NRTC/RITA Rotorcraft Airloads Workshop

UH-60 Rotor Airloads/Blade Loads - Comments

Robert A. Ormiston

Army/NASA Rotorcraft Division

Aeroflightdynamics Directorate

US Army Research Development & Engineering Command

Ames Research Center, Moffett Field, California

Stanford University

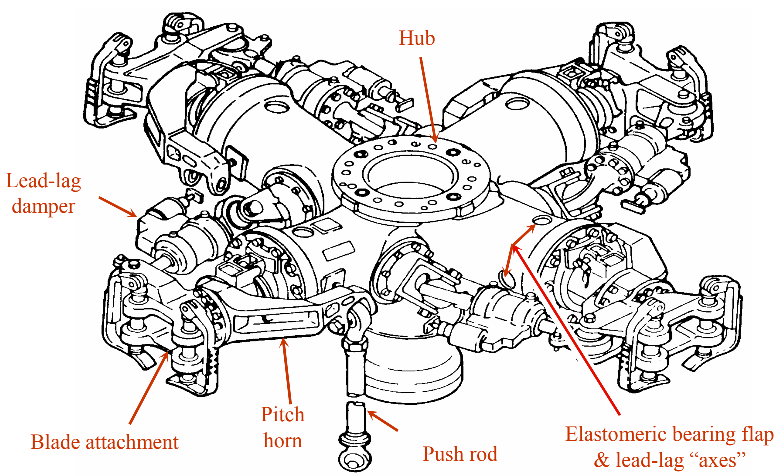
Aug 31 - Sept 1, 2004

Overview of Recent Activities

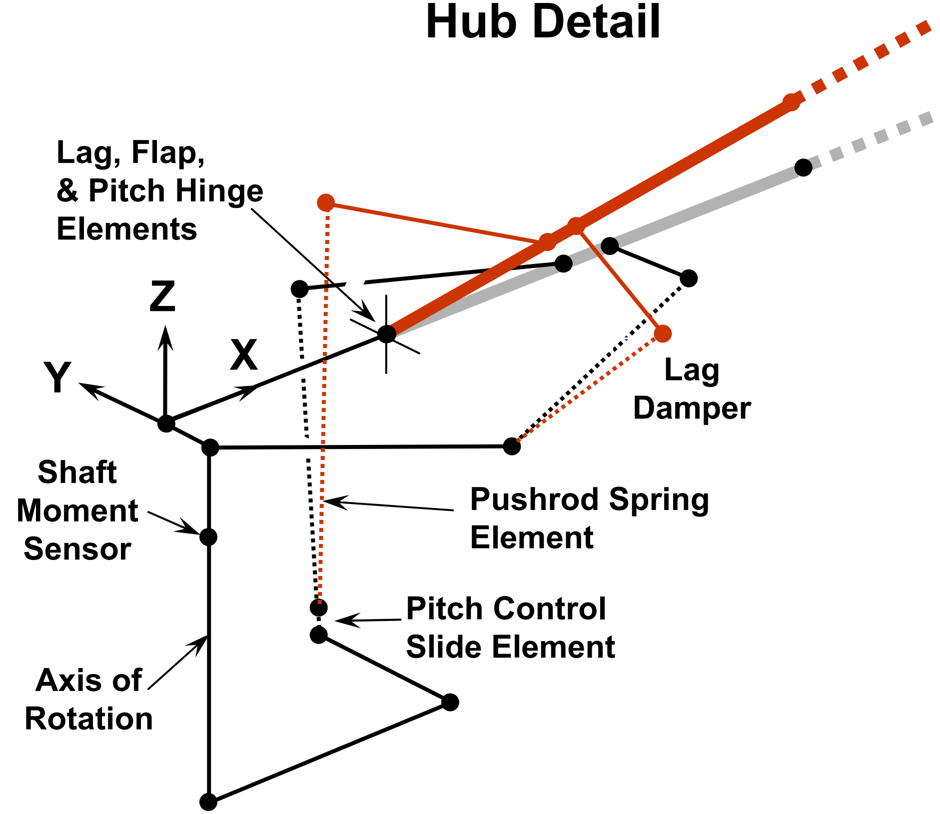
- Mechanical Airloads Analysis - calculation of dynamic response from measured airloads & damper force
  - Summary findings & adequacy of structural dynamics analysis
  - Experimental test data accuracy & blade property data issues
- Comprehensive Analysis Airloads & Blade Loads
- CFD Airloads
- Some suggested actions

