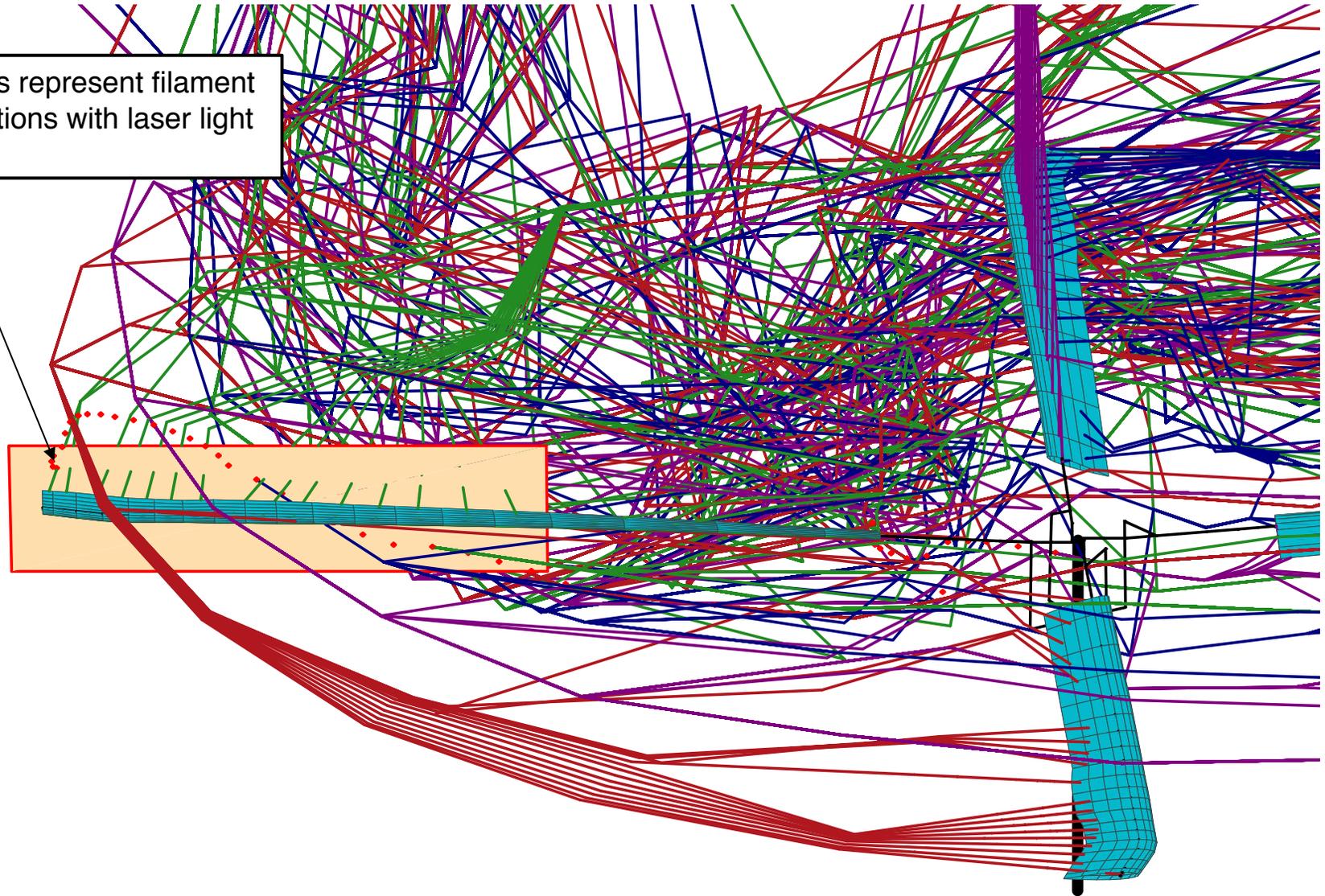
Status of Data Processing

- 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



