AePW Aeroelastic Prediction Workshop

HIRENASD Comparison Plots

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Principal contributors to assembling and interpreting and presenting the comparison data

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- Jennifer Florance, NASA
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- Jennifer Heeg, NASA

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- Markus Ritter; DLR
- Thorsten Hansen; Ansys
- Mats Dalenbring & Adam Jirasek; FOI
- Pawel Chwalowski; NASA
- Anne Sophie Sens & Jean Pierre Grisval; ONERA
- Daniella Raveh; Technion University
- Melike Nikbay, Pinar Acar, Chagri Kilich & Zhichao Zhang; Istanbul TU, Zona
- Sergio Ricci, Andrea Parrinello & Giulio Romanelli; Politecnico di Milano
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- Alan Mueller & Sergey Zhelzov; CD Adapco
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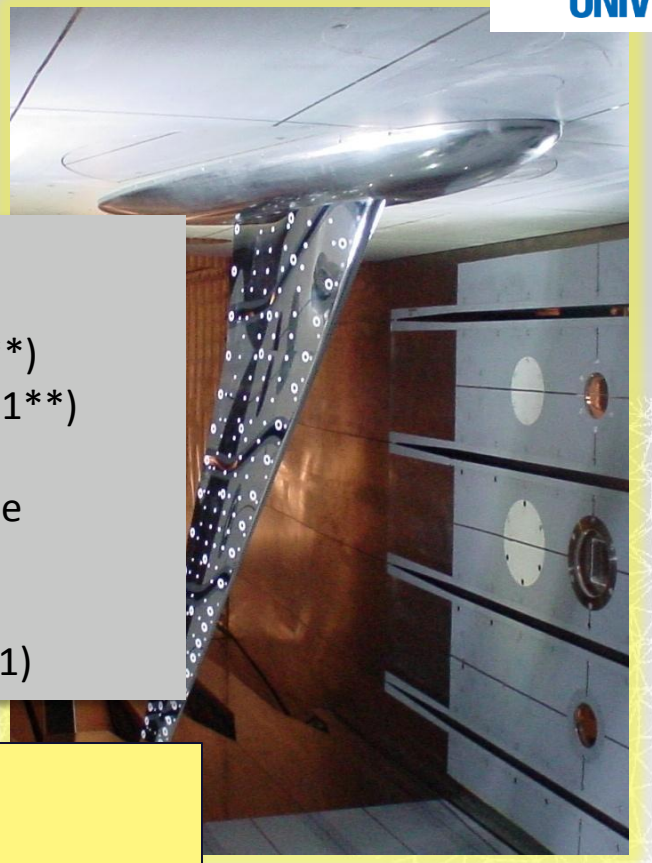
Contributing to the Experimental Data Reduction

- Josef Ballmann, Aachen University
- Alexander Boucke, Aachen University
- Carol Wieseman, NASA
- Jennifer Heeg, NASA

HIRENASD
funded by DFG

RWTH AACHEN UNIVERSITY

HIRENASD



M = 0.80, test medium: Nitrogen

a) Steady (Static Aeroelastic) Cases

i. Re_c = 7.0 million, $\alpha = 1.5^\circ$, q/E = 0.22 (ETW159**)

ii. Re_c = 23.5 million, $\alpha = -1.34^\circ$, q/E = 0.48 (ETW271**)

b) Dynamic Cases: forced oscillation at 2nd Bending mode frequency

i. Re_c = 7.0 million, $\alpha = 1.5^\circ$, q/E = 0.22 (ETW159)

ii. Re_c = 23.5 million, $\alpha = -1.34^\circ$, q/E = 0.48 (ETW271)

M = 0.70, test medium: Nitrogen

a) Steady (Static Aeroelastic) Cases

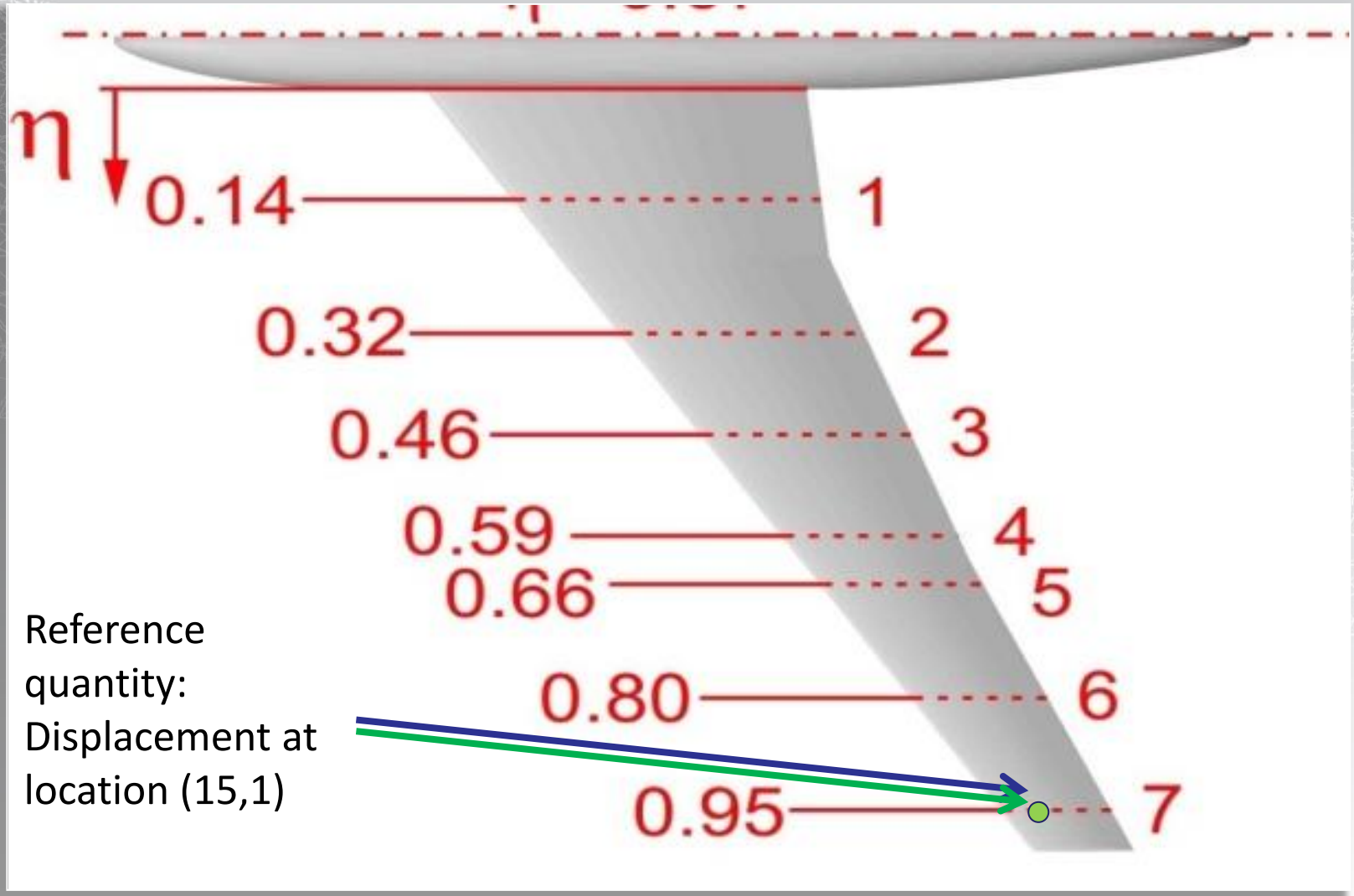
i. Re_c = 7.0 million, $\alpha = 1.5^\circ$, q/E = 0.22 (ETW155**)

b) Dynamic Cases: forced oscillation at 2nd Bending mode frequency

i. Re_c = 7.0 million, $\alpha = 1.5^\circ$, q/E = 0.22 (ETW155)

Data Point	Excitation Frequency, Hz
155	79.3
159	78.9
271	80.4

HIRENASD Sensor Locations



Reference quantity: Displacement at location (15,1)

	Summary of HIRENASD Entries				
Analyst	A	B	C	D	E
CODE	ENFLOW	NSMB	CFD++ & NASTRAN	EZNSS	Edge
TURBULENCE MODEL	kTNT	k-ω MSS	2 Eq. Realizable k-ε	SA	SA
GRID TYPE	Strmb	Str	Unstr	Str	Unstr

Analyst	G	H	I	J	K
CODE	elsA	NSU3D	ZEUS	FUN3D	ANSYS CFX
TURBULENCE MODEL	SA	SA	Unknown	SA	SST
GRID TYPE	Str	Unstr	Str	Unstr	Str

Str = Structured

Strmb = Structured multi-block

Unstr = Unstructured

Comparison Data Matrix: Experimental Data Status

Completed | In progress | Stalled

CONFIGURATION	REQUIRED CALCULATIONS			
	GRID CONVERGENCE STUDIES	TIME CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M	n/a
Steady-Aeroelastic Cases (HIRENASD)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M • Vertical displacement vs. chord • Twist angle vs. span	n/a
Forced Oscillation Cases (all configurations)	• Magnitude and Phase of CL, CD, CM (vs. $N^{-2/3}$ at excitation frequency)	• Magnitude and Phase of C_L, C_D, C_M (vs. Δt at excitation frequency)	n/a	• Magnitude and Phase of C_p vs. x/c at span stations corresponding to transducer locations • Magnitude and Phase of C_L, C_D, C_M at excitation frequency • Time histories of C_p's at a selected span station for two upper- and two lower-surface transducer locations

Convergence of steady results, spatial

Experimental comparison data currently in progress

CONFIGURATION	REQUIRED CALCULATIONS			
	GRID CONVERGENCE STUDIES	TIME CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M	n/a
Steady-Aeroelastic Cases (HIRENASD)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M • Vertical displacement vs. chord • Twist angle vs. span	n/a
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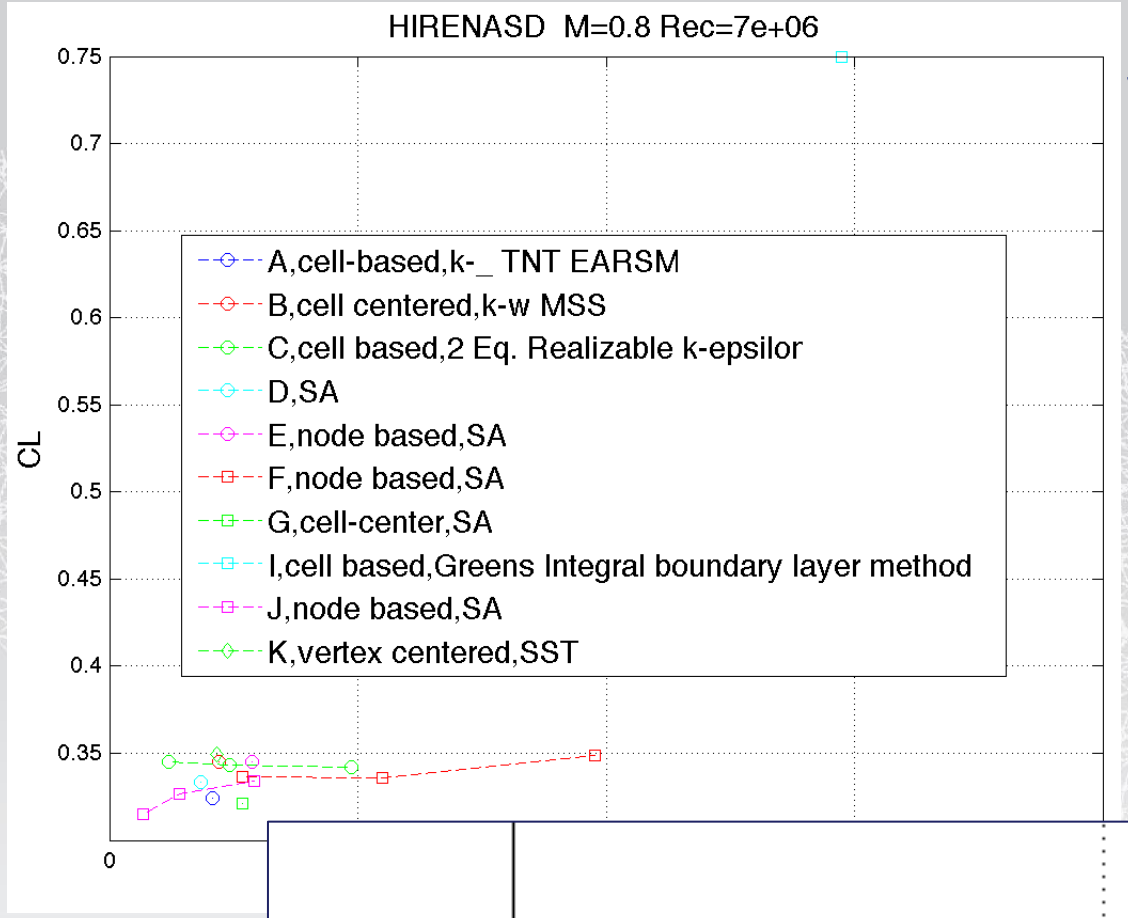
Spatial convergence, CL, steady



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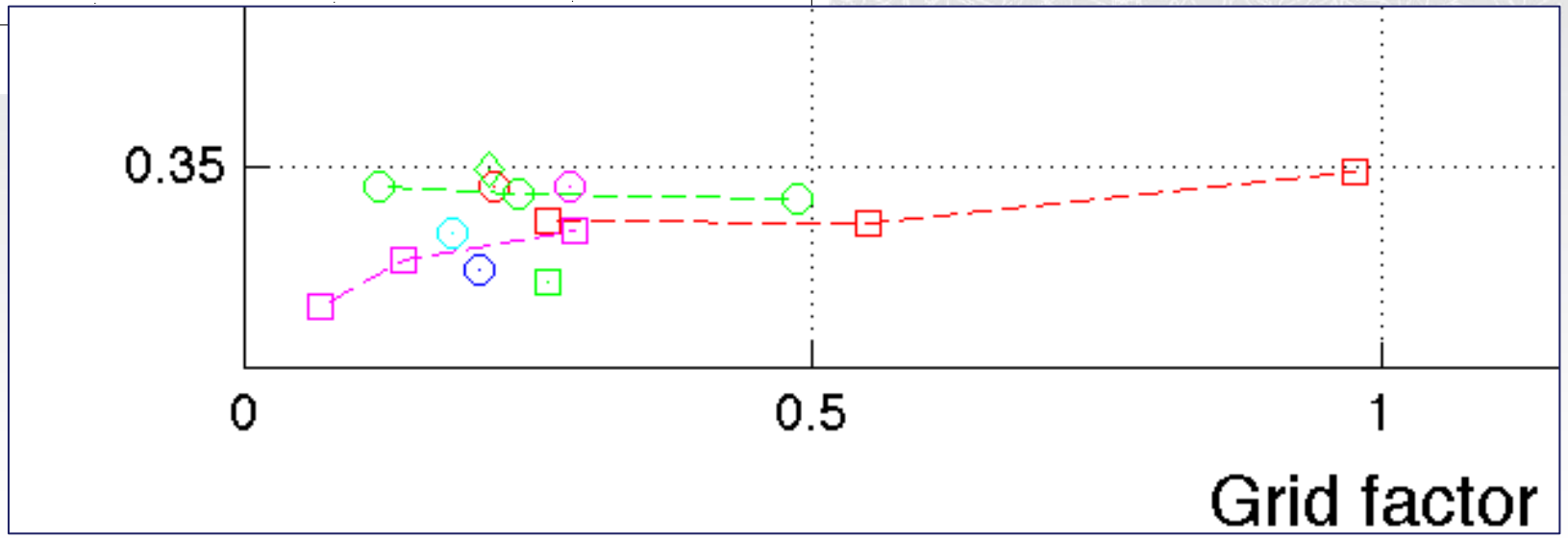
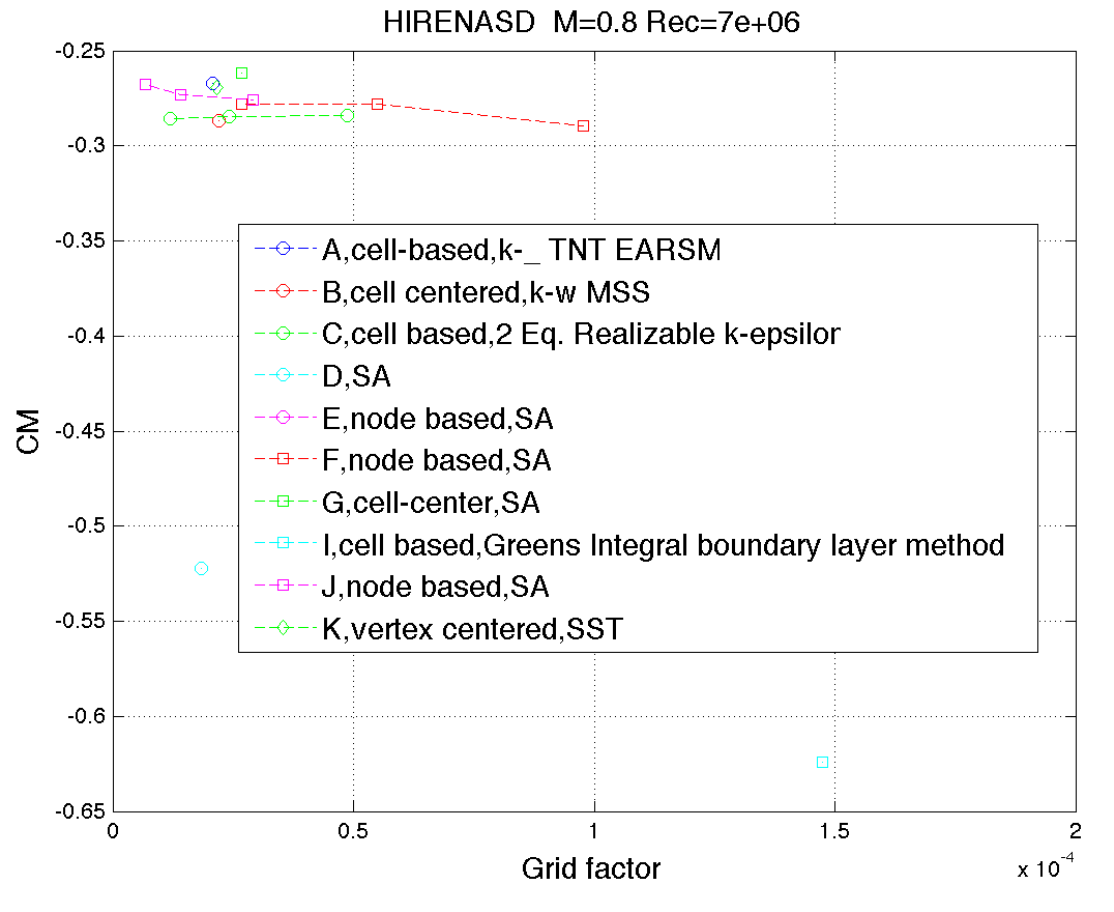


Spatial convergence, CM, steady



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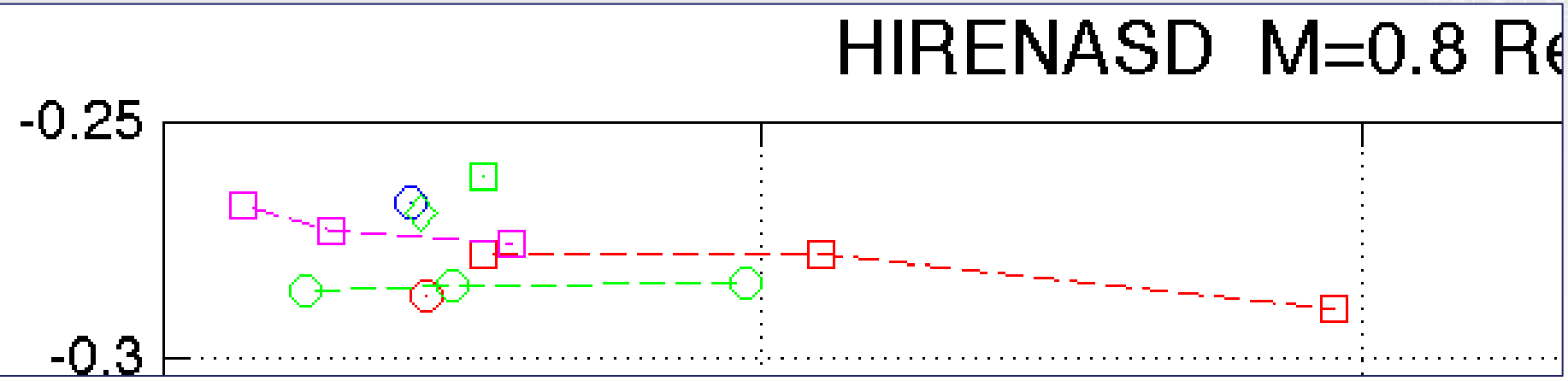
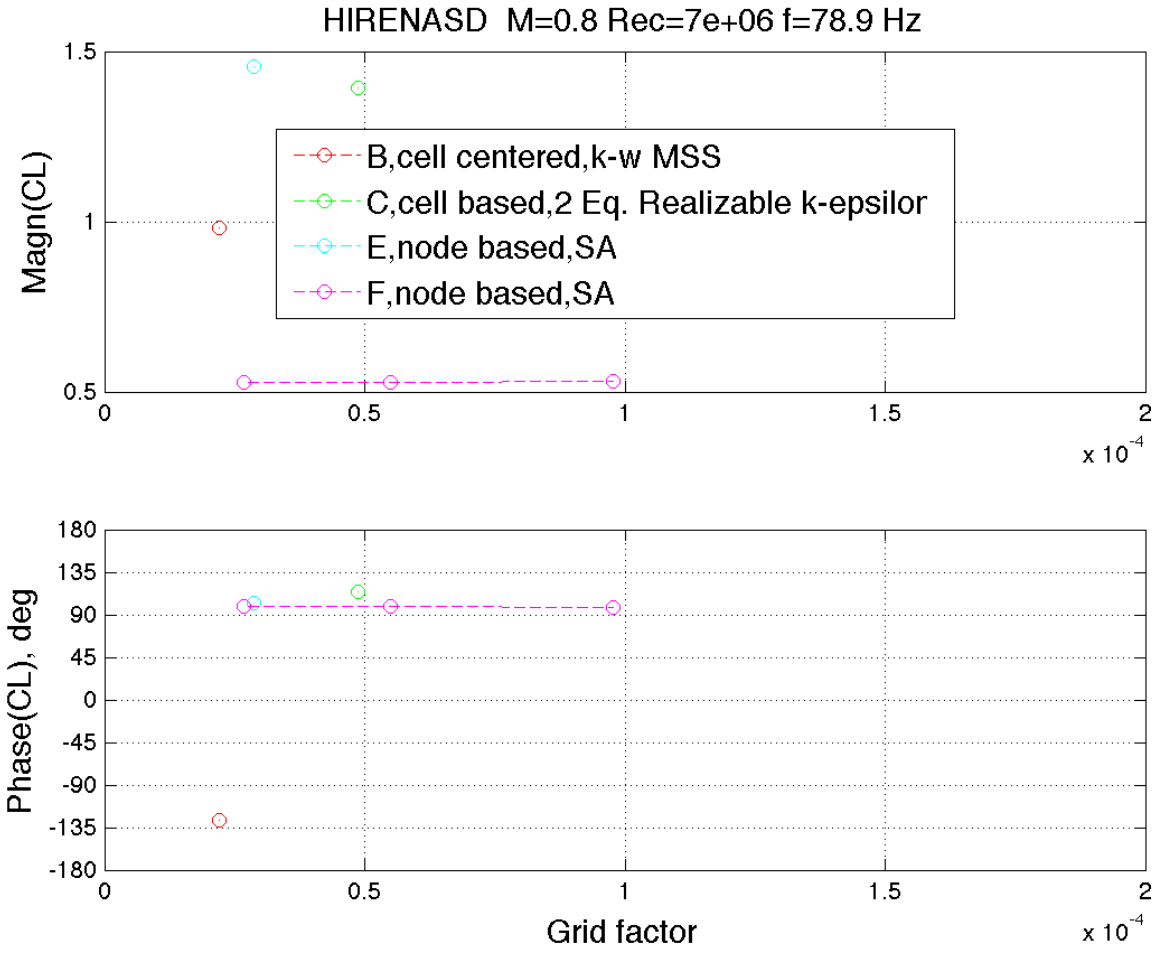


