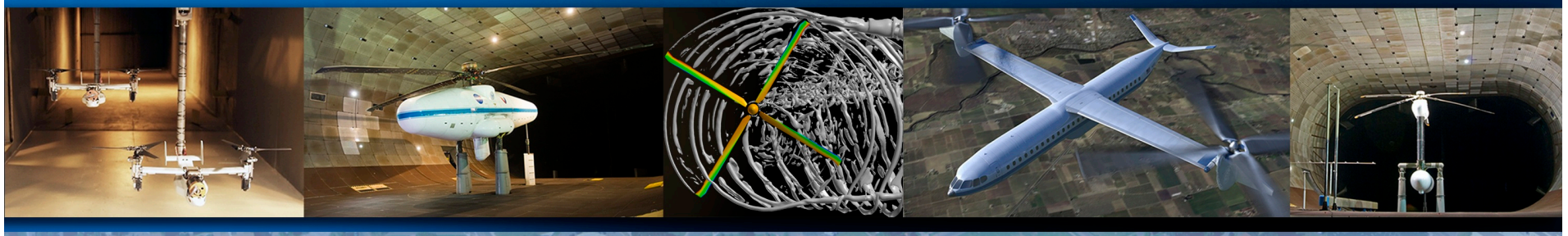
Improved Coupling for UH-60 Performance Prediction

Ethan Romander

UH-60 Airloads Workshop – March 8, 2012



Aeromechanics Branch - NASA Ames Research Center

Overview

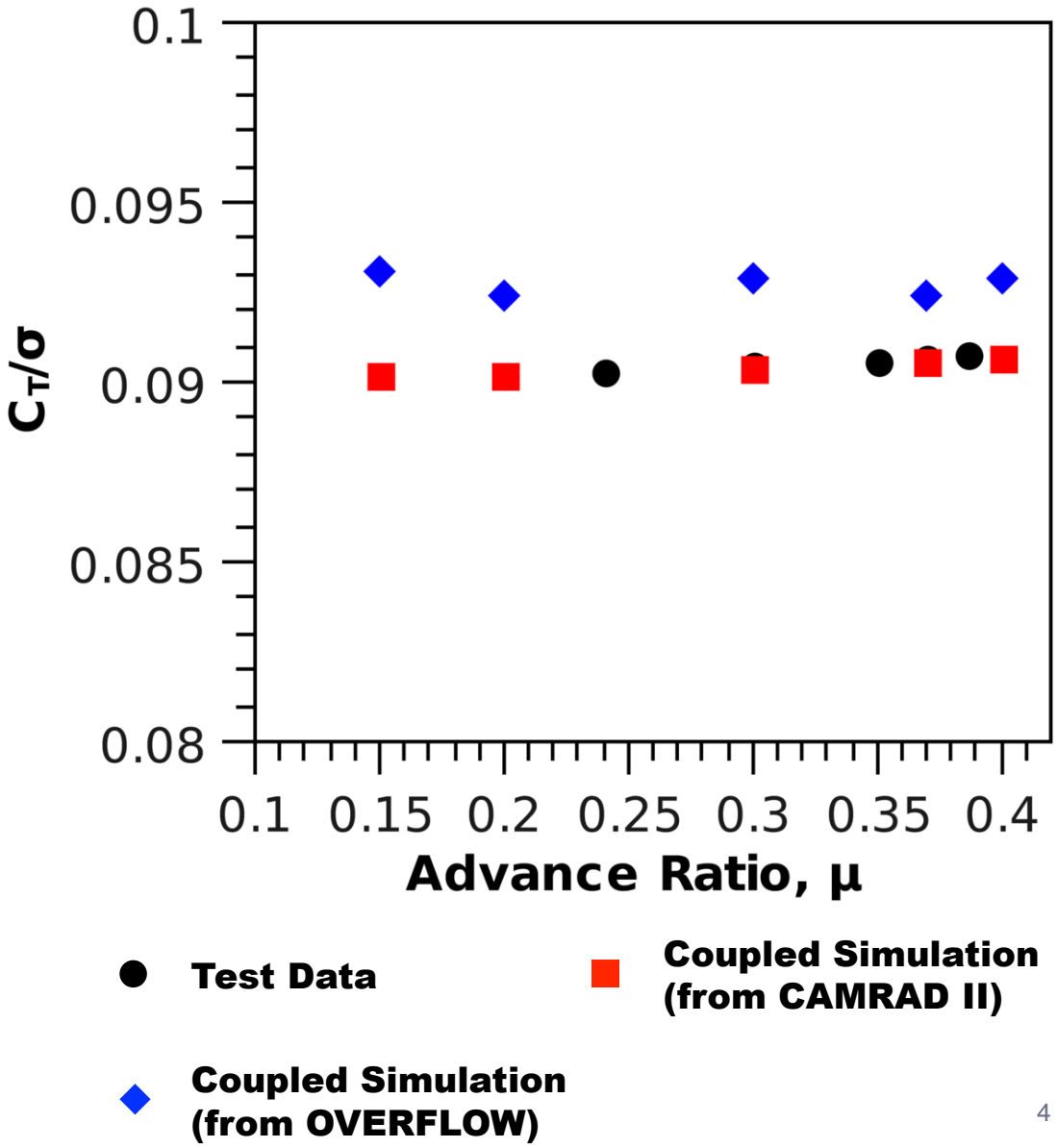
- Part 1 – Force Conservation in Coupled Simulations
  - Review of presentation from Aug. 2011
  - New results with improved azimuthal resolution
- Part 2 – Preliminary Comparisons of Measured/ Predicted Blade Motion
  - Introduction to measurement technique
  - Rigid Body Motion (RBM) comparisons
  - Elastic deformation comparisons

Software Toolkit

- CFD: OVERFLOW2 v2.2b
  - 4^{th} order central differencing in space; 2^{nd} 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

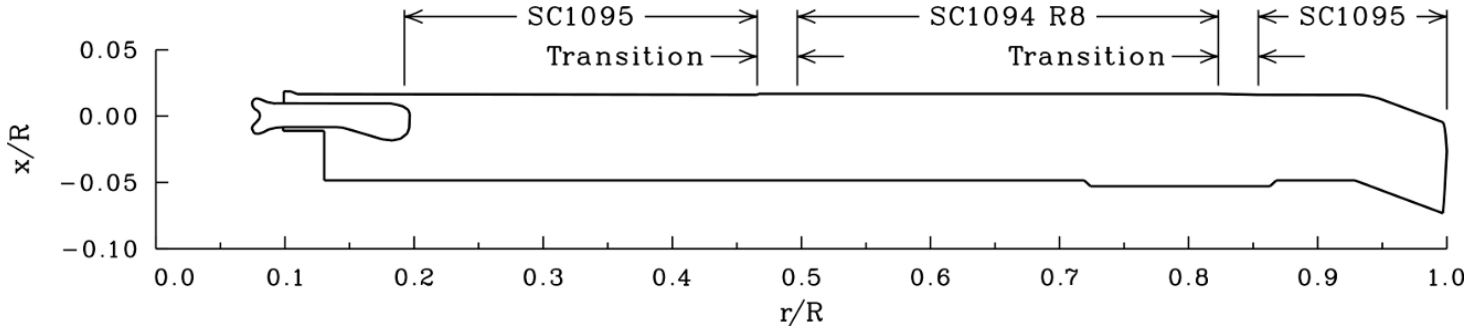
- Run 52 from 40x80 Airloads test
- μ=0.15–0.4, M_{tip}=0.65, C_L/σ=0.09
- Predictions matched corrected α_s and trimmed to match tunnel loads—C_T, $C_{M,R}$, $C_{M,P}$—at each speed.
- All performance indices are integrated from CFD solution.
  Comprehensive code predicts somewhat different values.



