



Fundamental Aeronautics Program

Subsonic Rotary Wing Project

Overview of the Experimental Capabilities Discipline and UH-60 Particle Image Velocimetry Measurements

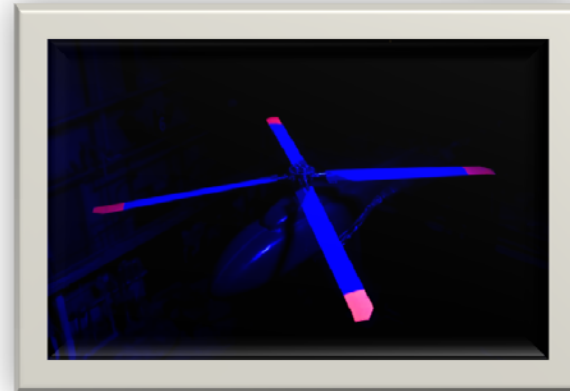
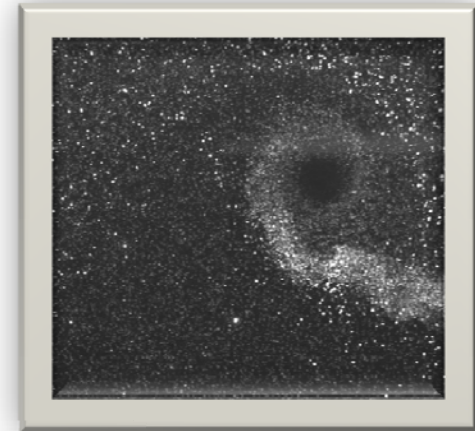
Luther N. Jenkins
Technical Lead
Experimental Capabilities Discipline



2011 Technical Conference
March 15-17, 2011
Cleveland, OH

Areas of Research & Application

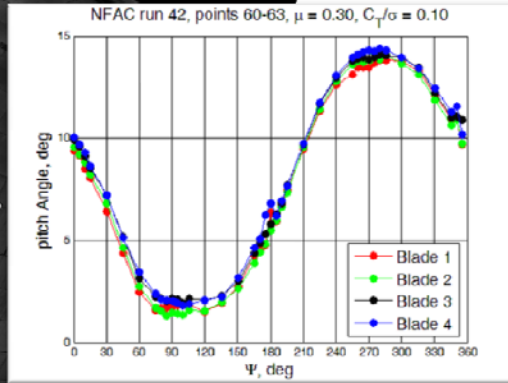
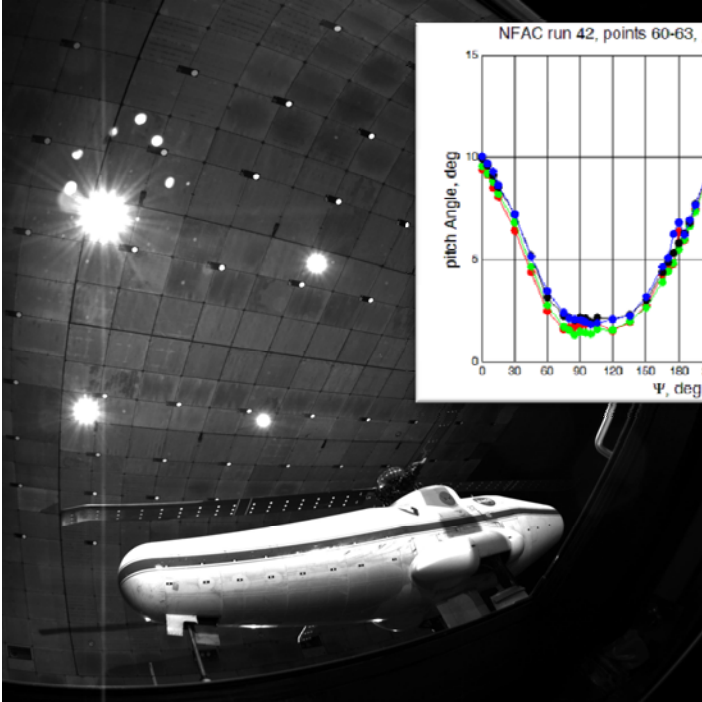
- **Rotor Blade Position Measurement**
 - Photogrammetry
 - Projection Moire Interferometry (PMI)
 - On-hub Video Systems
- **Rotor Wake Measurements**
 - Particle Image Velocimetry (PIV)
 - Retro-Reflective Background-Oriented Schlieren (RBOS)
 - Laser Velocimetry (LV)
- **Surface Pressure Measurements**
 - Pressure Sensitive Paint (PSP)
 - Shear stress sensors
- **Advanced Measurement Tools**



