



RDECOM



Presented at
2nd STAR Prediction Meeting
Daejeon, Korea
February 8-10, 2012

STAR Prediction Activities



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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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- Six partners' results are included in common presentations
- Codes used by the partners

US	CAMRAD II v4.7
DLR	S4
KARI	CAMRAD II
KU	CAMRAD II v4.8
Onera	HOST
JAXA	rFlow3D

Common Presentation

Fan Plot

by Sung Jung

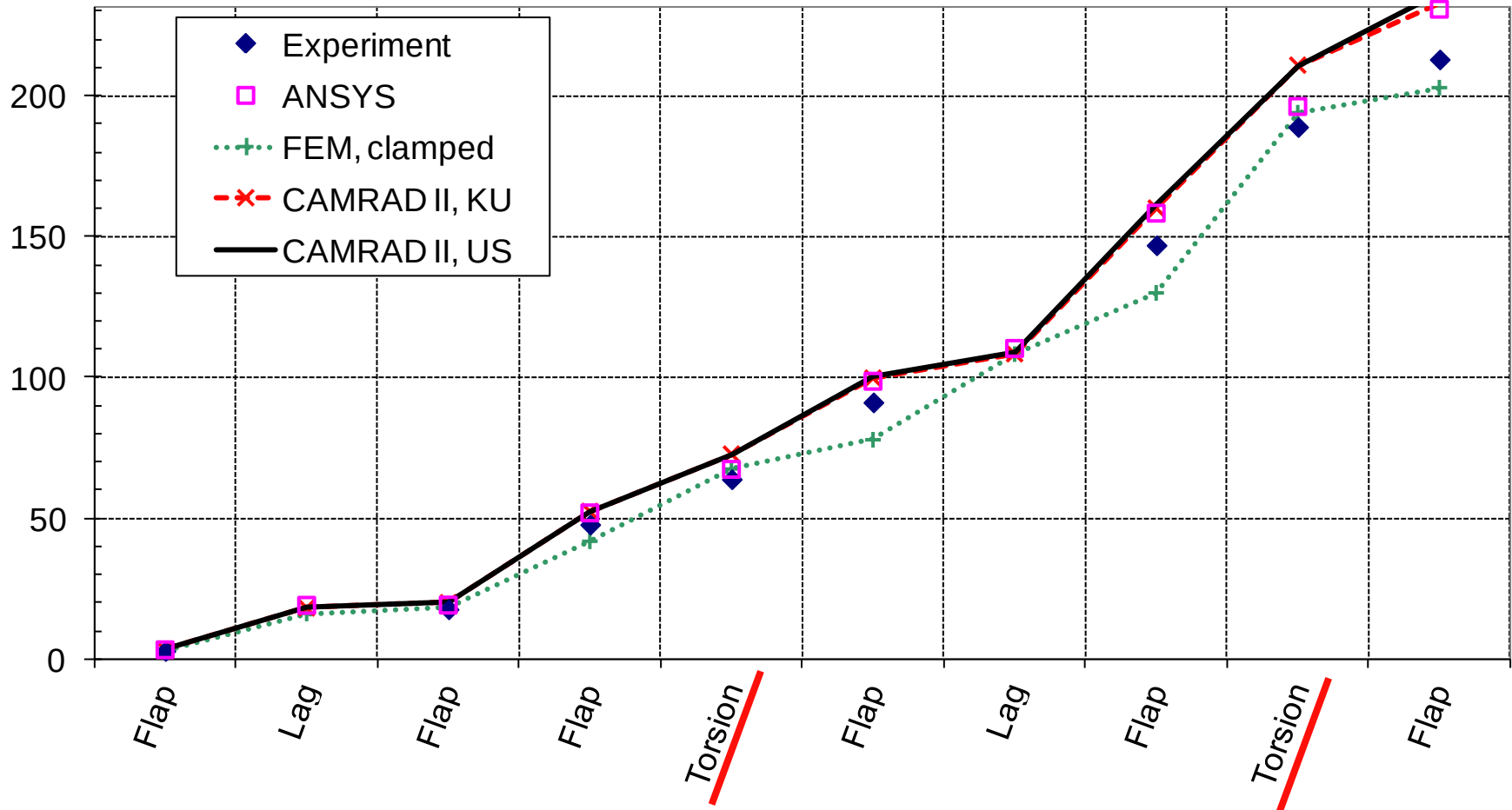
Individual Presentation US

Fan Plot

by J. Lim / D. Boyd

- **CAMRAD II v4.7**
- **Structural model**
 - 16 finite elements and 1 rigid element
 - Each finite element has 15 DOFs
- **Aerodynamic model**
 - C81 Table look-up
 - Onera edlin unsteady aero model
 - 8 multiple free trailers

STAR Nonrotating Frequencies, Clamped

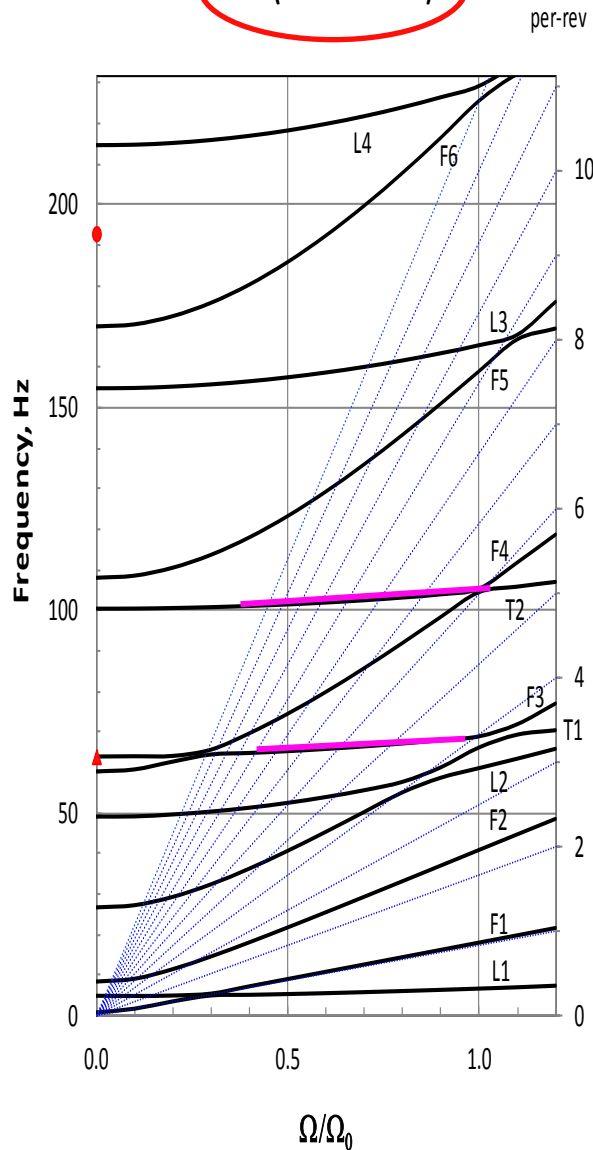


Torsion mode	Experiment	ANSYS	FEM, clamped	CAMRAD, KU	CAMRAD, US
1st	63.9	67.3	67.4	72.7	72.6
2 nd	189.0	196.2	194.0	210.9	210.6

