Measured / Predicted Blade Motion Comparisons

Ethan Romander

Anita Abrego

Al Burner

Danny Barrows

Larry Meyn

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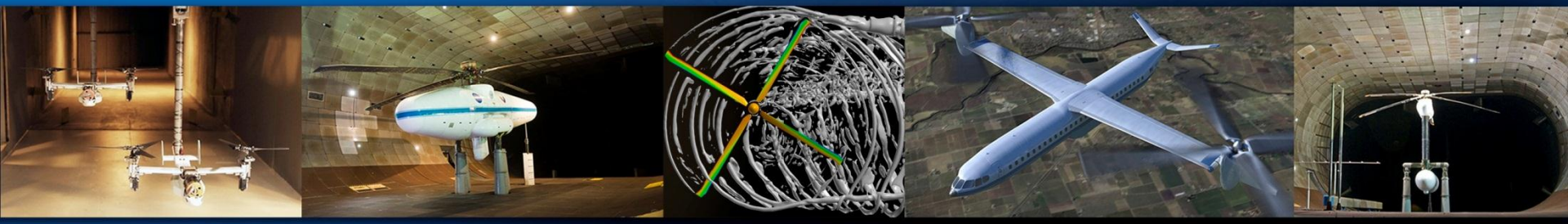


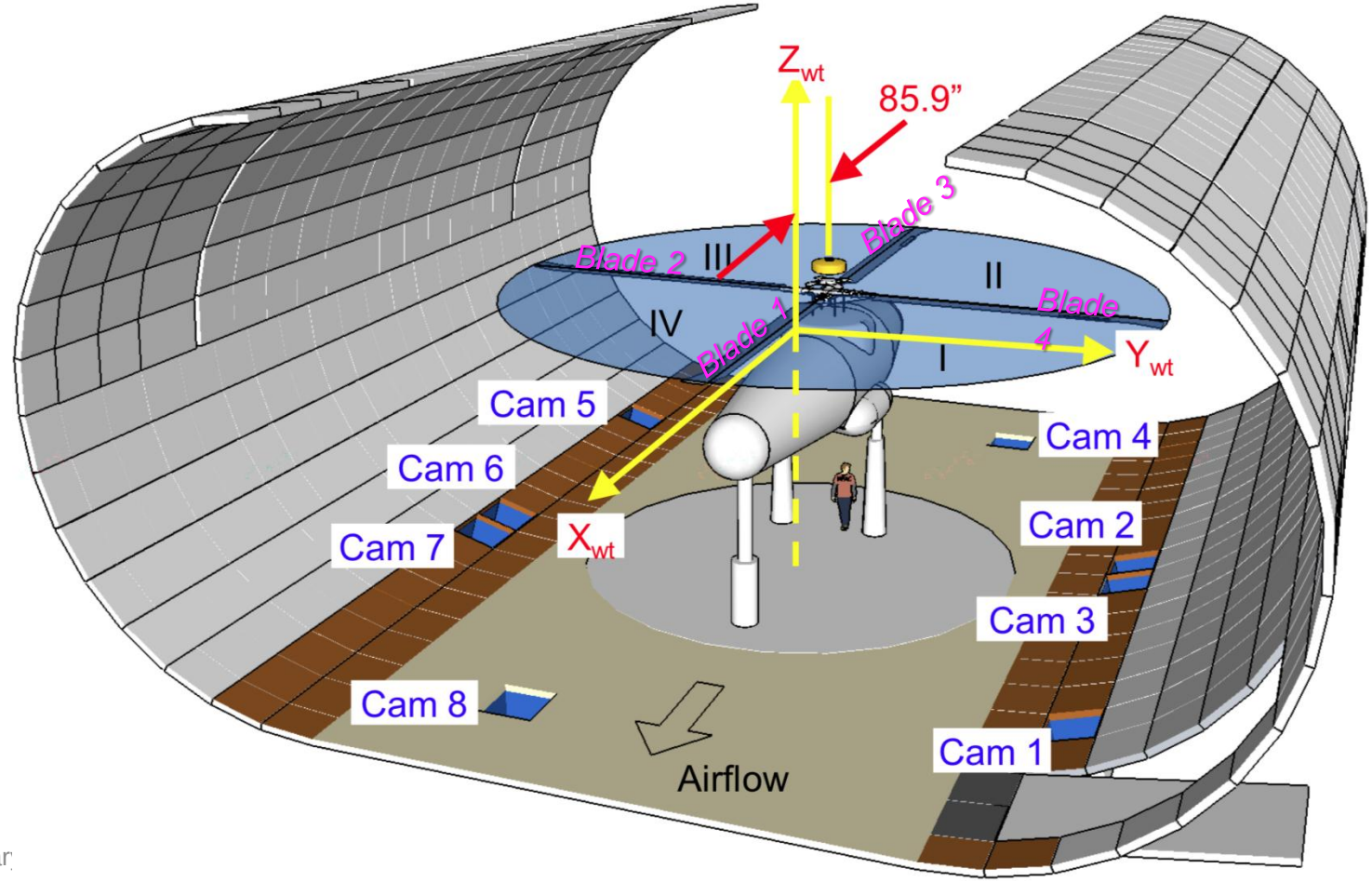
Overview

- Blade Displacement measurement overview
- Simulation overview
- Blade motion comparisons
  - Run 53, points 20-25 (High speed)
  - Run 42, points 46-49 (High thrust)

Blade Displacement Measurement

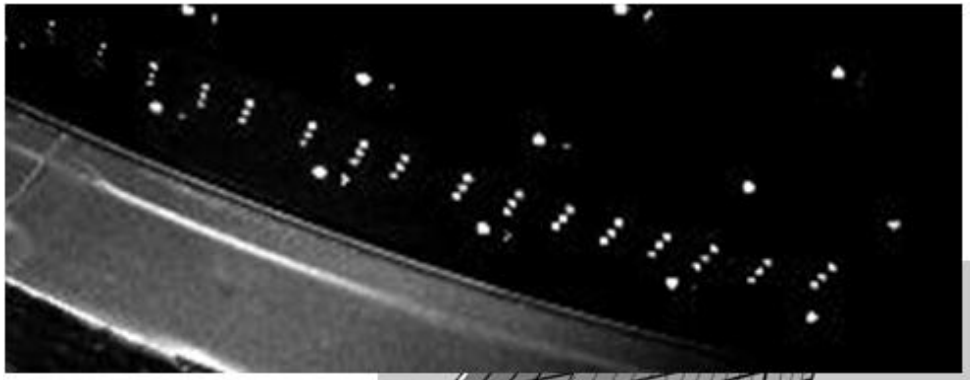
Model & Camera Installation

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



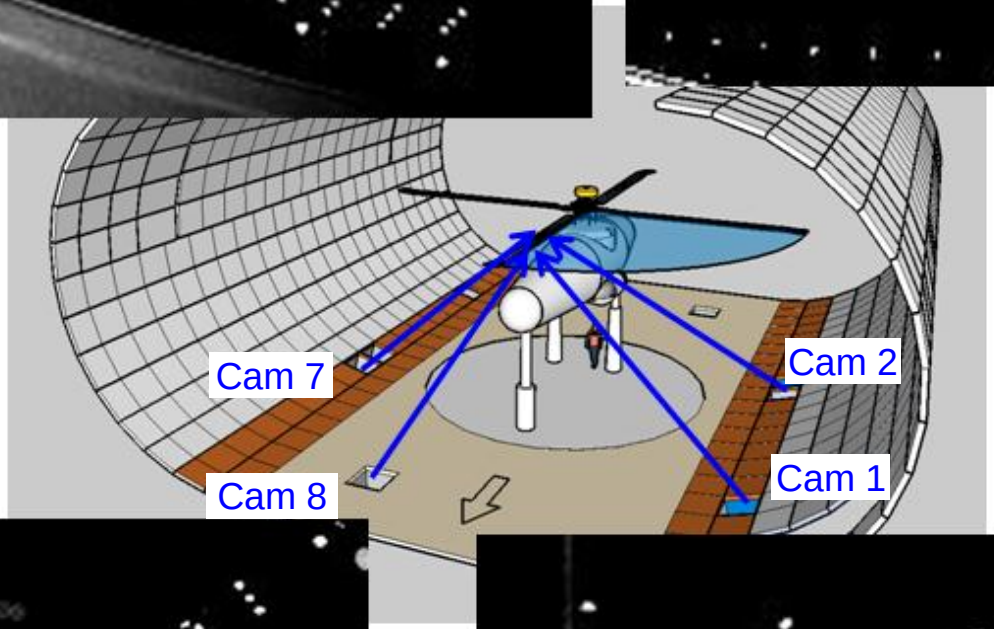
Blade Displacement Measurement

Multiple Camera Intersection



Camera 7

Camera 2



Camera 8

Camera 1

Blade Displacement Measurement Sets

	Primary	Secondary
Quadrants per blade	4	1
Azimuth positions, total	40	11
Images per camera per azimuth	60	12
Total acquisition time per operating condition	10 min	1 min