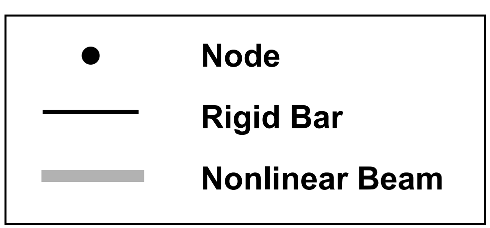
UH-60 Structural Model

UH-60 Hub and Blade Attachment Components

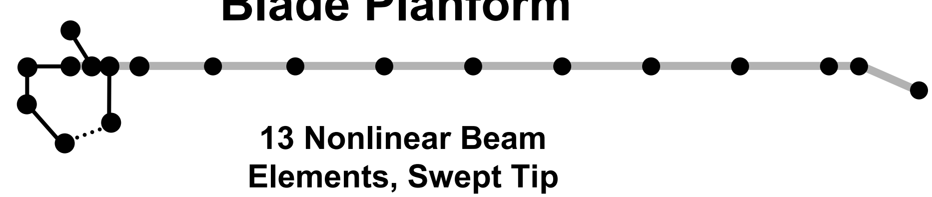


Hub Detail





Blade Planform



Structural Dynamics Analysis

- Mechanical Airloads Analysis results
  - Analysis & test data correlation involves
    - Code accuracy
    - Modeling errors
    - Property data errors
    - Experimental test data errors
  - Vibratory blade loads (flatwise, edgewise, torsion moments & pushrod force) calculated from measured airloads and damper forces generally agreed very well with measured blade loads
  - Mechanical airloads analysis accuracy sensitive to structural resonance (e.g., 1st flap & torsion freqs near 1 & 4/rev) measured airload & blade property errors
  - "Unresolved" accuracy issues
    - I/Rev blade motion
    - Blade 5/rev edgewise, 4 & 5/rev torsion moments
    - Mean pushrod loads, including blade-to-blade differences
    - Upper shaft bending moment, particularly 1/rev phase
    - Shaft torque, particularly mean value
- Modern *multi body, finite element (MB, FE)* rotorcraft structural dynamics codes appear reasonably satisfactory and accurate for rotorcraft applications