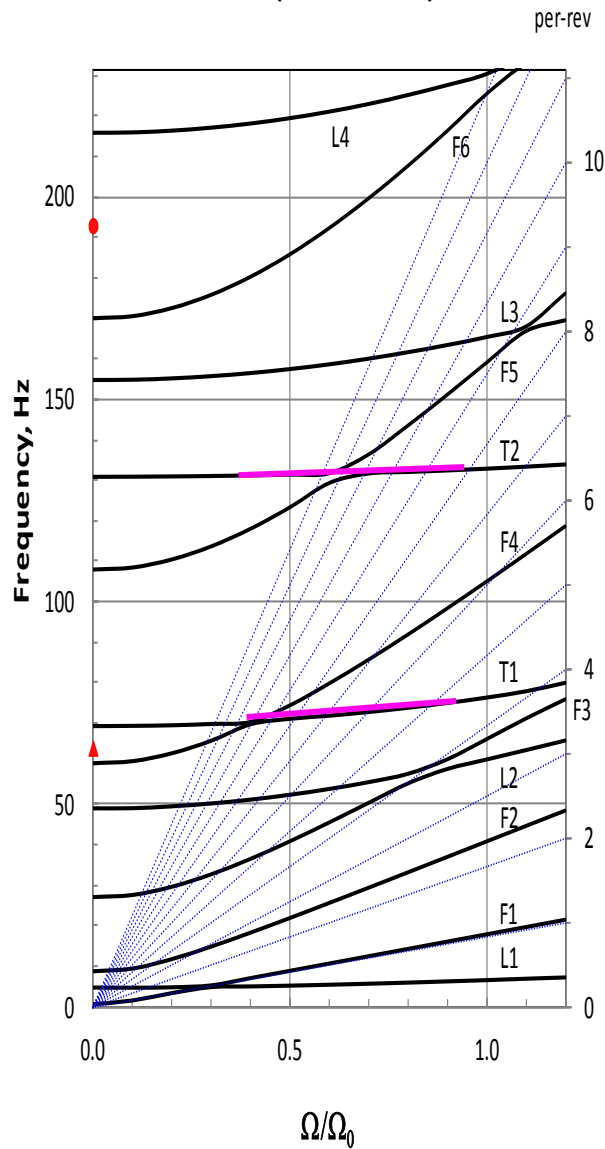
Relative errors

1st	--	5.3%	5.5%	13.8%	13.6%
2 nd	--	3.8%	2.6%	11.6%	11.4%

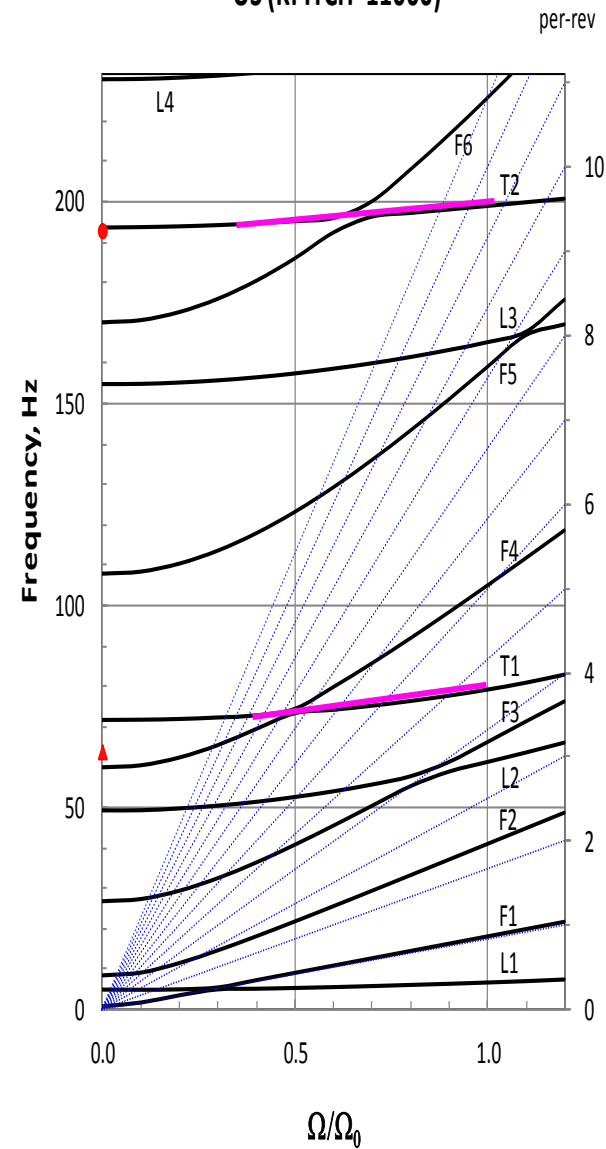
US (KPITCH=2000)



US (KPITCH=4034)



US (KPITCH=11000)



KPITCH	0% RPM		100% RPM	
	1st	2nd	1st	2nd
Measured	63.9	189.0		
2000	63.9	100.5	68.7	104.5
4034	69.3	130.6	76.1	132.7
11000	71.7	193.6	79.4	198.8

Relative errors

	1st	2nd
Measured	--	--
2000	0%	-47%
4034	8%	-31%
11000	12%	2%

- **How to determine the pitch control stiffness?**
- **Match the torsional frequencies with pitch spring stiffness**
 - 2000K Nm/rad: 6/rev resonance
 - 4034K Nm/rad
 - 11000K Nm/rad
- **More measured data are needed ASAP**

Common Presentation

Hover

by J. Lim / D. Boyd

- **Revisit “Hover test” – due January 9, 2012**
 - Will require iterations prior to the deadline, so send your results as early as possible
- **Trim setup**
 - Trimmed to a thrust of **1000N** for the 4-bladed STAR rotor at **100%** RPM (Non-actuated case)
 - Apply active twist actuation using all actuators with the trims computed (no re-trim)
- **Use advanced aerodynamics and wake models if possible**
- **Use control law provided by DLR**

$$A = B_0 + A_n \cos(n\psi), \quad n = 0, 1, 2, \dots, 6$$

(Ref: at4_input_data_documentation_rel_1.1.pdf)

Note : A positive voltage results in a nose-down moment

Prediction Proposal – Hover (cont'd)

- **Cases: NA (non-actuated) and 0-6P actuation**
 - **Output: elastic responses at the blade tip**
 - Flap response: positive up
 - Elastic twist: positive nose up
 - ✓ elastic twist = total torsion – trim controls
-
- a. Non-actuated case: perform a trim
 - b. 0 per-rev: apply +700V (nose-down moment)
 - c. 1-6 per-rev: apply $+100V + 600V \cos(n\psi)$, $n = 1, 2, \dots, 6$
 - d. Provide the means and the changes relative to the mean

$$[\Delta w = w_n - w_{\text{mean}}, \Delta \phi = \phi_n - \phi_{\text{mean}}]$$

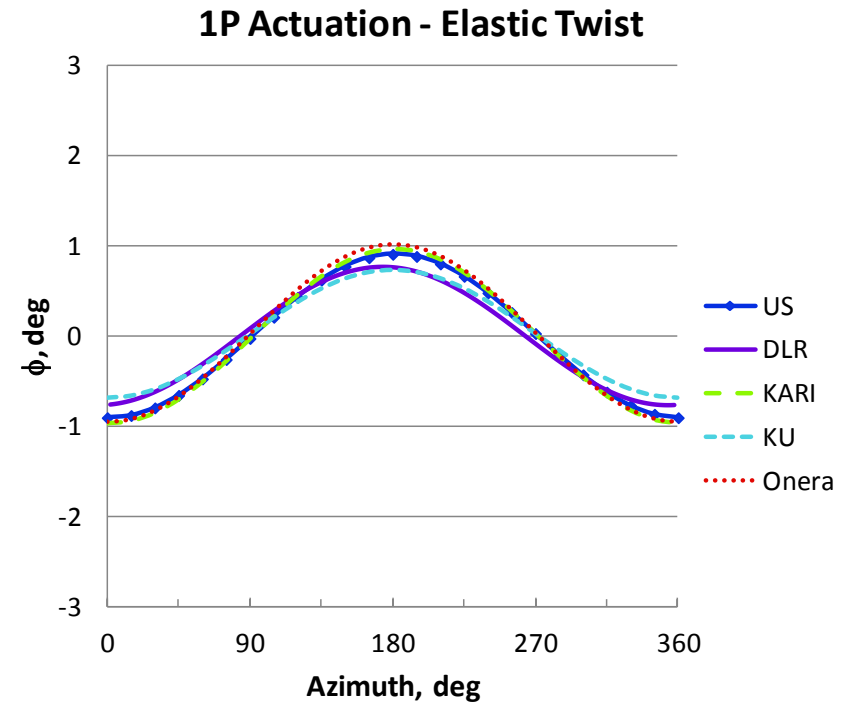
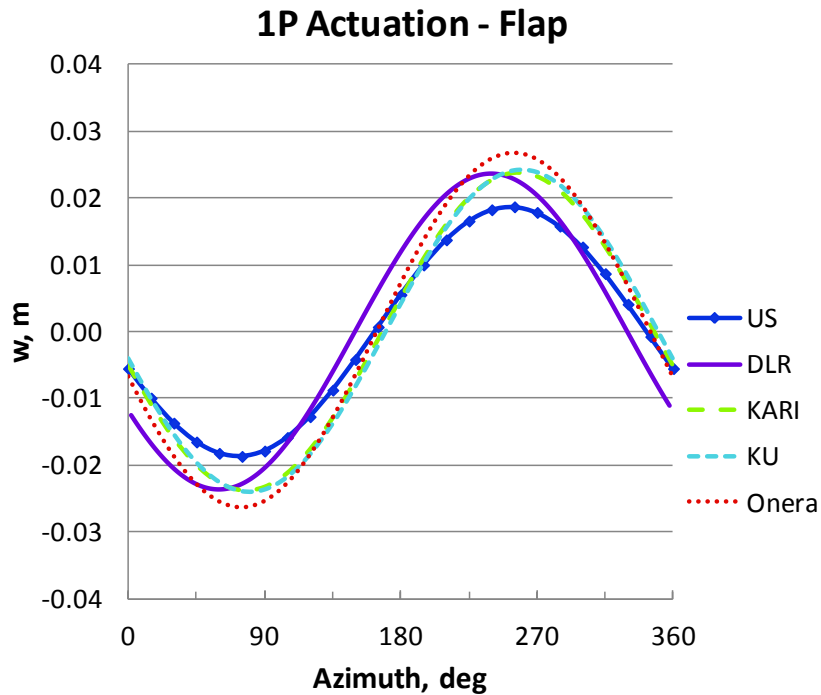
- **Baseline: collectives after trim [deg]**