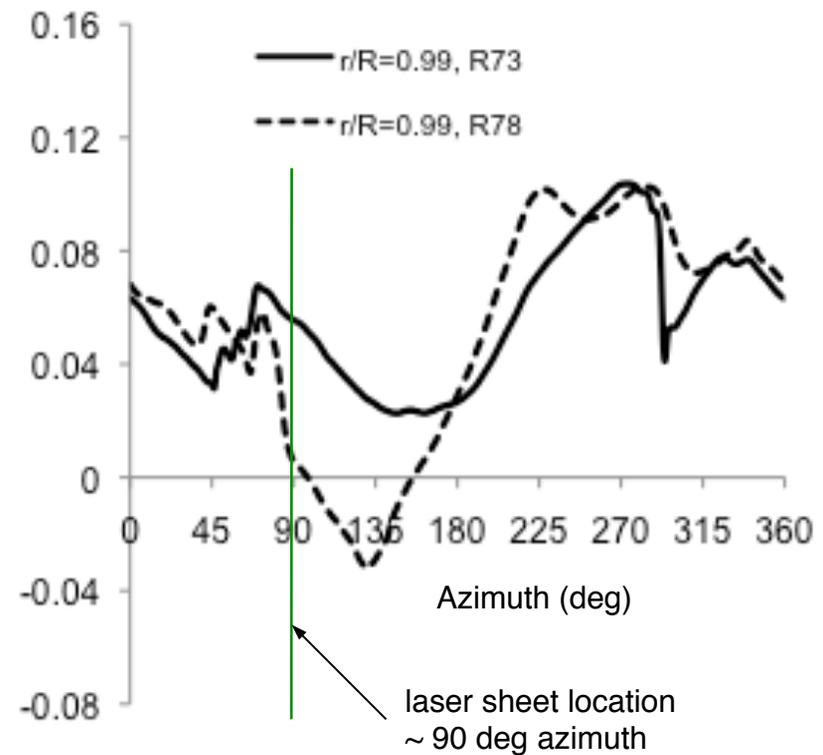
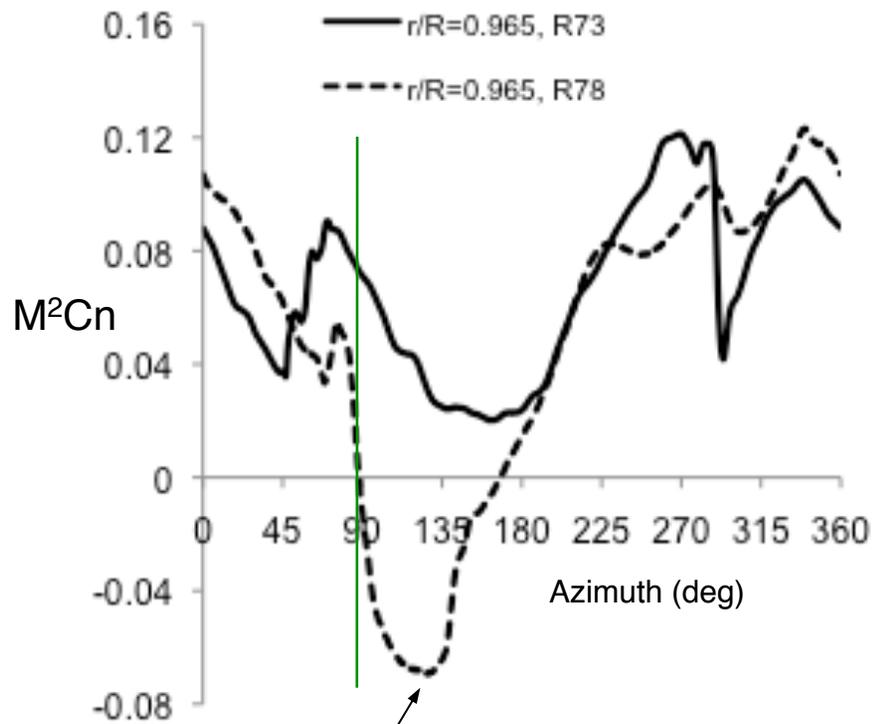
CAMRAD II tip vortex trajectory calculations for Run 73

