EMBRAER

CFD Results for AePW-2

Cleber Spode

&

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03/Jan/2016

CFD Codes & Parameters

- **CFD++ (MetacompTech)**

  Meshes: Mixed node based (coarse, medium, fine)
  Solver: Compressible Navier-Stokes
  Turbulence Model: k-omega SST
  Time Step: 0.00078168 (128 pts/cycle)
  Simulation Time: 8 cycles
  Cycles for FFT: last 4 cycles

- **Aero (CMSoft)**

  Meshes: Mixed node based (coarse, medium, fine)
  Solver: Compressible Navier-Stokes
  Newton-Krylov
  Turbulence Model: SA-fv3
  Time Step: 0.001s (100 pts/cycle)
  Simulation Time: 10 cycles
  Cycles for FFT: last 5 cycles

Case 1

	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 $f = 10\text{Hz}, \lvert\theta\rvert = 1^\circ$	Flutter	Unforced Unsteady	Forced oscillation $f = 10\text{Hz}, \lvert\theta\rvert = 1^\circ$	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 1 – Summary of Results

STEADY Runs:

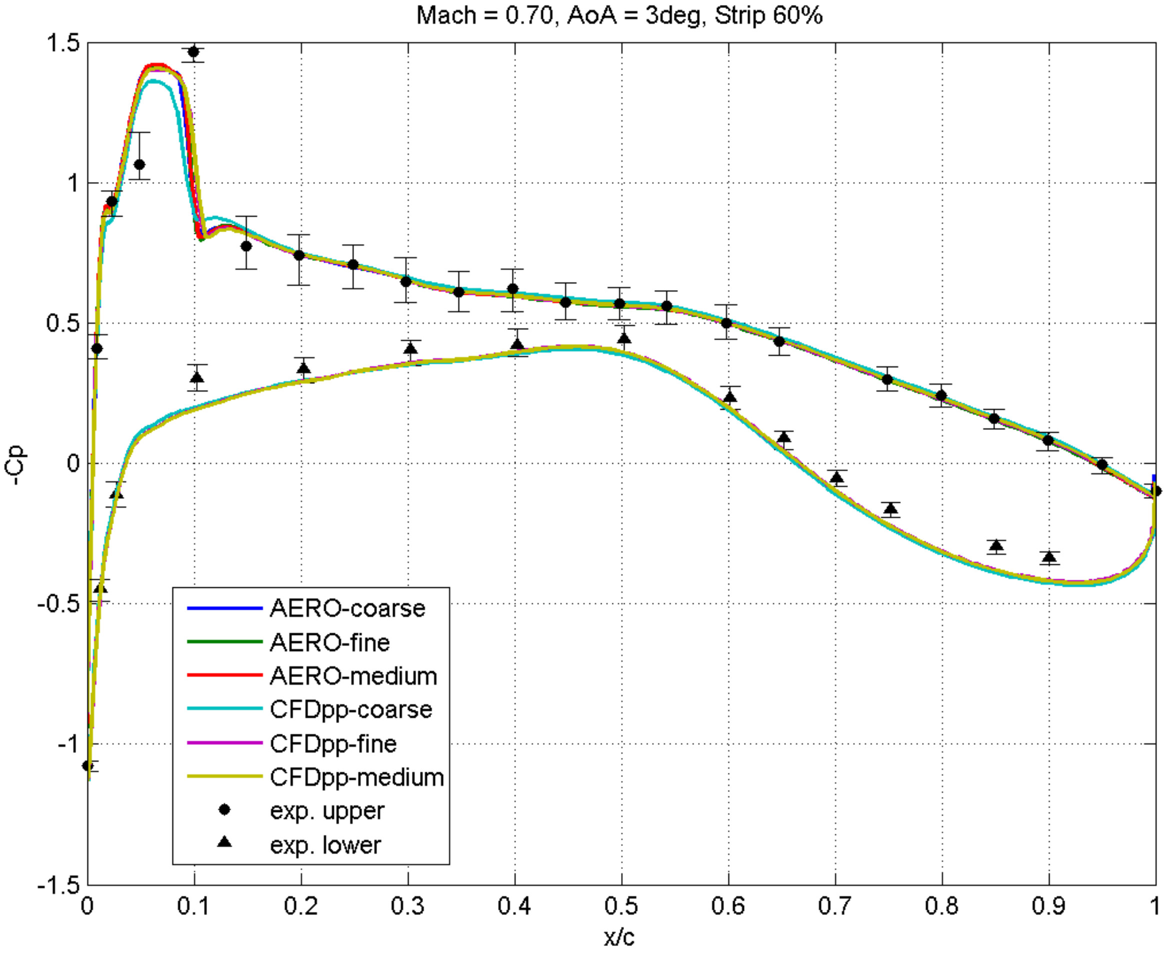
- All runs converged to a steady state solution