	US	DLR	KARI	KU	Onera	JAXA
NA	1.67	2.60	1.16	1.86	2.81	2.63

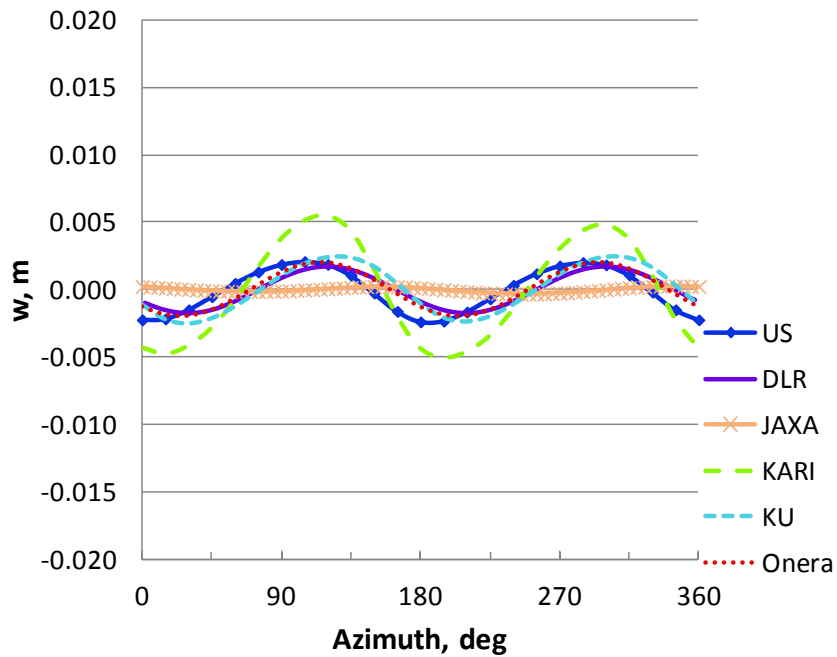
mean	min	max	std
2.12	1.16	2.81	0.66

Means of flap response at the tip [m]											
	US	DLR	KARI	KU	Onera	JAXA		mean	min	max	std
NA	0.015	0.011	0.015	0.013	0.015	0.010		0.013	0.010	0.015	0.002
0P	0.011	0.009	0.009	0.000	0.006	0.008		0.007	0.000	0.011	0.004
1P	0.014	0.009	0.014	0.011	0.013			0.012	0.009	0.014	0.002
2P	0.015	0.009	0.016	0.011	0.014	0.010		0.012	0.009	0.016	0.003
3P	0.015	0.009	0.016	0.011	0.014	0.011		0.013	0.009	0.016	0.003
4P	0.015	0.009	0.016	0.011	0.014	0.010		0.012	0.009	0.016	0.003
5P	0.014	0.009	0.016	0.011	0.014	0.011		0.012	0.009	0.016	0.003
6P	0.016	0.009	0.015	0.011	0.014	0.010		0.012	0.009	0.016	0.003

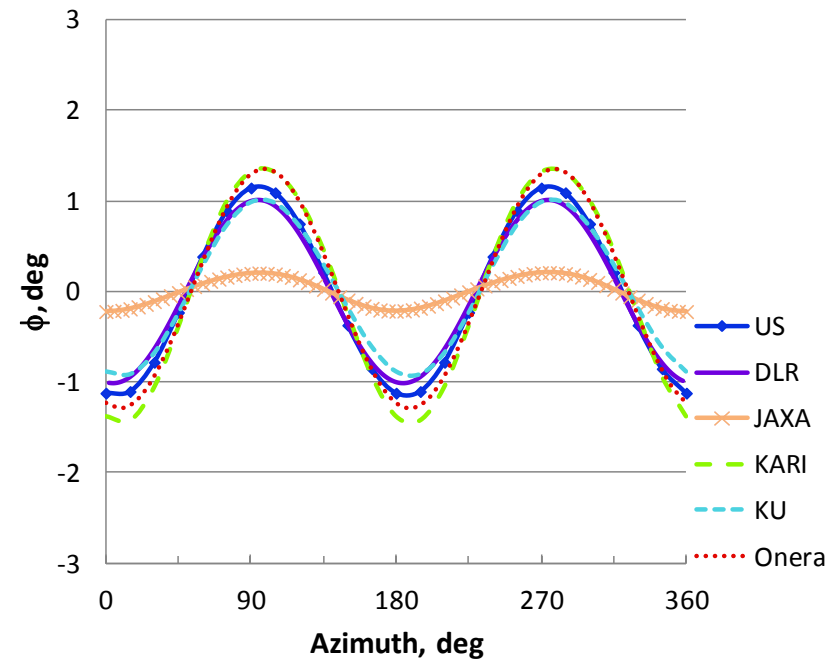
Means of elastic twist at the tip [deg]											
	US	DLR	KARI	KU	Onera	JAXA		mean	min	max	std
NA	-0.28	-0.69	0.23	-0.03	-0.92	-1.12		-0.47	-1.12	0.23	0.53
0P	-1.14	-0.83	-0.63	-0.87	-2.01	-1.25		-1.12	-2.01	-0.63	0.49
1P	-0.25	-0.84	0.16	-0.18	-1.10			-0.44	-1.10	0.16	0.51
2P	-0.24	-0.84	0.17	-0.19	-1.11	-1.13		-0.56	-1.13	0.17	0.54
3P	-0.24	-0.84	0.18	-0.19	-1.11	-1.12		-0.55	-1.12	0.18	0.54
4P	-0.24	-0.84	0.18	-0.18	-1.08	-1.14		-0.55	-1.14	0.18	0.54
5P	-0.25	-0.84	0.16	-0.12	-1.06	-1.12		-0.54	-1.12	0.16	0.54
6P	-0.24	-0.84	0.16	-0.13	-1.07	-1.14		-0.54	-1.14	0.16	0.54