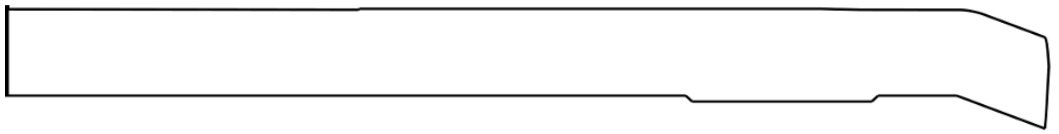
Planform Unification

- 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 μ

Design



CAMRAD II



CFD Grid

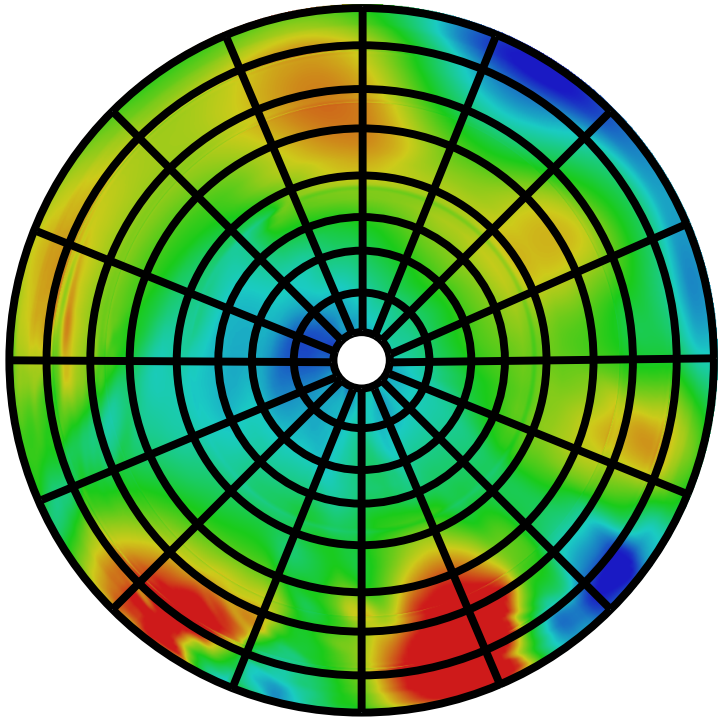
Airload Transfer Resolution

- CFD provides airloads at ~170 radial and 360 azimuthal stations
- Old model downsampled to 21 radial and 24 azimuthal locations
- Define sampling error:

$$\text{exact} = \int_{\text{CFD disk}}\int c_{n,c,m}\, dr\, d\psi$$

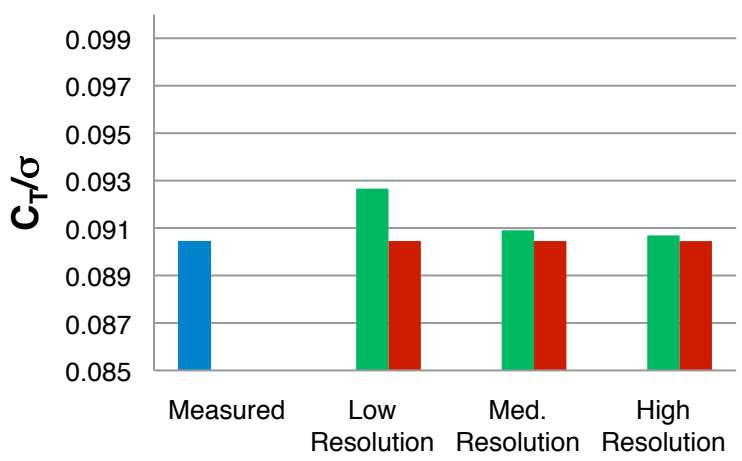
$$\text{sampled} = \int_{\text{Sampled Disk}}\int c_{n,c,m}\, dr\, d\psi$$

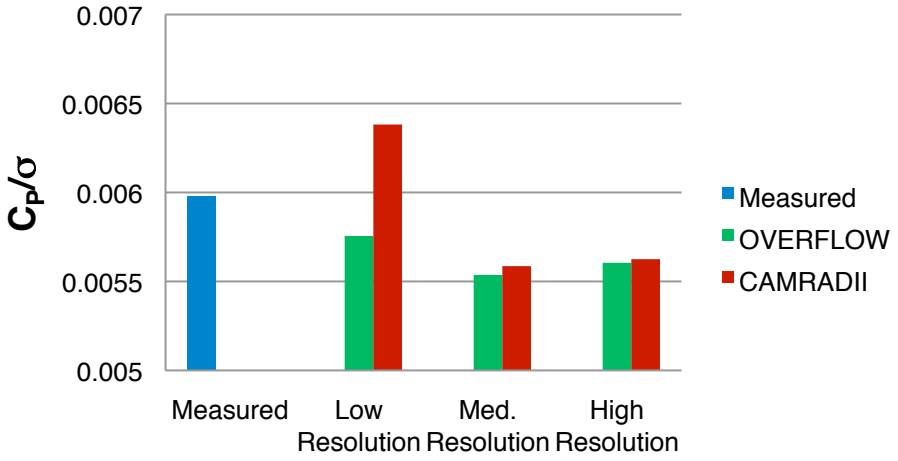
$$\text{error} = \frac{\text{sampled}}{\text{exact}} - 1$$



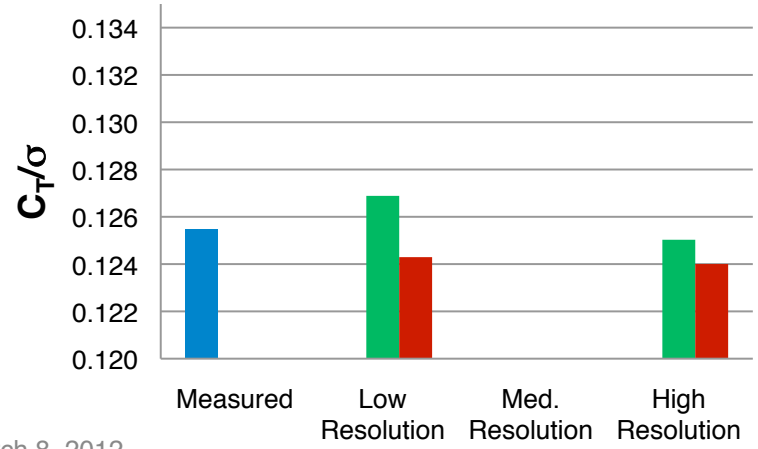
Force Conservation vs. Coupling Resolution

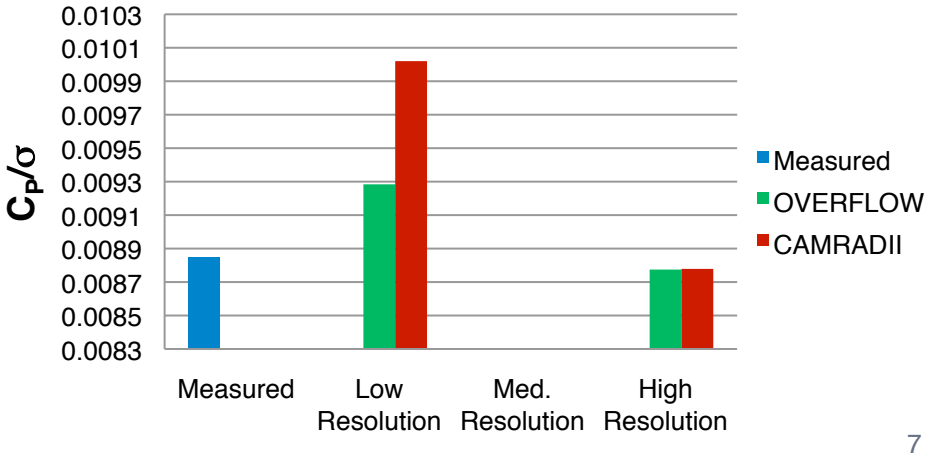
C_T/σ=0.09, M_{tip}=0.65, μ=0.3





C_T/σ=0.1255, M_{tip}=0.625, μ=0.3





Measured / Predicted Blade Motion Comparisons

Ethan Romander

Anita Abrego

Al Burner

Danny Barrows

Larry Olson

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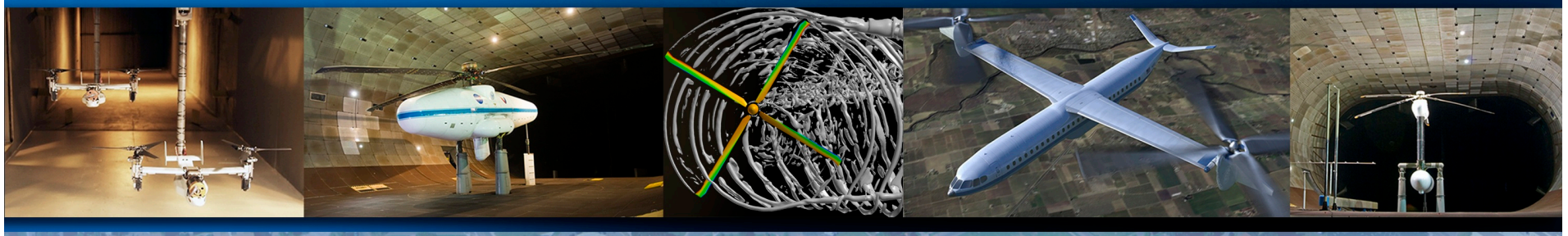

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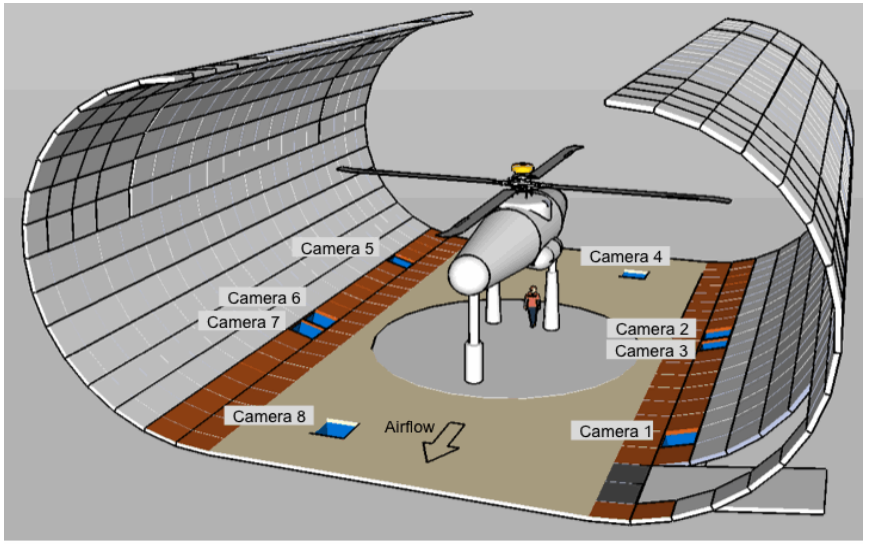
Blade Displacement Measurements

