



Linear Methods Results for AePW-2

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&

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Case 2

	Case 1	Case 2	Optional Case 3A	Optional Case 3B	Optional Case 3C
Mach	0.7	0.74	0.85	0.85	0.85
AoA	3°	0°	5°	5°	5°
Dynamic Data Type	Forced oscillation $f = 10\text{Hz}, \theta =1^\circ$	Flutter	Unforced Unsteady	Forced oscillation $f = 10\text{Hz}, \theta =1^\circ$	Flutter
Notes:	- Attached flow - OTT exp. data - R-134a	- Flow state(?) - PAPA exp. data - R-12	- Separated flow - OTT exp. data - R-134a	- Separated flow - OTT exp. data - R-134a	- Separated flow - No exp. data - R-134a



Case 2 – Linear Methods

- AIC-based: NASTRAN & ZTRAN
- NASTRAN with Generalized Aerodynamic Forces from CFD (AERO – Euler_Linearized)
- Time-Domain CFD (AERO – Euler_Linearized)

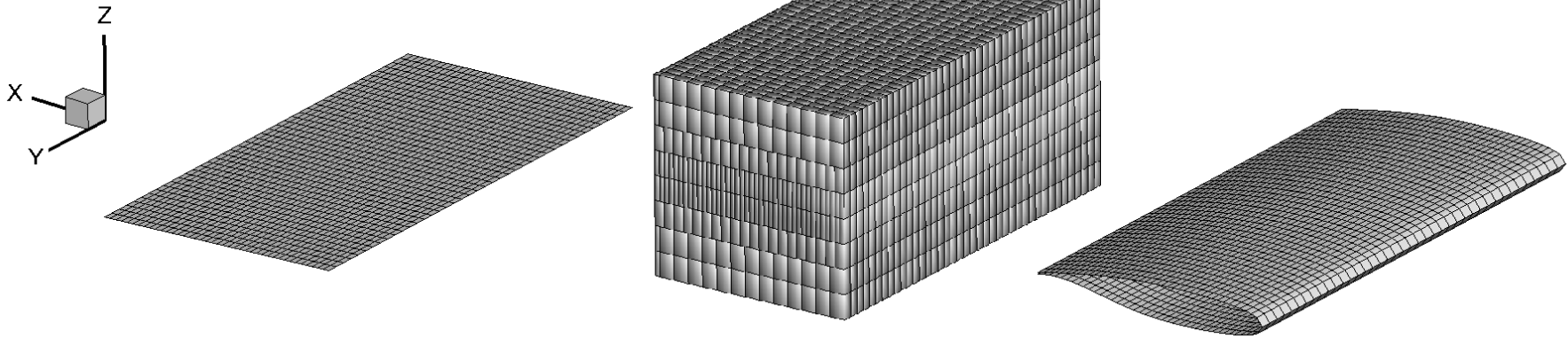
- Nonlinear Analysis (for comparison):
- Time-Domain CFD
 - today: AERO – Euler
 - tomorrow: AERO - RANS



Case 2 – AIC-Based Methods

- Solvers: Nastran (DLM) – corrected and uncorrected
ZTRAN (TDLM)
- Flutter Prediction: Nastran (PKNL method)
ZTRAN (g-method)
- Set of Reduced Frequencies: 0.03, 0.04, 0.05, 0.06, 0.07
- Panels Aspect Ratio = 2 (No. Chordwise Panels = No. Spanwise Panels)
- Surface Mesh: 40x40 panels
- No Structural Damping considered

Case 2 – Aerodynamic Meshes



Surface Mesh:
ZTRAN = NASTRAN

Volume Mesh:
ZTRAN only

Airfoil Mesh:
ZTRAN only



Case 2 – Nastran Aerodynamic Correction

Steady Correction - correction for $k=0$ used for $k \neq 0$

- CLa & Cmy correction (CLa&Cmy)
 - matches wing global CLa and Cmy
- Pre-Multiplying Diagonal Matrix (Pre-Diag)
 - try to match chordwise $d\Delta C_p/da$, spanwise CLa and Xac distributions, and global coefficients (factors limited to 3.0)

Unsteady Correction – different corrections for each k
(uses Pre-Multiplying Diagonal Matrix correction)

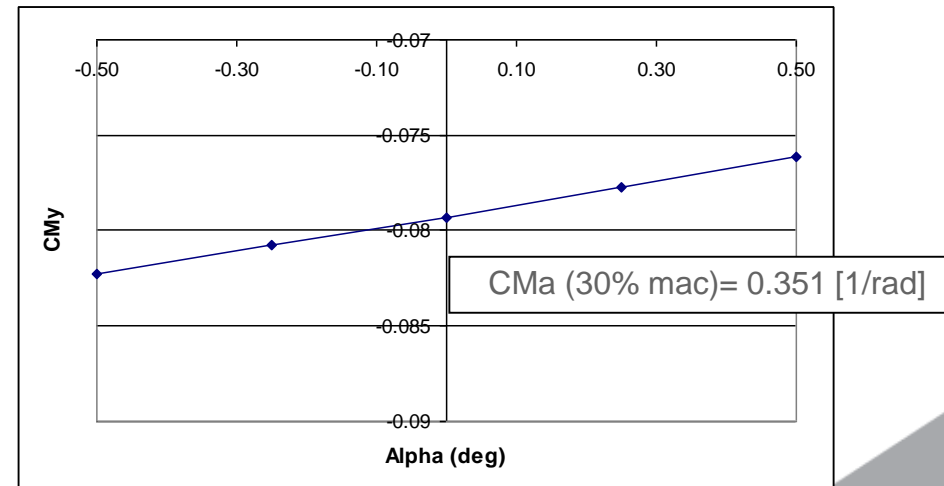
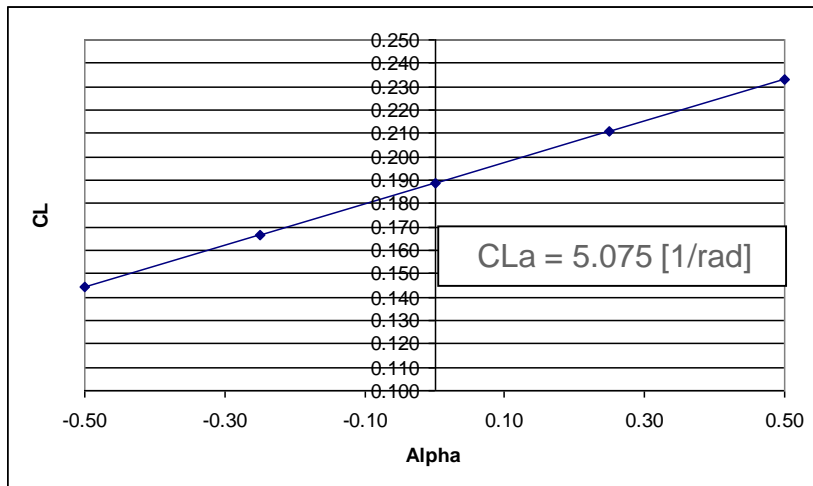
- Pitch Mode Adjust (Unsteady - Pitch)

Case 2 – Steady CFD Data for Aerodynamic Correction

- Steady CFD data obtained from CFD++ (medium mesh)
- $d\Delta C_p/d\alpha$ distribution computed for a pair of angles of attack: (-0.25 & 0.25 deg.)

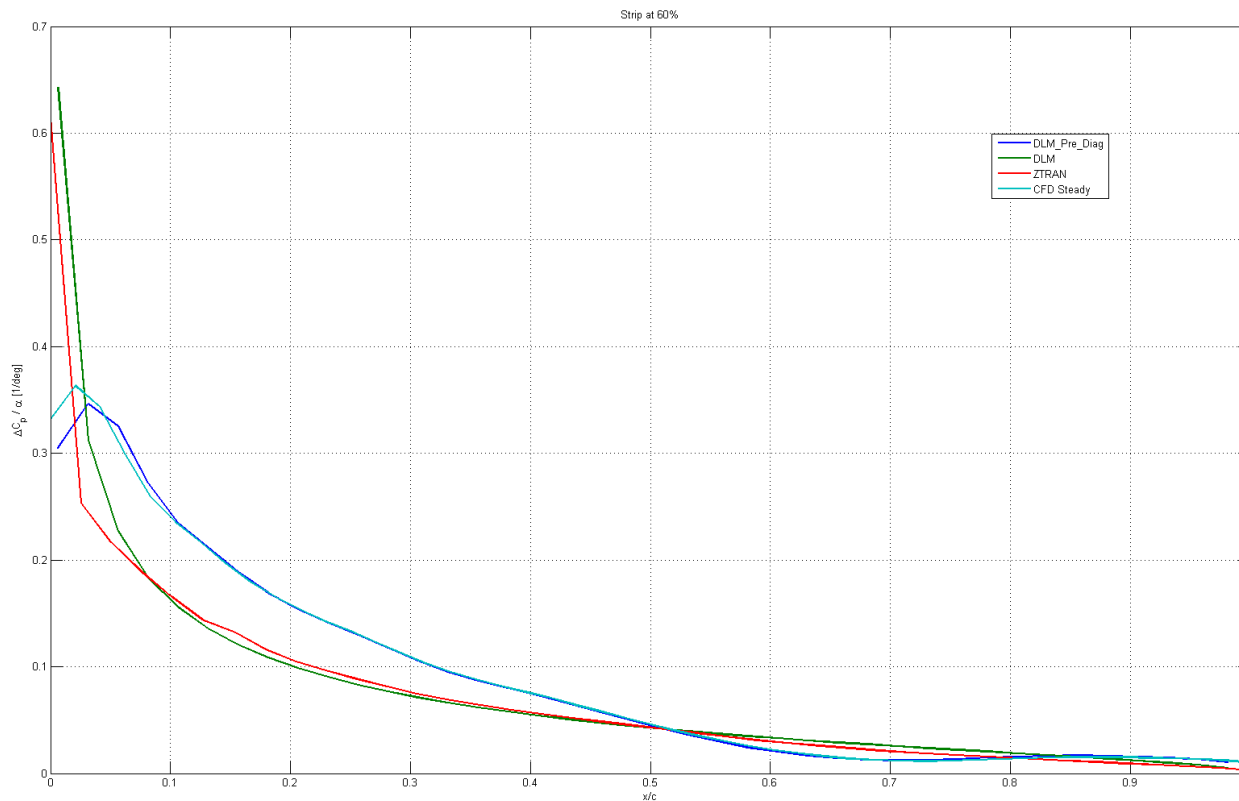
$$\frac{d\Delta C_p}{d\alpha} = \frac{\Delta C_p^{\alpha_2} - \Delta C_p^{\alpha_1}}{\alpha_2 - \alpha_1}$$