UNSTEADY Runs:

- No effects due to number of points used for FFT

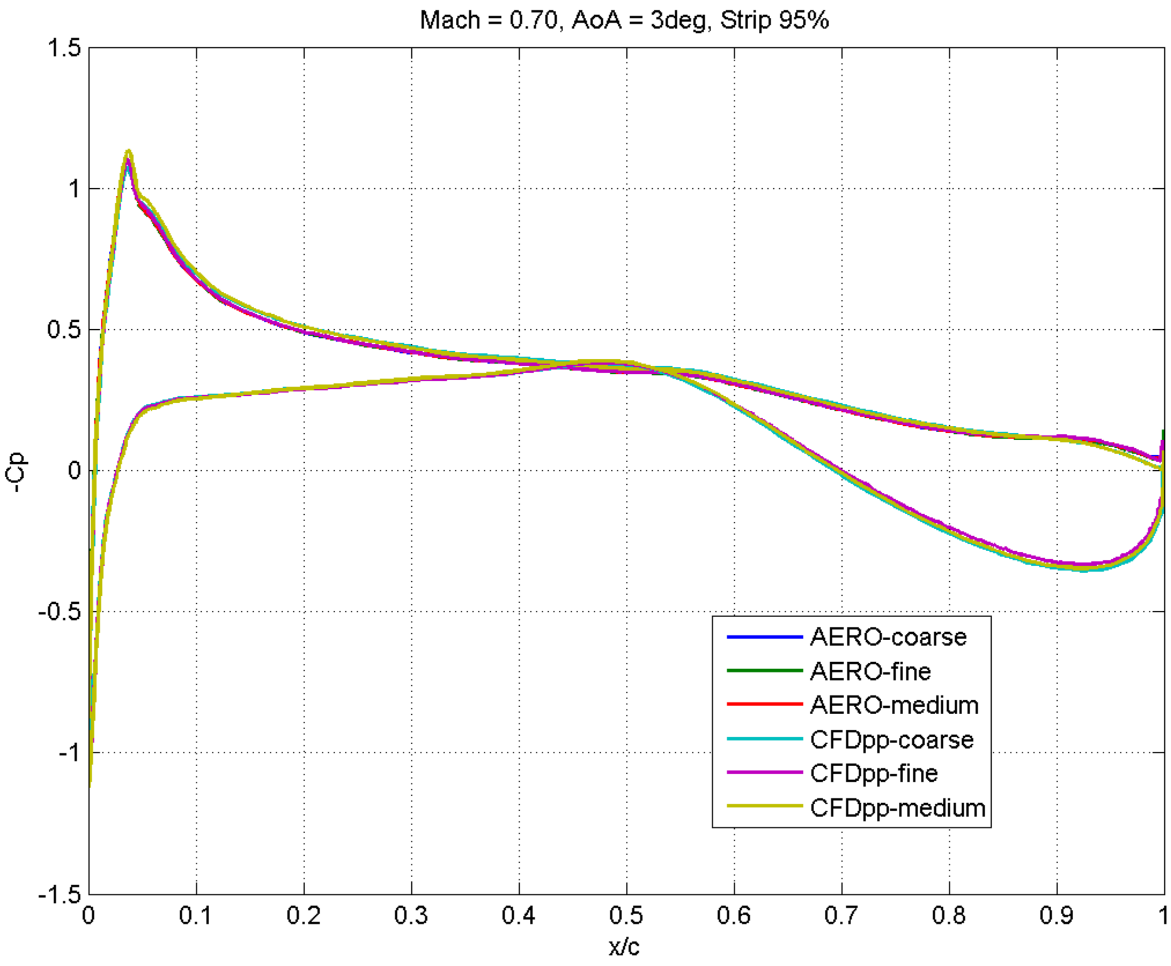
