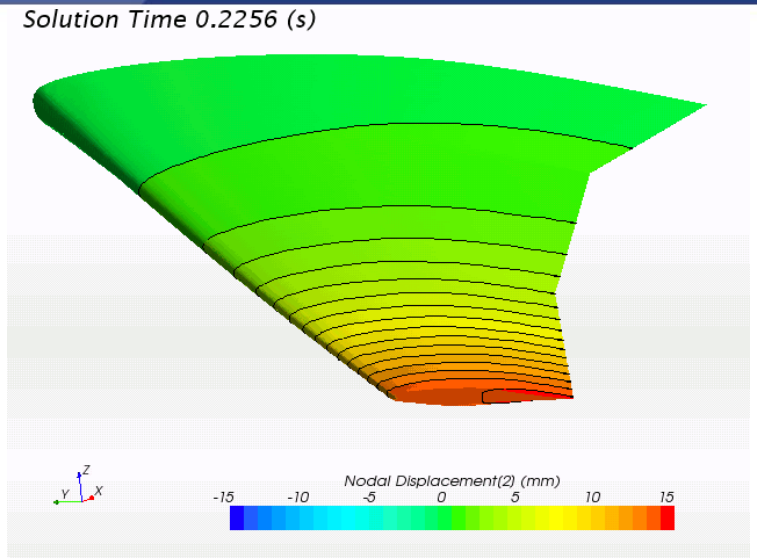
HIRENASD: Validations

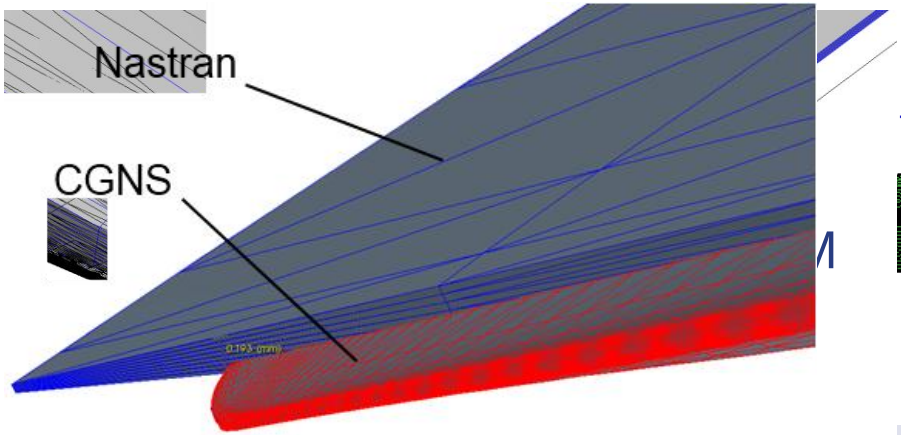


Alan Mueller & Sergey Zhelzov

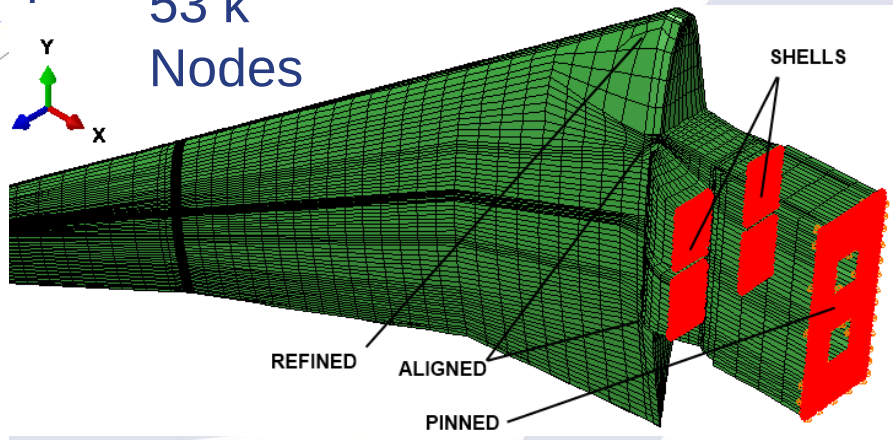
1st Aeroelastic Prediction Workshop
Honolulu, April 2012

CFD and CSM Geometry Correspondence

Rear edge zoomed close to the wing tip

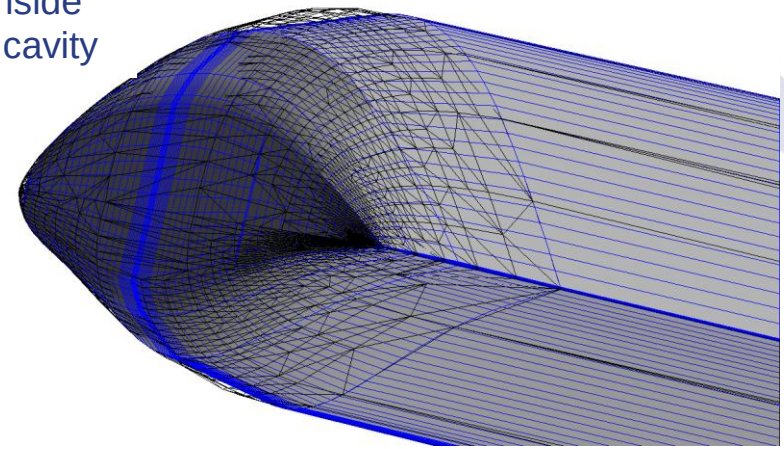


53 k Nodes



Between edges: 0.8 mm max.

CSM is inside the CDF cavity



CSM base: fem_structured_wing.bdf;
- Nastran bdf converted to Abaqus inp;
- c3d8i FE used;
- minor modifications of the some nodes location to improve FSI coupling;
- DOF 1, 2, 3 fixed for PINNED nodes;
- Excitation SHELLS added.

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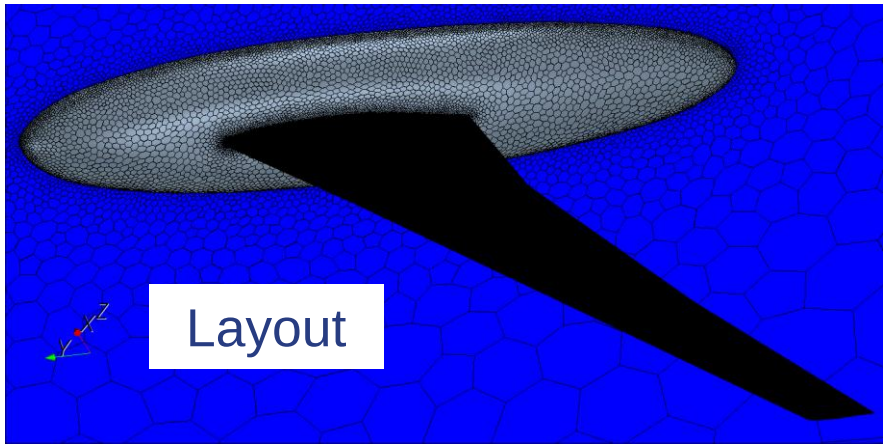
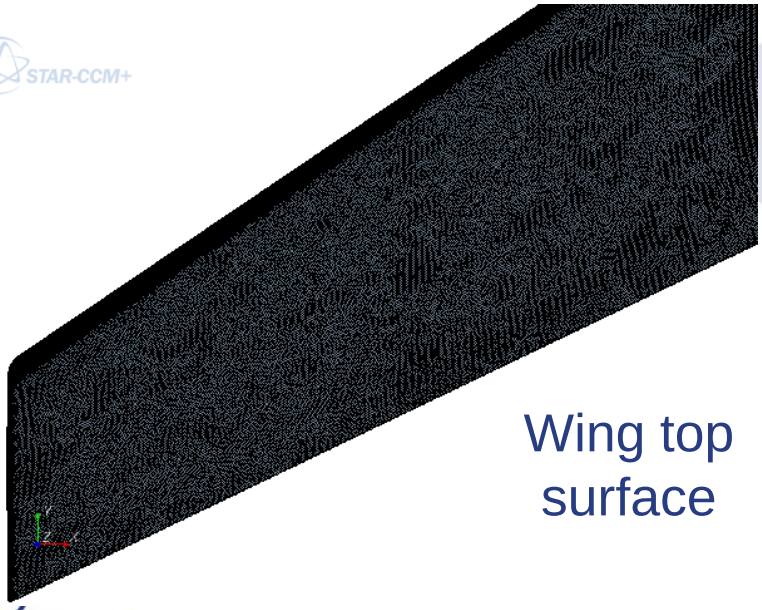
STAR-CCM+ coupled to Abaqus

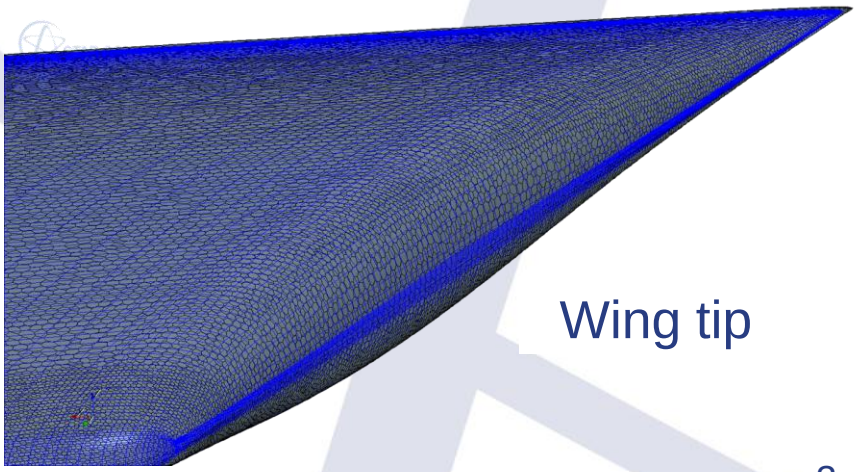
CFD Polyhedral Mesh



Mesh size: 2.4M, 8.5 M and 13.9 M
Top surface grid density: 1.4 mm
Bottom surface grid density: 20 mm
Prism layer thickness: 1.5 mm
# of prism layers: 18
Mesher type: Polyhedral
Wall Thickness: 1e-3 mm
Leading edge grid density: 288 Pts/circle