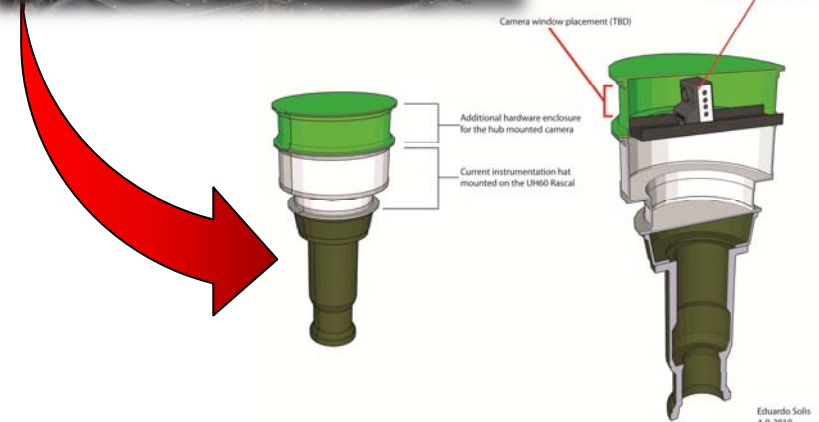
Rotor Blade Position Measurement



Photogrammetry

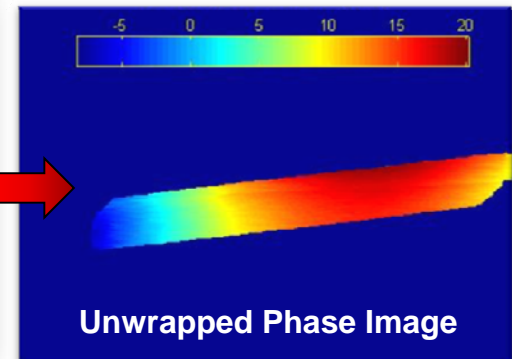
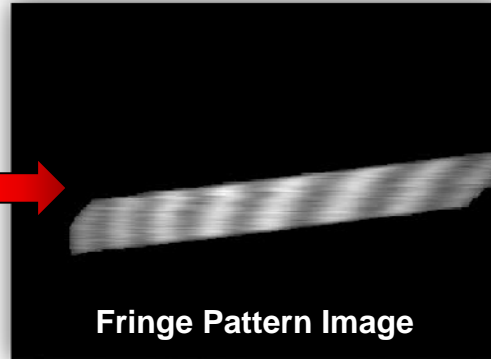
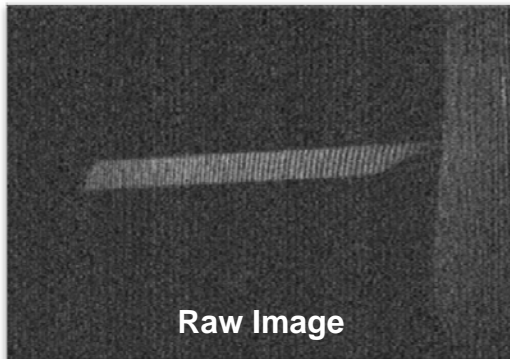