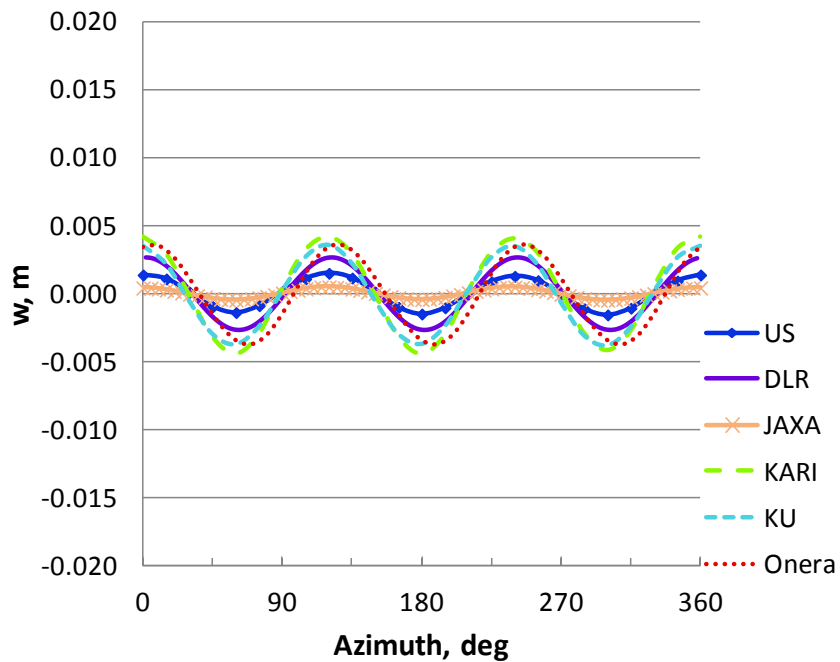
2P Actuation - Flap



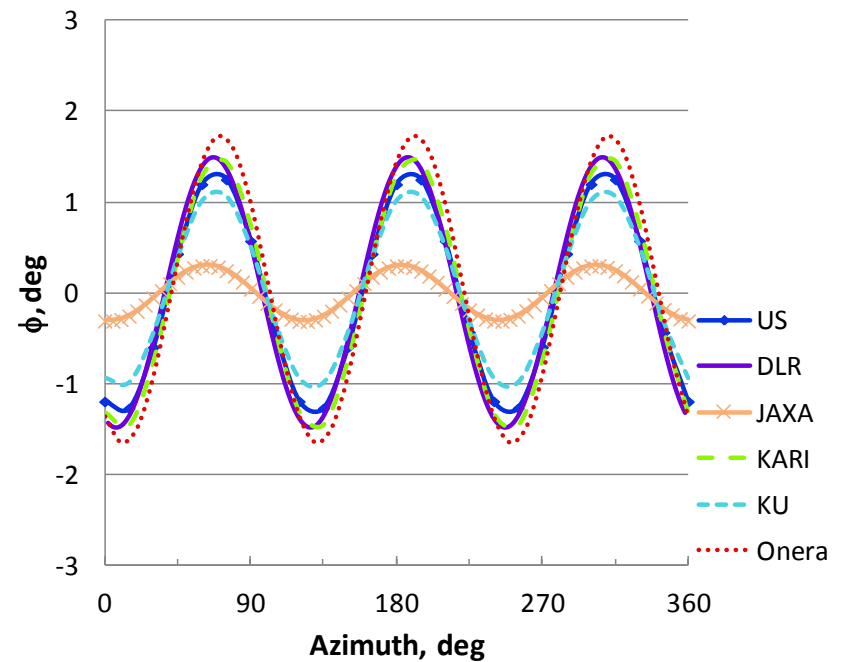
2P Actuation - Elastic Twist



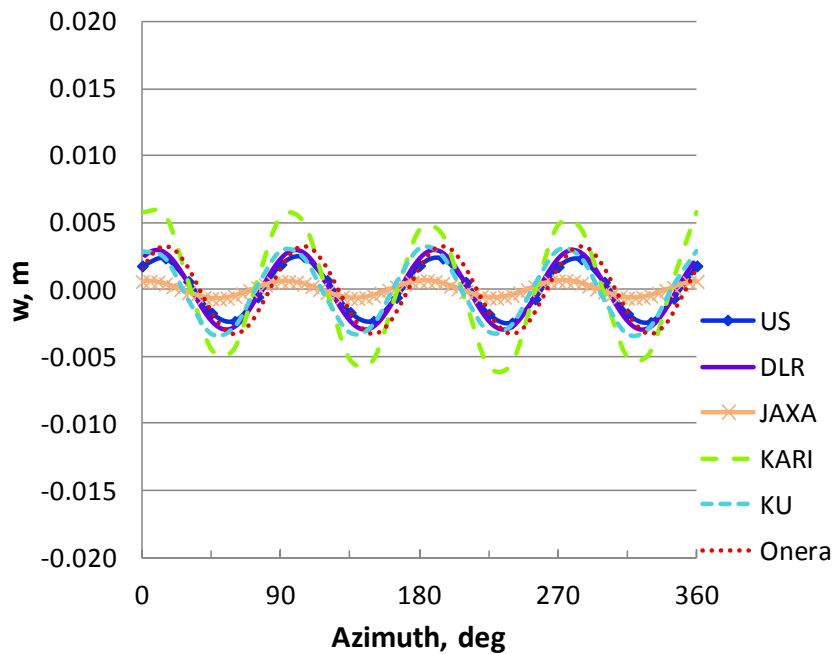
3P Actuation - Flap



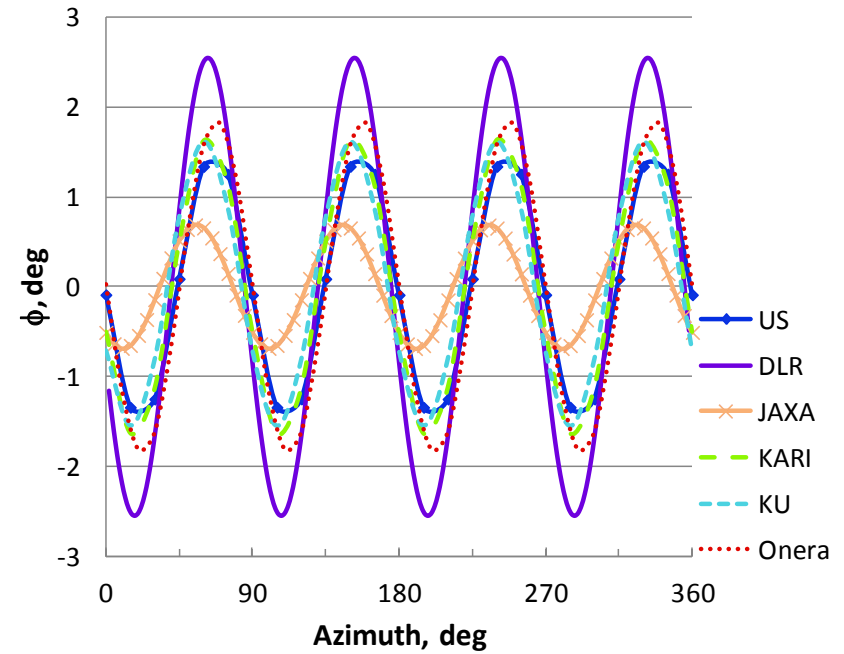
3P Actuation - Elastic Twist



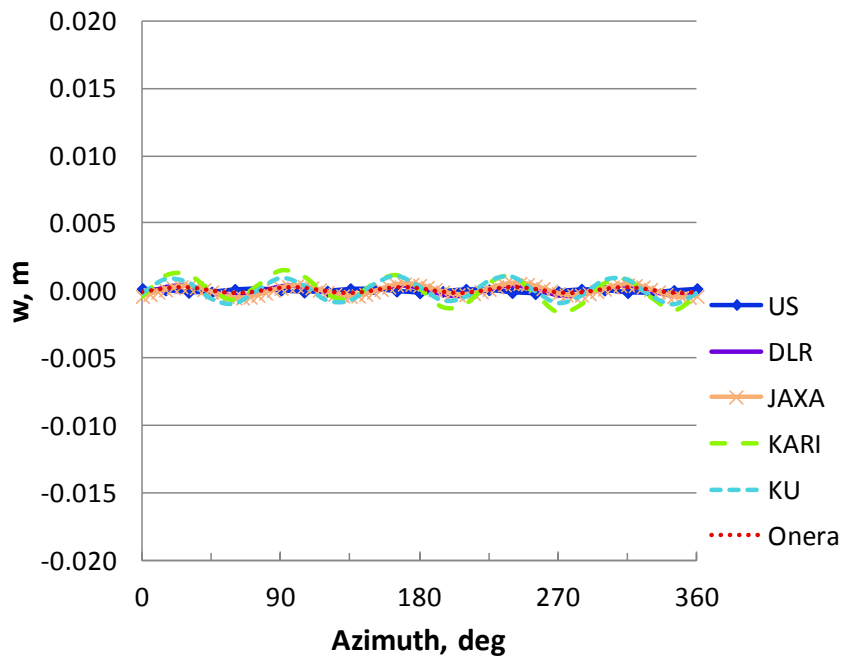
