Fundamental Aeronautics Program

Subsonic Rotary Wing Project

Recent Developments from the UH-60A Airloads Wind Tunnel Test

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Outline

- Organization
- Aeromechanics Task Areas
- Aeromechanics Highlights
- Near-Term Plans

- Questions?

UH-60A Airloads Wind Tunnel Test Summary

Outline

- Test Objectives
- Test Description
- Test Phases and Conditions
- Sample Results
- Summary
- Near-Term Plans

Test Objectives

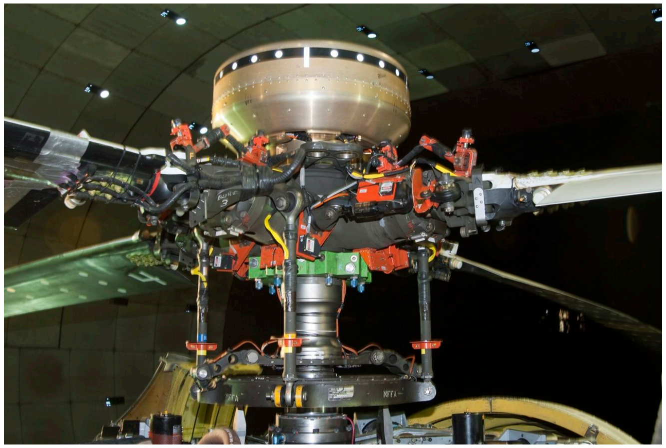
- Objectives
  - Acquire comprehensive set of validation-quality data (including airloads) to challenge SOA modeling and simulation tools
  - Acquire data to evaluate similarities/differences between small-scale wind tunnel, full-scale wind tunnel, and full-scale flight tests

- UH-60A Airloads Test successfully completed (May 2010) in USAF 40- by 80-Foot Wind Tunnel

Hardware

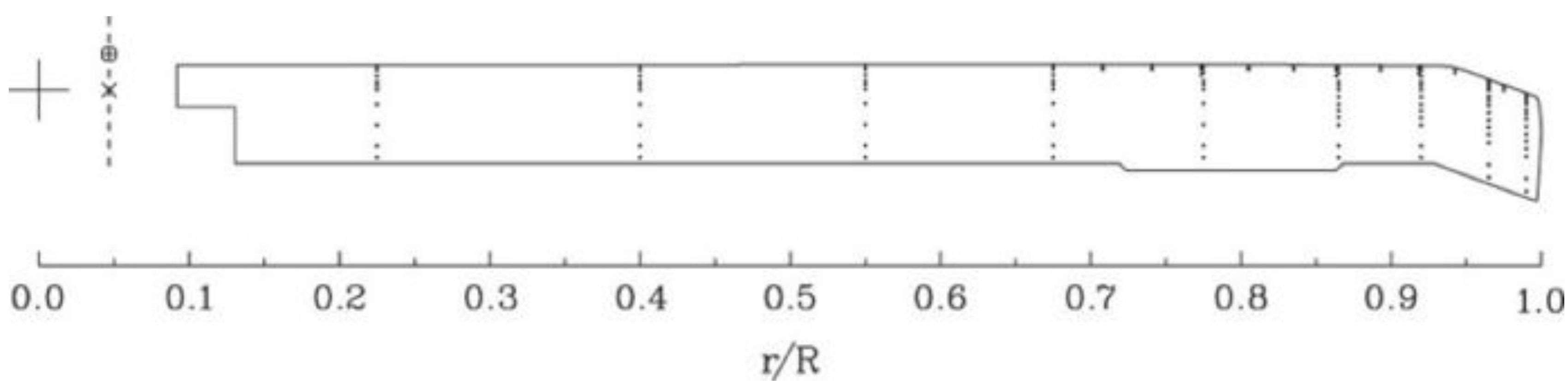
- Testing conducted in USAF National Full-Scale Aerodynamic Complex (NFAC) 40- by 80-Foot Wind Tunnel

- UH60A rotor system mounted on Large Rotor Test Apparatus (LRTA)
  - Rotor system uses same blades as used during 1993 flight testing, including pressure blade
  - Production UH-60 rotor system (hub, spindles, shaft extender, swashplate, pitch links)
  - LRTA provides rotor mount and calibrated rotor balance



