AEPW2 SIMULATIONS WITH THE EZNSS CODE

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TEST CASES

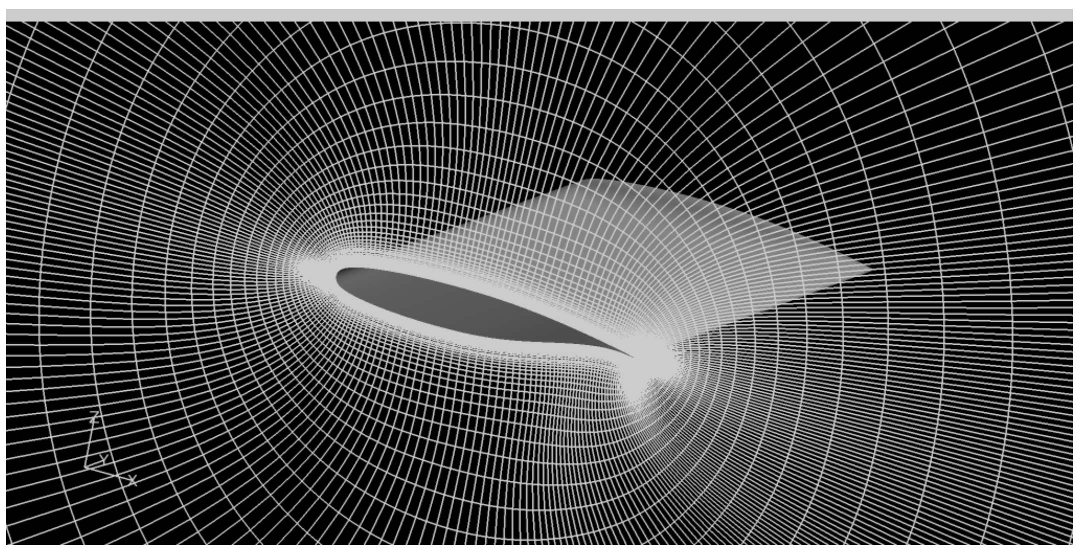
	Case 1	Case 2	Optional Case 3		
Mach	0.7	0.74	0.85	0.85	0.85
AoA	3°	0°	5°	5°	5°
Data Type	Forced Oscillation	Flutter	Unforced Unsteady	Forced Oscillation	Flutter
Notes:	• OTT • R-134a	• PAPA • R-12	• OTT • R-134a • Separated flow	• Repeat of AePW-1 • OTT • R-134a	• No experimental data • R-134

EZNSS

- Elastic Zonal Navier-Stokes Solver (EZNSS)
- Finite difference method
- Several implicit algorithms
- Second-order in space and time
- In this study:
  - Implicit ADI time-marching
  - Flux splitting - AUSM+-up

COARSE AND MEDIUM MESHES

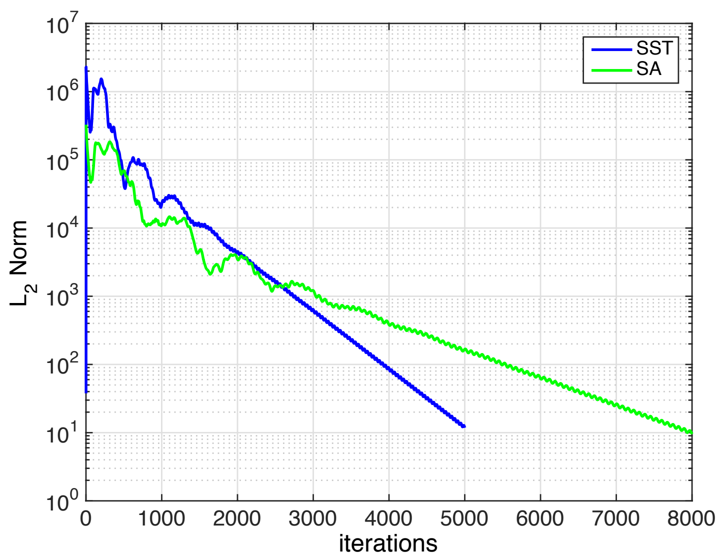
- Coarse Mesh: 71x253x99 (1.8 Mil)
- Medium Mesh: 126x361x184 (8.4 Mil)



CASE 1 (M 0.7, AOA 3^{O}, R-134A) - STATIC ANALYSIS

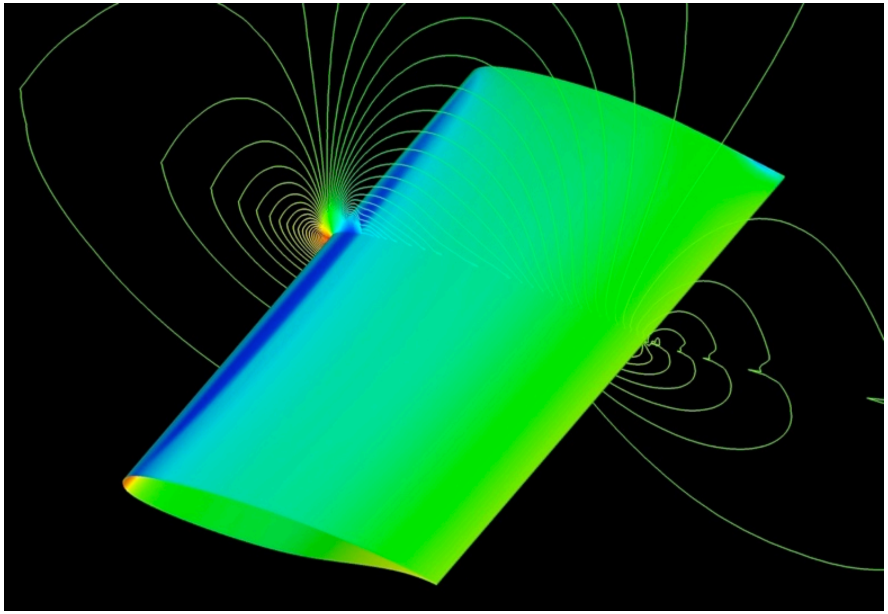
- Two linear eddy viscosity models: k-ω-SST, SA
- Coarse Mesh
- CL=0.425 (0.410), CD=0.026 (0.026), CM=-0.075 (-0.072)

Convergence



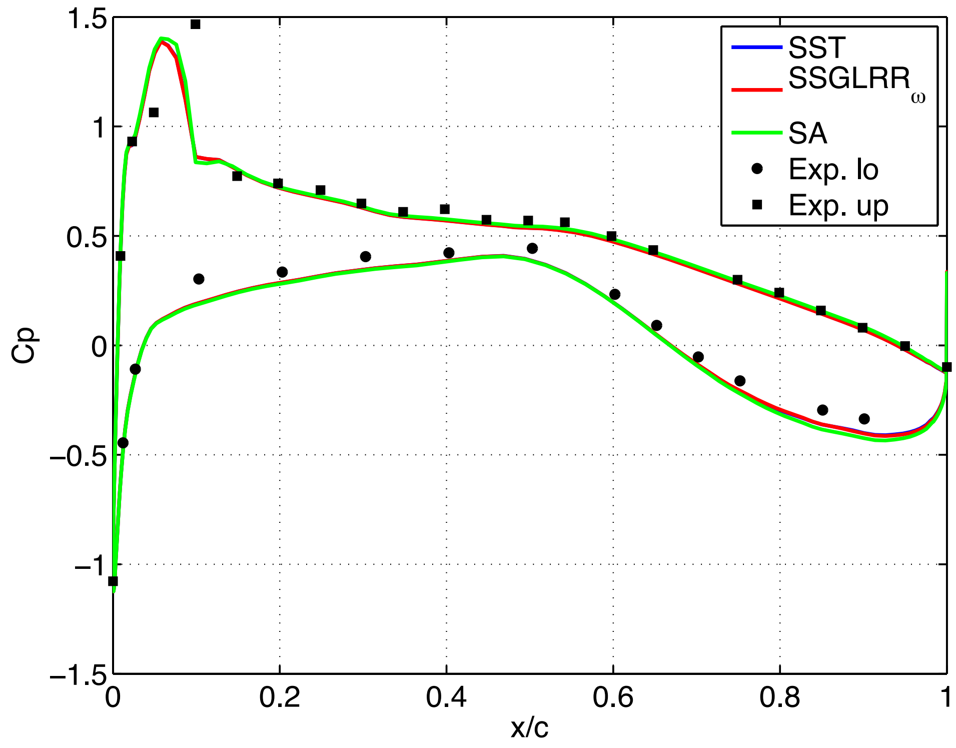
$$L_2Norm = \sqrt{\sum_{\xi=1}^{\xi_{max}} \sum_{\eta=1}^{\eta_{max}} \sum_{\zeta=1}^{\zeta_{max}} \sum_{m=1}^{5} \hat{R}_{dt}^{k}}$$

Pressure Map



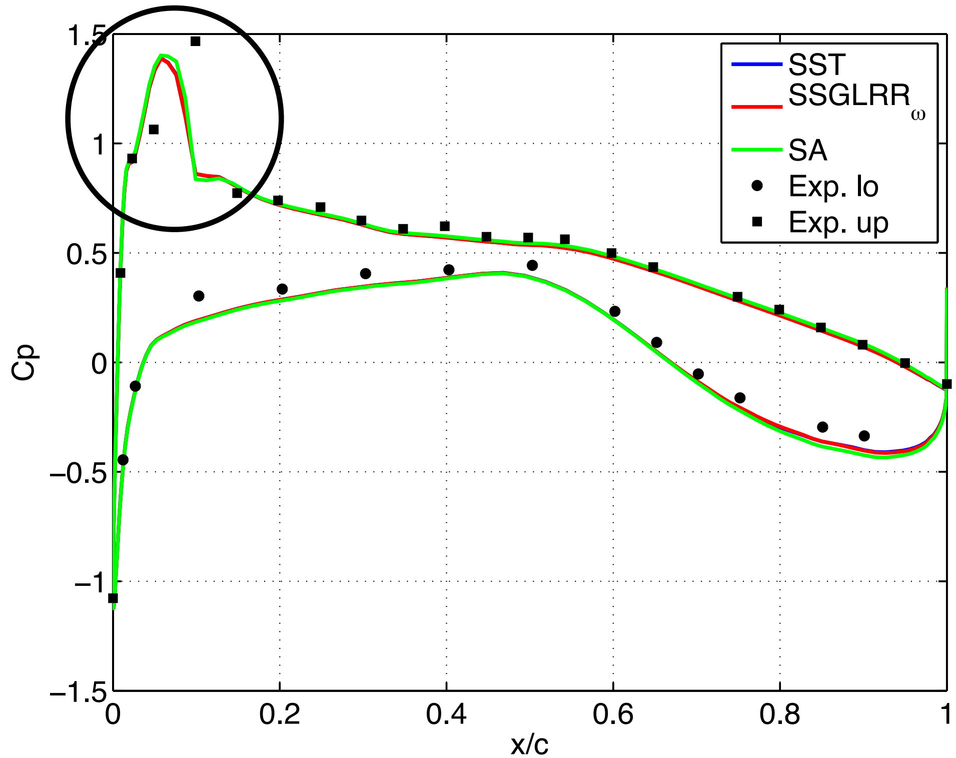
CASE 1 (M 0.7, AOA 3^{o}, R-134A) - STATIC ANALYSIS

Cp at 0.6 span



CASE 1 (M 0.7, AOA 3^{O}, R-134A) - STATIC ANALYSIS

Cp at 0.6 span



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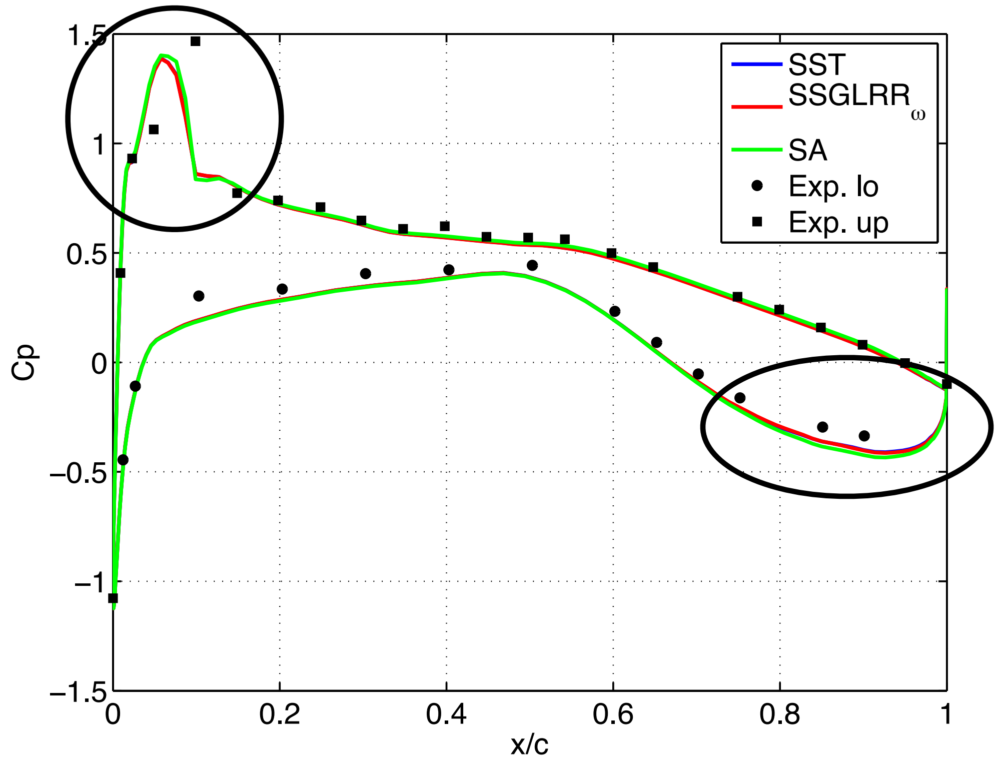
CASE 1 (M 0.7, AOA 3^{O}, R-134A) - STATIC ANALYSIS

