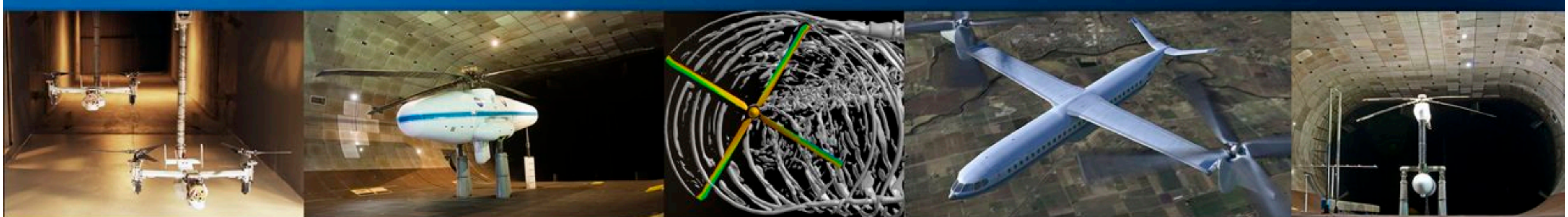
UH-60A Airloads
Wind Tunnel Data Update

Tom Norman

Airloads Workshop – August 9, 2012



Outline

- Data Availability
- Publications
- Recent Test Findings
- Current Activities
- Wind Tunnel/Flight Test Comparisons

Data Availability

- Selected wind tunnel data made available to Workshop participants Nov 2011
  - Includes speed sweep (8 pts) and thrust sweep (12 pts)
  - Data accessible through NASA's NSC Knowledge Now website https://nsckn.nasa.gov/community/Views/Home.aspx?Filter=930

- 8 organizations currently have approved access (NASA, Army, Sikorsky, Bell, Boeing, Penn State, CDI, Georgia Tech)

Publications Since March 2012

- 6 conference papers at 2012 AHS Forum
  - **Aero/Structural Loads**
    - "Loads Correlation of a Full-Scale UH-60A Airloads Rotor in a Wind Tunnel", Yeo et al
    - "Evaluation of Wind Tunnel and Scaling Effects with the UH-60A Airloads Rotor", Norman et al
  - **High Advance Ratio**
    - "Investigation of Performance and Loads of a UH-60A Rotor at High Advance Ratios", Yeo
    - "Computational Investigation and Fundamental Understanding of a Slowed UH-60A Rotor at High Advance Ratios", Potsdam et al
  - **Experimental Capabilities**
    - "Wind Tunnel Measurements of Full-Scale UH-60A Rotor Tip Vortices", Yamauchi et al
    - "Blade Displacement Measurement Technique Applied to a Full-Scale Rotor", Abrego et al

Recent Test Findings

- From March 2012 Meeting
  - LRTA control system stiffness measured - similar to aircraft (somewhat stiffer under collective loading)
  - As-tested blade tab angles measured – similar to flight measurements
  - 7 deg azimuth difference identified between wind tunnel data and currently used CFD model
    - Must correct model or data for valid comparisons
    - Also identified azimuthal “errors” with flight test data due to anti-aliasing filter corrections
- New information
  - Post-test blade inspections identified error in locations of TE blade pressure transducer
    - All TE transducers actually at x/c=93.9% instead of 96.3%
    - Effect on flight test airloads (correct value used for WT) is minimal for normal flight condition

Current Activities

- Continuing data evaluation efforts for blade pressures and integrated parameters
- Making progress with PIV and Blade Displacement data reduction efforts
  - PIV processing procedures nearly finalized; significant data reduction to begin this CY
  - Initial comparisons of blade displacement measurements with CFD helping to identify necessary improvements in data reduction
- Continuing CFD validation efforts with both OVERFLOW and FUN3D

OVERFLOW

- Completed coupling of hi-res CAMRAD with OVERFLOW
- Currently modeling in-board blade shank for better performance calculations
- Using wind tunnel and LRTA models to investigate effects on rotor loads and performance
  – Also investigating differences between wind tunnel and flight test measurements

FUN3D

- Troubleshooting coupling of hi-res CAMRAD with FUN3D (working with Romander)
- Developed model for LRTA fuselage and preparing for computations
- Preparing to perform detailed validation with thrust sweep data