Experimental Test Data Accuracy Issues

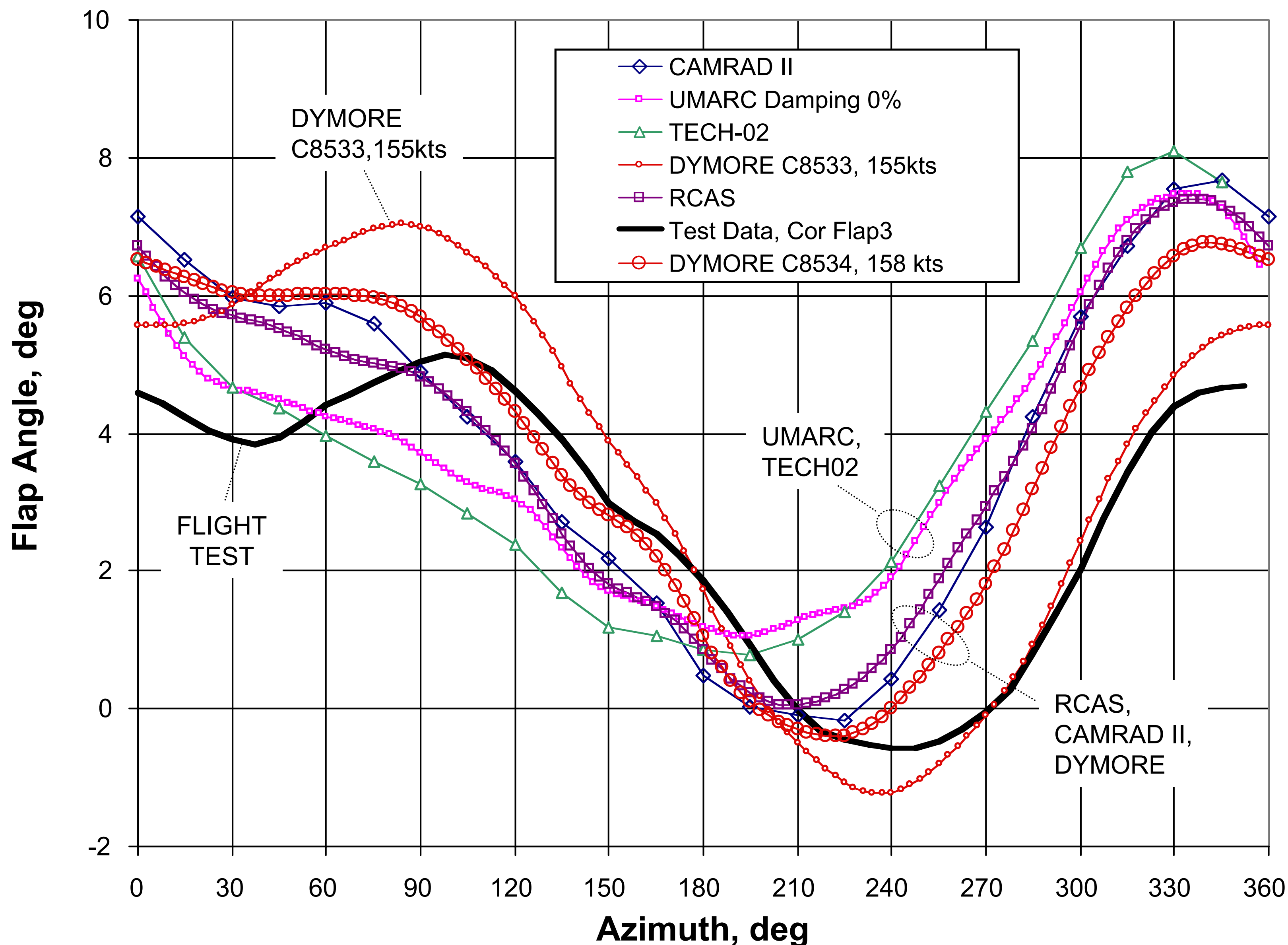
- Measured test data considered likely or possibly erroneous
  - Mean values of blade bending moments at two flatwise locations, several edgewise locations, and two torsion locations
  - Mean flapwise bending moments, 11.3%R, 70%R
  - Mean edgewise bending moments, 30%R, 40%R, 50%R, 60%R
  - Mean torsion moment, 30%R, 50%R
  - Mean aerodynamic pitch moments, 67.5%R, 96.5%R
  - Variation of mean lead-lag damper force, No. 1-4
  - Blade pitch, flap, lag, angles, variations and blade No. 4 pitch angle
  - Small unidentified errors in the measured airloads (cause discrepancy in the 1/rev flapping phase)
- Other considerations
  - Blade bending & torsion moment data interactions have been evaluated
    - (Hyeonsoo Yeo analyses)
  - Accuracy of Blade Motion Hardware (BMH) sensor calibration (data input for corrected blade motion) should be evaluated

Blade Property Data Issues

- Most, but not all, of the properties were sufficiently well known for the present problem. Some spec values have been revised.
- Lag damper geometry (refined, evaluated)
  - Small geometric details of the damper attachments were shown to have a large effect on pushrod and torsion loads
- Uncertain pushrod stiffness (62,631 vs 187,792 lb/ft ….1st torsion frequency < or > 4/rev)
- Elastomeric bearing flap, lag, and pitch rotational springs and dampers
- Pushrod and pitch bearing damping strongly influence 1/rev and 4/rev pushrod and blade torsion loads
  - Pitch bearing damping, spec value OK, 20 ft-lb/rad/sec
  - Pushrod damping was needed to achieve reasonable 4/rev torsion moments, 240lb/ft/sec (specification value = 0)
- Structural damping unknown, RCAS used 0.02% (not critical)
- Blade structural twist @ 11.3%R corrected from original spec
- Spec blade root cutout reduced from 20% to 13.04%