Case 1 – Steady Results

- Strip 60%

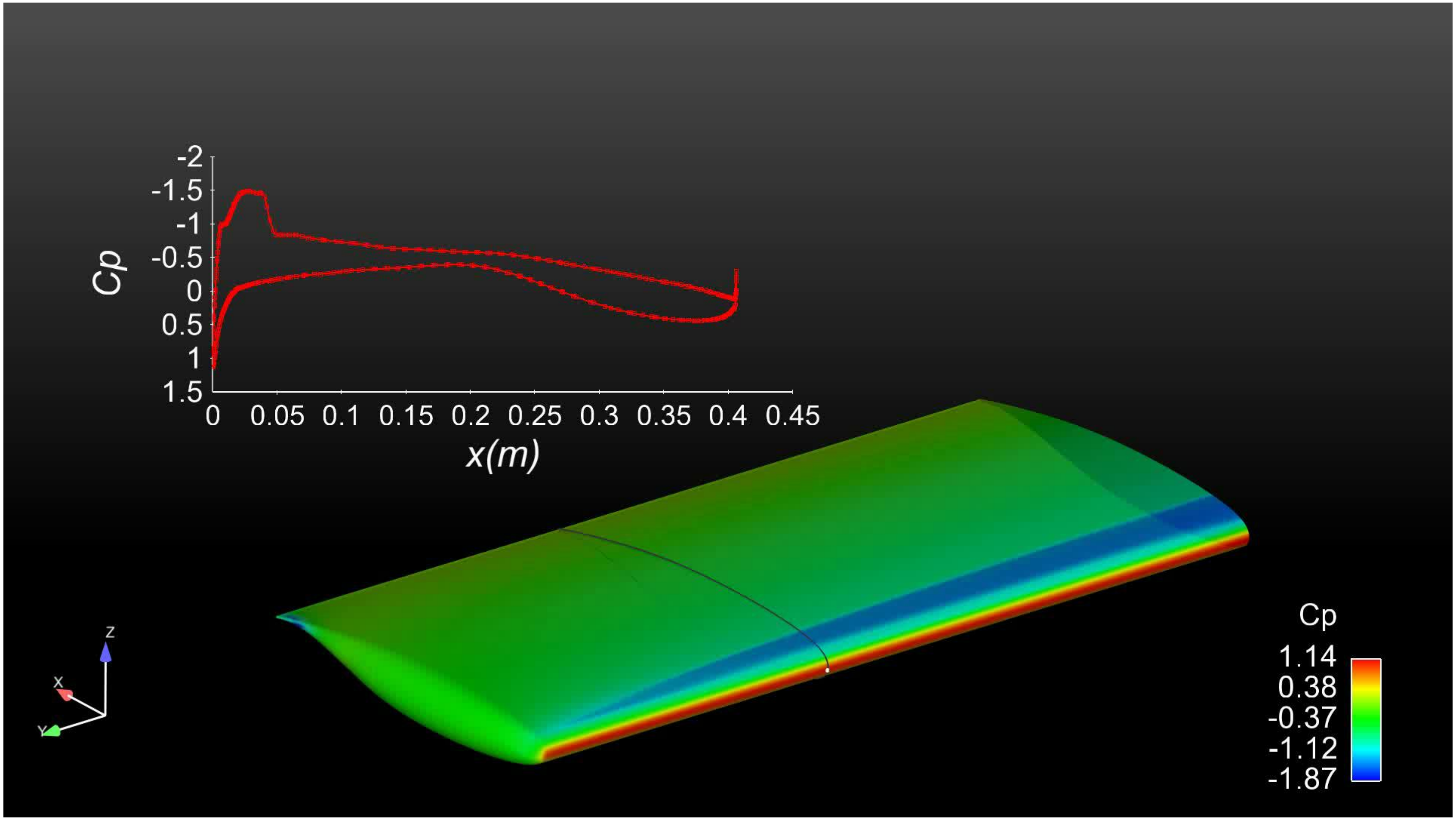


Case 1 – Steady Results