Near-Term Plans

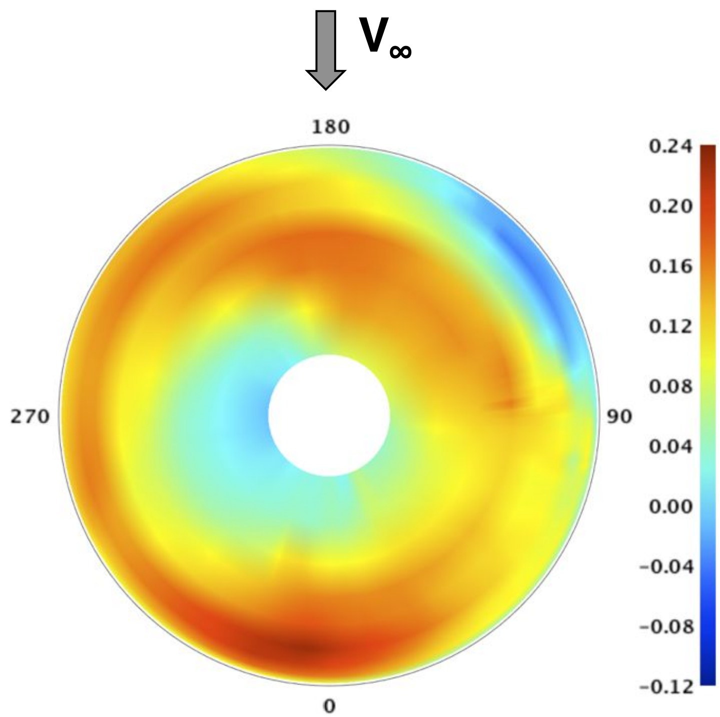
- Continue data evaluation/correction and database updates
  - Pressures/integrated loads – complete remaining runs
  - Blade motion measurements – correct for RPM effects and transducer drift (mean effects)
  - Slowed Rotor runs – account for blade gage coupling and rotor balance drift
- Continue analysis 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

Background

- Full-scale UH-60A Airloads wind tunnel test conducted in USAF National Full-Scale Aerodynamic Complex (NFAC) 40- by 80-Foot Wind Tunnel (2010)
- Test provided unique opportunity to evaluate tunnel and scaling effects by comparing acquired data with
  – 1994 UH-60A Airloads flight test
  – 1989 UH-60A Airloads small-scale wind tunnel test in German-Dutch Wind Tunnel (DNW)

Flight Comparisons - Airloads

Flight (c8424)
Section Normal Force (M^2c_n)
μ=0.30, C_T/σ=0.088



Flight Comparisons - Airloads

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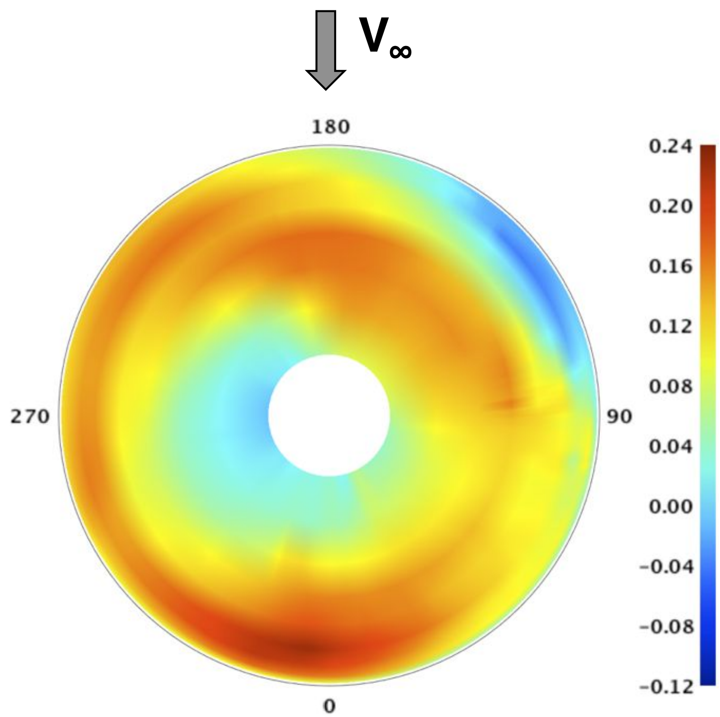
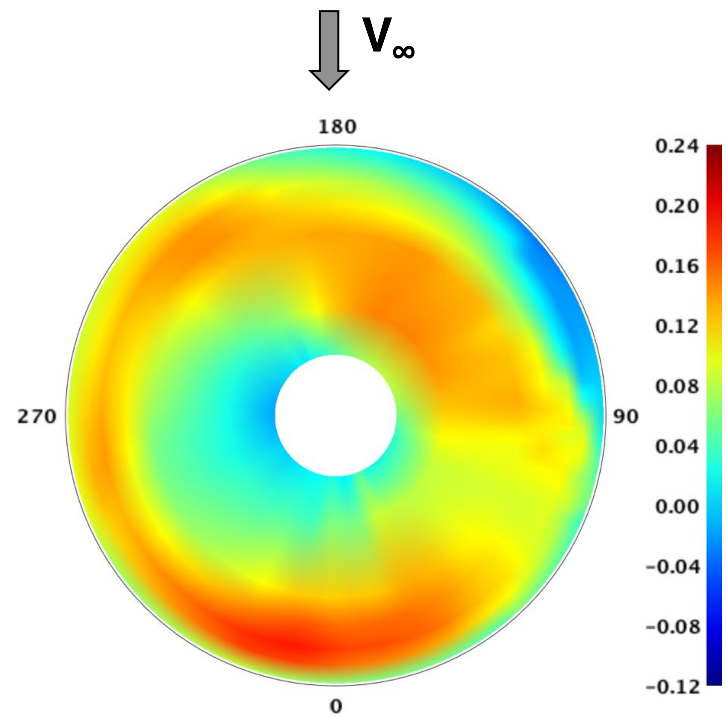