Hub-Mounted Video System



Eduardo Solis
4-9-2010

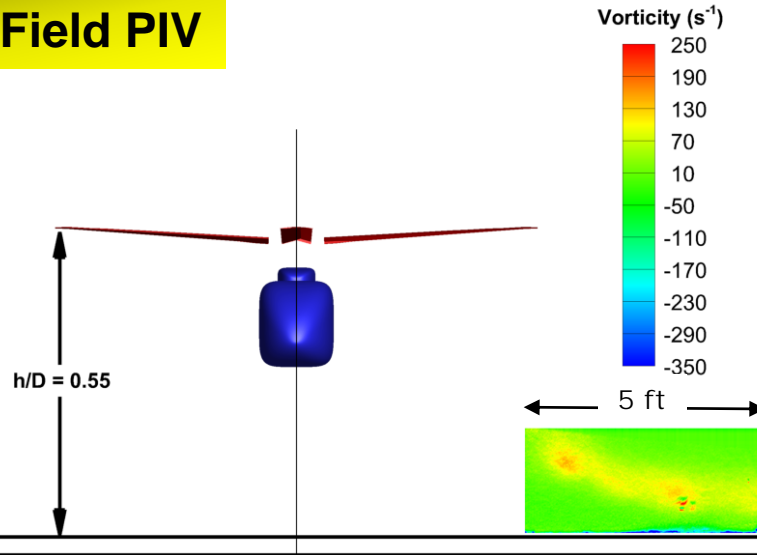
PMI



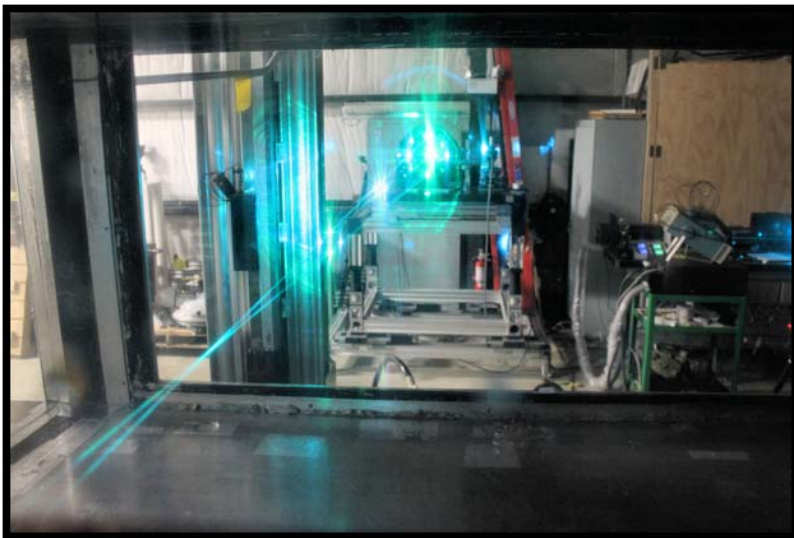
Rotor Wake Measurements



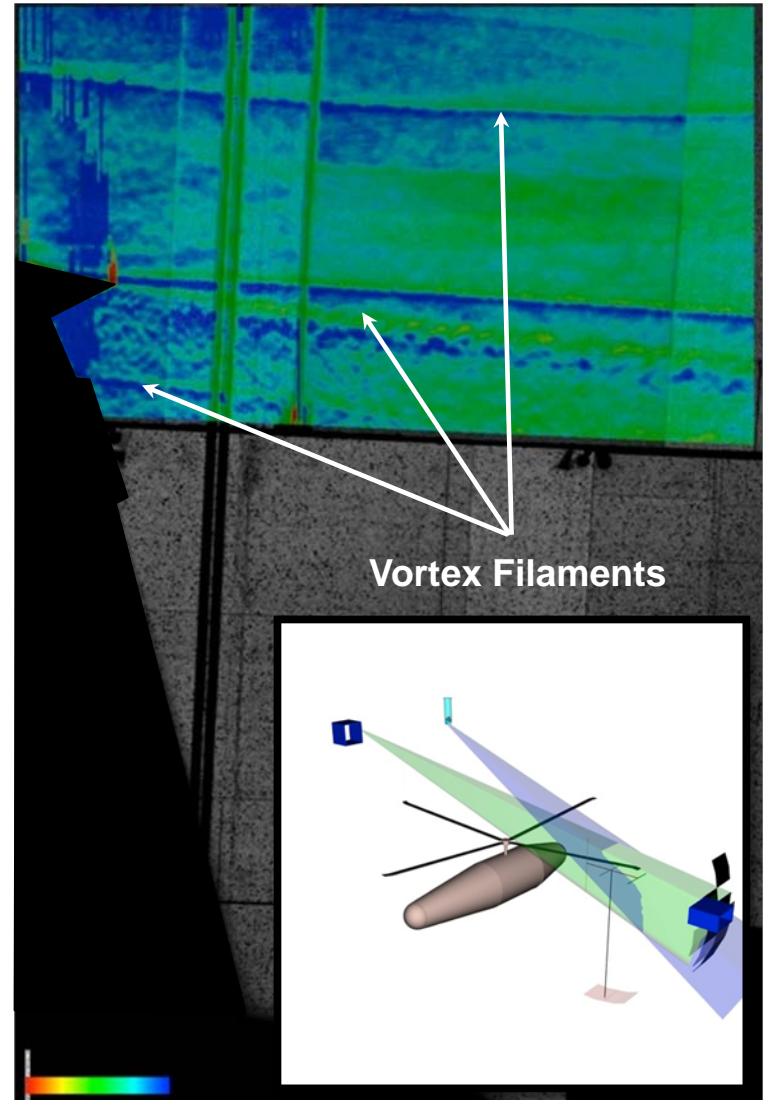
Large-Field PIV



Laser Velocimetry



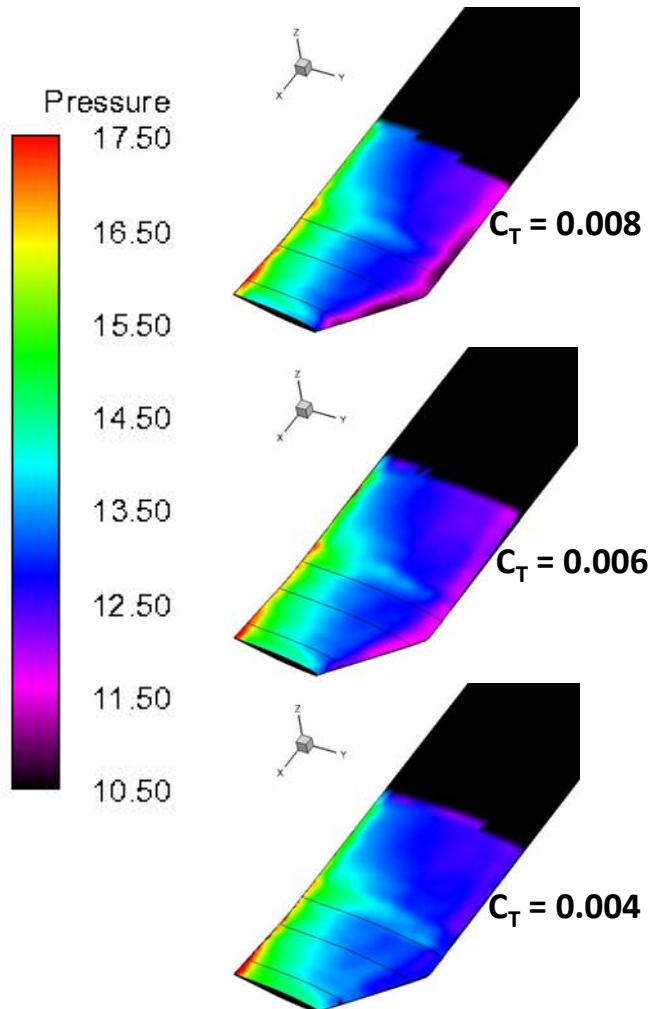
RBOS



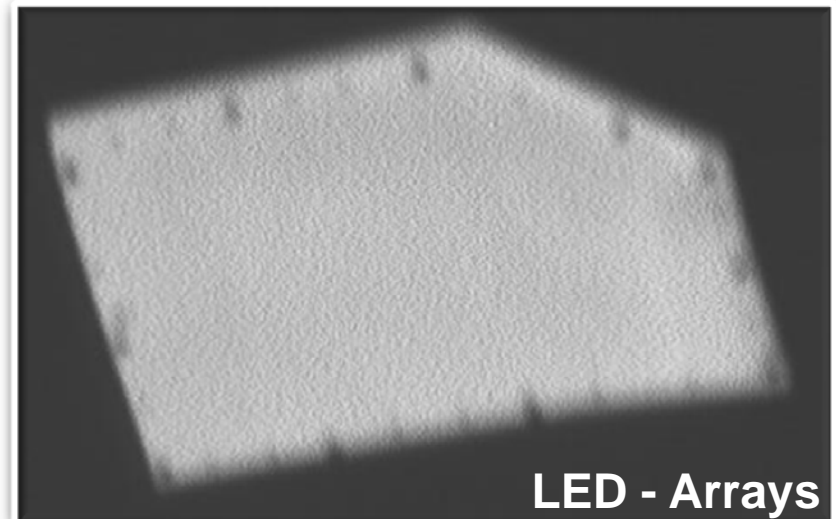
Surface Pressure Measurements*



Pressure Sensitive Paint (PSP)