- Strip 95%



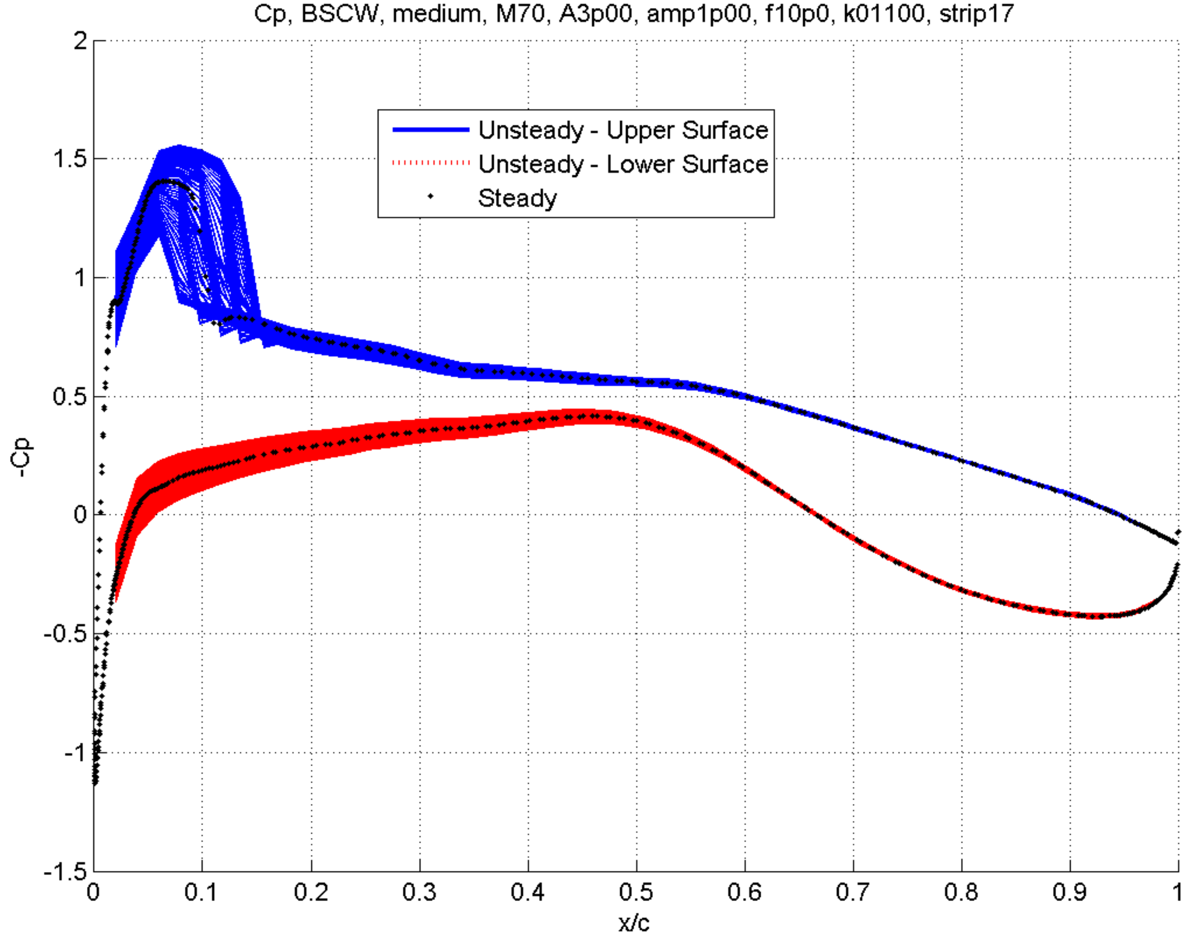
Case 1 – Unsteady Forced → α = 3° + sin(2π f t)