4P Actuation - Flap



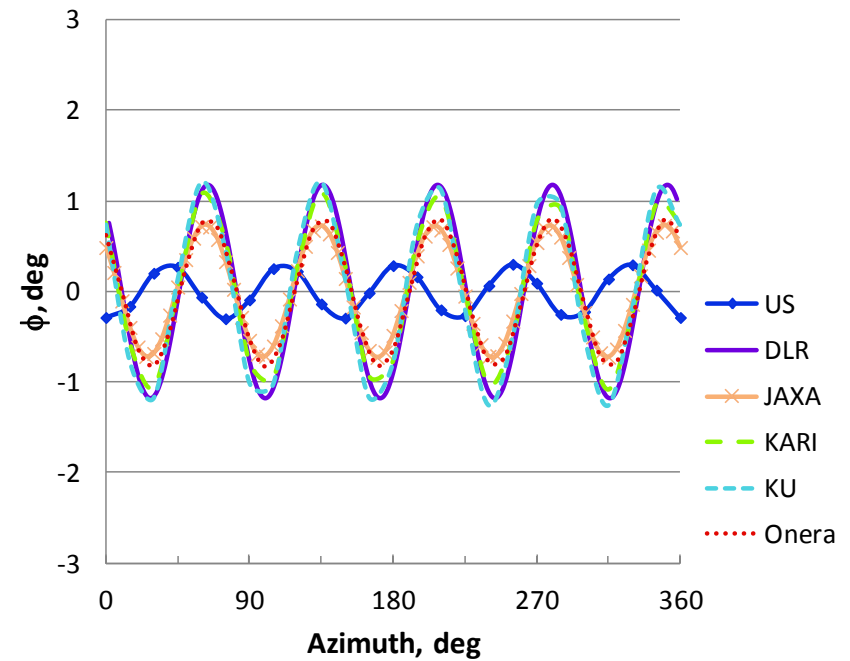
4P Actuation - Elastic Twist



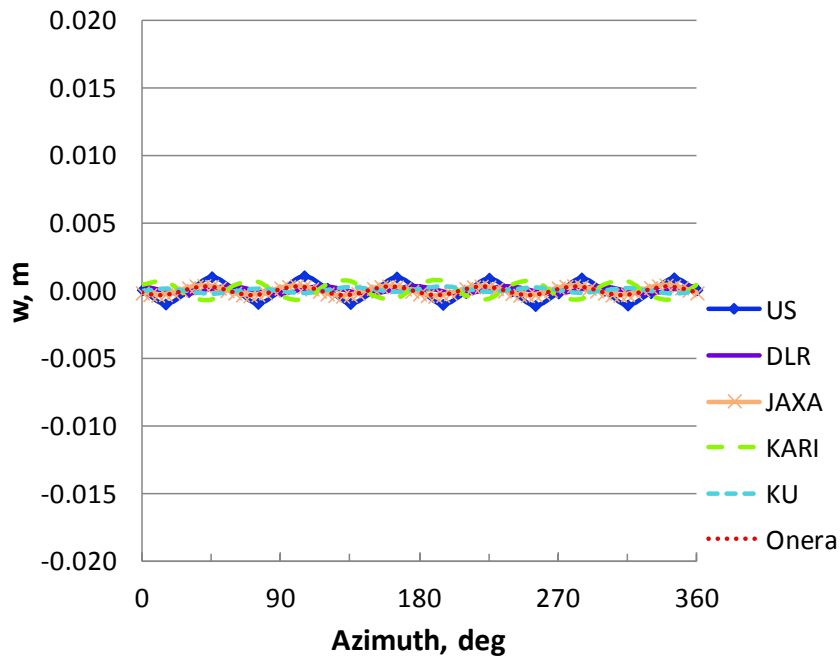
5P Actuation - Flap



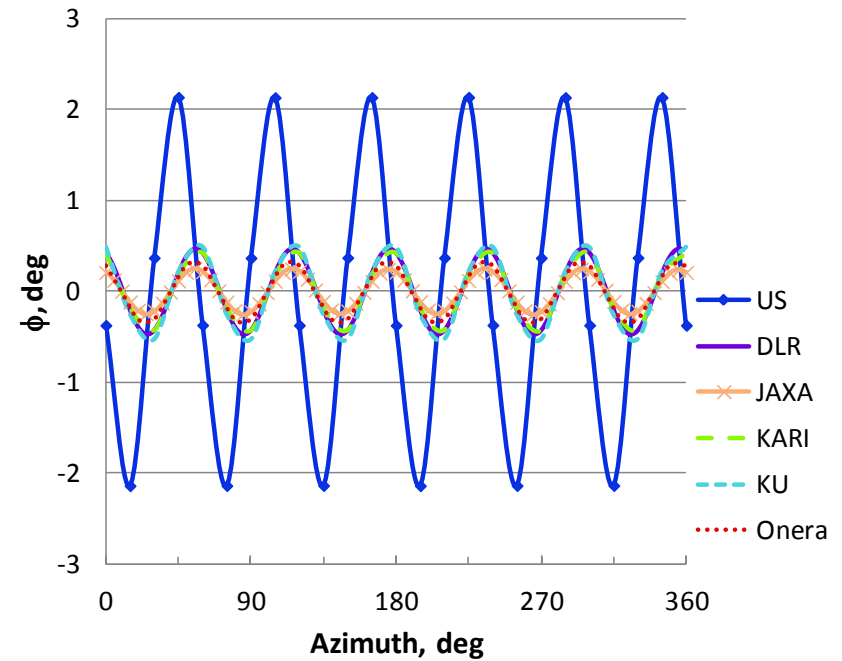
5P Actuation - Elastic Twist

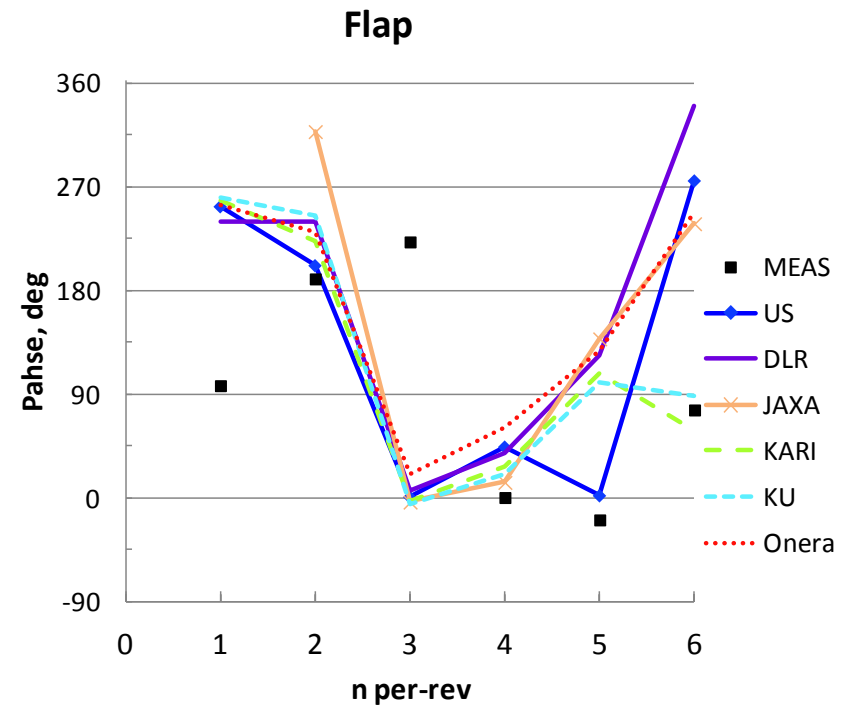
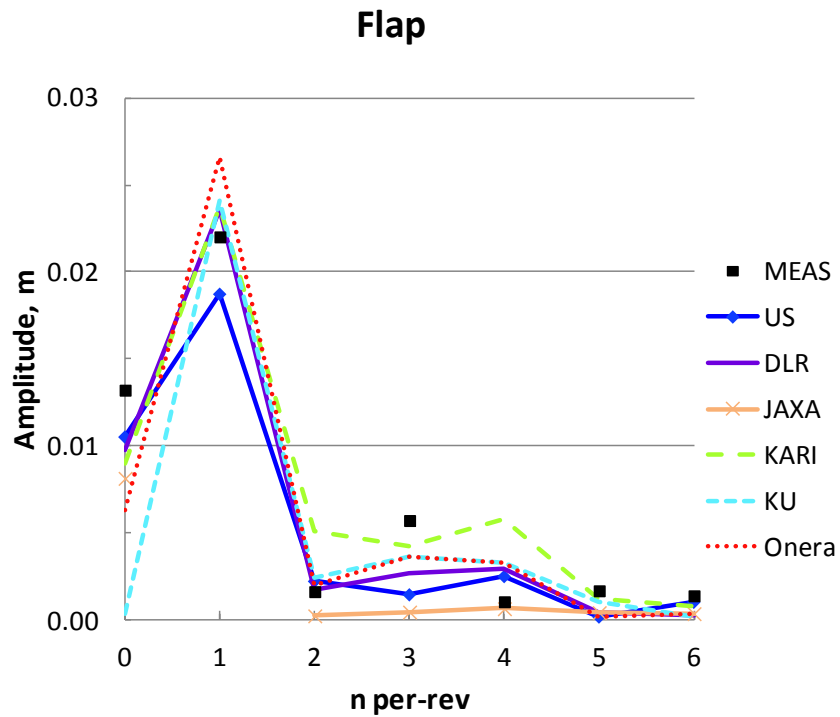


