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
Sample Data – Stall Sweep

• Time history of section normal force (M2CN) at $r/R = 0.92$ for collective pitch sweep ($M_{tip}=0.625$, $\mu=0.30$, $\alpha=0$)
• Lift stall evident at $\psi=290$ 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
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)
  – 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)**, $Ct/s=0.09$, $M_{tip}=0.650$, representative moments
  - $\mu = 0.15, 0.20, 0.24, 0.30, 0.35, 0.37, 0.385, 0.40$

- **Stall/collective sweep (12 points)**, $\mu=0.30$, $\alpha=0$, $M_{tip}=0.625$, 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