Mach = 0.7, Re = 4.56E6, f = 10Hz

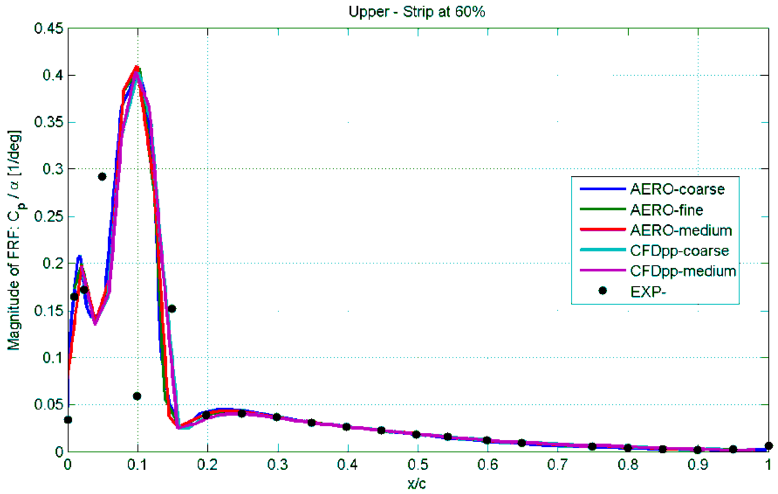
Case 1 – Unsteady Forced

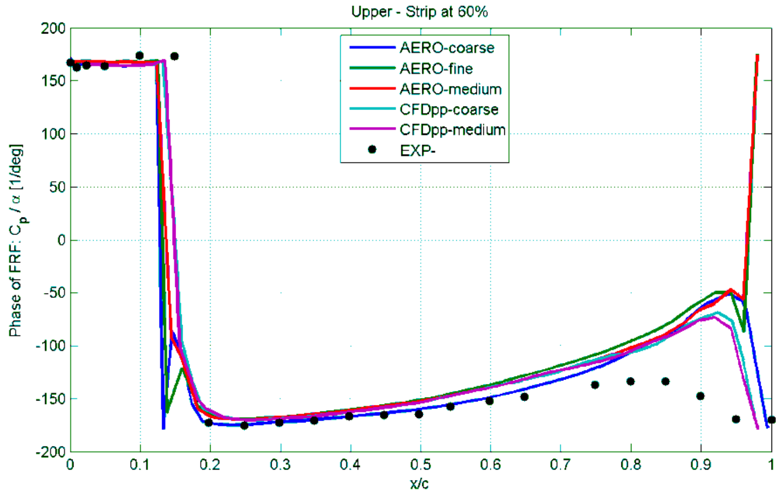
- Strip 60%



Case 1 – Unsteady Results (Mag & Phase)