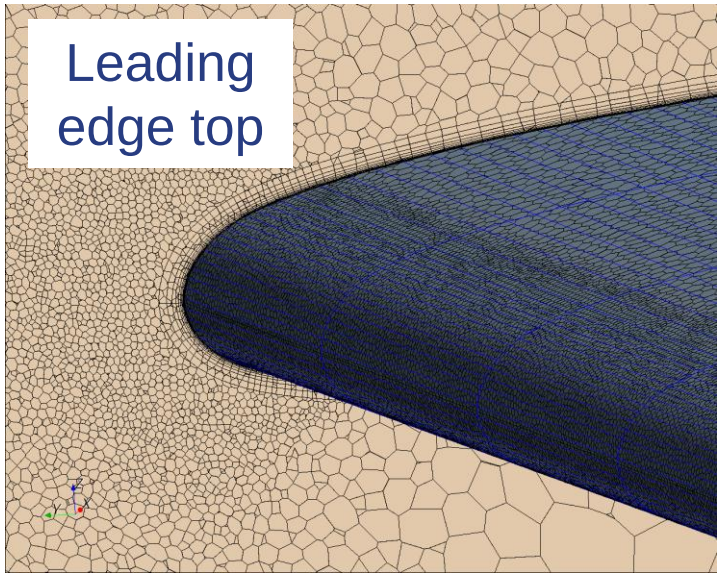


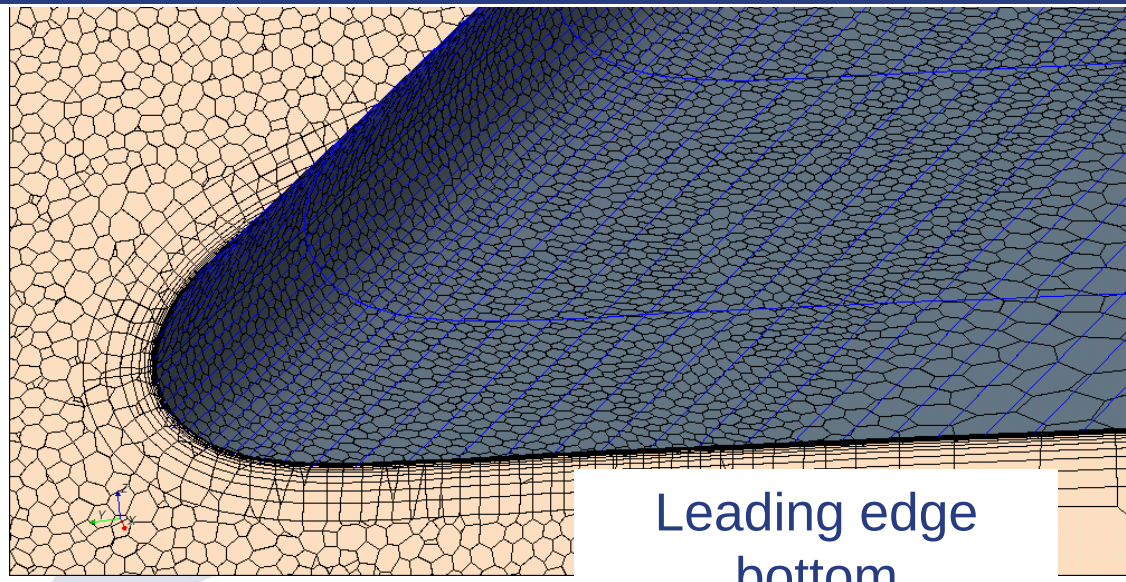
Wing top surface

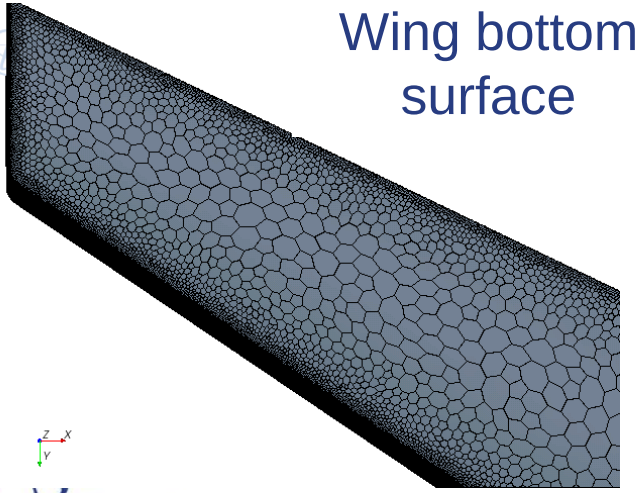


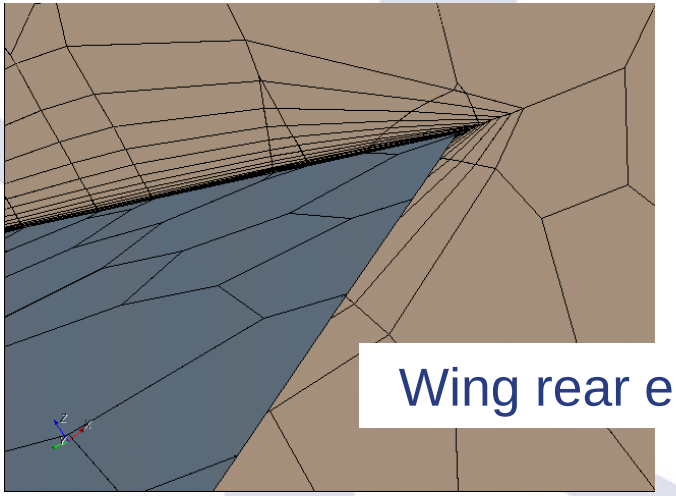
Wing tip

CFD Mesh Details









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CFD + CSM Numerics and Physics

- CFD:Navier Stokes, Finite Volume, Roe FDS or AUSM+, SA & K-ω SST Turbulence, Least Square Gradients
- CSM:C3D8I hex, elastic, minimal damping, n-l geom
- Steady-state, Static Equilibrium
  - Steady state rigid + 3 exchanges with static CSM
  - Transient 1st order, 100 subiterations after exchanges
- Transient Free and Forced
  - 2nd order time, 85 to 170 steps/cycle,
  - 20 to 60 subiterations, convergence criteria CI
- Morphed Mesh (Multiquadric, Radial Basis Function)
- S2S Mapping (least square, shape functions)

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Turbulence and slip wall

- SA & K-ω SST
- Only for rigid wing, none for aeroelastic

m17	Slp_kw	Nsl_kw	Nsl_SA	Slp_kw	Nsl_kw	Nsl_SA
alpha, deg	CL	CL	CL	CD	CD	CD
-2	-0.055	-0.031	-0.032	0.0142	0.0140	0.0139
0	0.171	0.166	0.179	0.0122	0.0127	0.0123
2	0.375	0.379	0.402	0.0177	0.0183	0.0186
4	0.579	0.573	0.611	0.0322	0.0324	0.0350
6	0.698	0.693	0.686	0.0629	0.0621	0.0609

Simulation Parameters

Test medium	-	-	Nitrogen
Mach number	M	-	0.8
Reynolds number (based on ref chord)	Re_c	-	2.35E+07
Static temperature	Tstat	deg K	204.0
Static pressure	P	kPa	201
Dynamic viscosity	μ	Pa-s	1.12E-05
Load factor	q /E	-	4.80E-07

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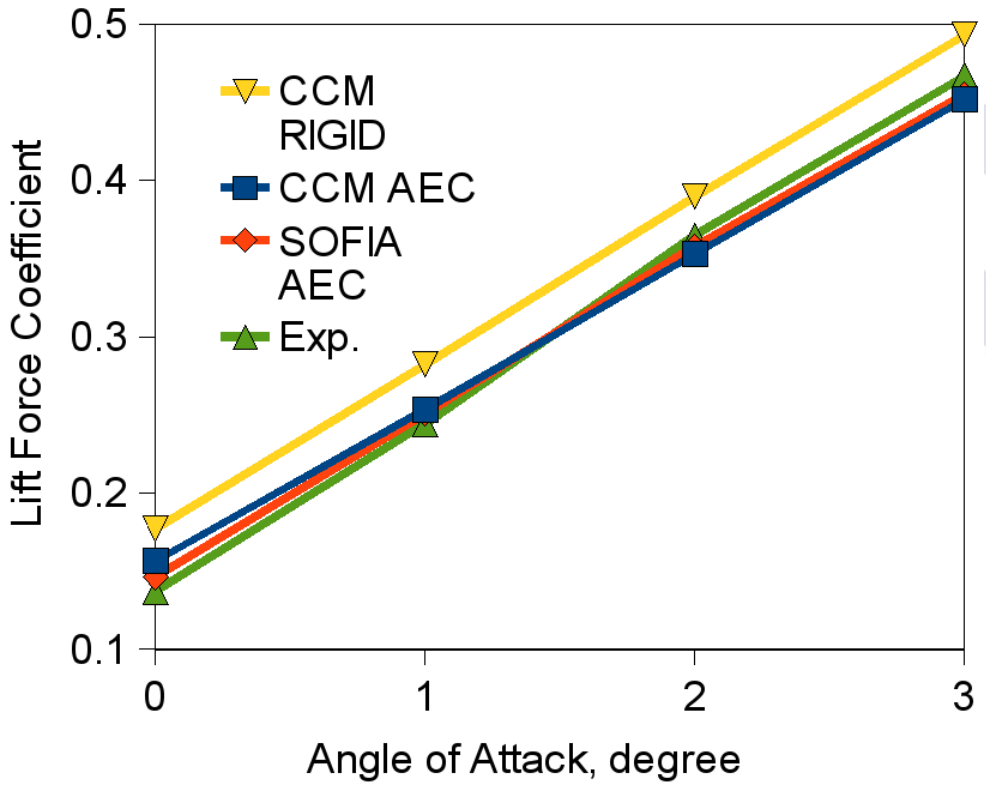
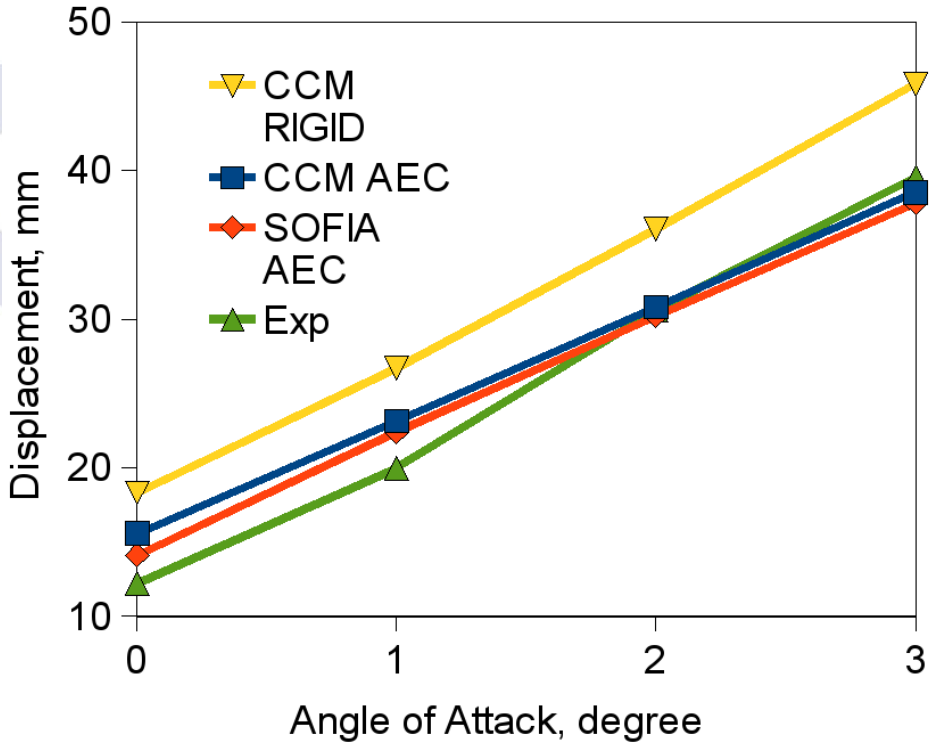
Aerodynamic Equilibrium Wing at different AOA

- Static Structure, Steady airflow at deformed shape
- Ma=0.8, Re=23.5×10^{6}, q/E=0.48×10^{-6}