Convergence, time step size

Very few data sets submitted up to this point

CONFIGURATION	REQUIRED CALCULATIONS			
	GRID CONVERGENCE STUDIES	TIME CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M	n/a
Steady-Aeroelastic Cases (HIRENASD)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M • Vertical displacement vs. chord • Twist angle vs. span	n/a
Forced Oscillation Cases (all configurations)	• Magnitude and Phase of CL, CD, CM vs. $N^{-2/3}$ at excitation frequency	• Magnitude and Phase of C_L, C_D, C_M vs. Δt at excitation frequency	n/a	• Magnitude and Phase of C_p vs. x/c at span stations corresponding to transducer locations • Magnitude and Phase of C_L, C_D, C_M at excitation frequency • Time histories of C_p's at a selected span station for two upper- and two lower-surface transducer locations

Spatial convergence, CL, unsteady



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Comparison Data Matrix

CONFIGURATION	REQUIRED CALCULATIONS			
	GRID CONVERGENCE STUDIES	TIME CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. $N^{-2/3}$ ✓	n/a	• Mean C_p vs. x/c ✓ • Means of C_L, C_D, C_M ✓	n/a
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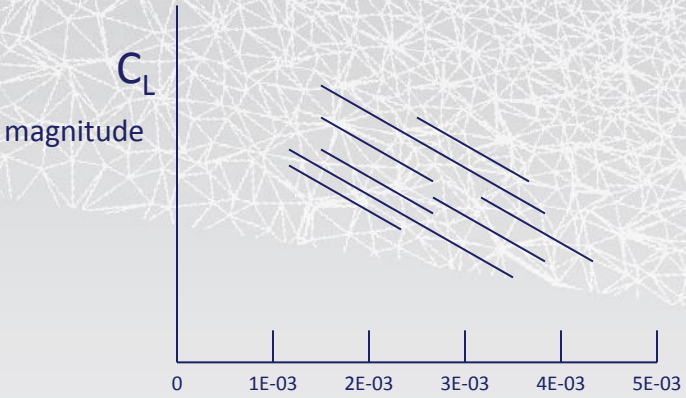
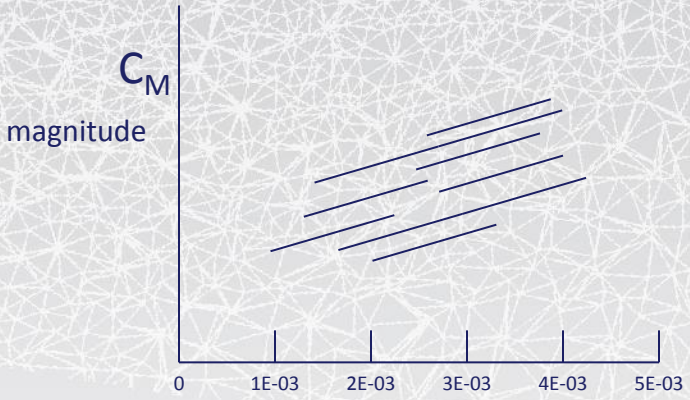
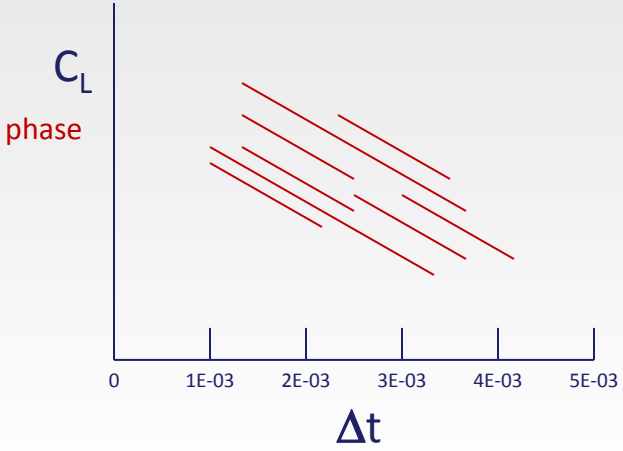
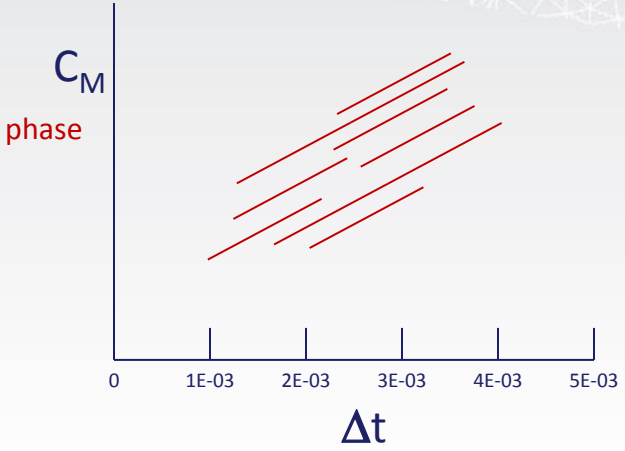
Forced Oscillation Cases (all configurations)	• Magnitude and Phase of C_L, C_D, C_M vs. $N^{-2/3}$ at excitation frequency ✓	• Magnitude and Phase of C_L, C_D, C_M vs. Δt at excitation frequency	n/a	• Magnitude and Phase of C_p vs. x/c at span stations corresponding to transducer locations • Magnitude and Phase of C_L, C_D, C_M at excitation frequency • Time histories of C_p's at a selected span station for two upper- and two lower-surface transducer locations

Envisioned time convergence assessments: Forced Oscillation Cases









Convergence, time step size

Very data sets submitted up to this point

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Upper surface, steady Mach 0.8, Re 7M, α 1.5

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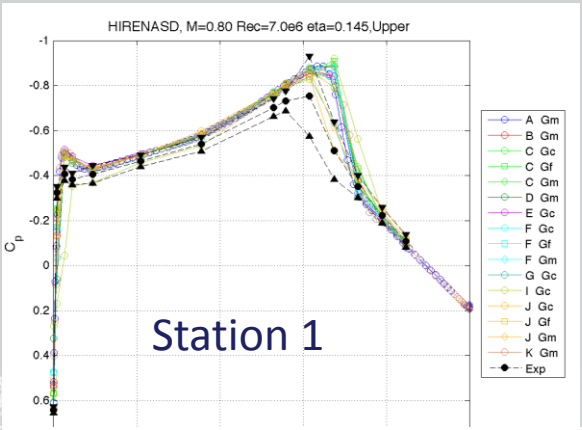

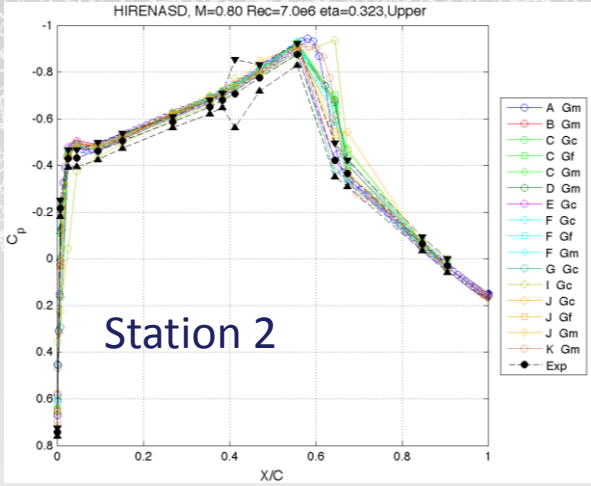

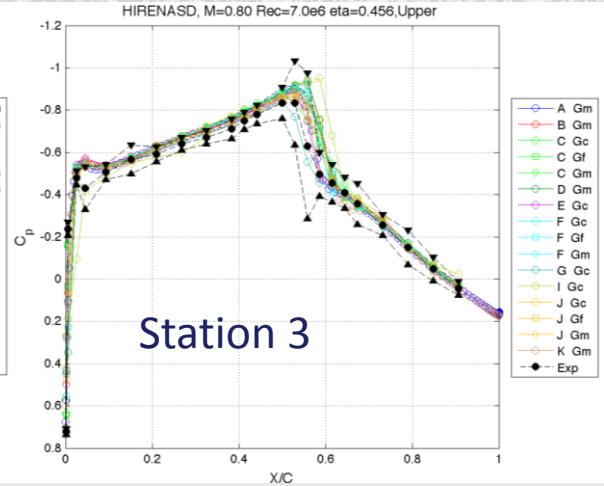

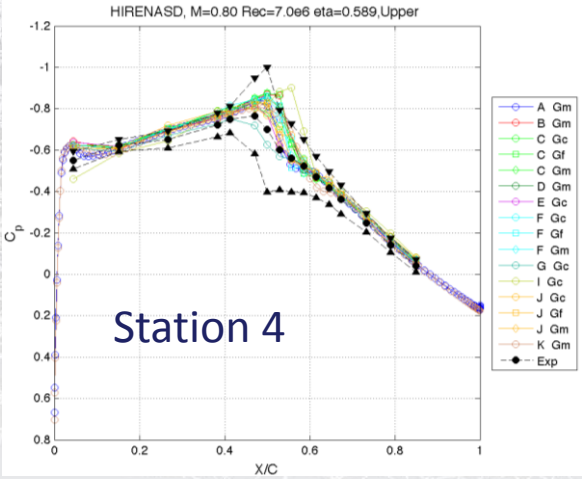

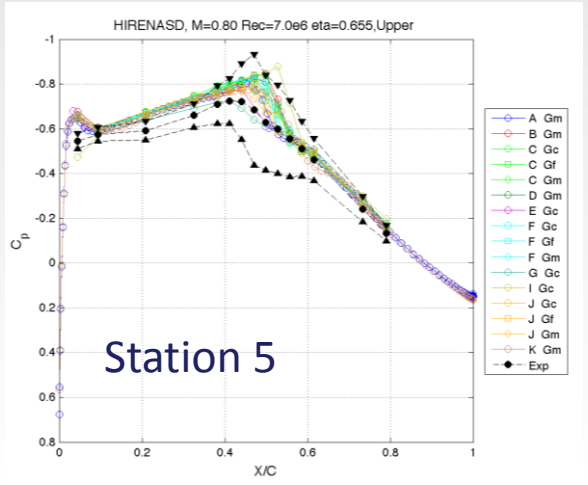

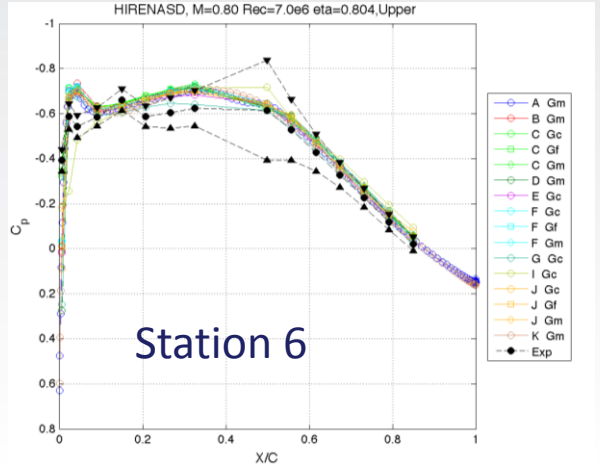

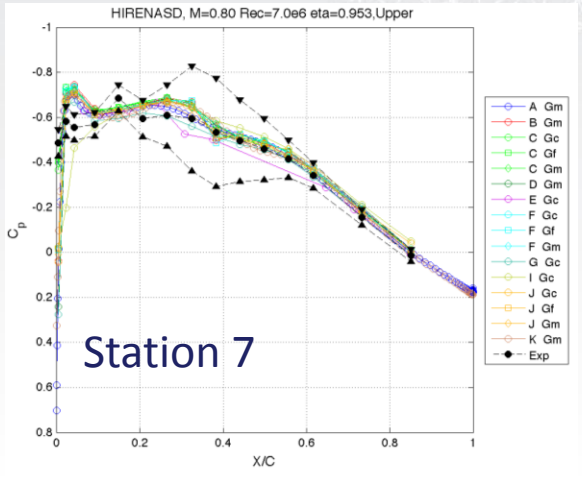

Lower surface, steady
Mach 0.8, re 7M

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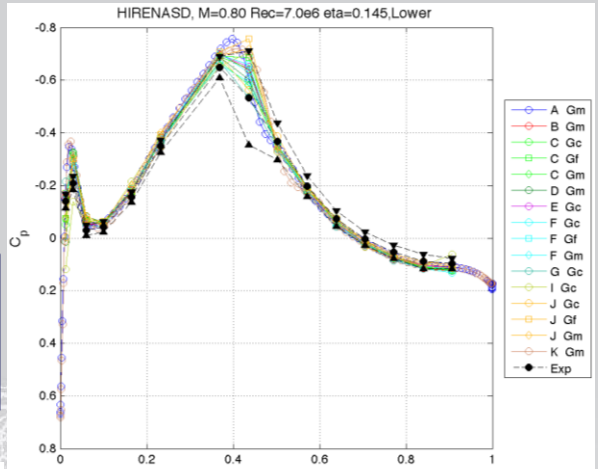
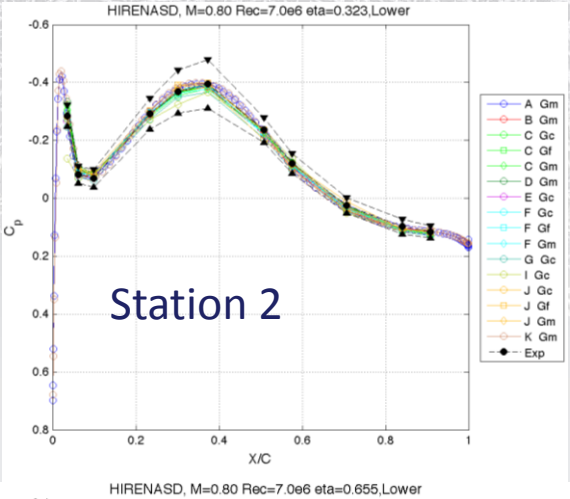
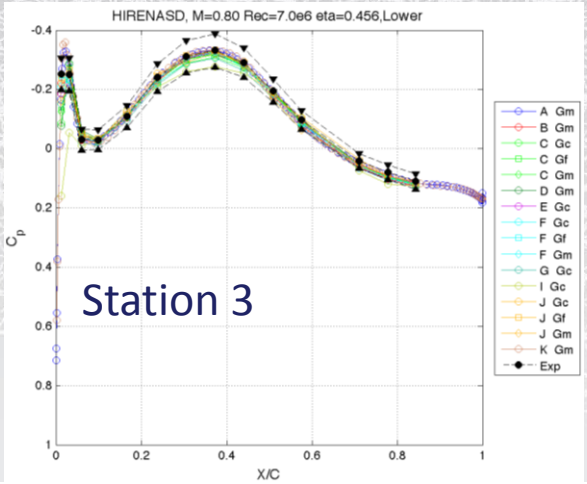
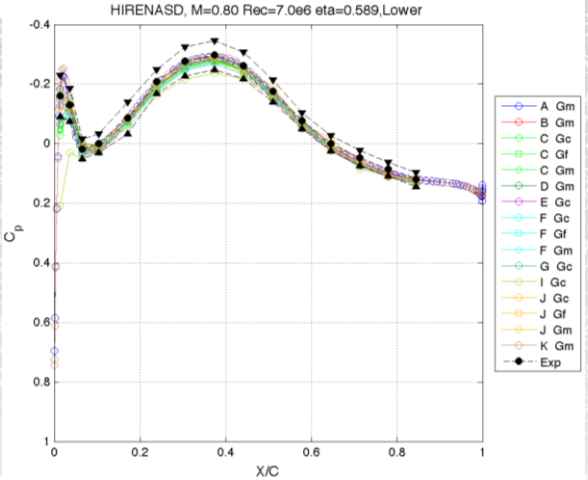
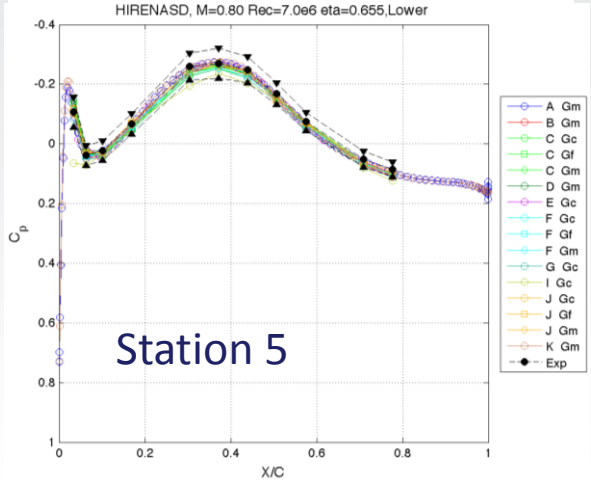
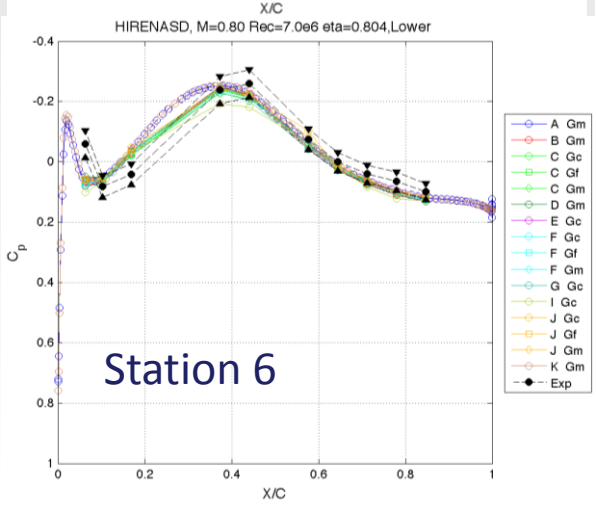