Primary data

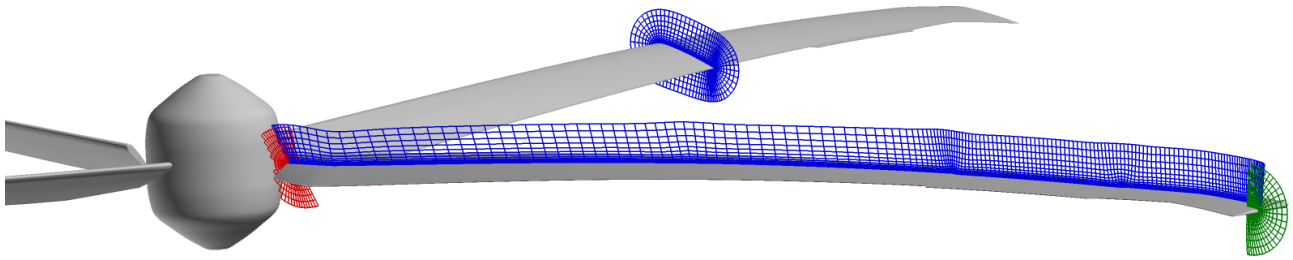
- 27 primary operating conditions
- Includes test conditions from each test phase
- Matched conditions with PIV

Secondary data

- 1000+ Airloads data points

Simulation

CFD Grid



- As-built blade geometry with notional centerbody
- Blade grid: 241x271 chord/span, O-mesh, y^+=1
- Free-air simulation using wall corrected data
- Finest off-body spacing was 10% C_{tip}
- 40M points total (26M in near-body)

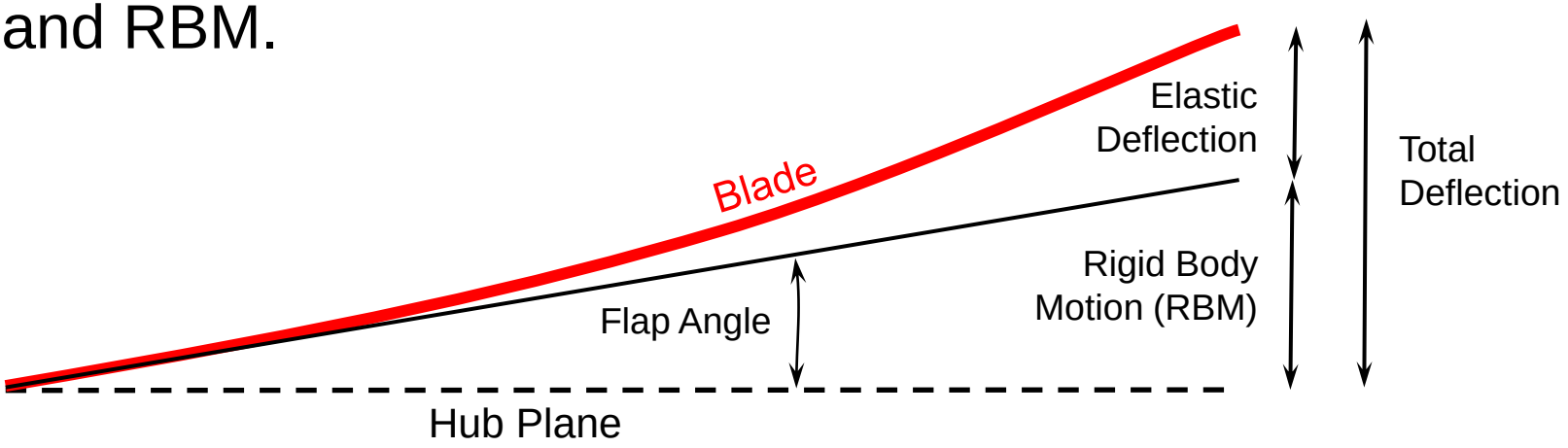
Simulation

Software Toolkit

- CFD: OVERFLOW2 v2.2e
  - 5th order central differencing in space; 2nd order dual timestepping
  - Spalart-Almaras 1-eq. turbulence model with rotational corrections and DDES
  - Blade surfaces modeled as fully-turbulent, viscous, adiabatic walls
- Comprehensive: CAMRADII v4.9
  - 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)

Components of Blade Motion

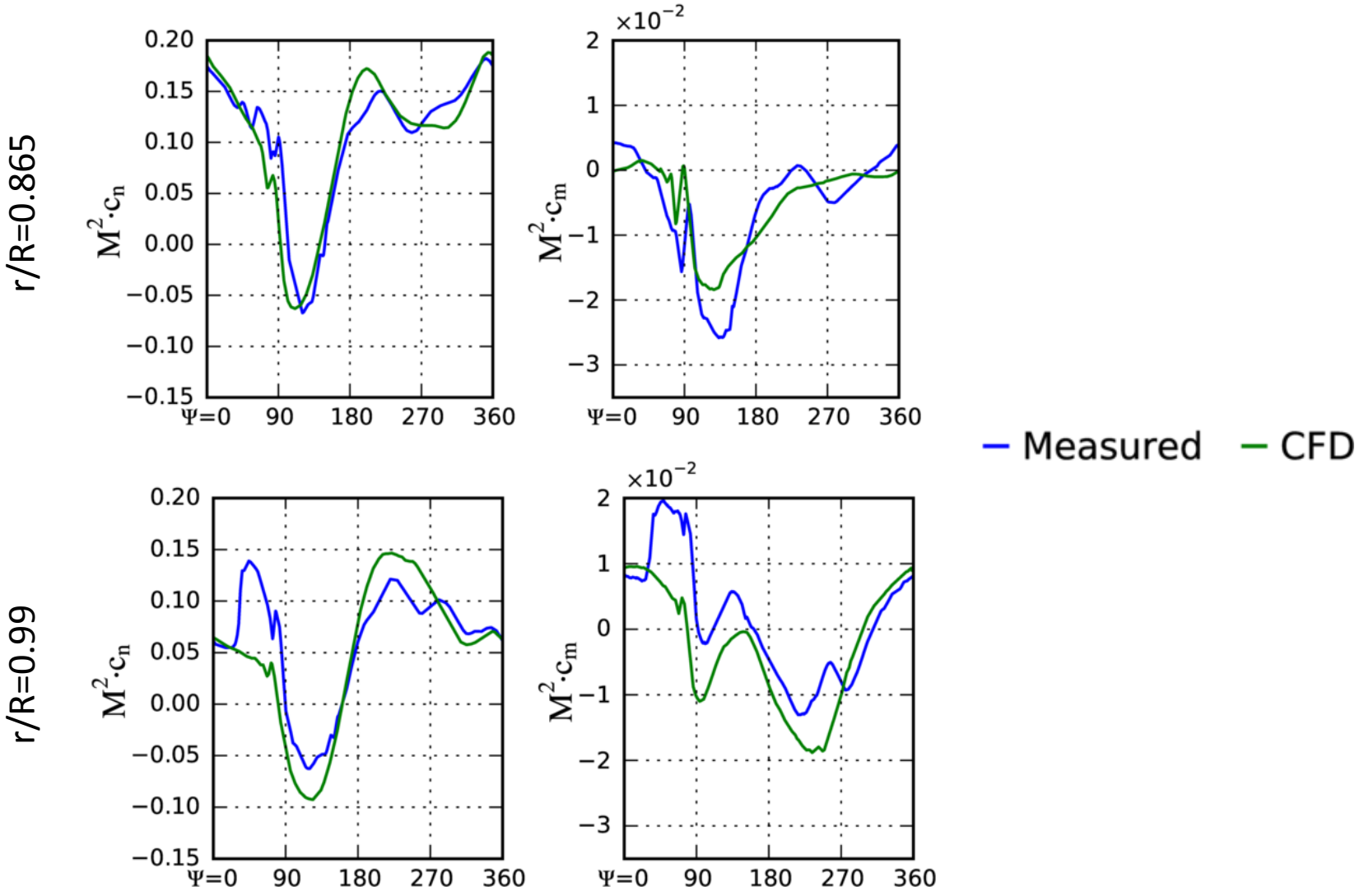
- Total deflection
  - Measured directly
  - Predicted quantity comes from motion.txt file
- Rigid Body Motion (RBM)
  - Estimated from measurements using inboard targets
  - Extracted from CAMRAD output for predictions
- Elastic deflection is the difference between total deflection and RBM.