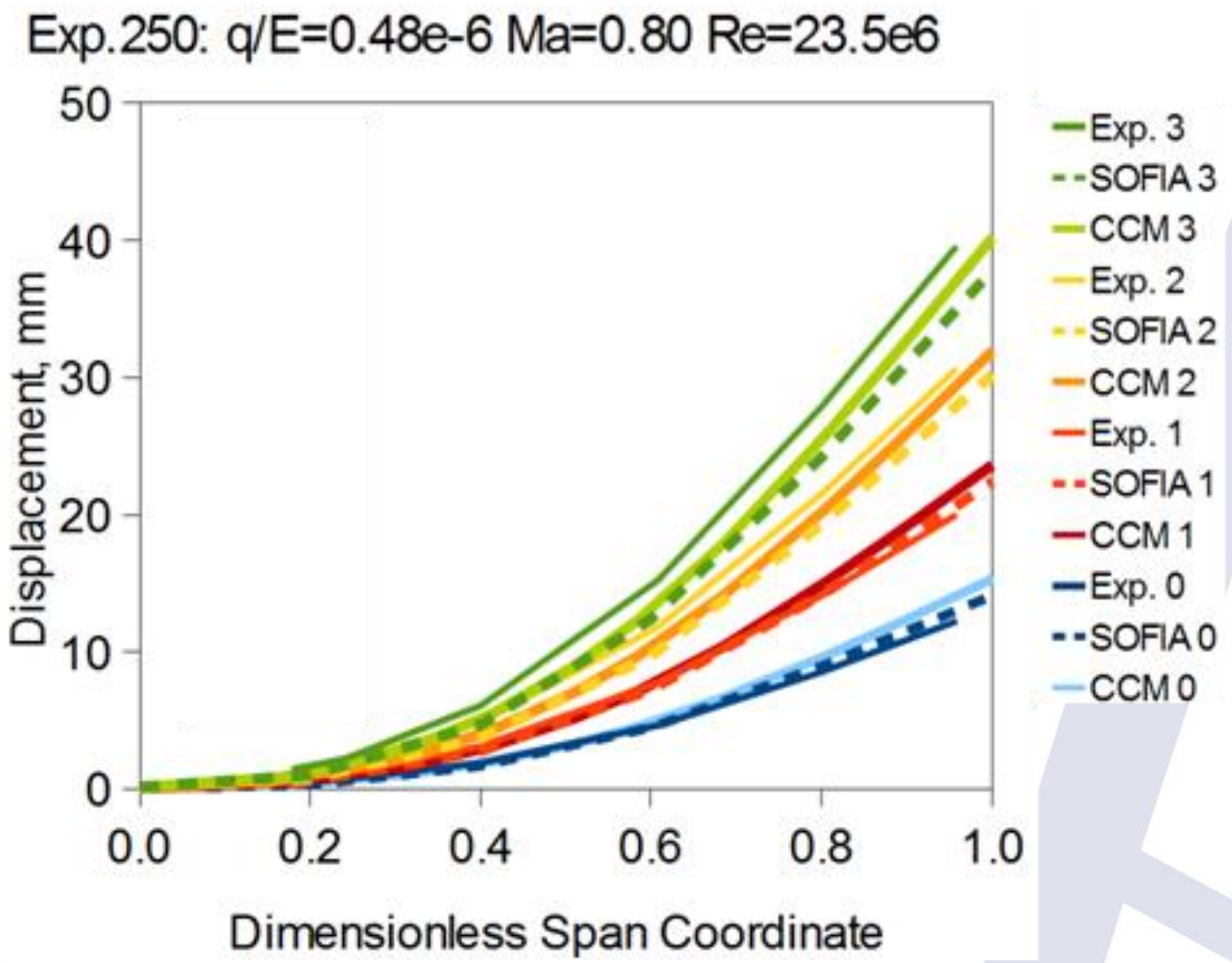
Lift Coefficient



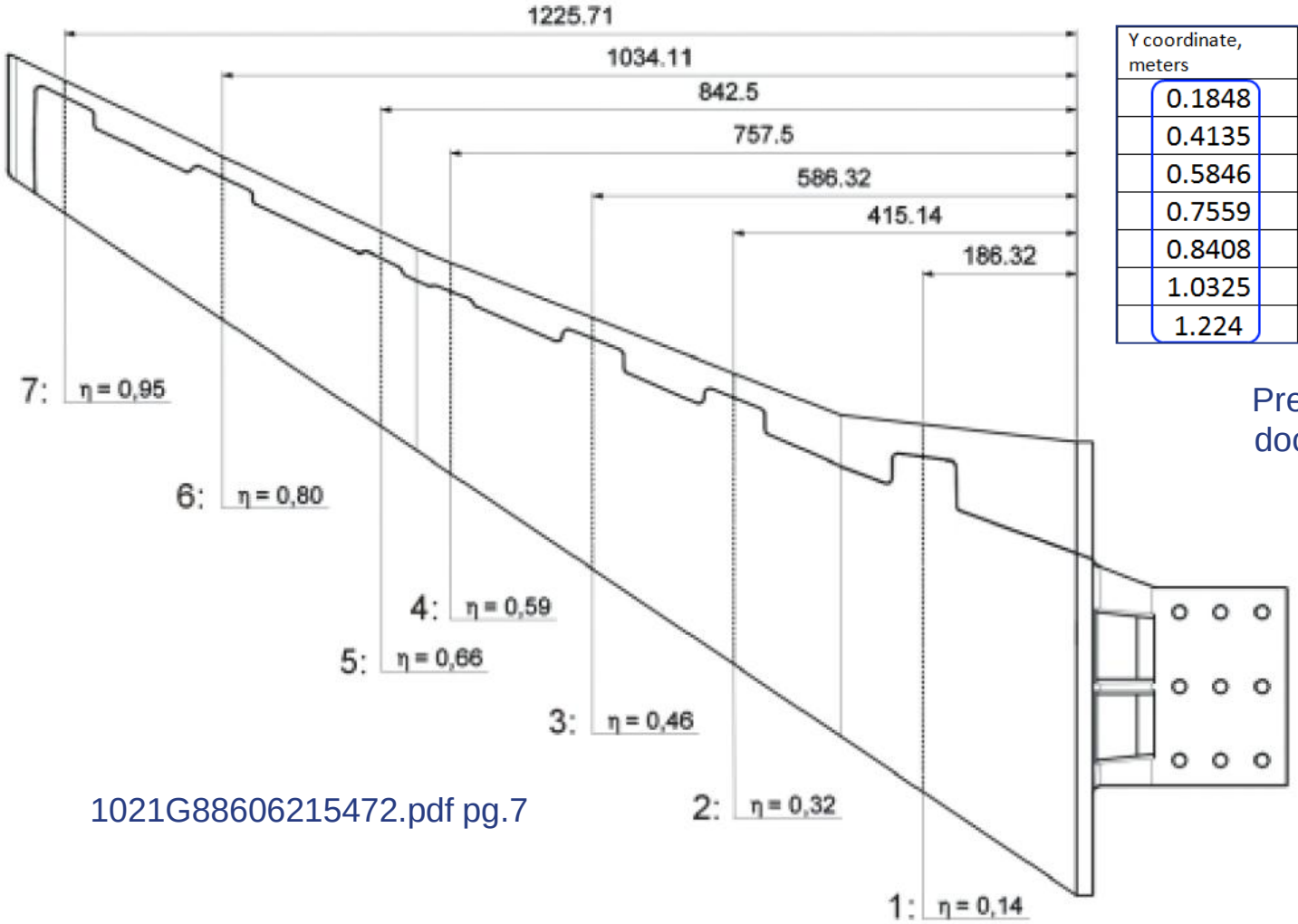
Wing Tip Displacement



Spanwise Wing Deformation at AOA 0,1,2,3°



Pressure Sections

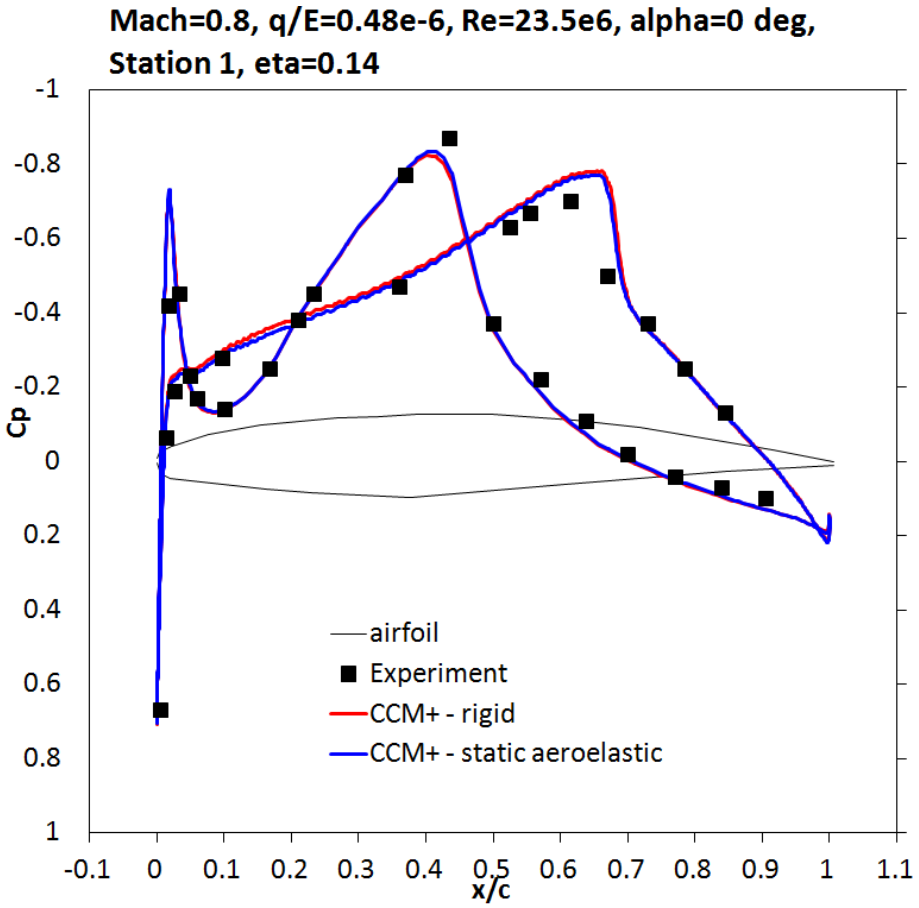


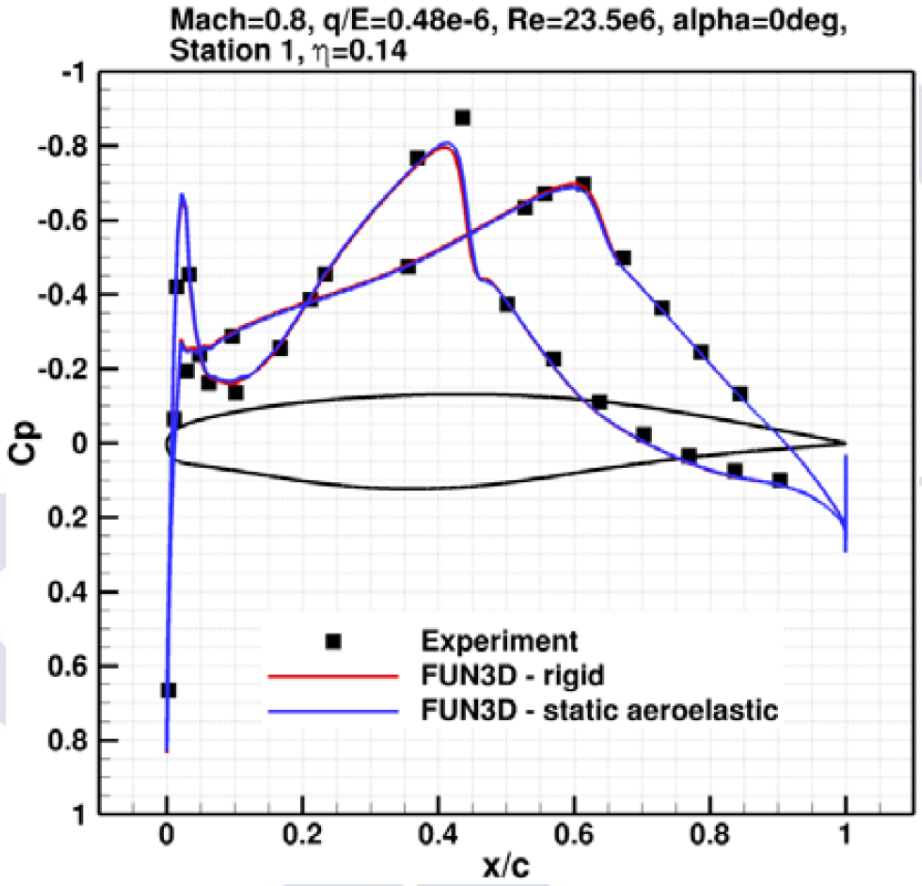
Y coordinate, meters	Eta	Eta * span
0.1848	0.145	0.1863
0.4135	0.323	0.4151
0.5846	0.456	0.586
0.7559	0.589	0.7569
0.8408	0.655	0.8417
1.0325	0.804	1.0331
1.224	0.953	1.2246

Pressure_locations_documentation.docx pg.3

1021G88606215472.pdf pg.7

Cp: AOA 0°, Station 1





Reference:
J.Heeg, J.Florance, P.Chwalowski, B. Perry, C.Wieseman. Information Package: Workshop on Aeroelastic Prediction. Aeroelasticity Branch, NASA Hampton, Virginia. October 2010

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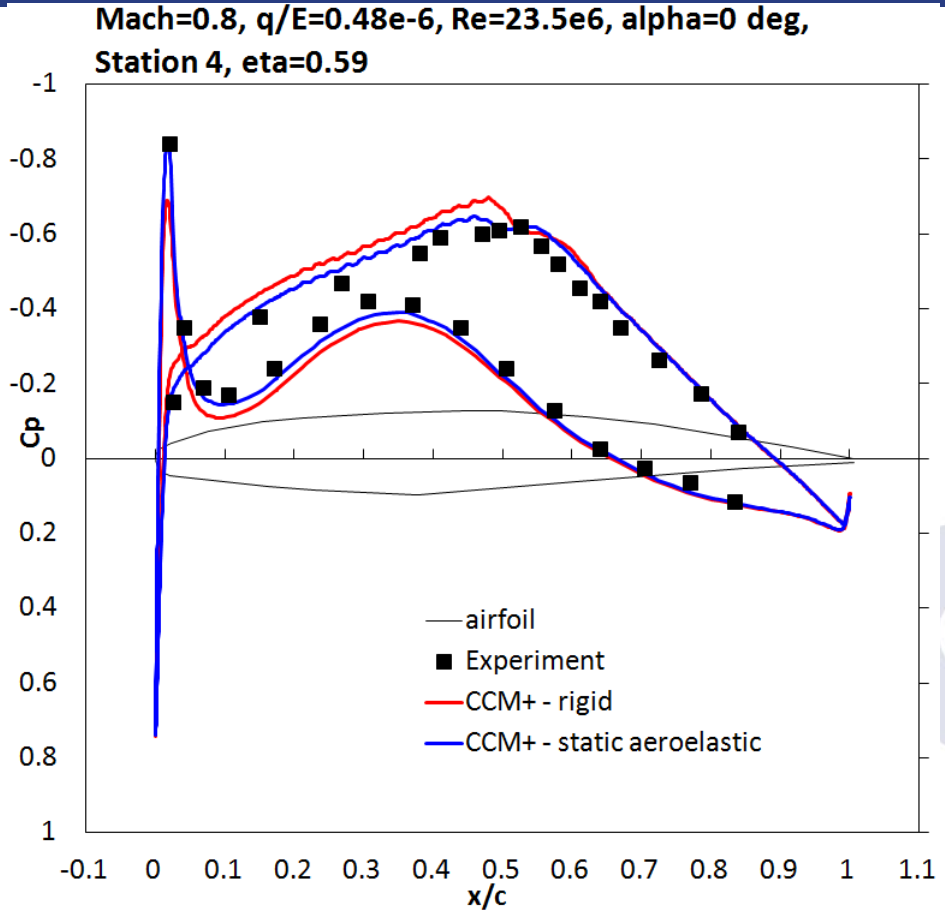
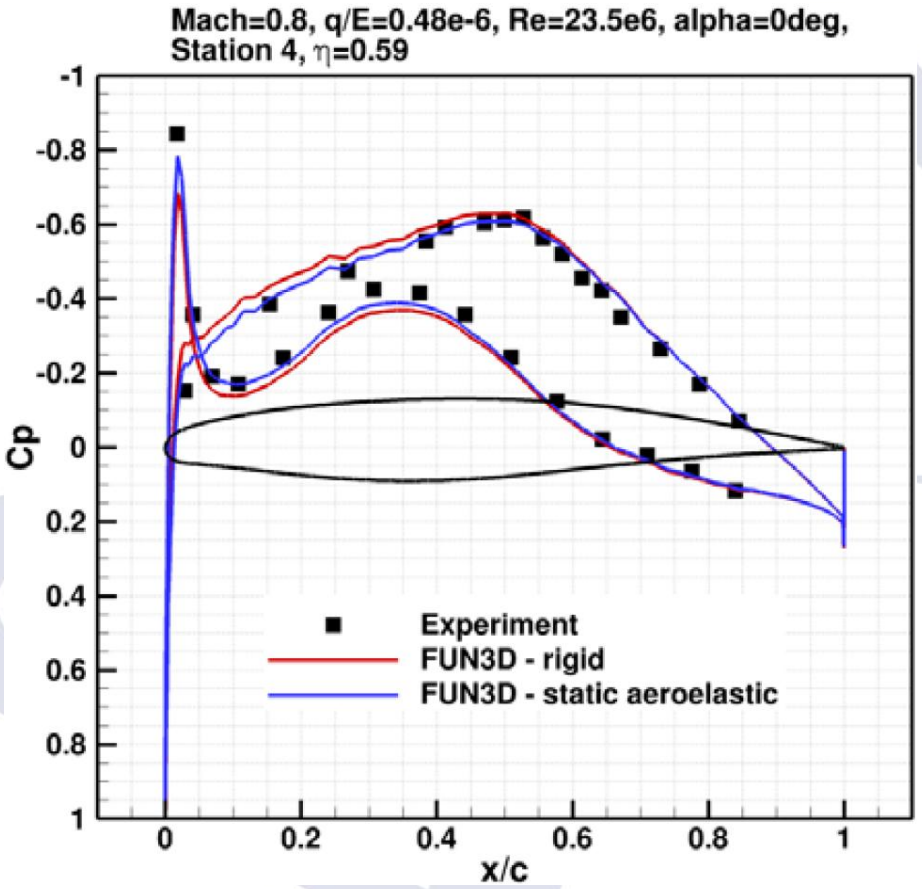
Cp: AOA 0°, Station 4