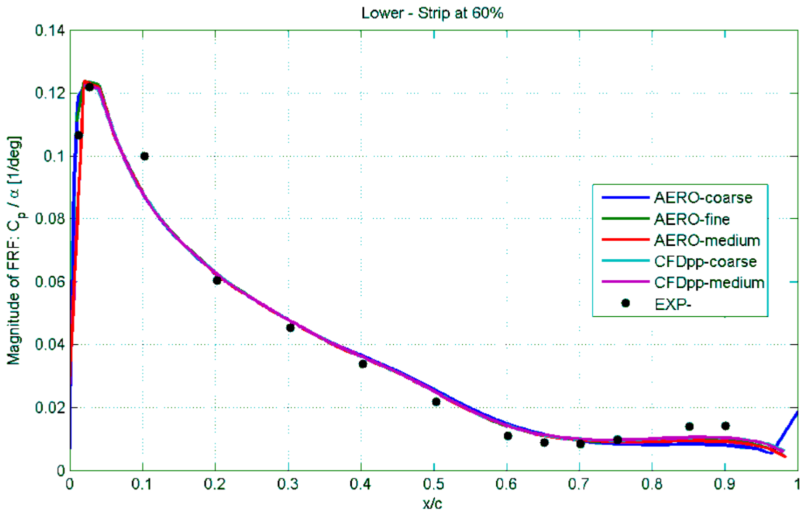
- Upper Side – 60%

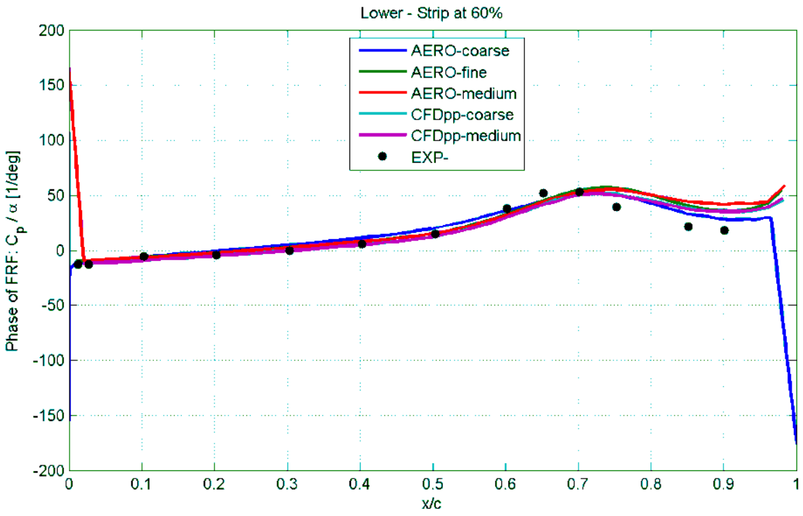




Case 1 – Unsteady Results (Mag & Phase)