Run 53

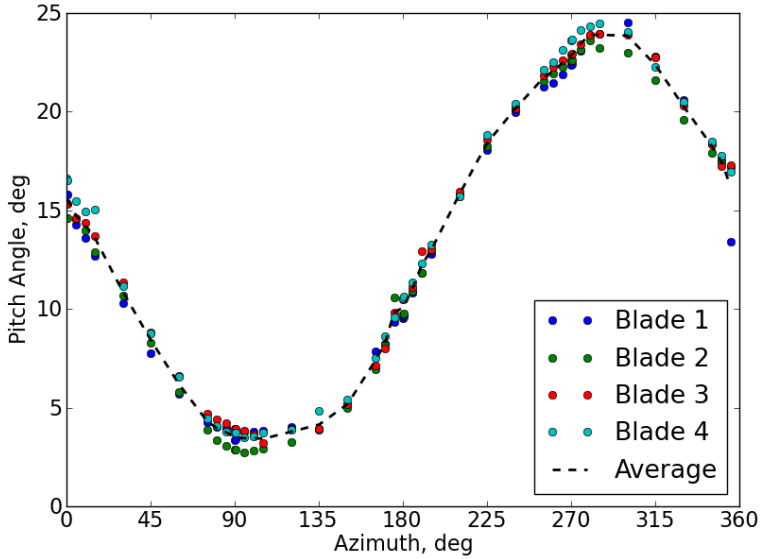
- Selected points 20-25: “5320”
  - C_T/s=0.08
  - M_{tip}=0.65
  - m=0.37
  - α_s=-8.4° (geometric)
  - Representative hub moments
- BD primary data point: 4 quadrants of data for each blade.

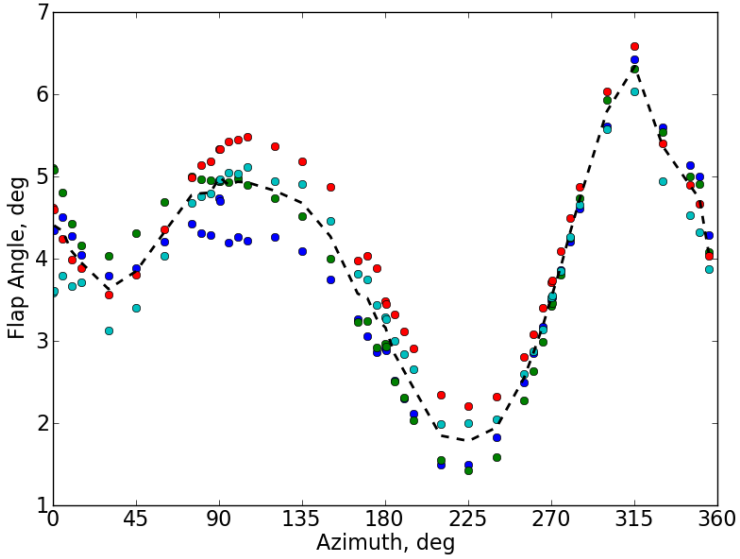
5320 Airloads

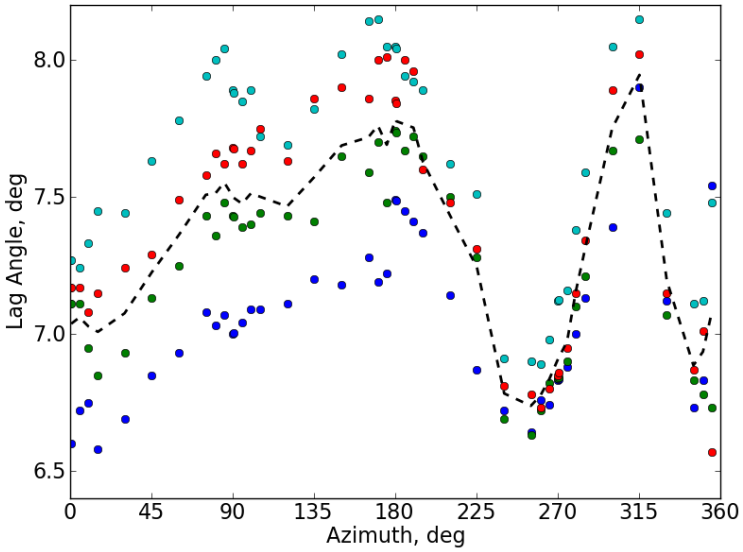


5320 Measured Rigid Body Motions

- Approximately 2 deg of scatter between blades for all measurements
- Blade-to-blade differences exceed rev-to-rev standard deviation suggesting blade differences are real.
- Blade-to-blade differences will cause difficulty when analyzing secondary data points.

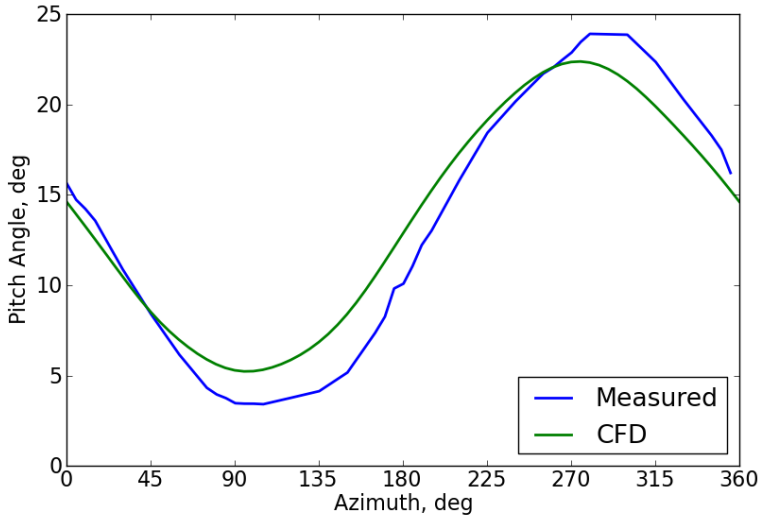


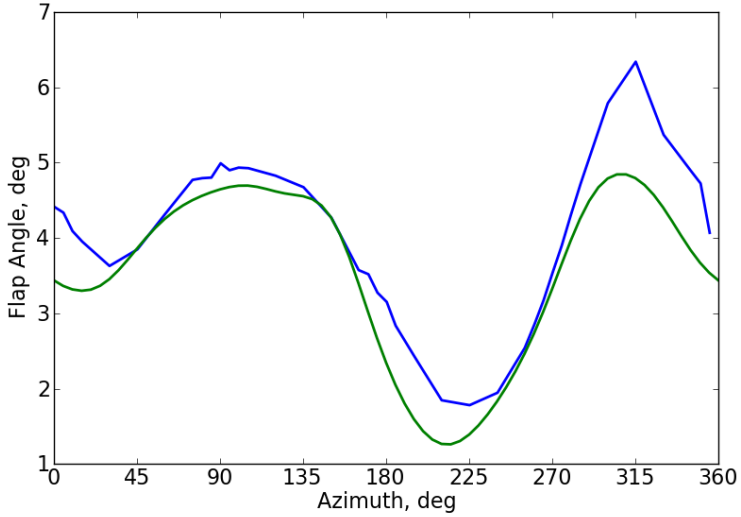


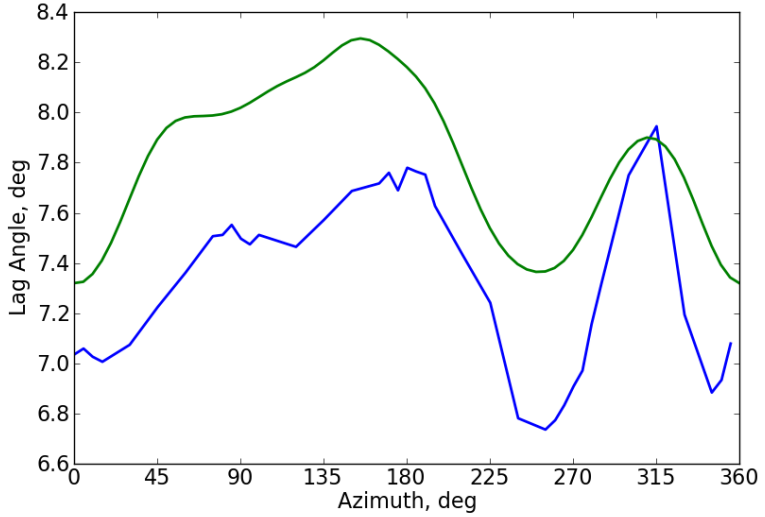


5320 RBM Correlation

- Trends look very good
- Mean values generally look good, however predicted power is low by about 6% so there should be more difference in mean lag.
- Predicted cyclic is low by about 2 deg
- Flap correlation degrades on the retreating side