Cp at 0.6 span

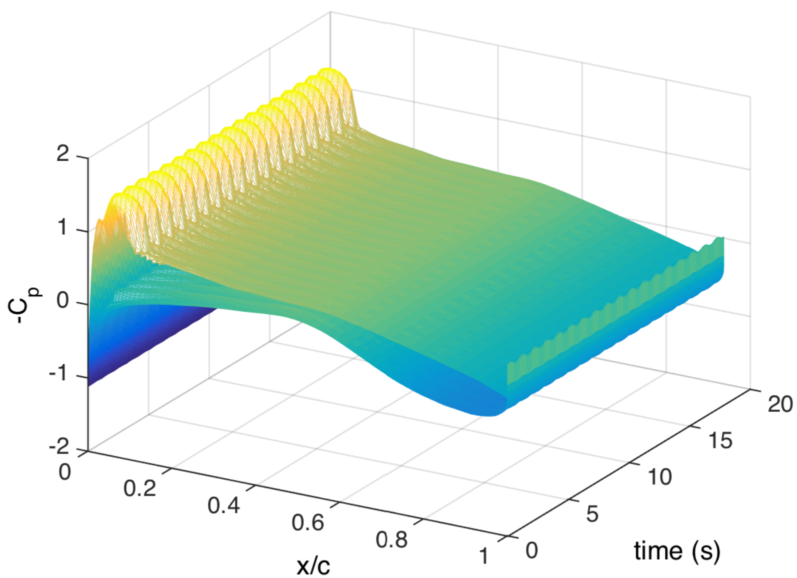


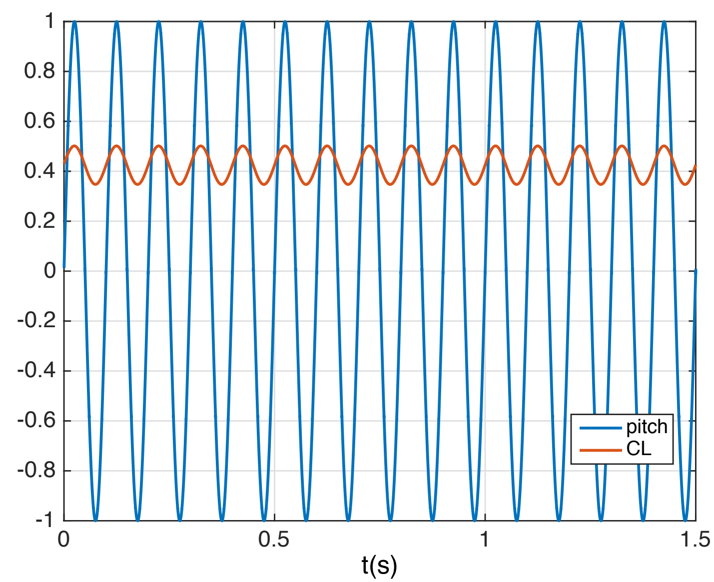
CASE 1 (M 0.7, AOA 3^{o}, R-134A) - FORCED EXCITATION, 10HZ

- SA turbulence model
- dt=2e-4 sec -> 500 time steps in a cycle
- Snapshots every 10 time steps -> 50 snapshots in a cycle
- Reduced frequency:

$$k = \frac{2\pi f b}{V} = 0.1$$

- 2% difference between simulated CL and CL based on Theodorsen (and the steady CL)





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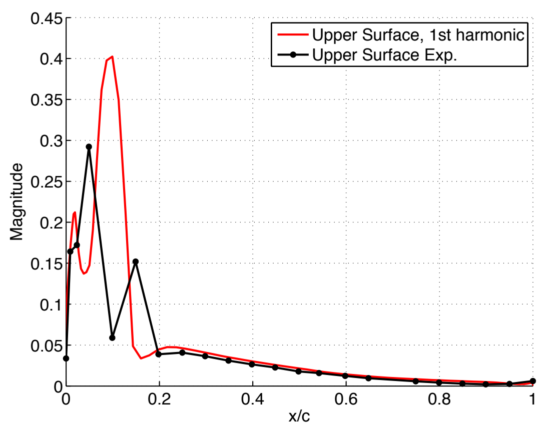
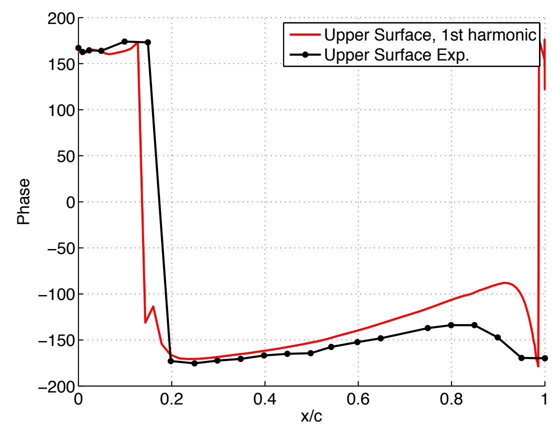
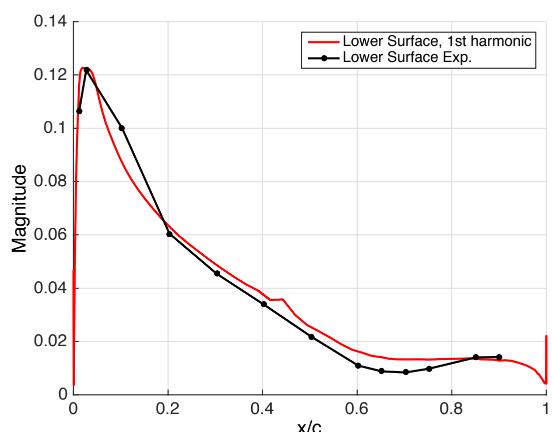
CASE 1 (M 0.7, AOA 3^{O}, R-134A) - FORCED EXCITATION, 10HZ

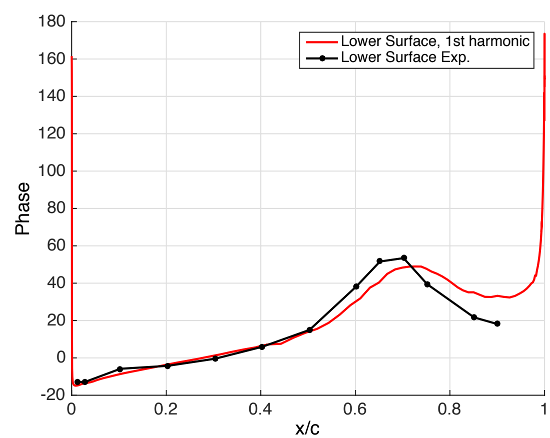
Upper Surface C_p/θ Transfer Function





Lower Surface C_p/θ Transfer Function





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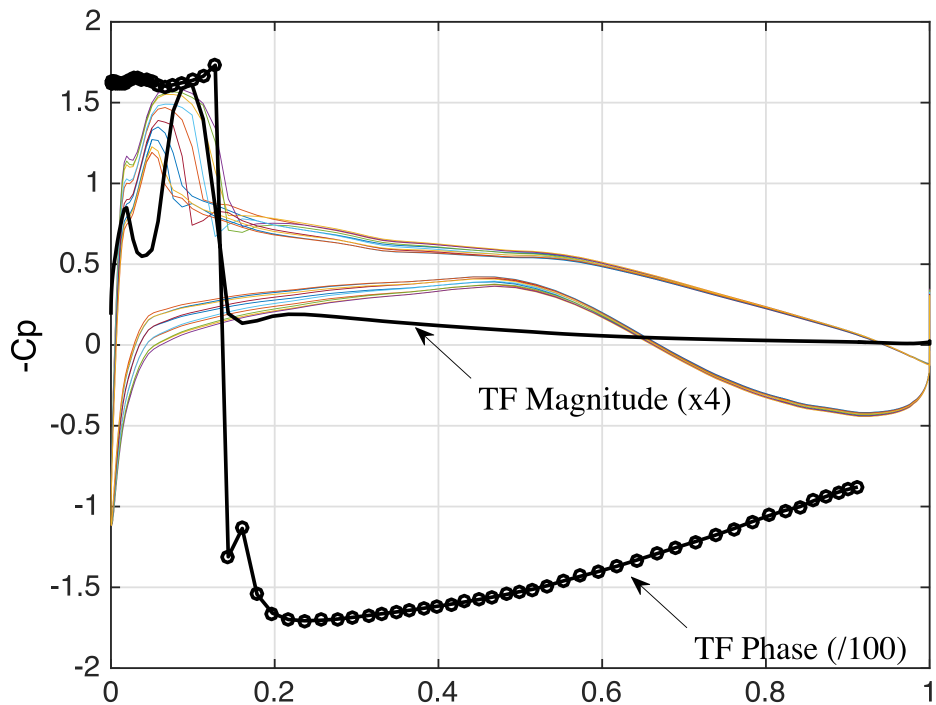
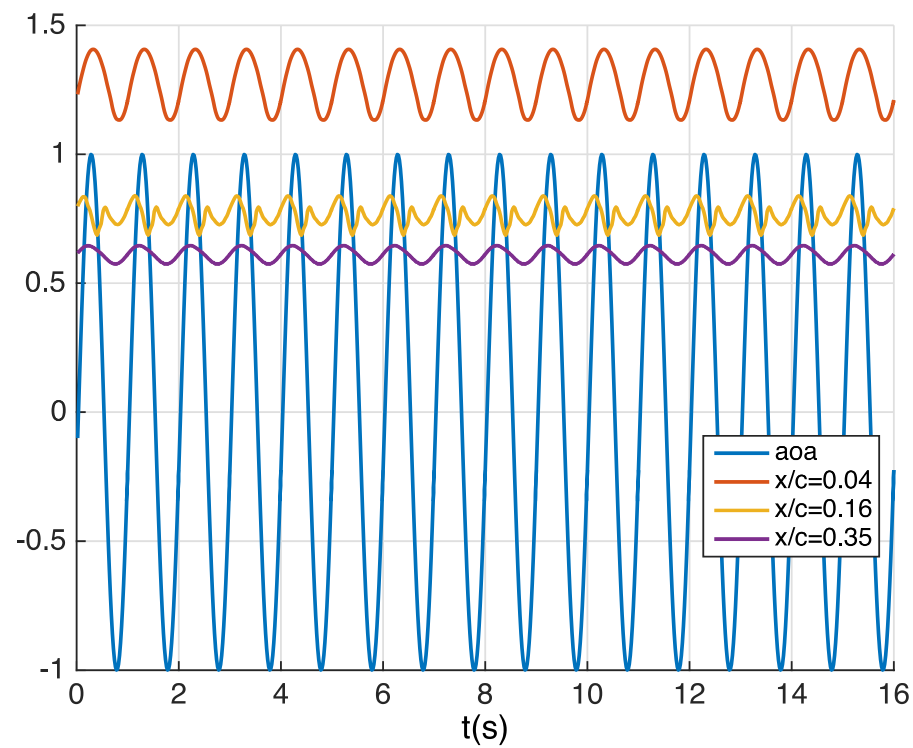
CASE 1 (M 0.7, AOA 3^{o}, R-134A) - FORCED EXCITATION, 10HZ