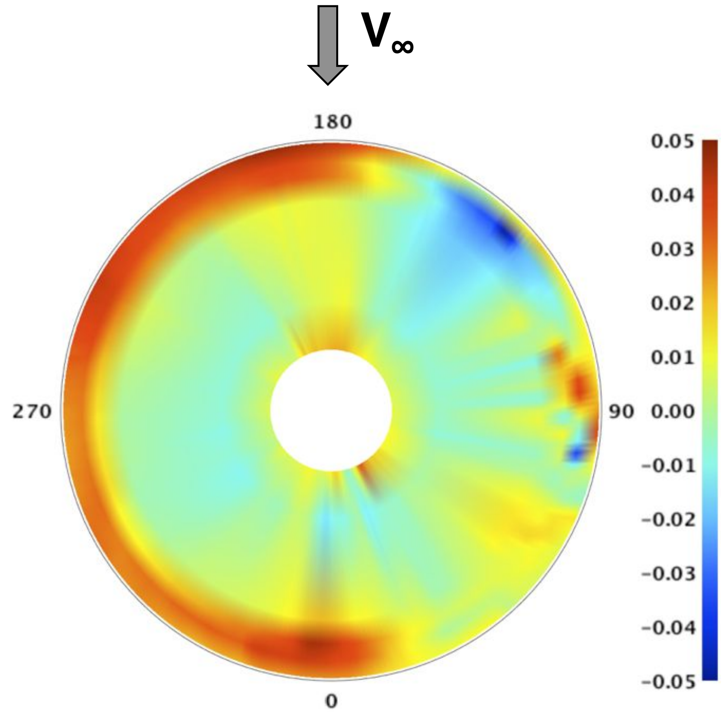
NFAC
Section Normal Force (M^2c_n)
μ=0.30, C_T/σ=0.088



- NFAC baseline matches well with flight, although noticeable differences outboard