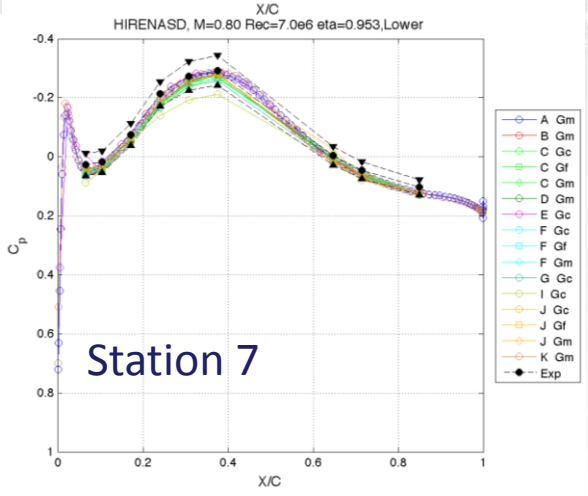




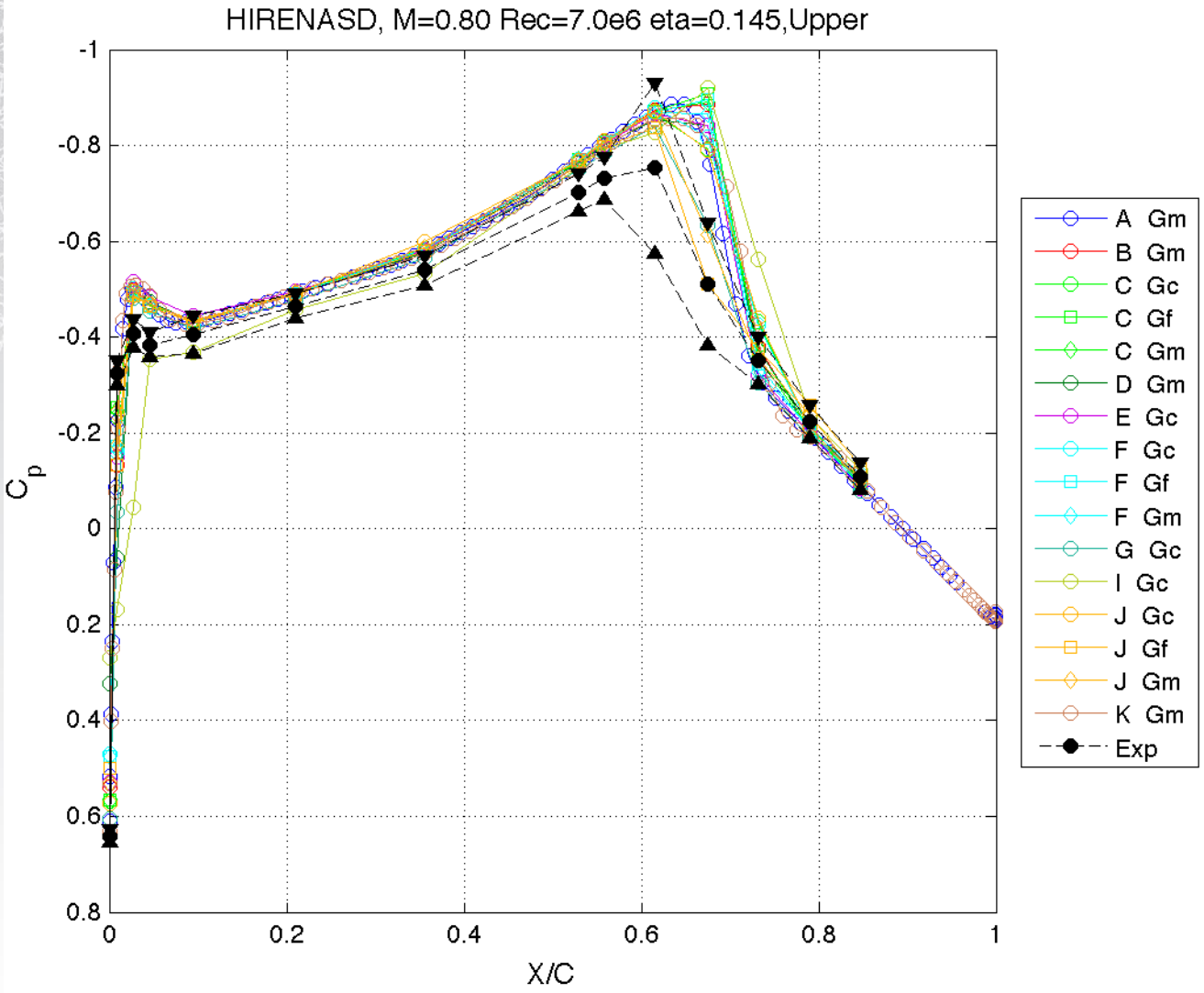








Upper surface, steady
Mach 0.8, Re 7M, α 1.5



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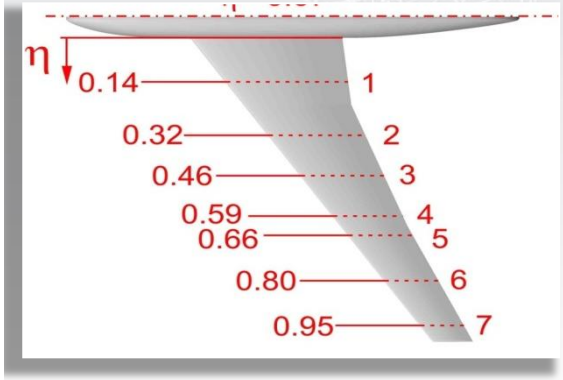
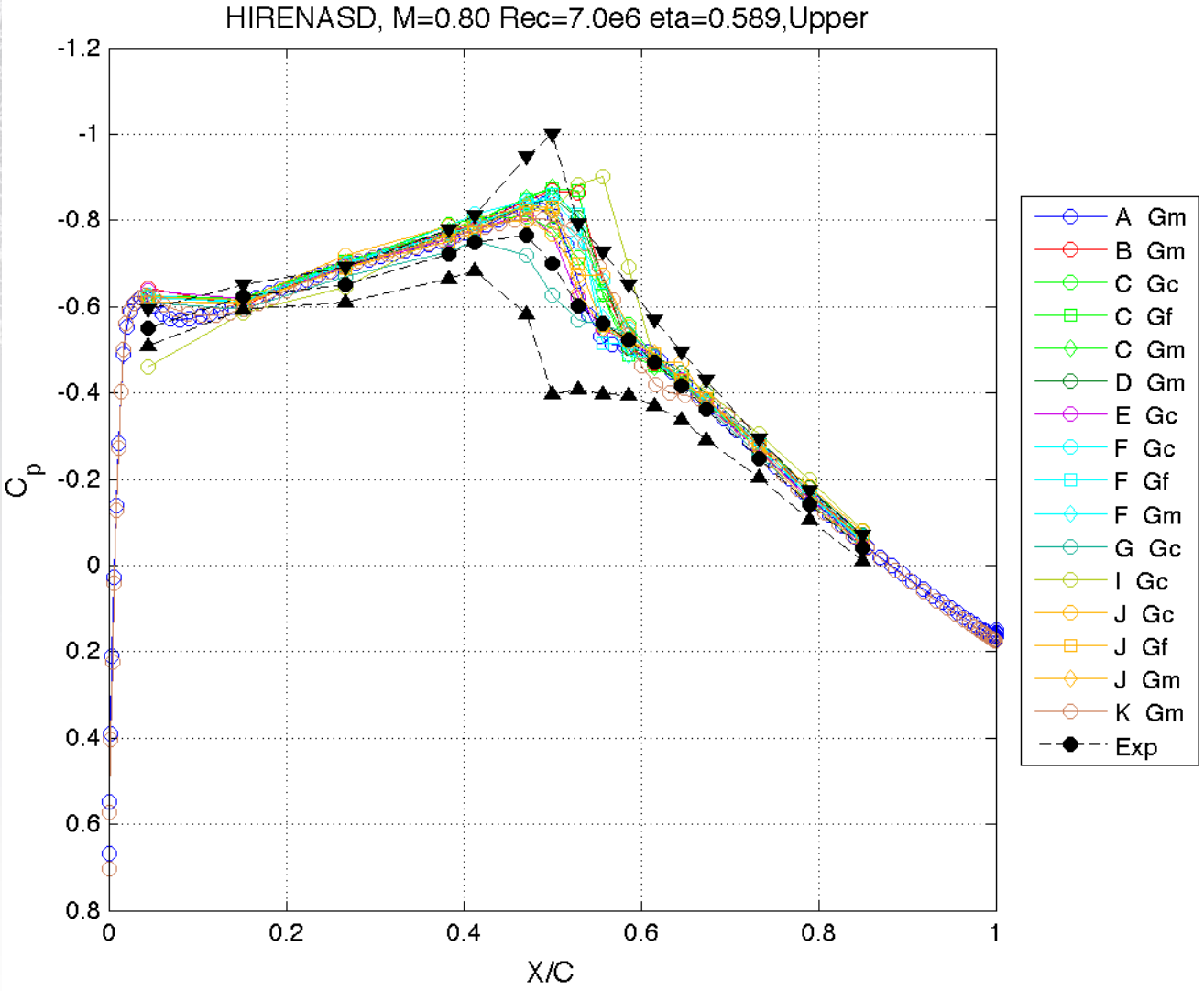


Station 1

Upper surface, steady
Mach 0.8, Re 7M, α 1.5



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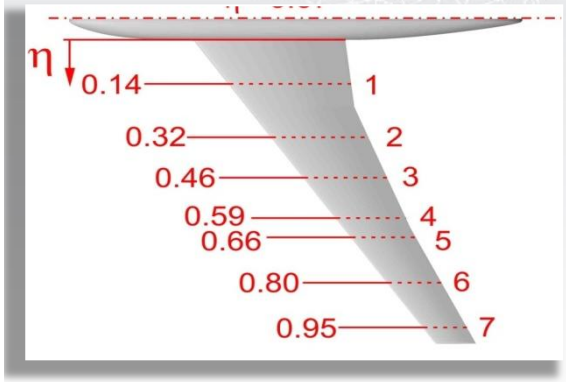
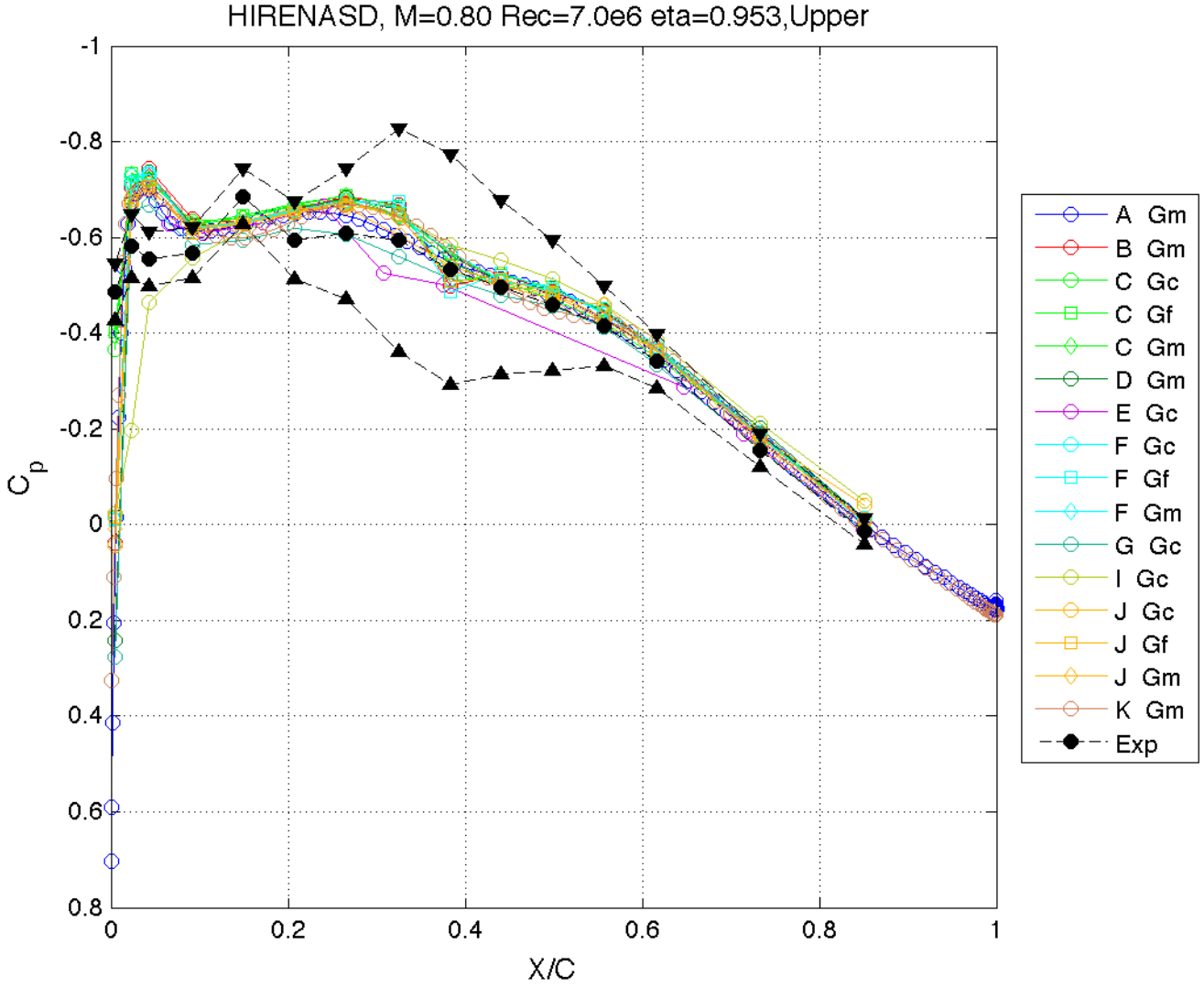


Station 4

Upper surface, steady
Mach 0.8, Re 7M, α 1.5



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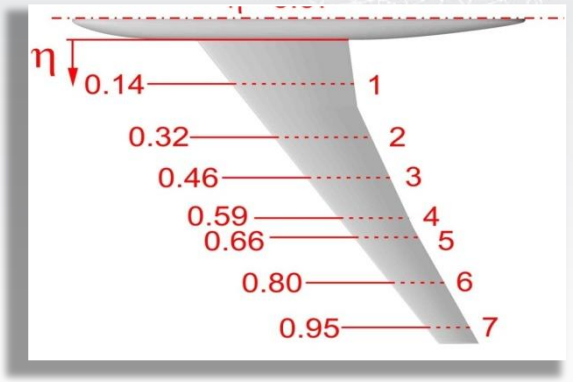
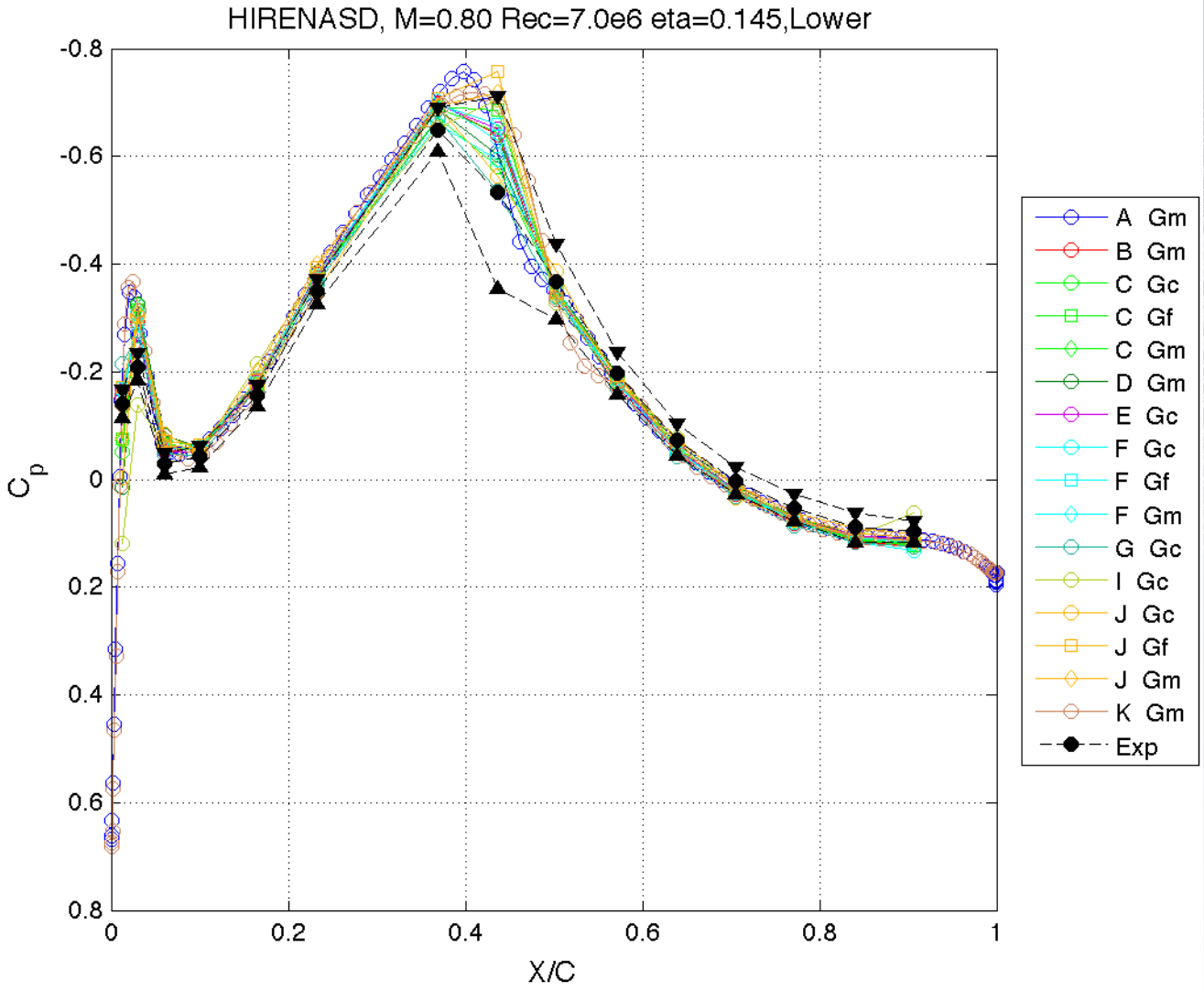


Station 7

Lower surface, steady
Mach 0.8, Re 7M, α 1.5



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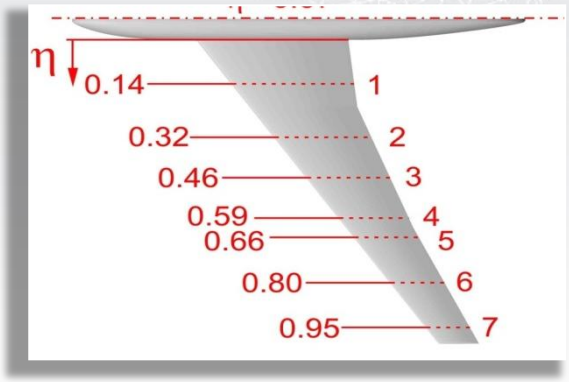
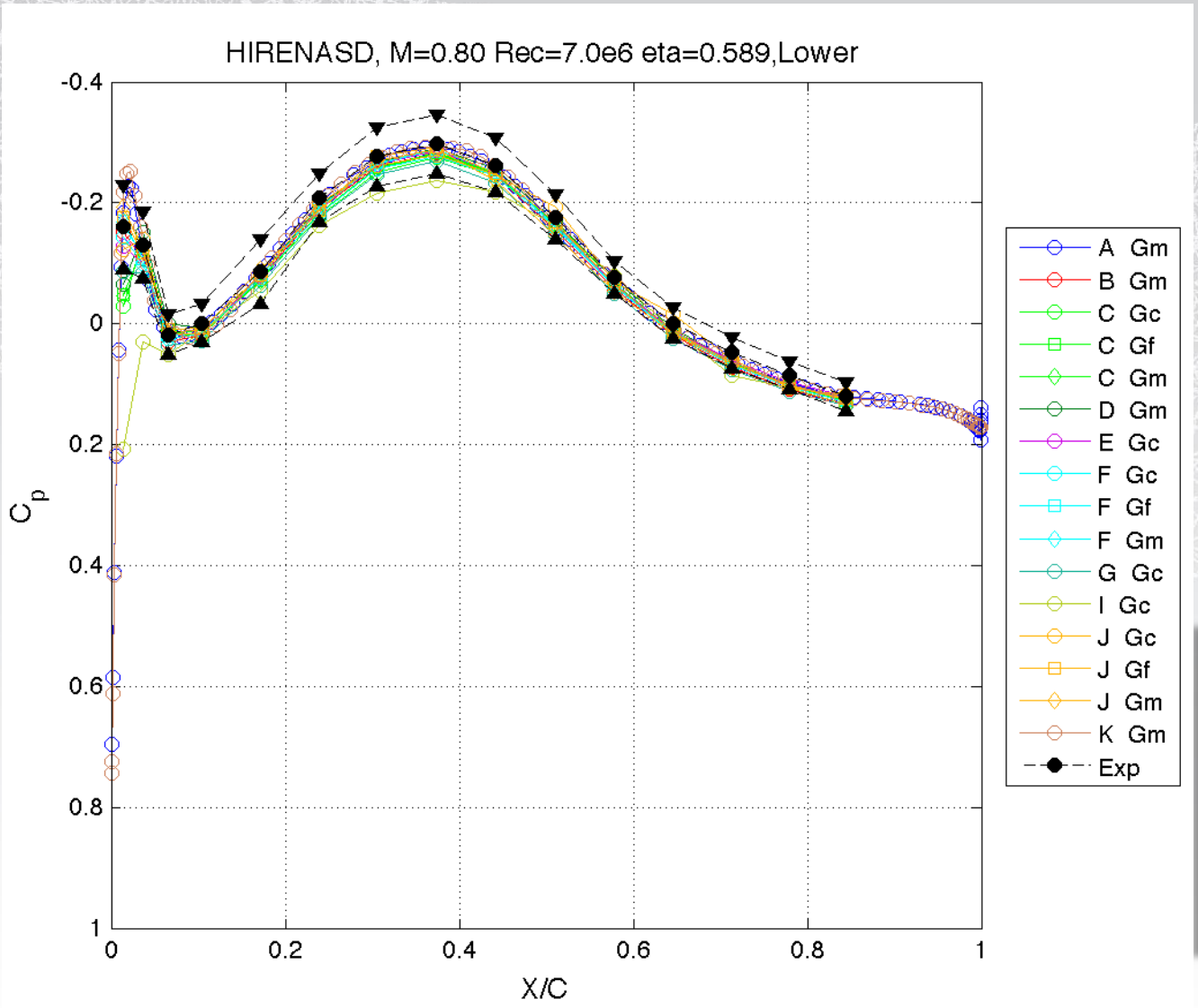


Station 1

Lower surface, steady
Mach 0.8, Re 7M, α 1.5



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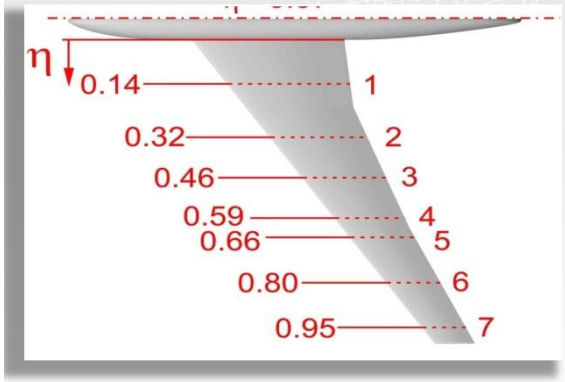
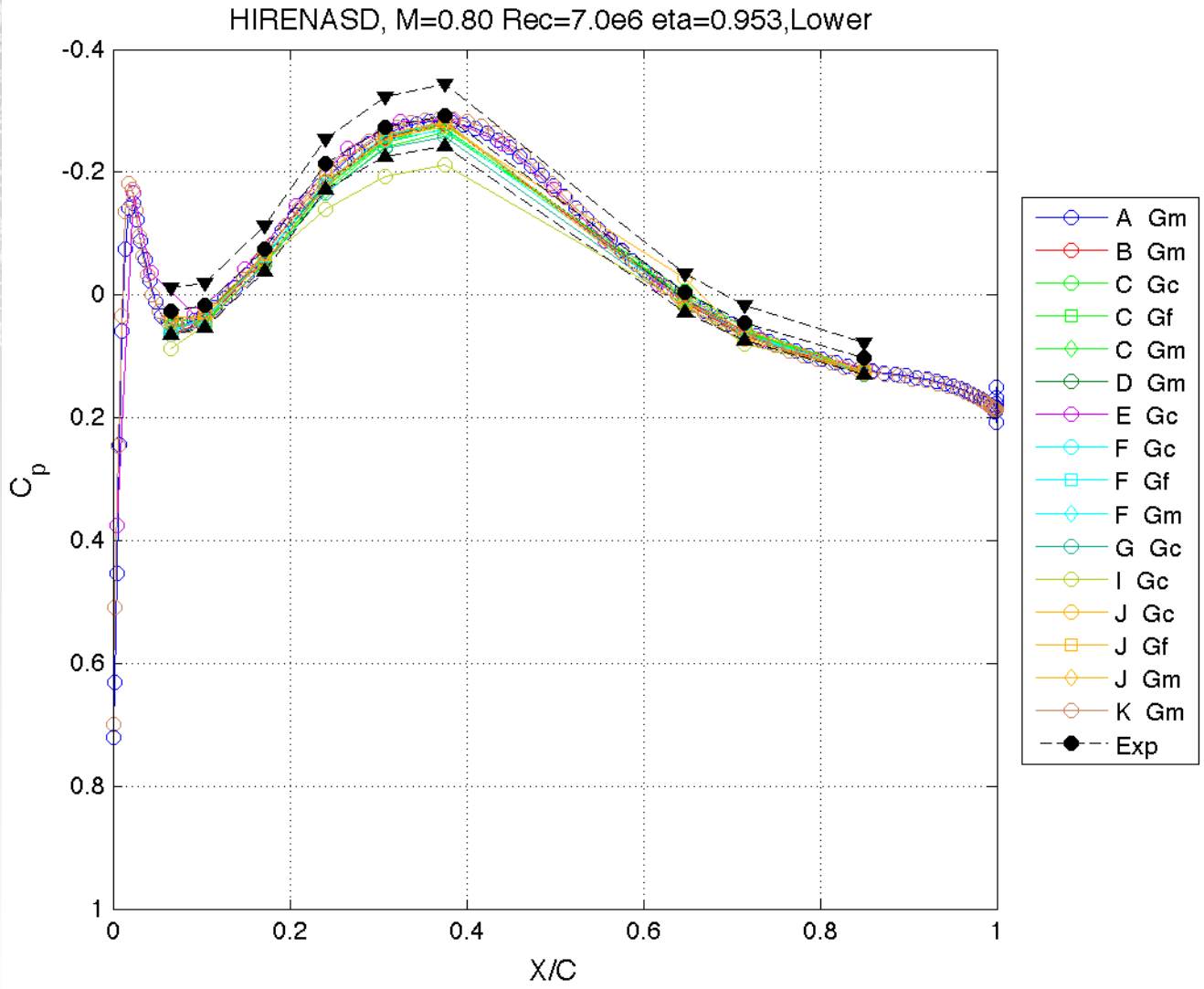