Setup/Hardware

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

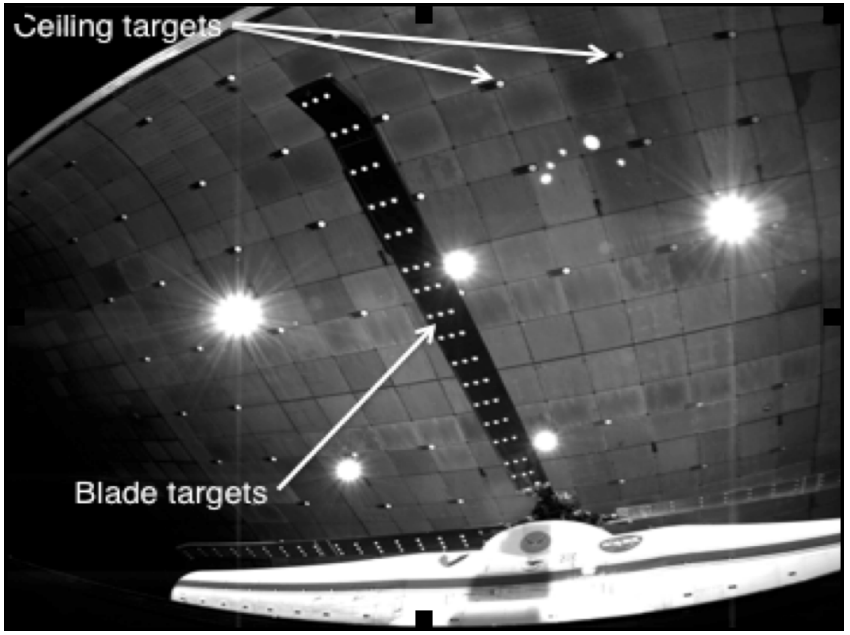


Blades

- 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

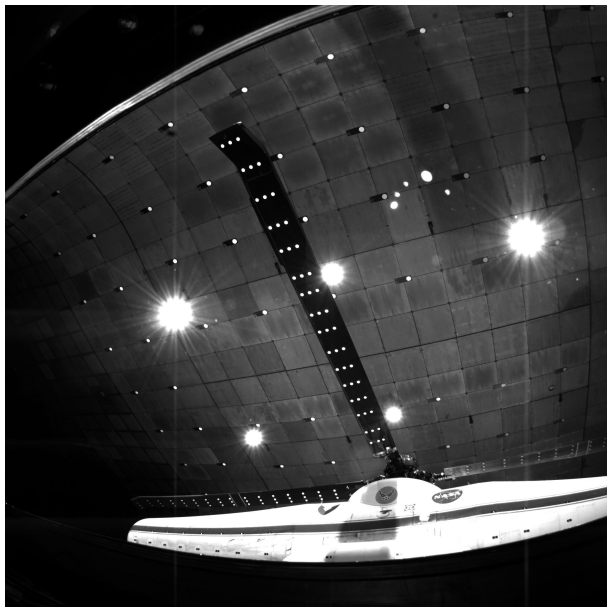
- 84 retro-reflective targets, 6 inch dia.
- 84 coded targets



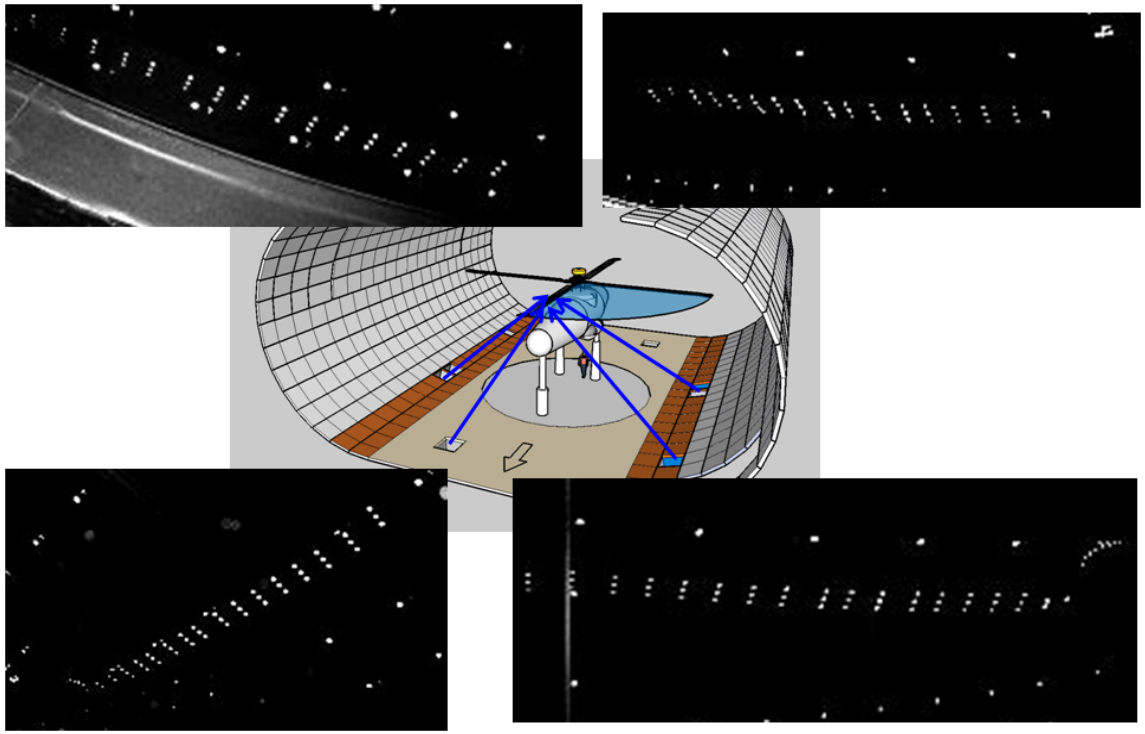
Data Reduction and Validation

BD 4- camera intersection

Synchronously captured images from 4 different cameras of blade 1



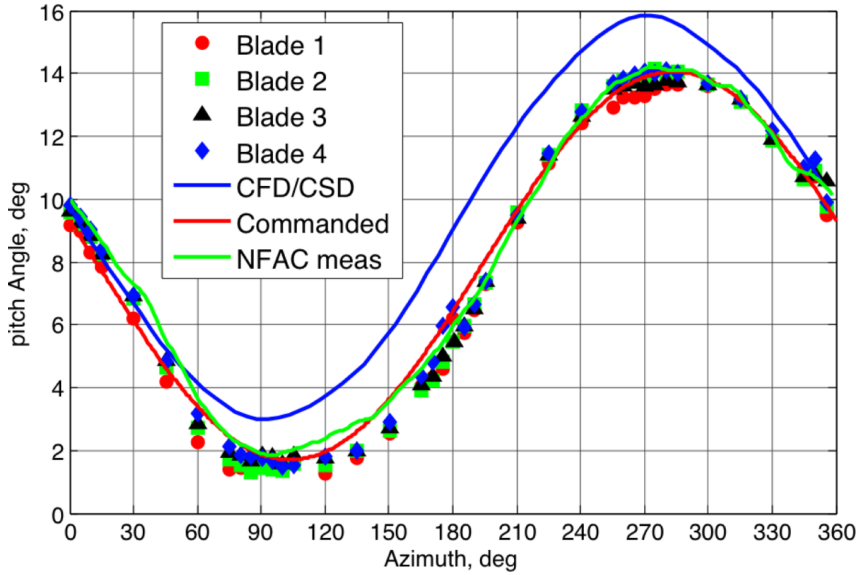
Long-exposure (~10ms) view of quadrant-1 from BD data camera 2