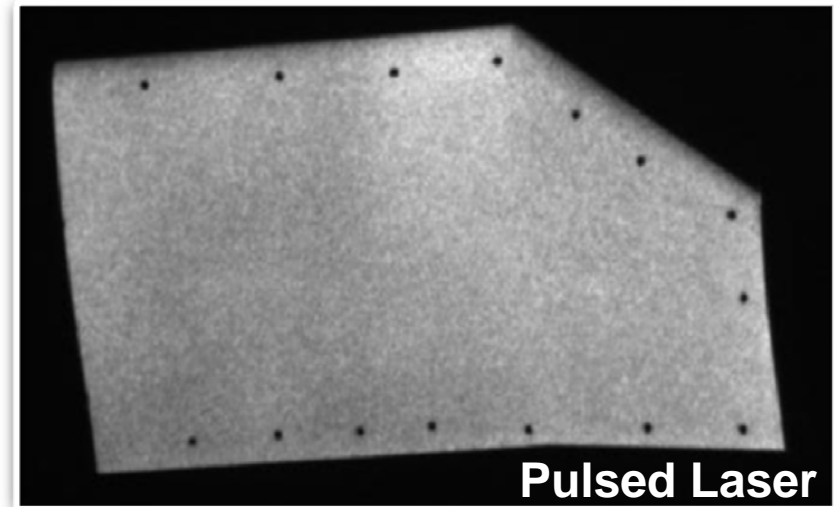


LED Acquisition vs Laser Acquisition



LED - Arrays

~750 revolutions Required to acquire one image



Pulsed Laser

Image acquired from a single blade rotation

*Collaboration with Army JRPO

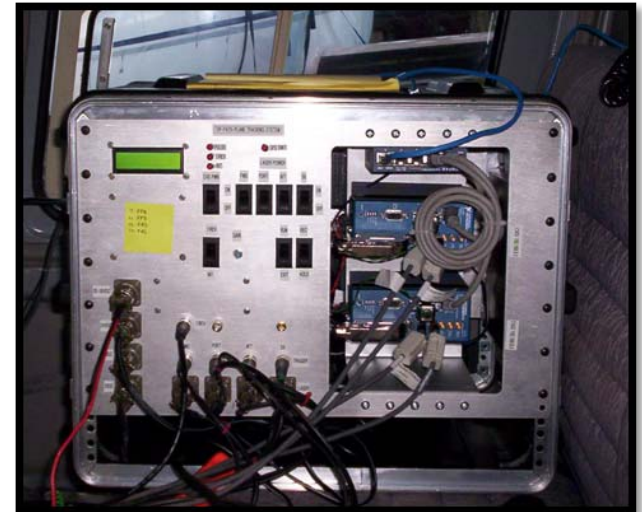
Advanced Measurement Tools



Tip-Path Plane Measurement System

NASA NRA: University of Maryland

PIs: Dr. Frederick Schmitz and Rick Sickenberger



Tracking System Installed in Aircraft



Camera Assembly

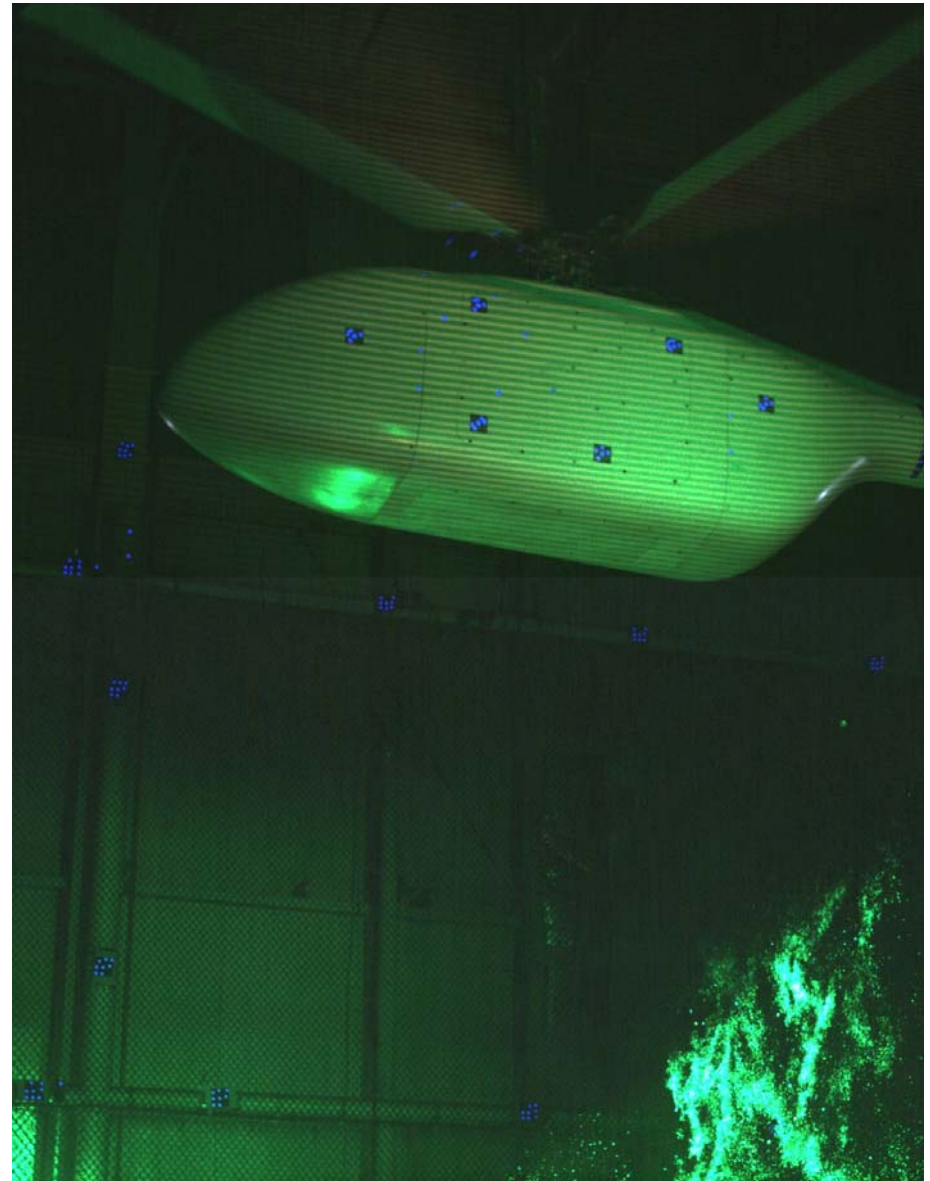
Bell 206B
Bracket attached at maintenance grip

Unified Instrumentation



Spectrum Usage

Source	Wavelength (nm)
IR Illuminators	850, 920
PIV Laser	532
Flow Visualization	516
PMI Laser	795
PSP Laser	532
PSP Emission	600 – 650
S3F Illumination	600 - 650
Photogrammetry	432





PIV Measurements During the UH-60A Airloads Test

Alan J. Wadcock
Gloria K. Yamauchi
Eduardo Solis
Ashley Pete
NASA Ames Research Center

We gratefully acknowledge the assistance from:
James T. Heineck (NASA Ames Research Center)
Louise Walker (Aerospace Computing, Inc.)
Mani Ramasamy (UARC/US Army AFDD)
Luther Jenkins and CS Yao (NASA Langley Research Center)