Upper Surface -Cp during a cycle
TF Magnitude, and phase shift region



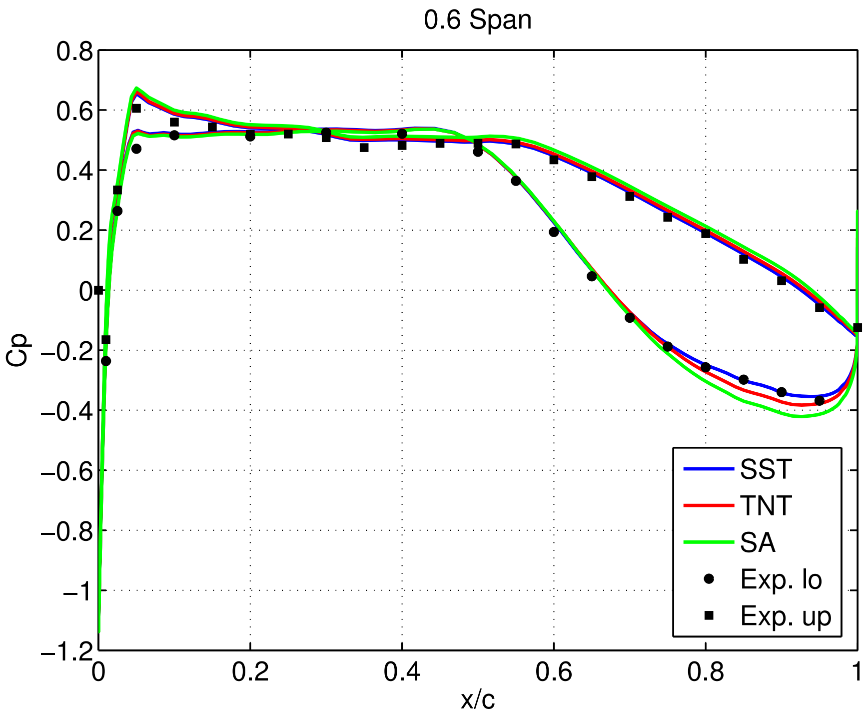
AoA, and -Cp at various chord locations

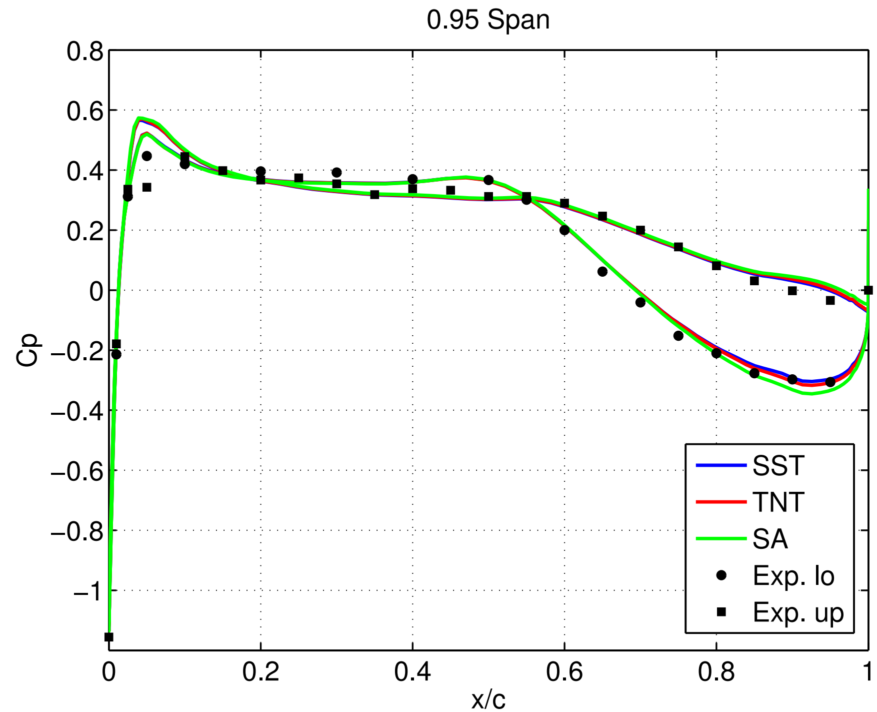


CASE 2 (FLUTTER, M 0.74, AOA 0^{O}, R-12) - STATIC ANALYSIS

- Three linear eddy viscosity models:

  k-ω-SST, k-ω-TNT, SA





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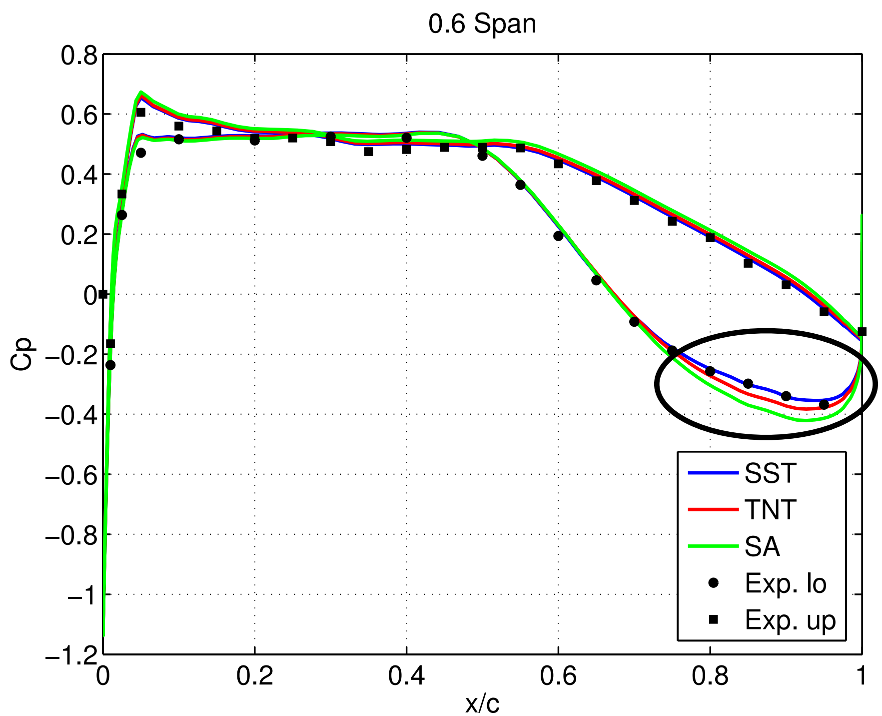
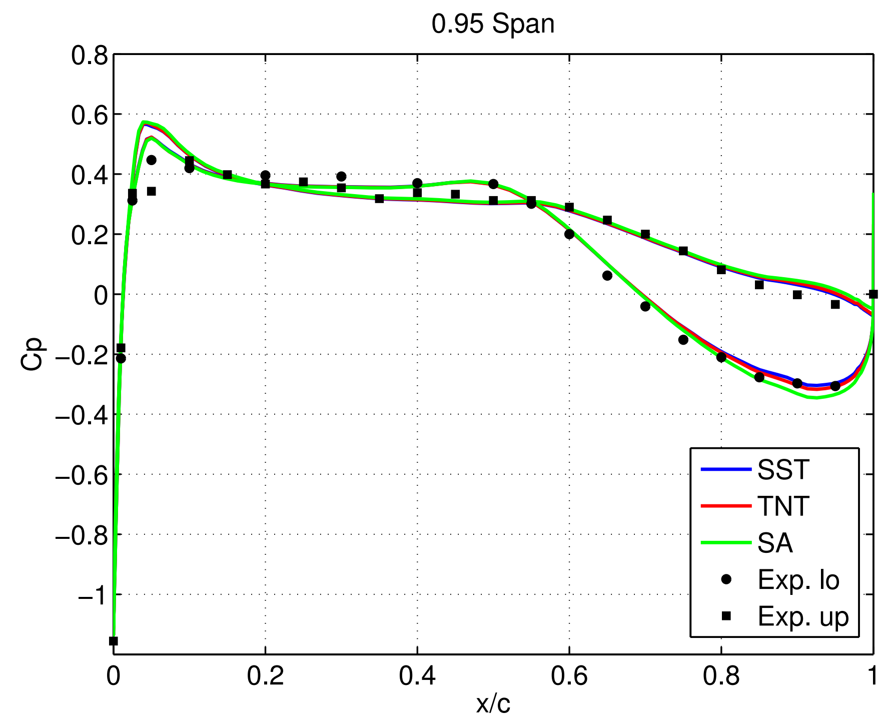
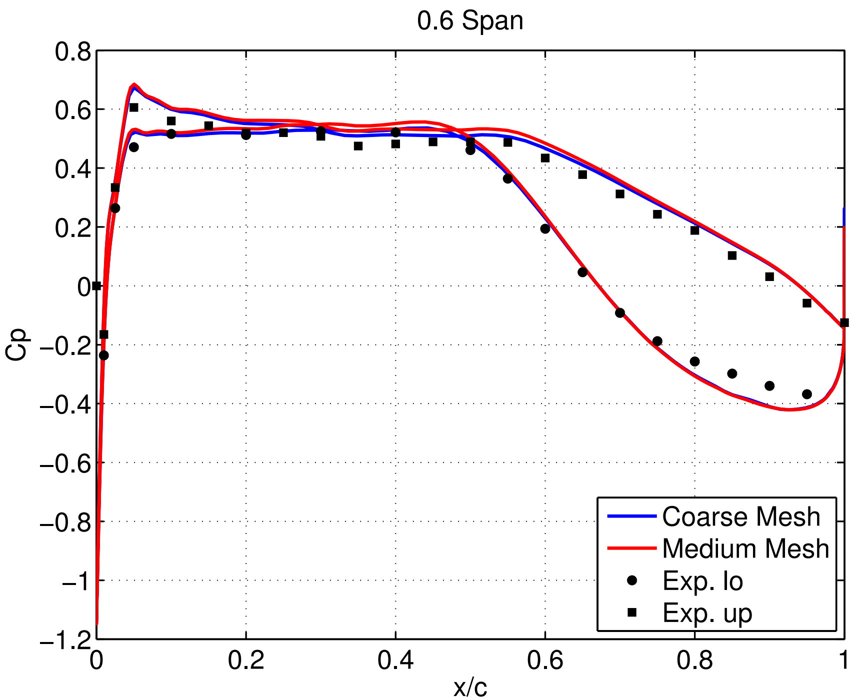
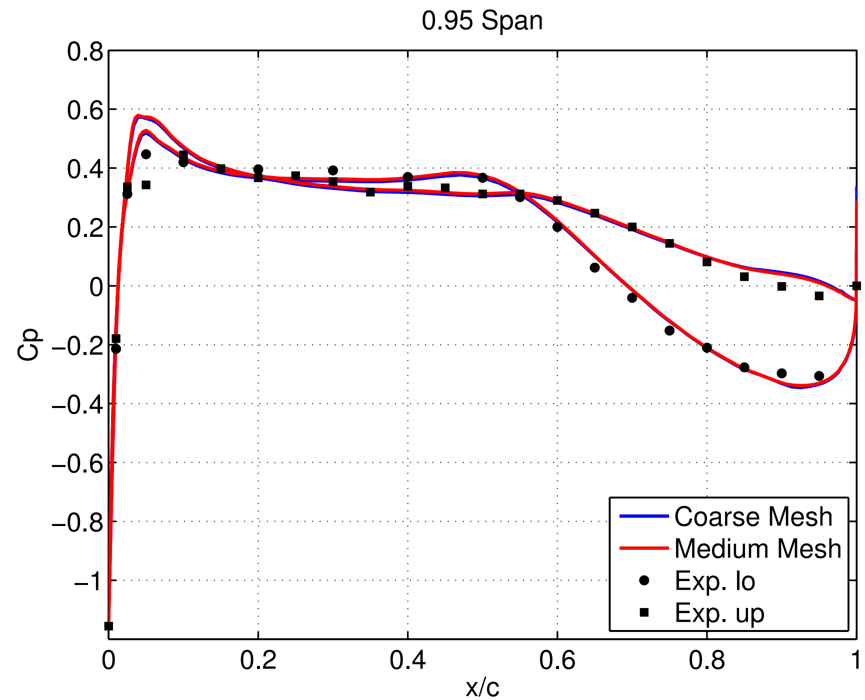