- Reference values for global CL_a and CM_a (30% mac) obtained from the slope of the following curves



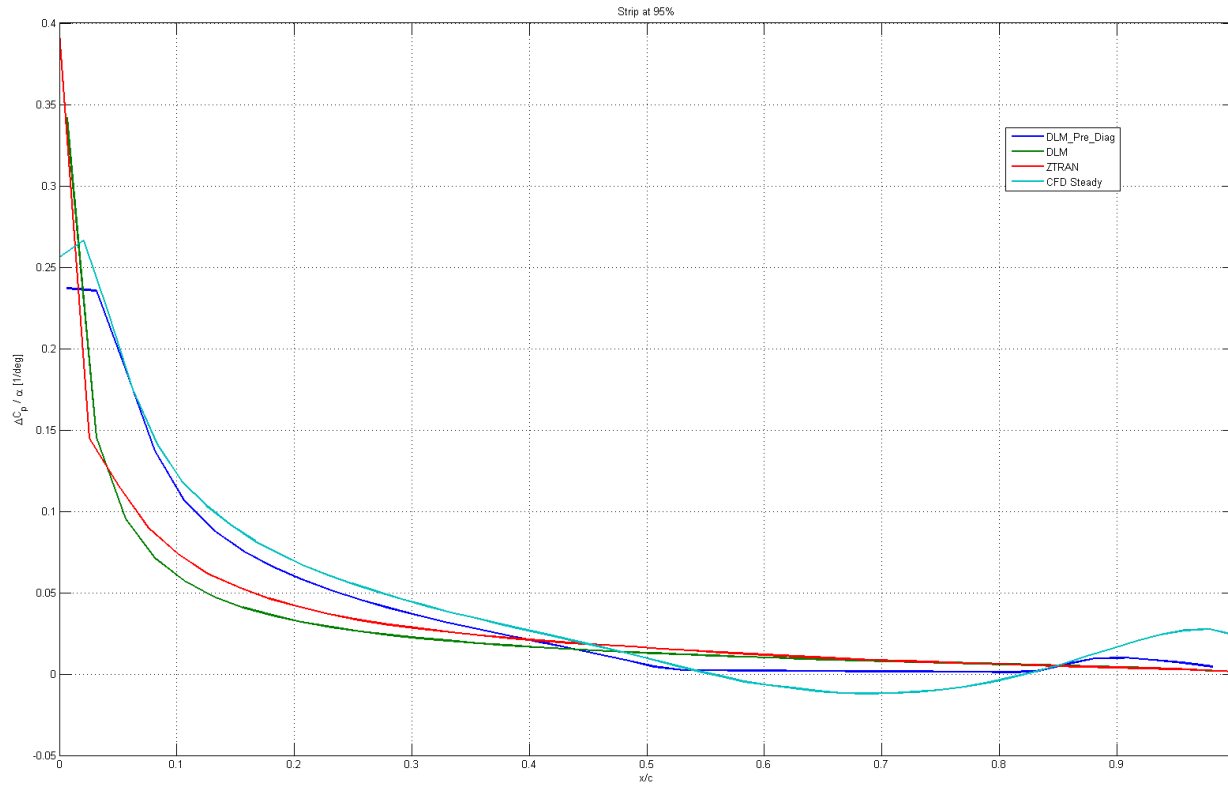
Case 2 – $d\Delta C_p/da$ Distribution at $k=0$