Red dots represent filament intersections with laser light sheet



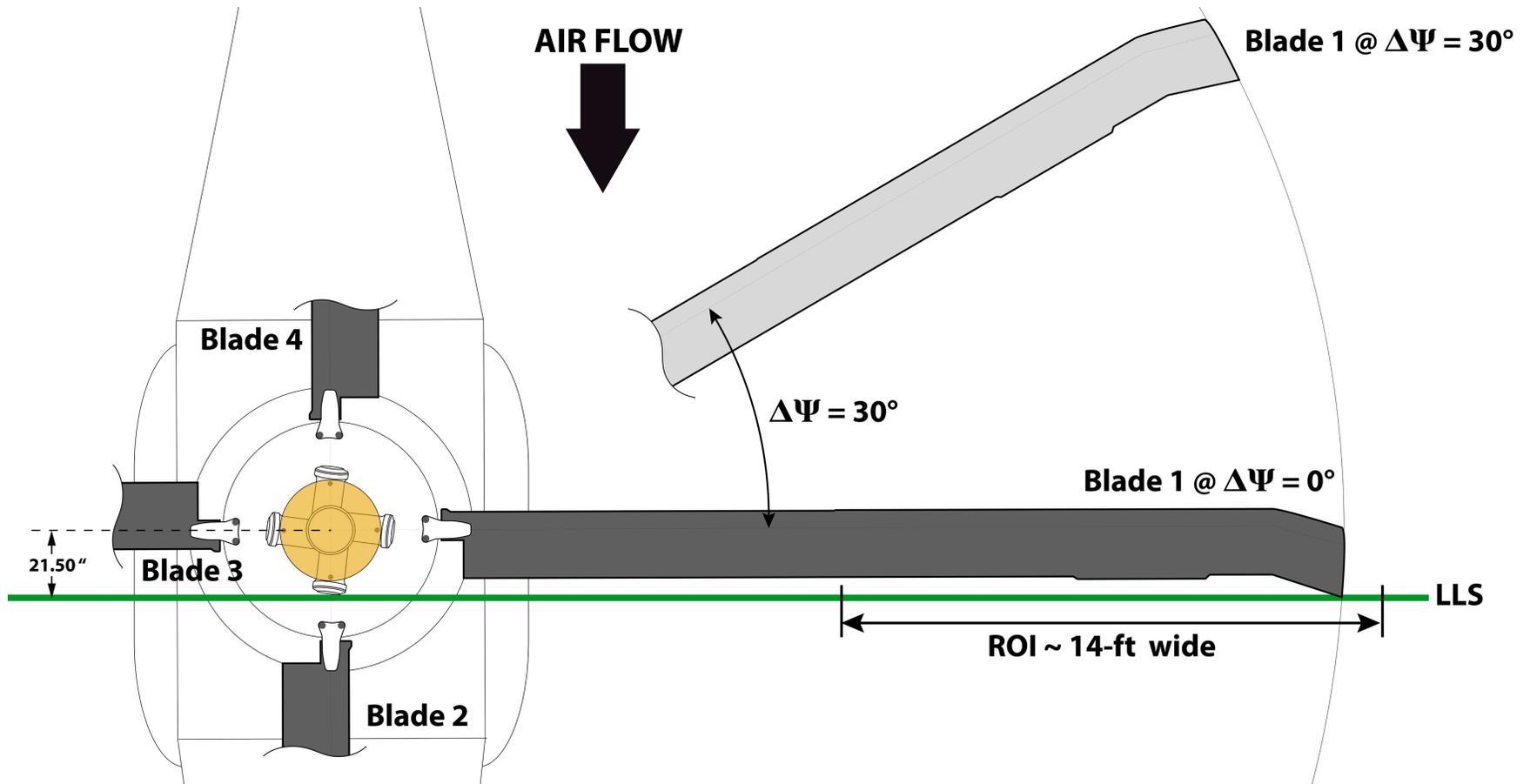


Runs 73 and 78: Blade loading