Flight Comparisons - Airloads

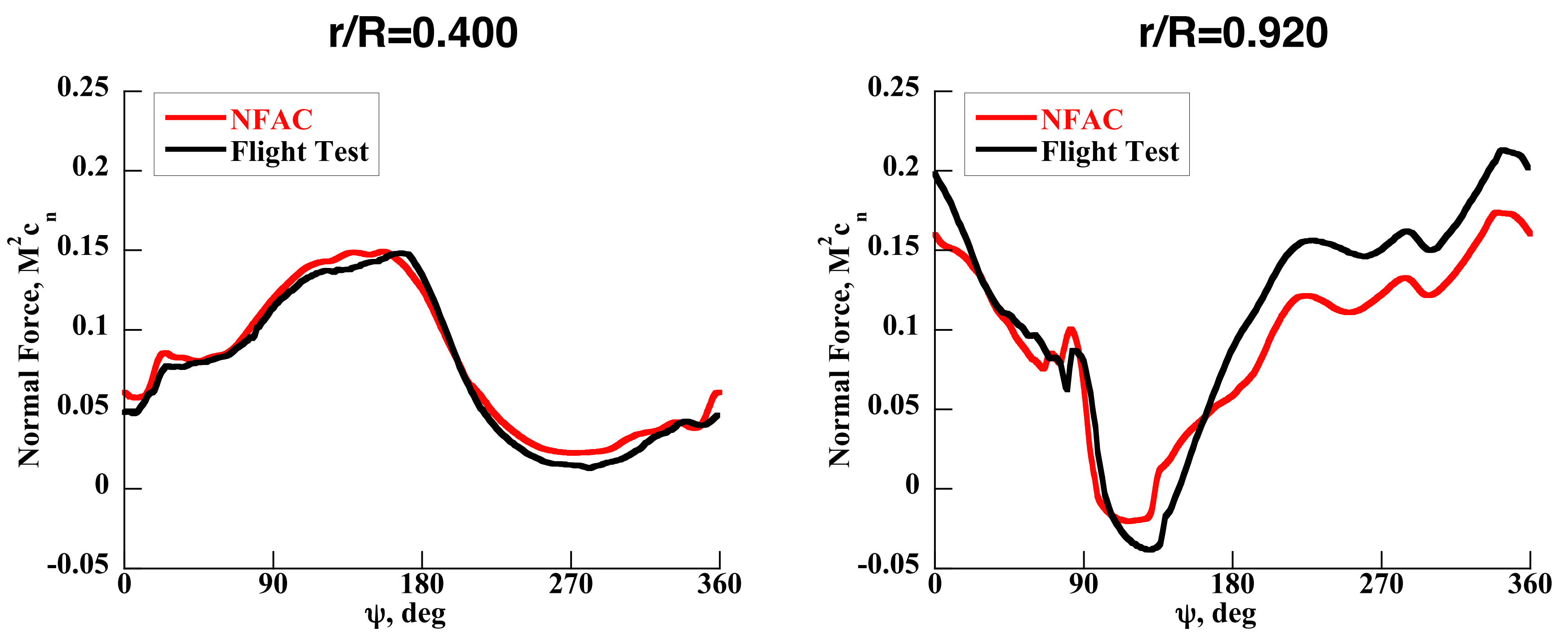
Difference between Flight and NFAC
Section Normal Force (M^2c_n)
μ=0.30, C_T/σ=0.088



- NFAC baseline matches well with flight, although noticeable differences outboard

Flight Comparisons - Airloads

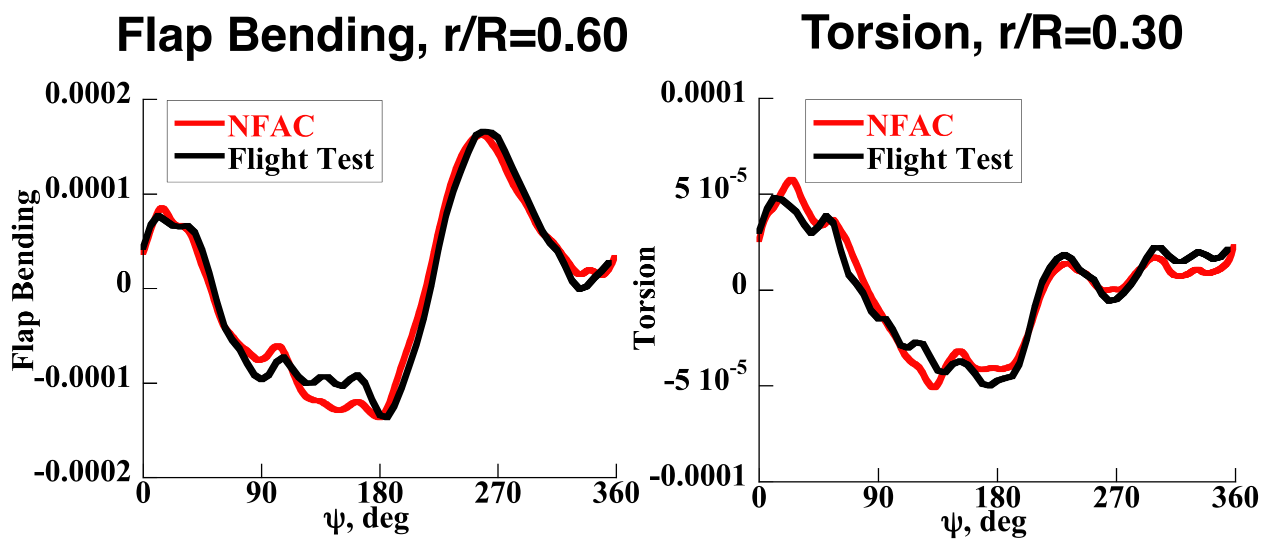
Section Normal Force – μ=0.30, C_T/σ=0.088 (c8424)



- Biggest differences near negative lift peak and on retreating side for outboard stations