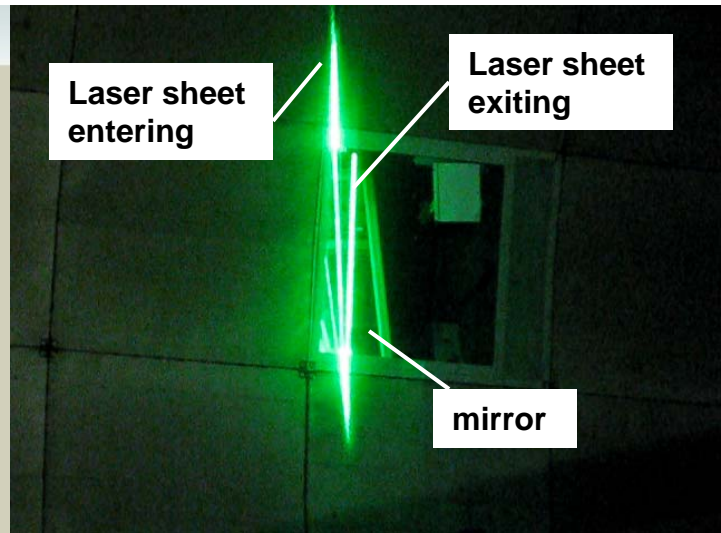
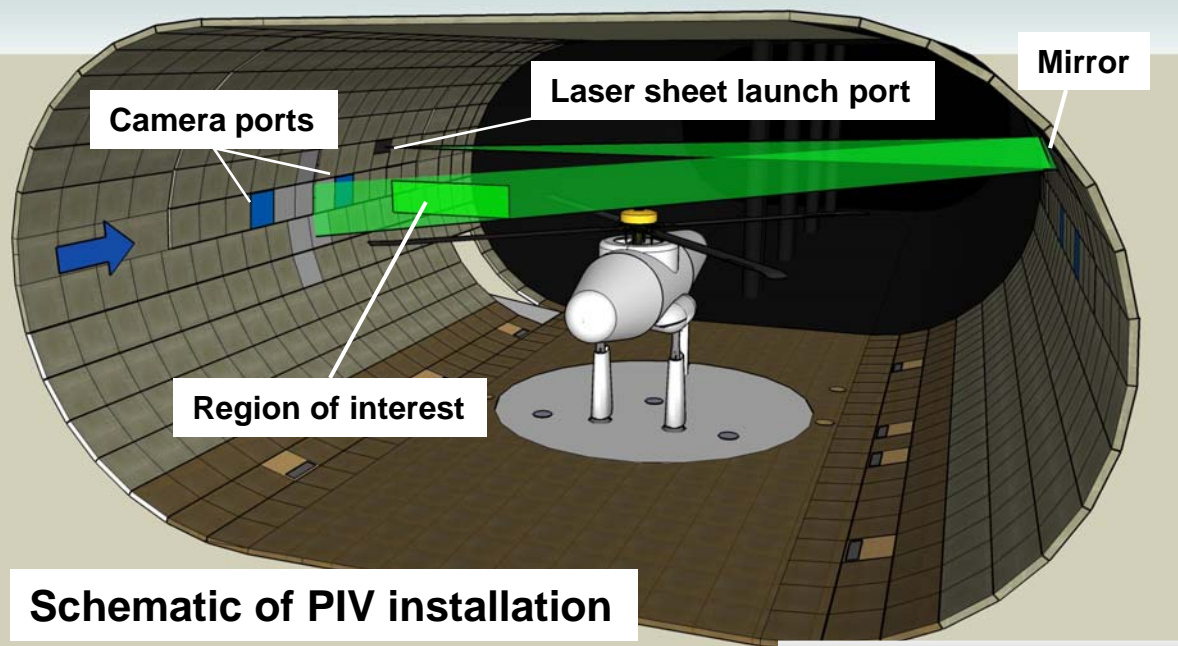
What was measured?

- 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
 - Tip vortex core size
 - Blade tip vortex position and trajectory in laser sheet
 - Blade trailed wake position and trajectory in laser sheet
 - Vortex strength and vortex structure



Installation Challenges

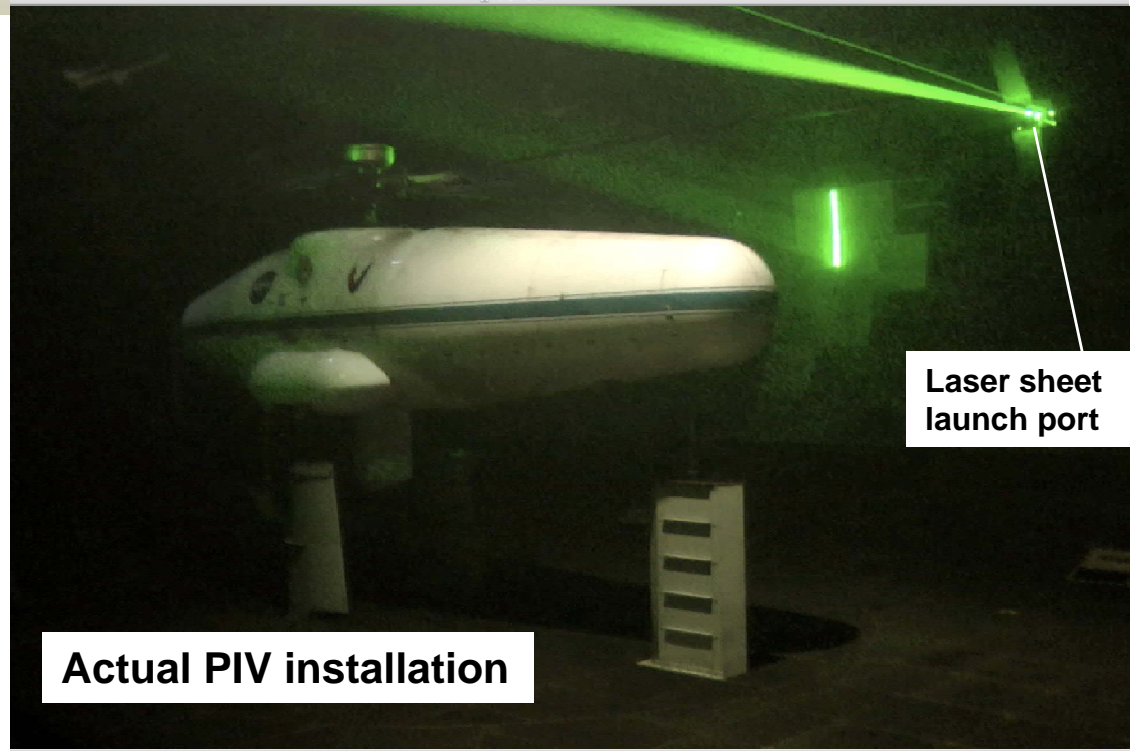
- Very limited optical access in the 40 x 80 test section
- Long distances
 - Laser beam divergence
 - Large (3.5 ft H x 14 ft W) region of interest (ROI)
 - Camera resolution
- Tunnel vibration
- Seeding a very large volume
- Camera calibration
 - Two calibrations required to cover large ROI
 - ROI located over 20 ft above a partially curved floor
- Securing a large area against Class IV laser hazard



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.)

