Prediction of UH-60A blade loads: an insight on Confluence Algorithm to correct internally generated airloads

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Introduction

- **Objectives**
  - Develop an effective procedure for strain mapping using experimental measurements
  - Achieve accurate internal loads predictions using simplified aerodynamic and CSD models

- **Motivation**
  - Improve stress/strain predictions to be used for Condition Based Maintenance for rotating components

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Outline

- Overview of Load Confluence Algorithm
- UH-60 numerical model
- Validation of performance of LCA for level-flight
  - High speed condition (C-8534)
  - High thrust condition (C-9017)
  - Low speed condition (C-8513)
Concept

Step 1

Step 2

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The Load Confluence Algorithm

- Measure strains
- Compare measurements with predictions
- Iteratively increment applied loads

DYM ORE
Full non-linear mechanical algorithm

Input Airloads, F(t)

- A simplified airload distribution can be applied (e.g., lifting line theory, as opposed to more computationally-intensive CFD) and iteratively modified to reach a solution that matches measured response

Dynamic analysis

Predicted strains, e

| e - ê | < tolerance?

Iterate until convergence is reached

Linearized loads update

Compute corrected loads, DF(t)

Compute strain increments
De = e - ê

Convergence reached

Strain mapping algorithm

Measured strains (ê) and state parameters

Blade (flapwise, edgewise, torsion), hub/controls (pitch link, pitch horn, lead-lag damper, etc.), fuselage (accel)

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Strain Mapping Algorithm

- Compute a linearized increment to applied loads
  - Modal approximation of response
  - Expansion in Fourier’s series

- Obtain algebraic relations between Fourier’s coefficients of response and applied loads

- Increment applied loads

Parameters
- # modes: \( m \)
- # harmonics: \( h \)
Use of simplified airloads is sufficient for accurate prediction of internal loads because of iterative corrections of applied loads!!!
High speed condition C-8534

Flap moment along span (15 sensors, 10 modes, 4 harmonics)

- @ 20%
- @ 40%
- @ 70%
- @ 30%
- @ 60%
- @ 90%

Before LCA

After LCA

Measured
High speed condition C-8534

Lag moment along span (15 sensors, 10 modes, 4 harmonics)

@ 20%

@ 40%

@ 70%

@ 30%

@ 60%

@ 90%

Measured

Before LCA

After LCA
High speed condition C-8534

Torsional moment along span (15 sensors, 10 modes, 4 harmonics)

@ 30%

@ 50%

@ 70%

@ 90%

Before LCA

After LCA

Measured
Comments

- 3-4/rev flap moment predicted within 5%
Comments

- 3-4/rev flap moment predicted within 5%
- 4/rev lag moment predicted within 10%, 3-5/rev discrepancies compatible with CFD/CSD predictions

Lag moment

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High speed condition C-8534

Comments

- 3-4/rev flap moment predicted within 5%
- 4/rev lag moment predicted within 10%, 3-5/rev discrepancies compatible with CFD/CSD predictions
- 3-4-5/rev torsion moment improved, but discrepancies due to lack of experimental data
Analysis of LCA convergence

- Number of harmonics: 4
- Number of modes: 6

Torsional moment

Flap moment

Lag moment
Analysis of LCA convergence

- Number of harmonics: 6
- Number of modes: 6

Torsional moment

Flap moment

Lag moment

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Analysis of LCA convergence

- Number of harmonics: 4
- Number of modes: 10

- Torsional moment
- Flap moment
- Lag moment

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Analysis of LCA convergence

- Torsional moment at 70% span

Before LCA

4 harmonics, 4 modes

6 harmonics, 4 modes

4 harmonics, 10 modes

After LCA

Measured

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Analysis of LCA convergence

4 harmonics, 10 modes
- Lowest iterations
- Lowest oscillations

Before LCA

After LCA

Measured
High thrust condition C-9017

Torsional moment along span (11 sensors, 8 modes, 4 harmonics)

Before LCA

After LCA

@ 30%

@ 50%

@ 70%

@ 90%
High thrust condition C-9017

Flap moment along span (11 sensors, 8 modes, 4 harmonics)

@ 10%
@ 20%
@ 40%
@ 60%
@ 70%

Measured

After LCA

Before LCA
High thrust condition C-9017

Lag moment along span (11 sensors, 8 modes, 4 harmonics)

Before LCA

Measured

After LCA

@ 10%

@ 70%

@ 60%
Comments

- # sensors reduced to 11 (30% reduction)
- Improvement in accuracy of flap moment, large discrepancies due to lack of measurements
- Critical prediction of lag moment because of lack of measurements
- 3-4-5/rev torsion moment predicted within 20%, discrepancies compatible with CFD/CSD analysis
Low speed condition C-8513

Flap moment along span (15 sensors, 10 modes, 4 harmonics)

Before LCA

After LCA

Measured

@ 20%

@ 40%

@ 60%

@ 90%

@ 30%

@ 50%

@ 70%
Low speed condition C-8513

Lag moment along span (15 sensors, 10 modes, 4 harmonics)

@ 20%

@ 40%

@ 70%

@ 30%

@ 60%

@ 90%

After LCA

Before LCA

Measured
Low speed condition C-8513

Torsional moment along span (15 sensors, 10 modes, 4 harmonics)

@ 30%

@ 50%

@ 70%

@ 90%

Before LCA

Measured

After LCA
Low speed condition C-8513

Comments

- 3-4/rev flap moment predicted within 5%

Flap moment

3/rev

4/rev

5/rev

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Comments

- 3-4/rev flap moment predicted within 5%
- 3-4/rev lag moment predicted within 5%, 5/rev within 20% due to unmodeled dynamics
Comments

- 3-4/rev flap moment predicted within 5%
- 3-4/rev lag moment predicted within 5%, 5/rev within 20% because of unmodeled dynamics
- 3-4-5/rev torsion moment improved, but discrepancies due to lack of experimental data

Low speed condition C-8513

Torsional moment

After LCA

Measured
Conclusions

- Choice of # of modes and # of harmonics critical for convergence
- Availability of sufficient # of sensors critical for accuracy
- Fast, accurate and general procedure
- Future work: influence on pitch-link loads
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