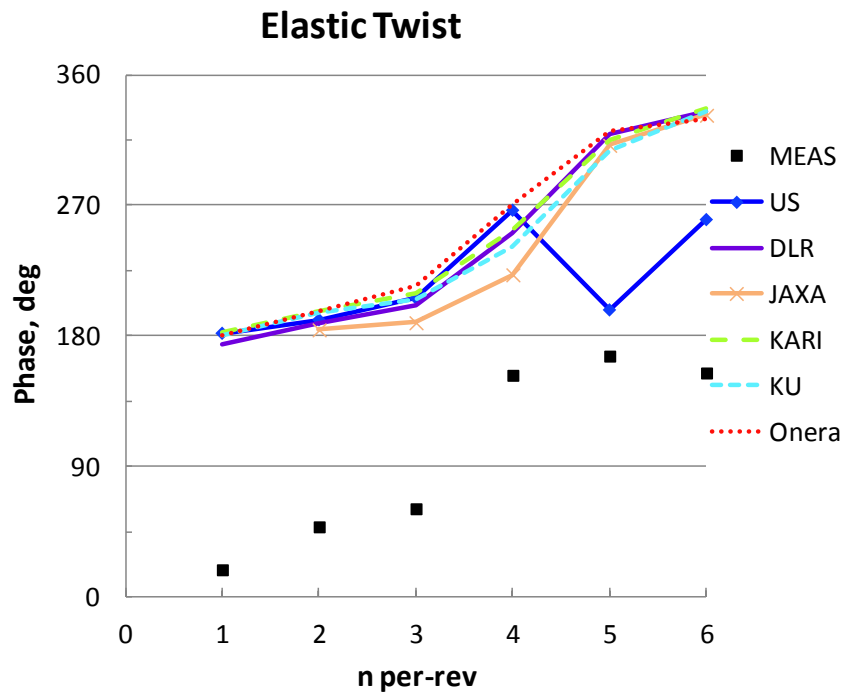
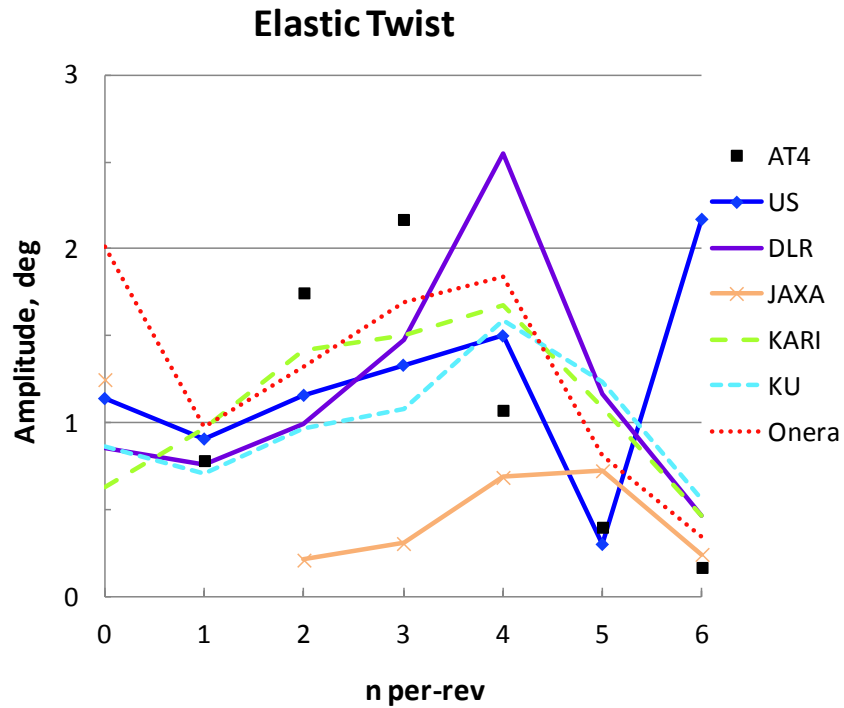
6P Actuation - Flap



6P Actuation - Elastic Twist







- The baseline trim collectives have a variation of 1.65 degrees
- Tip flap responses appear less concern and the magnitudes are small for the 2-6P actuation
- Tip elastic twists show a standard deviation of 0.5 degrees for the 0-6P actuation
- Large scatter is observed in the partners' FRFs with 4-6P actuation

Individual Presentation US

Hover

by J. Lim / D. Boyd

- All results are from CAMRAD II
- Baseline: collectives after trim [deg]

Means of the collective with 2K								
	US	KARI	KU		mean	min	max	std
NA	1.67	1.16	1.86		1.56	1.16	1.86	0.37

Means of the collective with 11K								
	US,11K	KARI	KU		mean	min	max	std
NA	1.31	1.16	1.86		1.44	1.16	1.86	0.37

Mean Response in Hover - Flap

Means of flap response at the tip [m] with 2K								
	US	KARI	KU		mean	min	max	std
NA	0.008	0.015	0.013		0.012	0.008	0.015	0.004
0P	0.005	0.009	0.000		0.005	0.000	0.009	0.005
1P	0.014	0.014	0.011		0.013	0.011	0.014	0.002
2P	0.015	0.016	0.011		0.014	0.011	0.016	0.003
3P	0.015	0.016	0.011		0.014	0.011	0.016	0.002
4P	0.015	0.016	0.011		0.014	0.011	0.016	0.003
5P	0.014	0.016	0.011		0.014	0.011	0.016	0.002
6P	0.016	0.015	0.011		0.014	0.011	0.016	0.002

Means of flap response at the tip [m] with 11K								
	US,11K	KARI	KU		mean	min	max	std
NA	0.015	0.015	0.013		0.015	0.013	0.015	0.001
0P	0.004	0.009	0.000		0.004	0.000	0.009	0.005
1P	0.007	0.014	0.011		0.011	0.007	0.014	0.004
2P	0.006	0.016	0.011		0.011	0.006	0.016	0.005
3P	0.006	0.016	0.011		0.011	0.006	0.016	0.005
4P	0.006	0.016	0.011		0.011	0.006	0.016	0.005
5P	0.006	0.016	0.011		0.011	0.006	0.016	0.005
6P	0.007	0.015	0.011		0.011	0.007	0.015	0.004

Mean Response in Hover - Elastic twist

Means of elastic twist at the tip [deg] with 2K

	US	KARI	KU		mean	min	max	std
NA	-0.28	0.23	-0.03		-0.03	-0.28	0.23	0.26
0P	-1.14	-0.63	-0.87		-0.88	-1.14	-0.63	0.25
1P	-0.25	0.16	-0.18		-0.09	-0.25	0.16	0.22
2P	-0.24	0.17	-0.19		-0.09	-0.24	0.17	0.23
3P	-0.24	0.18	-0.19		-0.09	-0.24	0.18	0.23
4P	-0.24	0.18	-0.18		-0.08	-0.24	0.18	0.23
5P	-0.25	0.16	-0.12		-0.07	-0.25	0.16	0.21
6P	-0.24	0.16	-0.13		-0.07	-0.24	0.16	0.20

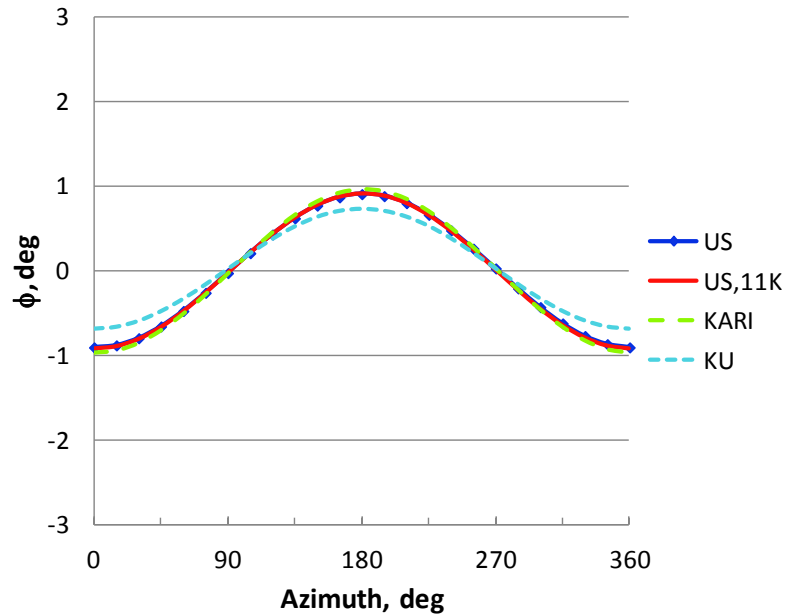
mean std
=0.23

Means of elastic twist at the tip [deg] with 11K

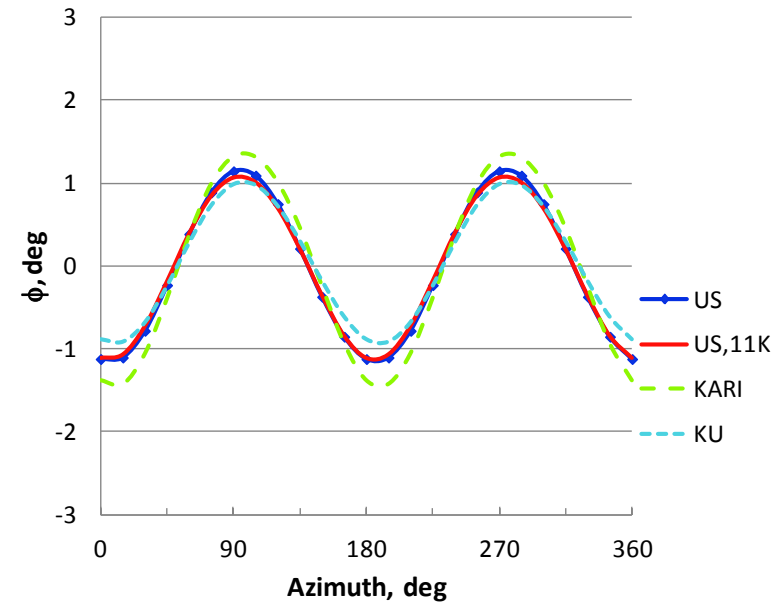
	US,11K	KARI	KU		mean	min	max	std
NA	0.07	0.23	-0.03		0.09	-0.03	0.23	0.13
0P	-1.03	-0.63	-0.87		-0.84	-1.03	-0.63	0.20
1P	-0.11	0.16	-0.18		-0.05	-0.18	0.16	0.18
2P	-0.13	0.17	-0.19		-0.05	-0.19	0.17	0.20
3P	-0.13	0.18	-0.19		-0.05	-0.19	0.18	0.20
4P	-0.12	0.18	-0.18		-0.04	-0.18	0.18	0.20
5P	-0.13	0.16	-0.12		-0.03	-0.13	0.16	0.17
6P	-0.11	0.16	-0.13		-0.03	-0.13	0.16	0.16