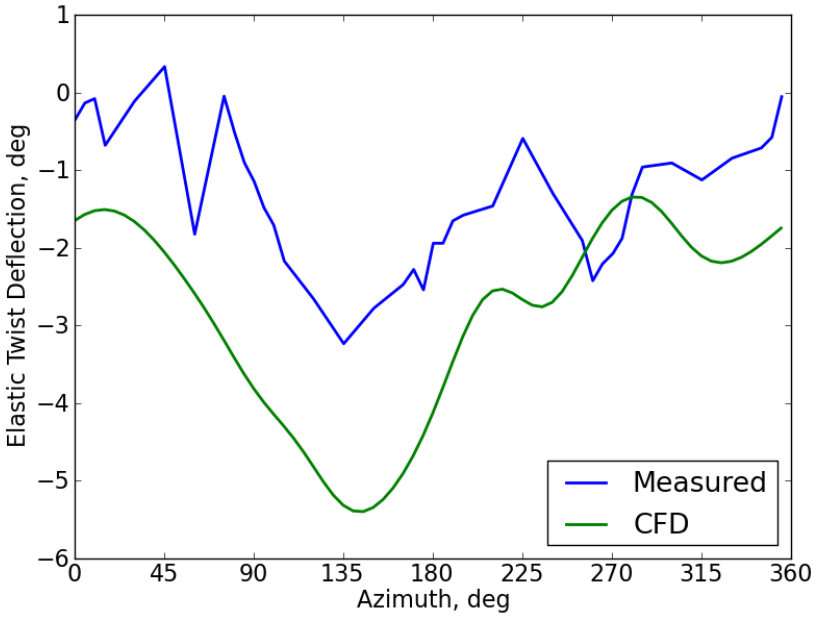


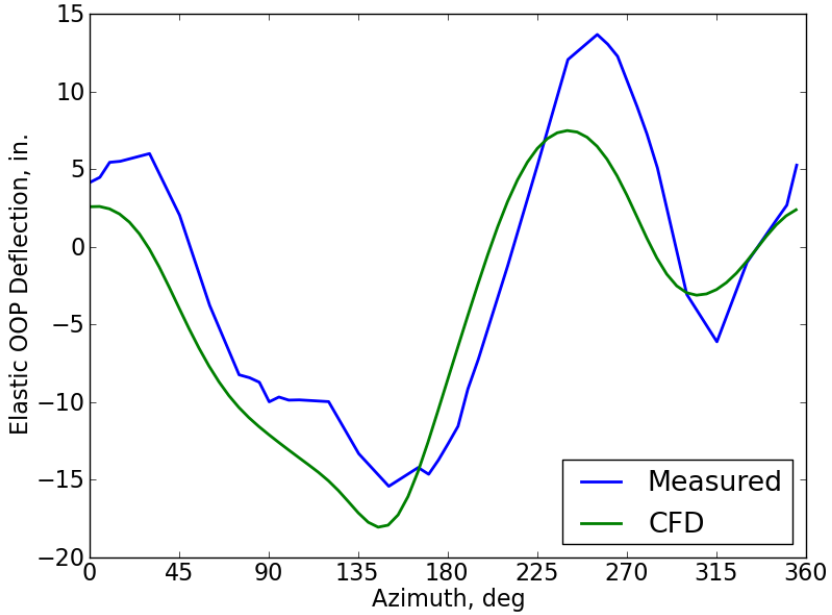




5320 Elastic Deformation: r/R=0.97

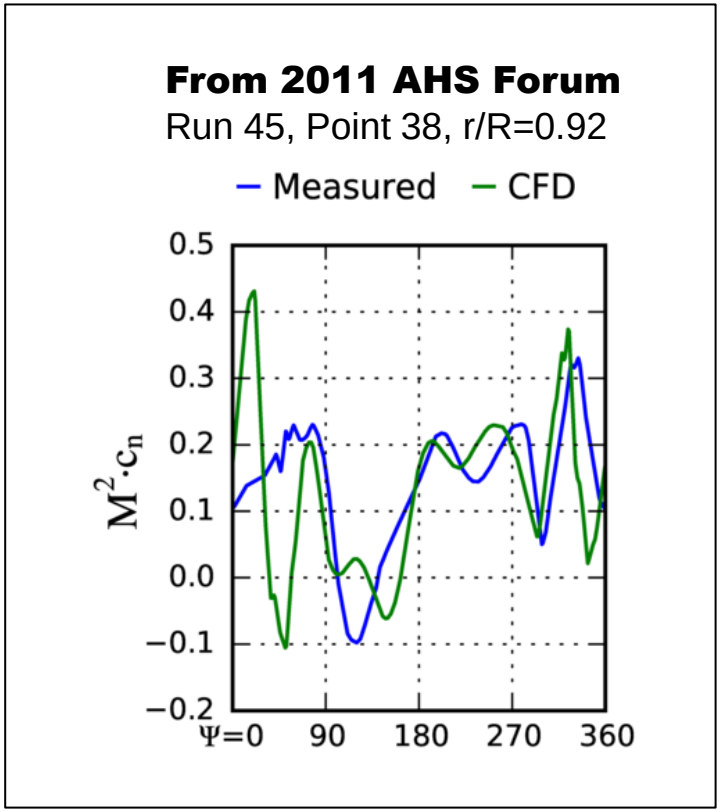
- Elastic deformation accumulates along blade span, so values at the tip are worst-case.
- Curves are very sensitive to error in RBM, especially flap bending.