Reference:
J.Heeg, J.Florance, P.Chwalowski, B. Perry, C.Wieseman. Information Package: Workshop on Aeroelastic Prediction. Aeroelasticity Branch, NASA Hampton, Virginia. October 2010

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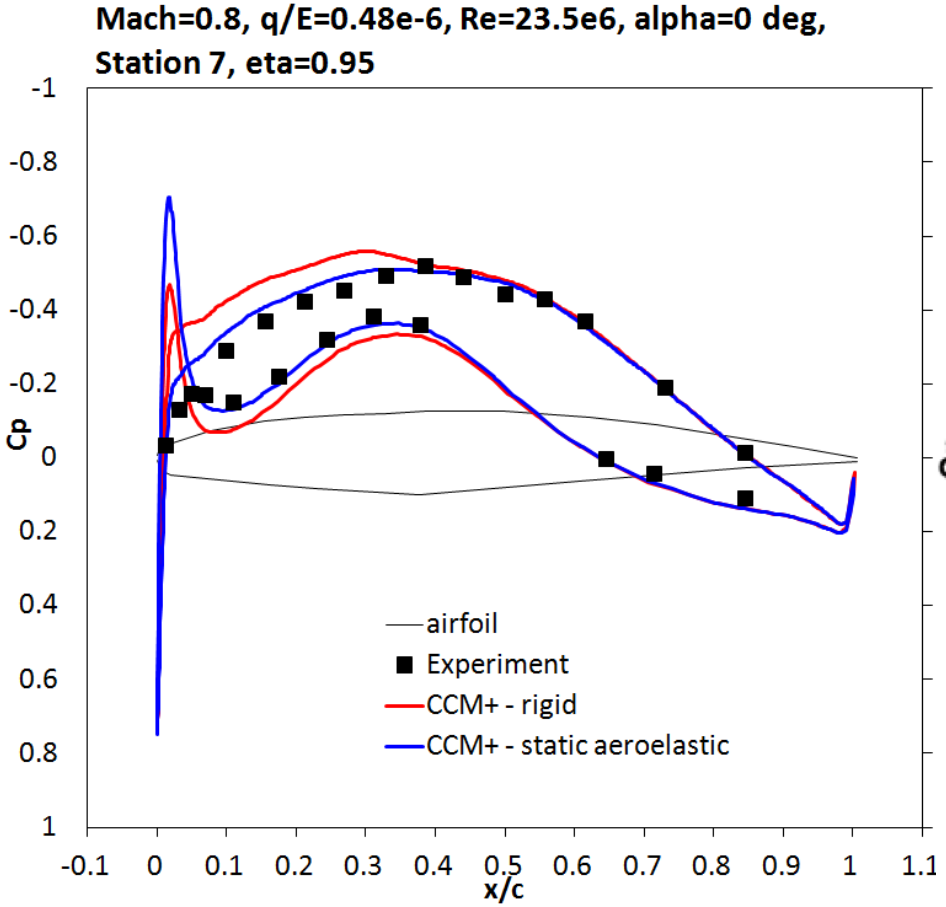
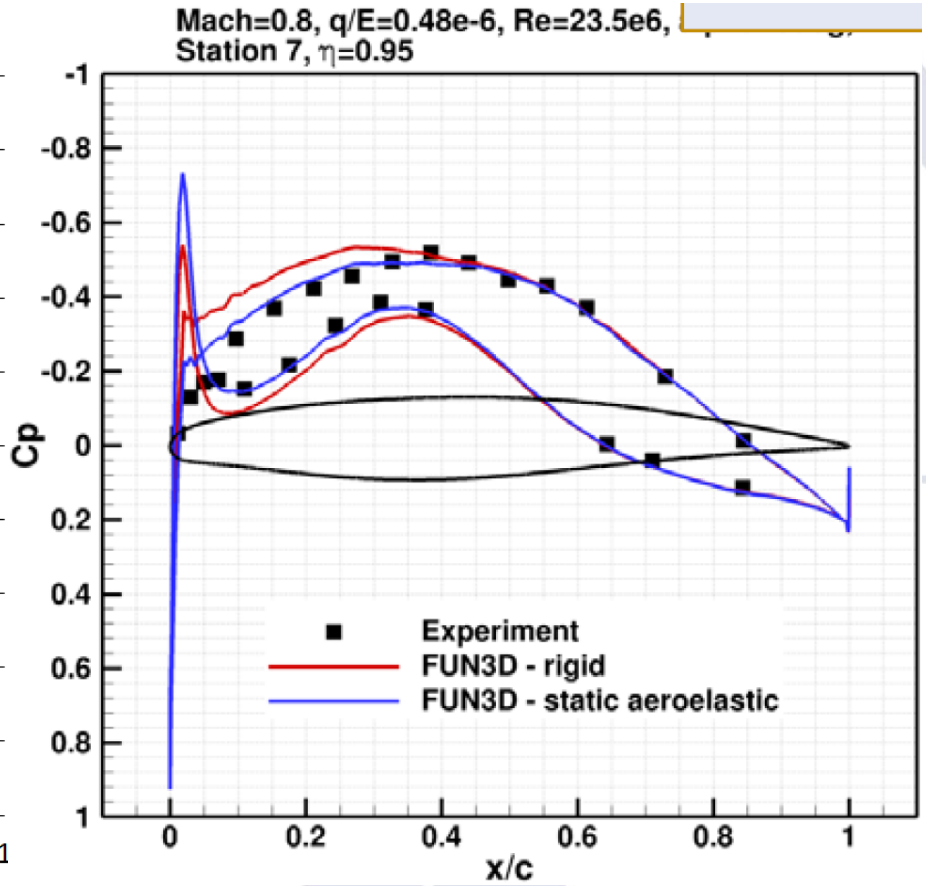
Cp: AOA 0°, Station 7





Reference:
J.Heeg, J.Florance, P.Chwalowski, B. Perry, C.Wieseman. Information Package: Workshop on Aeroelastic Prediction. Aeroelasticity Branch, NASA Hampton, Virginia. October 2010

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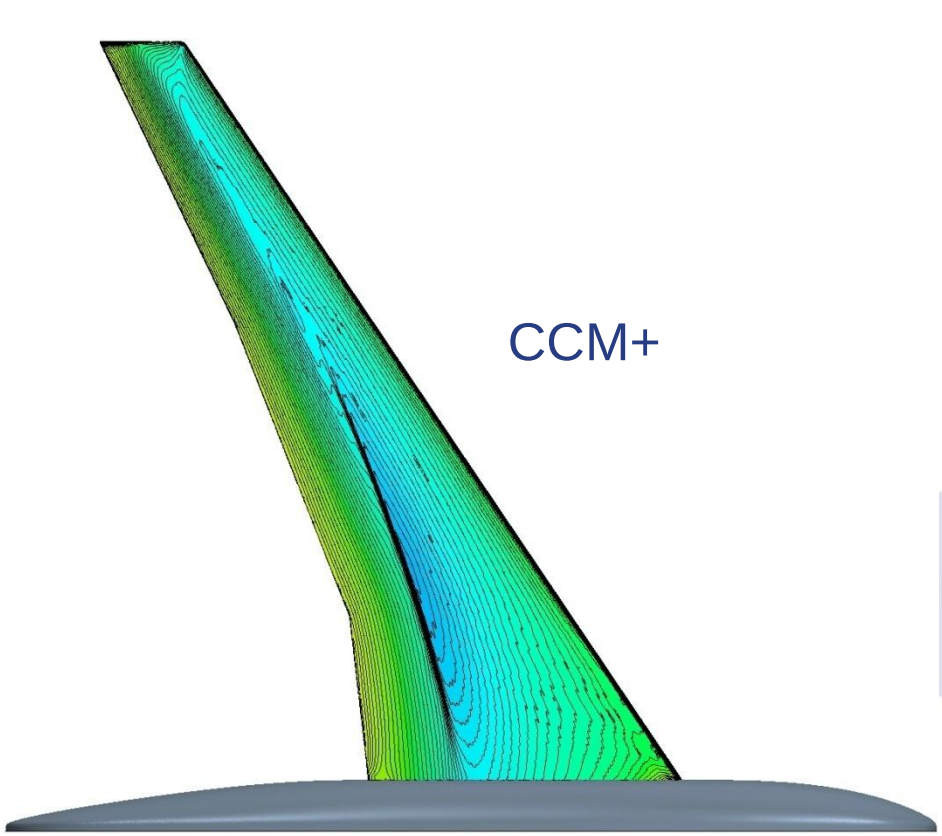
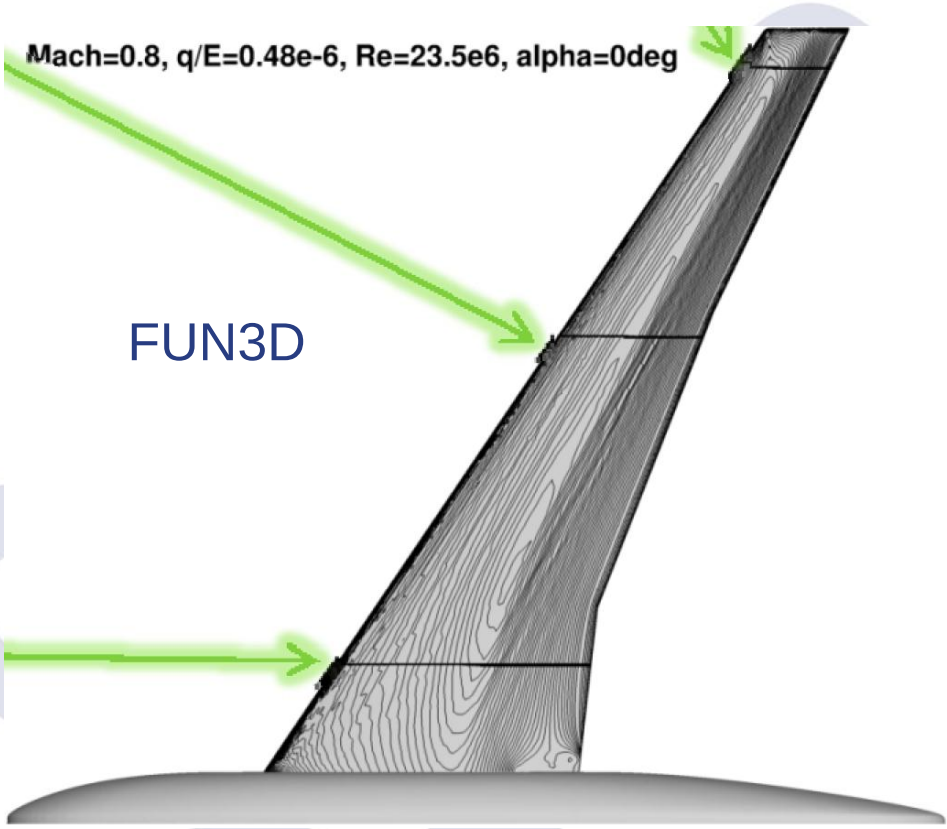
Cp: AOA 0°