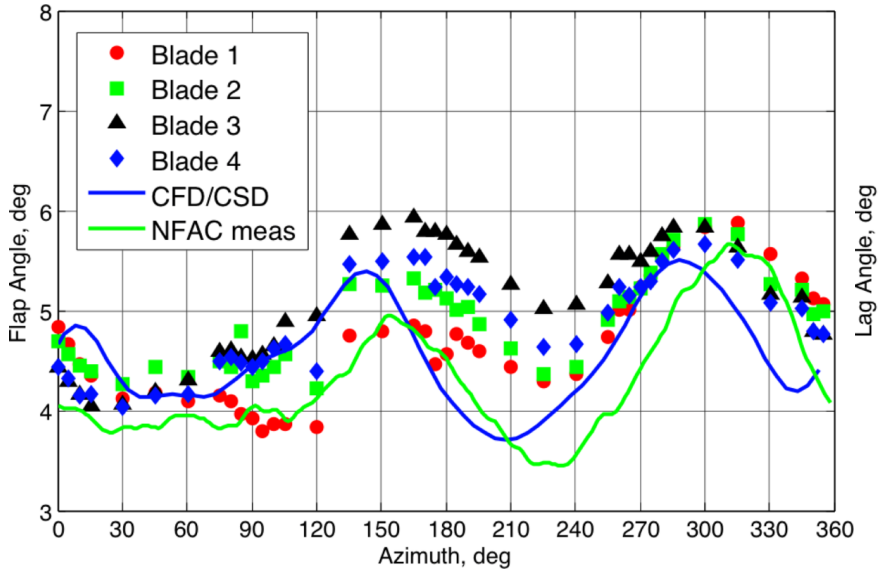


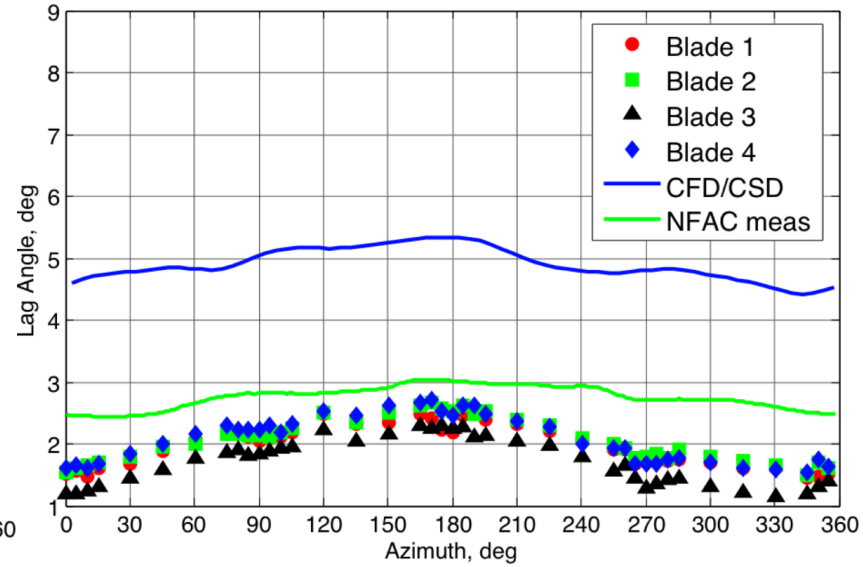
10 μ-sec data shot exposures

Rigid Body Motions

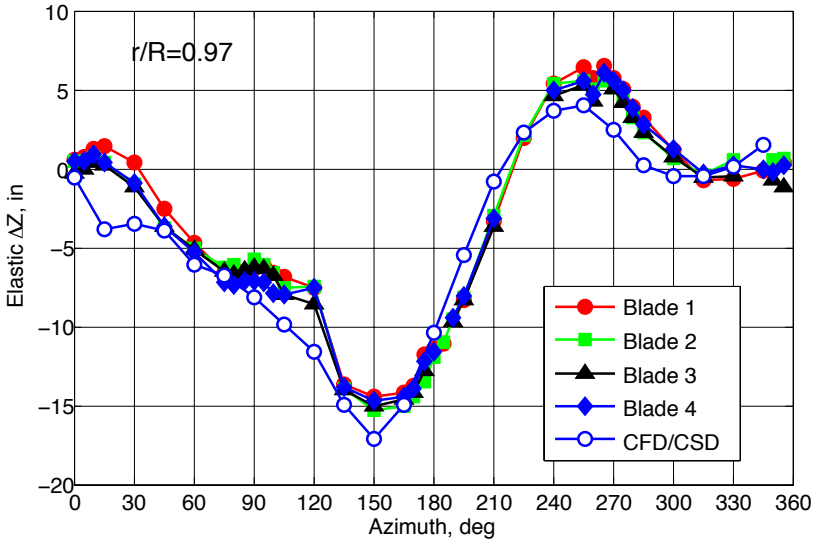
- Run 42, Points 60-63
- C_T/σ=0.10, M_{tip}=0.65, μ=0.3
- Measured Rigid Body Motions (RBM) estimated from targets at r/R=0.2, 0.25, 0.3, 0.35.