Station 4

Lower surface, steady
Mach 0.8, Re 7M, α 1.5



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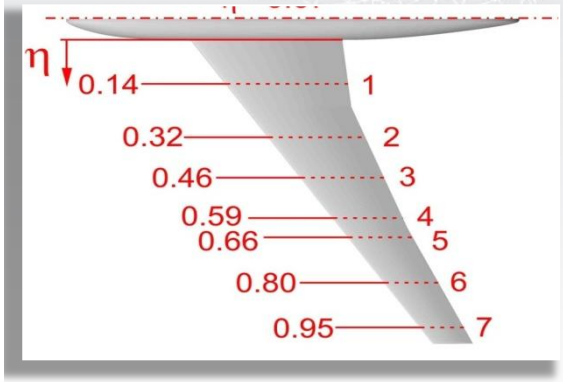
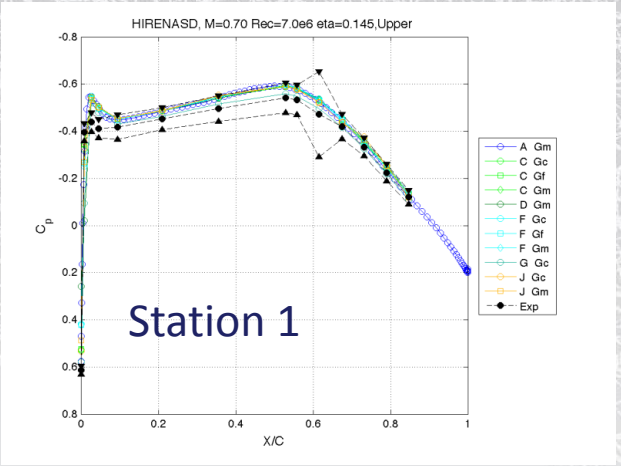
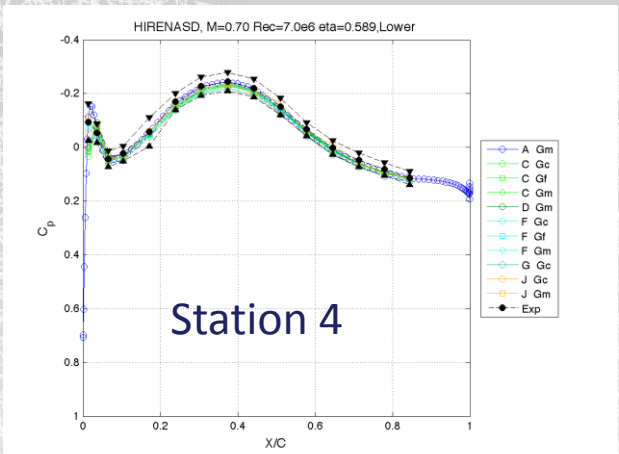


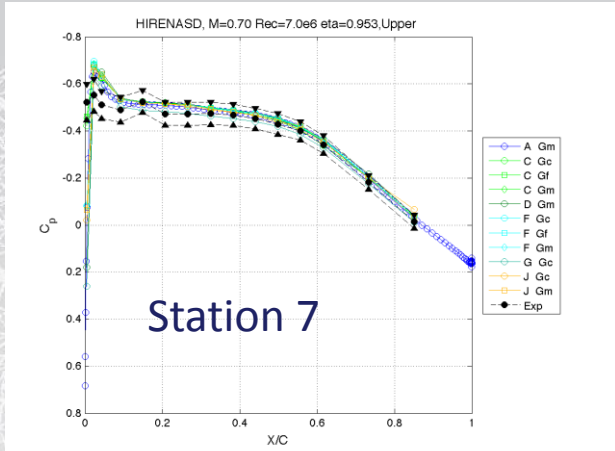
Station 7

Mach 0.7, Re 7M, α 1.5, Steady Cp distribution

Upper surface







Lower surface

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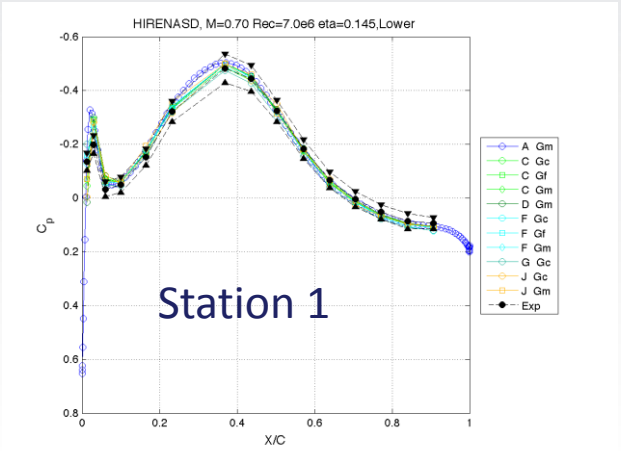
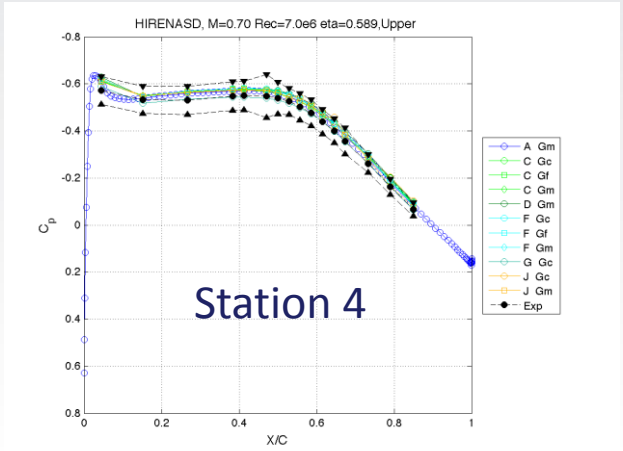
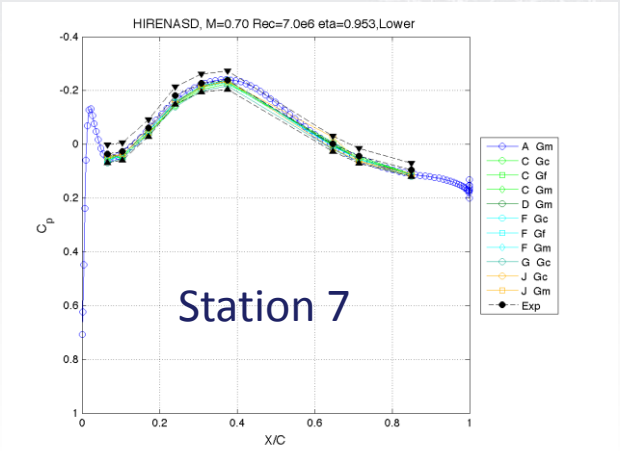
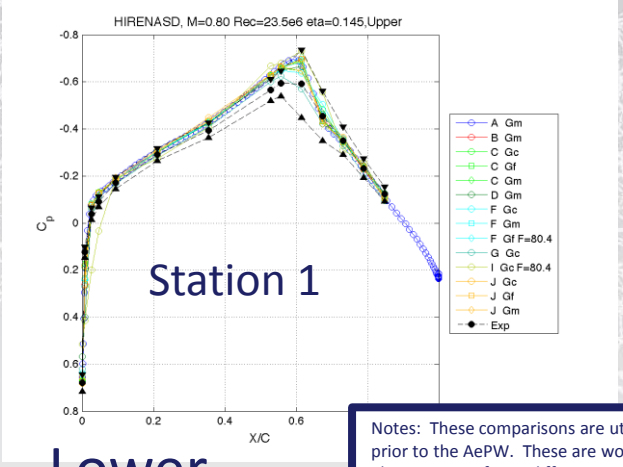


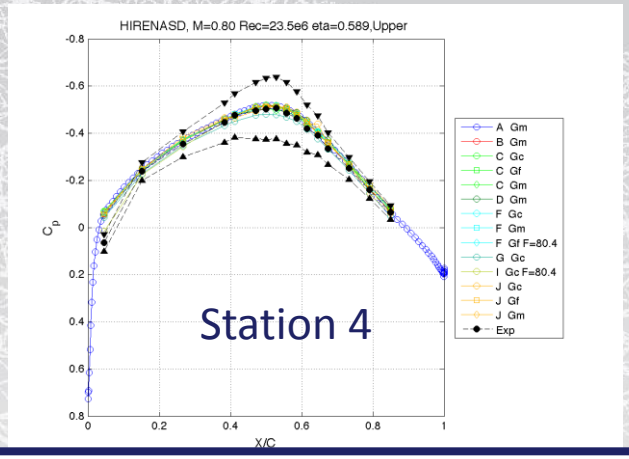


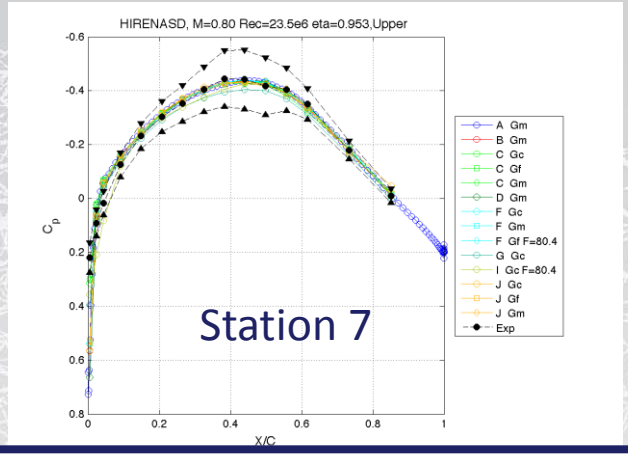


Mach 0.8, Re 23.5M, α= -1.341, Steady Cp distribution

Upper surface







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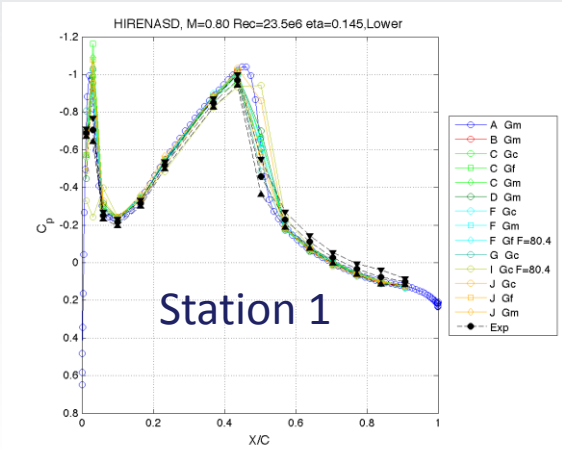
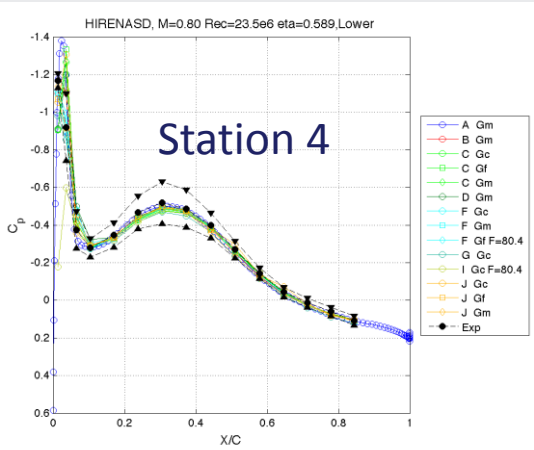
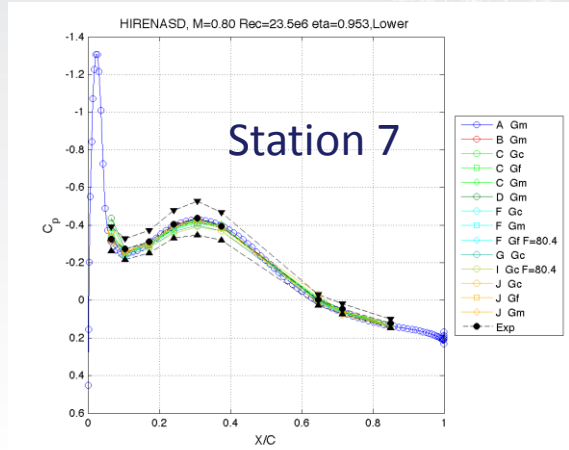
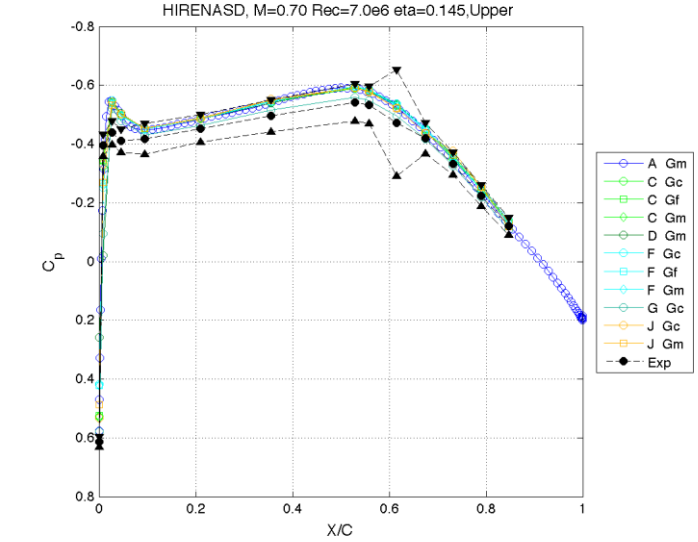
Lower surface







Inboard span station, upper surface



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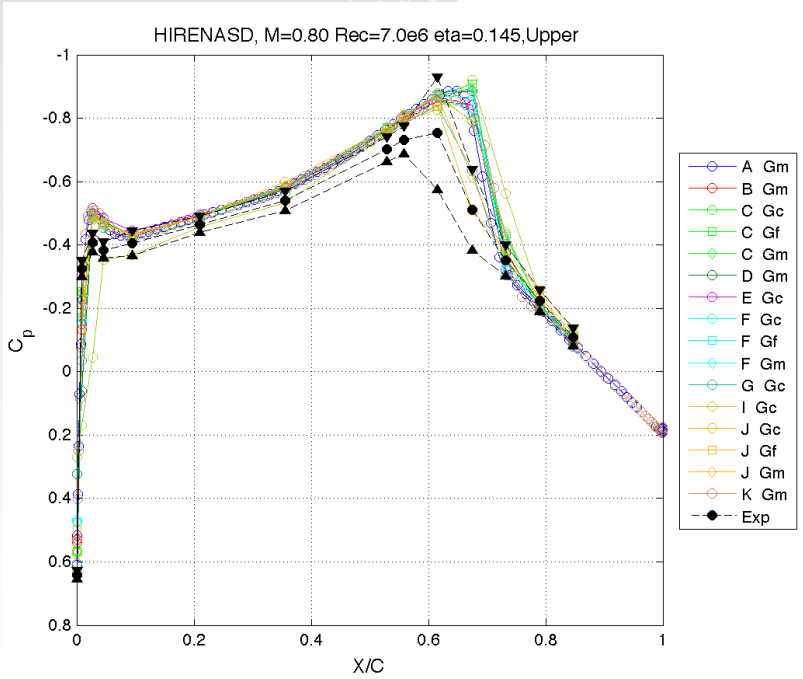
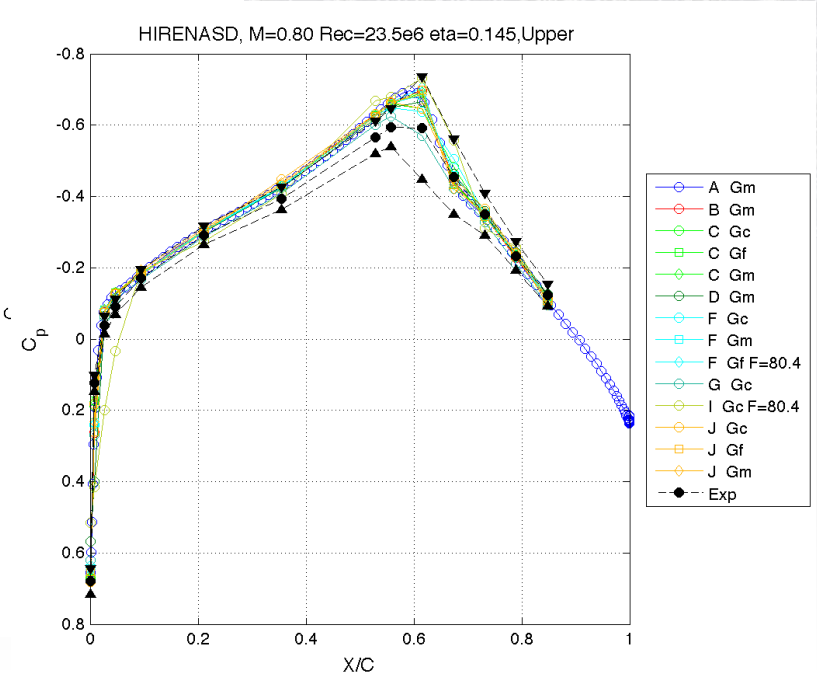
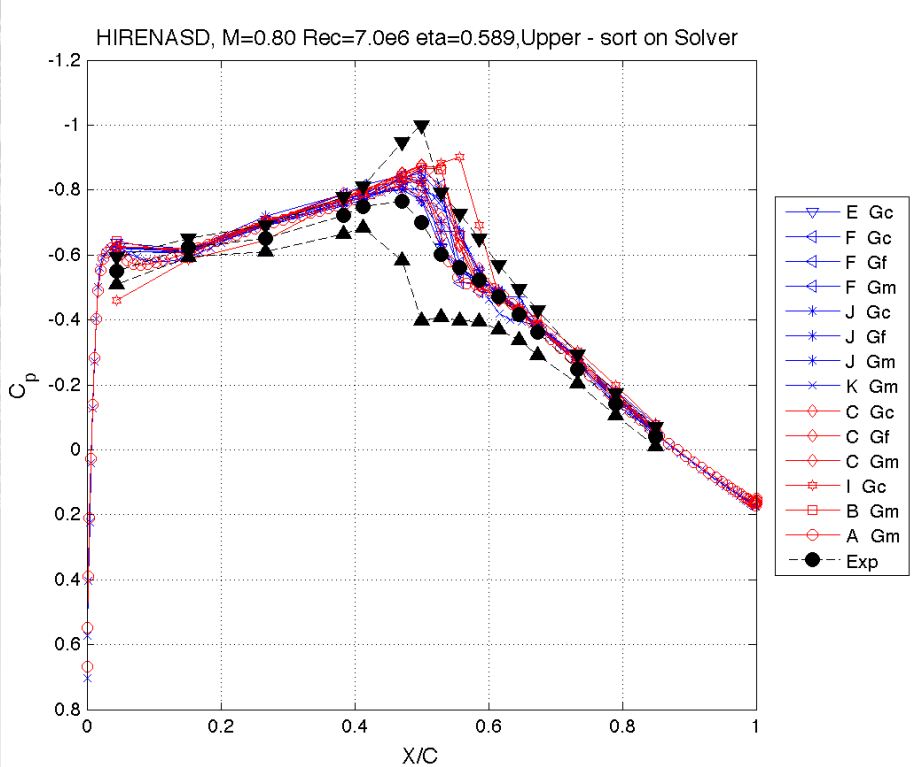