CASE 2 (FLUTTER, M 0.74, AOA 0^{O}, R-12) - STATIC ANALYSIS

- SA
- Two meshes: Coarse 253x71x99, Medium 361x126x184





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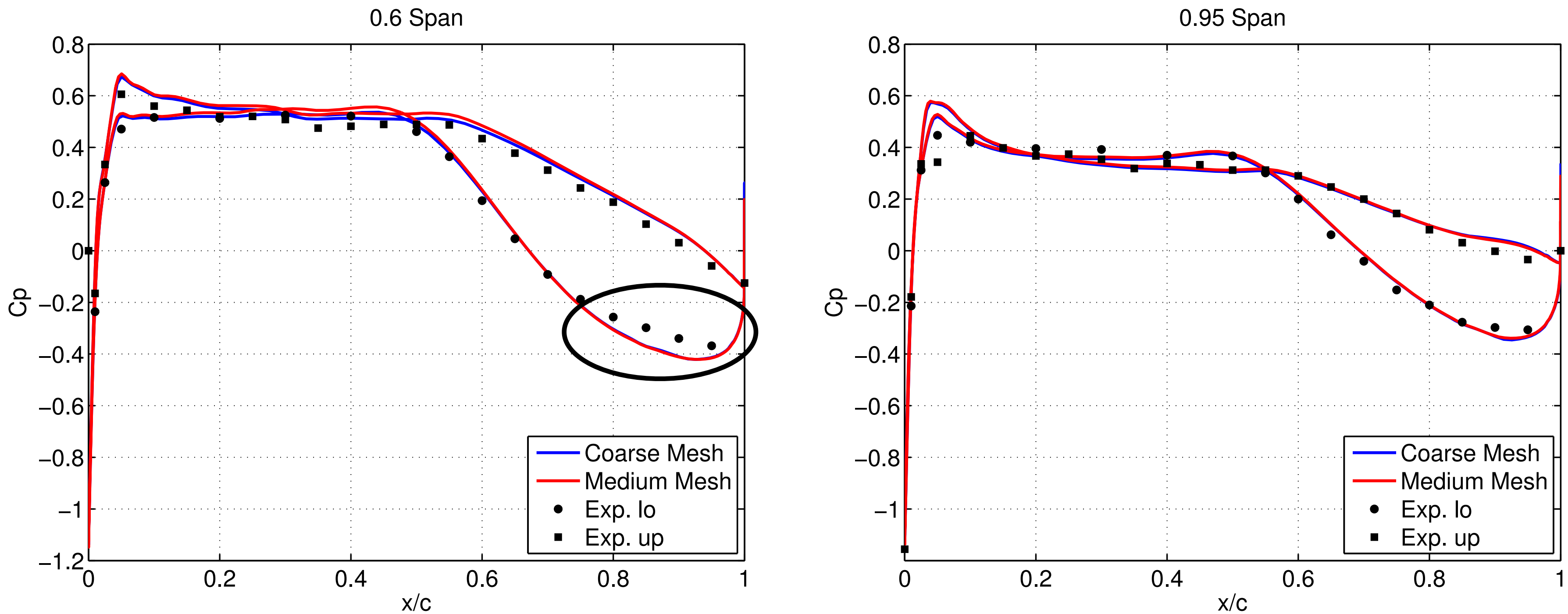
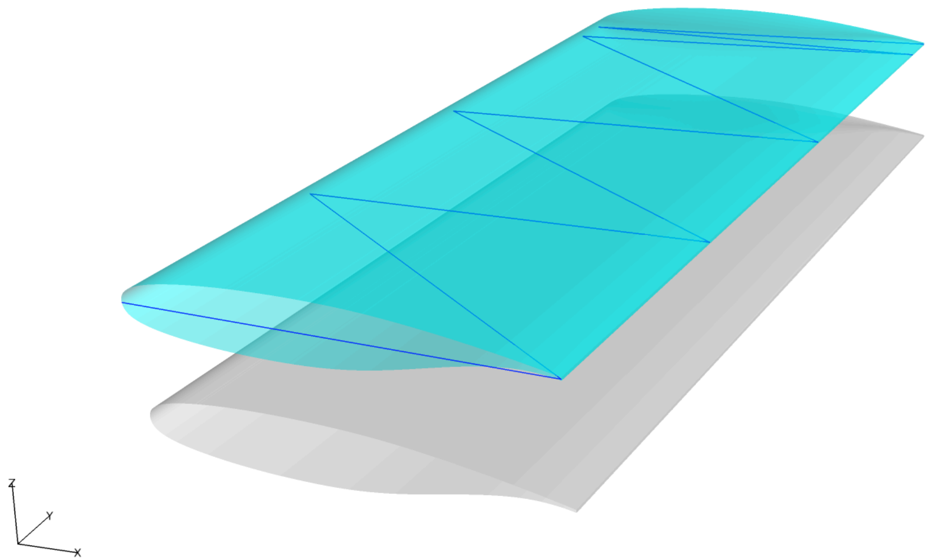
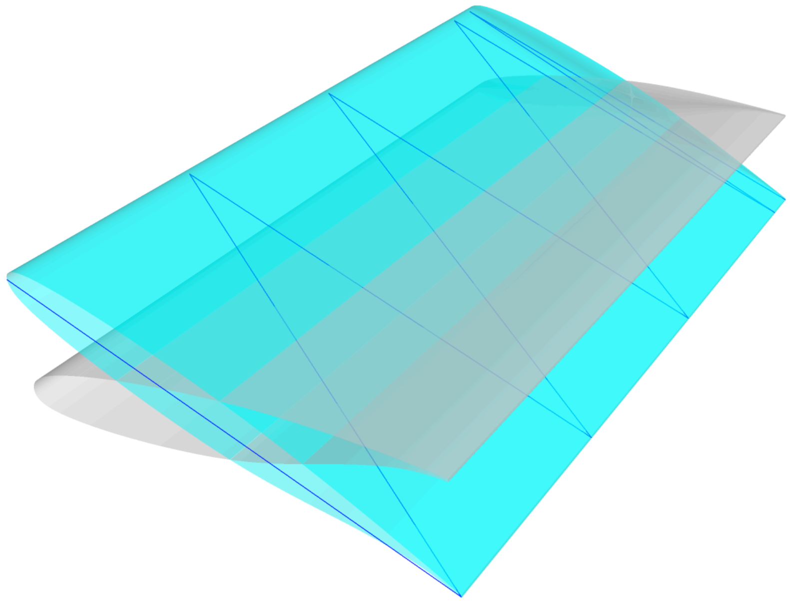


STRUCTURAL MODEL



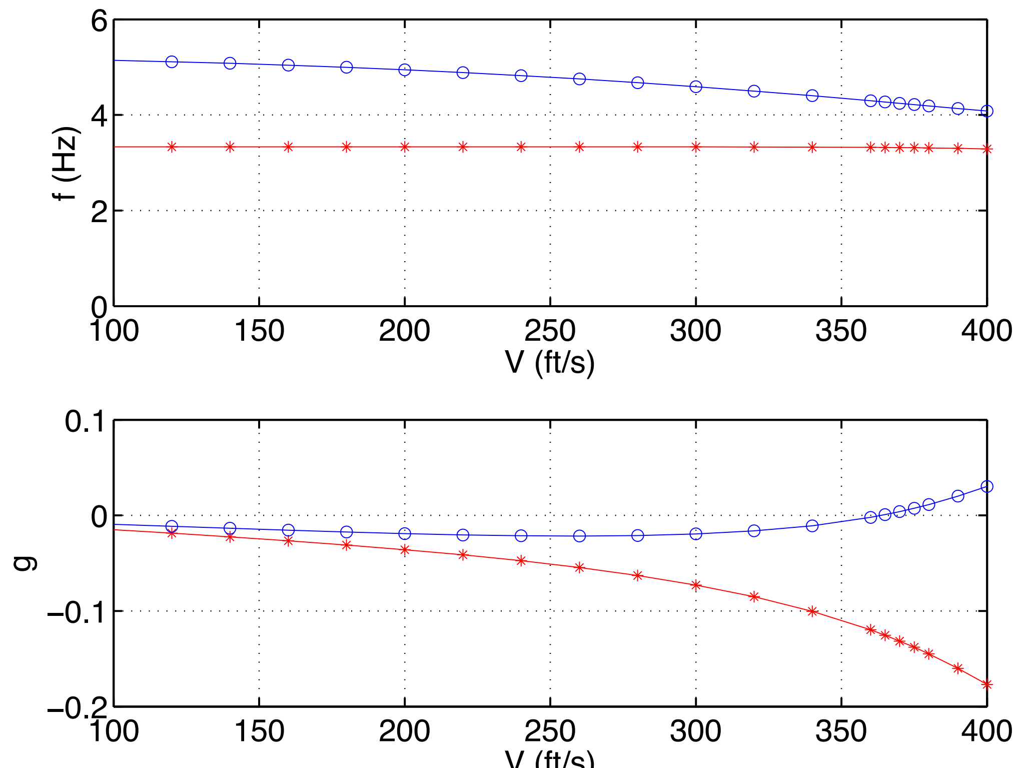


Heave - 3.33 Hz

Pitch - 5.20 Hz

CASE 2 (FLUTTER, M 0.74, AOA 0^O, R-12) LINEAR FLUTTER ANALYSIS

- Linear flutter analysis in ZAERO:
  - Flutter dynamic pressure 157 psf (169 psf in the WT)
  - Flutter frequency 4.3 Hz (4.3 in the WT)



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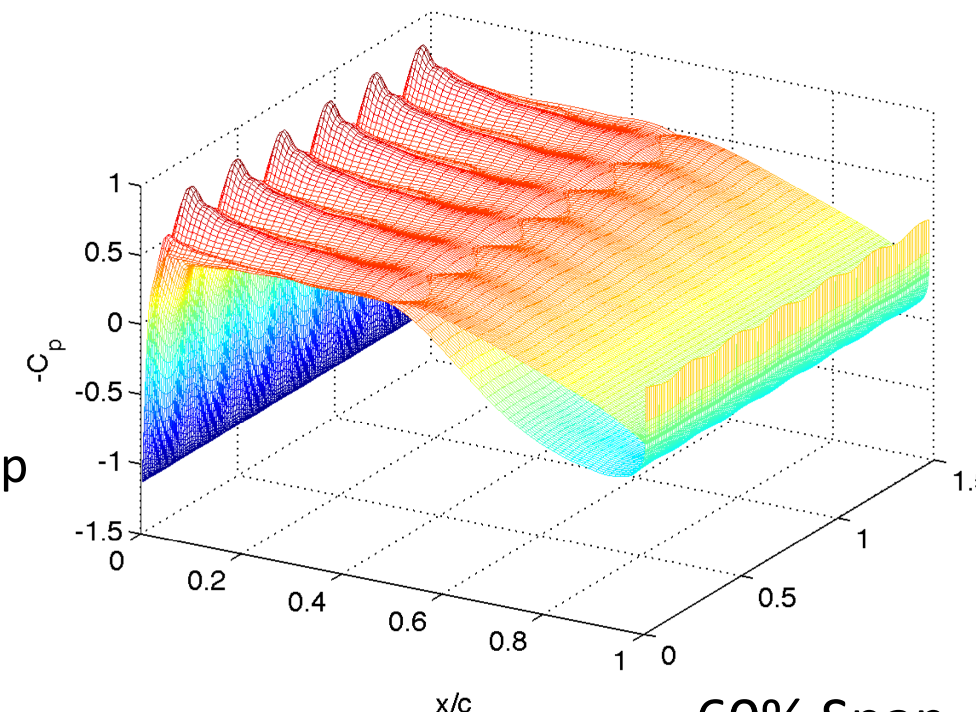
CASE 2 (FLUTTER, M 0.74, AOA 0^{O}, R-12) AEROELASTIC SIMULATION

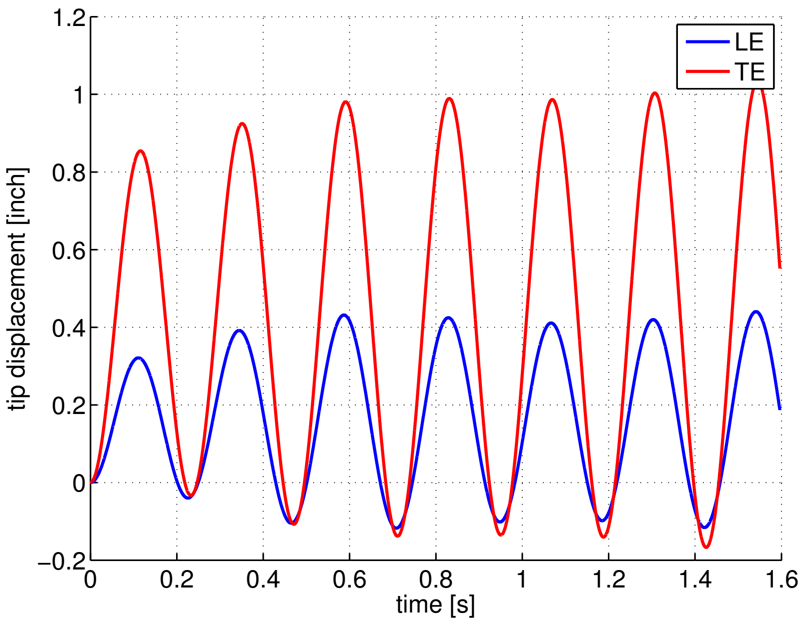
- Analysis dynamic pressure 169 psf (as in WT)
- Nominal computational parameters:
  - Coarse mesh
  - SA model
  - dt=2e-4 s
  - Sub-iteration convergence criterion: 5 OOM residual drop