Reference:
J.Heeg, J.Florance, P.Chwalowski, B. Perry, C.Wieseman. Information Package: Workshop on Aeroelastic Prediction. Aeroelasticity Branch, NASA Hampton, Virginia. October 2010

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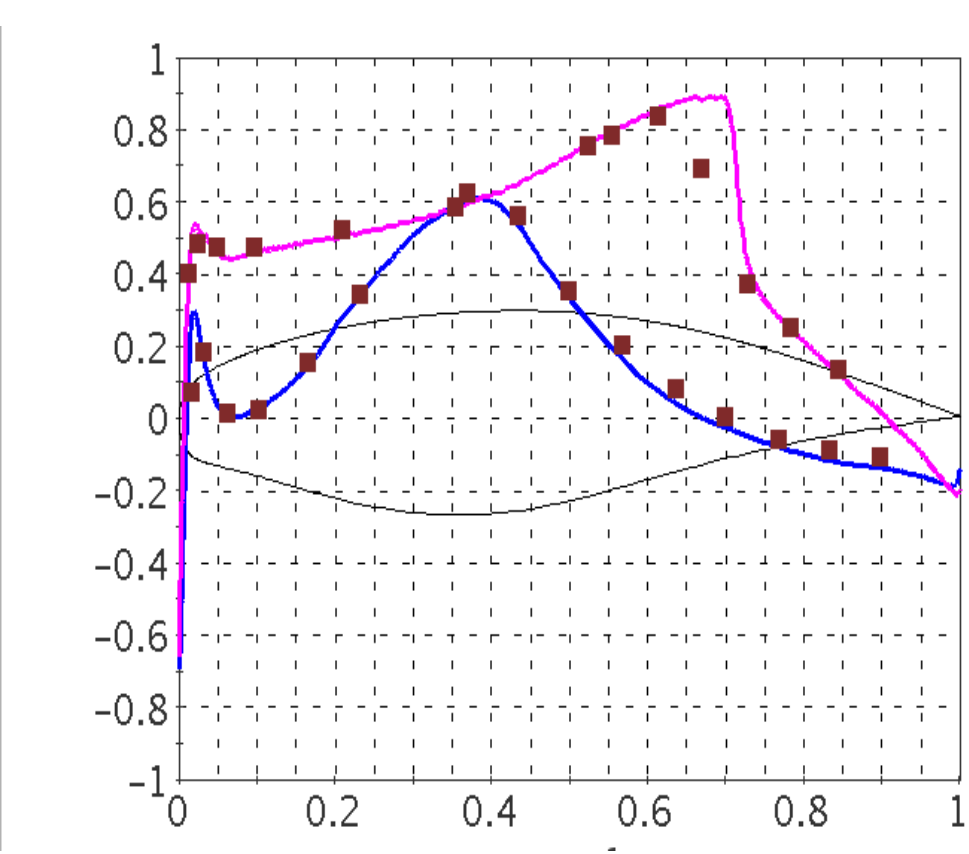
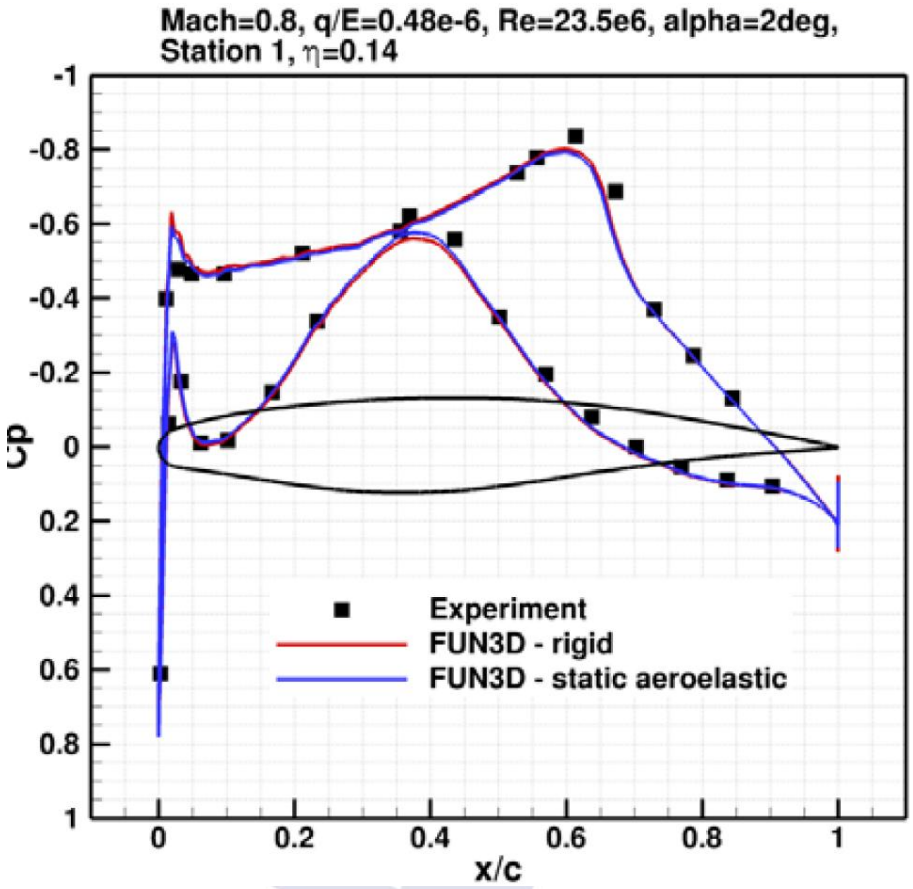
Cp: AOA 2°, Station 1





Reference:
J.Heeg, J.Florance, P.Chwalowski, B. Perry, C.Wieseman. Information Package: Workshop on Aeroelastic Prediction. Aeroelasticity Branch, NASA Hampton, Virginia. October 2010

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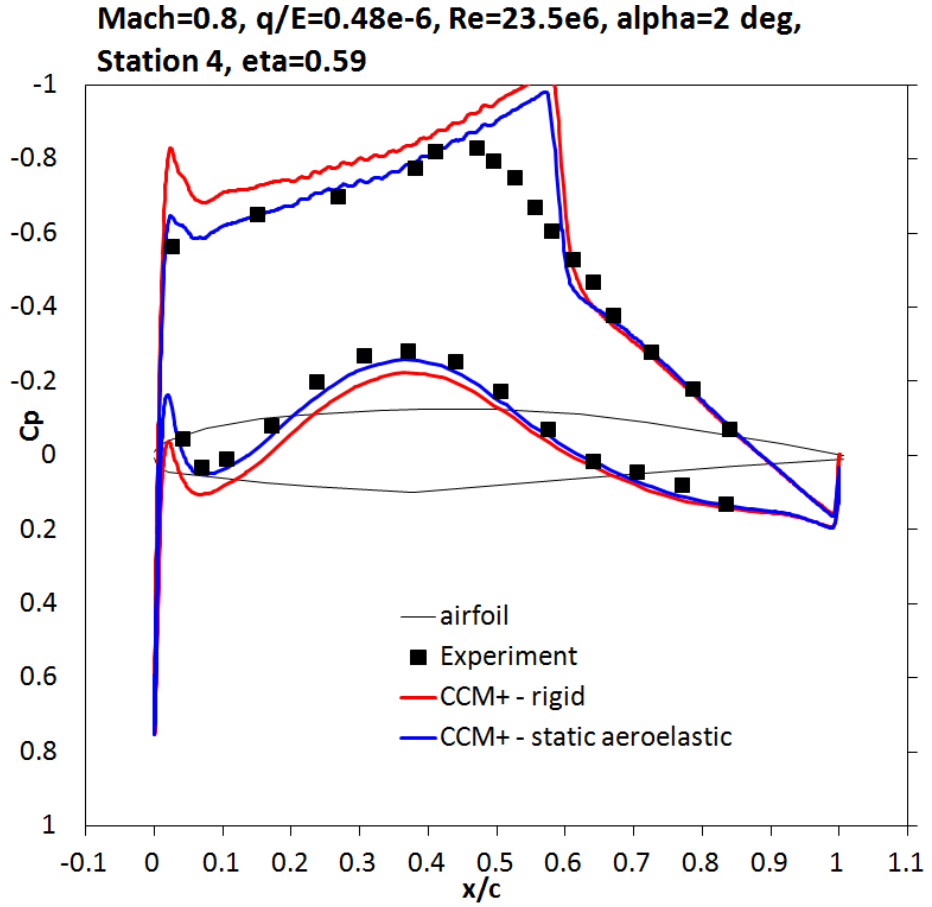
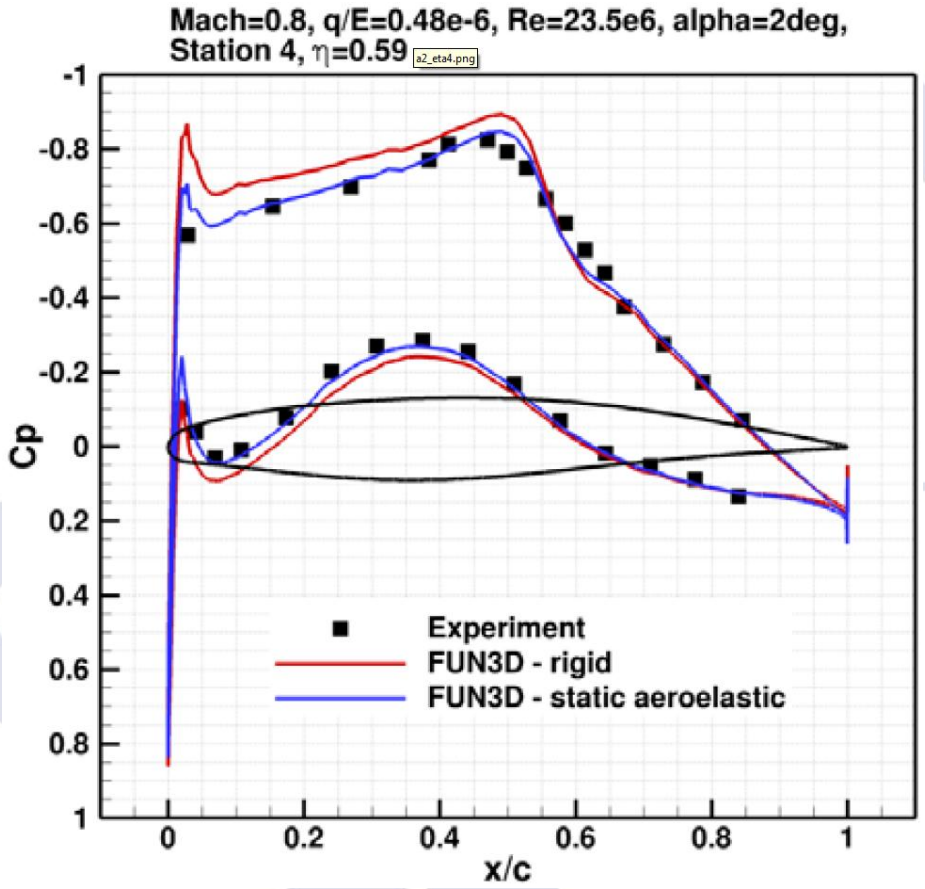
Cp: AOA 2°, Station 4





Reference:
J.Heeg, J.Florance, P.Chwalowski, B. Perry, C.Wieseman. Information Package: Workshop on Aeroelastic Prediction. Aeroelasticity Branch, NASA Hampton, Virginia. October 2010