1/Rev Flapping Summary Comparison

Measured Airloads, Counter C8534, 158 kts

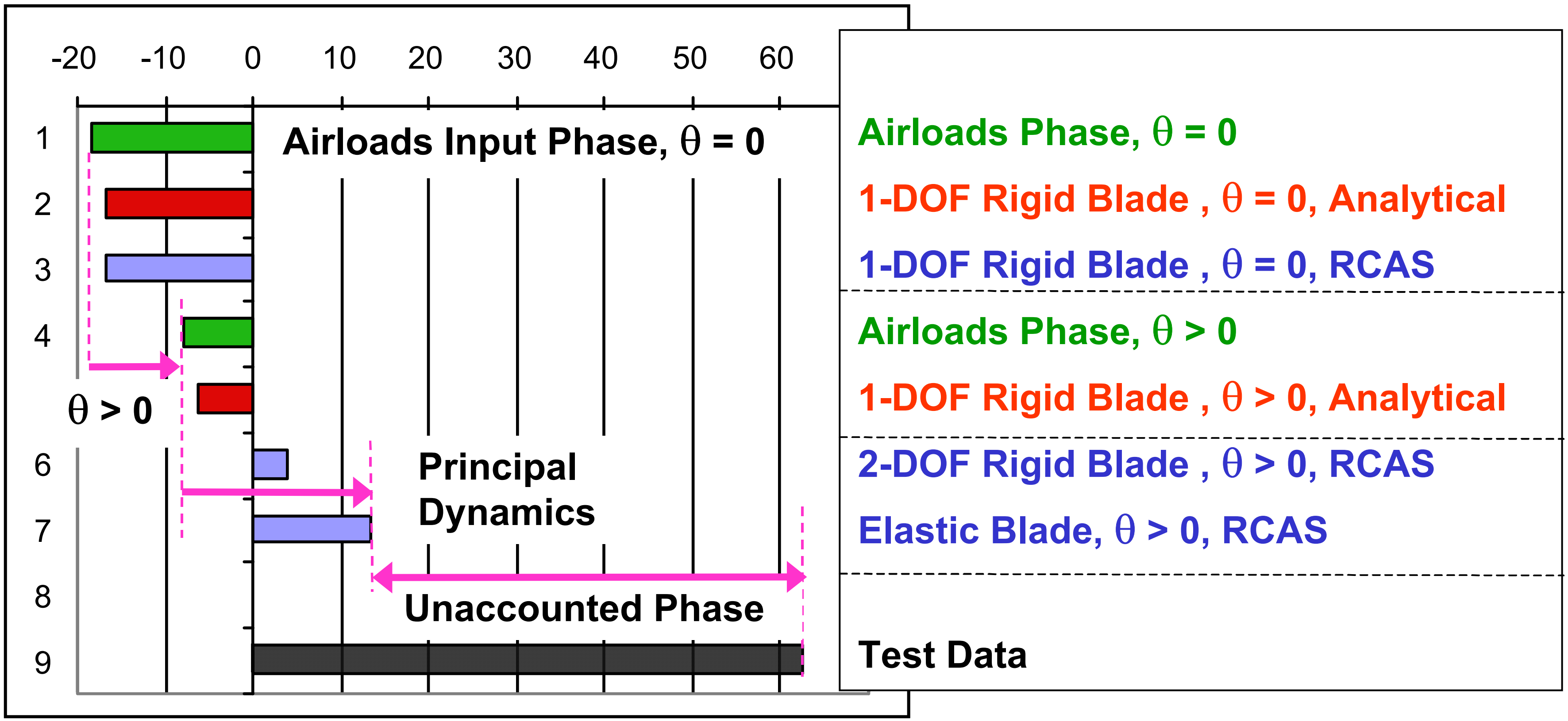


1/rev Flapping Phase Contributions

Flapping Phase = FRF Phase (Blade Dynamics) + Flap Moment Phase

$$[\beta_N]_{Phase} = \left[\frac{\beta}{\bar{\bar{M}}_{\beta}}{}_{\omega=N}(\omega)\right]_{Phase} + \left[M_{\beta_{aero\,N}}\right]_{Phase}$$