- Strip 60%

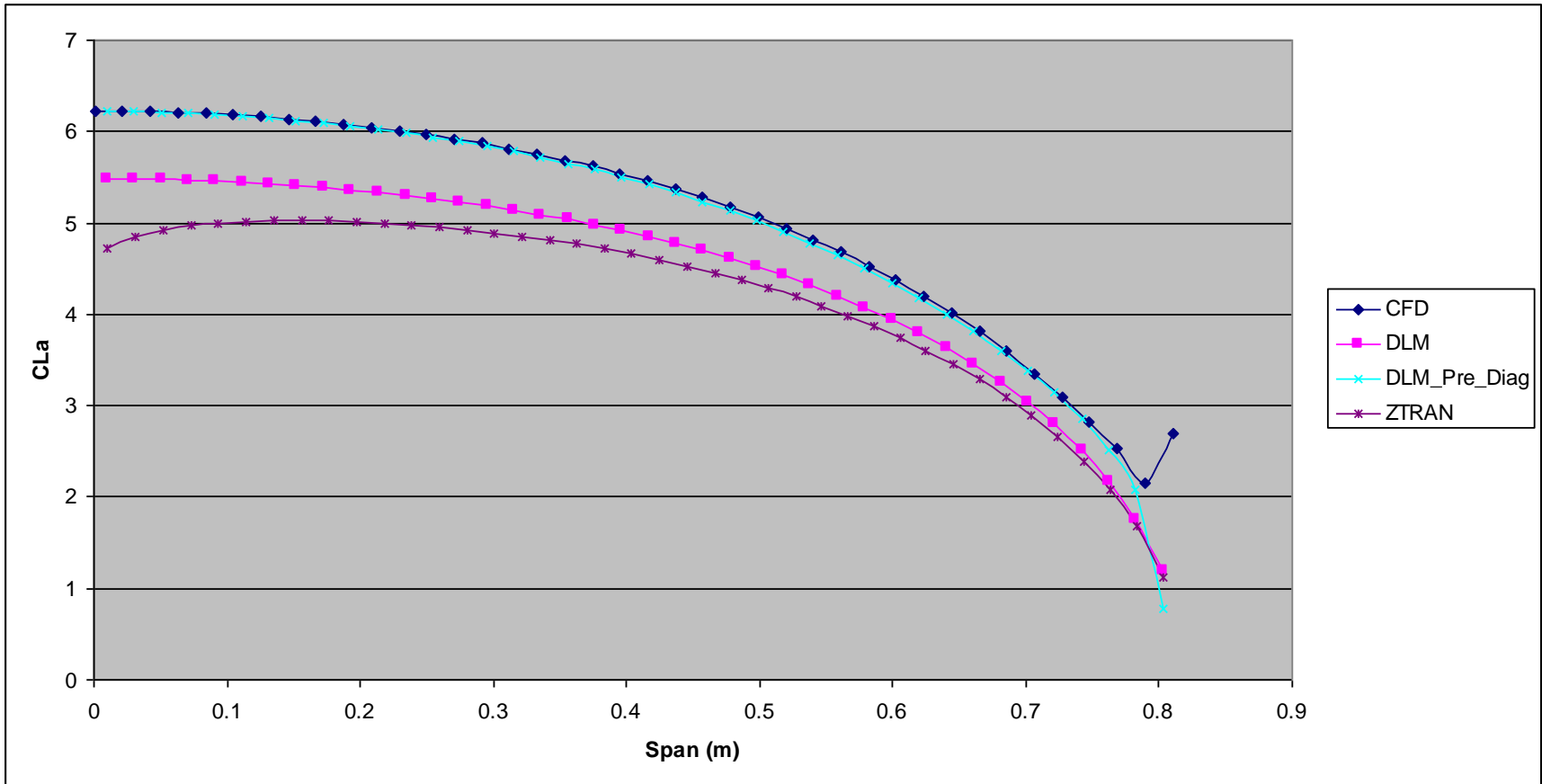


Case 2 – $d\Delta C_p/da$ Distribution at $k=0$

- Strip 95%

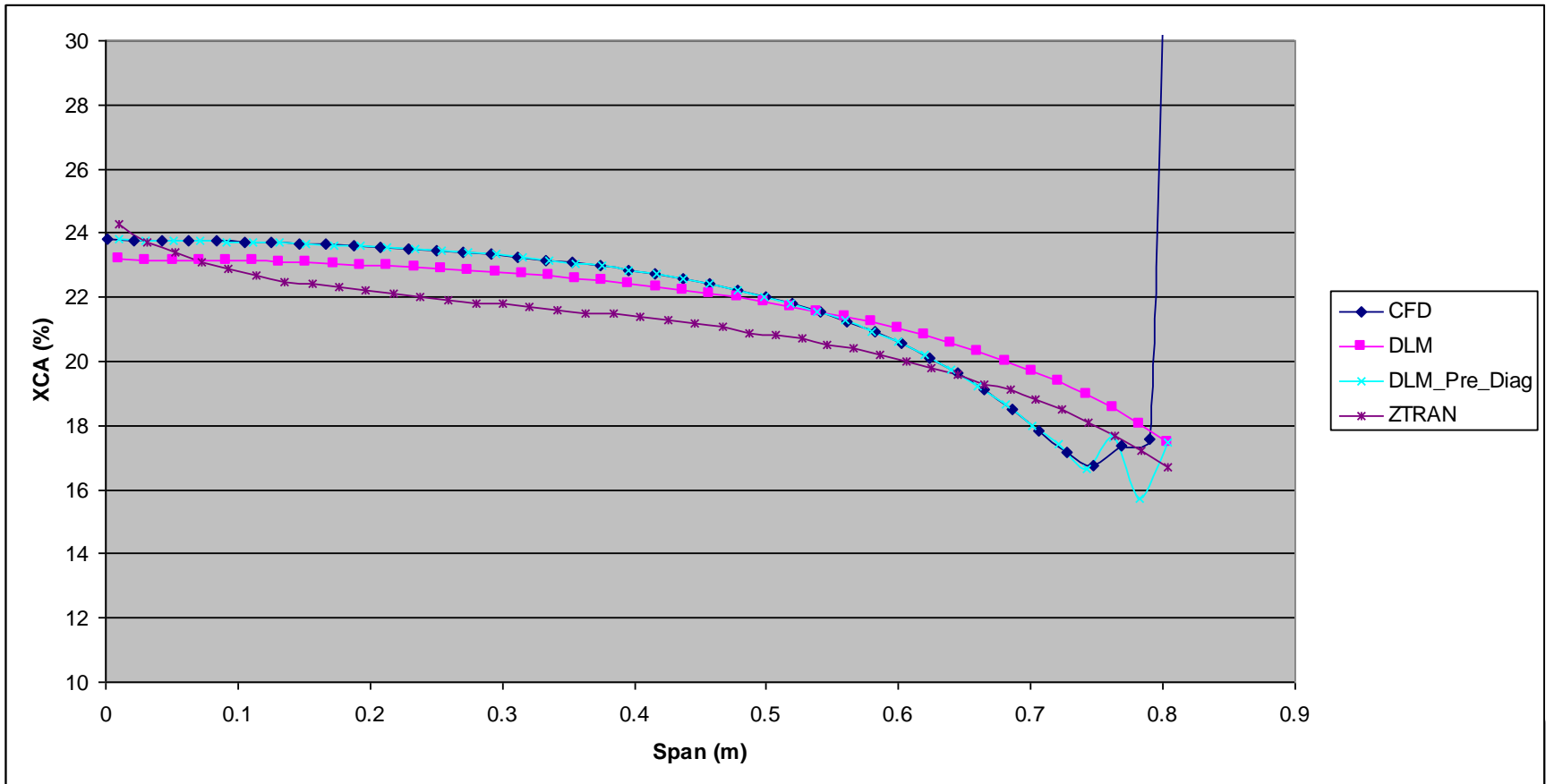


Case 2 – Spanwise CLa Distribution at k=0



Case 2 – Spanwise Xac Distribution at k=0

$$Xac = \frac{CMa}{CLa}$$



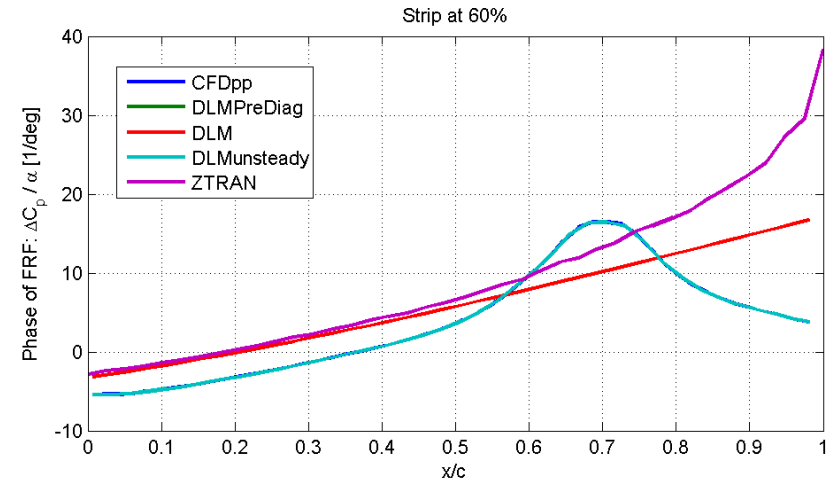
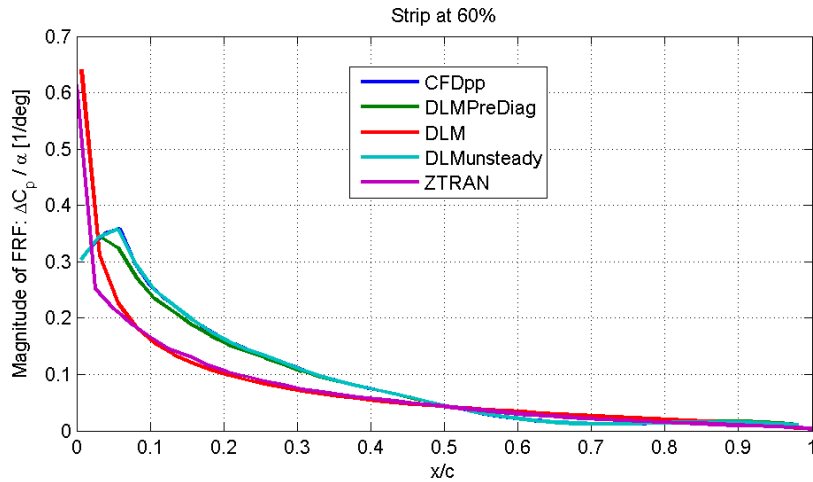


Case 2 – Aerodynamic Coefficients Verification

Method	CLa	Difference CLa	Cmy (30% mac)	Difference Cmy
CFD++ (medium)	5.075	Ref.	0.3508	Ref.
Nastran	4.450	-12.3%	0.3499	-0.3%
Nastran - Unsteady-Pitch				
Nastran - Cla&Cmy	5.075	0.0%	0.3508	0.0%
Nastran - Pre-Diag	5.070	-0.1%	0.3932	12.1%
ZTRAN	4.183	-17.6%	0.3596	2.5%

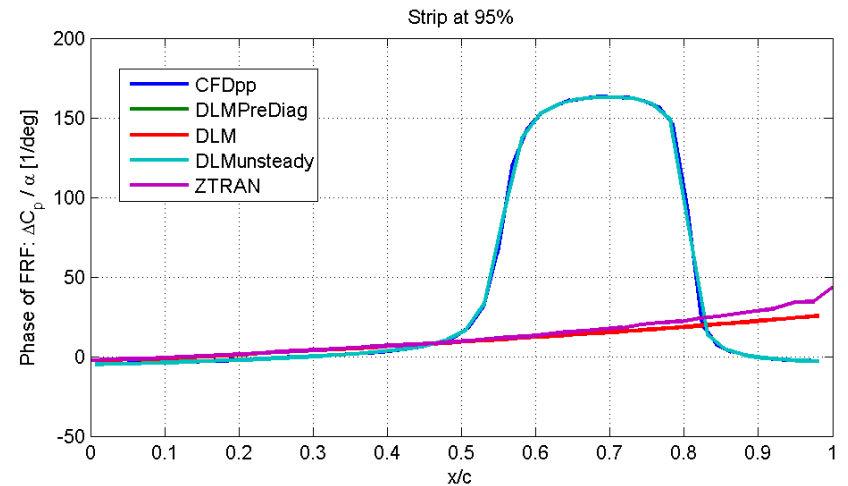
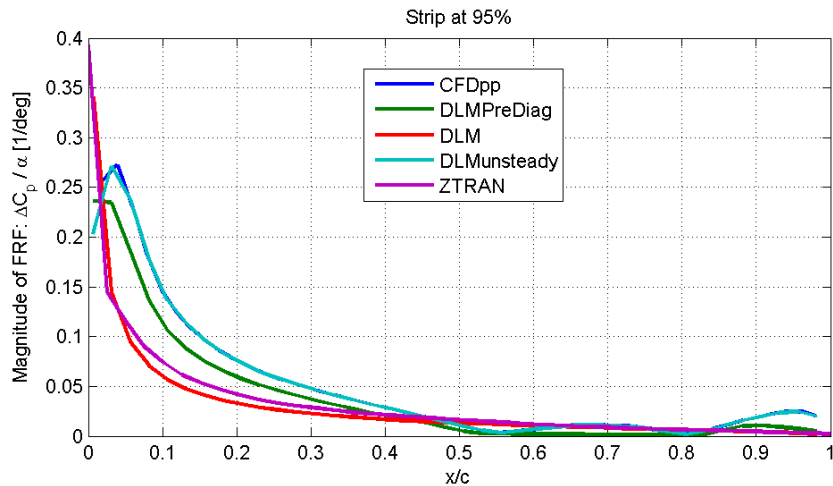
Case 2 – $d\Delta C_p/da$ Distribution at $k=0.03$