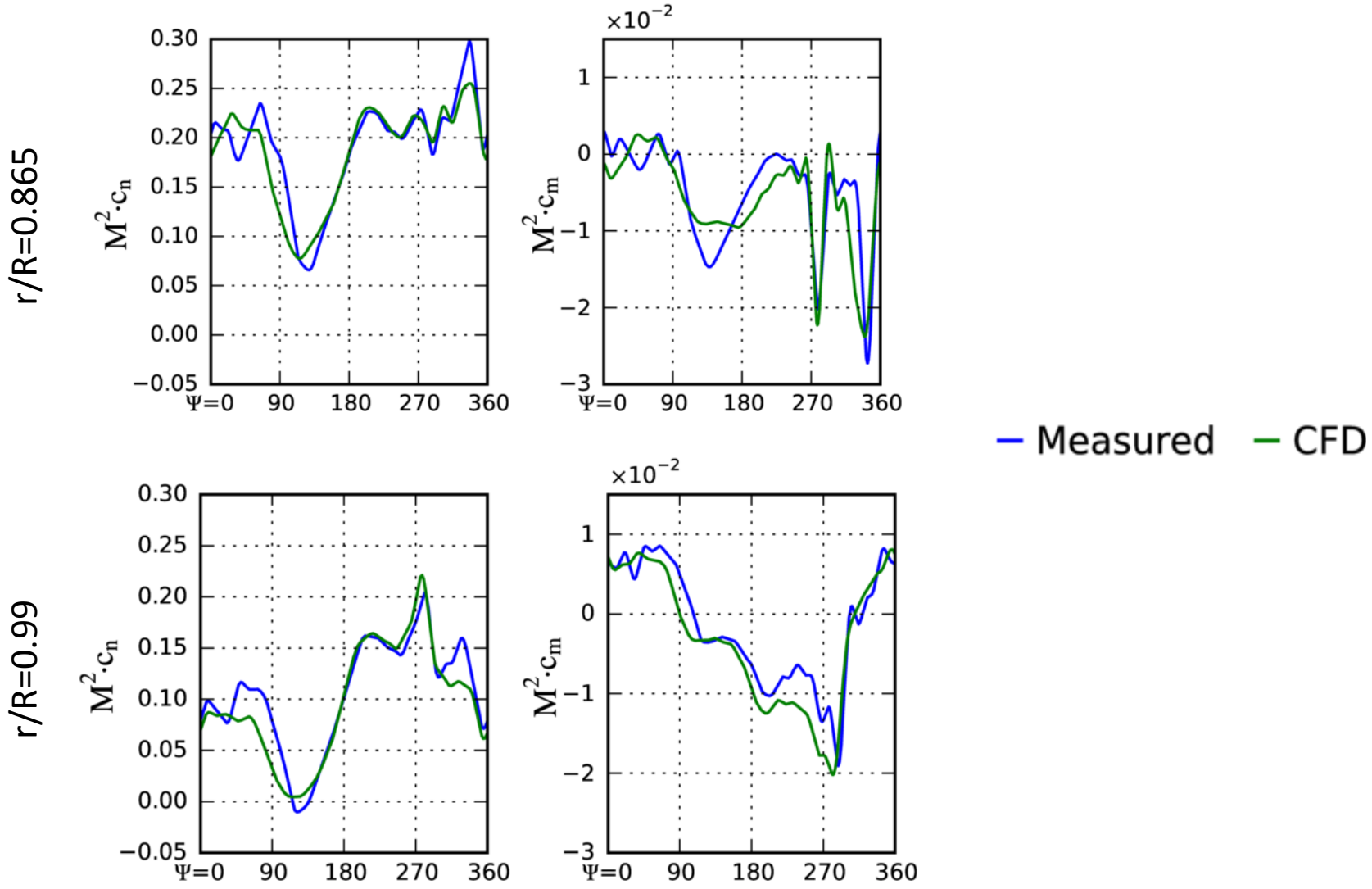


Run 42

- Parametric sweeps
- Selected points 46-49: “4246”
  - C_T/s=0.13
  - M_{tip}=0.65
  - μ=0.24
  - α_s=0° (geometric)
  - Zero hub moments
- BD primary data point: 4 quadrants of data for each blade.

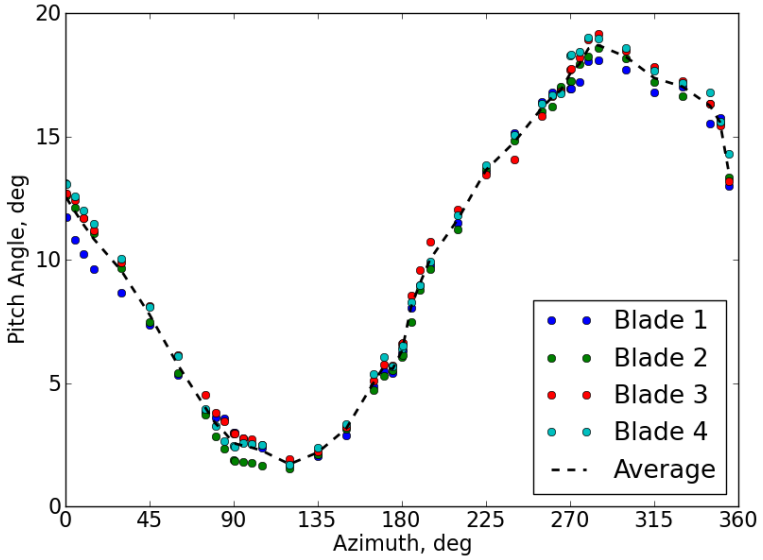


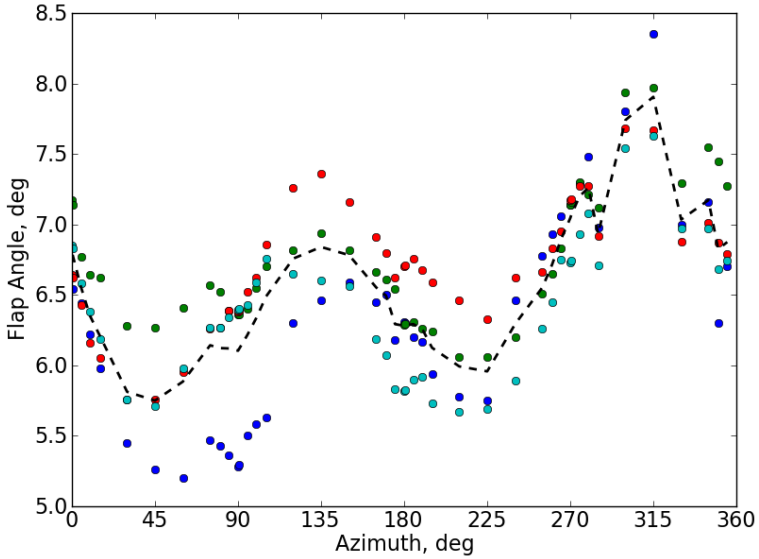
4246 Airloads

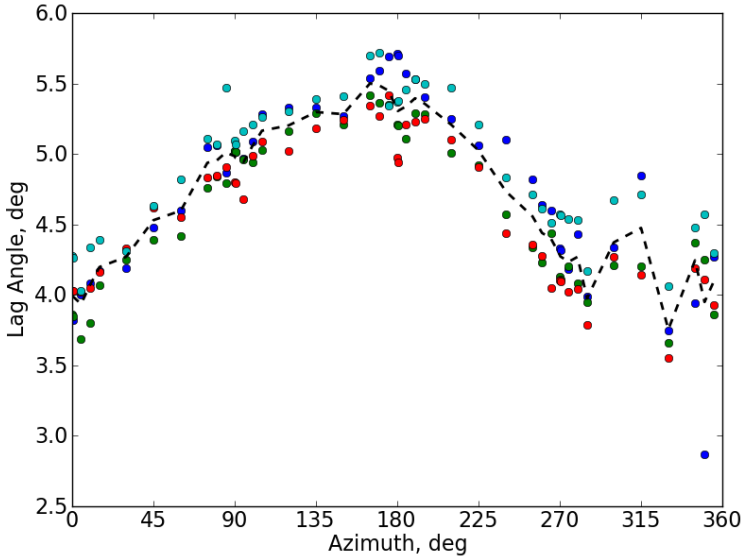


4246 Rigid Body Motions

- Blade-to-blade differences are similar to 5320.