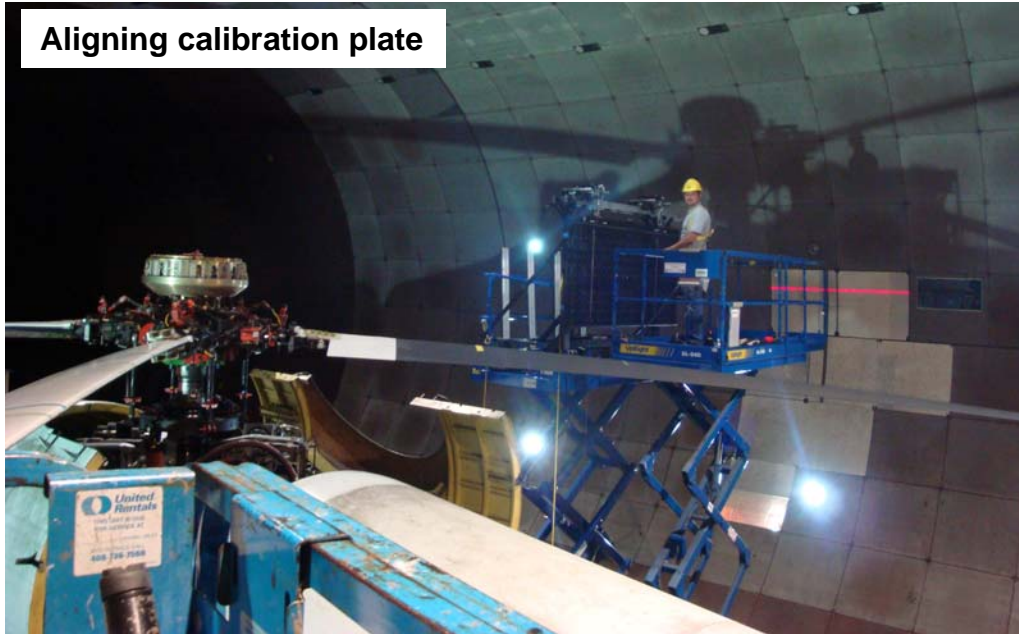


Actual PIV installation

Installation Challenges and Opportunities



Aligning calibration plate



Aligning rods for camera focusing



Adjusting optics in laser launch port



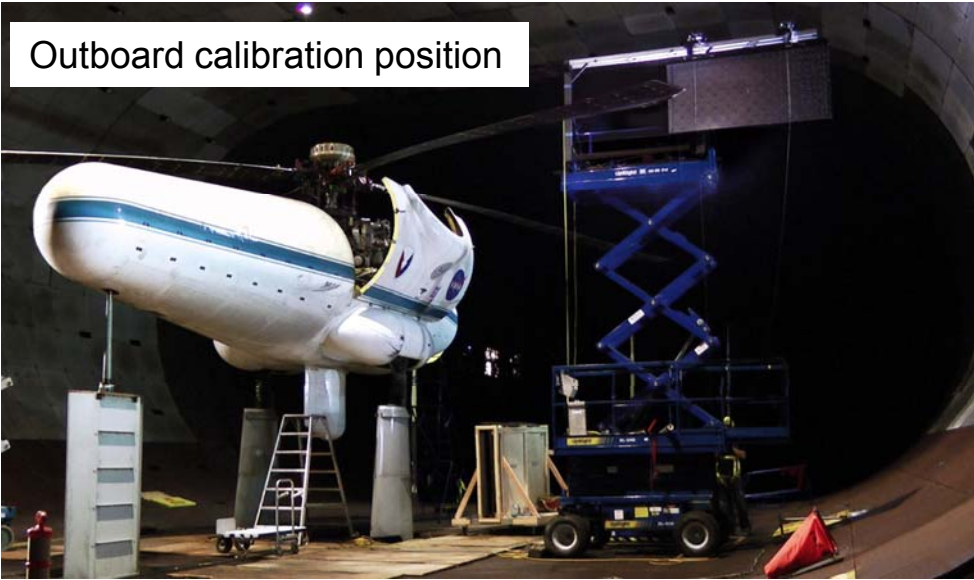
Measuring sheet thickness



Calibration Plate



Outboard calibration position

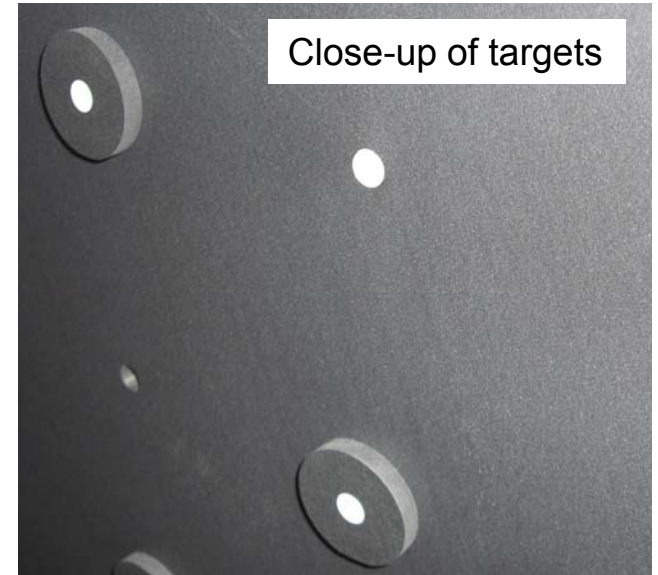


- Dual-plane MIC 6 aluminum plate: 8 ft x 4 ft x 0.25 in
- 137 flush targets, 138 raised targets on each side of plate
- Target diameter = 0.375 in
- Plate is reinforced with steel tubing
- Weight of plate: ~ **190** lbs
- Two calibrations required to cover 14-ft wide region of interest