- Strip 60%



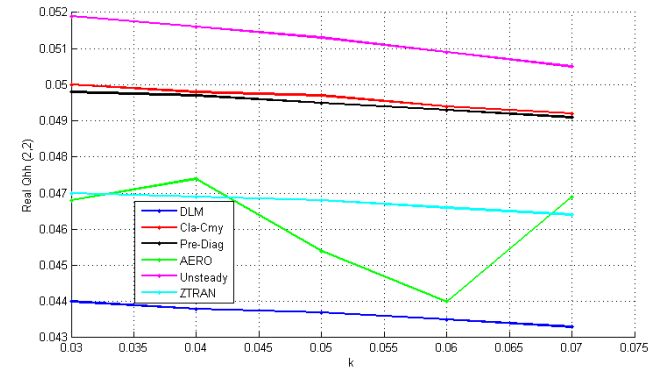
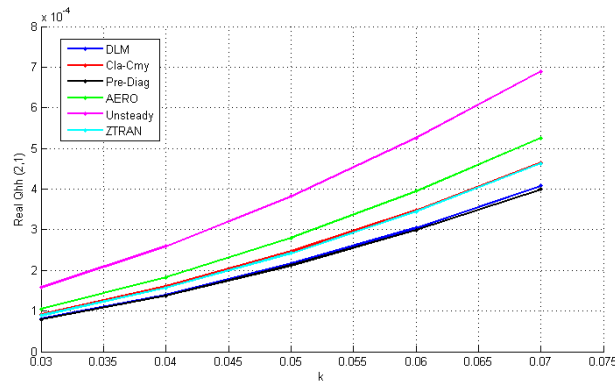
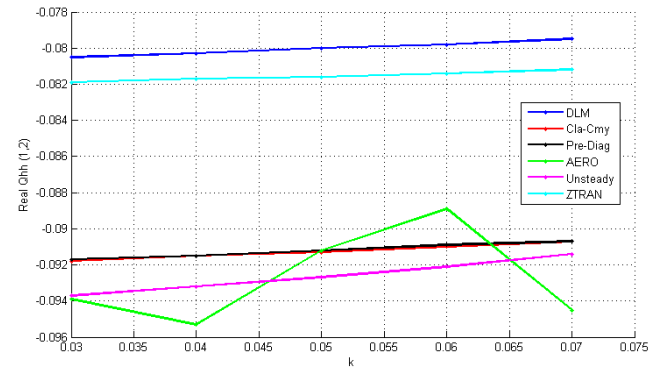
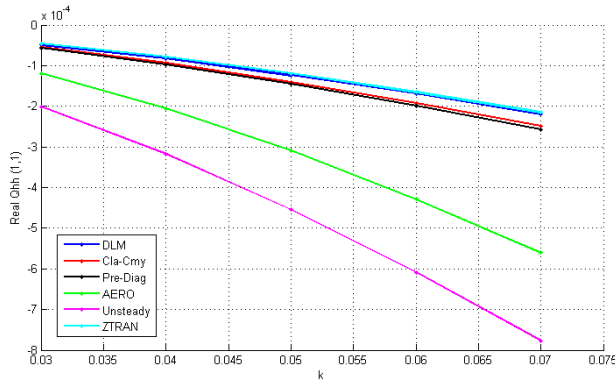
Case 2 – $d\Delta C_p/da$ Distribution at $k=0.03$

- Strip 95%



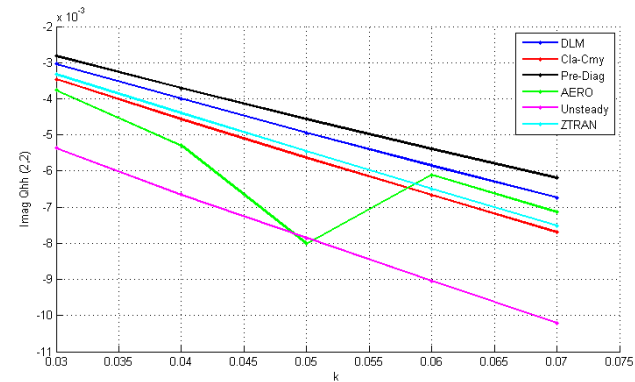
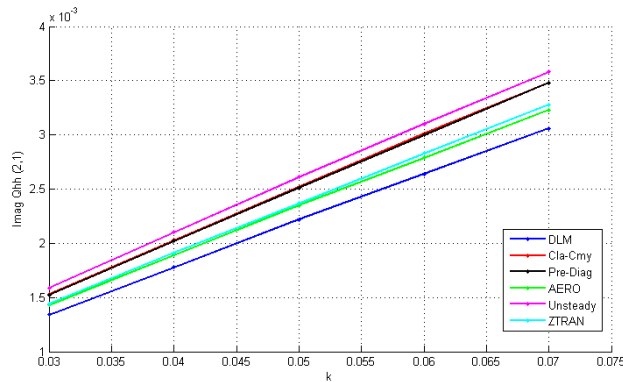
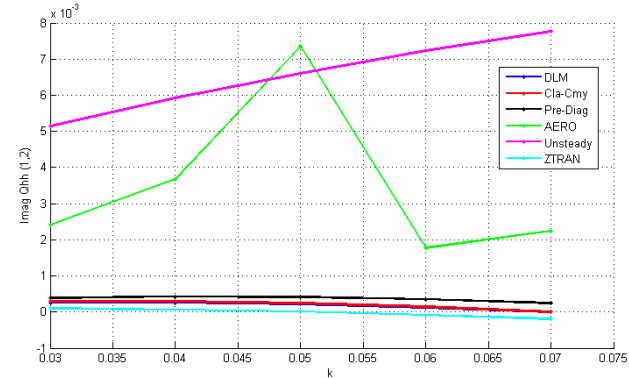
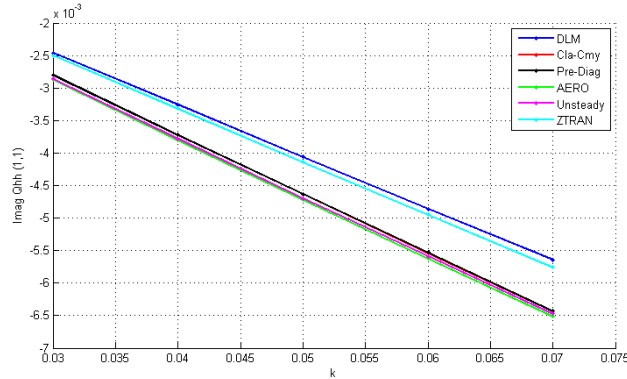
Case 2 – Generalized Aerodynamic Forces

- Real Part

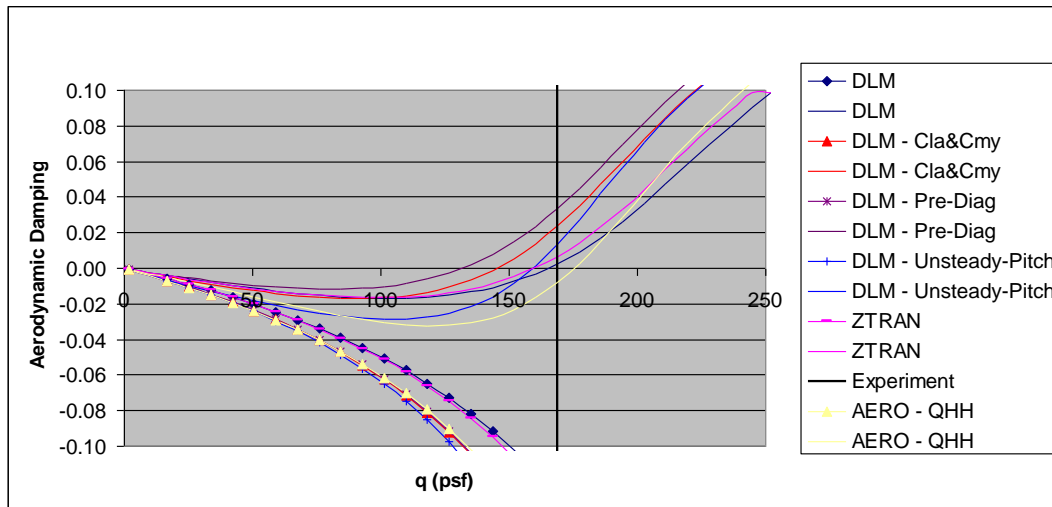
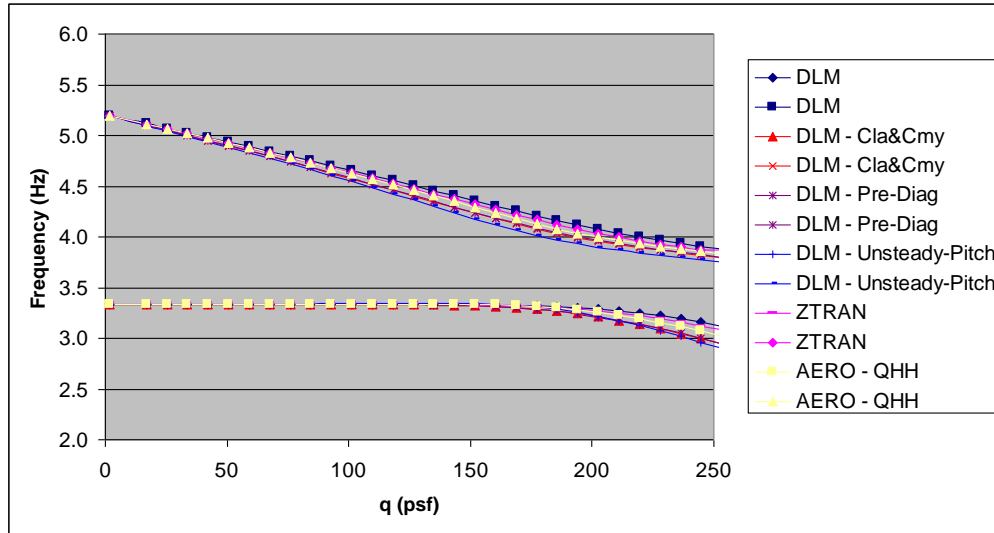