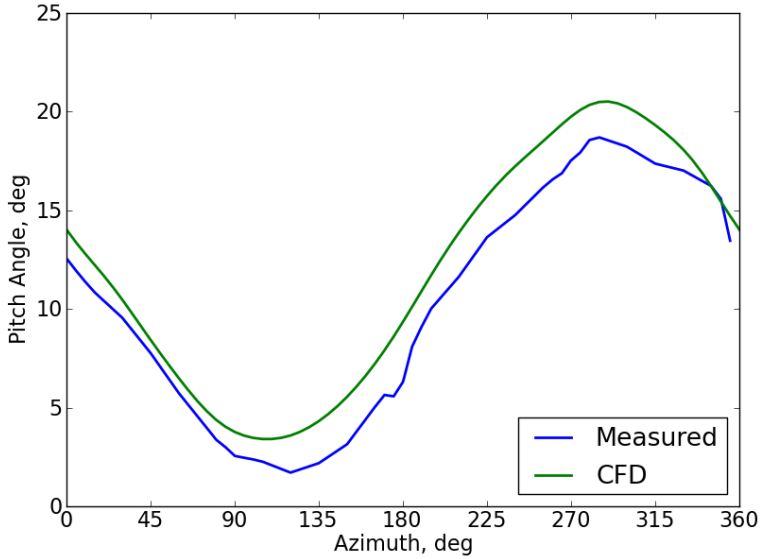


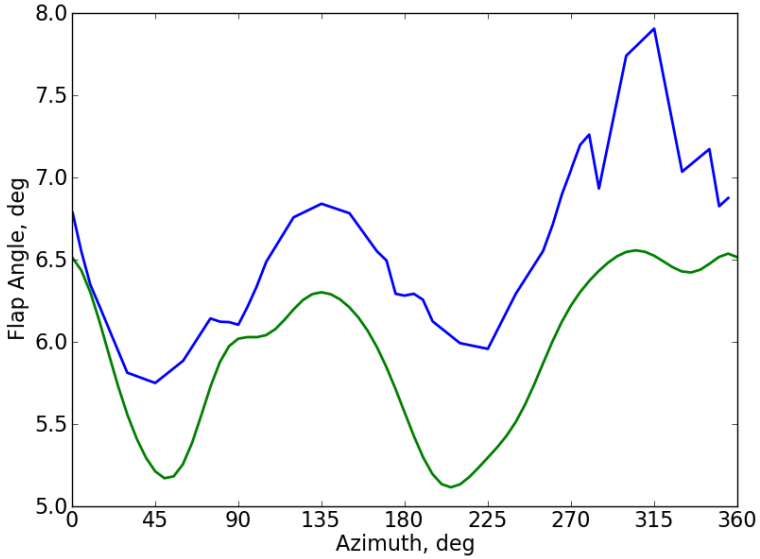


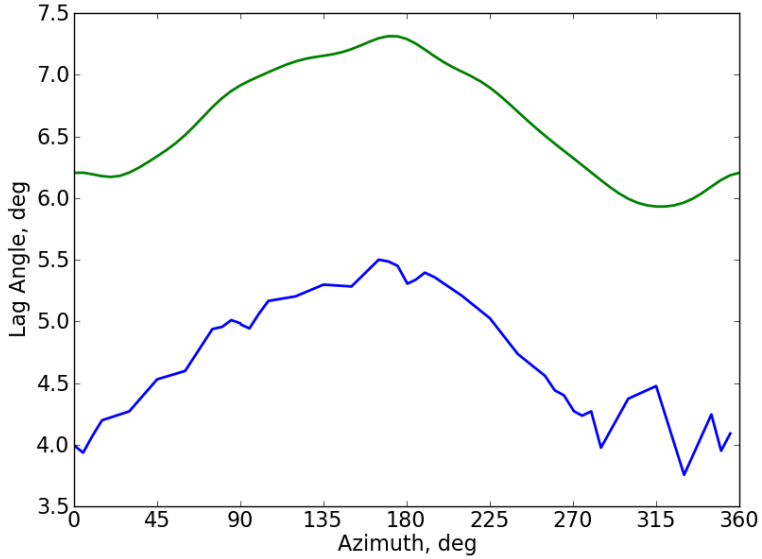


4246 RBM Correlation

- Small mean differences in both pitch and flapping angle.
- Lag trend is good but mean value is very wrong. Power is predicted within 1%, so lag angle should be very close if we know the blade properties well.

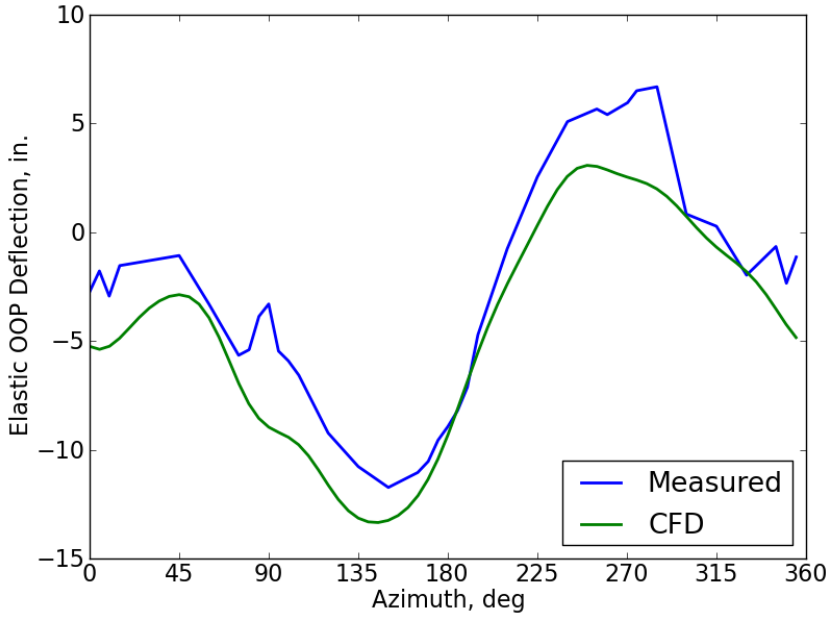


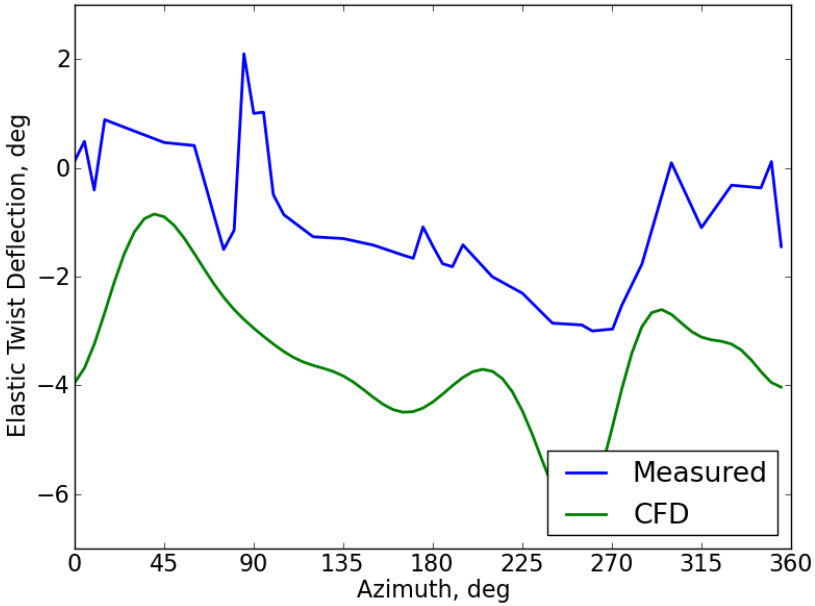




4246 Elastic Deformation: r/R=0.97

- Mean shift in twist arises from collective discrepancy
- Flap bending differences are consistent with errors in RBM



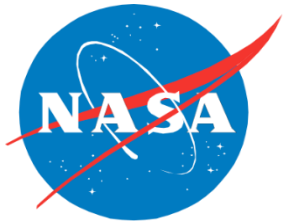


Summary

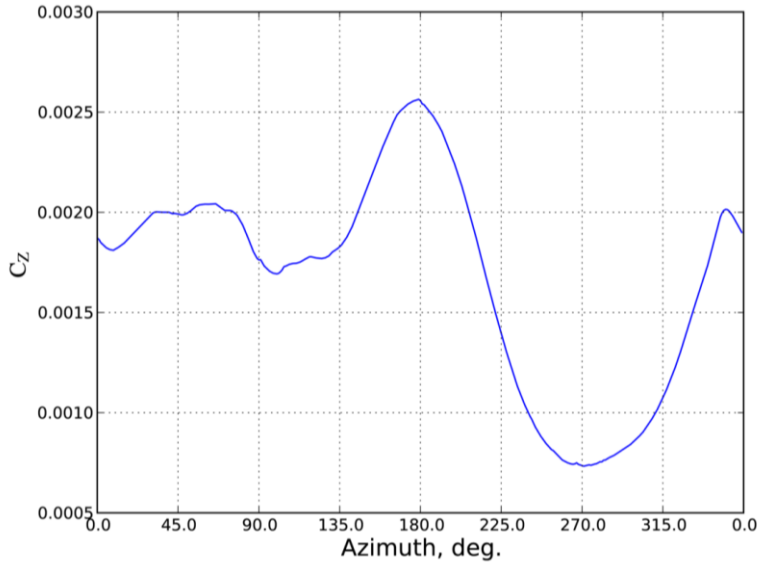
- Primary BD data exists for a limited number of flight conditions.
- Blade-to-blade differences in RBM scatter measured data. Averaging corrects the problem for primary data. This will remain an issue for secondary data.
- Predicted and measured RBM agree within a few degrees.
  - In pitch this is a trim issue.
  - Flap angle correlation is good on advancing side and degrades slightly on retreating side.
  - Mean lag appears to be overpredicted for a given rotor power.
- Elastic motions appear to be accurate within the confines of RBM accuracy.