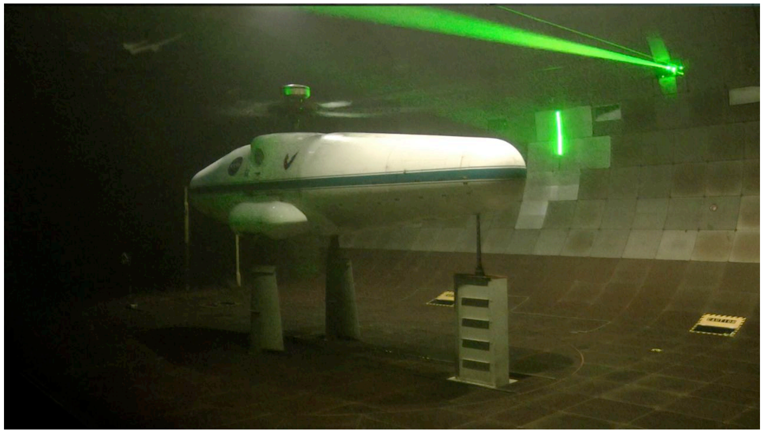
Instrumentation

- 456 unique measurements acquired at each data point
- Key Instrumentation
  - Blade Pressures
    - 235 pressure transducers, mostly in chord-wise arrays at 9 radial stations
  - Rotor Performance
    - 28 LRTA balance gages to determine rotor forces and moments
  - Blade Structural Loads
    - 28 blade bending gages at 9 radial stations
  - Blade Root Motion Measurements
    - Two sets of 12 measurements each to measure blade root motion

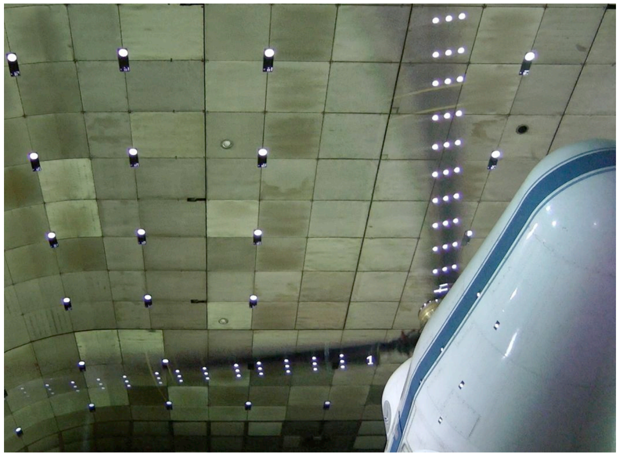


Independent Measurement Systems

- Three new systems developed specifically for this test
  - Blade Displacement System
    - Blade displacement and deformation
  - Retro-reflective Backward Oriented Schlieren (RBOS)
    - Tip vortex trajectory and orientation
  - Particle Image Velocimetry (PIV)
    - Flow velocities and vortex properties



Laser for Particle Image Velocimetry



Retro-reflective Blade Displacement Targets

Test Phases and Conditions

- 1-G Level Flight Sweeps
- Parametric Sweeps
- Airloads Flight Test Simulation
- DNW Wind Tunnel Test Simulation
- Slowed Rotor Testing
- PIV Testing

Test Phases and Conditions

- 1-G Level Flight Sweeps
  - Simulated 1-g level-flight speed sweeps (matching lift and propulsive force)
  - Advance ratio sweeps up to 0.4 for 3 lift levels

- Parametric Sweeps
  - Controlled variations of thrust, advance ratio, hover tip Mach number, and shaft angle across and beyond flight operating conditions
  - Thrust sweeps at 6 advance ratios, 3 tip Mach numbers, and 5 shaft angles

Test Phases and Conditions

- Airloads Flight Test Simulation
  - Matched conditions from Airloads Flight Test, including derivative points around the baseline to determine sensitivities
  - 3 flight conditions matched (c8425, c8525, c9020)

- DNW Wind Tunnel Test Simulation
  - Matched conditions from DNW small-scale test, including derivative points around baseline
  - 3 DNW conditions matched (11.24, 13.12, 13.20)