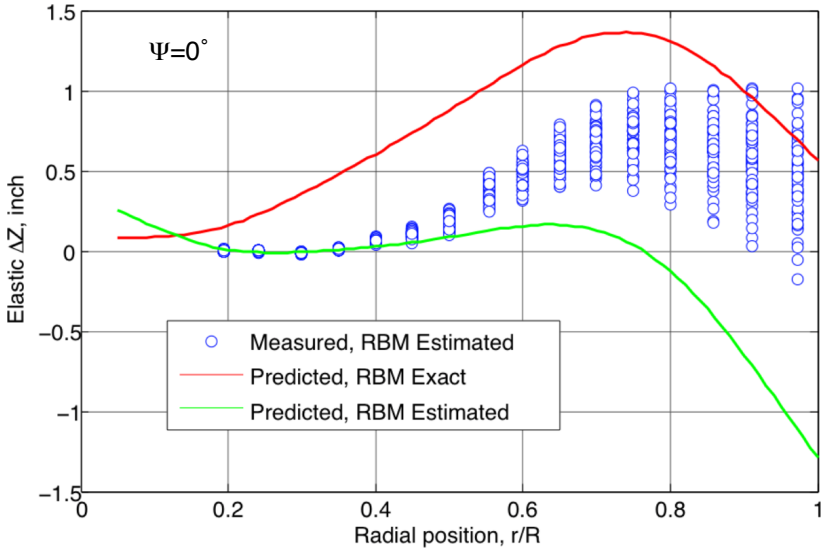


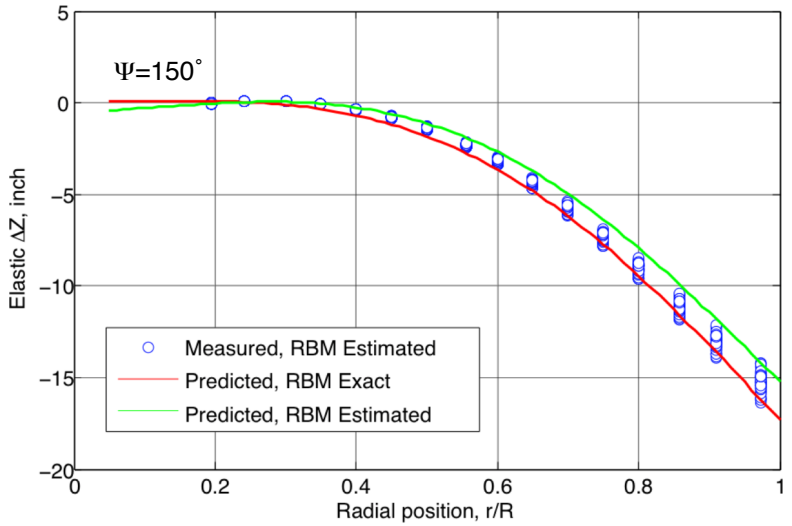


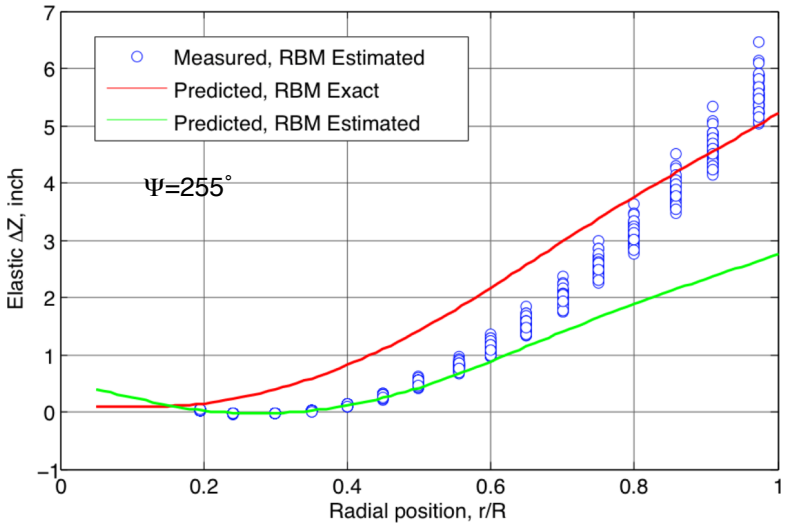


Out of Plane Bending

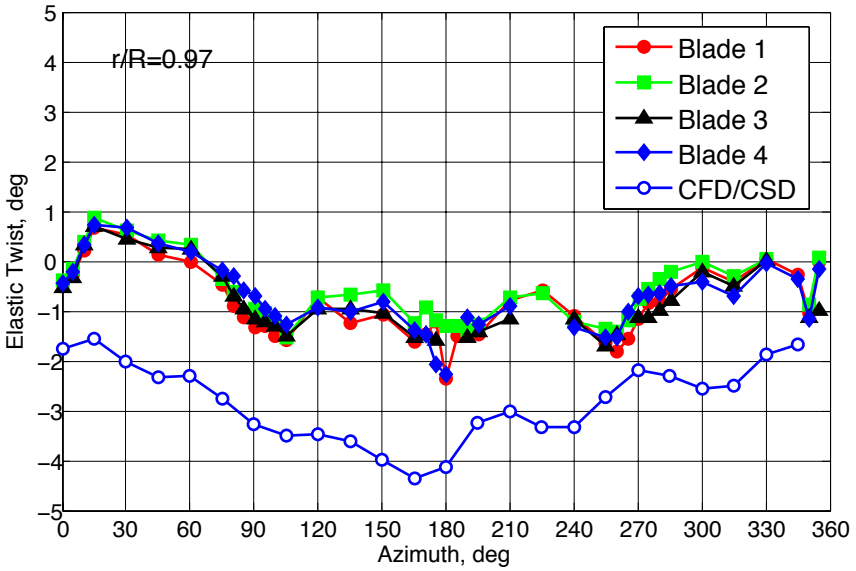


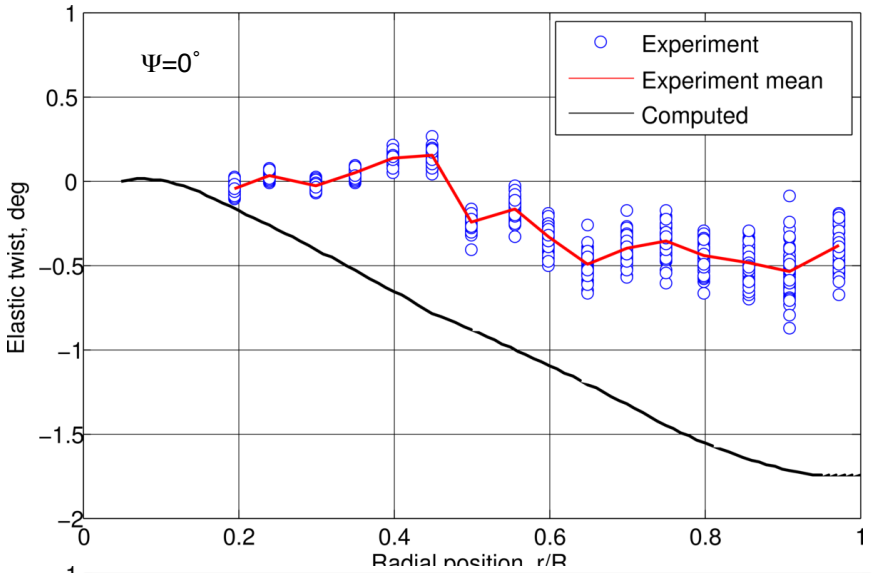


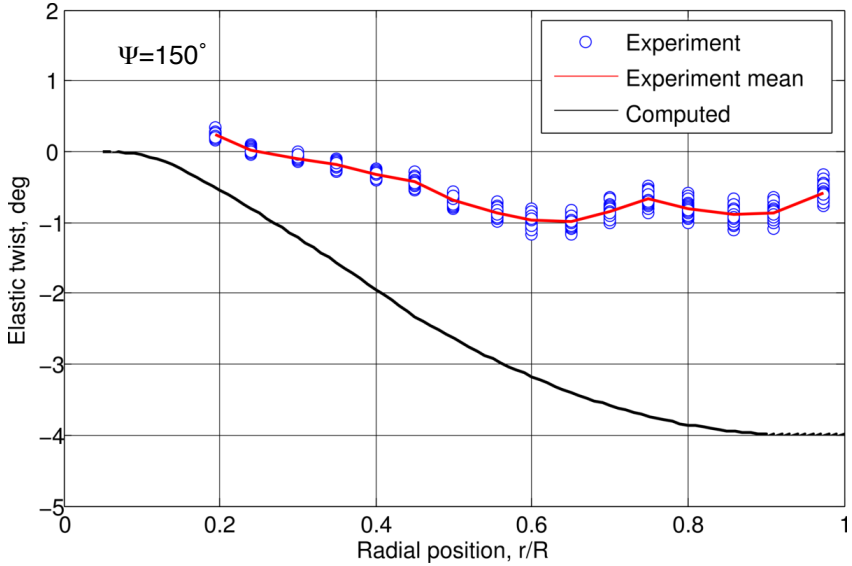


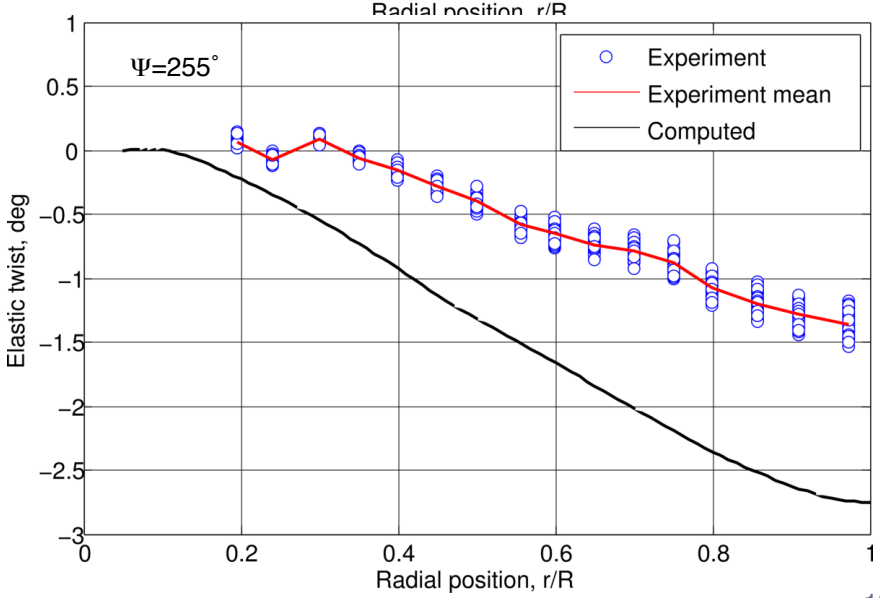


Elastic Twist



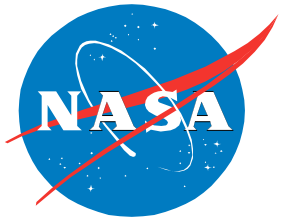




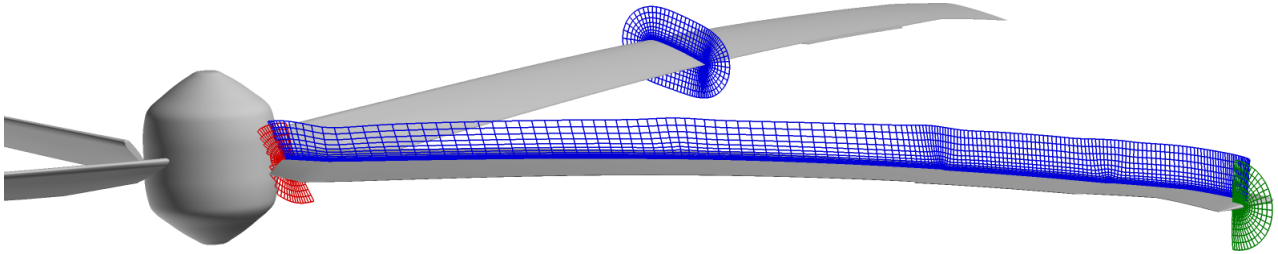


Summary

- 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.
  - Abrego, A., et al. “Blade Displacement Measurement Technique Applied to a Full-Scale Rotor Test”. 2012 AHS Forum.