Sort by solver example, steady, M 0.8, 7M



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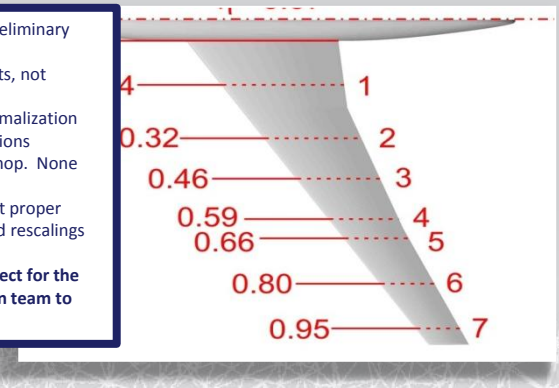
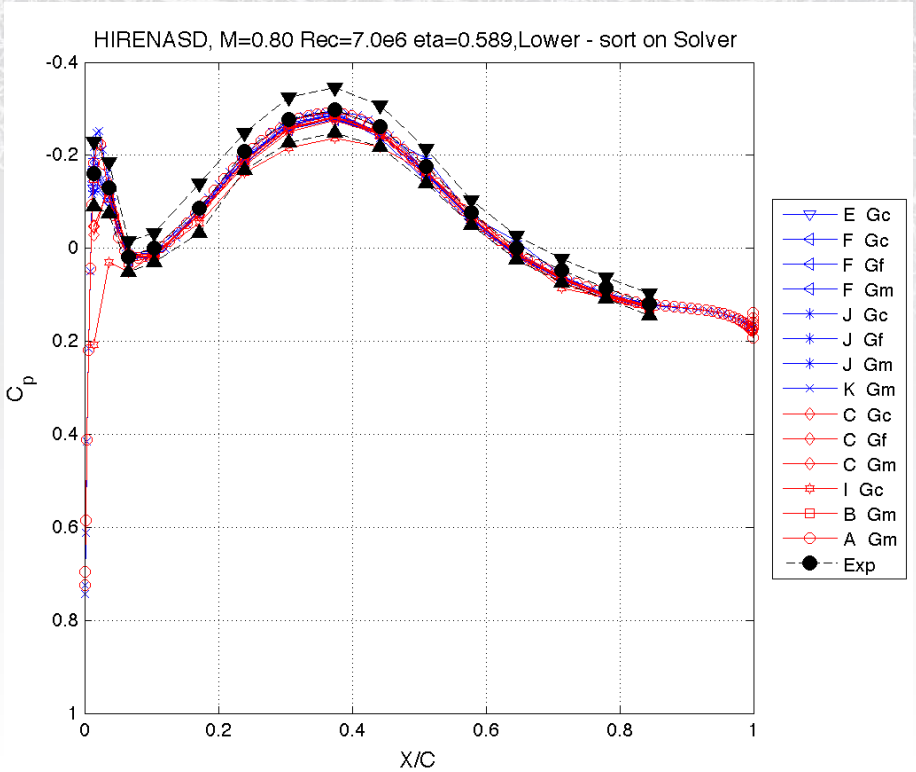
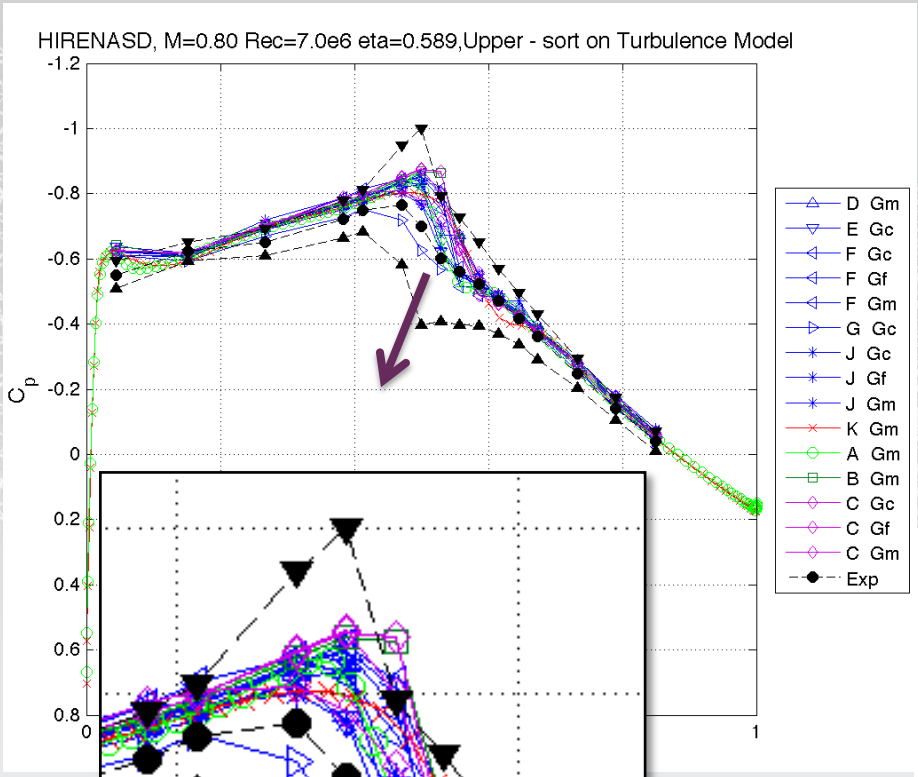


Station 4



node based
cell based

Sort by turbulence model example, steady, M 0.8, 7M



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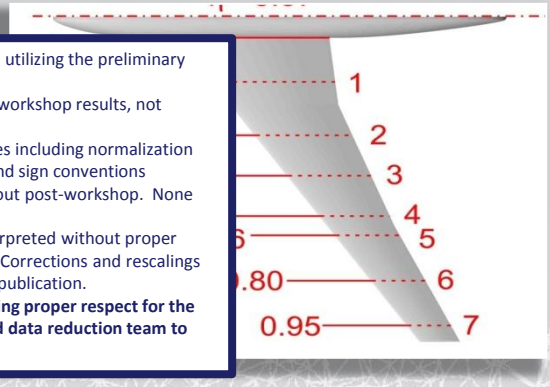
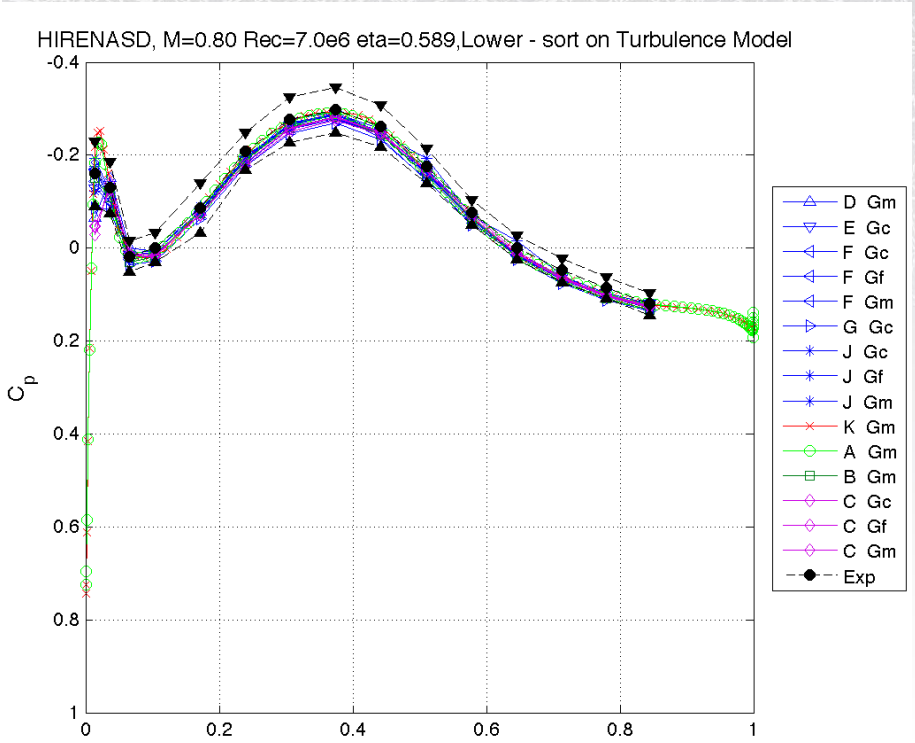
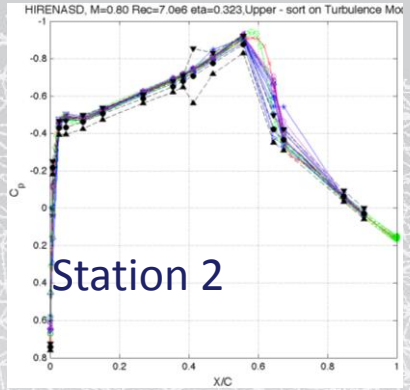
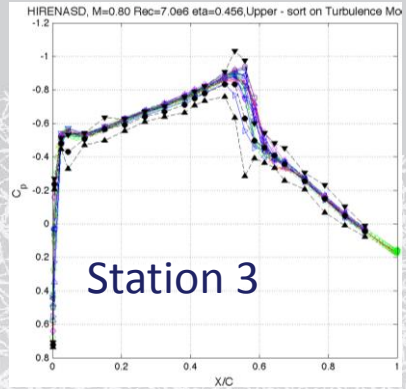


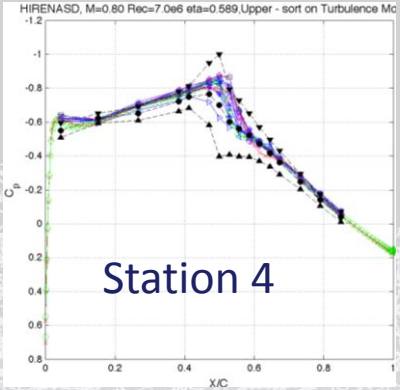
Station 4

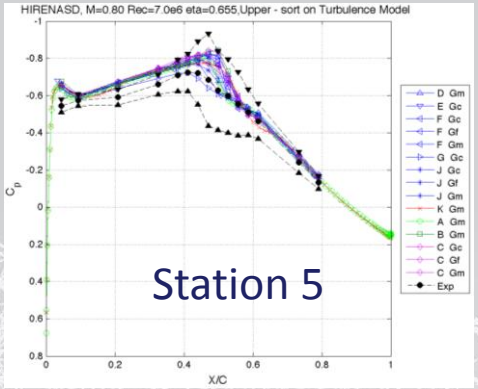


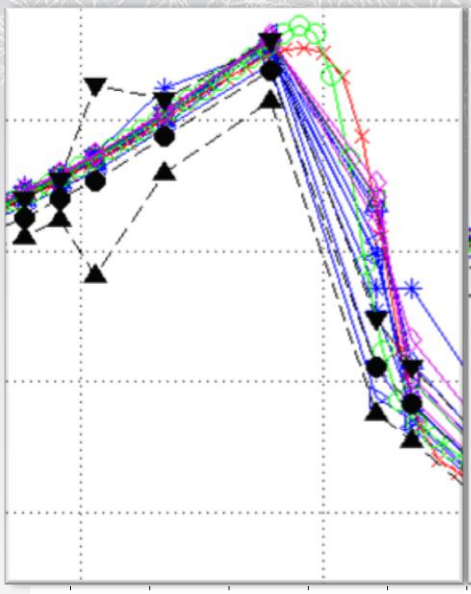
Sort by turbulence model example, steady, M 0.8, 7M

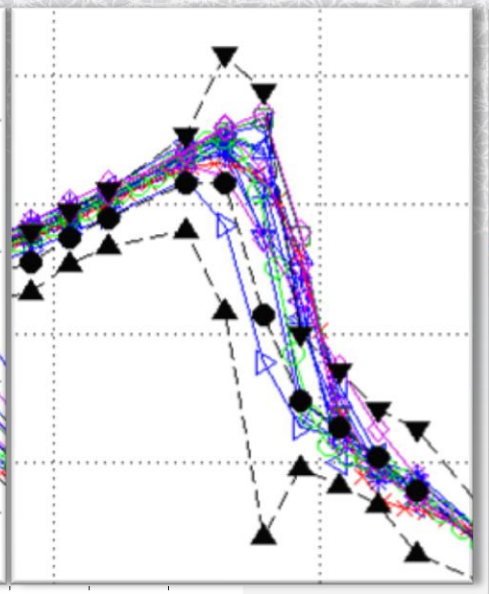


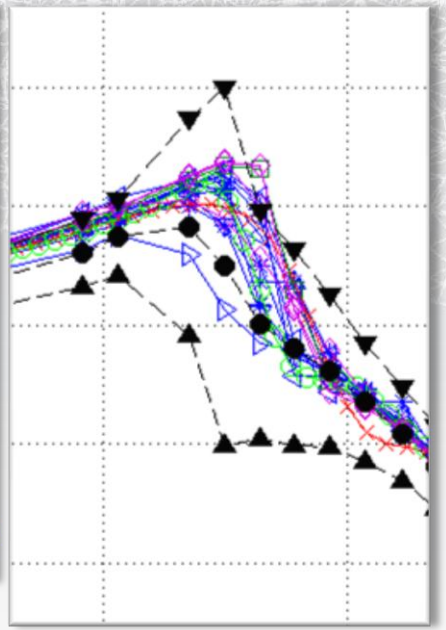


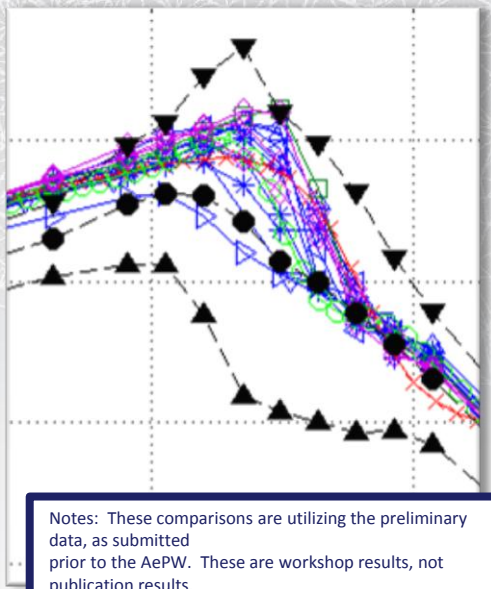












SA
SST
k-_ TNT EARSM
k-w MSS
2 Eq. Realizable k-epsilon

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Comparison Data Matrix

CONFIGURATION	REQUIRED CALCULATIONS			
	GRID CONVERGENCE STUDIES	TIME CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M	n/a
Steady-Aeroelastic Cases (HIRENASD)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M • Vertical displacement vs. chord • Twist angle vs. span	n/a
Forced Oscillation Cases (all configurations)	• Magnitude and Phase of CL, CD, CM vs. $N^{-2/3}$ at excitation frequency	• Magnitude and Phase of C_L, C_D, C_M vs. Δt at excitation frequency	n/a	• Magnitude and Phase of C_p vs. x/c at span stations corresponding to transducer locations • Magnitude and Phase of C_L, C_D, C_M at excitation frequency • Time histories of C_p's at a selected span station for two upper- and two lower-surface transducer locations

2nd bending mode oscillatory data

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Unsteady comparison results, M 0.8, Re 7M Upper surface FRF Magnitude

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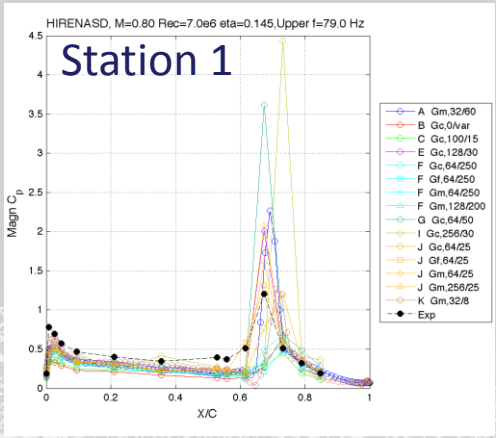

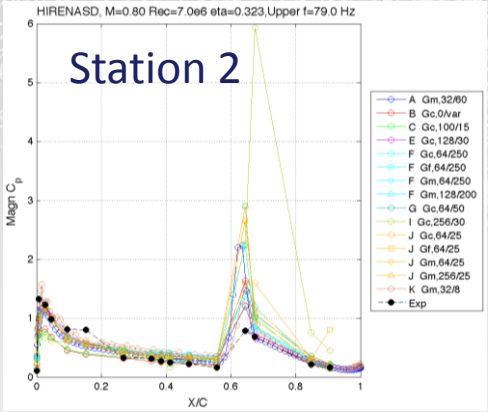

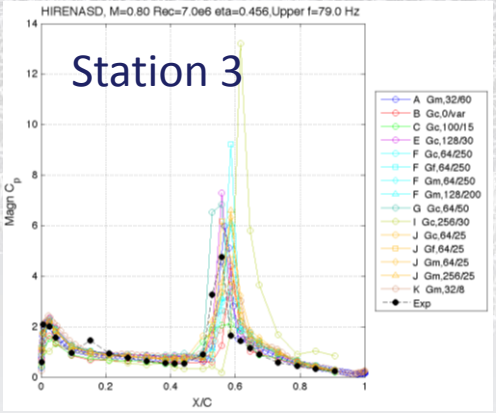

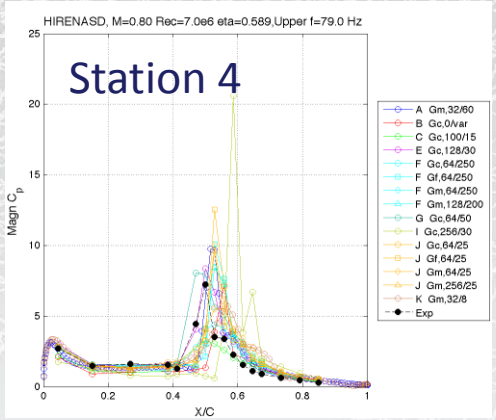

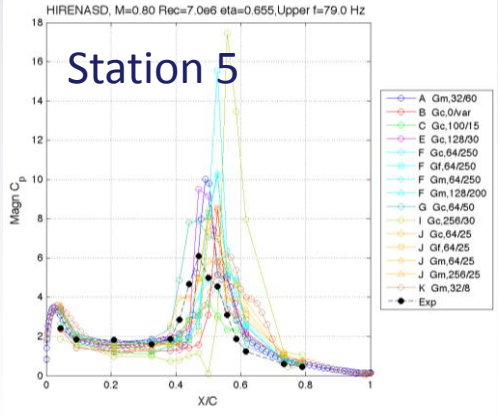

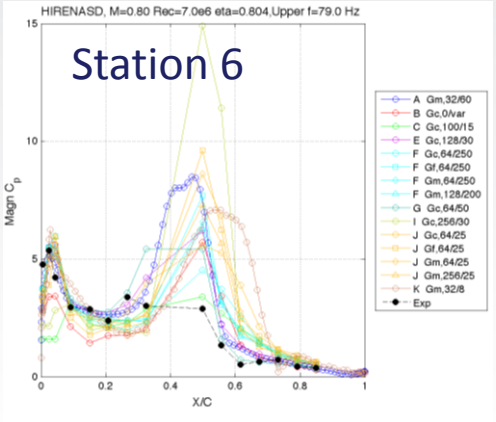

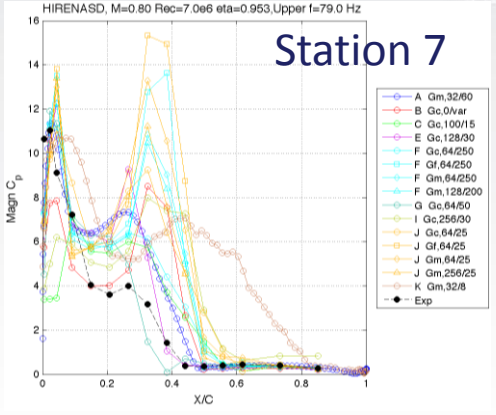

Unsteady comparison results, M 0.8, Re 7M Lower surface FRF Magnitude

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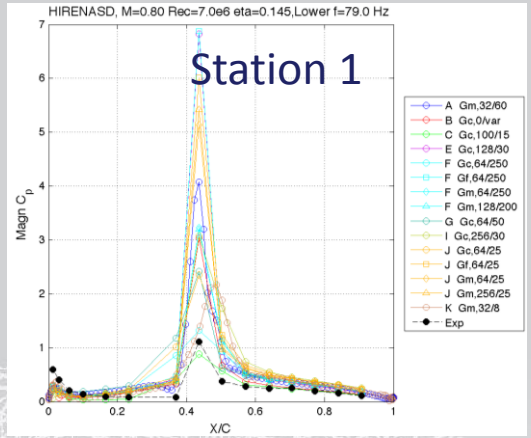
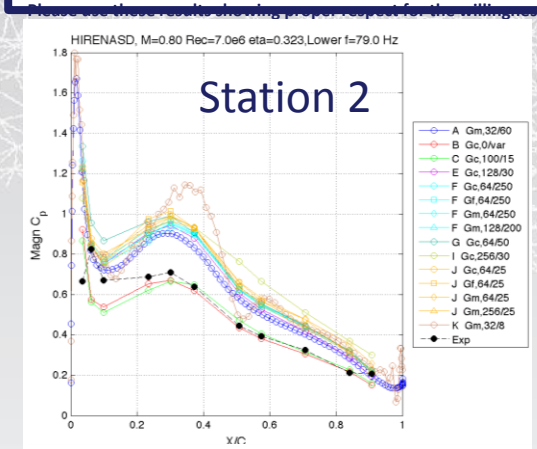
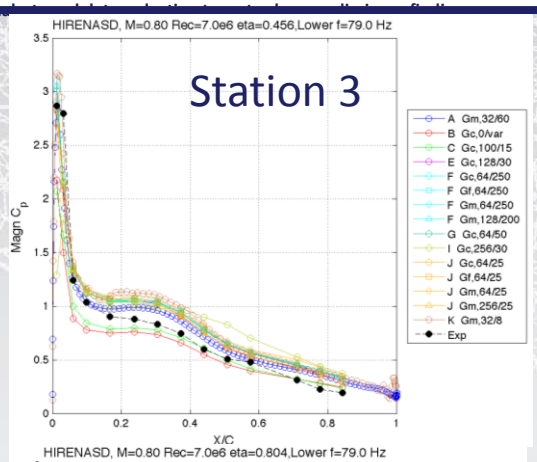
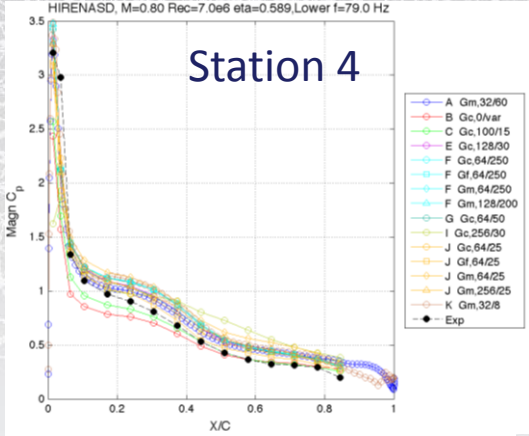
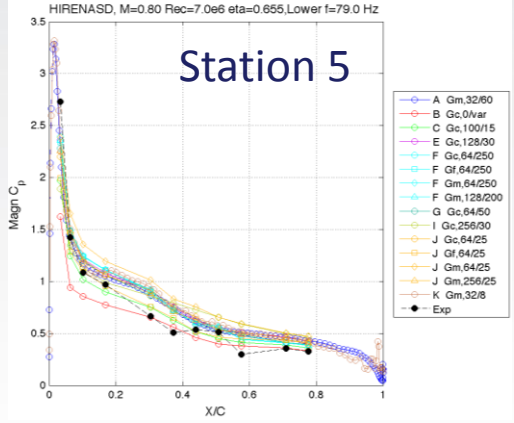
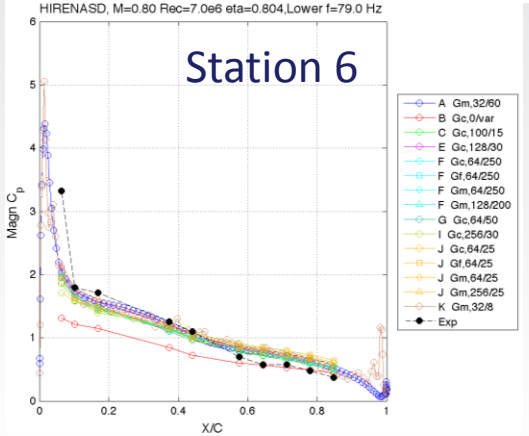