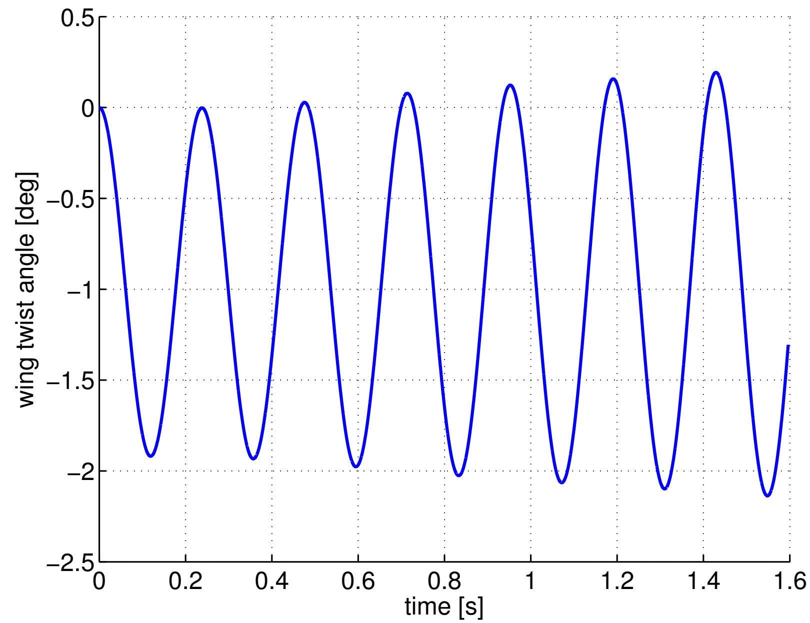


60% Span

CASE 2 - FLUTTER, M 0.74, AOA 0^{O}, R-12

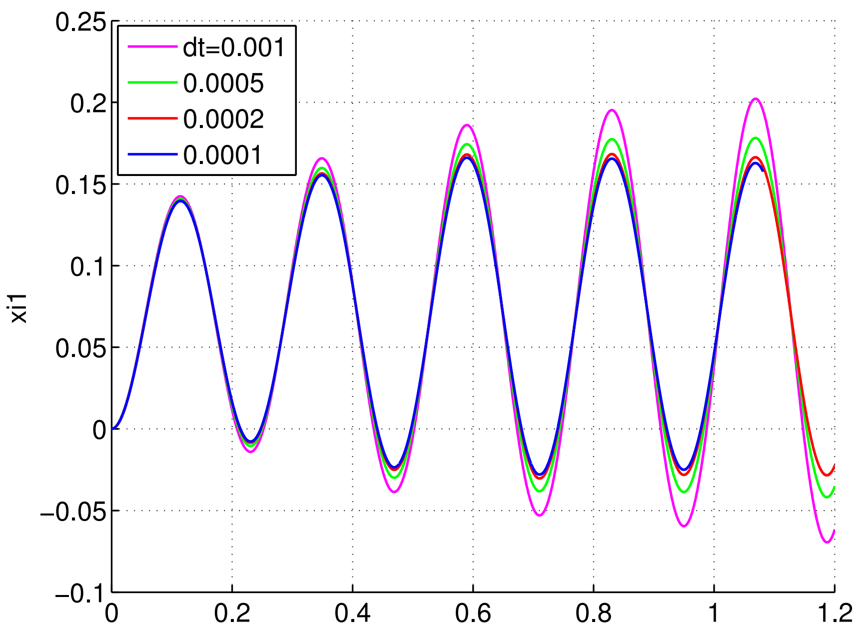
- Flutter frequency: Computed 4.2 Hz, WT 4.3 Hz
- Tip displacement and wing twist during flutter:



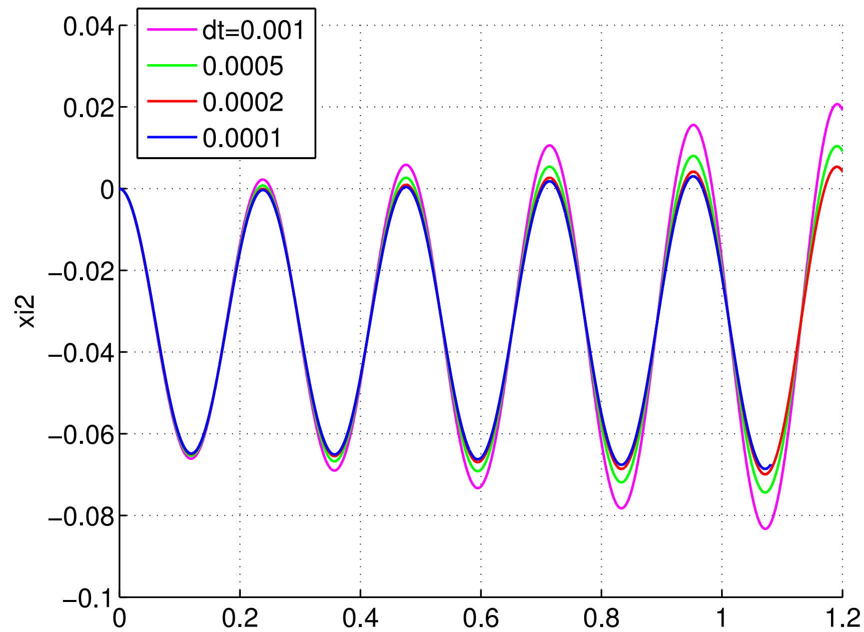


CASE 2 (FLUTTER, M 0.74, AOA 0^O, R-12) AEROELASTIC SIMULATION

- Temporal convergence - effect of time-step



Heave



Pitch

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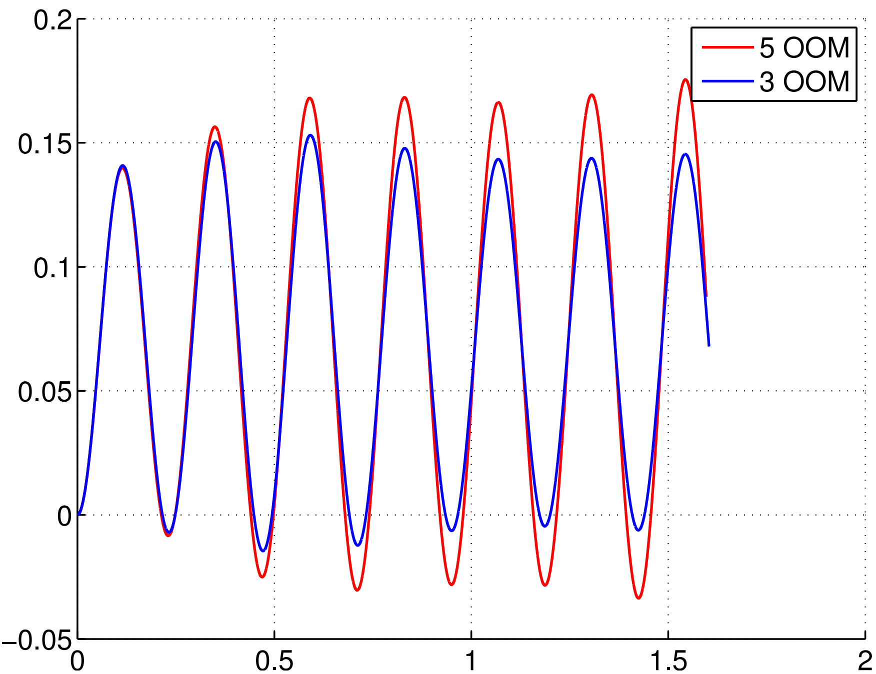
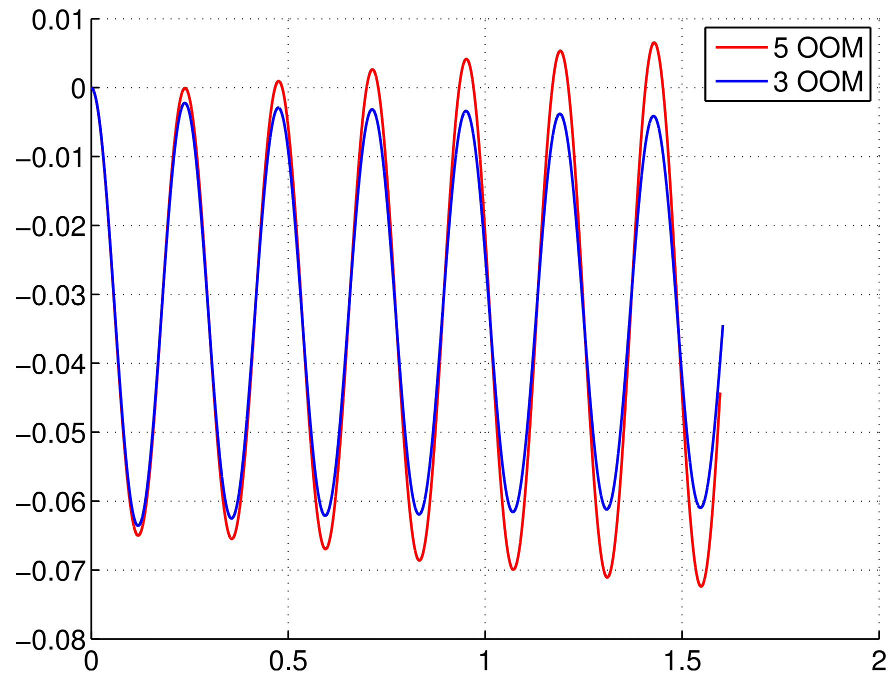
CASE 2 (FLUTTER, M 0.74, AOA 0^{O}, R-12) AEROELASTIC SIMULATION

- Temporal convergence - effect of convergence in sub-iterations



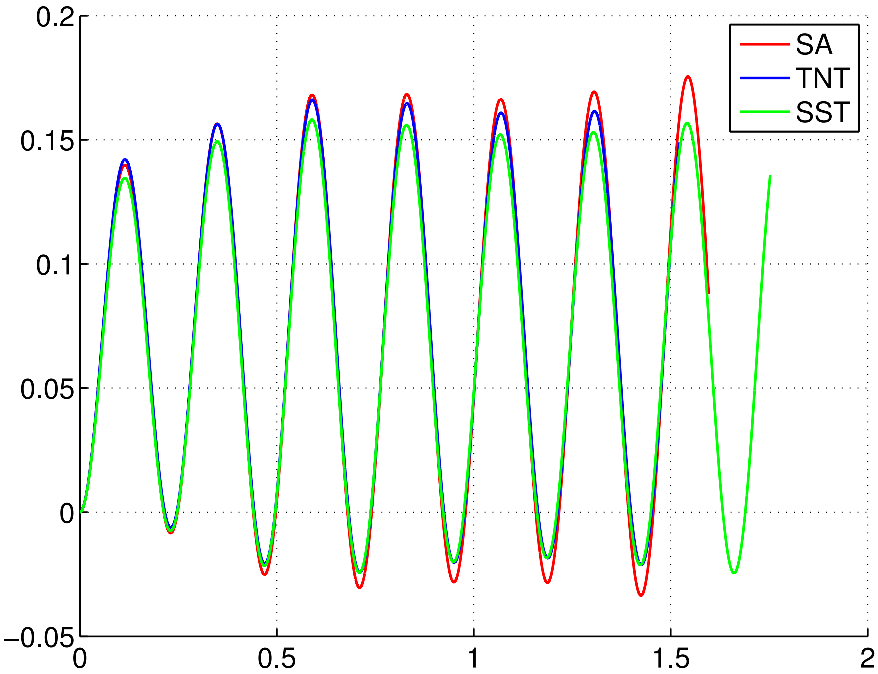
Heave

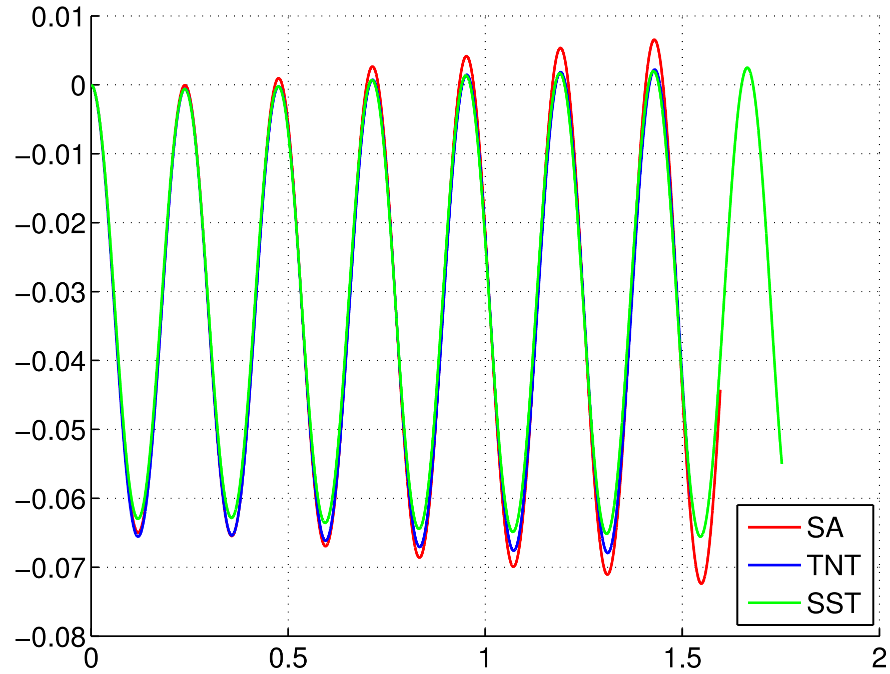


Pitch

CASE 2 - FLUTTER, M 0.74, AOA 0^{O}, R-12

- Turbulence model:



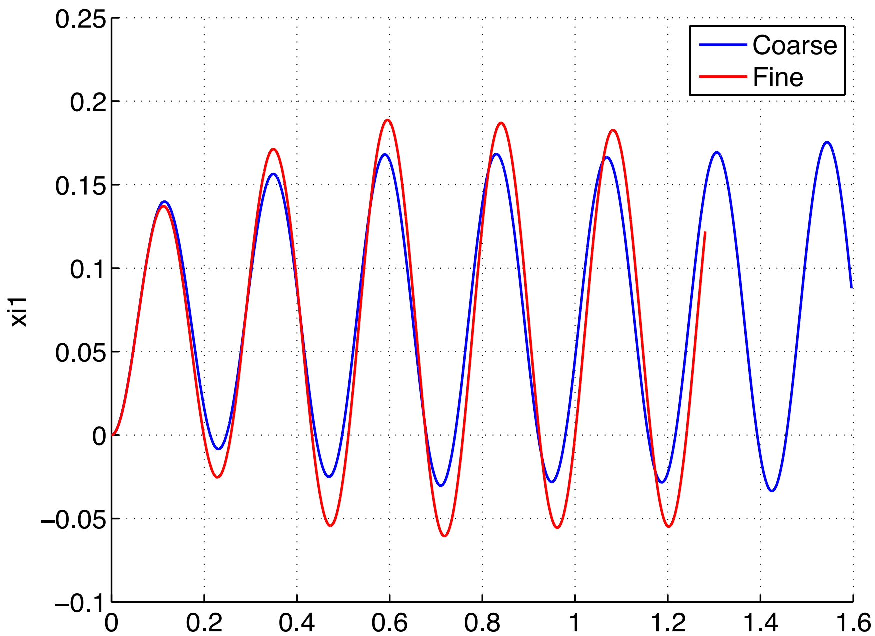


Heave

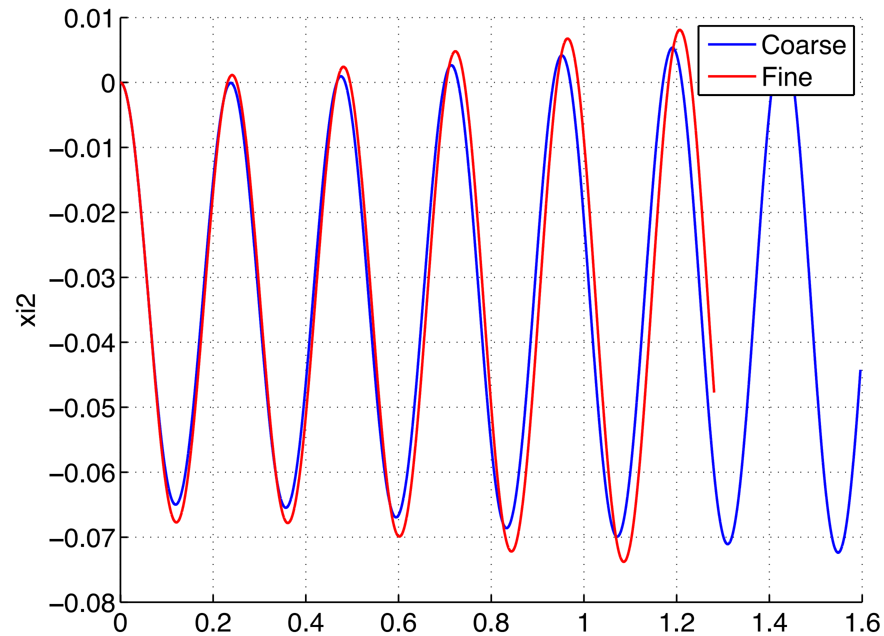
Pitch

CASE 2 - FLUTTER, M 0.74, AOA 0^{O}, R-12

- Mesh (SA):



Heave



Pitch

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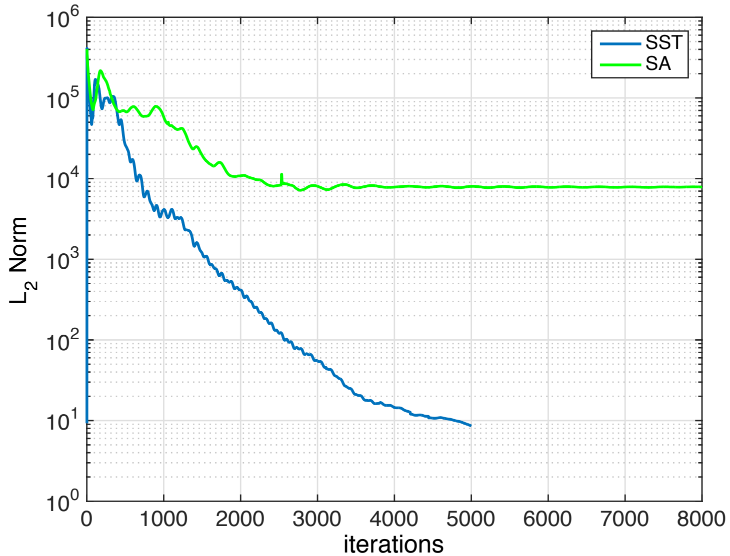
CASE 3 (M 0.85, AOA 5^{O}, R-134A) - STATIC ANALYSIS

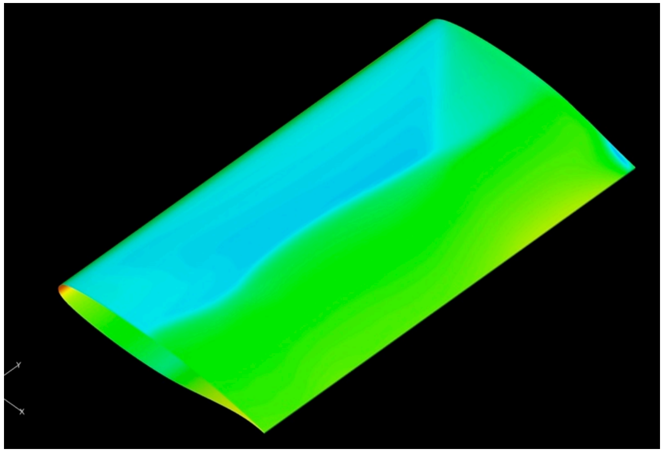
- Turbulence models: SST, SA
- Coarse Mesh
- CL=0.465, CD=0.065, CM=-0.075 (SST)

Convergence

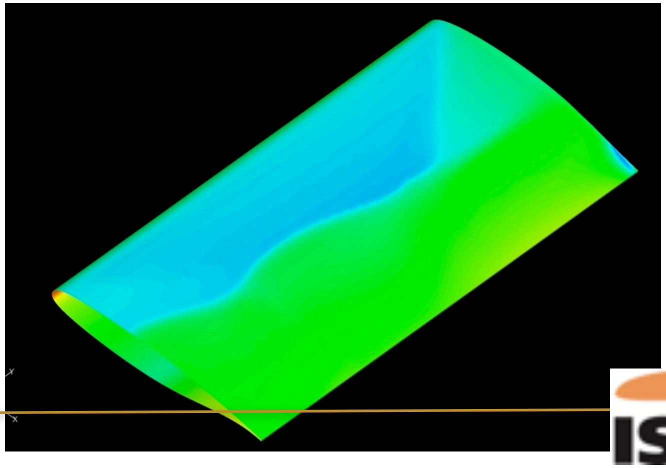


$$L_2 Norm = \sqrt{\sum_{\xi=1}^{\xi_{max}} \sum_{\eta=1}^{\eta_{max}} \sum_{\zeta=1}^{\zeta_{max}} \sum_{m=1}^{5} \hat{R}_{dt}^{k}}$$

Pressure Map - SST

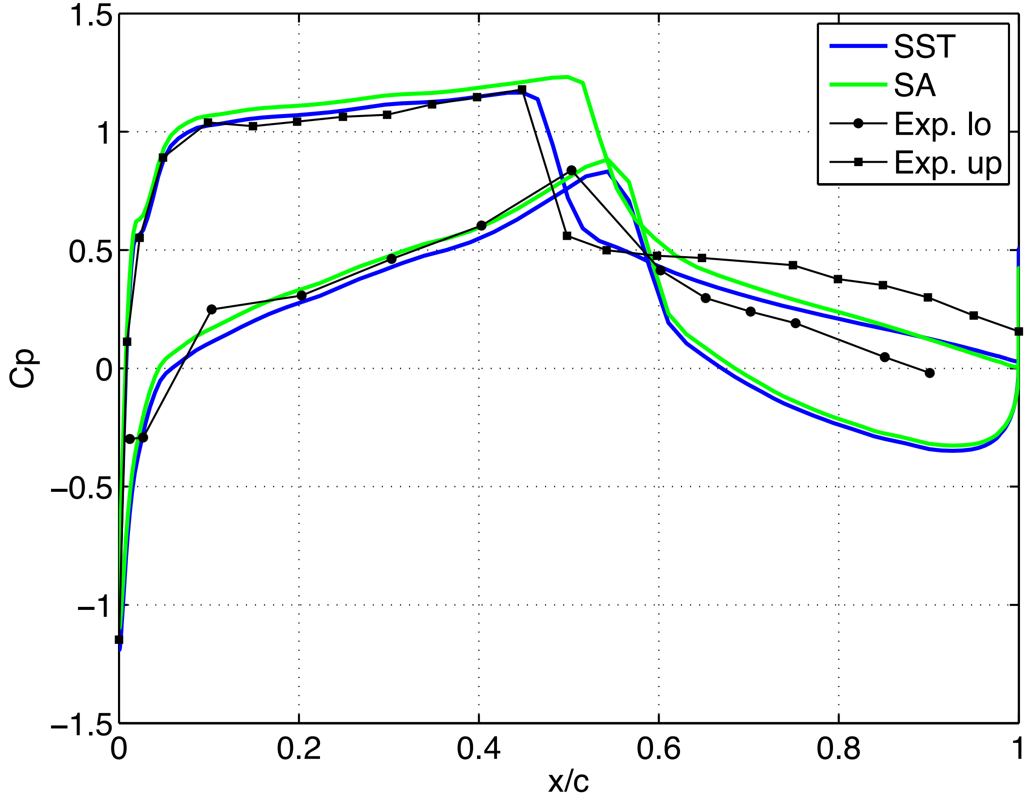


Pressure Map - SA



CASE 3 (M 0.85, AOA 5^{O}, R-134A) - STATIC ANALYSIS

Cp at 0.6 span



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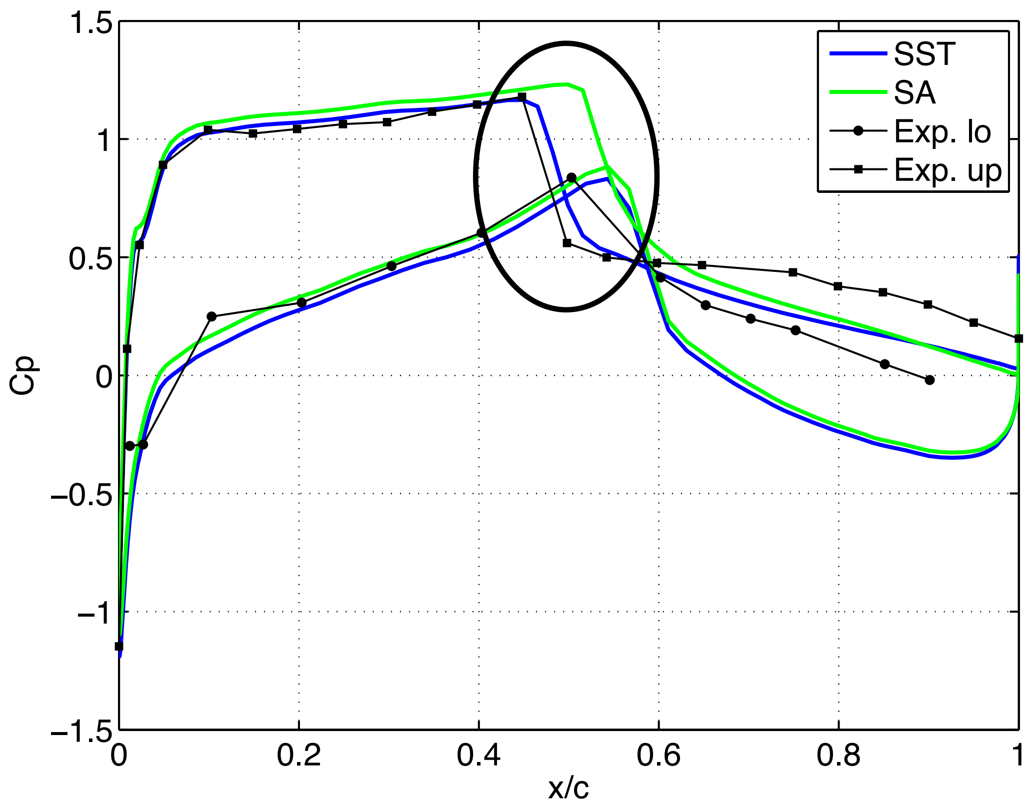
Cp at 0.6 span