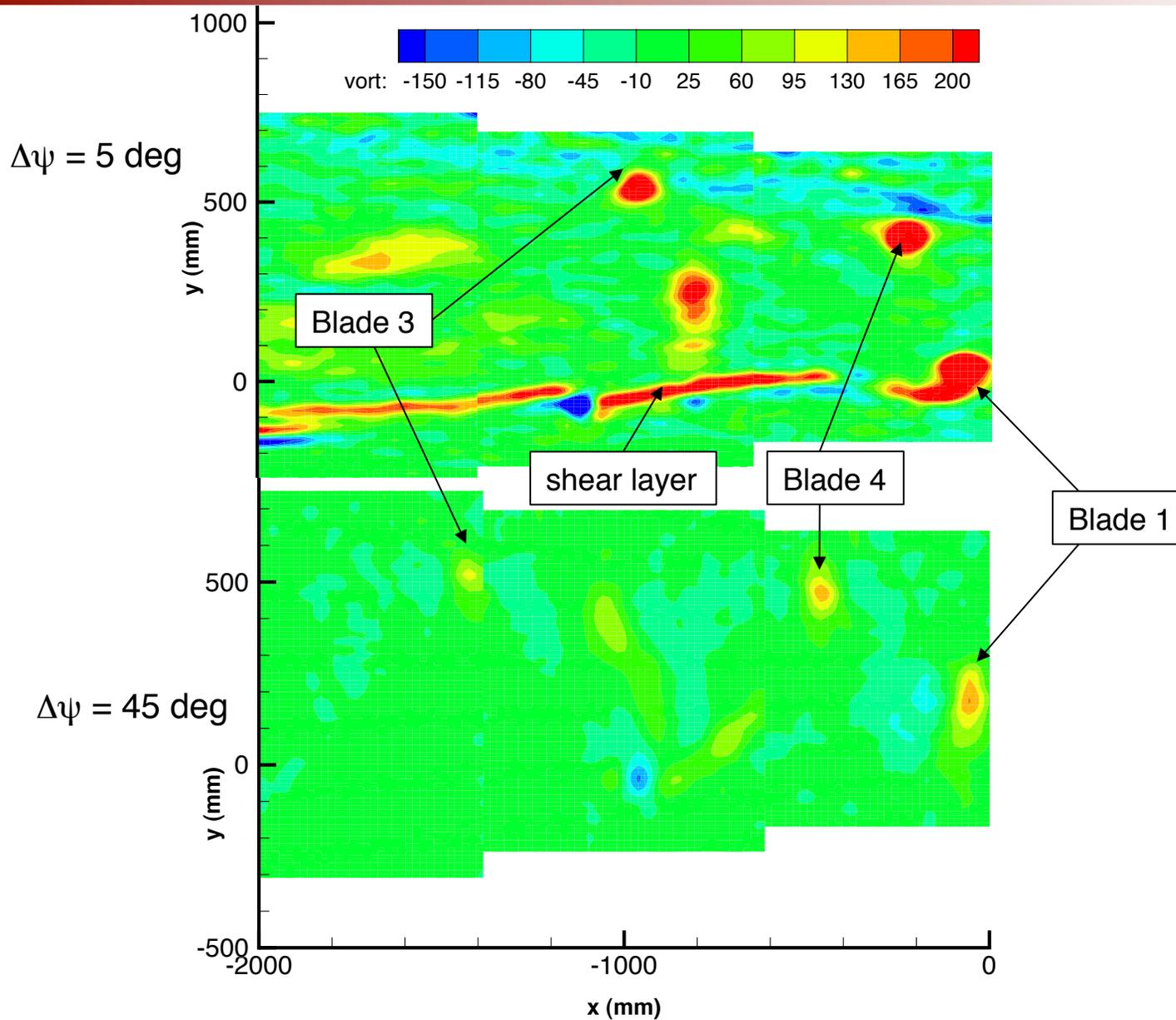
Negative loading at blade tip for Run 78 will generate tip vortices of opposite sign compared to Run 73