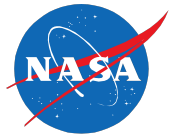

NASA

CFD Grid



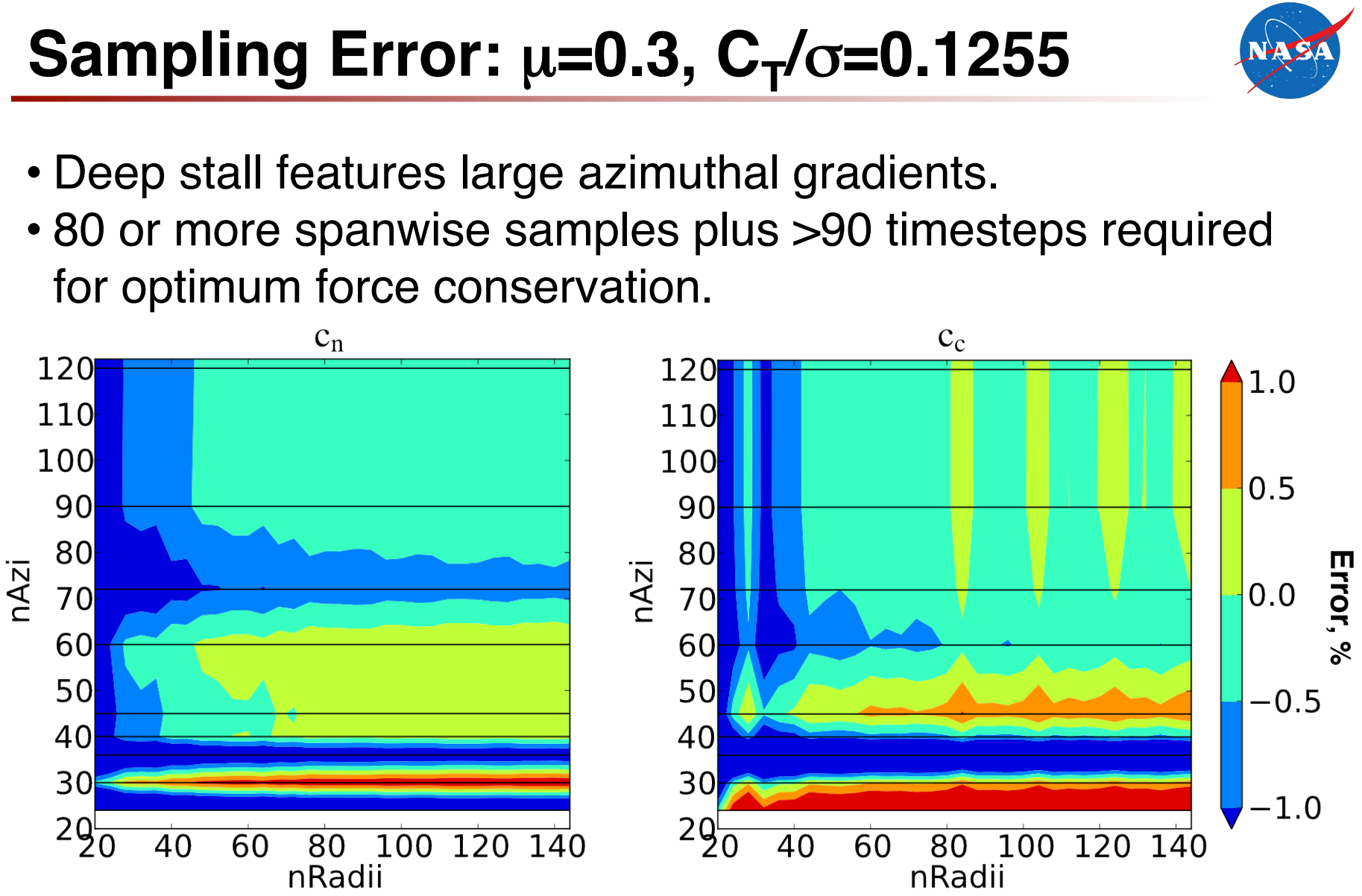
- As-built blade geometry with notional centerbody
- Blade grid: 157x163 chord/span, O-mesh, y^+=1
- Free-air simulation using wall corrected data
  - Tunnel wall model available
- Finest off-body spacing was 10% C_{tip}
- 27M points total (11.5M in near-body)

Modeling Improvements



- CAMRAD II / OVERFLOW planform unification
- High resolution airload transfer

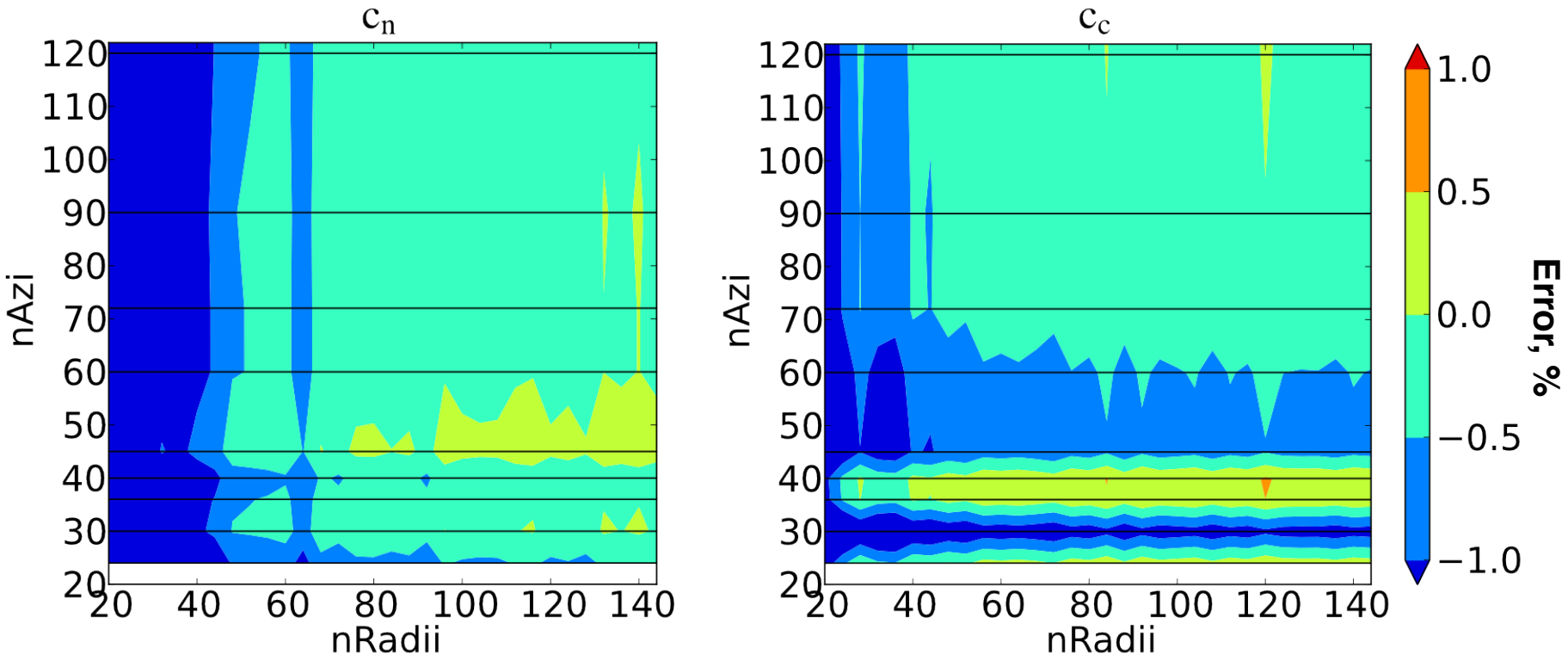
Sampling Error: μ=0.3, C_T/σ=0.1255



- Deep stall features large azimuthal gradients.
- 80 or more spanwise samples plus >90 timesteps required for optimum force conservation.

Sampling Error: μ=0.3, C_L/σ=0.09

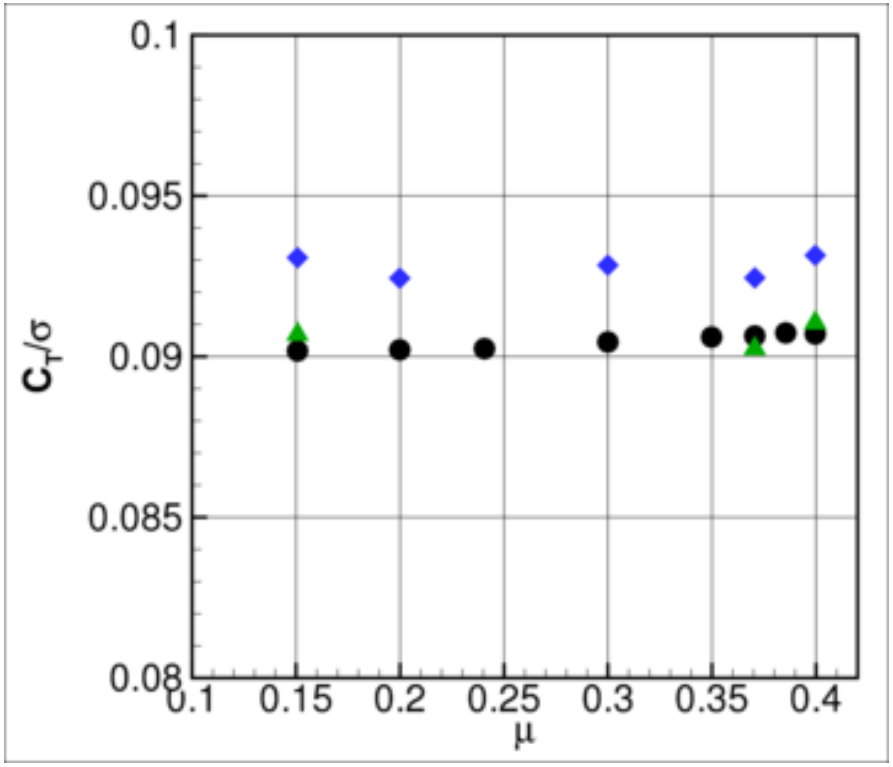
- Radial gradients dominate at this condition.
- 100 or more spanwise samples required for optimum force conservation.