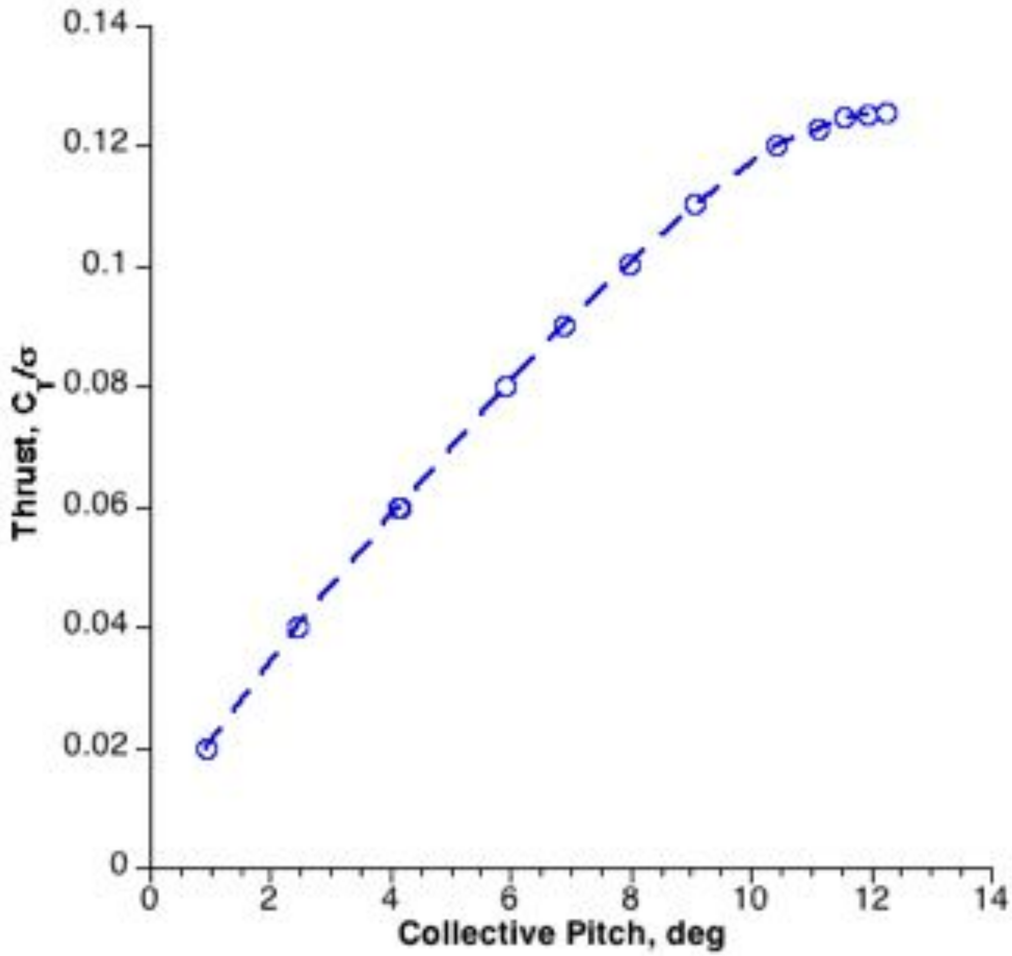
Test Phases and Conditions

- Slowed Rotor Testing
  - Parametric sweeps to evaluate non-conventional operating envelopes made possible by large reductions in rotor RPM
  - Collective sweeps at 3 hover tip Mach numbers and 3 shaft angles up to advance ratios as high as 1.0

- PIV Testing
  - Acquired detailed velocity data at selected test points to better understand flow physics
  - 11 different flight conditions

Sample Data – Stall Sweep

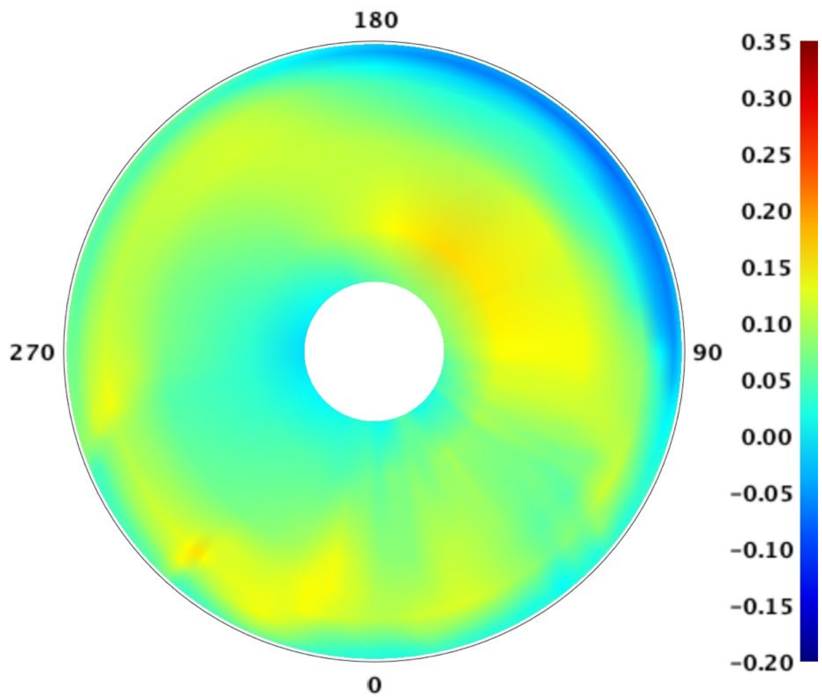
- Thrust vs. collective for collective pitch sweep (Mtip=0.625, mu=.30, alpha=0)
- Roll-off of thrust at high collectives indicative of stall