Blade Position for PIV Measurements



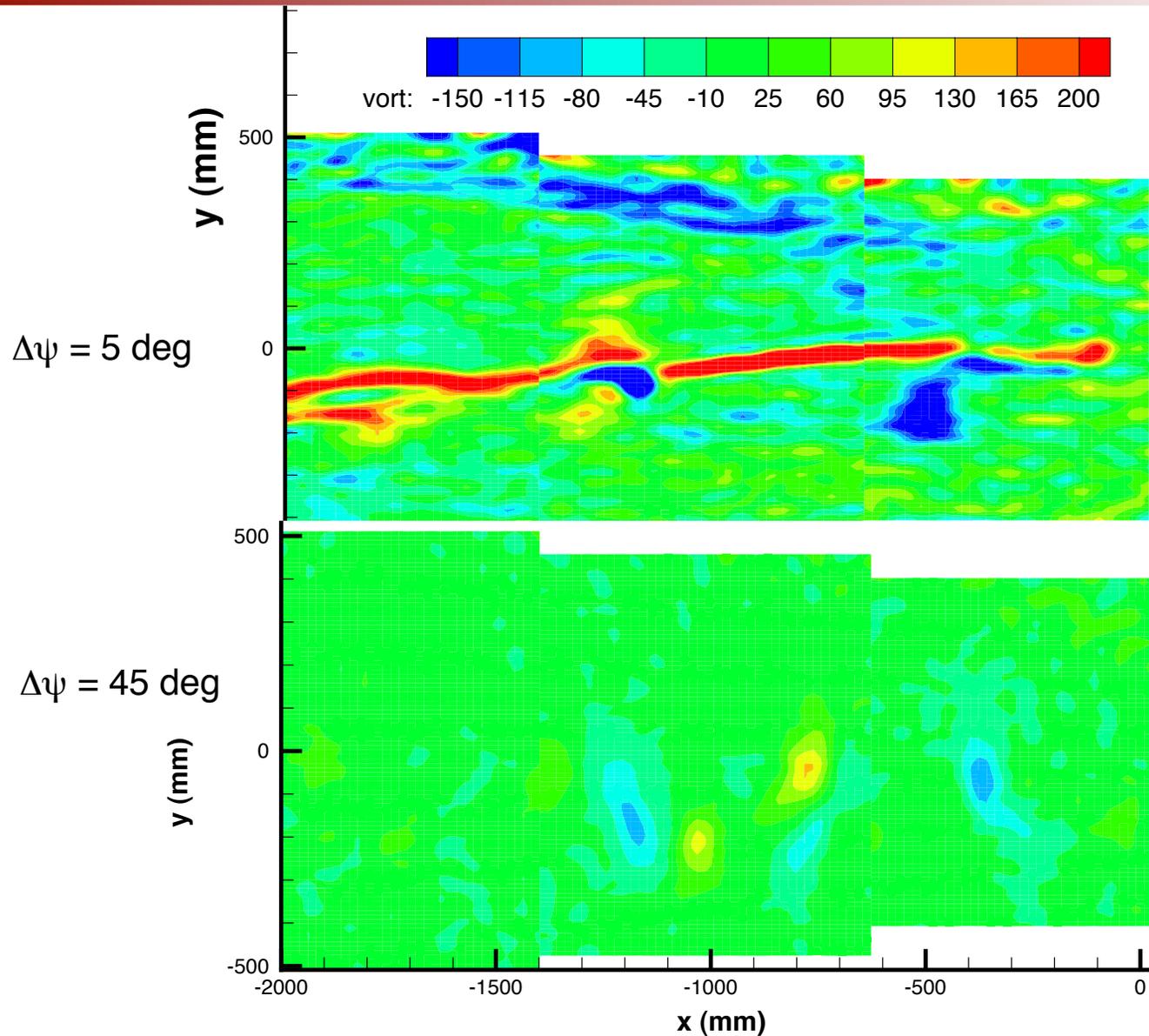
Preliminary Results: Vorticity Field for Run 73