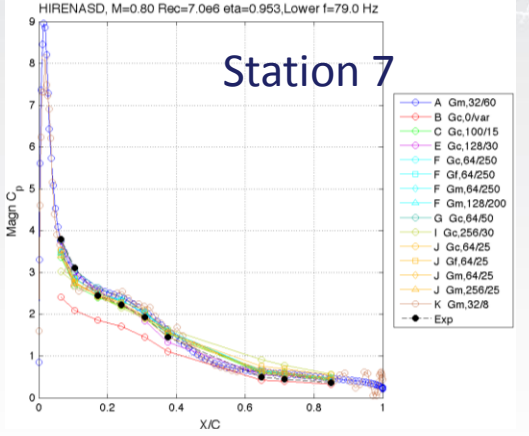




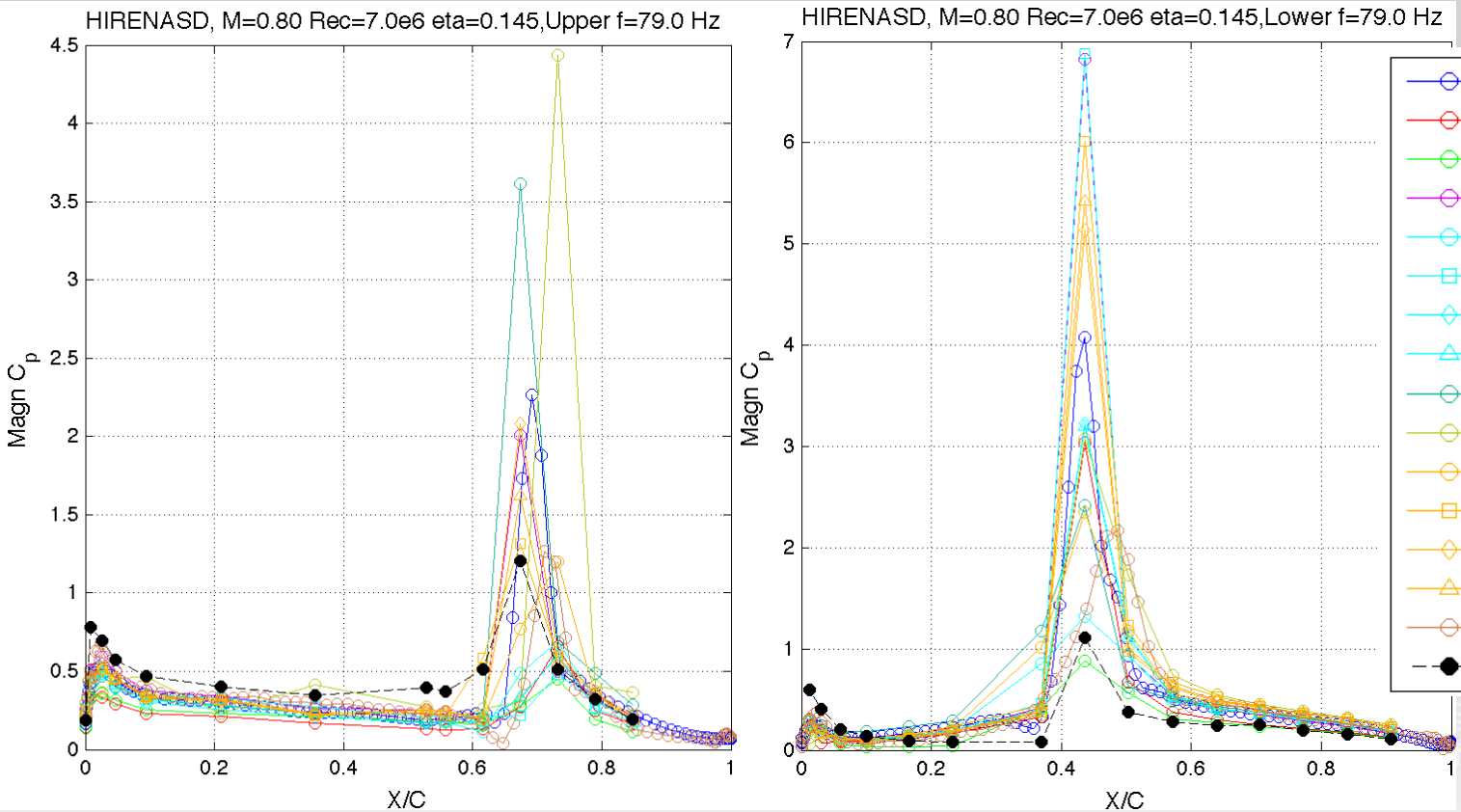


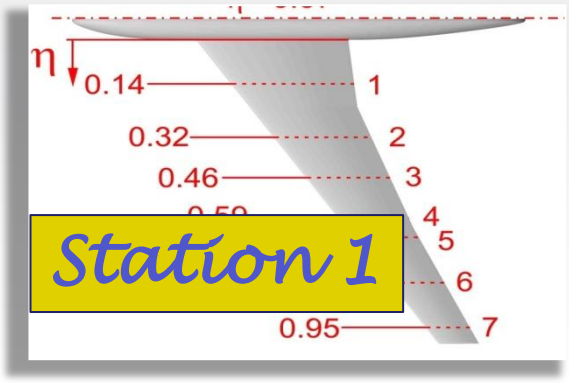






FRF Magnitude, Mach 0.8, Re 7M, α 1.5





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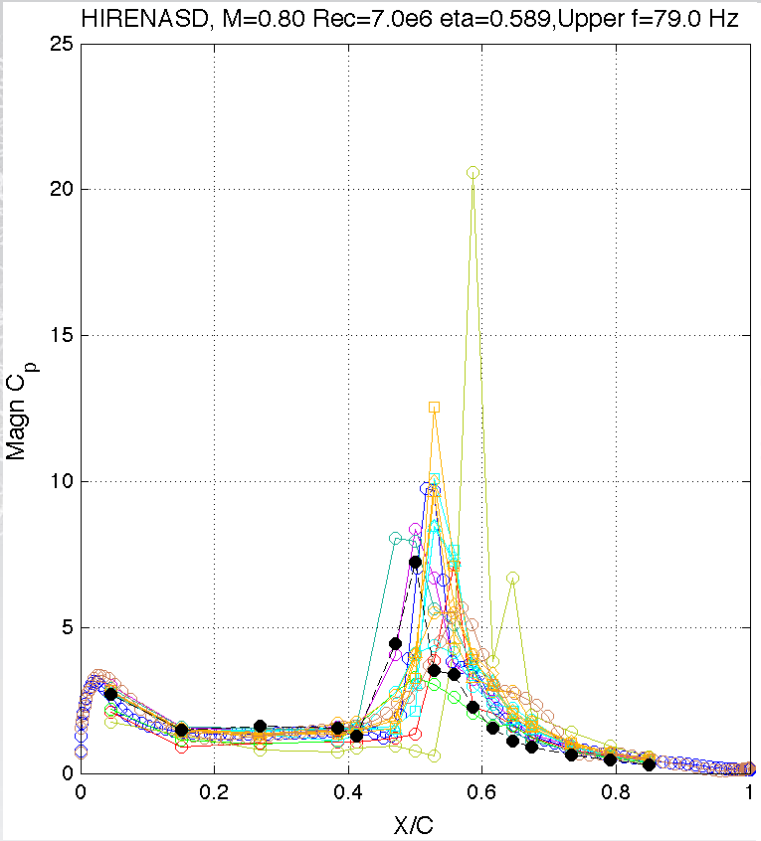
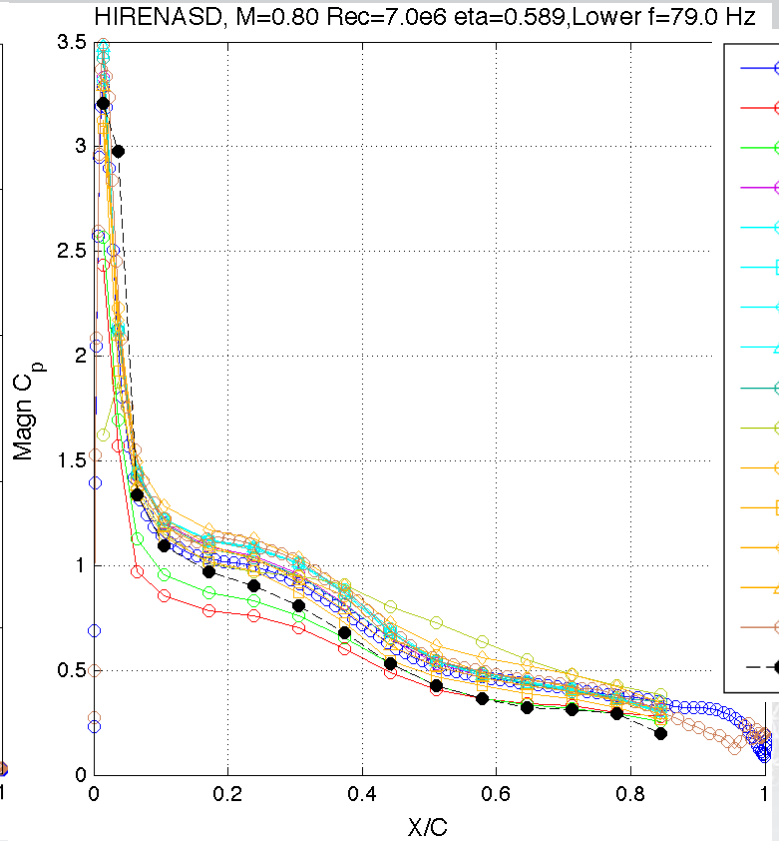
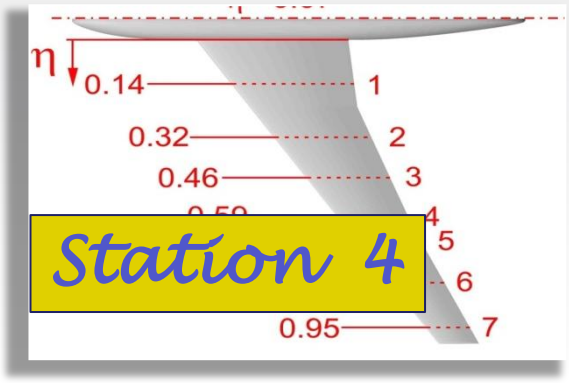
FRF Magnitude, Mach 0.8, Re 7M, α 1.5







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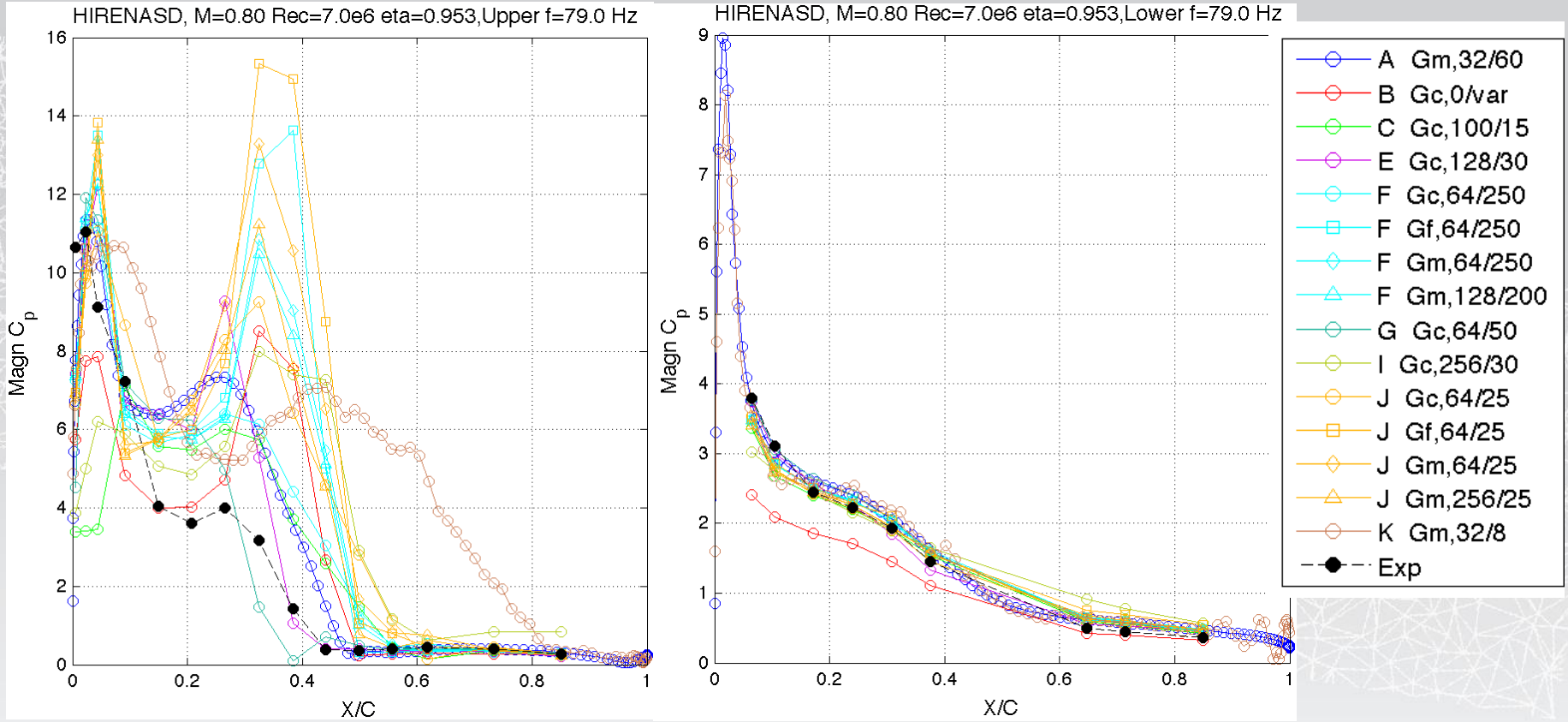
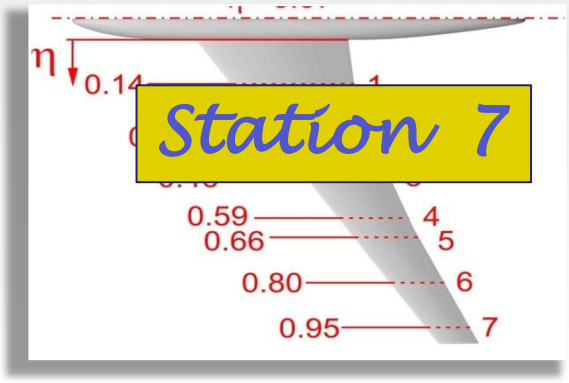
FRF Magnitude, Mach 0.8, Re 7M, α 1.5





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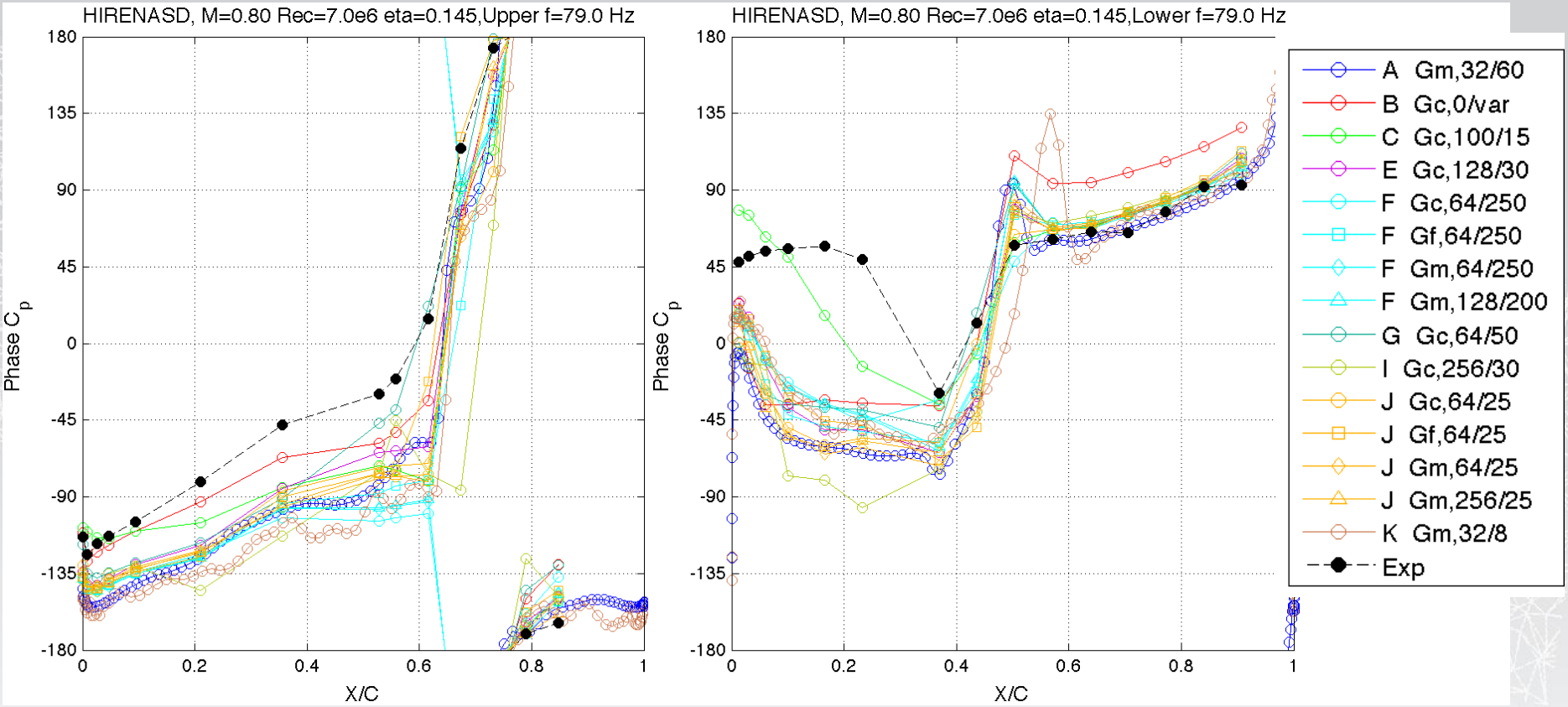
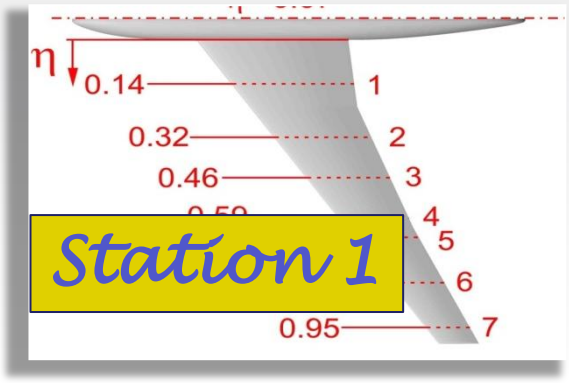
FRF Phase, Mach 0.8, Re 7M, α 1.5





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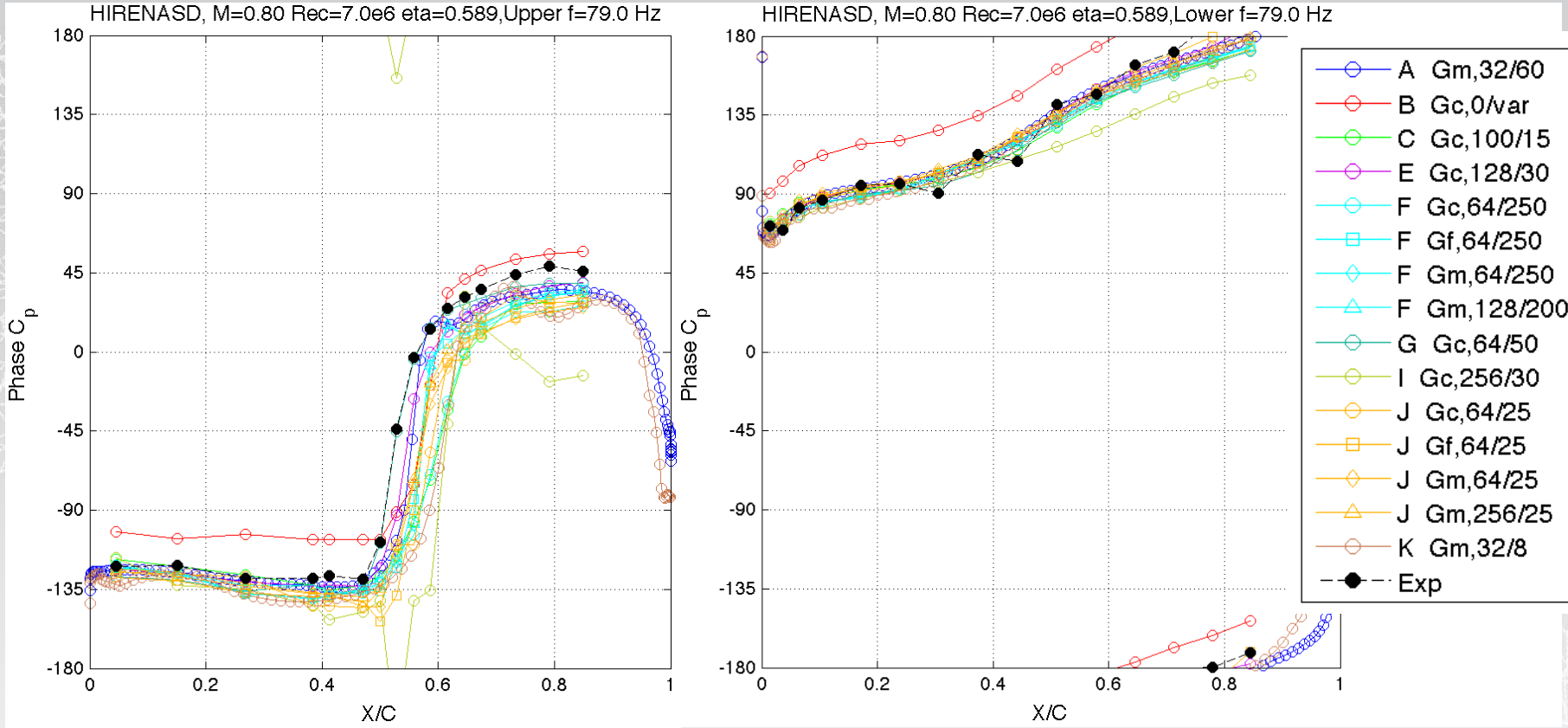
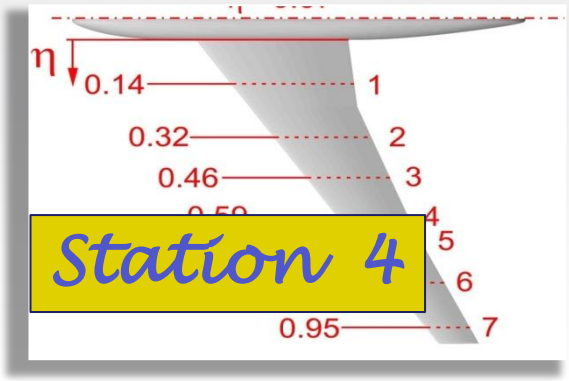
FRF Phase, Mach 0.8, Re 7M, α 1.5