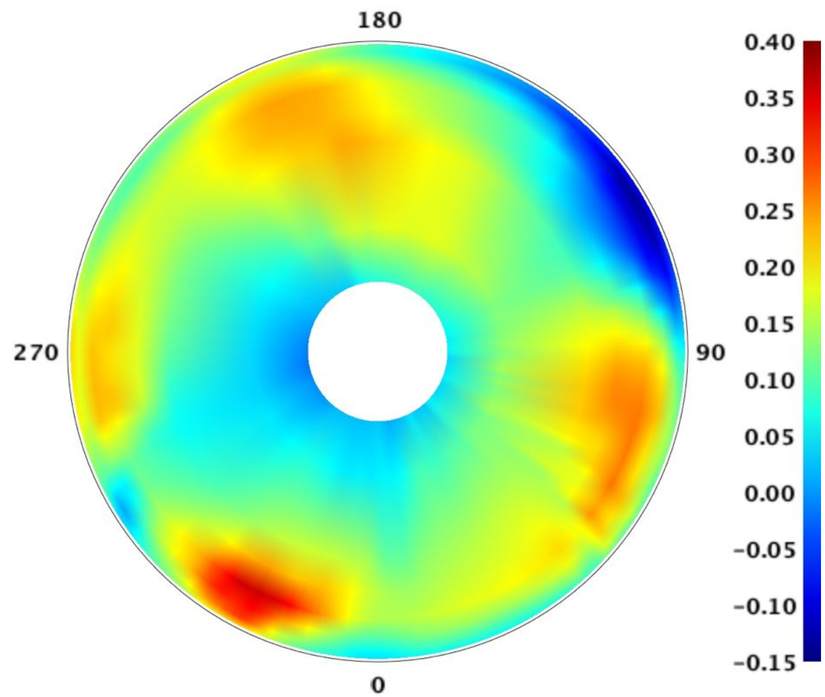
Sample Data – Stall Sweep

- Radial plots of section normal force (M2CN) at nominal and deep stall conditions (Mtip=0.625, mu=.30, alpha=0)
- Significant changes in lift distribution at stall