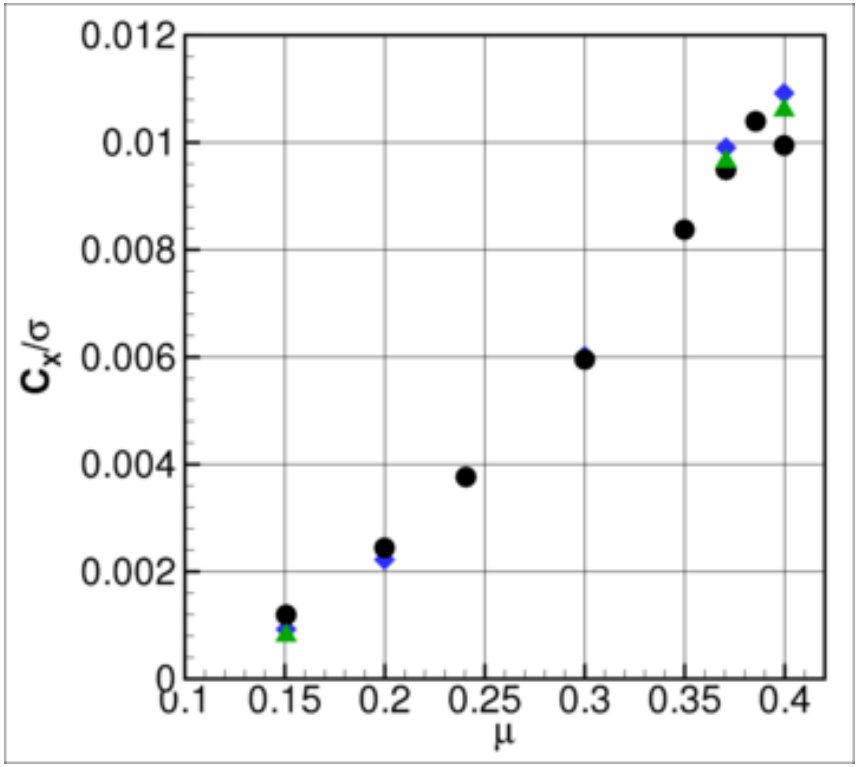


Force Prediction with New Model

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

● Test ◆ Old CAMRAD Model ▲ Improved CAMRAD Model

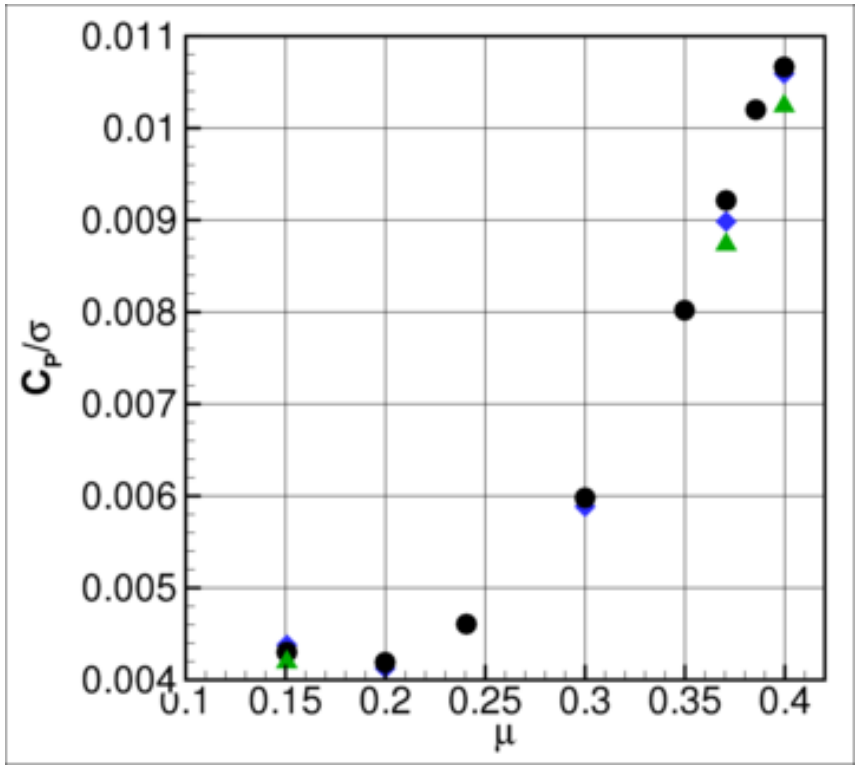


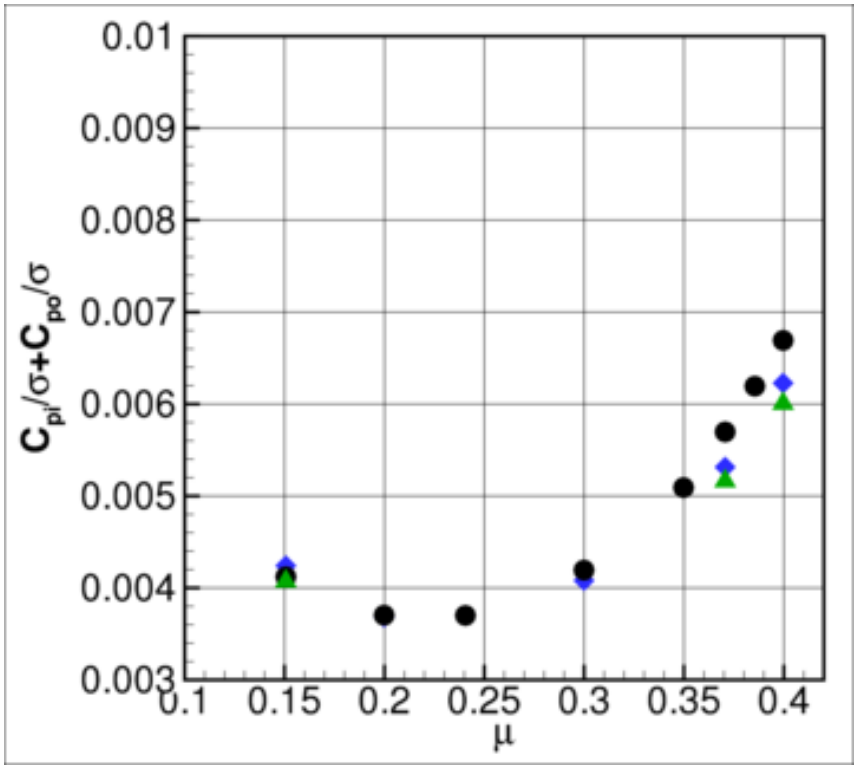


Power Prediction with New Model

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

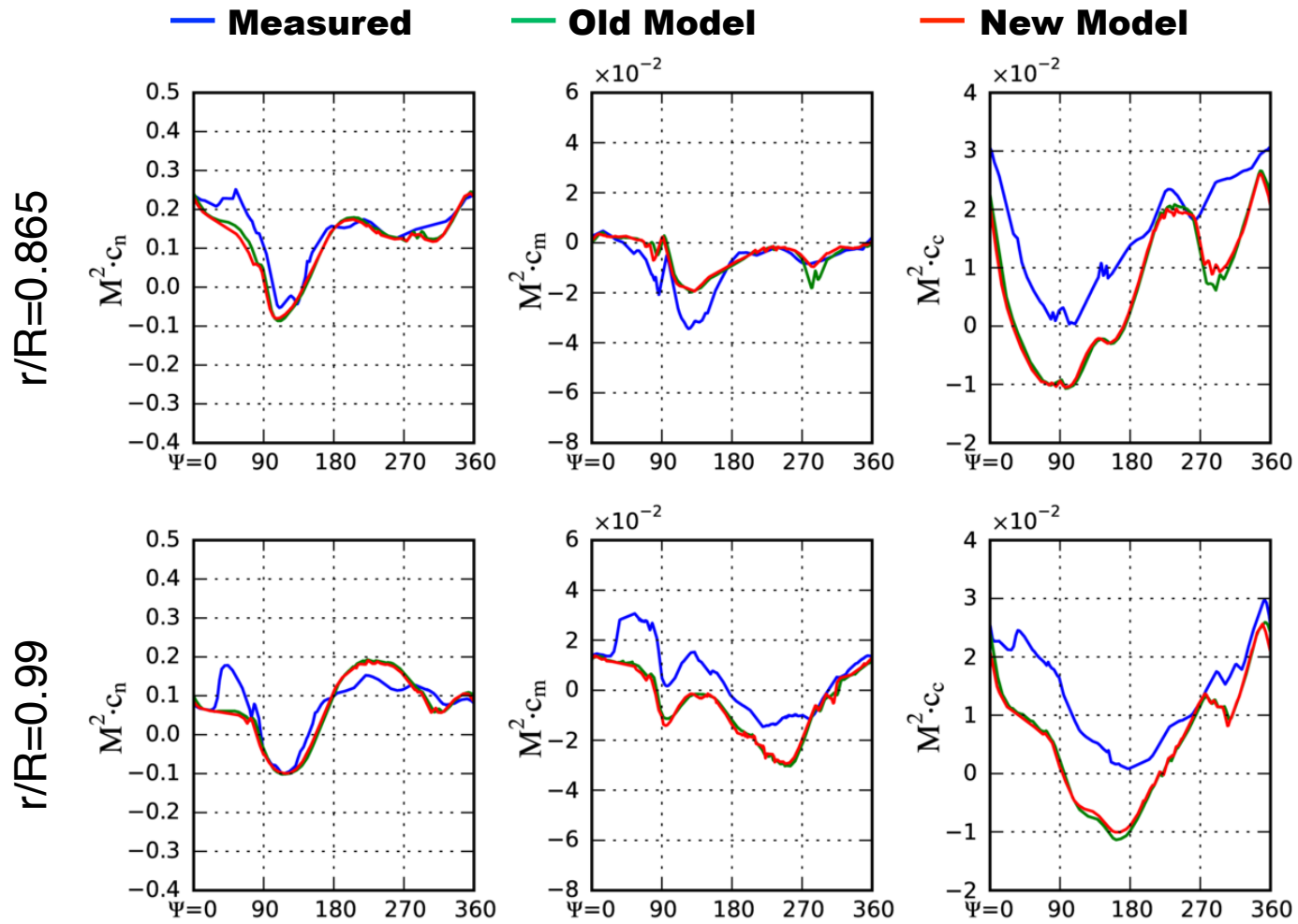
● **Test** ◆ **Old Model** ▲ **Improved Model**