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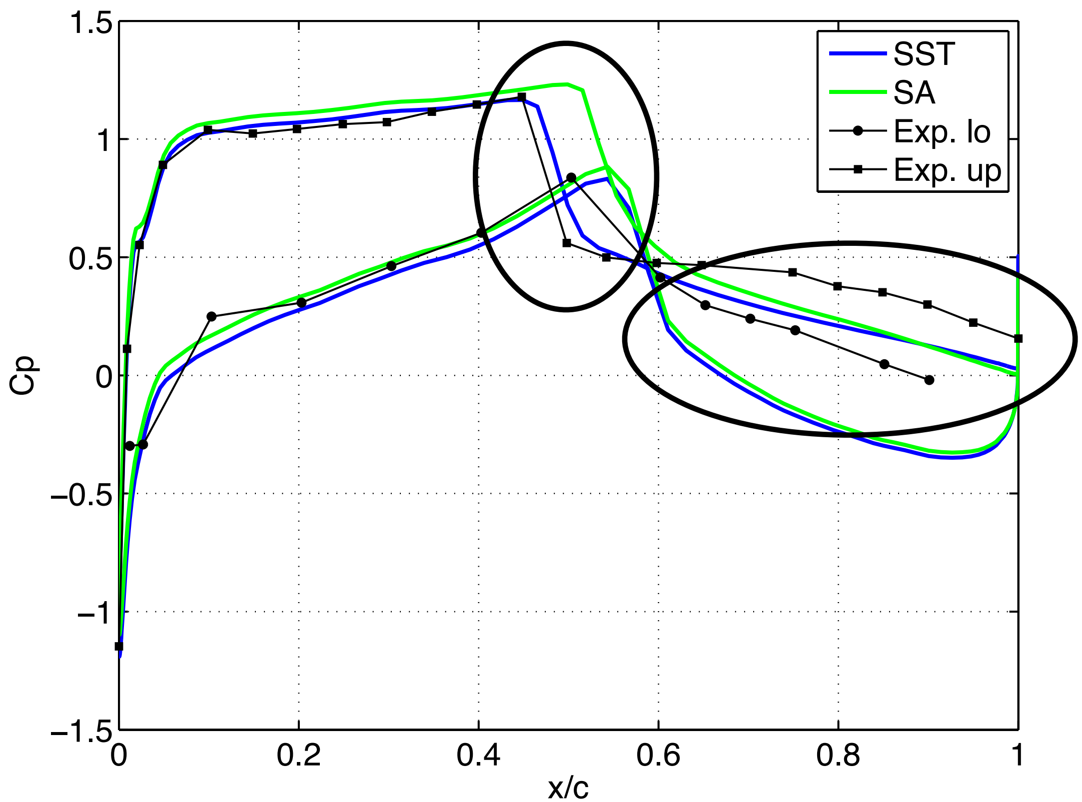
Cp at 0.6 span



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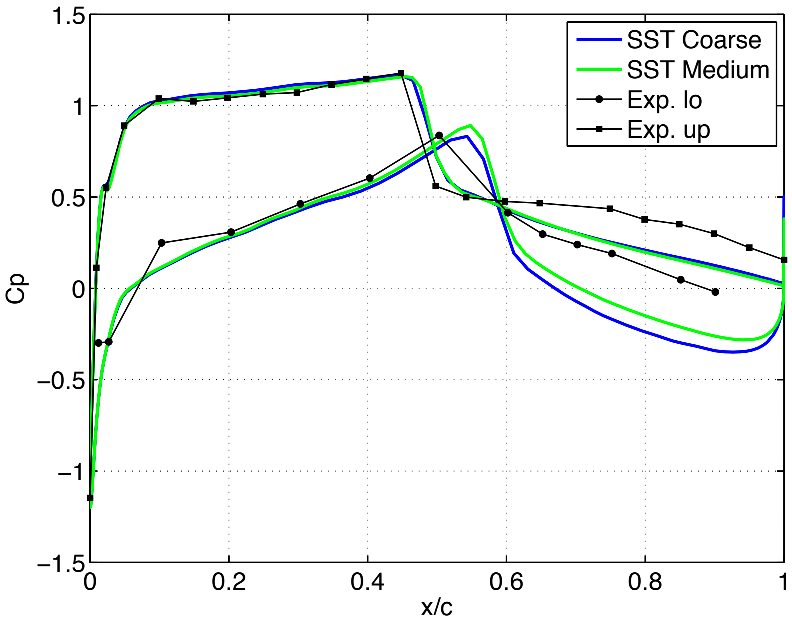
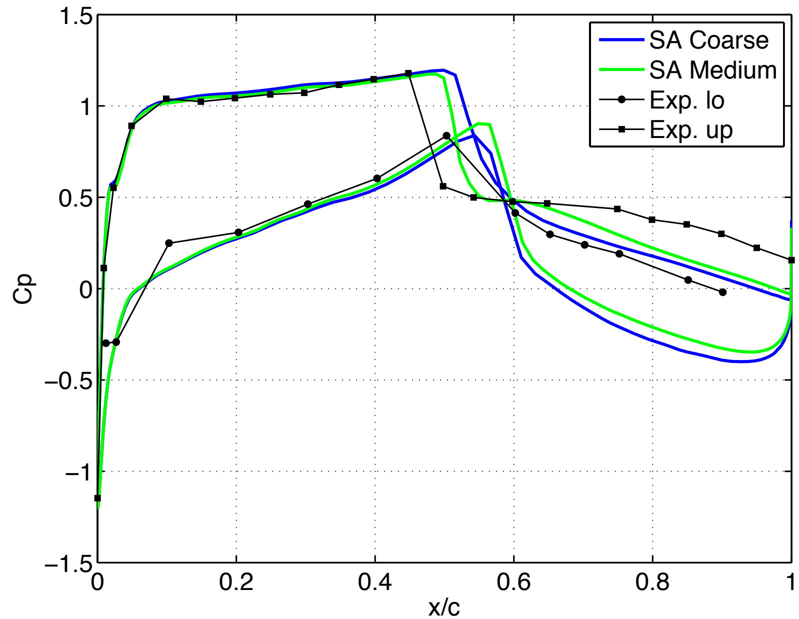
CASE 3 (M 0.85, AOA 5^{O}, R-134A) - STATIC ANALYSIS

- Mesh effect



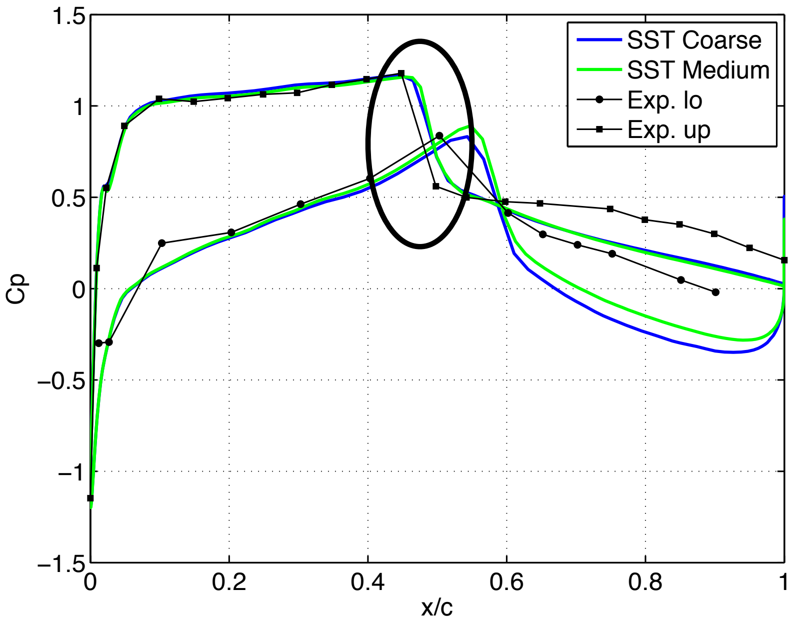
Cp at 0.6 span (SST)



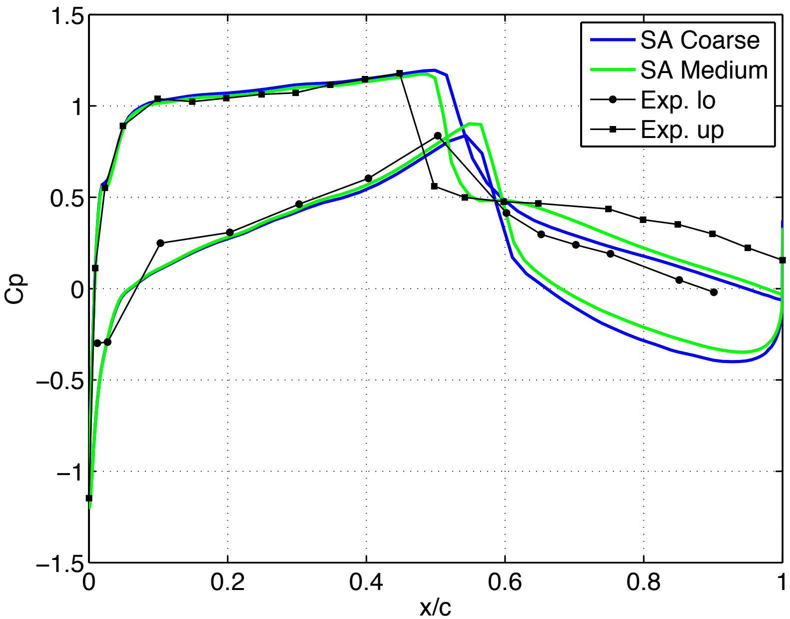
Cp at 0.6 span (SA)

CASE 3 (M 0.85, AOA 5^{O}, R-134A) - STATIC ANALYSIS

- Mesh effect



Cp at 0.6 span (SST)



Cp at 0.6 span (SA)

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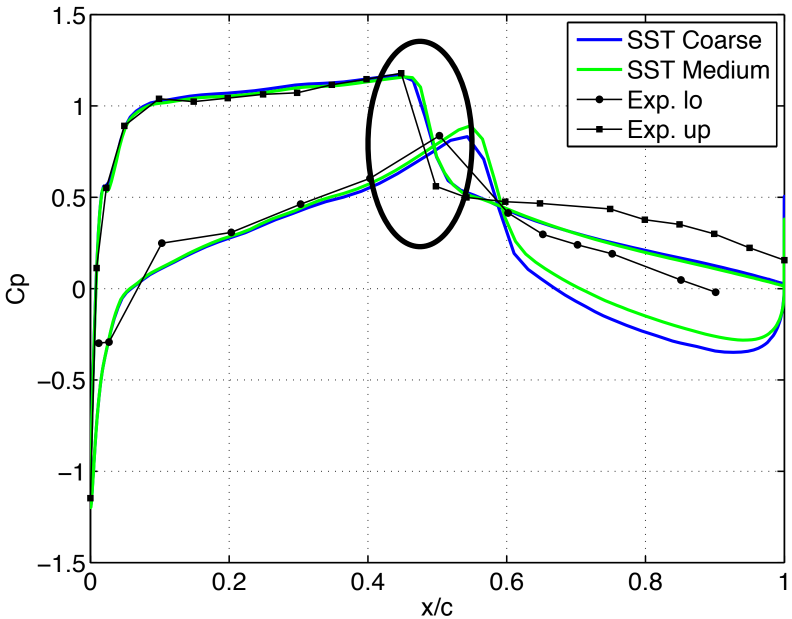
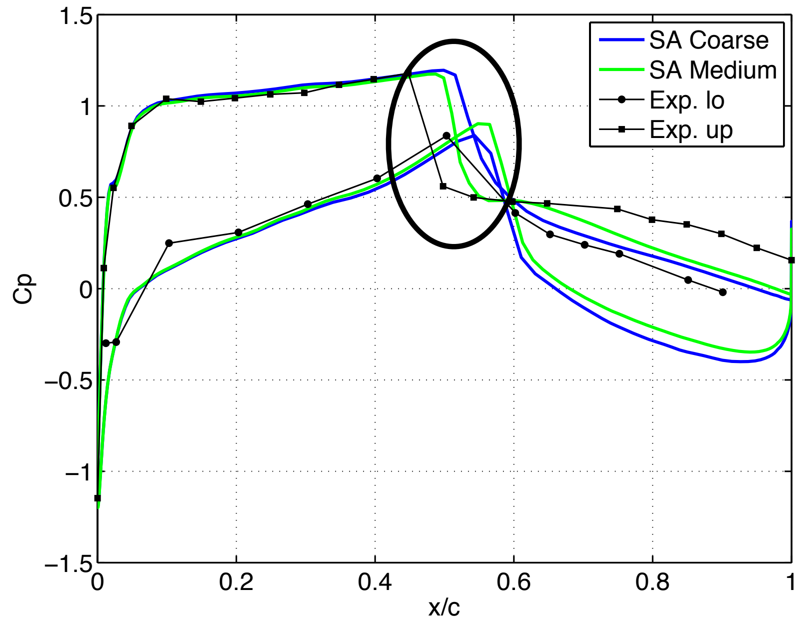
CASE 3 (M 0.85, AOA 5^{O}, R-134A) - STATIC ANALYSIS