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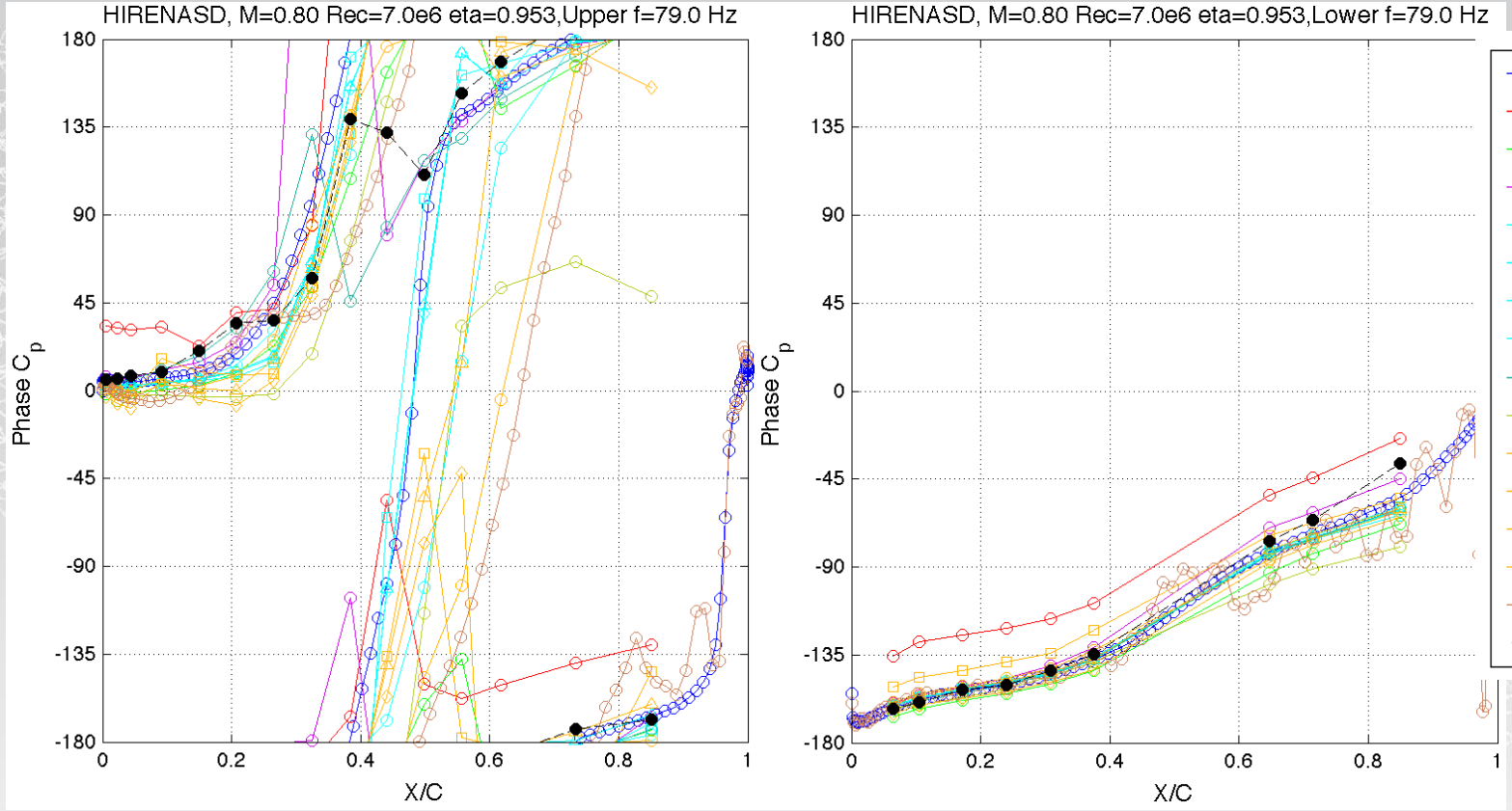
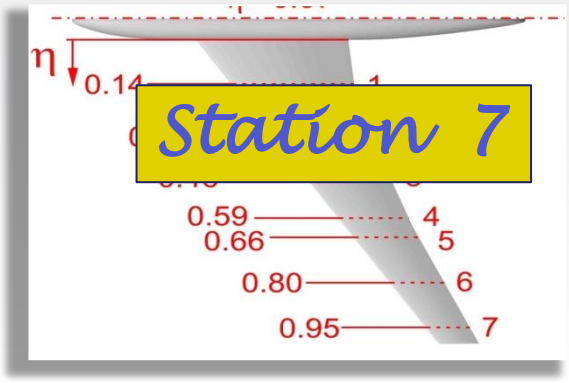
FRF Phase, Mach 0.8, Re 7M, α 1.5





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Mach 0.7, Re 7M, α 1.5, FRF Ma

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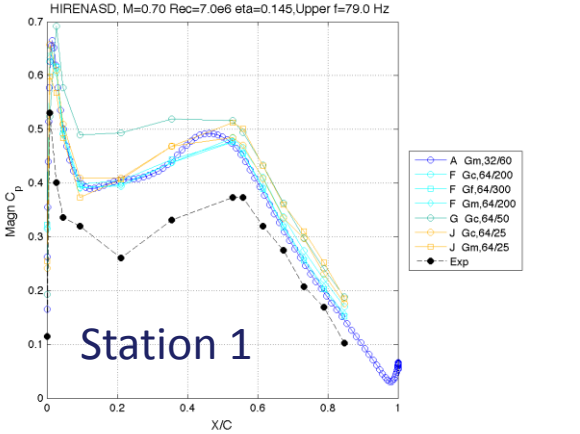
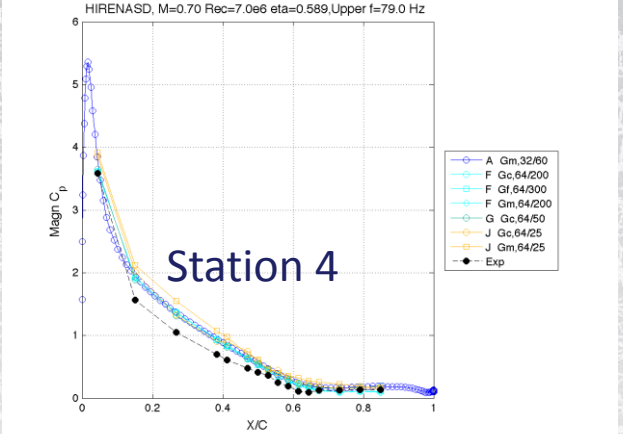
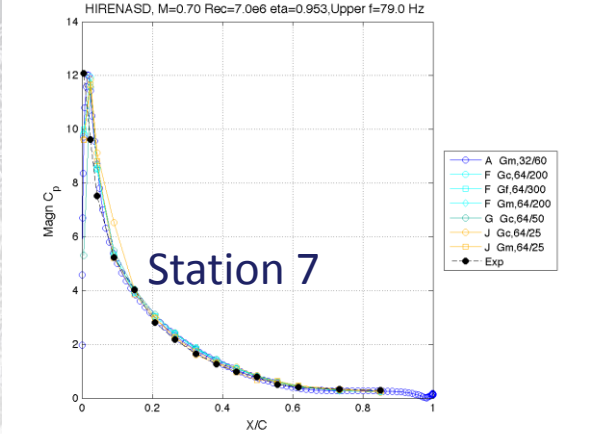
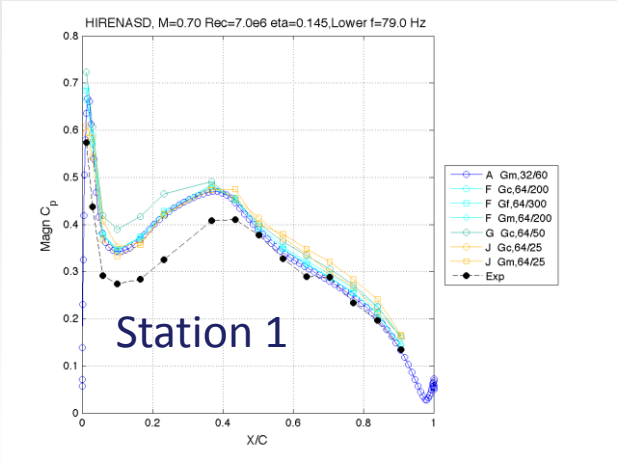
Upper surface

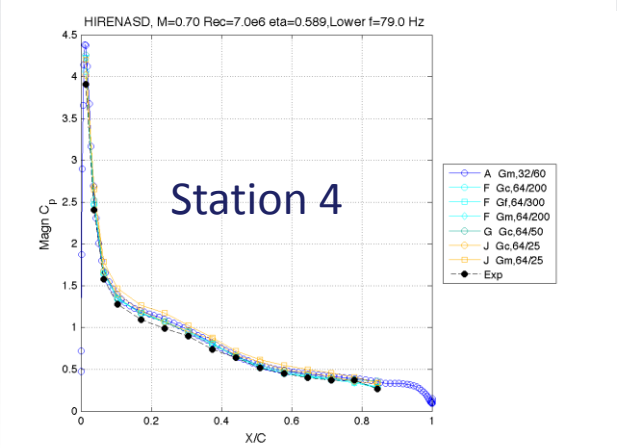


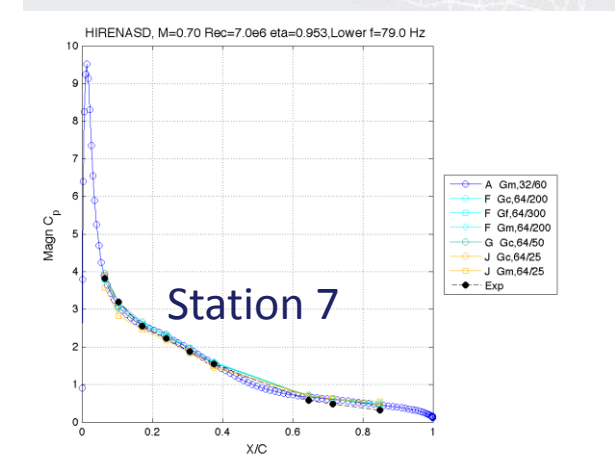




Lower surface







Mach 0.8, Re 23.5M, α= -1.341, FRF

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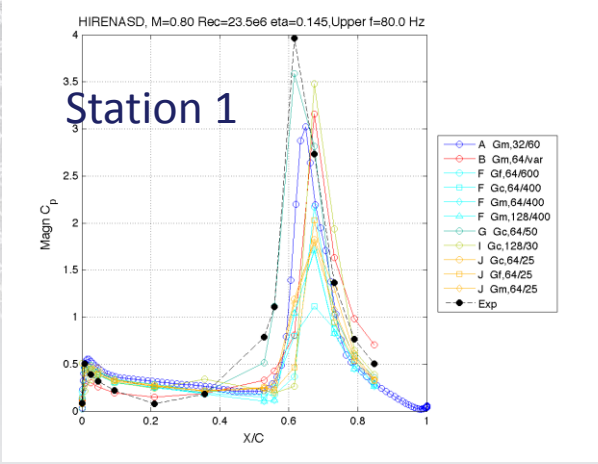
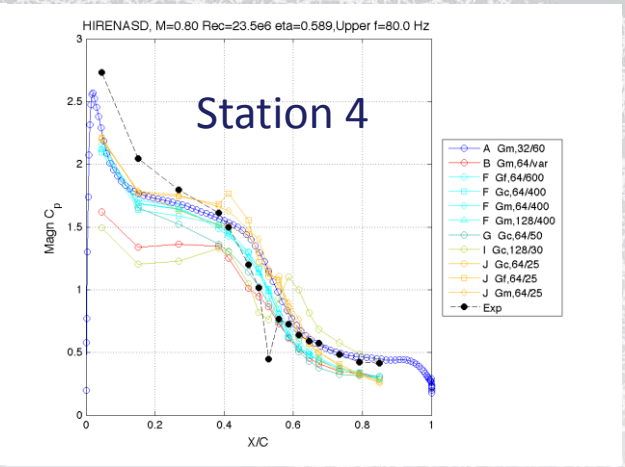
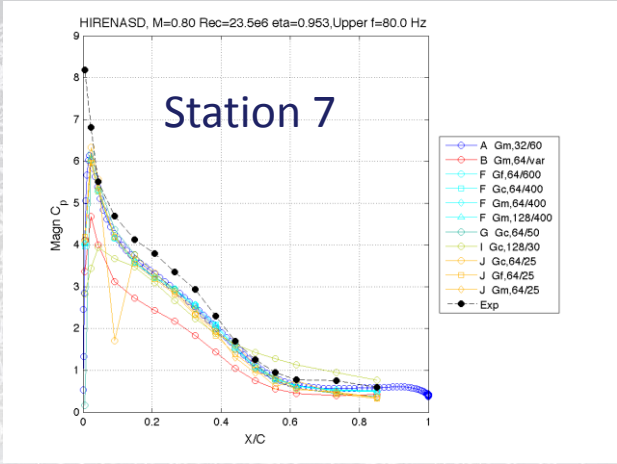
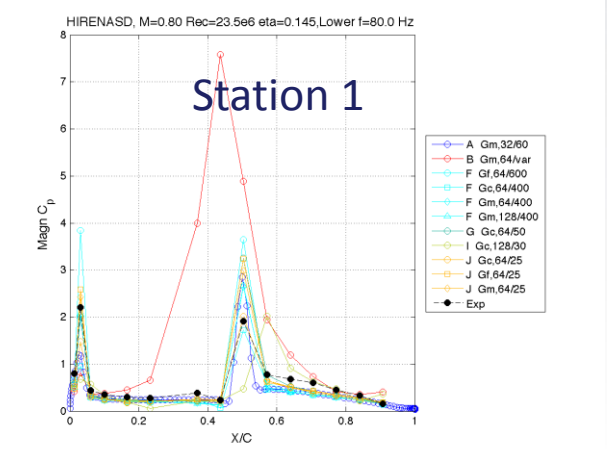
Upper surface

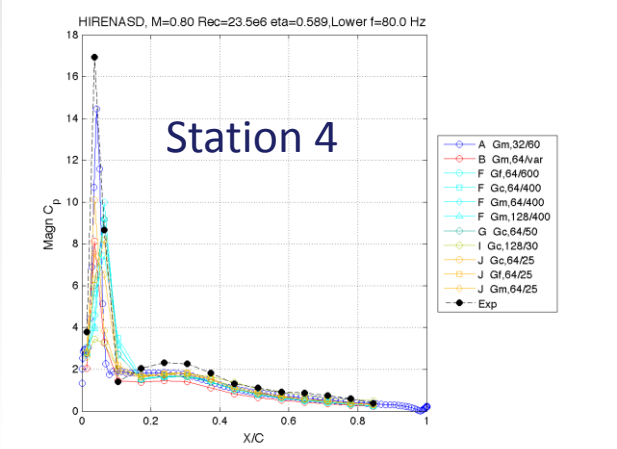


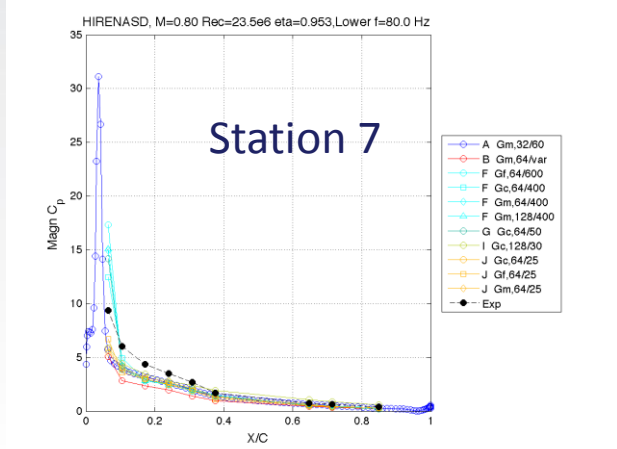




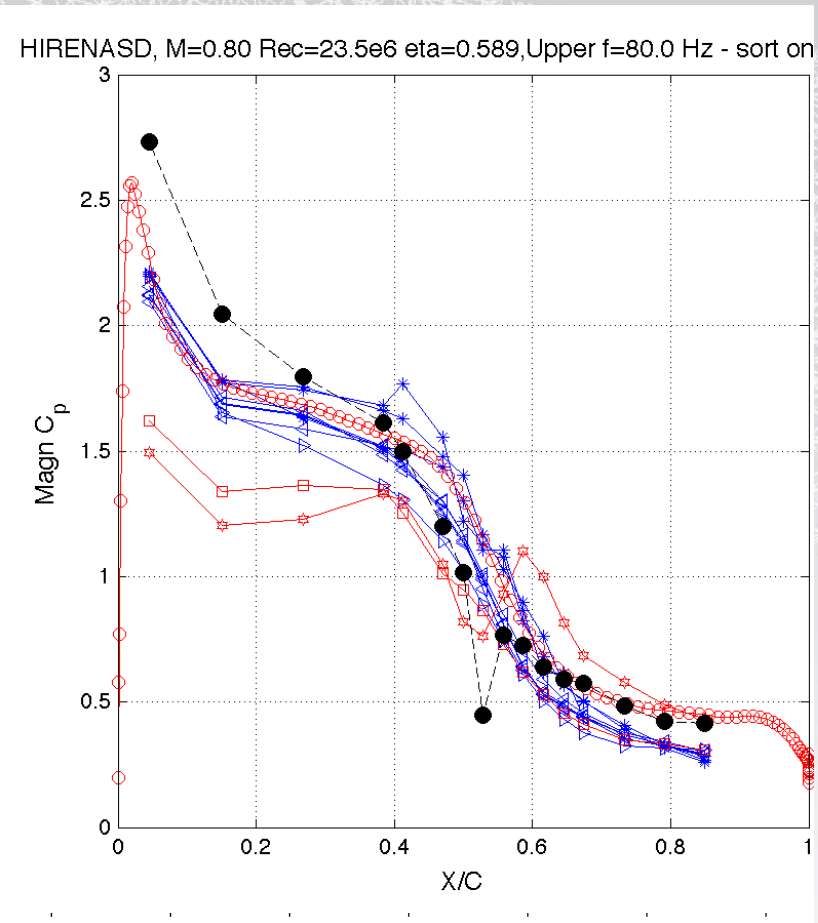
Lower surface

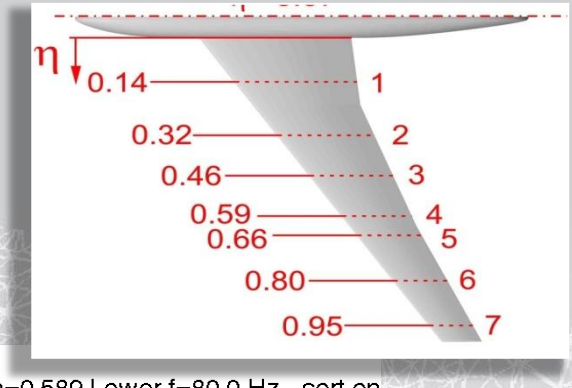


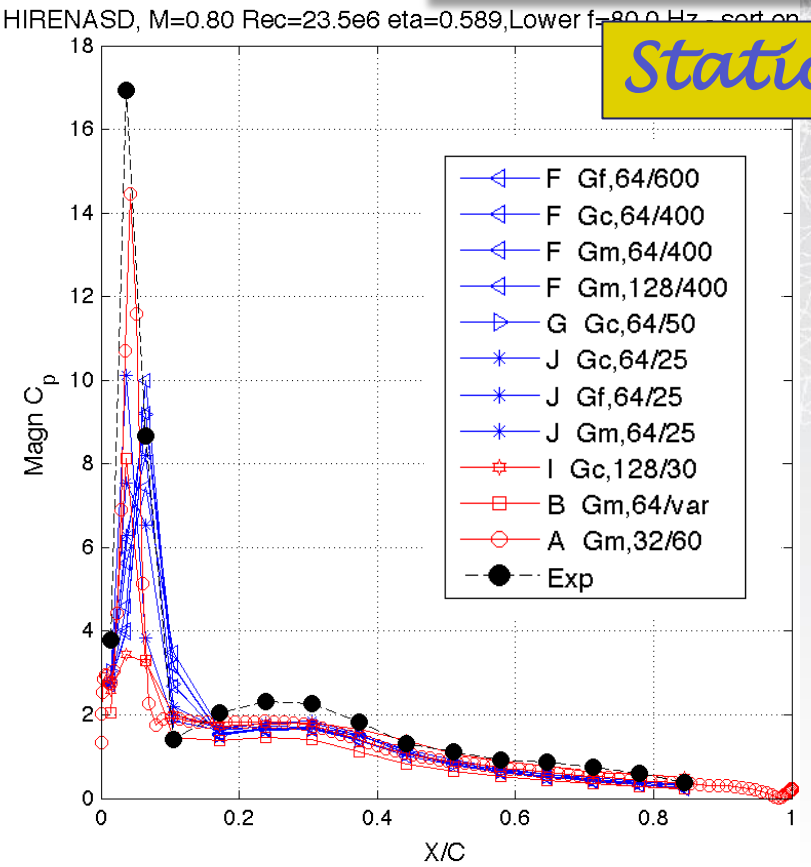




Sort by solver example, FRF Magnitude, M 0.8, 7M





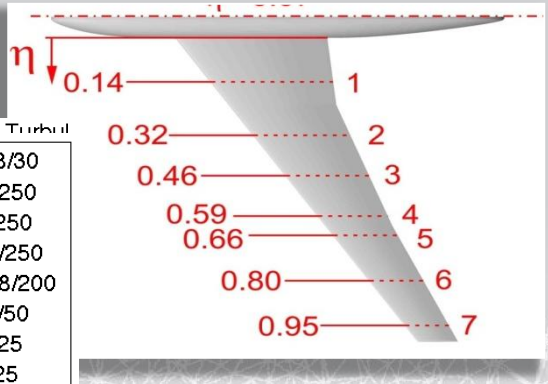


node based

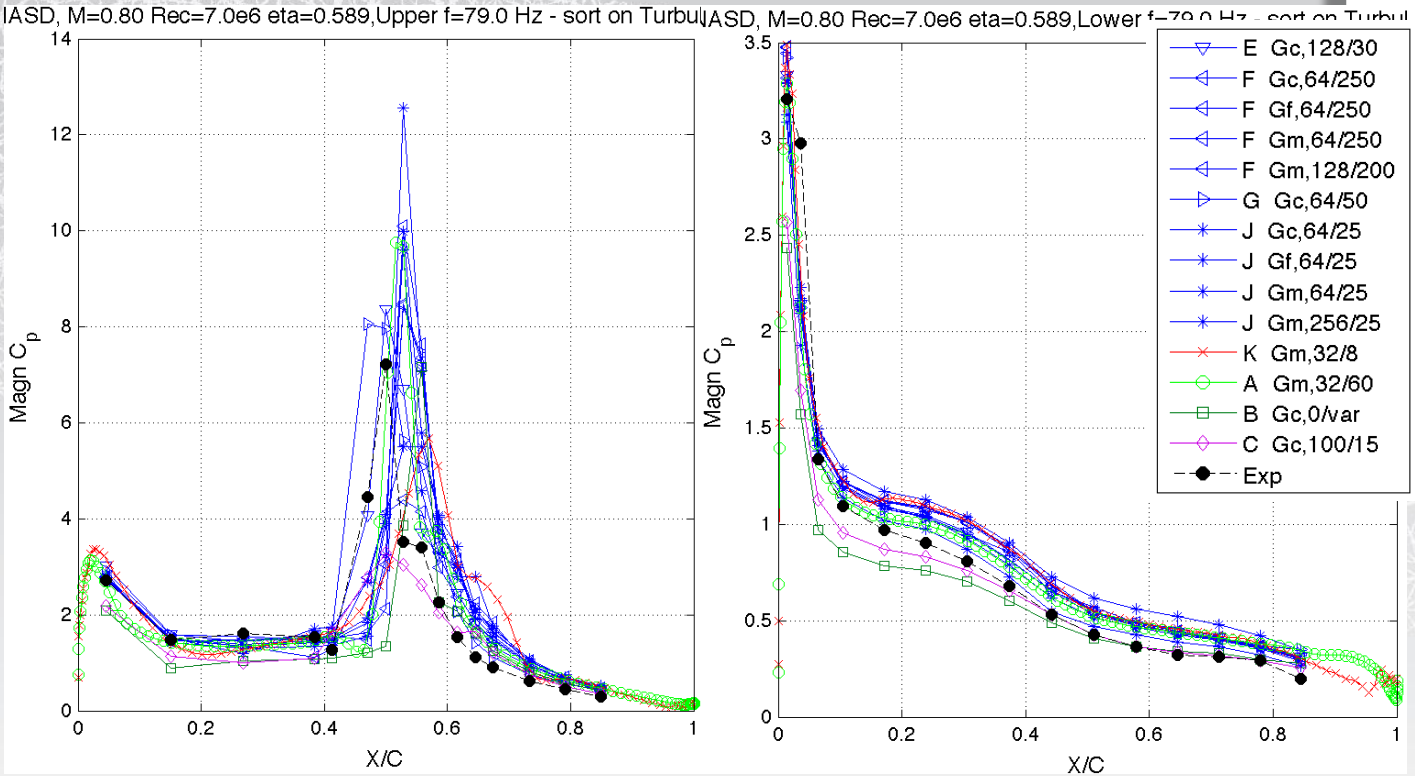
cell based

Sort by turbulence model, FRF Magnitude, M 0.8, 7M

There aren't enough results submitted with alternate turbulence models to draw meaningful conclusions