Case 2 – Generalized Aerodynamic Forces

- Imag Part



Case 2 – Flutter Results: V-g-f Plots



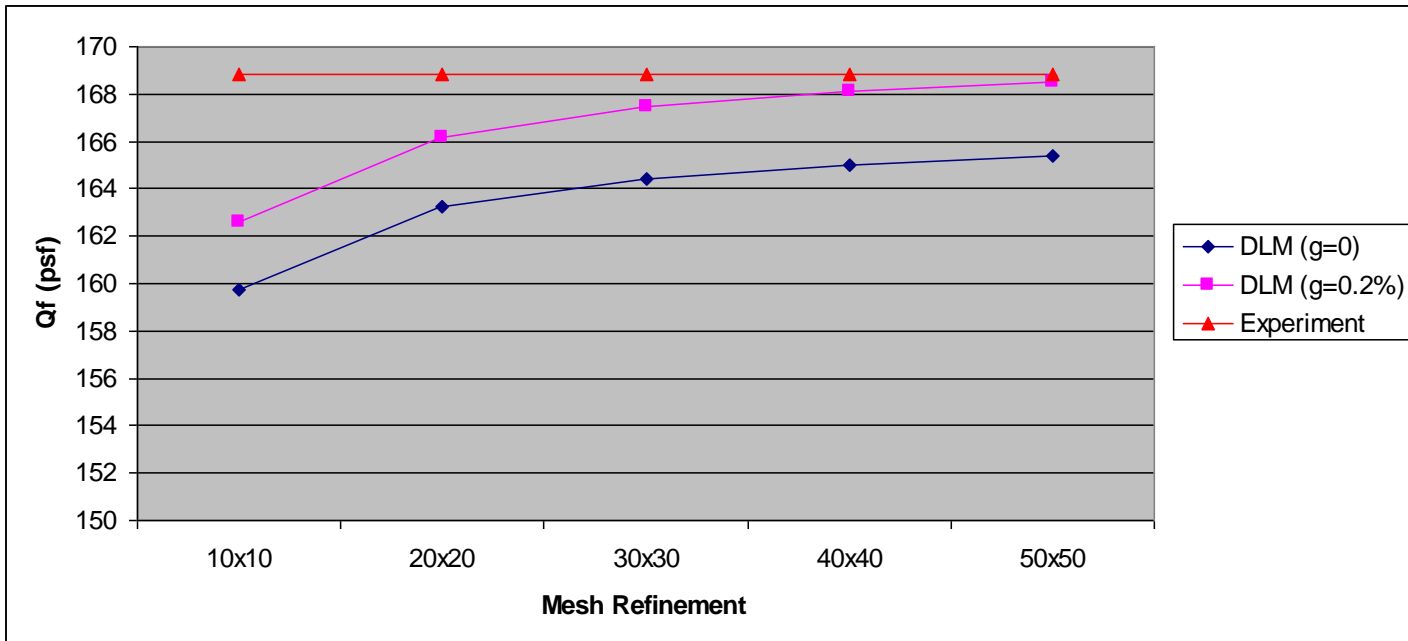


Case 2 – Flutter Results

Method	Flutter Frequency (Hz)	Difference (Freq)	Flutter Dynamic Pressure (psf)	Difference (Dyn. Pres.)
Experiment	4.30	Ref.	168.8	Ref.
Nastran	4.28	-0.5%	165.0	-2.2%
Nastran - Cla&Cmy	4.28	-0.5%	144.8	-14.2%
Nastran - Pre-Diag	4.37	1.7%	131.5	-22.1%
Nastran - Unsteady-Pitch	4.13	-4.0%	159.1	-5.8%
ZTRAN	4.31	0.2%	160.7	-4.8%
AERO – Euler_Linearized Qhh	4.14	-3.8%	175.1	3.7%
AERO – Euler_Linearized Time Domain	4.11	-4.4%	179.2	6.2%
AERO – Euler Nonlinear Time Domain	4.09	-4.9%	176.8	4.7%

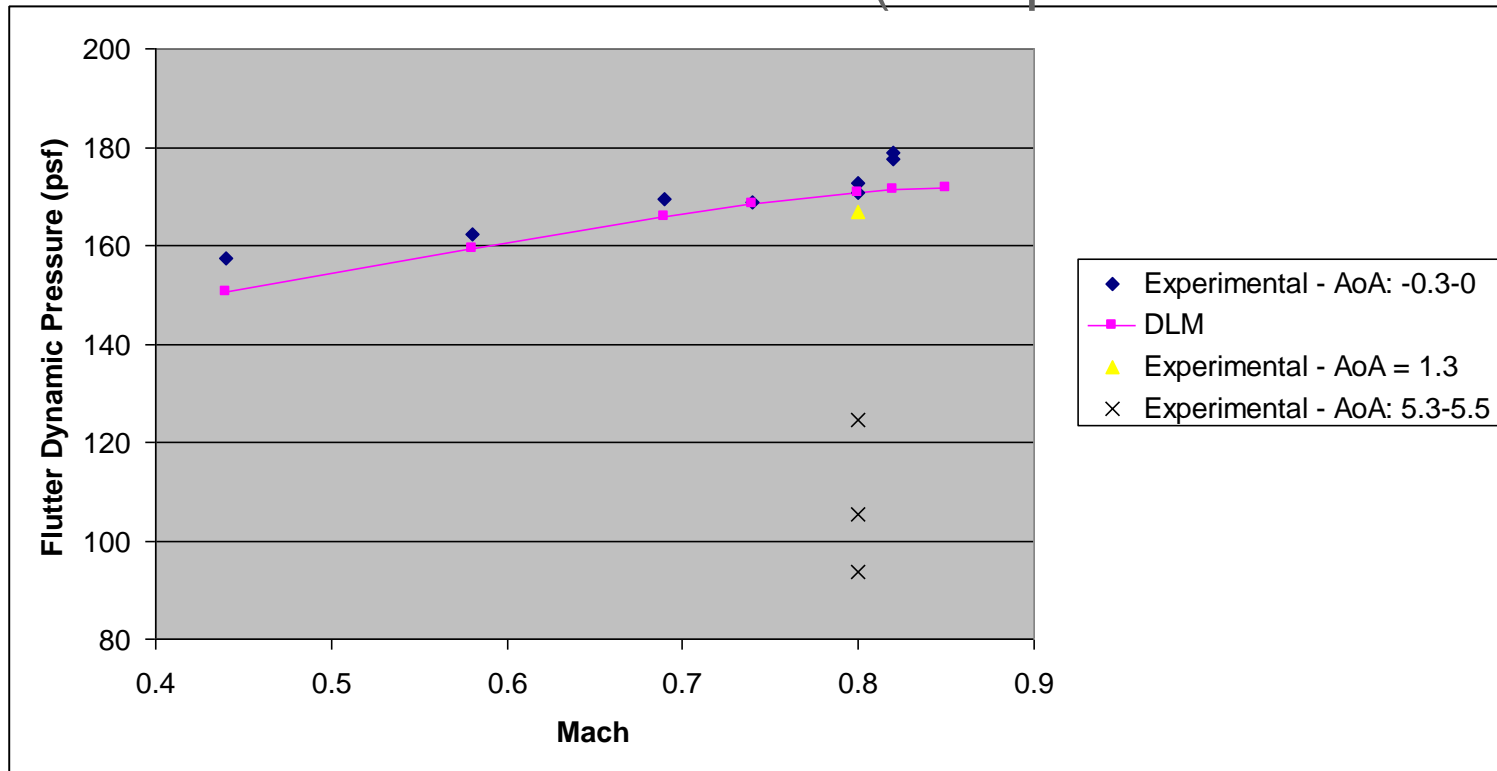
Case 2 – Effect of DLM Mesh Refinement & Structural Damping

- Analysis Default: Mesh = 40 x 40, g=0



Flutter Results – Additional Cases

- Mesh = 50 x 50, $g=0.2\%$
- Most results within 5% error (except those for AoA ~ 5)