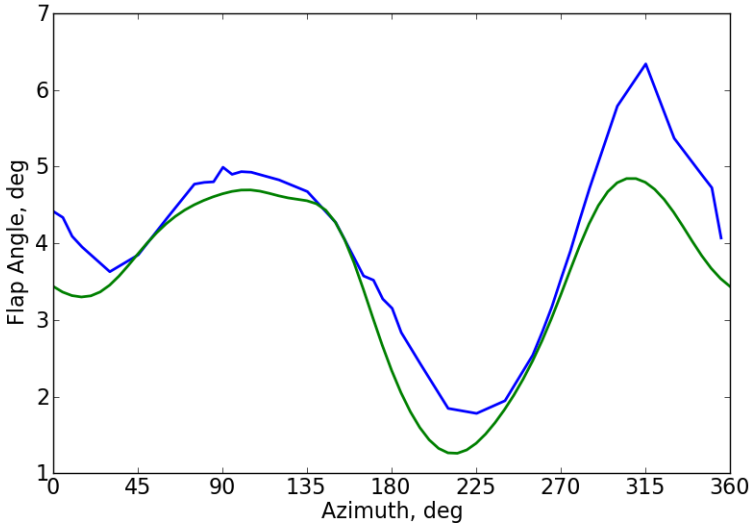
Future Work

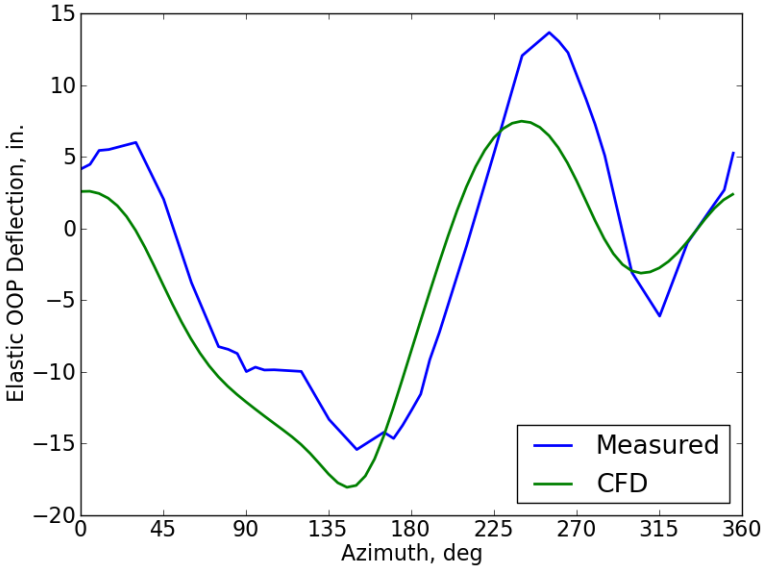
- Modeling condition 3819: a low-speed, BVI condtion.
- Modeling high advance ratio points from run 42.
- Improved data reduction techniques for measured data.
- Correlate with crabarm/laser measurements of RBM.
- Continue troubleshooting mean lag discrepancy.