$C_T/\sigma = 0.080$, $\mu = 0.150$, $\alpha_{\text{shaft}} = 0$ deg, $M_{\text{tip}} = 0.6$ (view looking upstream)



Preliminary Results: Vorticity Field for Run 78

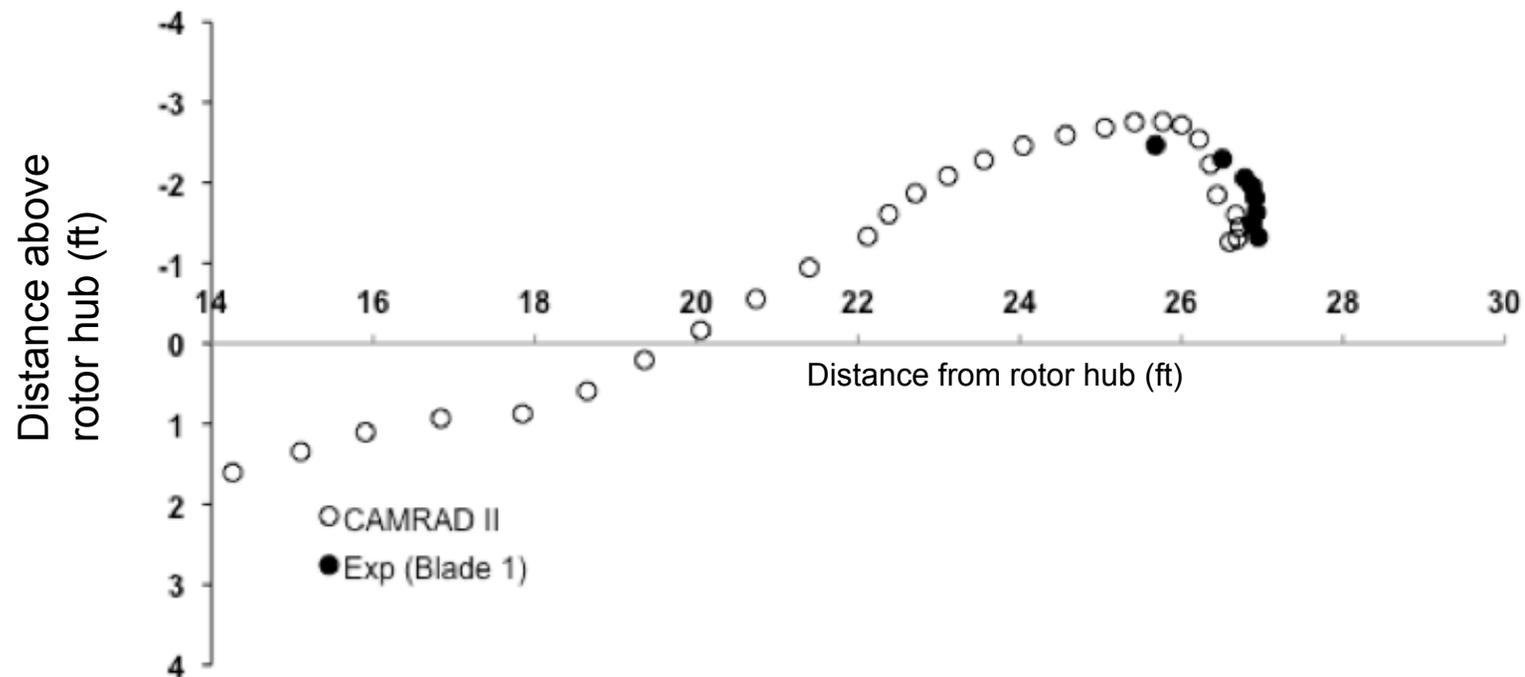
$C_T/\sigma = 0.087$, $\mu = 0.303$, $\alpha_{\text{shaft}} = -4.82$ deg, $M_{\text{tip}} = 0.638$ (view looking upstream)



Preliminary Results: Comparison of predicted and measured vortex trajectory



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