Inboard calibration position



Close-up of targets



PIV Test Conditions



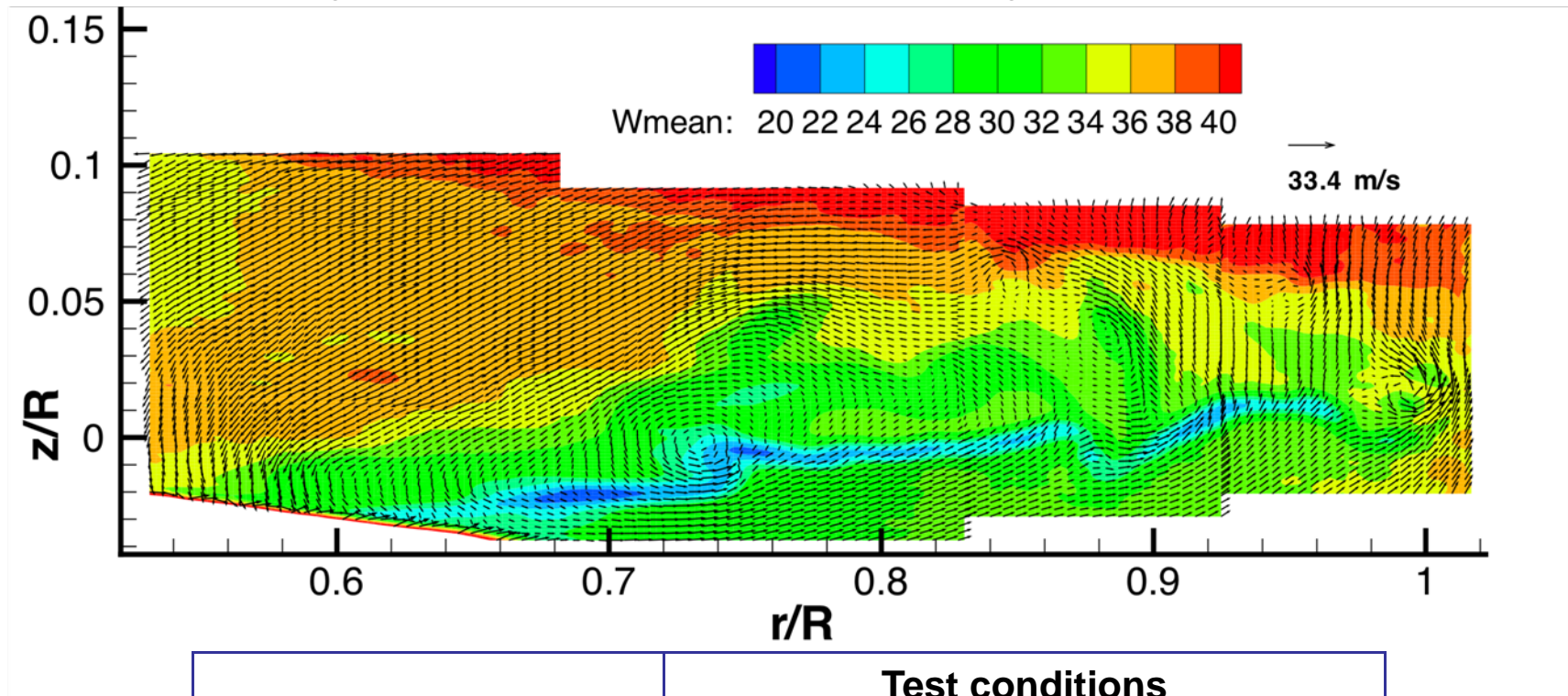
NFAC Run No.	Rotor Shaft Angle (deg)	Tip Mach Number	Advance Ratio	C_T/σ	Azimuth delay (deg)
73	0	0.65	0.15	0.08	5, 15, 30, 45, 60, 75, 95, 135, 185, 225, 275, 315
75	4	0.65	0.15	0.08	5, 15, 30, 45, 60, 75, 95, 135, 185, 225, 275, 315
78*	-4.82	0.638	0.303	0.087	5, 15, 30, 45, 60, 75, 95
81	0	0.65	0.24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

Preliminary Data: *Ensemble-averaged Velocity Field*



View looking upstream, every other vector shown. Average of 100 velocity fields.