Station 4



SA
SST
k-_ TNT EARSM
k-w MSS
2 Eq. Realizable k-epsilon

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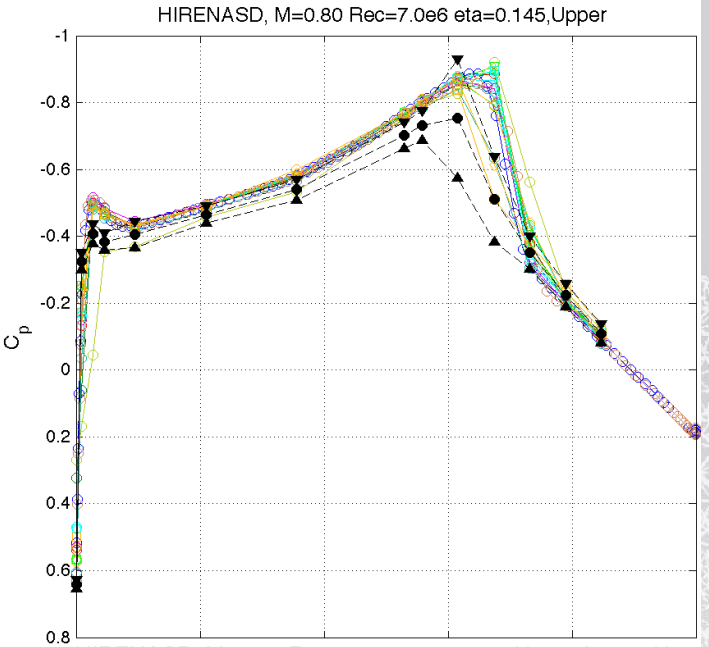
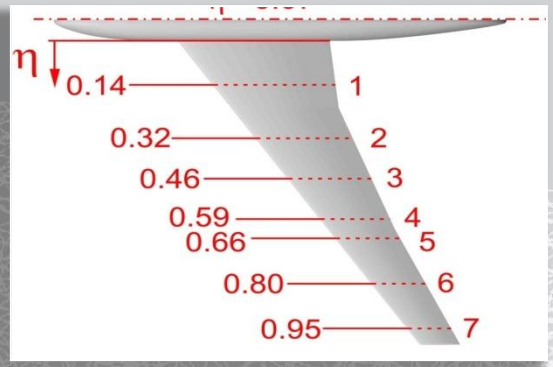
Upper surface, Mach 0.8, Re 7M, α 1.5





Station 1

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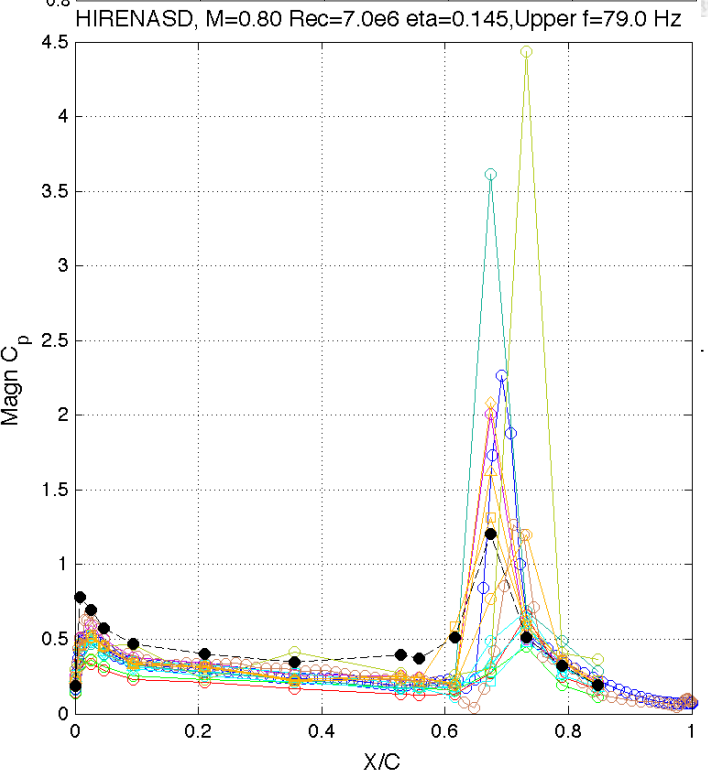
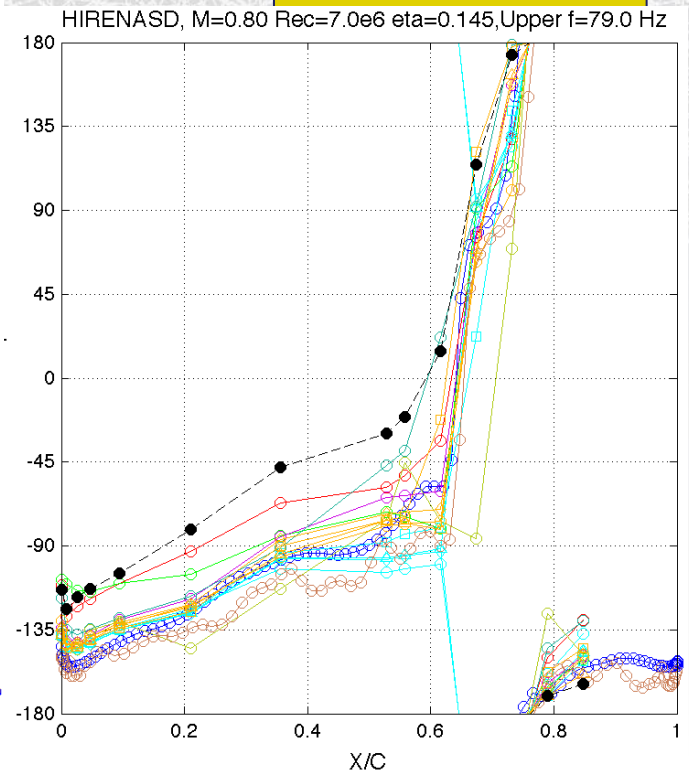
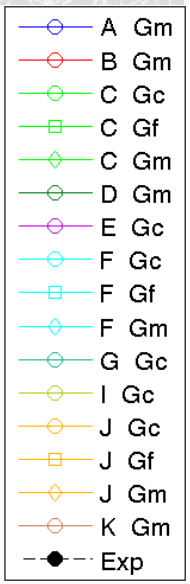
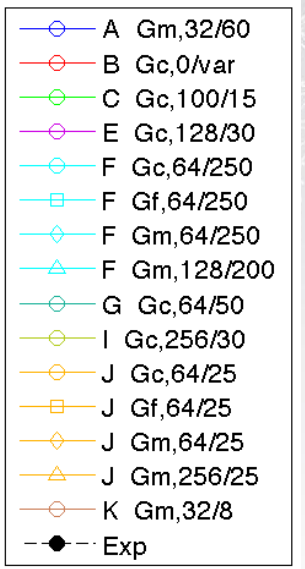
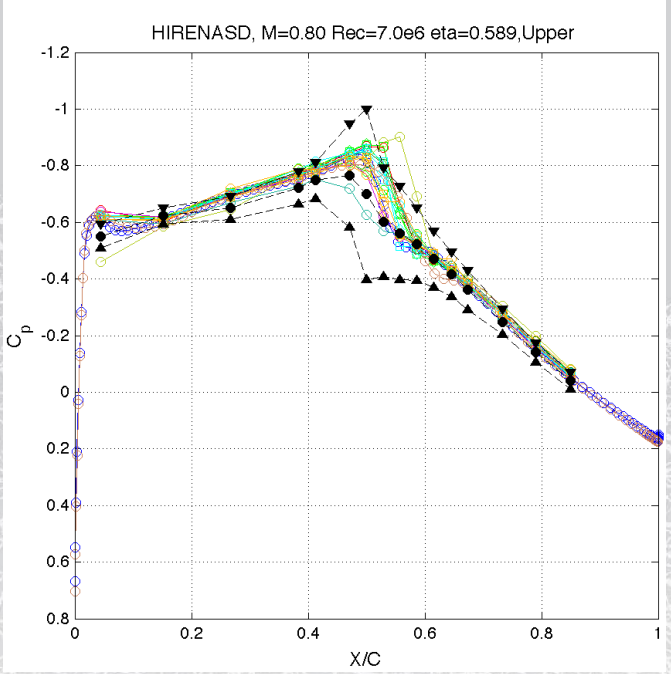


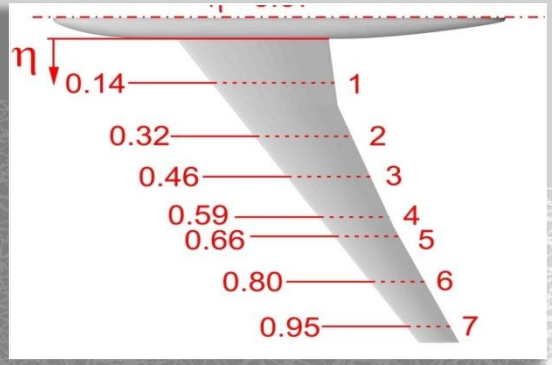






Upper surface, Mach 0.8, Re 7M, α 1.5





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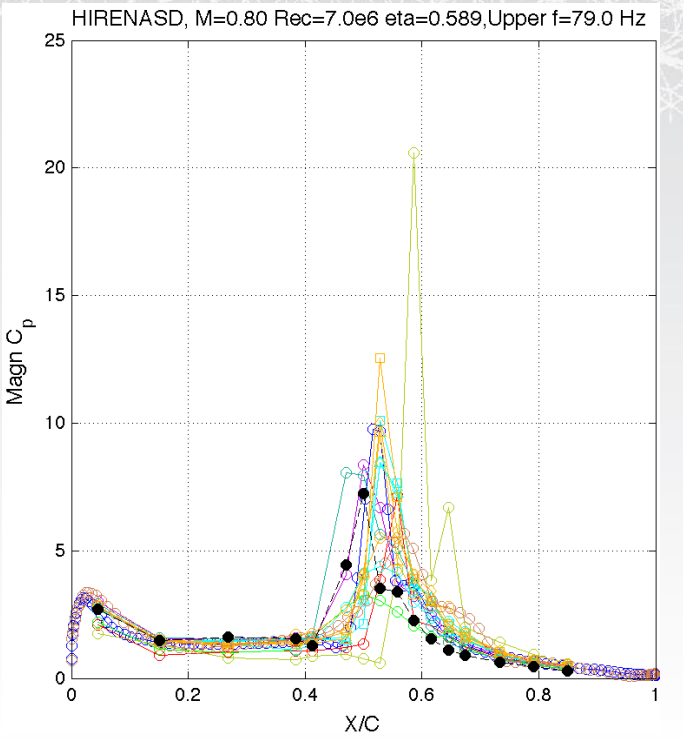
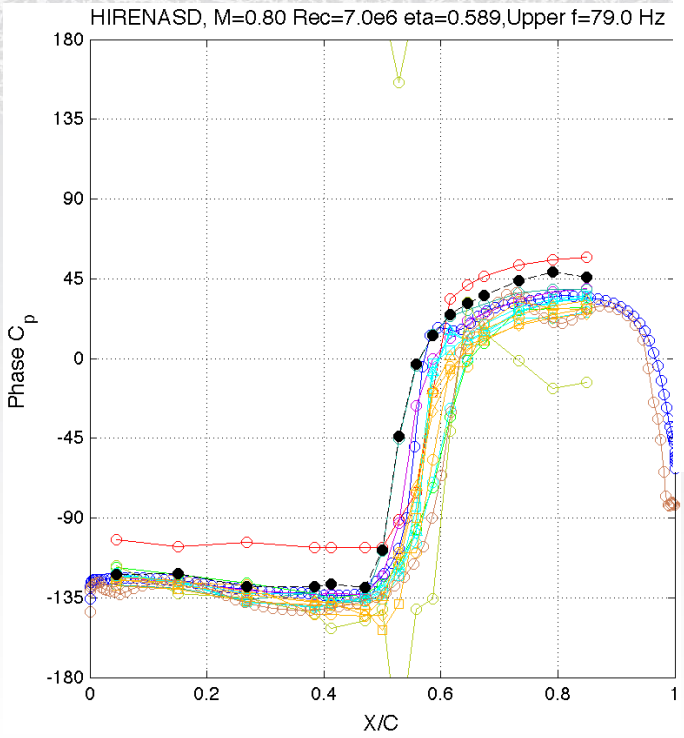
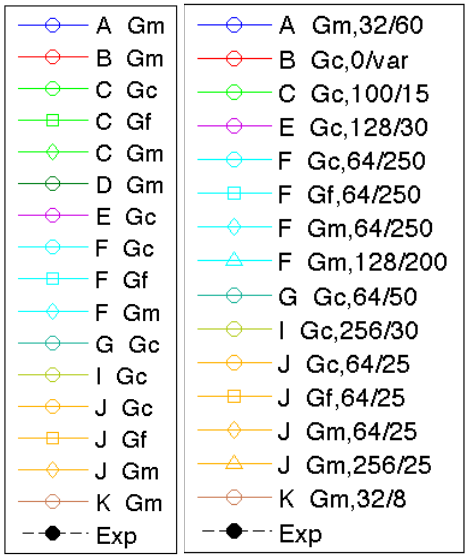
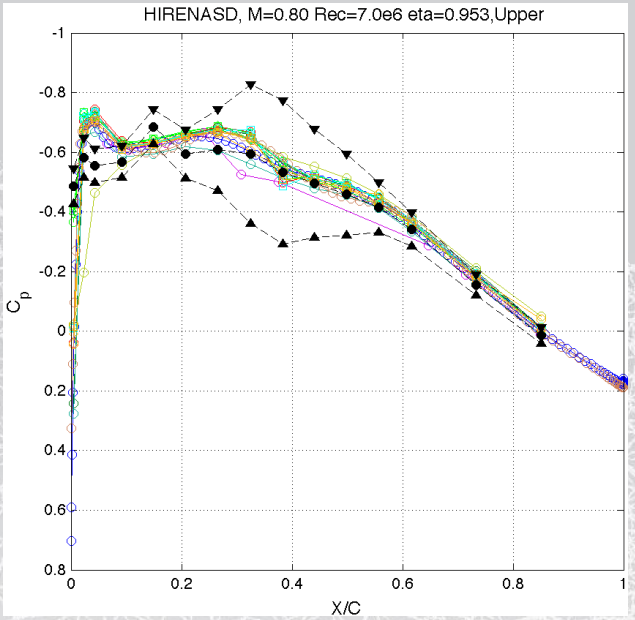
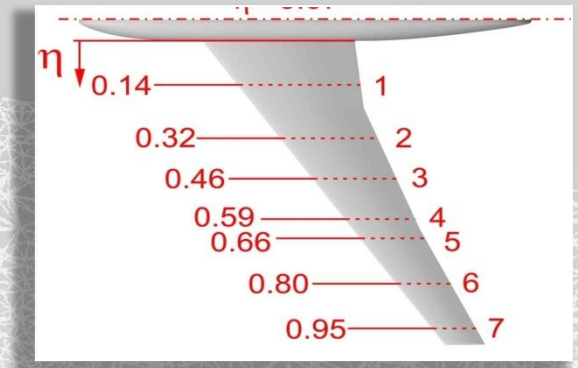






Upper surface, Mach 0.8, Re 7M, α 1.5





Station 7

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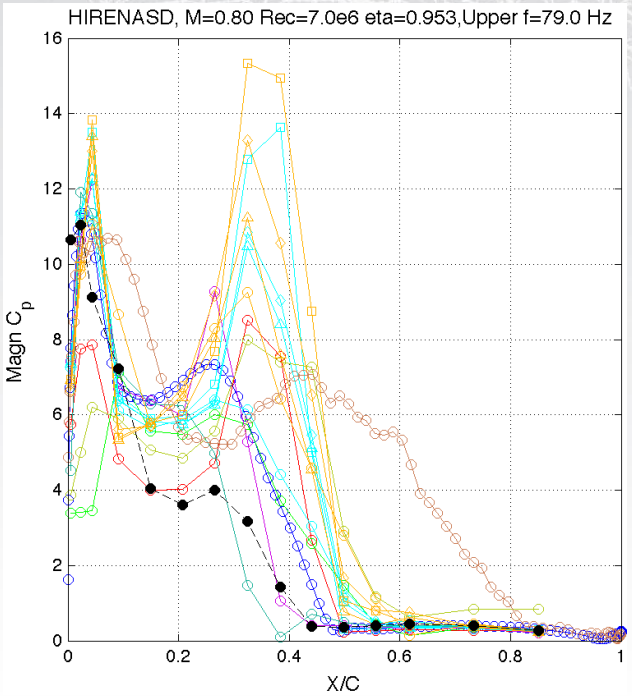

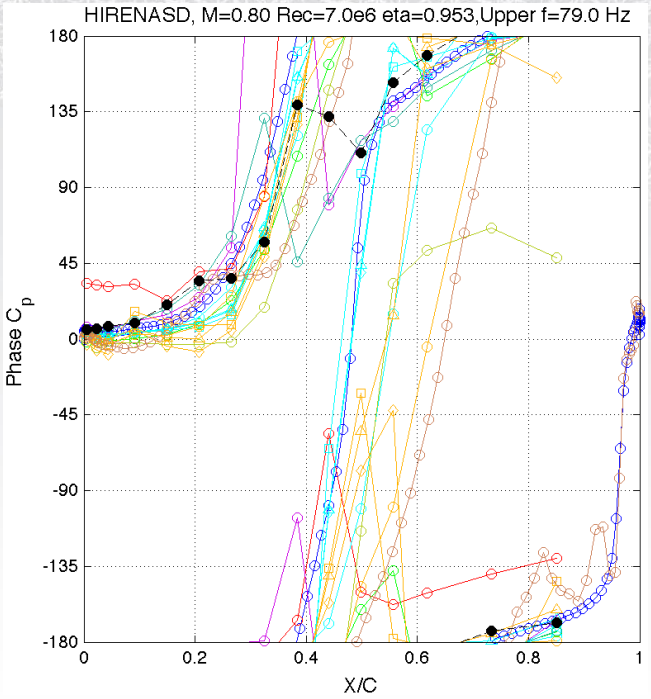

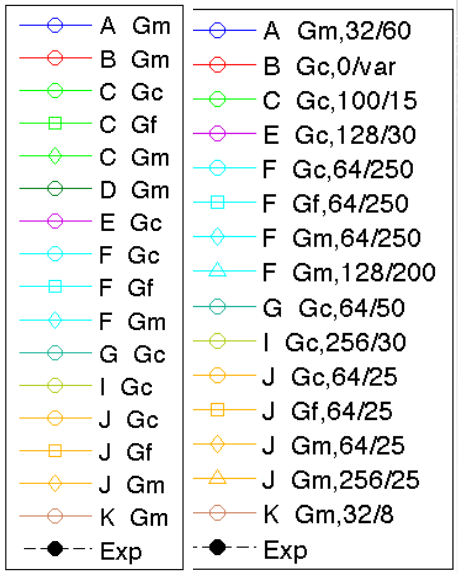

Comparison Data Matrix

CONFIGURATION	REQUIRED CALCULATIONS			
	GRID CONVERGENCE STUDIES	TIME CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. $N^{-2/3}$ ✓	n/a	• Mean C_p vs. x/c ✓ • Means of C_L, C_D, C_M ✓	n/a
Steady-Aeroelastic Cases (HIRENASD)	C_L, C_D, C_M vs. $N^{-2/3}$ ✓	n/a	• Mean C_p vs. x/c ✓ • Means of C_L, C_D, C_M ✓ • Vertical displacement vs. chord ✓ • Twist angle vs. span ✓	n/a
Forced Oscillation Cases (all configurations)	• Magnitude and Phase of C_L, C_D, C_M vs. $N^{-2/3}$ at excitation frequency ✓	• Magnitude and Phase of C_L, C_D, C_M vs. Δt at excitation frequency ✓	n/a	• Magnitude and Phase of C_p vs. x/c at span stations corresponding to transducer locations ✓ • Magnitude and Phase of C_L, C_D, C_M at excitation frequency ✓ • Time histories of C_p's at a selected span station for two upper- and two lower-surface transducer locations