- Mesh effect



Cp at 0.6 span (SST)



Cp at 0.6 span (SA)

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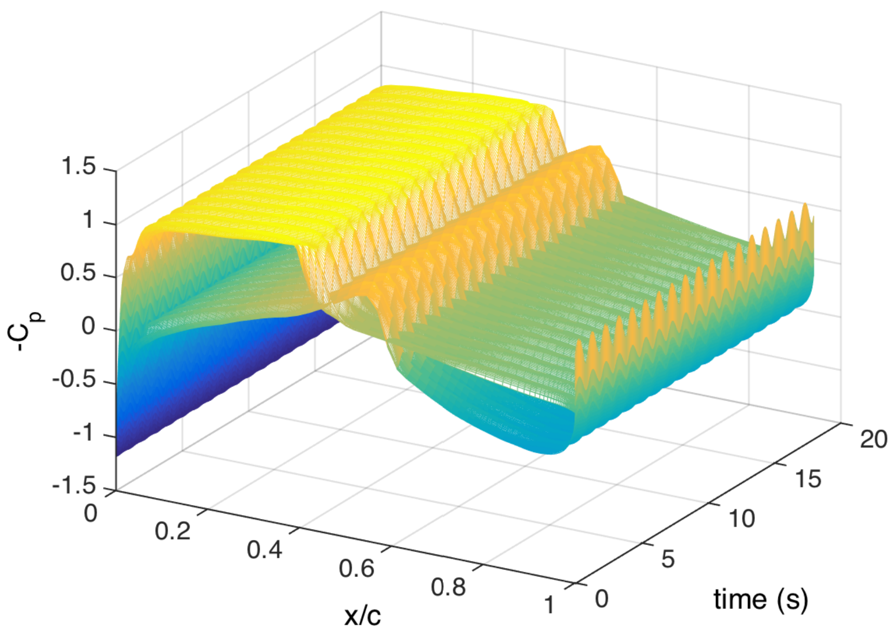
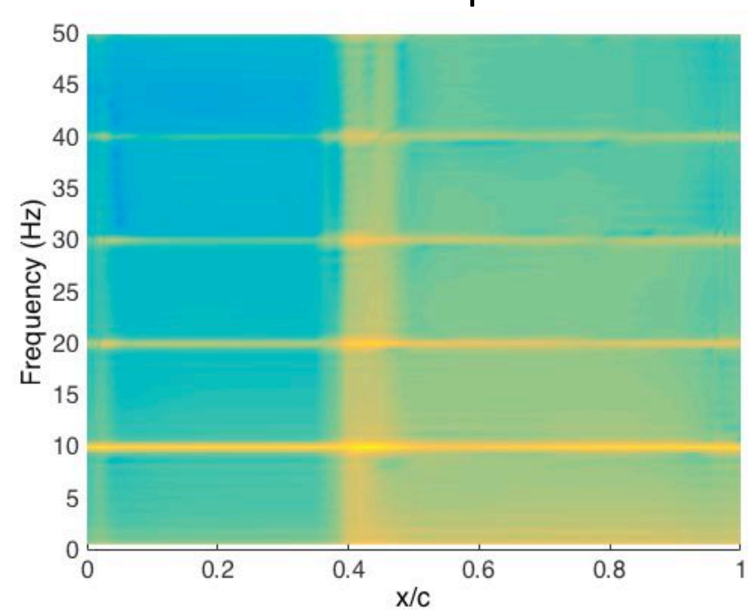
CASE 3 (M 0.85, AOA 5^O, R-134A) - FORCED EXCITATION, 10HZ

- SST (and SA) turbulence model
- dt=2e-4 sec -> 500 time steps in a cycle
- Snapshots every 10 time steps -> 50 snapshots in a cycle
- 18 cycles simulated

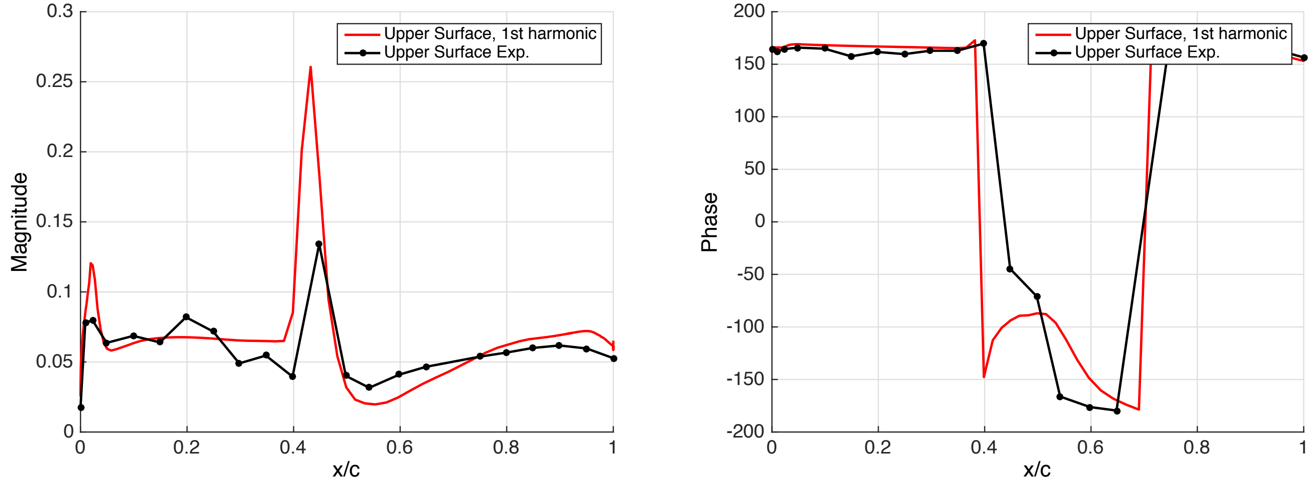


PSD of Cp

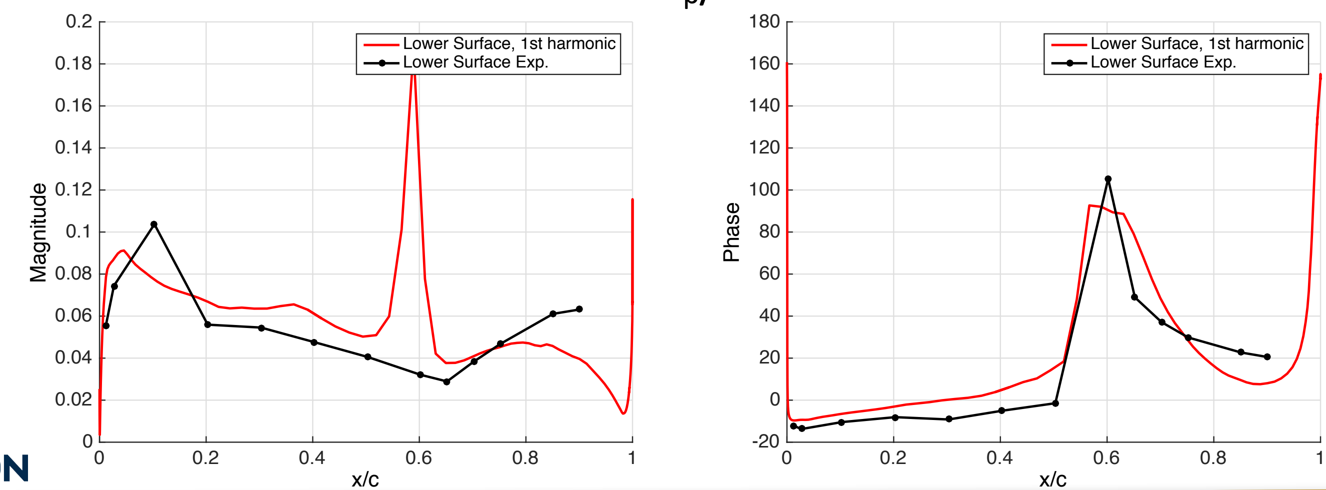


CASE 3 (M 0.85, AOA 5^{O}, R-134A) - FORCED EXCITATION, 10HZ

Upper Surface C_p/θ Transfer Function



Lower Surface C_p/θ Transfer Function



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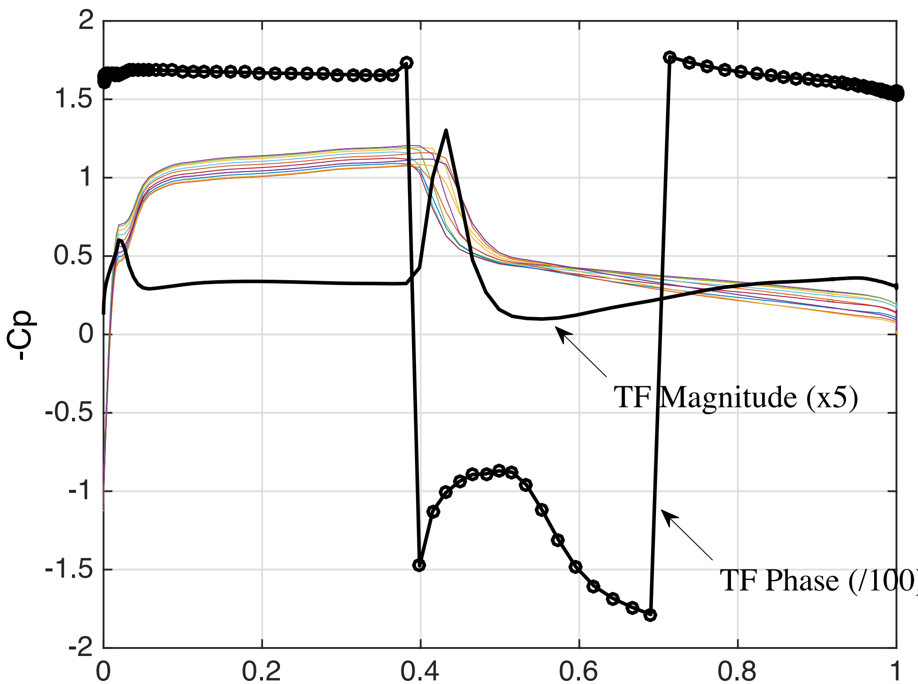
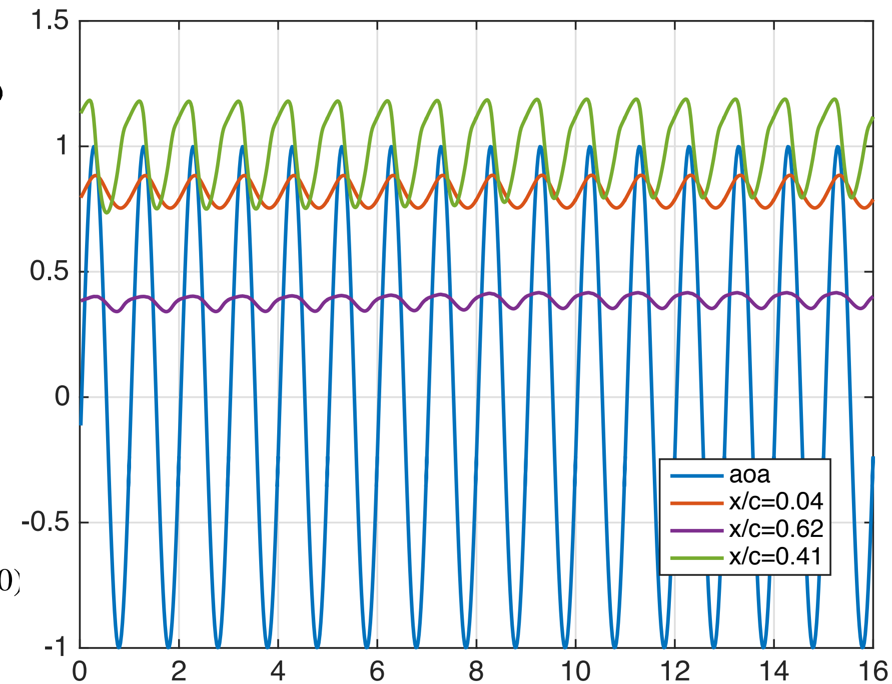
CASE 3 (M 0.85, AOA 5^{o}, R-134A) - FORCED EXCITATION, 10HZ

Upper Surface -Cp during a cycle
TF Magnitude, and phase shift region



$$k = \frac{2\pi f b}{V} = 0.09$$

AoA, and -Cp at various chord locations



SUMMARY

- Good prediction of WT results for the static, forced, and flutter experiments, in attached and mildly separated cases (Cases 1 and 2)
- Under massively separated flow conditions (Case 3) commonly used turbulence model can not accurately predict the complex flow physics
- Yet simulations of forced excitation response (and flutter?) are feasible, offering reasonable accuracy
- Some sensitivity to computational parameters (convergence)
- Little sensitivity to mesh
- Lack CFD-based flutter prediction capability