Airload Comparison: μ=0.4, C_L/σ=0.09

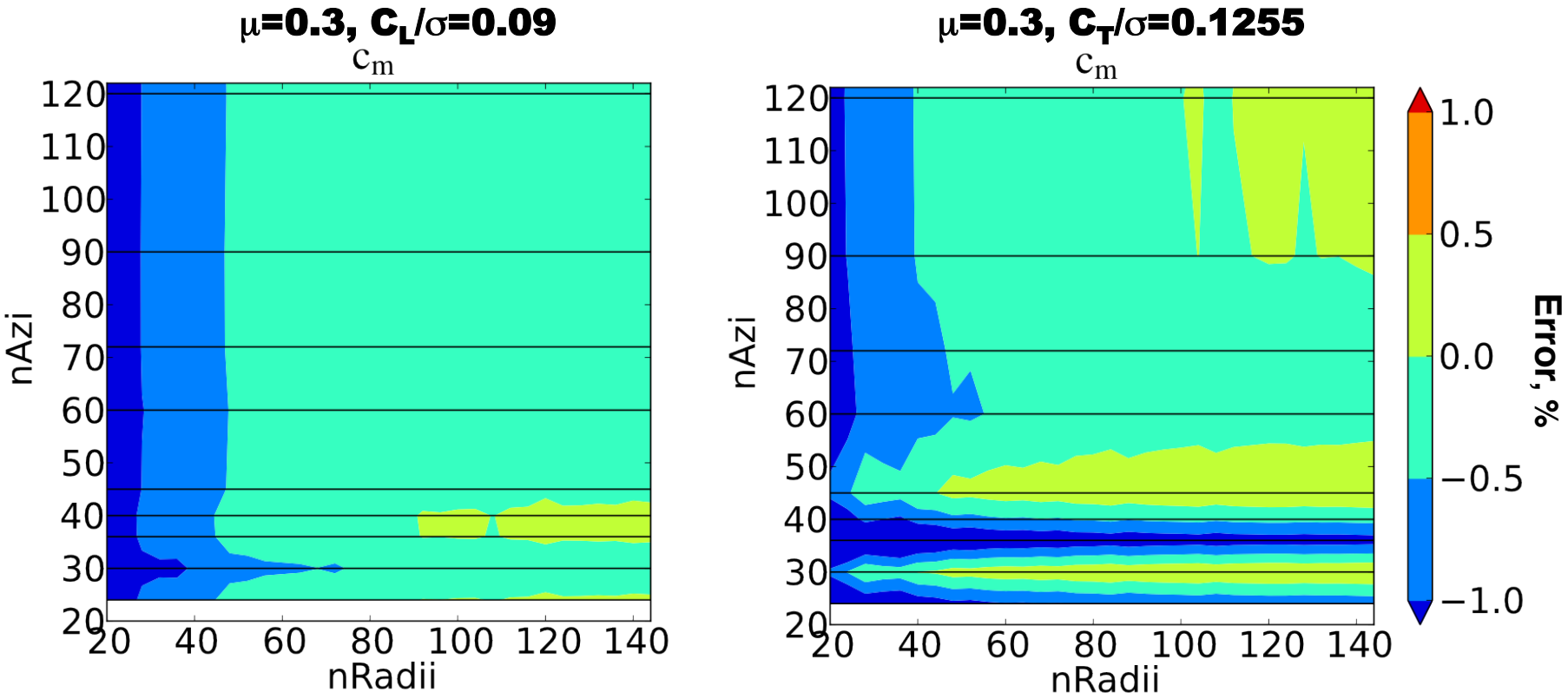
- Airload changes are small and consistent with reduced thrust.



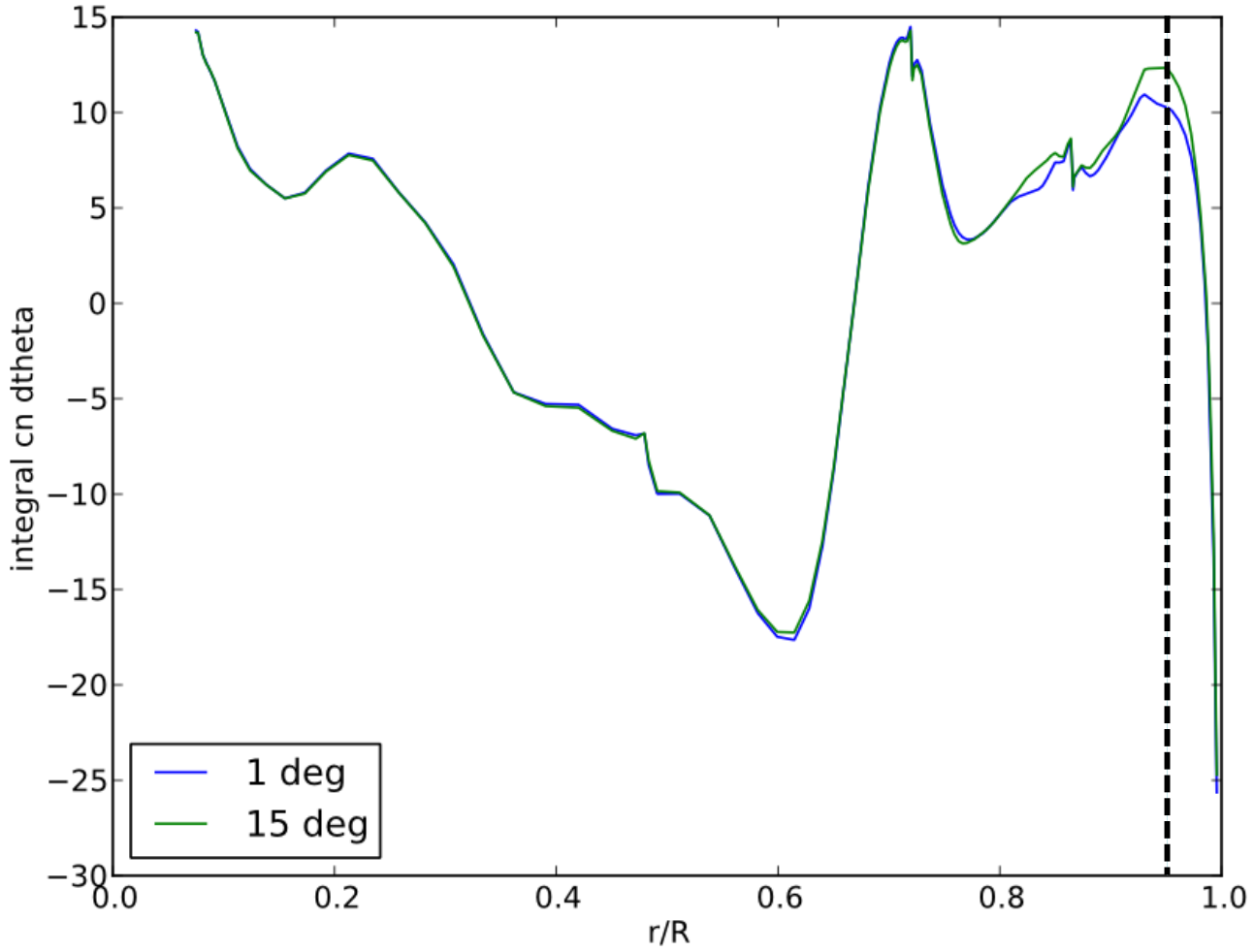
Summary

- 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



μ=0.3, C_T/σ=0.1255



μ=0.3, C_T/σ=0.1255