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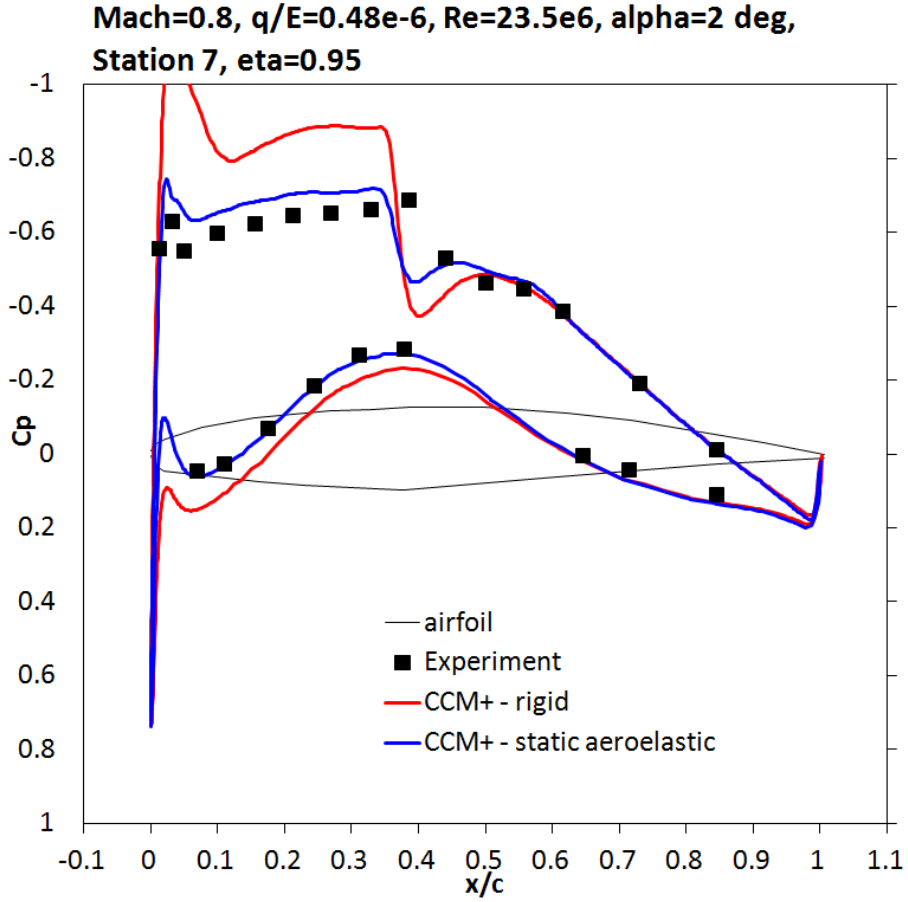
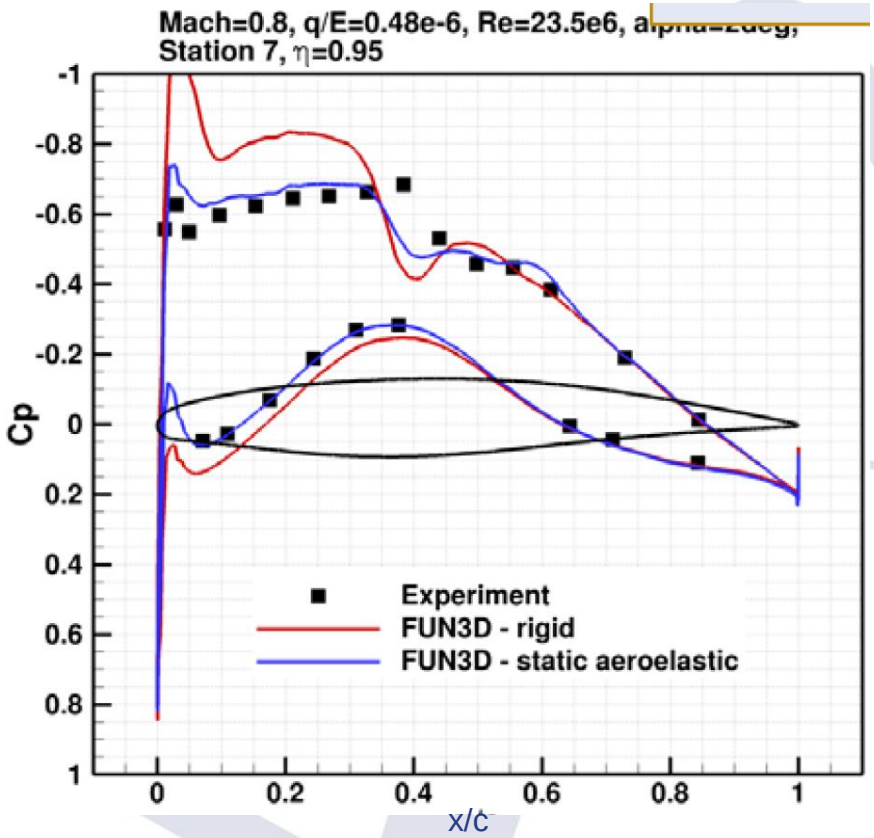
Cp: AOA 2°, Station 7





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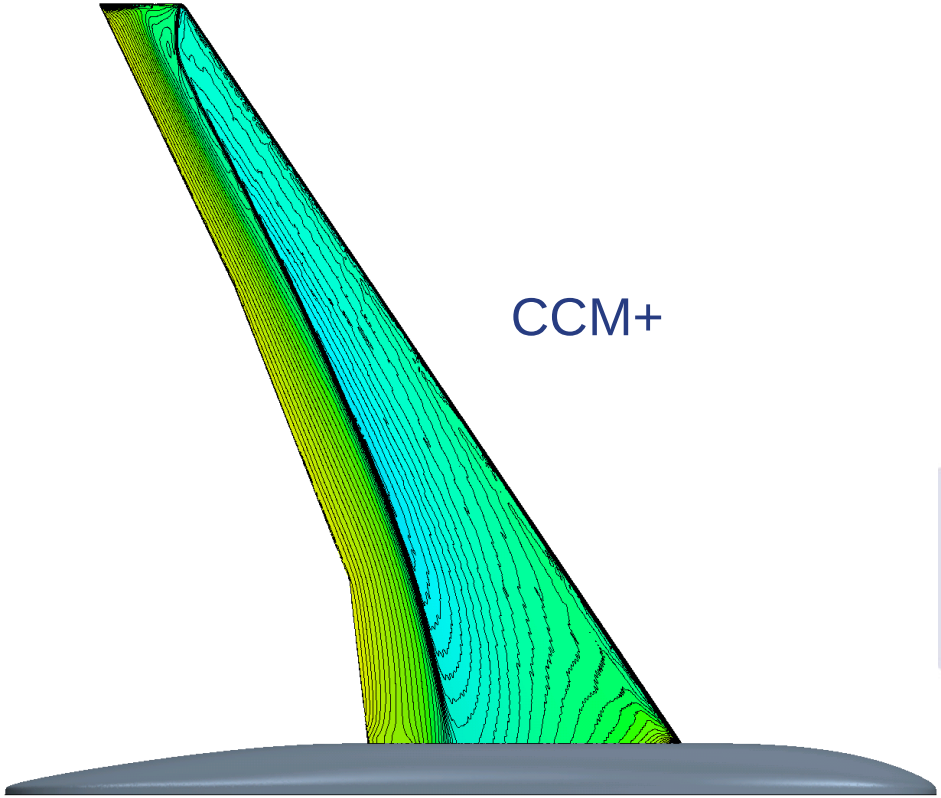
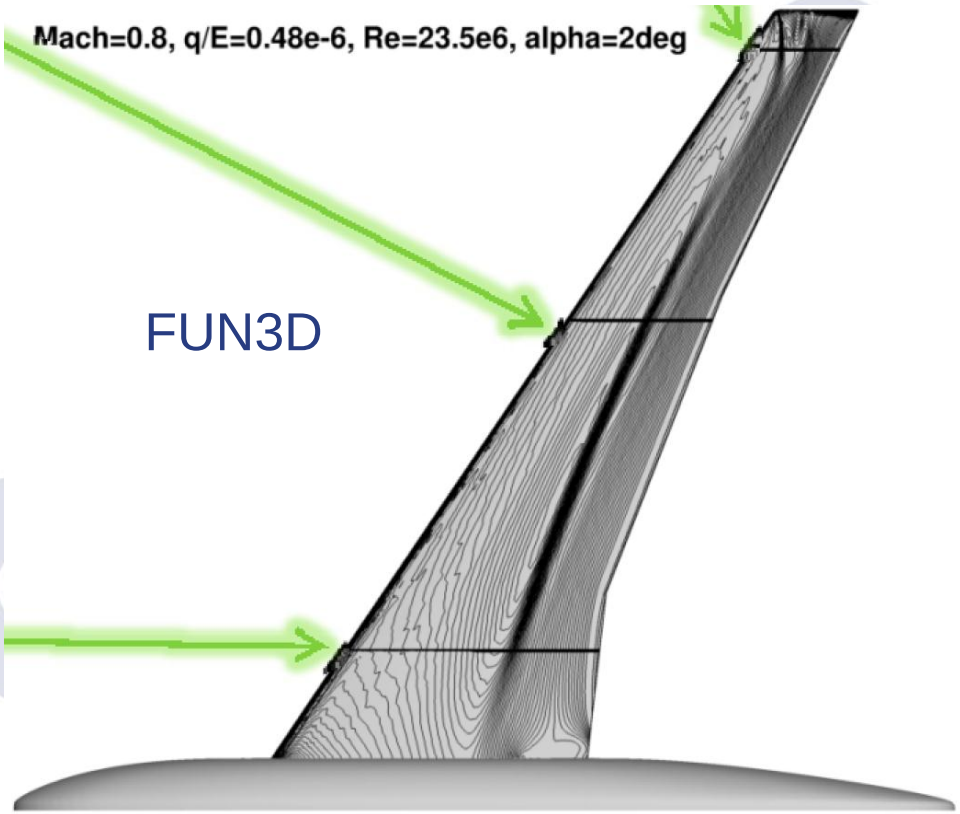
Cp: AOA 2°





Reference:
J.Heeg, J.Florance, P.Chwalowski, B. Perry, C.Wieseman. Information Package: Workshop on Aeroelastic Prediction. Aeroelasticity Branch, NASA Hampton, Virginia. October 2010

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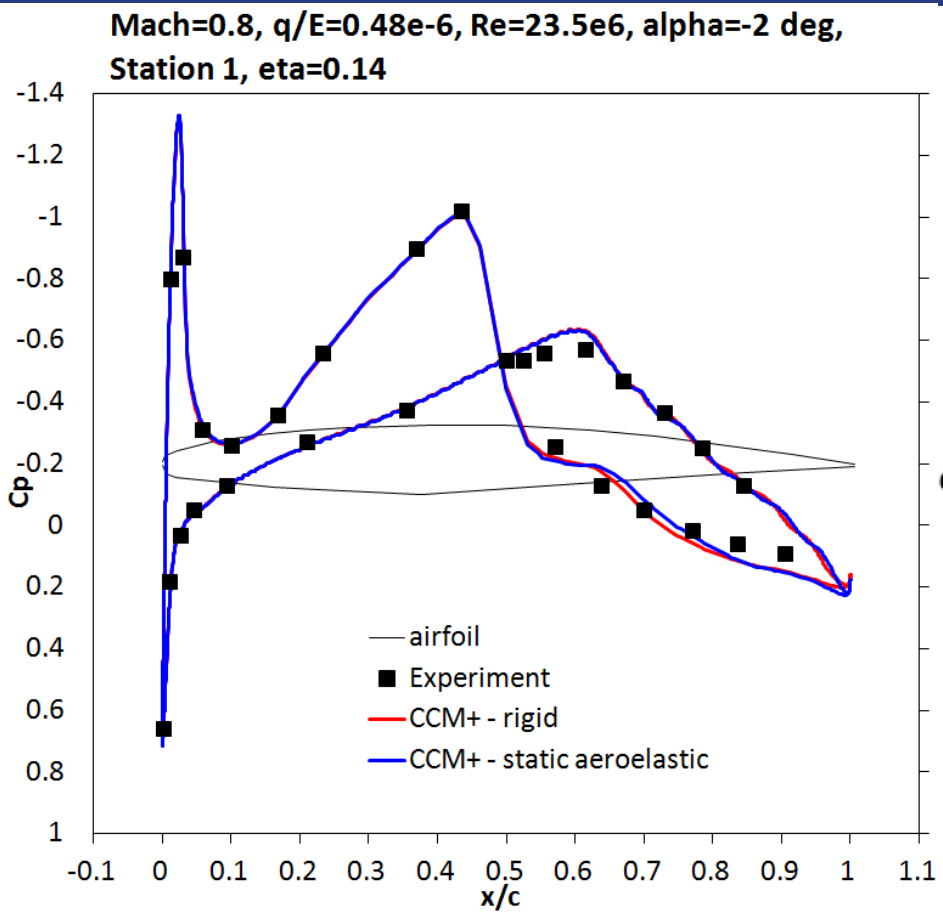
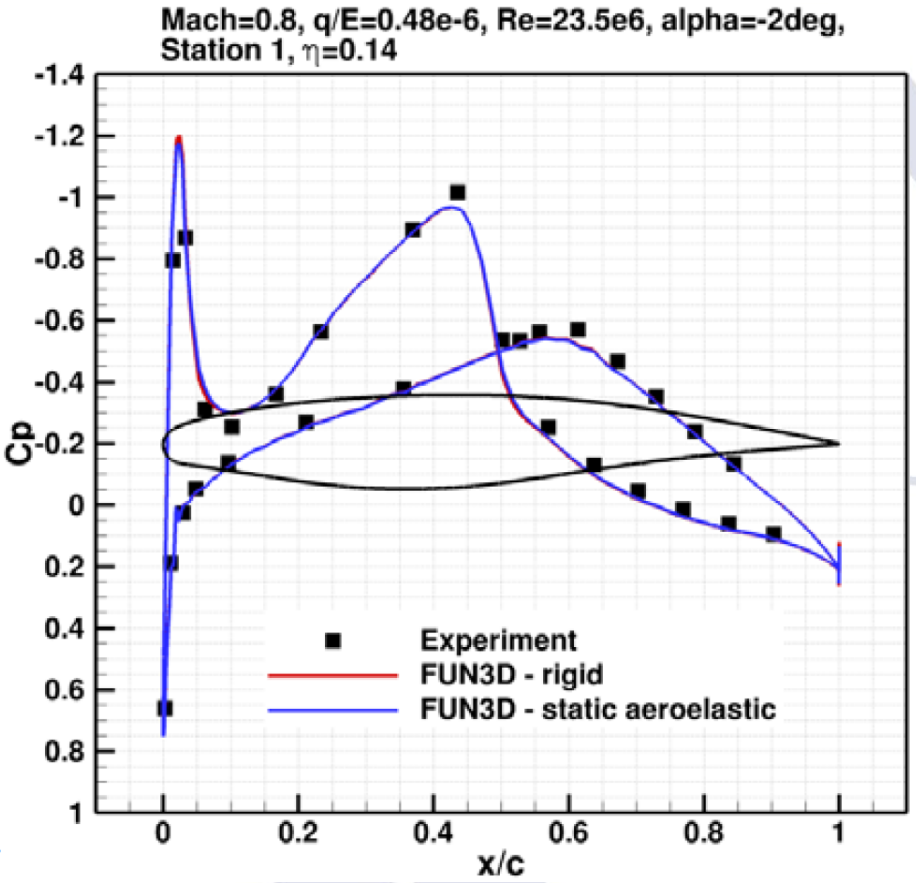
Cp: AOA -2°, Station 1