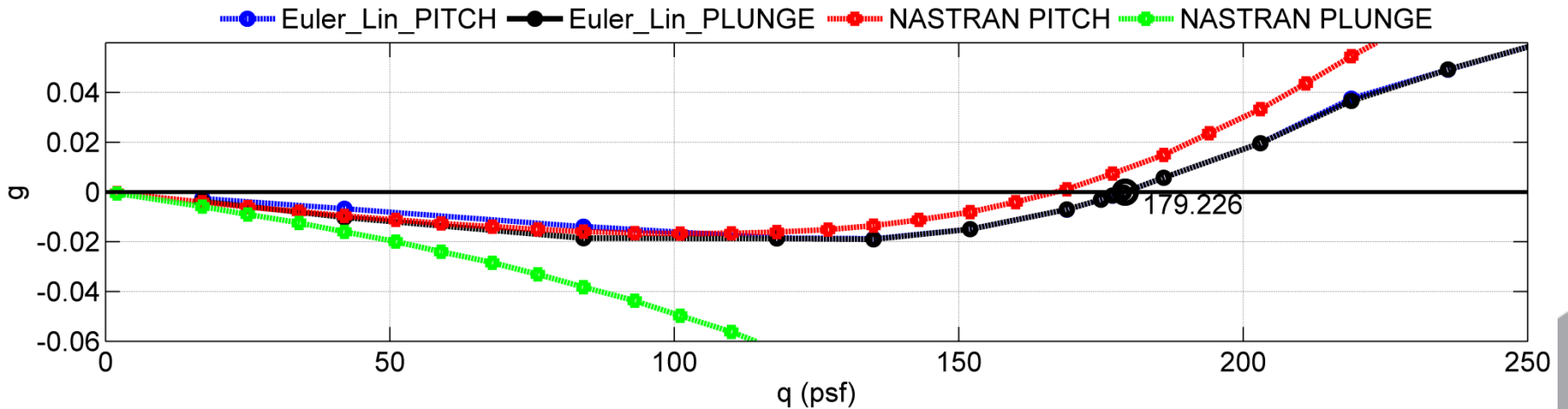
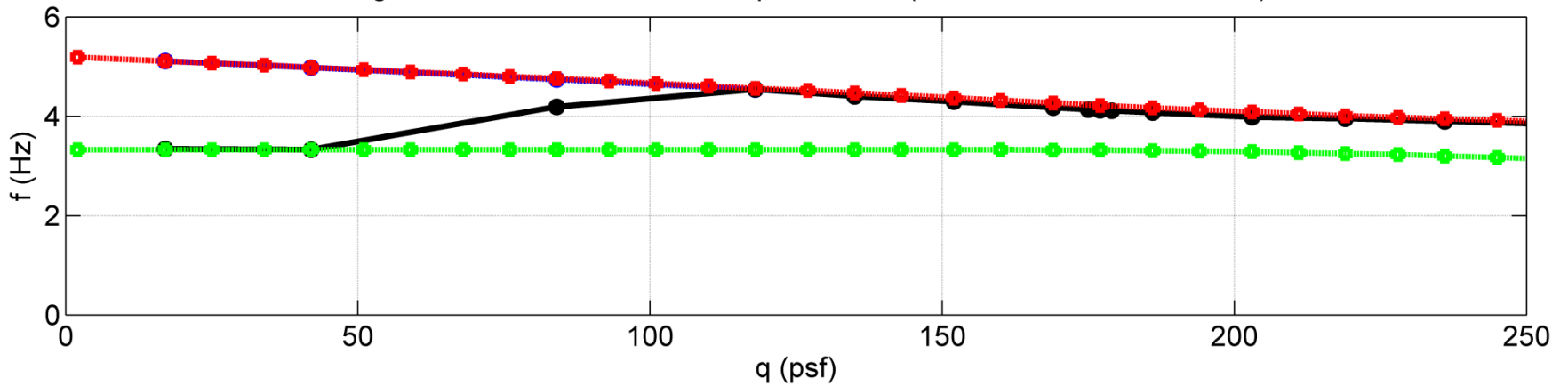


Ref: Heeg, J. et al., Plans and Example Results for the 2nd AIAA Aeroelastic Prediction Workshop, SciTech 2015.

Flutter Results – Time Domain Simulations

Euler linearized around Static Aeroelastic position for each Q

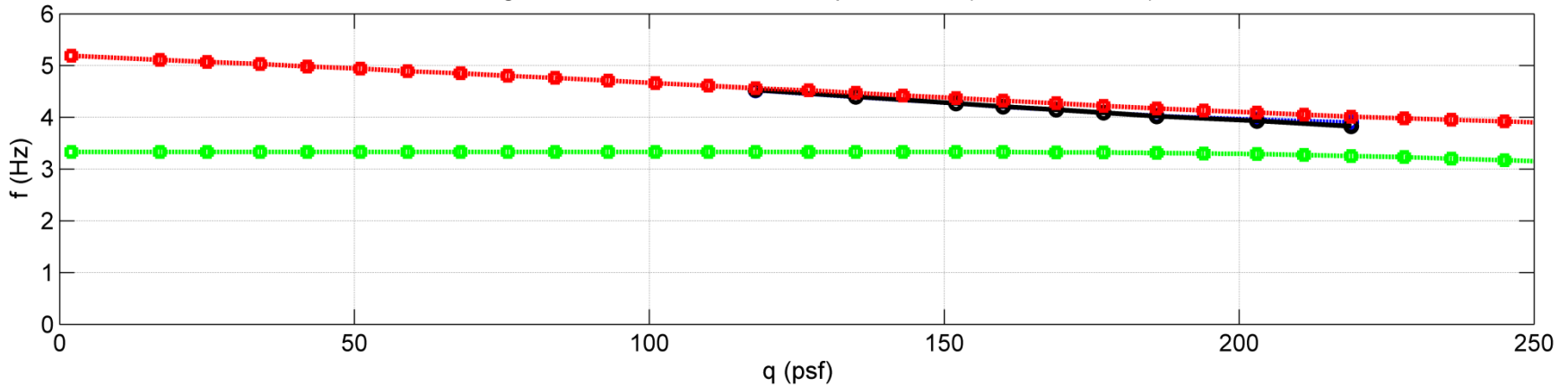
V x g x f Mach = 0.74 and time step = 0.001 s (Nastran X Euler Linearized)



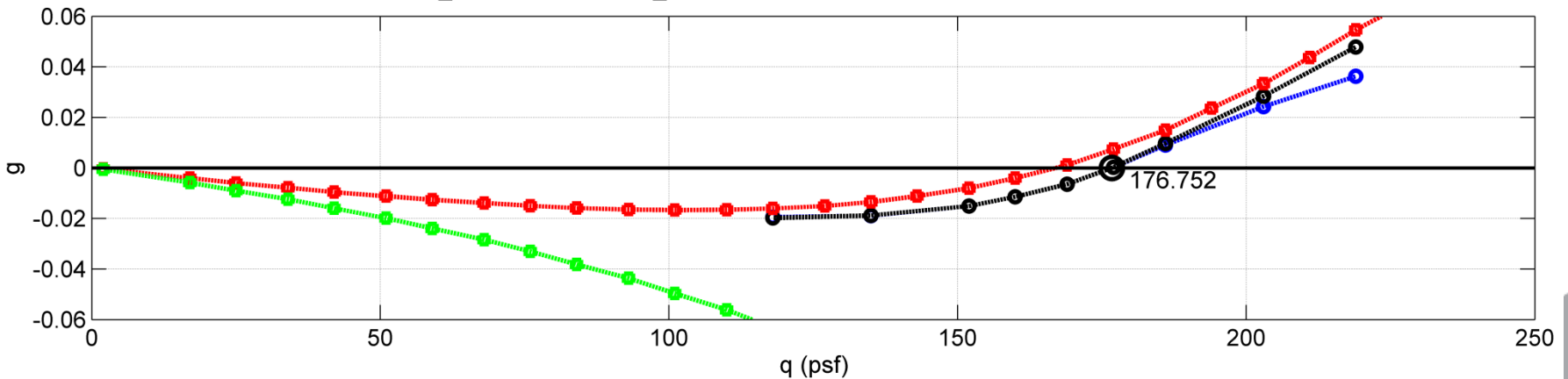
Flutter Results – Time Domain Simulations

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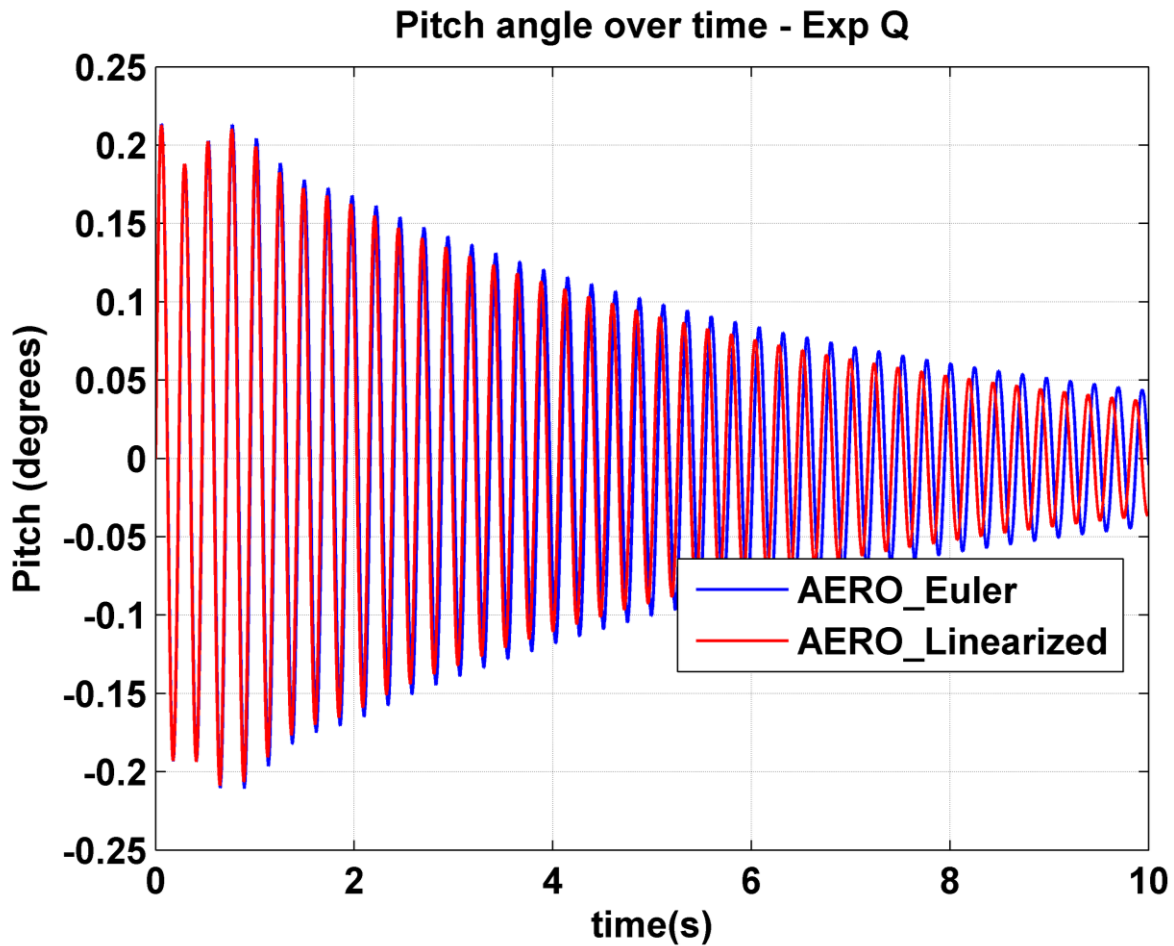
V x g x f Mach = 0.74 and time step = 0.001 s (Nastran X Euler)



