Improved Coupling for UH-60 Performance Prediction

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Overview

• Part 1 – Force Conservation in Coupled Simulations
  – Review of presentation from Aug. 2011
  – New results with improved azimuthal resolution

• Part 2 – Preliminary Comparisons of Measured/Predicted Blade Motion
  – Introduction to measurement technique
  – Rigid Body Motion (RBM) comparisons
  – Elastic deformation comparisons
Software Toolkit

• CFD: OVERFLOW2 v2.2b
  – 4th order central differencing in space; 2nd order dual timestepping
  – Spalart-Almaras 1-eq. turbulence model with rotational corrections (inviscid off-body)
  – Blade surfaces modeled as fully-turbulent, viscous, adiabatic walls

• Comprehensive: CAMRADII v4.6
  – CSD: non-linear finite elements
  – Control system, trim

• Loose delta-coupling technique
  – OVERFLOW2→CAMRADII = sectional airload deltas (normal force, chord force, and pitching moment)
  – CAMRADII→OVERFLOW2 = blade motions (elastic deformations plus rigid motions)
Speed Sweep Overview

- Run 52 from 40x80 Airloads test
- $\mu=0.15–0.4$, $M_{\text{tip}}=0.65$, $C_{L}/\sigma=0.09$
- Predictions matched corrected $\alpha_s$ and trimmed to match tunnel loads—$C_T$, $C_{M,R}$, $C_{M,P}$—at each speed.
- All performance indices are integrated from CFD solution. Comprehensive code predicts somewhat different values.

![Graph showing speed sweep overview with various data points and labels.](chart.png)
Planform Unification

• CAMRAD II model began just outboard of blade grip; CFD grid extends inboard to $r/R=7\%$
• Approx 1% of CFD predicted thrust comes from the region between $r/R=7\%$ and 19%
• Very small adjustments were also made to unify chord and twist distribution.
• Blade grip/shank will likely be necessary for accurate performance prediction at high $\mu$

![Diagram showing design, CAMRAD II model, and CFD grid.](attachment:image.png)
Airload Transfer Resolution

- CFD provides airloads at \( \sim 170 \) radial and 360 azimuthal stations
- Old model downsampling to 21 radial and 24 azimuthal locations
- Define sampling error:

\[
\text{exact} = \int \int \mathcal{C}_{n,c,m} \, dr \, d\psi \\
\text{sampled} = \int \int \mathcal{C}_{n,c,m} \, dr \, d\psi \\
\text{error} = \frac{\text{sampled}}{\text{exact}} - 1
\]
Force Conservation vs. Coupling Resolution

$C_T/\sigma = 0.09, M_{tip} = 0.65, \mu = 0.3$

$C_T/\sigma = 0.1255, M_{tip} = 0.625, \mu = 0.3$
Blade Displacement Measurements

Setup/Hardware

- 8-cameras, 2 per rotor quadrant
- 4-Mega-pixel, 12-bit CCD progressive scan digital cameras, with a pixel resolution of $2048 \times 2048$ pixels
- Nikon 10.5 mm f/2.8 DX (fish-eye) lenses
- Xenon flash-lamp 50 mJ strobes

Blades

- Targets on the lower surface of each blade
- 48 retro-reflective targets, 2 inch dia.
- 3 per radial station at $r/R$ from 0.2 to 0.97

Ceiling

- 84 retro-reflective targets, 6 inch dia.
- 84 coded targets
Data Reduction and Validation

BD 4- camera intersection

Synchronously captured images from 4 different cameras of blade 1

Long-exposure (~10ms) view of quadrant-1 from BD data camera 2

10 µ-sec data shot exposures
Rigid Body Motions

- Run 42, Points 60-63
- $C_T/\sigma=0.10$, $M_{\text{tip}}=0.65$, $\mu=0.3$
- Measured Rigid Body Motions (RBM) estimated from targets at $r/R=0.2$, 0.25, 0.3, 0.35.
Out of Plane Bending

Azimuth, deg

Elastic AZ, in

Blade 1
Blade 2
Blade 3
Blade 4
CFD/CSD

r/R=0.97

Ψ=0˚

Ψ=150˚

Ψ=255˚

Elastic AZ, inch

Radial position, r/R

Radial position, r/R

Measured, RBM Estimated
Predicted, RBM Exact
Predicted, RBM Estimated
Elastic Twist

\[ \Psi \]

\[ \Psi = 0^\circ \]

\[ \Psi = 150^\circ \]

\[ \Psi = 255^\circ \]
Summary

• Part 1 – Force Conservation
  – Increasing CAMRAD panel count and adding aerodynamic panels to account for inboard portion of rotor cures most of the force conservation issue.
  – Increasing azimuthal resolution improves conservation somewhat but can be a pain to implement.

• Part 2 – Blade Motion Comparisons
  – Preliminary comparisons of RBM look reasonable. Trends are good but there are issues with means (pitch, lag) and phase (flap).
  – Elastic deformation is more difficult to compare primarily due to difficulties in estimating and removing RBM.
CFD Grid

- As-built blade geometry with notional centerbody
- Blade grid: 157x163 chord/span, O-mesh, $y^+=1$
- Free-air simulation using wall corrected data
  - Tunnel wall model available
- Finest off-body spacing was 10% $C_{tip}$
- 27M points total (11.5M in near-body)
Modeling Improvements

• CAMRAD II / OVERFLOW planform unification
• High resolution airload transfer
Sampling Error: $\mu=0.3$, $C_T/\sigma=0.1255$

- Deep stall features large azimuthal gradients.
- 80 or more spanwise samples plus >90 timesteps required for optimum force conservation.
Sampling Error: $\mu=0.3$, $C_L/\sigma=0.09$

- Radial gradients dominate at this condition.
- 100 or more spanwise samples required for optimum force conservation.
Force Prediction with New Model

- CAMRAD II and OVERFLOW agree on F&M well within 1%
- Propulsive force decreased across speed range
Power Prediction with New Model

- Total power is reduced across speed range for new model
- Induced and profile power continue as the dominant sources of error

Test
Old Model
Improved Model
Airload Comparison: $\mu=0.4$, $C_L/\sigma=0.09$

- Airload changes are small and consistent with reduced thrust.
Summary

• Force conservation necessitates very careful coordination between CFD grid and CSD representation
• Downsampling airloads between CFD and CSD introduces significant error:
  – Benign conditions can tolerate large timesteps but still require sufficient spanwise resolution
  – Cases with large azimuthal gradients (BVI, Stall) necessitate small timesteps in addition to sufficient spanwise resolution
• The improved model cures trim error for the studied speed sweep
• Performance and airloads predictions demonstrate the expected response to improved trim
Moment Coefficient Sampling Error

\[ \mu = 0.3, \quad C_L / \sigma = 0.09 \]

\[ \mu = 0.3, \quad C_T / \sigma = 0.1255 \]
\( \mu = 0.3, \ \frac{C_T}{\sigma} = 0.1255 \)
$\mu=0.3, \ C_T/\sigma=0.1255$