Flight Comparisons – Structural Loads

Blade Bending Loads – μ=0.30, C_T/σ=0.088

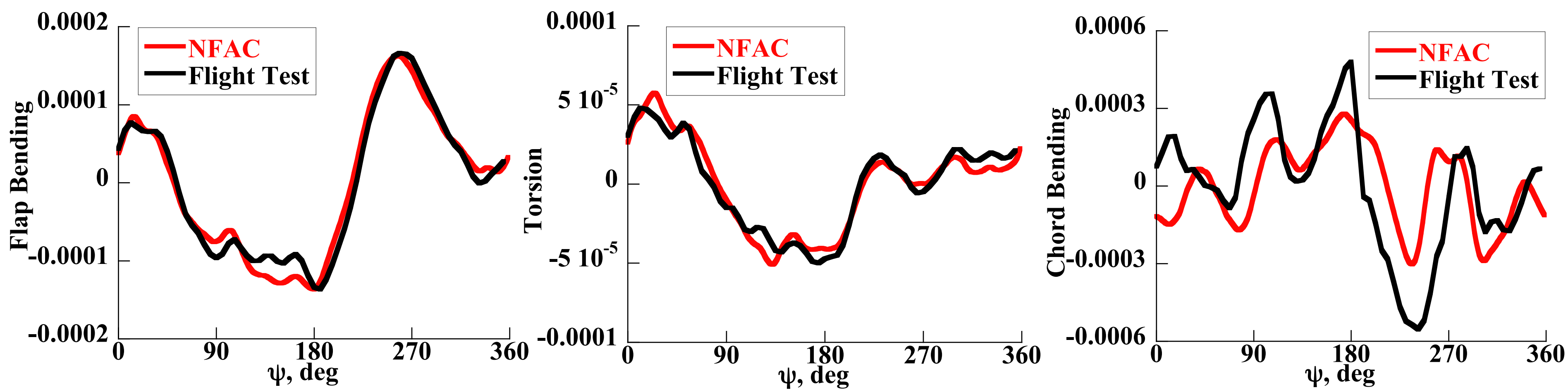


- NFAC flap bending and torsion match well with flight

Flight Comparisons – Structural Loads

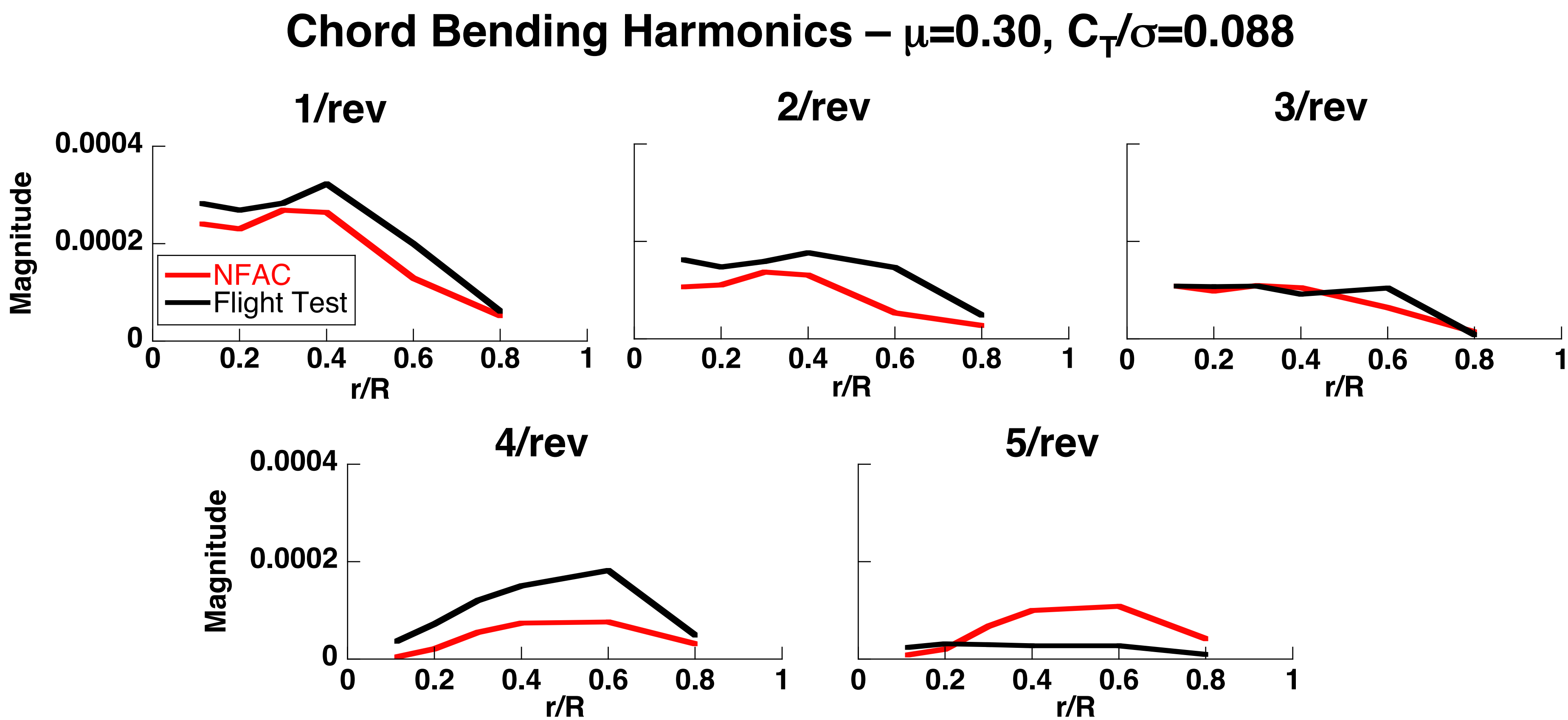
Blade Bending Loads – μ=0.30, C_T/σ=0.088