1P Flapping Phase, deg

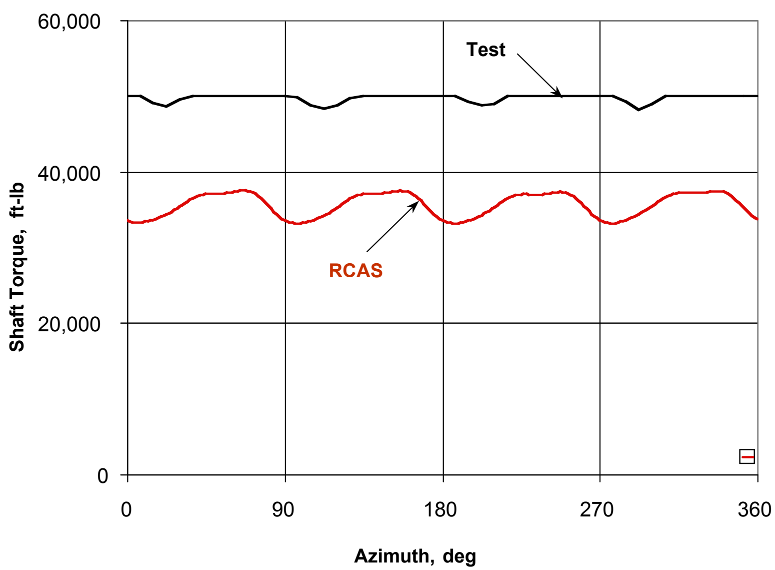


1/Rev Flapping Phase - Interpretation & Conclusions

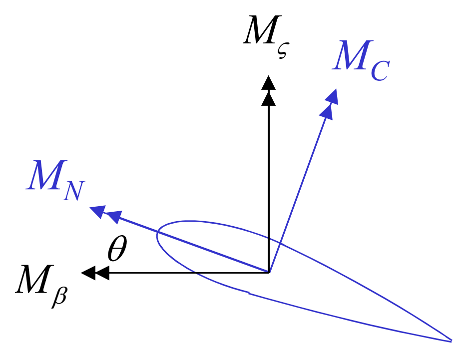
- Due to near resonance of flap mode frequency & 1/rev airloads excitation, the 1/rev flapping response amplitude and phase are determined by very small aerodynamic flapping moments
- Large flapping response sensitivity (FRF) amplifies flapping magnitude error due to 1/rev aero flapping moment experimental error
- Small errors in the measured airloads apparently cause the flapping phase discrepancy
- No specific source of this suggested error has been identified

Airloads Chord Force Contribution to 1/Rev Flapping

Rotor Shaft Torque "Error"



Contribution of chord force edgewise moment to 1/rev flapping excitation -



$$M_\beta = M_N \cdot \cos\theta - M_C \cdot \sin\theta$$

Airloads Workshop RCAS Activity

- Relevant RCAS Upgrades
  - Mechanical airloads analysis
    - Mechanical airloads analysis as standard option
    - Multiple algorithms
      - Direct coupling, with & w/out artificial initial damping
      - Loose coupling, arbitrary RCAS airloads for “delta” loads
      - Treat airloads, damper loads, other arbitrary loads
  - CFD Coupling, CHSSI Project
    - Rotor CFD/CSD coupling - loose, tight, intermediate
    - Rotor/fuselage/empennage
    - Maneuver, vibration, aeroelastic stability
    - Investigate algorithm solution convergence
- Mechanical airloads additional test conditions
  - Counters C8533, C8524, C9017, etc., in progress
  - Complete Blade Motion Hardware Analysis

Where Are We Going?
Suggestions & Action Items (1 of 2)

- Mechanical Airloads Problem
  - Refine participating code calculations, collect results for comparison plots. Plan for a joint workshop paper
  - Compare mechanical airloads for other flight conditions to address unresolved issues - e.g., how do flap phase or chord bending moment anomalies vary with flight speed
  - Collect and compare fan plots and mode shapes
  - Define simple proof problem - radially uniform properties & airloads
  - Modeling extensions - drive train dynamics, hub degrees of freedom, fuselage dynamics, vibration absorber, etc.
- Comprehensive Analysis Comparisons
  - Update lifting line aero calculations for consistency
  - Complete comparisons for uniform inflow and linear airfoil case
  - Plan for joint publication

Where Are We Going?
Suggestions & Action Items (2 of 2)

- CFD Activities
  - CFD - Current results show significant improvement over conventional lifting line methods
  - But... best current CFD results not quite good enough
  - Multiple CFD code and CFD/CSD coupling efforts in progress - these activities should proceed
  - Efficient loose and tight coupling algorithms will evolve in the near future
  - Hybrid CFD/vortex wake methods should evolve toward full wake capturing CFD methods
  - Advanced CFD methodologies should be pursued
  - To diagnose remaining correlation deficiencies, correlation of CFD analyses with reduced experimental data sets should be pursued, e.g., 2-D airfoils, wings, hovering rotors, etc.