Legend: Euler_PITCH (blue dotted line with circles), Euler_PLUNGE (black solid line with circles), NASTRAN PITCH (red dotted line with circles), NASTRAN PLUNGE (green dotted line with circles)



Flutter Results – Time Domain Simulations



**CPU time consumed
(wall time)**

Euler = **8200 s**

Euler Linearized = **700 s**

168 CPUs

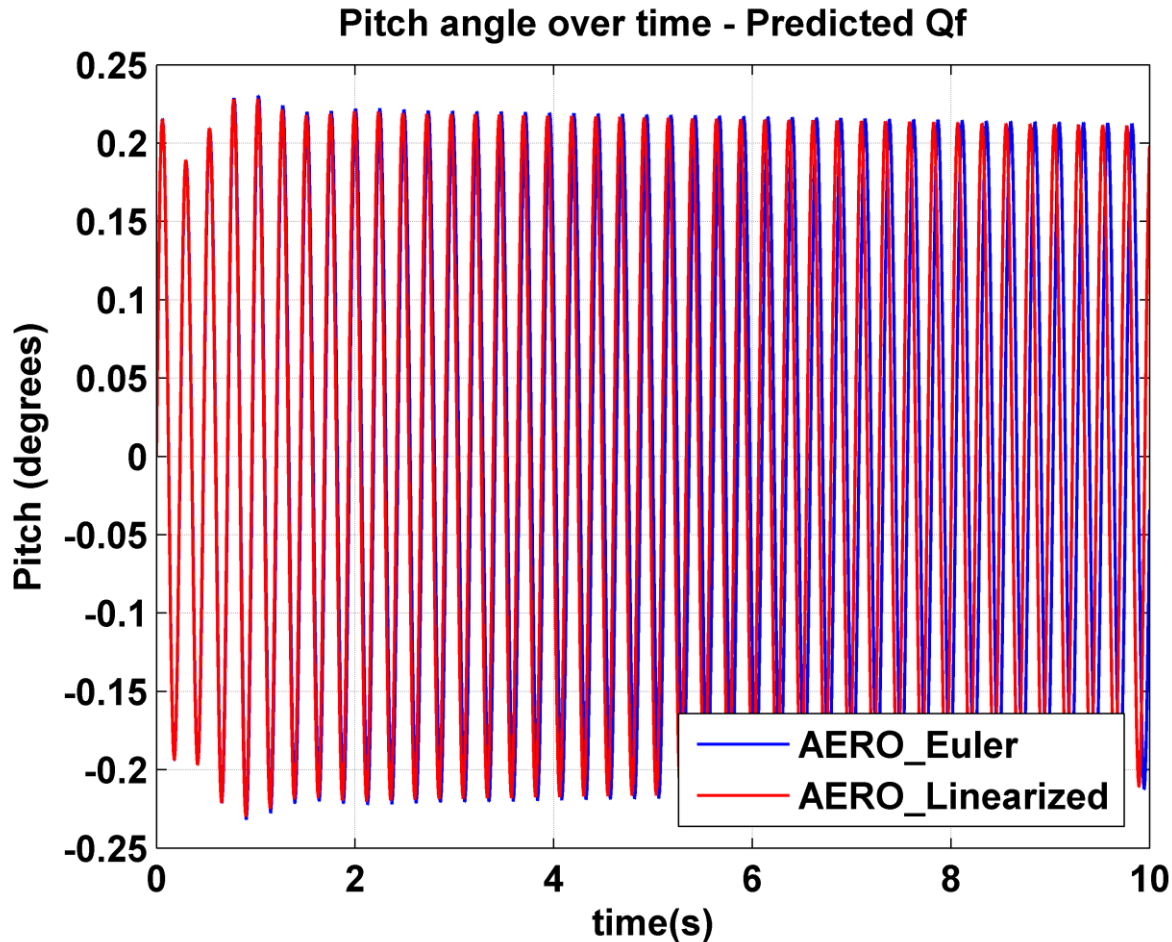
1,867,297 Tetra elements

432,456 nodes

Embraer mesh.

Perturbed in pitch mode velocity

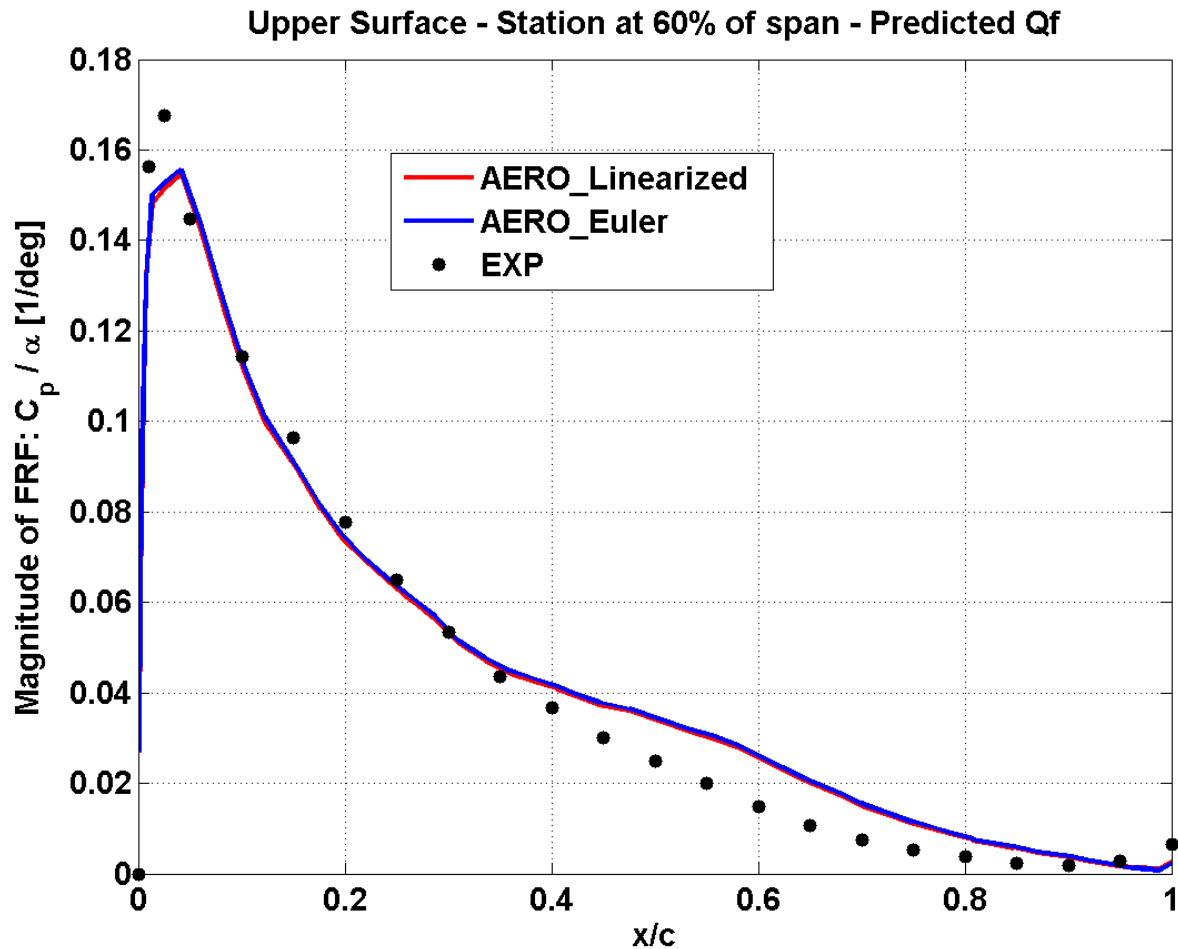
Flutter Results – Time Domain Simulations