Reference:
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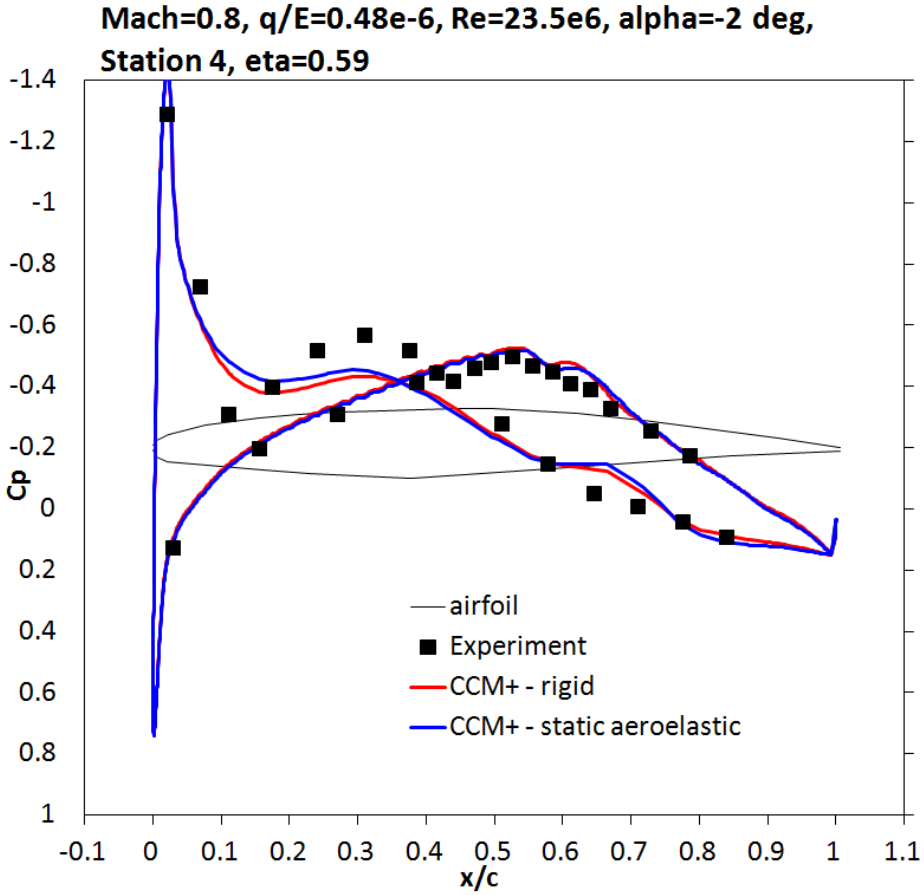
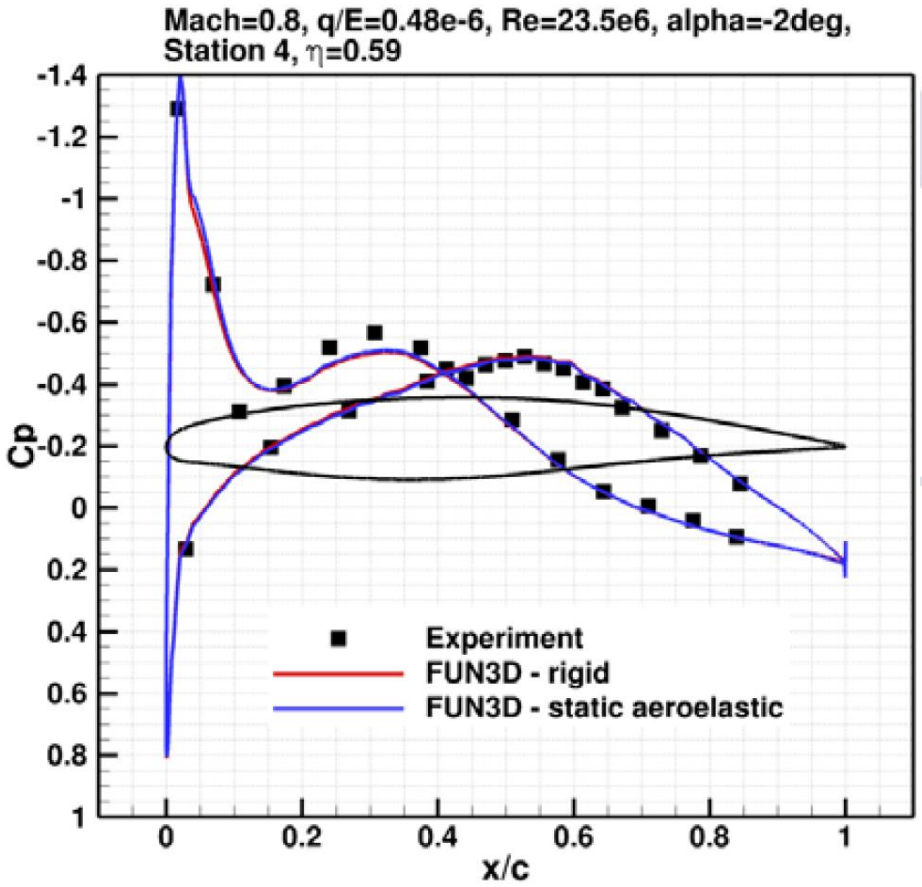
Cp: AOA -2°, Station 4





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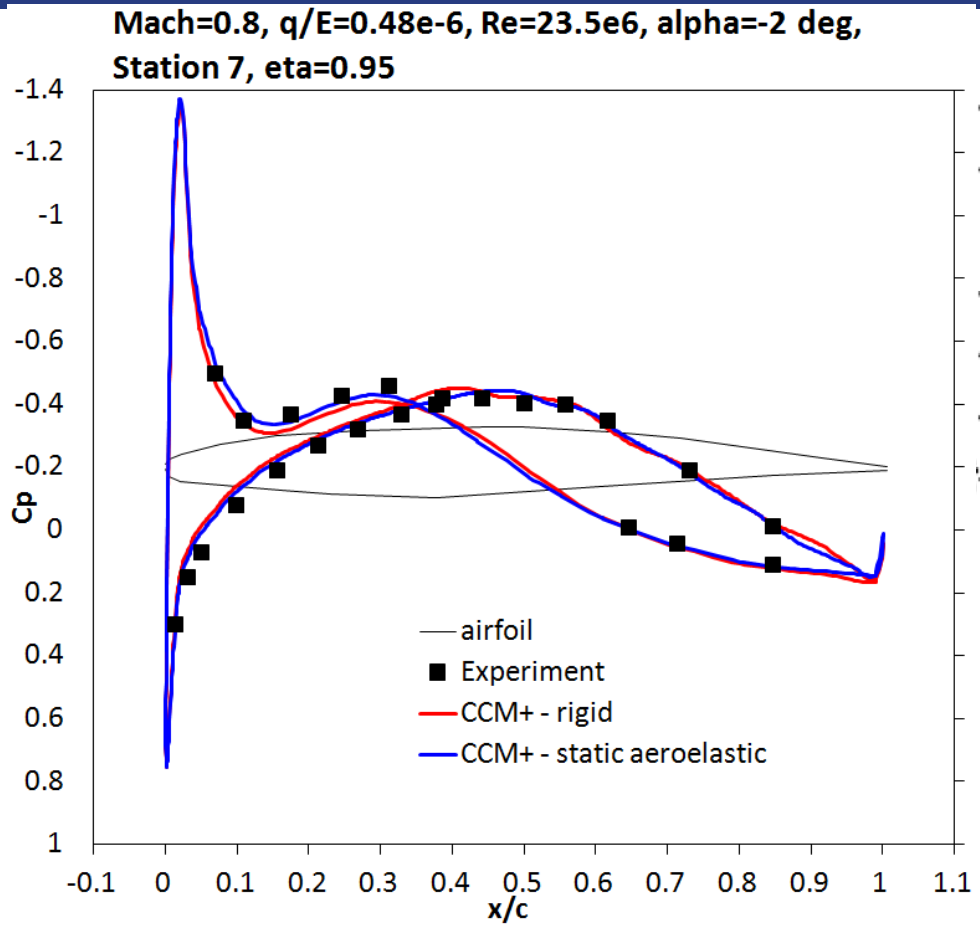
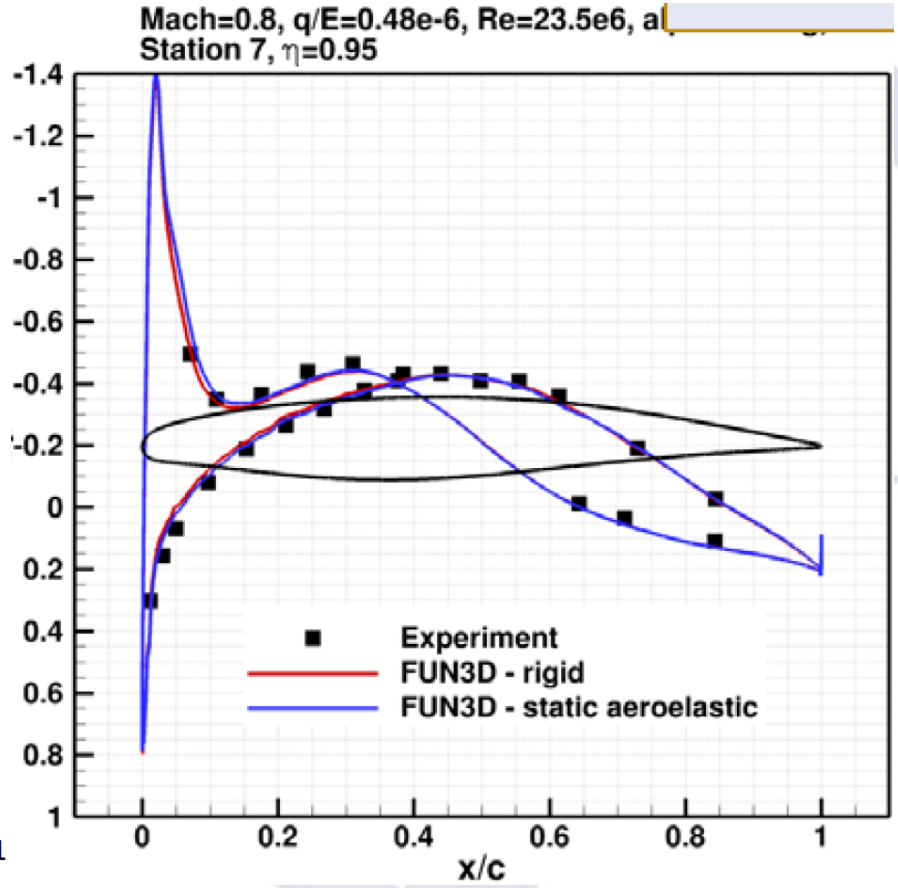
Cp: AOA -2°, Station 7