Nominal Thrust, C_T/σ=0.08

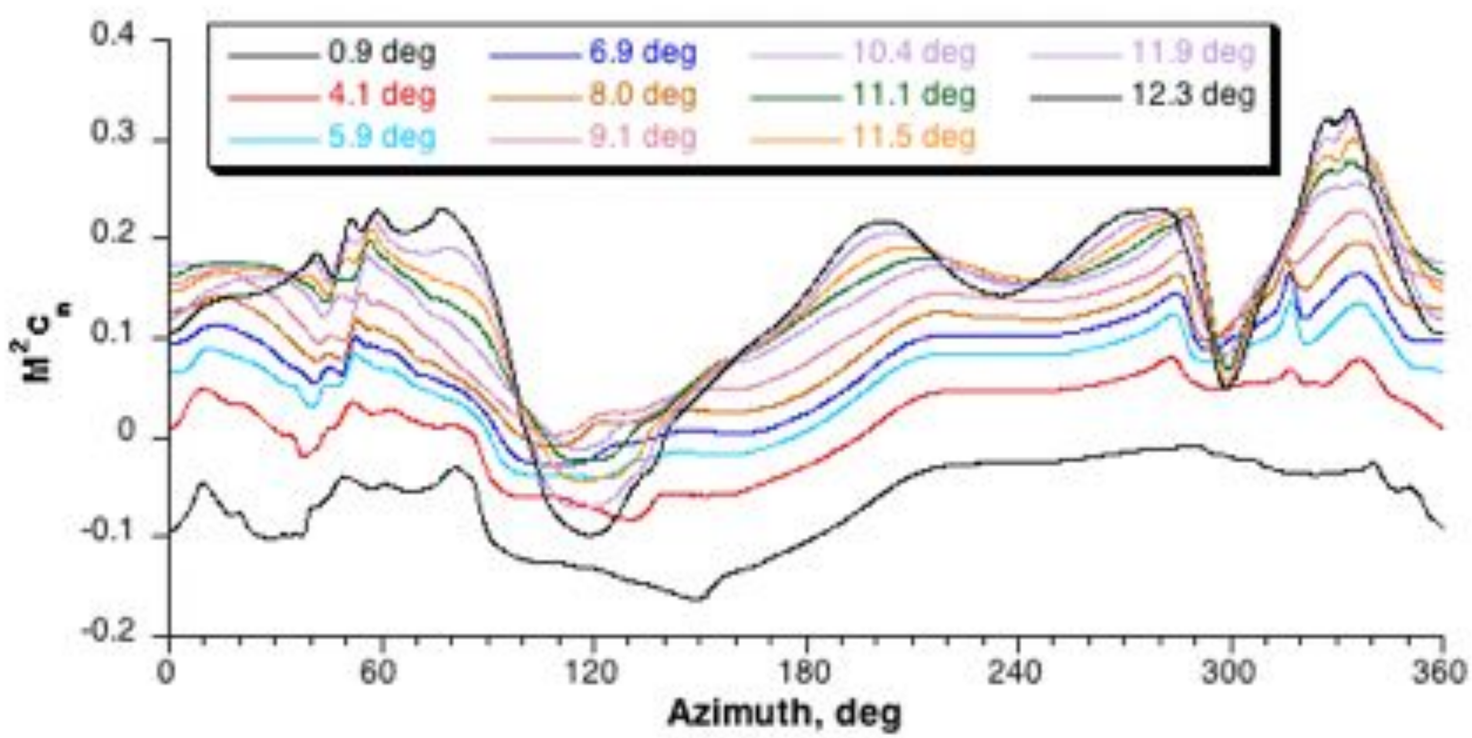


Deep Stall, C_T/σ=0.125



Sample Data – Stall Sweep

- Time history of section normal force (M2CN) at r/R = 0.92 for collective pitch sweep (Mtip=0.625, mu=.30, alpha=0)
- Lift stall evident at ψ= 290 deg and 340 deg at high collective
- Evidence of first stall cycle as low as 4.1 deg collective



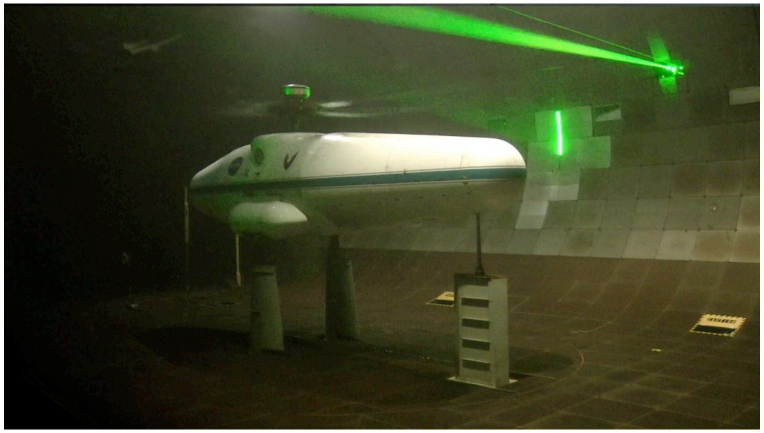
Summary

- UH-60A Airloads Test successfully completed (May 2010) in NFAC 40x80 Ft Wind Tunnel
  - Measurements included blade pressures, rotor performance, blade loads, blade displacement, and rotor wake (using large-field Particle Image Velocimetry (PIV) and Retro-reflective Background Oriented Schlieren (RBOS))
  - Data acquired (including airloads) should provide excellent resource for validation of SOA modeling and simulation tools

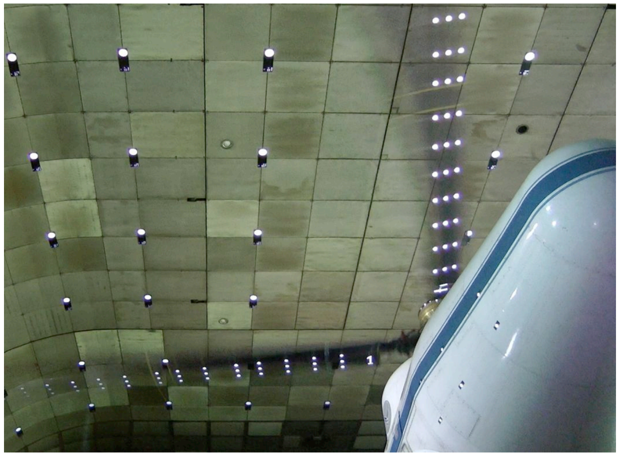
- Data acquired over wide range of test conditions
  - Speed and thrust sweeps up to 175 kt and 32000 lb
  - Specified conditions from previous full-scale flight test and small-scale DNW wind tunnel test
  - Slowed-rotor simulation data at reduced RPM, achieving advance ratios up to 1.0