NASA

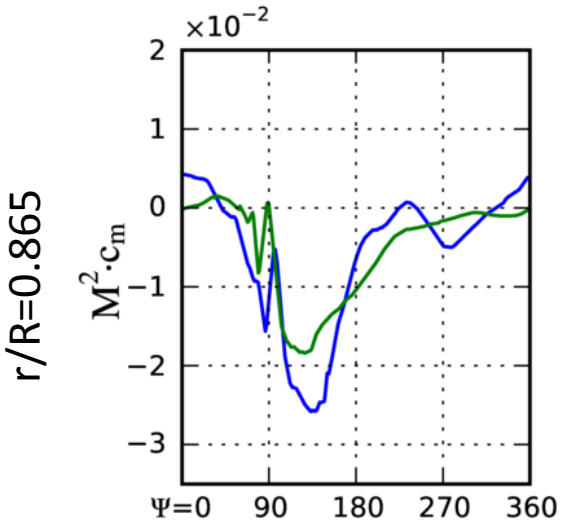
5320 OOP Loads and Deflections

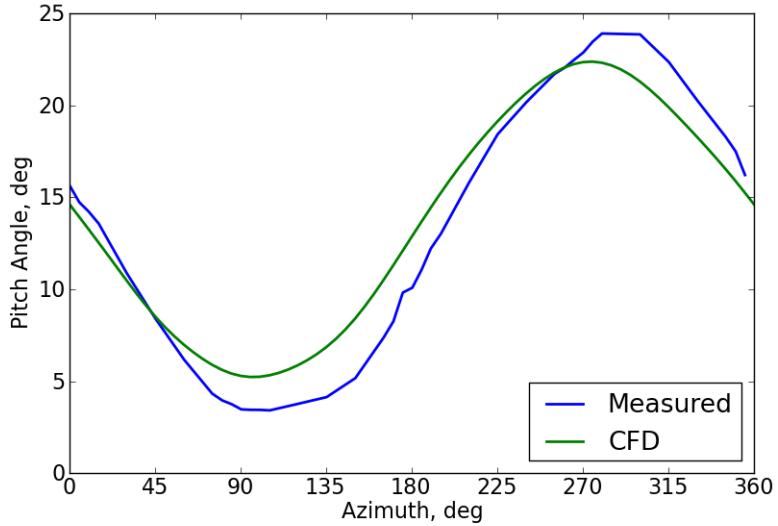


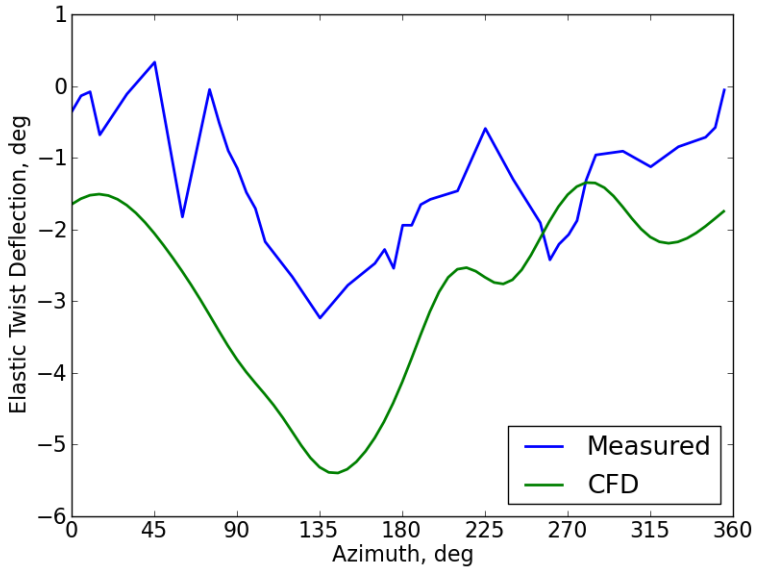




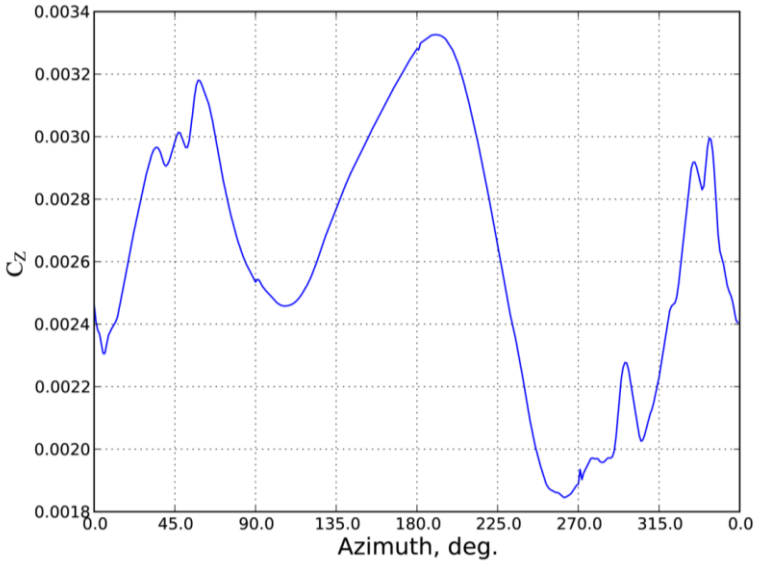
5320 Torsional Loads and Deflections

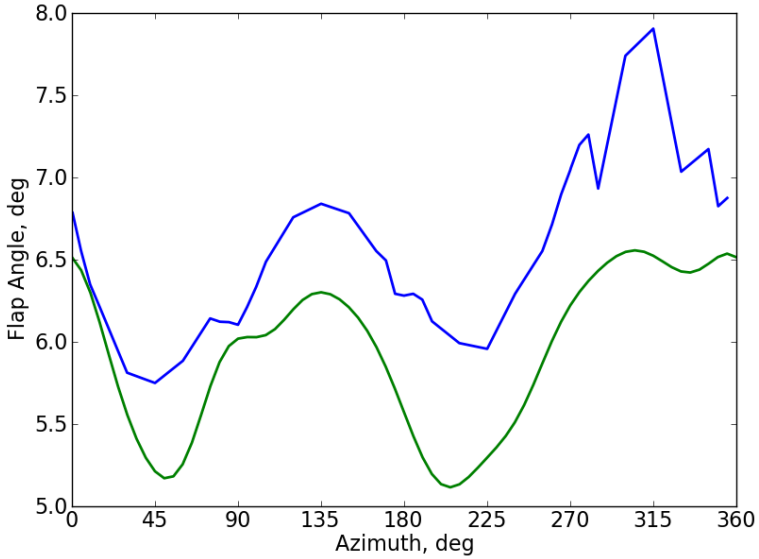


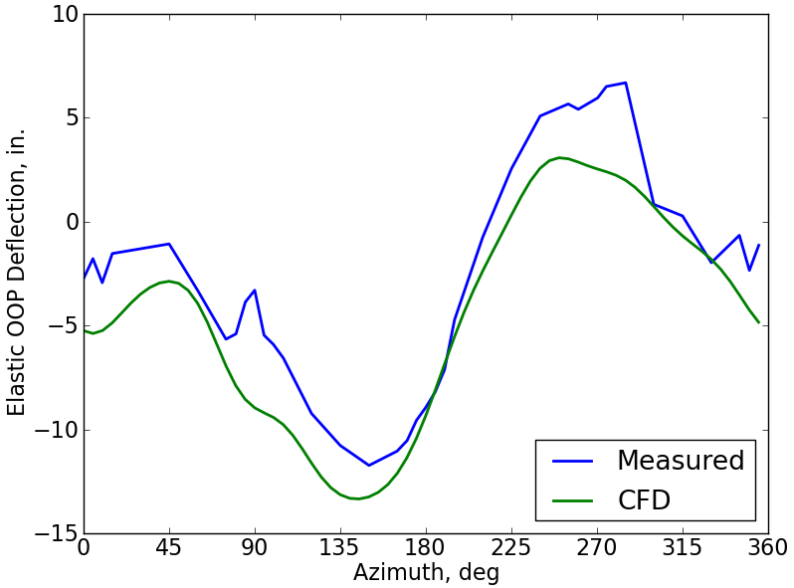




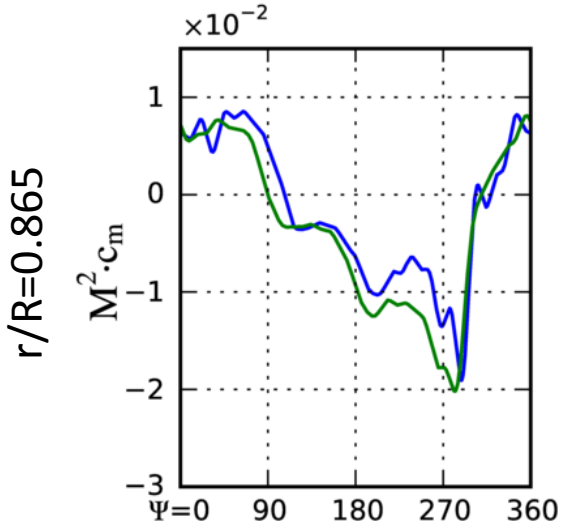
4246 OOP Loads and Deflections

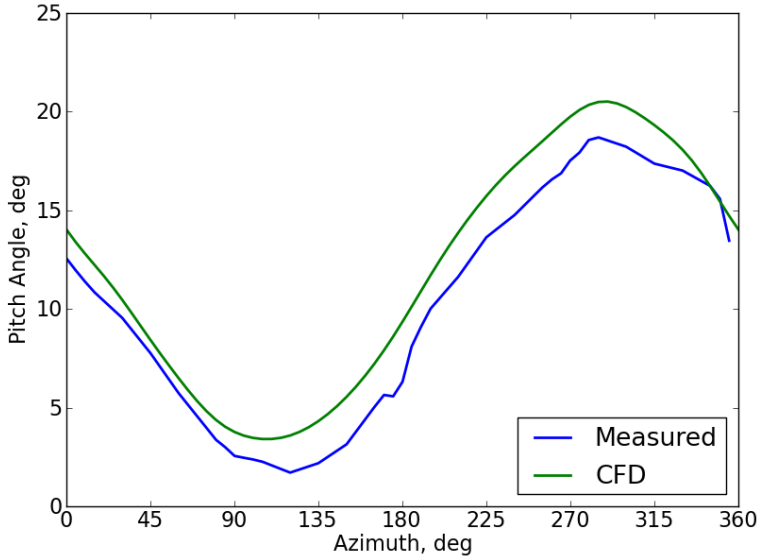


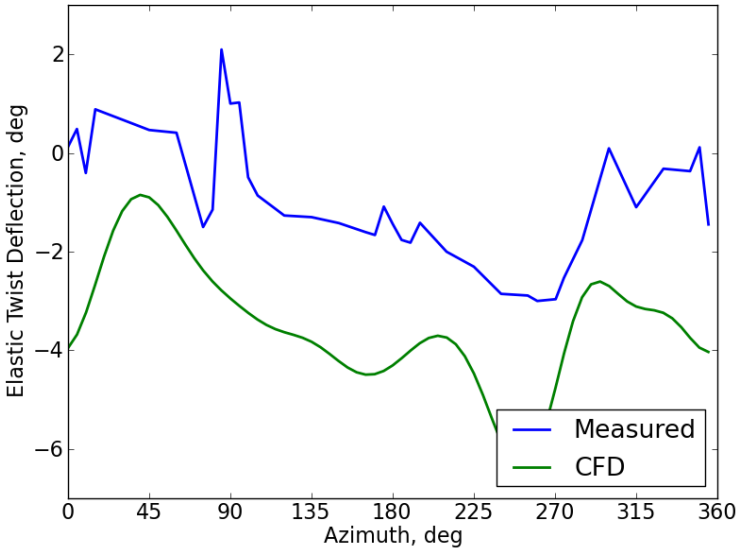




4246 Torsional Loads and Deflections







BD Primary Data Points

Run (BD)	PntStart (BD)	PntEnd (BD)	Run (NFAC)	PntStart (NFAC)	PntEnd (NFAC)	AdvRatio	CT/σ	AOA (deg)	M_{tip}	
24	2495	2534	50	12	15	0.15	0.08	4.0	0.65	Parametric Sweep 4
19	722	761	42	11	14	0.15	0.08	0.0	0.65	Parametric Sweep 1
20	1587	1626	43	28	31	0.15	0.08	-4.0	0.65	Parametric Sweep 2
17	562	601	38	19	23	0.15	0.08	-1.7	0.65	1-G Level Flight 1
20	1378	1417	43	8	11	0.15	0.08	-4.0	0.65	Parametric Sweep 2
22	2355	2394	47	52	58	0.24	0.12	-1.37	0.67	Airloads Data Point C9017. But did not match 9017.
19	1112	1152	42	46	49	0.24	0.13	0.0	0.65	Parametric Sweep 1
28	4024	4063	60	28	29	0.25	0.12	-1.9	0.67	Airloads Data Point C9020
22	2304	2343	47	33	37	0.30	0.10	-4.5	0.63	DNW Data Point 13.20
19	1263	1302	42	60	63	0.30	0.10	0.0	0.65	Parametric Sweep 1
22	2233	2272	47	10	15	0.30	0.087	-4.82	0.64	Airloads Match 1 (Airloads C8424)
18	650	689	40	29	34	0.35	0.08	-6.9	0.65	1-G Level Flight 1
26	3222	3261	53	20	25	0.37	0.08	-8.4	0.65	1-G Level Flight
26	3350	3389	53	34	39	0.40	0.08	-10.0	0.65	1-G Level Flight

BD Primary Data Points

Run (BD)	PntStart (BD)	PntEnd (BD)	Run (NFAC)	PntStart (NFAC)	PntEnd (NFAC)	AdvRatio	CT/σ	AOA (deg)	M_{tip}	
32	5032	5071	67	14	18	0.30	0.07	-0.6	0.64	DNW Data Point 13.12
32	5083	5122	67	34	39	0.15	0.07	4.76	0.64	DNW Data Point 11.24
38	5889	5928	81	12	16	0.24	0.11	0.0	0.65	Parametric Sweep 1 (PIV4a)
39	6017	6056	83	70	74	0.35	0.08	-6.9	0.65	1-G Level Flight (PIV5a)
41	6723	6762	87	37	41	0.60	0.01	0.0	0.42	Mtip=0.421 (65% Nom Mtip)
42	7123	7162	91	37	40	0.60	0.02	0.0	0.26	Mtip=0.260 (40% Nom Mtip)
42	7455	7494	91	68	73	1.00	0.02	0.0	0.26	Mtip=0.260 (40% Nom Mtip)
43	7792	7831	93	32	36	0.60	0.05	4.0	0.26	Mtip=0.260 (40% Nom Mtip)
44	8177	8216	95	31	36	1.00	0.06	4.0	0.26	Mtip=0.260 (40% Nom Mtip)
45	8283	8322	96	9	13	0.60	0.05	2.0	0.26	Mtip=0.260 (40% Nom Mtip)
45	8356	8395	96	17	21	1.00	0.04	2.0	0.26	Mtip=0.260 (40% Nom Mtip)
46	8440	8479	98	16	19	0.15	0.08	8.0	0.65	Parametric Sweep 4 (Alternate), AOA 8 deg
46	8712	8751	98	41	44	0.30	0.08	8.0	0.65	Parametric Sweep 4 (Alternate), AOA 8 deg
46	8785	8824	98	48	51	0.30	0.08	4.0	0.65	Parametric Sweep 4 (Alternate), AOA 8 deg