Euler flutter Q = 176.8 psf

Euler Linearized flutter Q = 179.2 psf

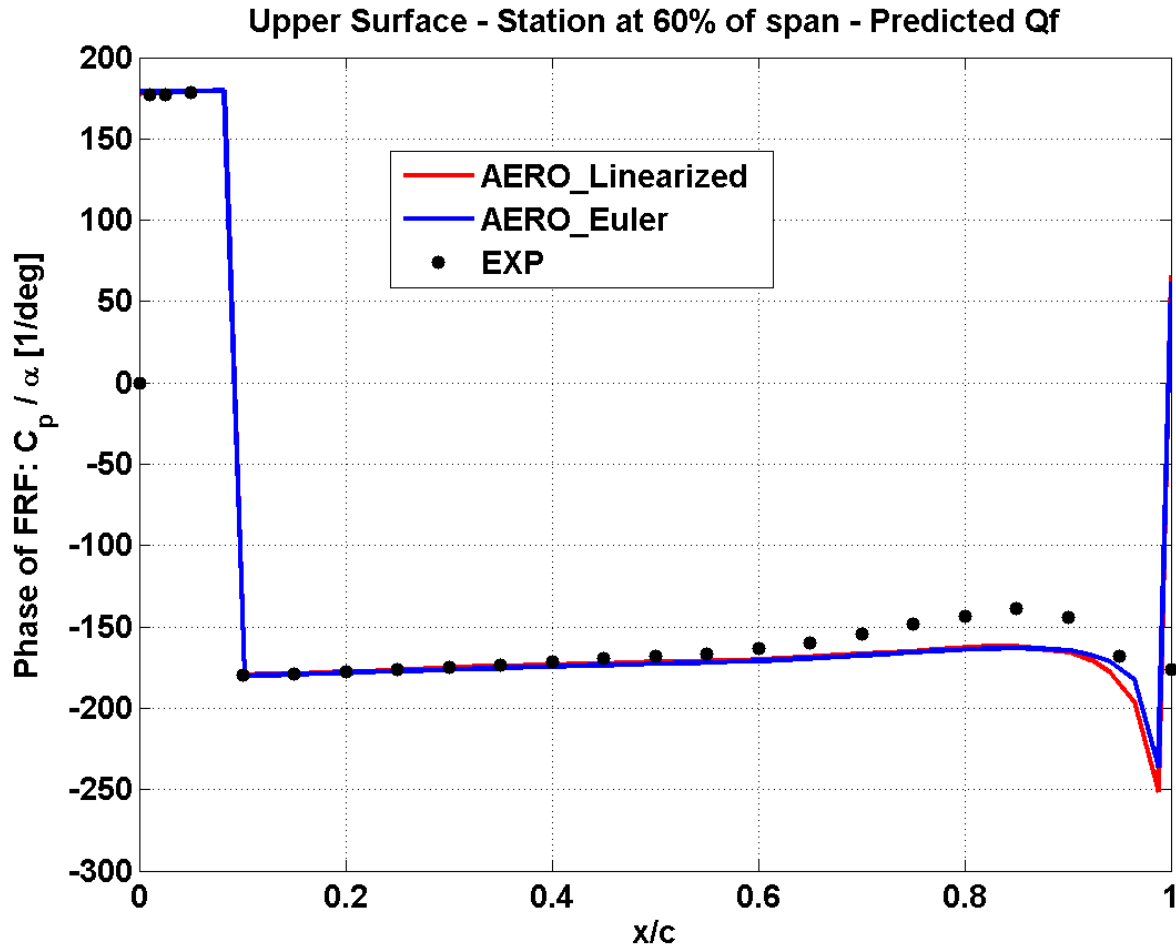
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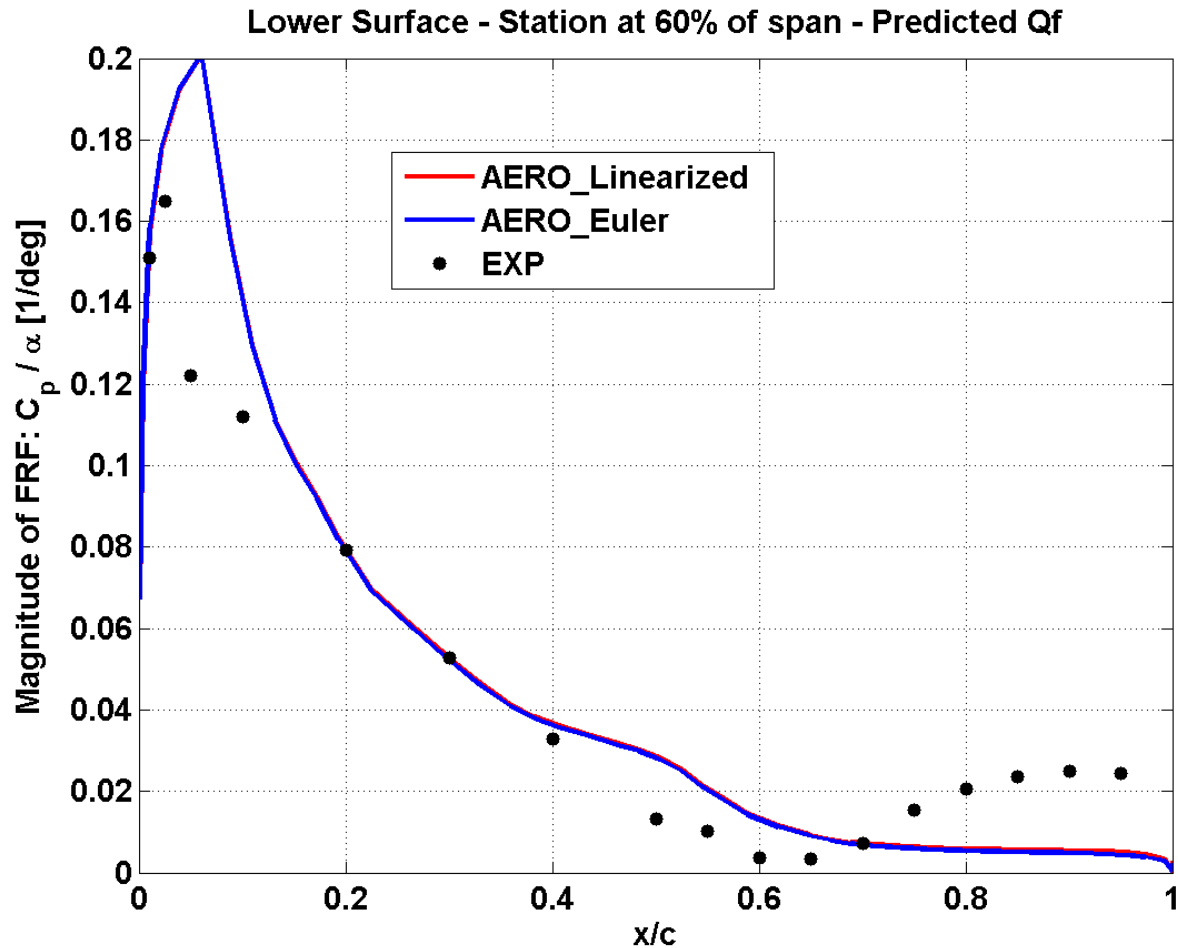
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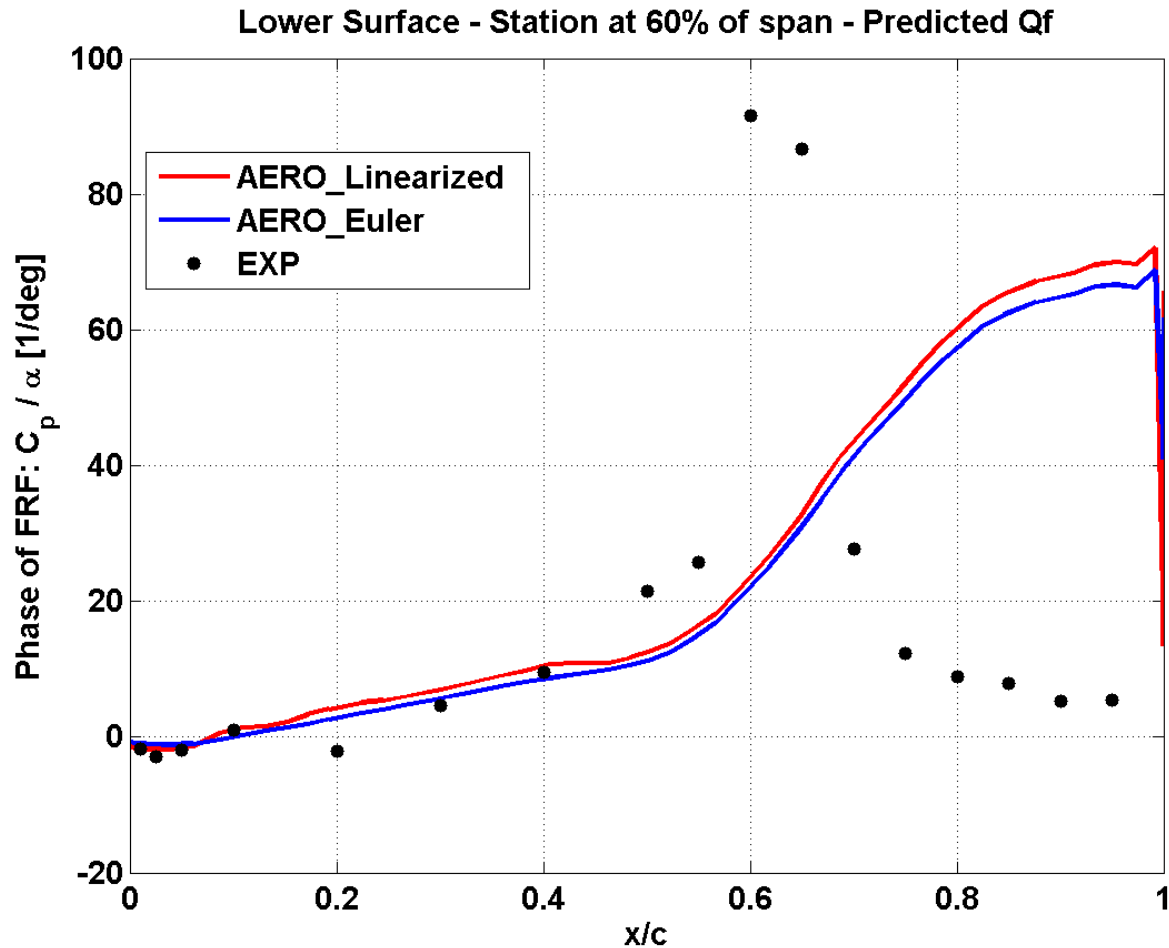
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