Summary

- Unique accomplishments
  - Most highly-instrumented rotor test ever conducted in the NFAC (including 235 rotating pressure transducers)
  - First test of production UH-60 rotor at high advance ratios (up to 1.0)
  - Successful acquisition of PIV data over the largest area ever attempted in NFAC (4 ft by 13 ft)
  - First ever use of an 8-camera, 4-quadrant photogrammetry technique to measure blade displacements



Laser for Particle Image Velocimetry



Retro-reflective Blade Displacement Targets

Near-Term Plans

- Prepare publications documenting test and techniques
  - 3 at May 2011 AHS Forum
    - Test overview
    - Slowed rotor
    - Analysis correlation
  - 2 at June 2011 AIAA meeting
    - PIV system development
    - Blade Displacement system development
- Continue data review, evaluation, and data reduction
- Prepare for external data release (documentation, data formatting)

Efforts Since February 2011

- Investigated numerous approaches for measuring as-built blade contours
  - Most concerned about blade deflections during measurements
  - Will likely use white-light scanning method (later this year)
- Began effort to understand discrepancies between blade tab measurements for flight test and wind tunnel test
  - Investigating differences between measurement tools and methods
  - Sikorsky provided very useful information to help define tab deflection definition for CFD analysis
- Completed preparations for and have begun (this week) control stiffness testing