Flap Bending, r/R=0.60 | Torsion, r/R=0.30 | Chord Bending, r/R=0.60



- NFAC flap bending and torsion match well with flight
- NFAC chord bending shows significant differences

Flight Comparisons – Structural Loads



- Notable differences at 1, 2, 4, and 5/rev
  - 1 and 2/rev differences consistent with damper responses
  - 4 and 5/rev may be caused by differences in lag modal frequencies (drive train differences)?

Conclusions

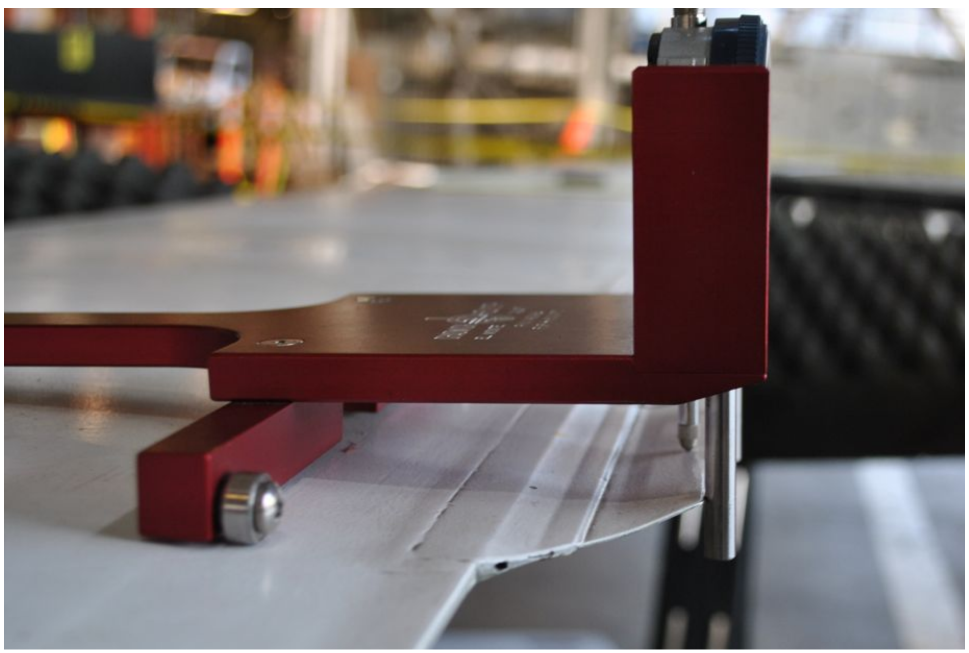
- NFAC measured rotor power compares well with matched flight and DNW test conditions
  - Procedures and trim targets used to match conditions are valid
- Flight comparisons
  - Airloads match well although some waveform differences found at outboard stations
  - Rotor structural loads match well except for chord bending
  - Further investigation necessary to determine cause of differences