mean std
=0.18

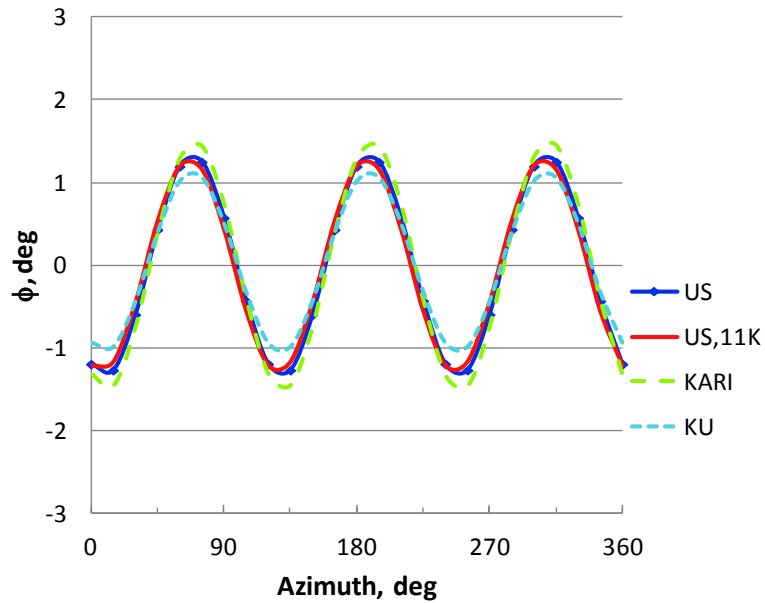
1P Actuation - Elastic Twist



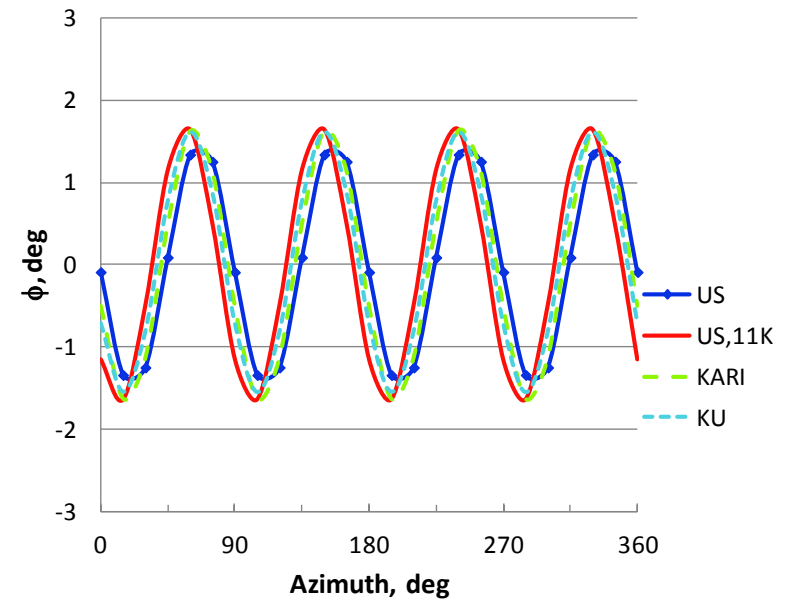
2P Actuation - Elastic Twist



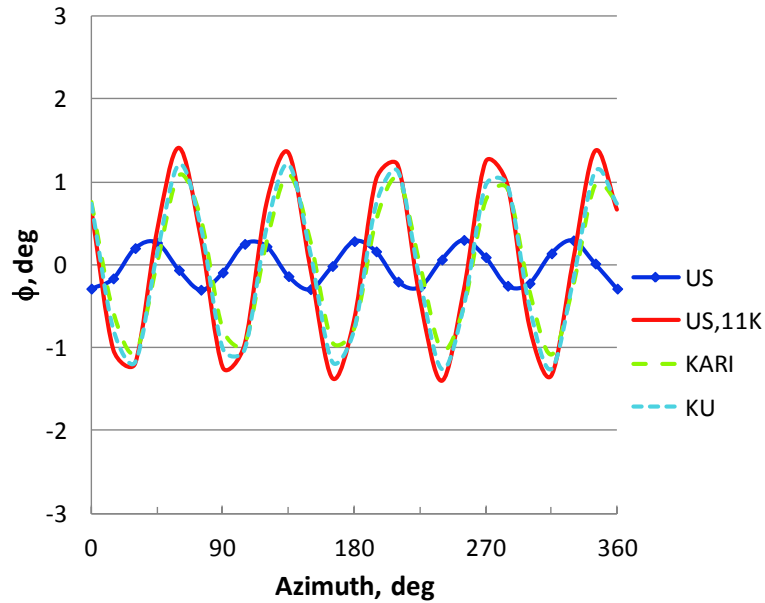
3P Actuation - Elastic Twist



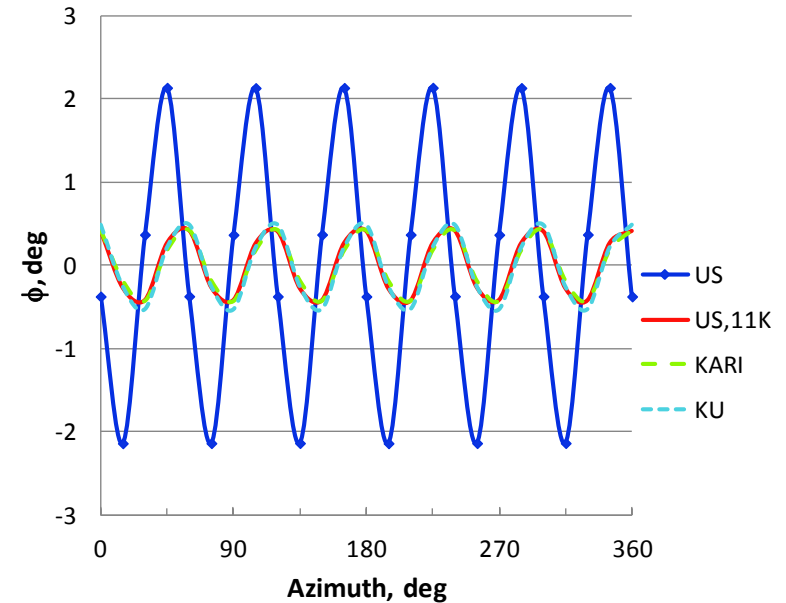
4P Actuation - Elastic Twist



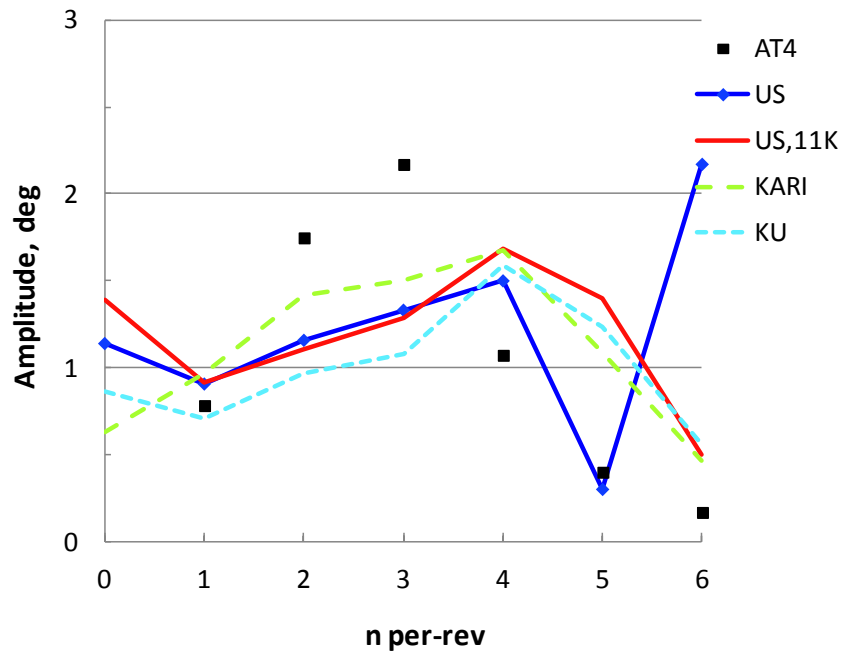
5P Actuation - Elastic Twist



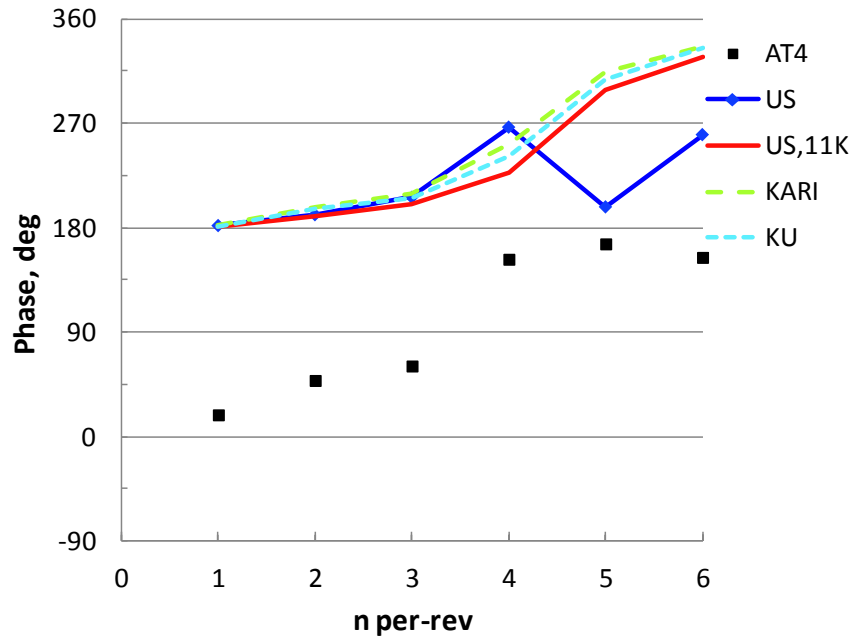
6P Actuation - Elastic Twist



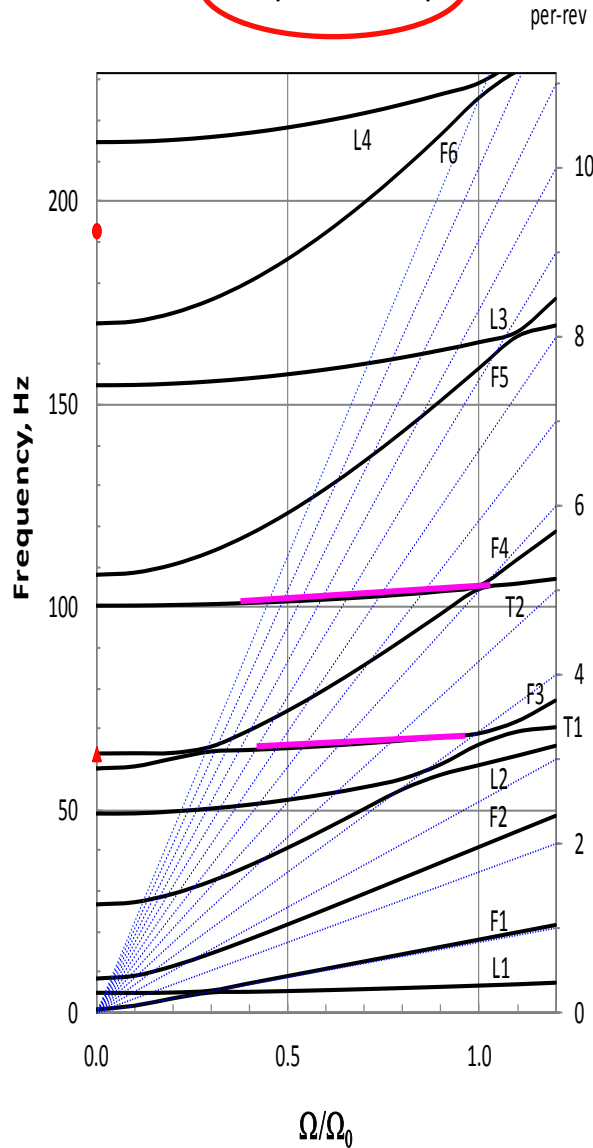
STAR Elastic Twist



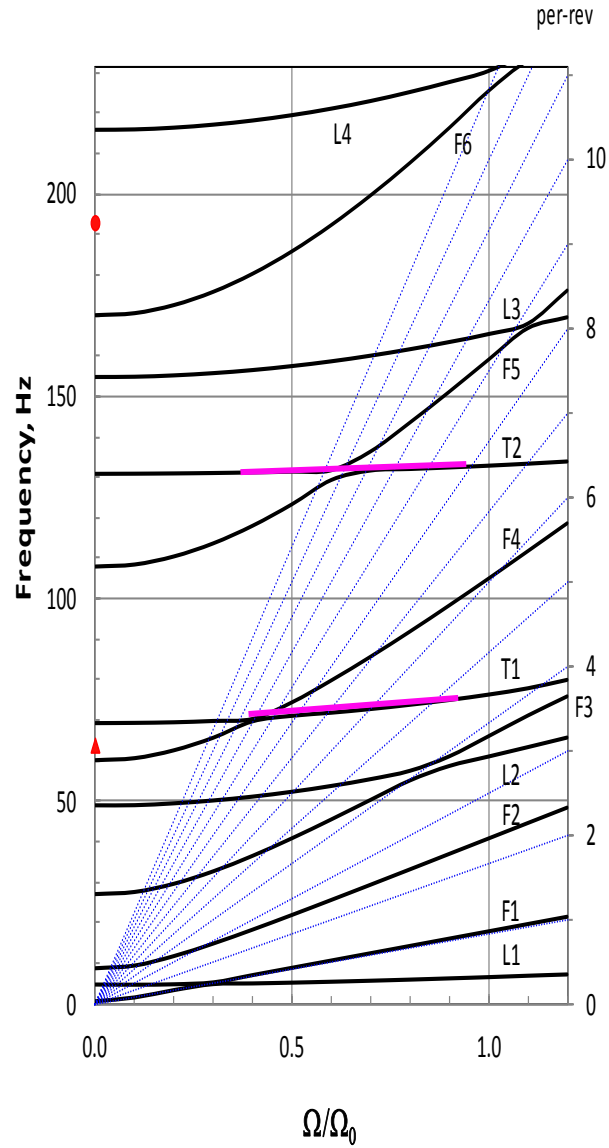