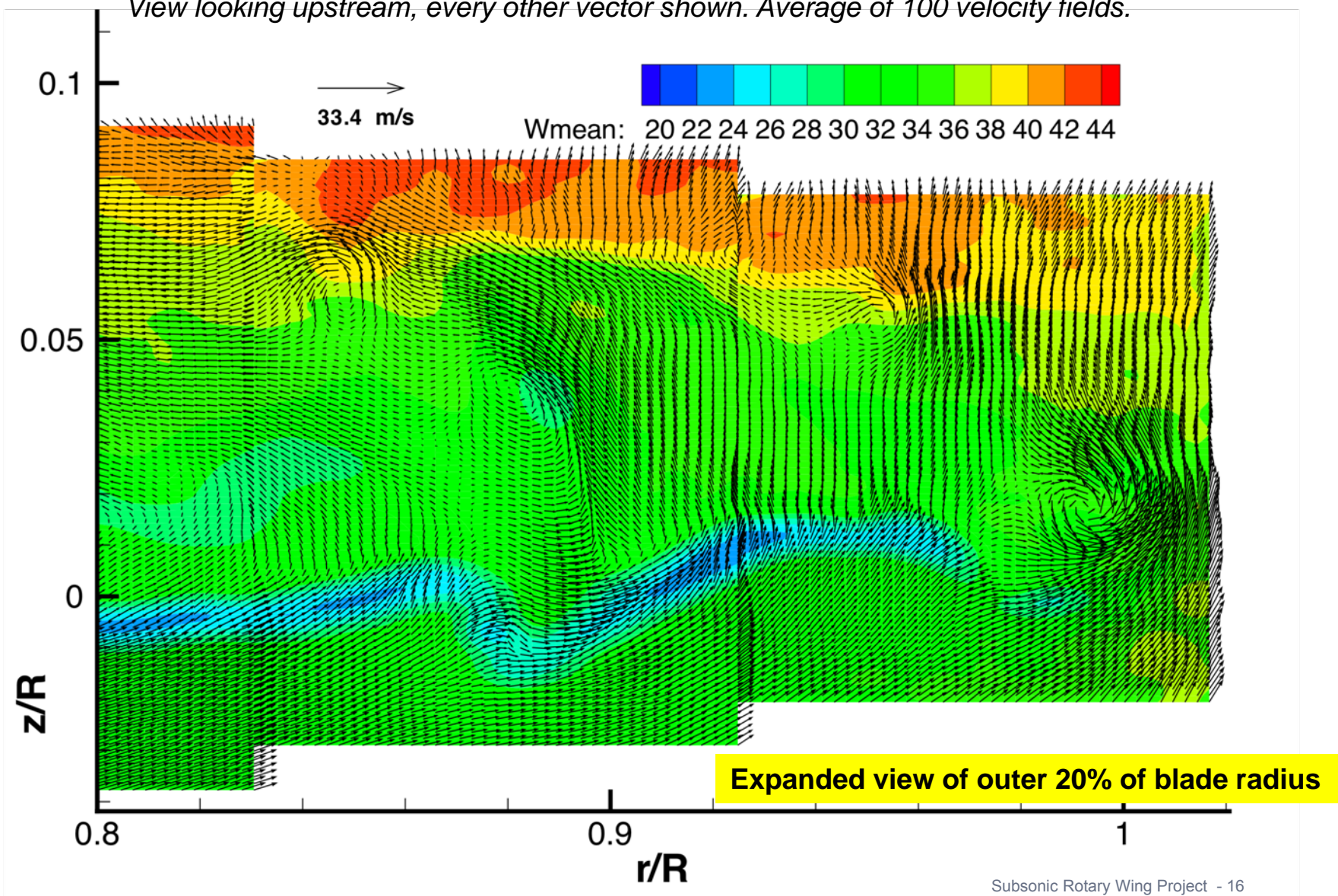


Run 73 NFAC Points 20-22	Test conditions
	Rotor shaft angle = 0 deg $M_{tip} = 0.650$ Advance Ratio = 0.149 $C_T/s = 0.080$ Test Section velocity = 33.4 m/s Azimuth delay=30 deg.

Preliminary Data: *Ensemble-Averaged Velocity Field*



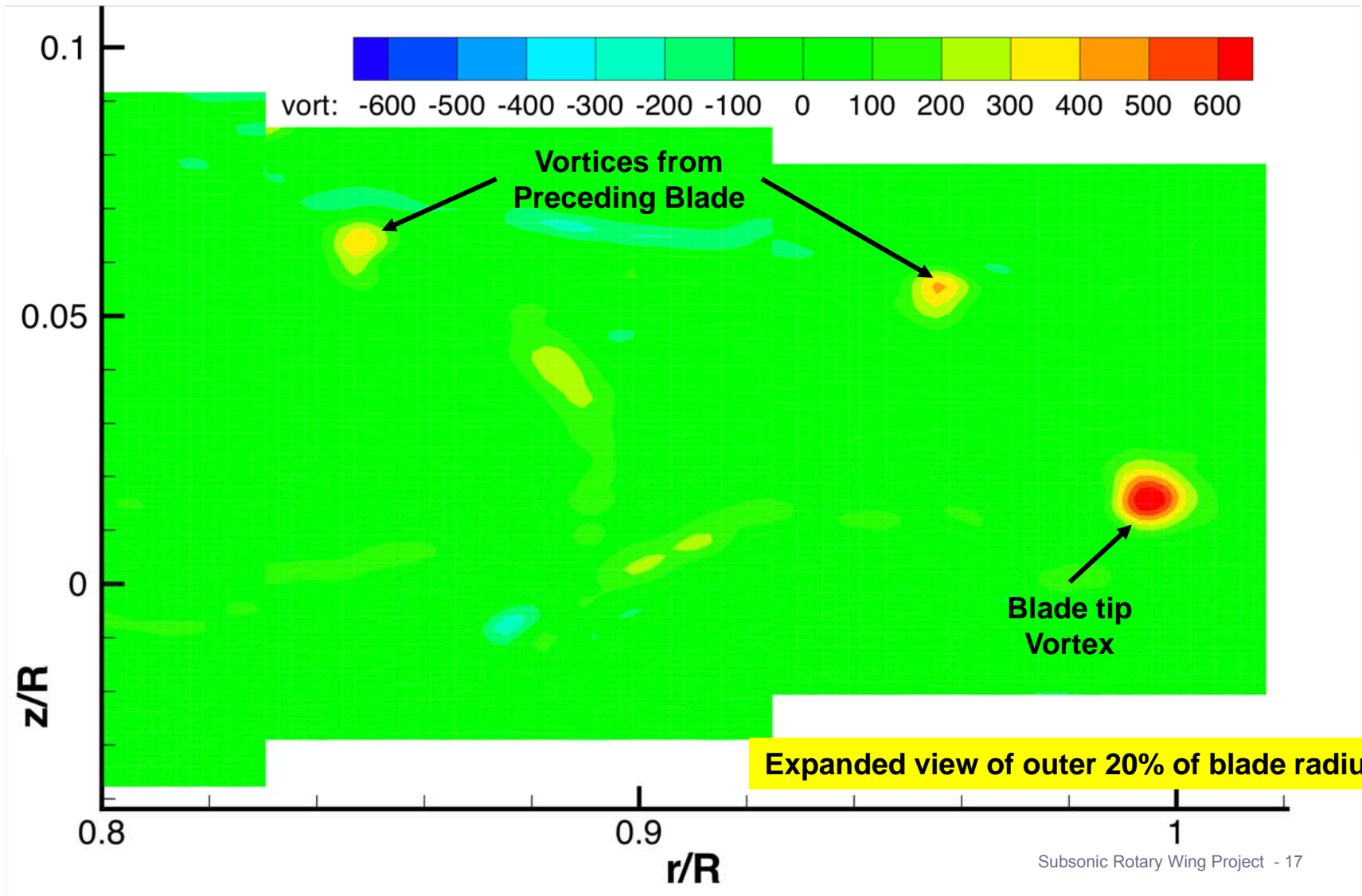
View looking upstream, every other vector shown. Average of 100 velocity fields.



Preliminary Data: *Ensemble-Averaged Vorticity Field*



View looking upstream, every other vector shown. Average of 100 velocity fields.



Data Reduction Status and Plans



- Completed first pass through images using approximate calibration and IDT proVISION software.
- Will begin analysis to extract vortex characteristics. This entails
 1. Image processing to correct for LLS movement
 2. Separate calibrations for the inner and outer half of the ROI
 3. Smaller cross-correlation window with greater overlap
 4. Conditional averaging of the vector fields to remove vortex wander effects
 5. Use of multiple tools: TSI Insight3G software, LaVision DaVis software, and in-house tools.
- Paper describing PIV installation and sample data:

Wadcock, A. J., Yamauchi, G. K., Solis, E., Pete, A. E., "PIV Measurements in the Wake of a Full-Scale Rotor in Forward Flight," 29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 27-30, 2011.