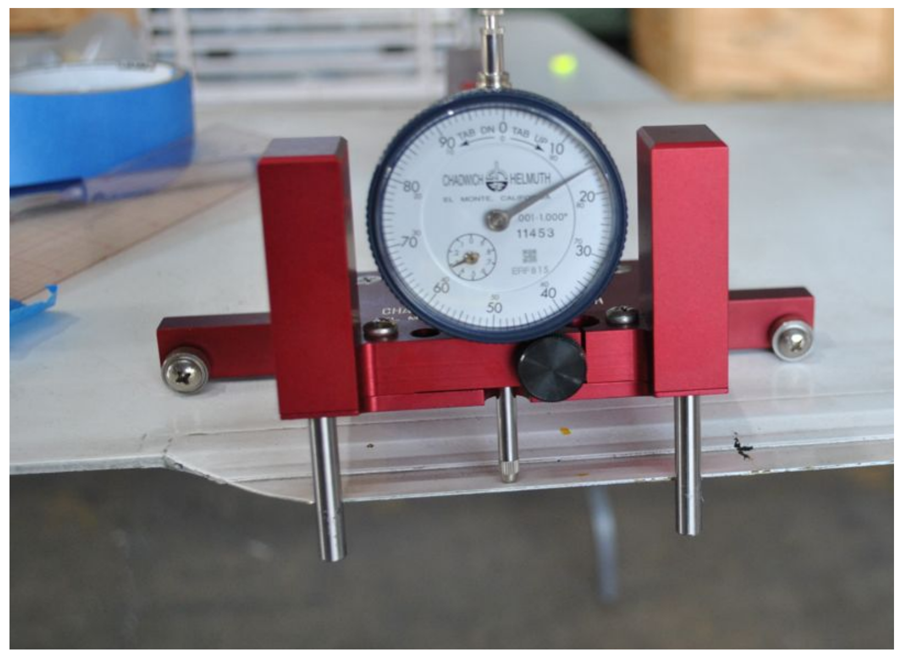
NASA

Backup Slides

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



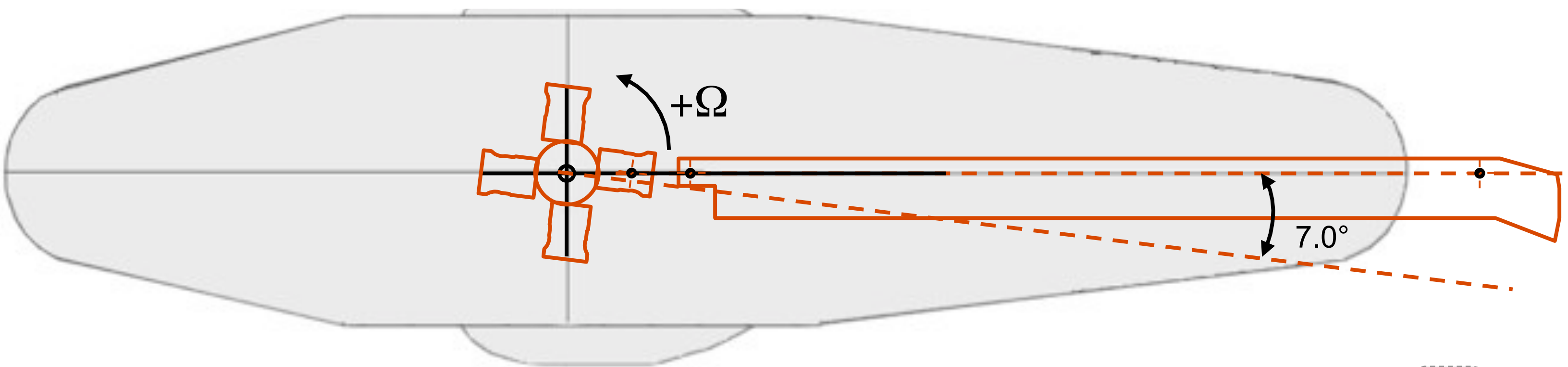


Azimuthal Diff. Between Flight and Wind Tunnel

- Known 7 deg azimuth ref. difference between wind tunnel and flight PdB files

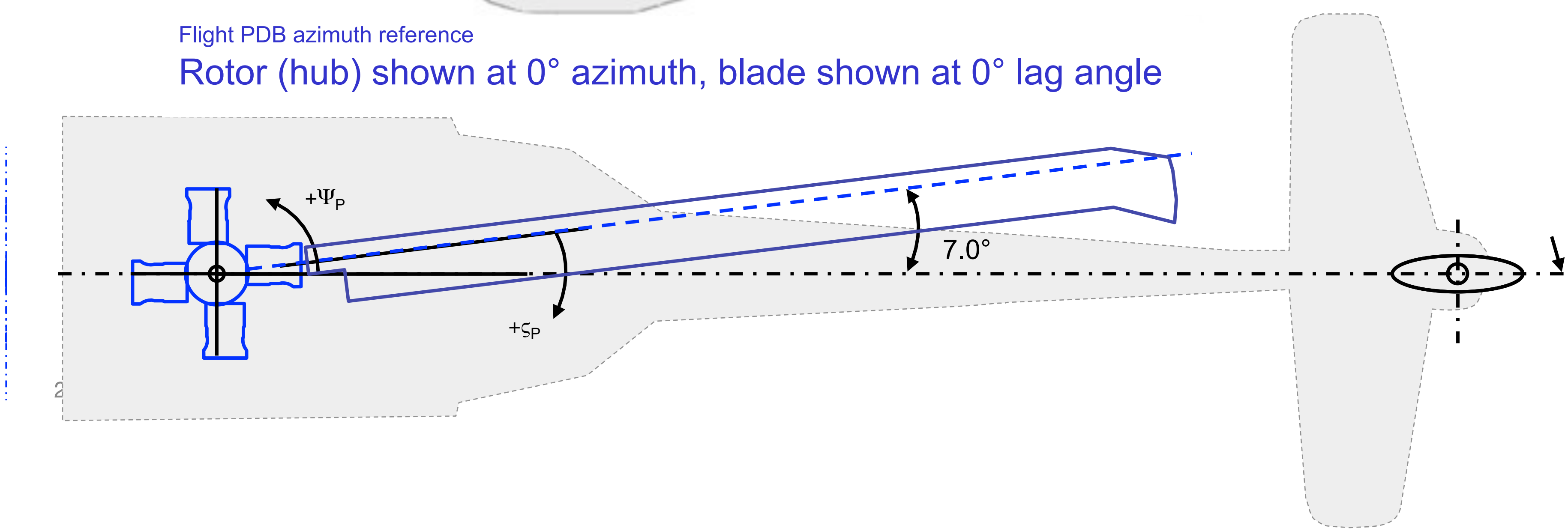
Wind Tunnel (and TRENDS) azimuth reference

Rotor (hub) shown at 0° azimuth, blade shown at 0° lag angle



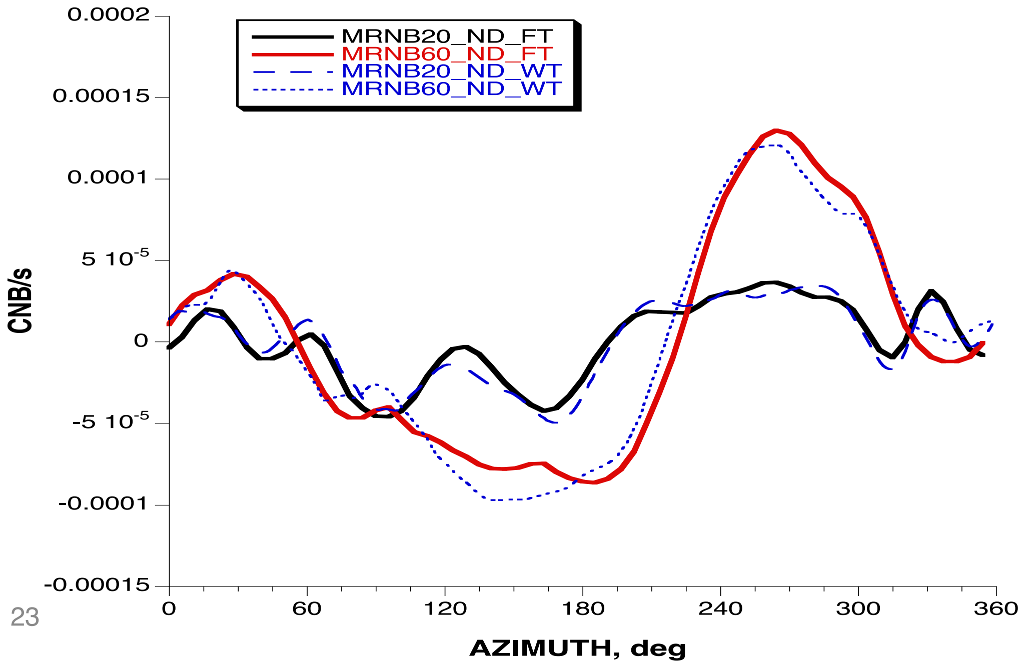
Flight PDB azimuth reference

Rotor (hub) shown at 0° azimuth, blade shown at 0° lag angle



Azimuthal Diff. Between Flight and Wind Tunnel

- Looked at possible causes for additional azimuthal differences
  - Encoder issues, post-processing errors, etc
- Found that wind tunnel data were corrected for phase delays caused by anti-aliasing filters; flight data were not
  - High speed data, 550 Hz Butterworth filter; approximately 1.8 deg delay
  - Low speed data, 110 Hz Butterworth filter, approximately 8.6 deg delay
- Also need to account for flight sideslip angle for comparisons (up to 4 deg)



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Flight/Wind Tunnel Flap Bending
(Flight corrected for phase)