STAR Elastic Twist



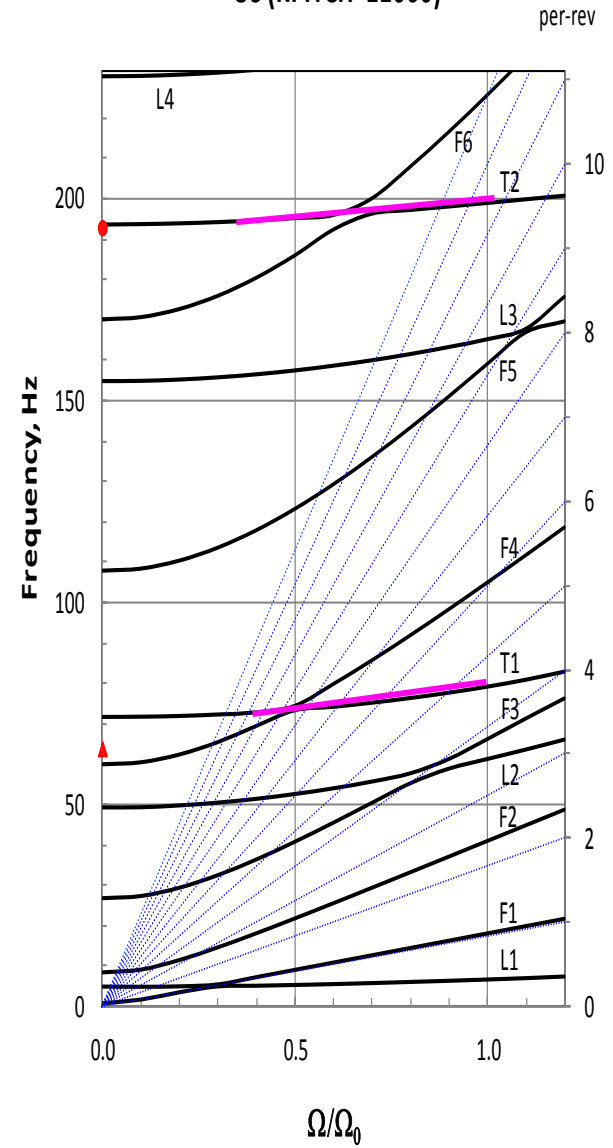
US (KPITCH=2000)



US (KPITCH=4034)



US (KPITCH=11000)



- **With 11K pitch spring, the baseline trim collectives have a variation of 0.7 degree**
- **Tip flap responses match well with 11K pitch spring**
- **For the tip elastic twists, a standard deviation with 11K pitch spring reduces to 0.18 degrees from 0.23 degrees with 2K spring**
- **FRFs match well with 11K pitch spring**
- **The blade with 2K pitch spring may experience a resonance at 4 per-rev**