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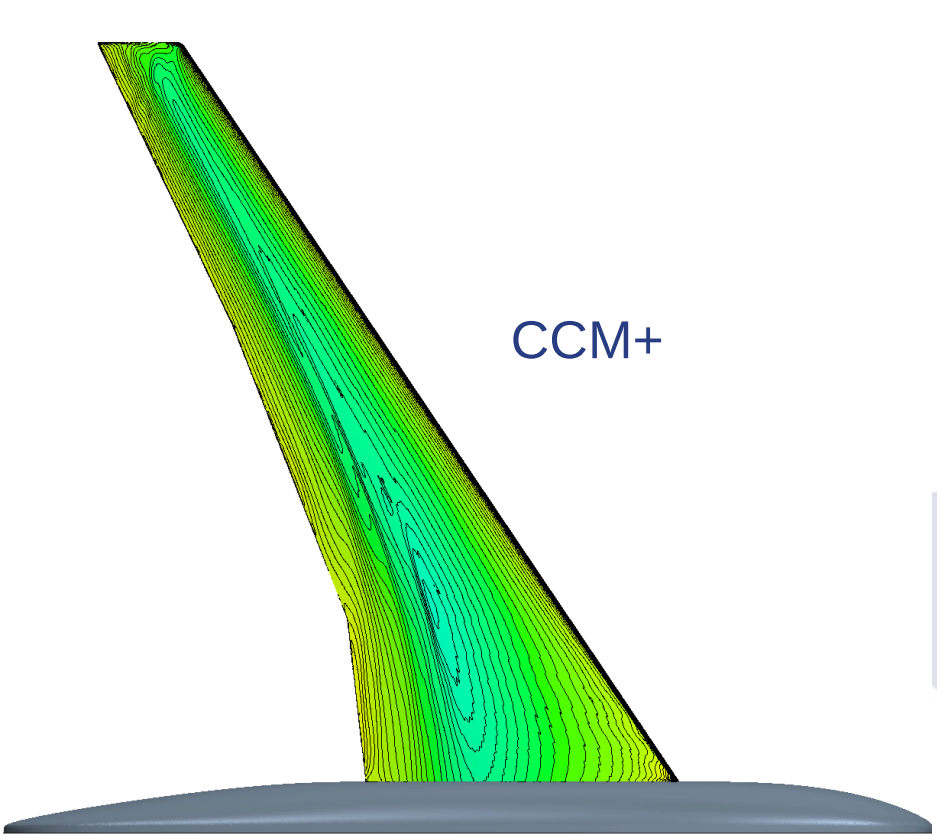
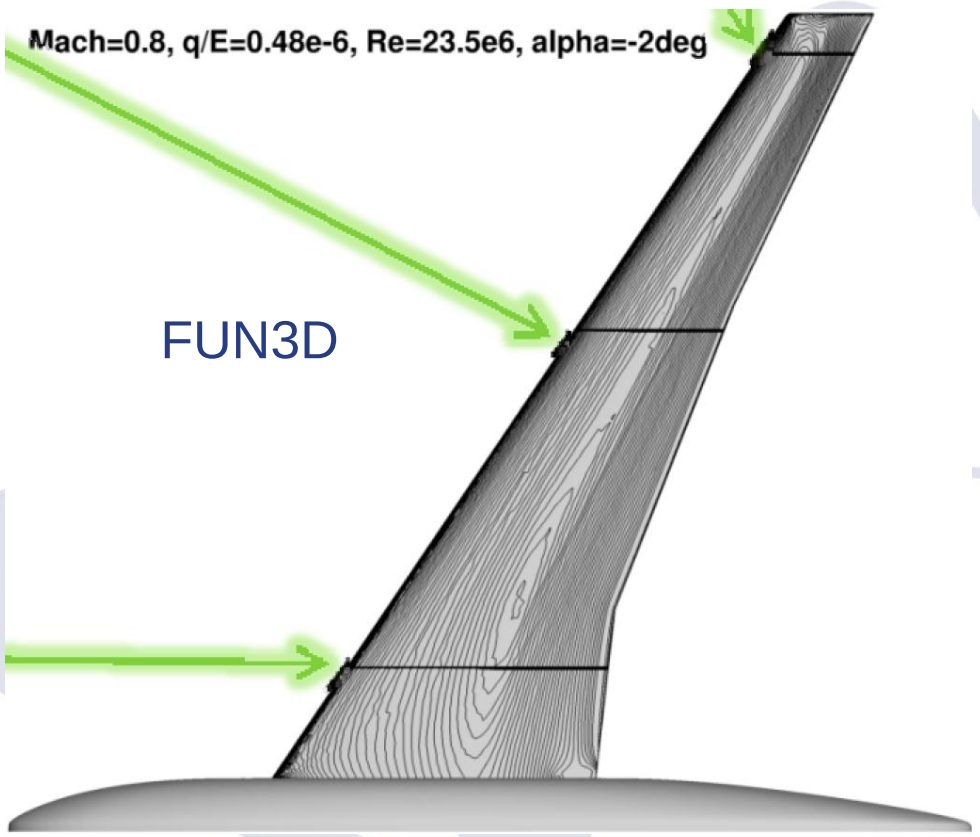
Cp: AOA -2°





Reference:
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Wind-off Free Vibration

- Comparisons

Mode	Eigenshape	Experiment, Hz	Base FEA, Hz	Abaqus, Hz	Error to exp., %	Error to Base, %
1	1. flap-bending	25.75	26.54	26.545	3.09	0.02
2	2. flap-bending	71.75	86.05	86.034	19.91	-0.02
5	1. torsion	262.90	272.9	273.35	3.97	0.16

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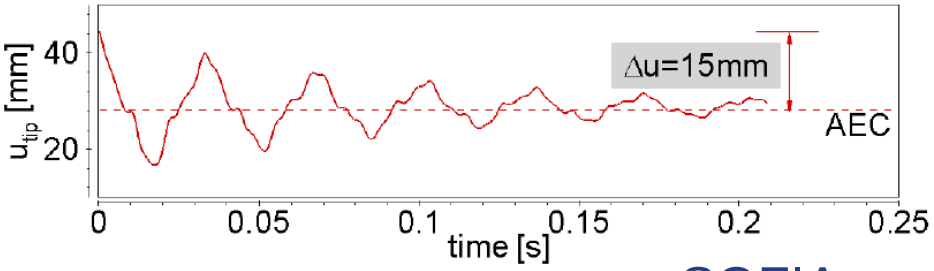
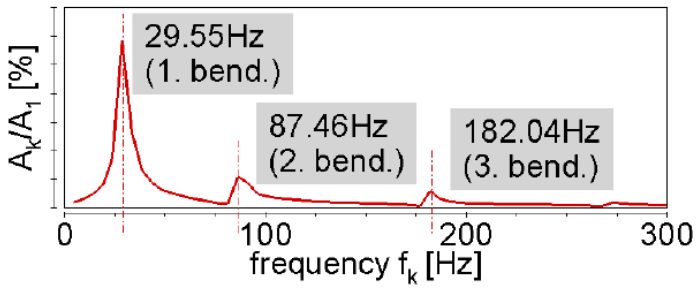
Wind-On Free Vibration

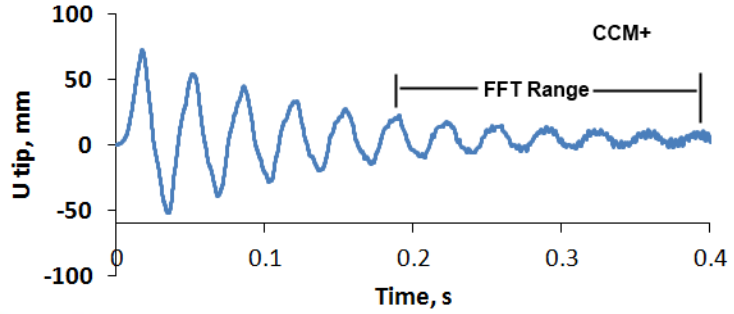
q/E = 0.48e-6, M = 0.8, Re = 23.5e6, AoA = -1.34°, weight impulse

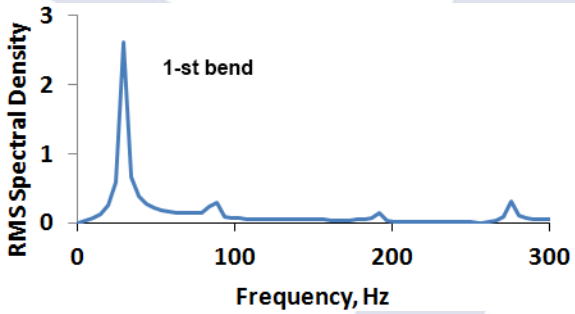
Medium	Frequency, Hz			Error, %	
	Experiment	Base	Result	to Exp.	to Base
Vacuum	25.75	26.54	26.55	3.09	0.02
Nitrogen	29.1	29.55	29.54	1.52	-0.03





SOFIA





STAR-CCM+/Abaqus

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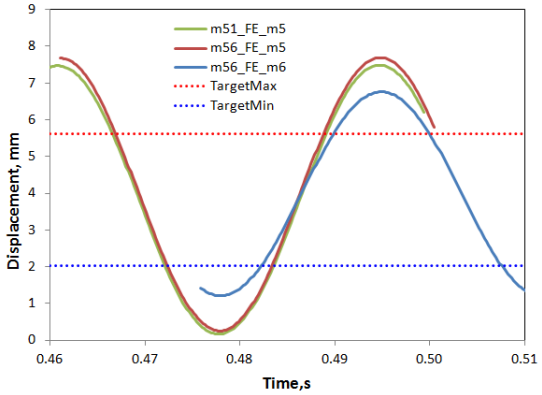
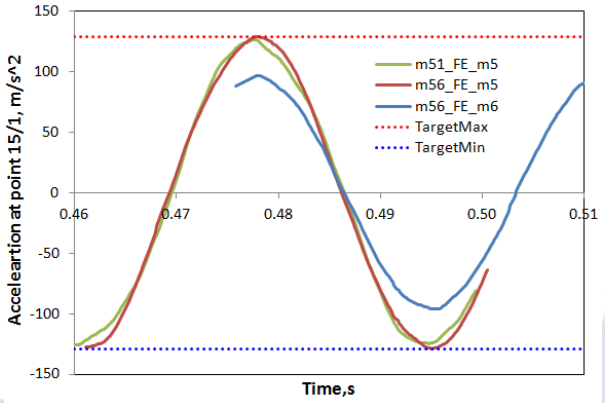
Wind-On Vibration 1st Flap-bending exp #270

AoA = -1.34° Moment 1430N-m applied on shells at 29.5 Hz

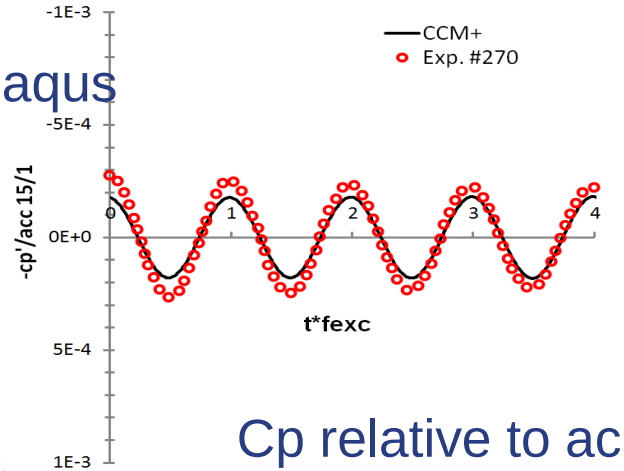


displacement

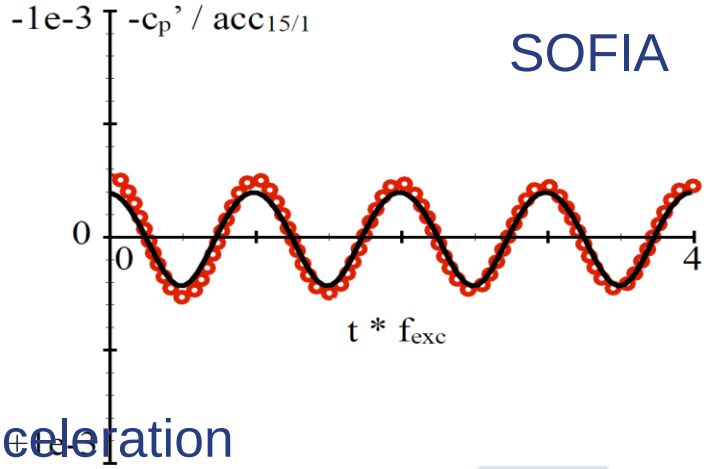


acceleration

ccm+/abaqus



SOFIA



Cp relative to acceleration

Conclusions

- Aeroelastic equilibrium
  - Reasonable comparisons to other codes and experiments in lift, drag and displacements
  - Overprediction of shock strength and slightly downstream
  - Aero Analyst is now previewing results (Deryl Snyder)
- Wind-off Vibration Structural model
  - Slight errors in frequencies to experiments
  - Closer to published numerical models
- Wind-on Free Vibration
  - Reasonable comparisons to experiments and other codes
  - Need data for damping coefficients to access structure damping
- Wind-on Forced Vibration 1st flap-bending mode
  - Uncertainty where to apply moment, need experimental details
  - Contradiction between published displacement and acceleration

CD-adapco