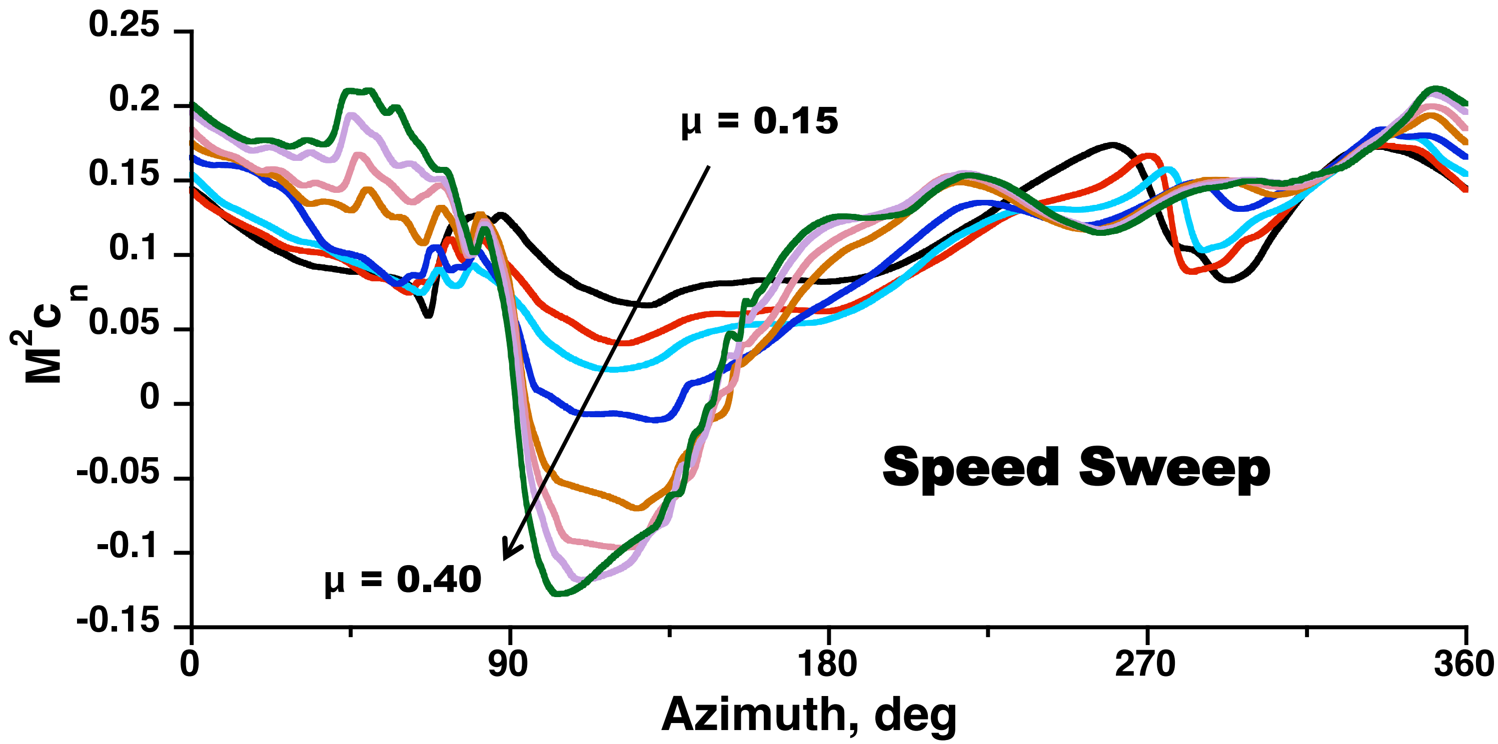
Data Availability

- Selected wind tunnel data **now available** to Workshop participants (as of 11/1/11)
  - Data accessible through NASA's NSC Knowledge Now website (https://nsckn.nasa.gov/community/Views/Home.aspx?Filter=930)
  - Requires approved data request form
    - Send email to Tom Norman (tom.norman@nasa.gov) to request form
  - Website includes multiple files, including
    - Selected wind tunnel data and format description
    - Parameter and test condition descriptions
    - PDF files of related papers and workshop presentations

- 8 requestors have approved access (3 NASA, Sikorsky, Bell, Boeing, Penn State, CDI)

Currently Available Data

- **Speed sweep (8 points)**, Ct/s=0.09, Mtip=0.650, representative moments
  - mu = .15, .20, .24, .30, .35, .37, .385, .40
- **Stall/collective sweep (12 points)**, mu=0.30, alpha=0, Mtip=0.625, zero moments
  - Collective = 0.9, 2.5, 4.1, 5.9, 6.9, 8.0, 9.1, 10.4, 11.1, 11.5, 11.9, 12.3



Publications

- 6 conference papers have been presented
  - AHS Forum (May 2011)
    - **Test overview** - “Full-Scale Wind Tunnel Test of the UH-60A Airloads Rotor”, Norman et al
    - **CFD correlation** – “Correlating CFD Simulation with Wind Tunnel Test for the Full-Scale UH-60A Airloads Rotor”, Romander et al
    - **High advance ratio** – “Experimental Investigation and Fundamental Understanding of a Slowed UH-60A Rotor at High Advance Ratios”, Datta et al
  - AIAA Applied Aero meeting (June 2011)
    - **PIV technique** – “PIV Measurements in the Wake of a Full-Scale Rotor in Forward Flight”, Wadcock et al
    - **Blade displacement technique** – “Blade Displacement Measurements of the Full-Scale UH-60A Airloads Rotor”, Barrows et al
  - AHS Design Conference (Jan 2012)
    - **High advance ratio predictions** – “Performance and Loads Correlation of a UH-60A Slowed Rotor at High Advance Ratios”, Kottapalli

Publications

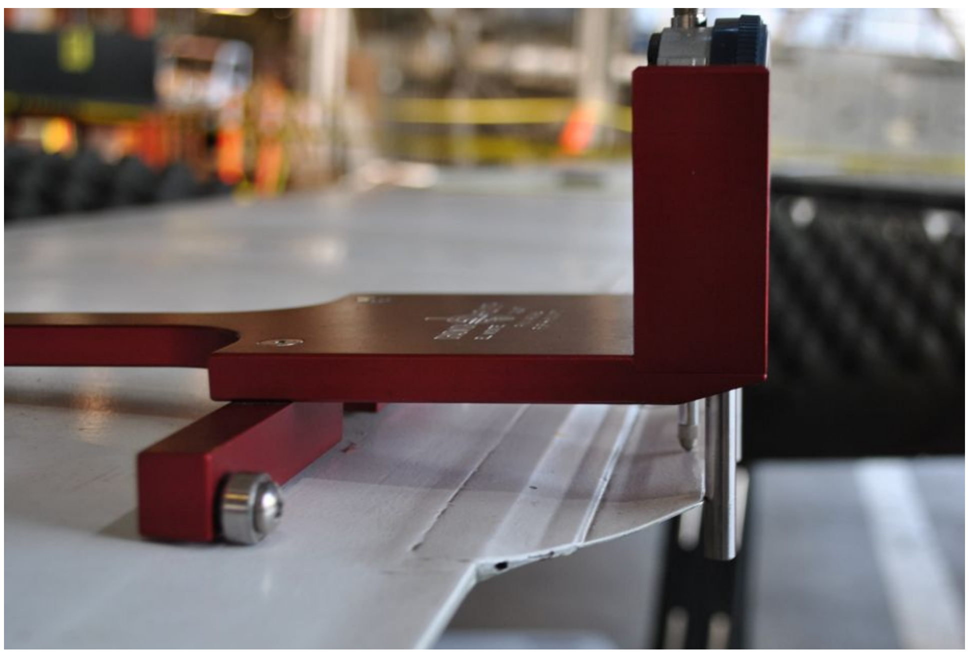
- 6 conference papers accepted for publication
  - AHS Forum (May 2012)
    - **CFD structural load correlation** – “Loads Correlation of a Full-Scale UH-60A Airloads Rotor in a Wind Tunnel”, Yeo et al
    - **PIV technique** – “Wind Tunnel Measurements of Full-Scale UH-60A Rotor Tip Vortices”, Yamauchi et al
    - **Blade displacement technique** – “Blade Displacement Measurement Technique Applied to a Full-Scale Rotor”, Abrego et al
    - **High advance ratio predictions** – “Investigation of Performance and Loads of a UH-60A Rotor at High Advance Ratios”, Yeo
    - **High advance ratio predictions** – “Computational Investigation and Fundamental Understanding of a Slowed UH-60A Rotor at High Advance Ratios”, Potsdam et al
    - **Scale/Wind Tunnel Effects**- “Evaluation of Wind Tunnel and Scaling Effects with the UH-60A Airloads Rotor”, Norman et al

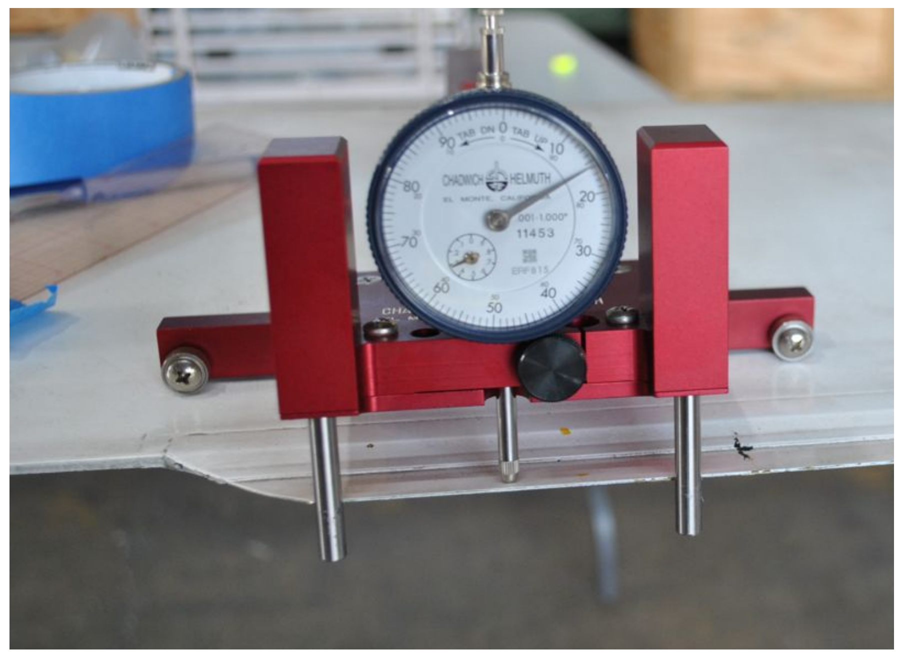
Other Efforts Since August 2011

- Continued data evaluation efforts for blade pressures and integrated parameters
  - Have completed pressure evaluations for 17 complete runs (out of 35)
- Continued making progress with PIV and Blade Displacement data reduction efforts
  - PIV processing now providing vortex core properties
  - Multiple Blade Displacement processing techniques applied to data set to identify best approach
- Completed control system stiffness testing
- Measured blade tab angles
- Investigated azimuthal differences between flight and wind tunnel

Blade Tab Angles

- Re-measured tab deflections on all 4 blades
- New measurements similar to flight test
- Tab angles dependent on location of tab bend radius and location of measurement
  - Approx location of bend radius 0.8 in from TE
  - Approx location of measurement .15 in from TE
- Tab angles vary from 0.3 to 3.6 deg up





Near-Term Plans

- Continue data evaluation/correction and database updates
  - Pressures/integrated loads – complete remaining runs
  - Blade motion measurements – correct for RPM effects and transducer drift (mean effects)
  - Slowed Rotor runs – account for blade gage coupling and rotor balance drift
- Continue analysis of PIV and Blade Displacement data
- Complete documentation of control stiffness testing and tab deflection measurements
- Investigate blade contour measurements
- Investigate measured dynamic hub loads; evaluate rotor balance calibration issues

NASA