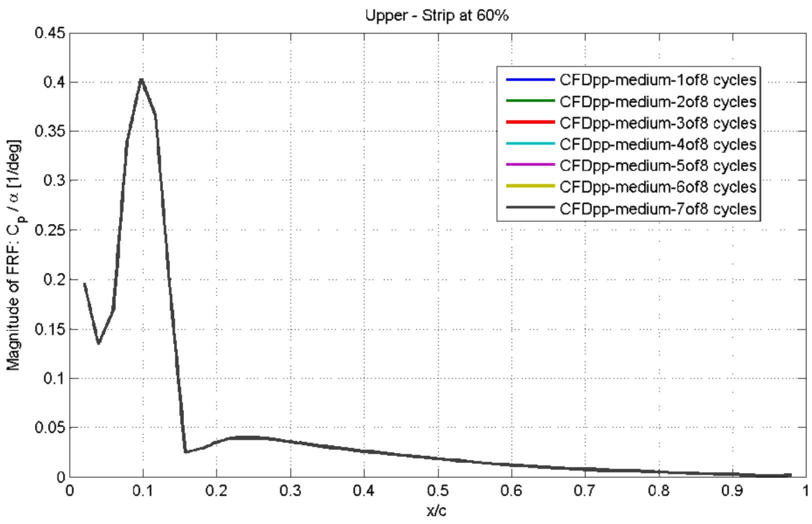
- Lower Side – 60%

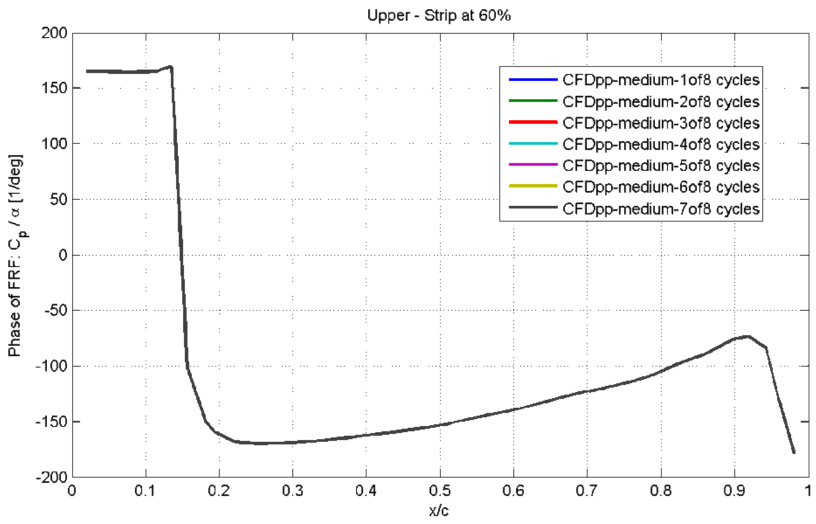




Case 1 – Unsteady Results (Mag & Phase)

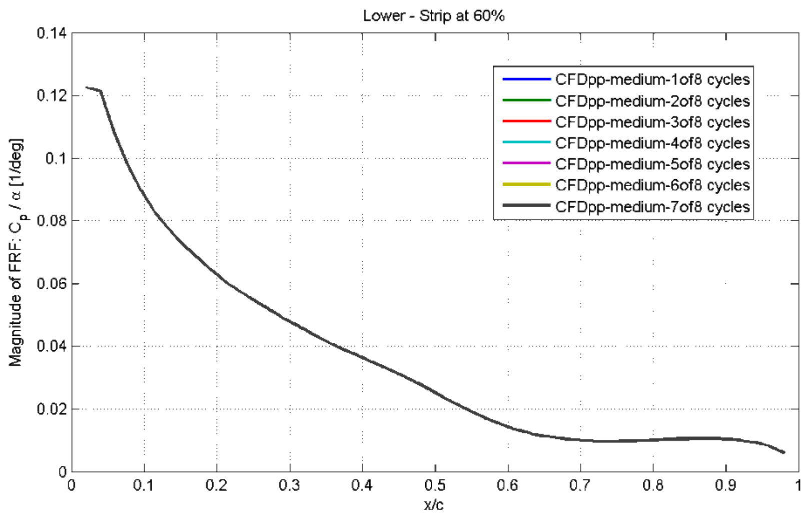
- Effect of Number of Cycles used for FFT - Upper Side – 60%

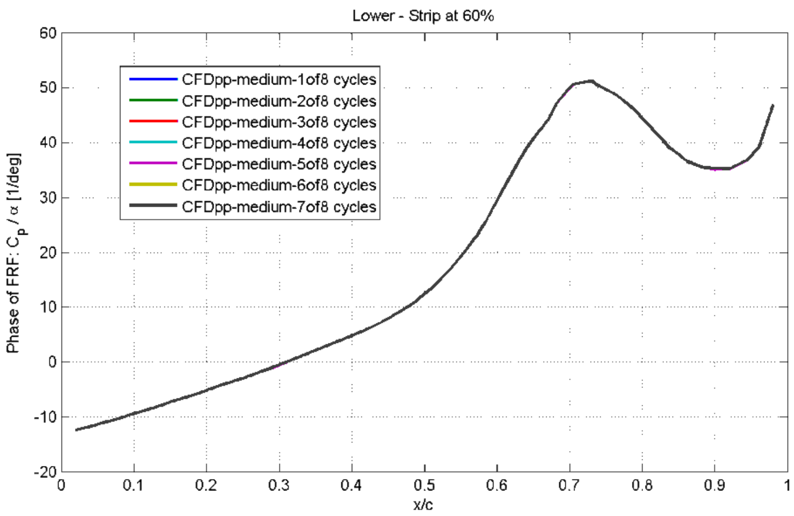




Case 1 – Unsteady Results (Mag & Phase)

- Effect of Number of Cycles used for FFT - Lower Side – 60%

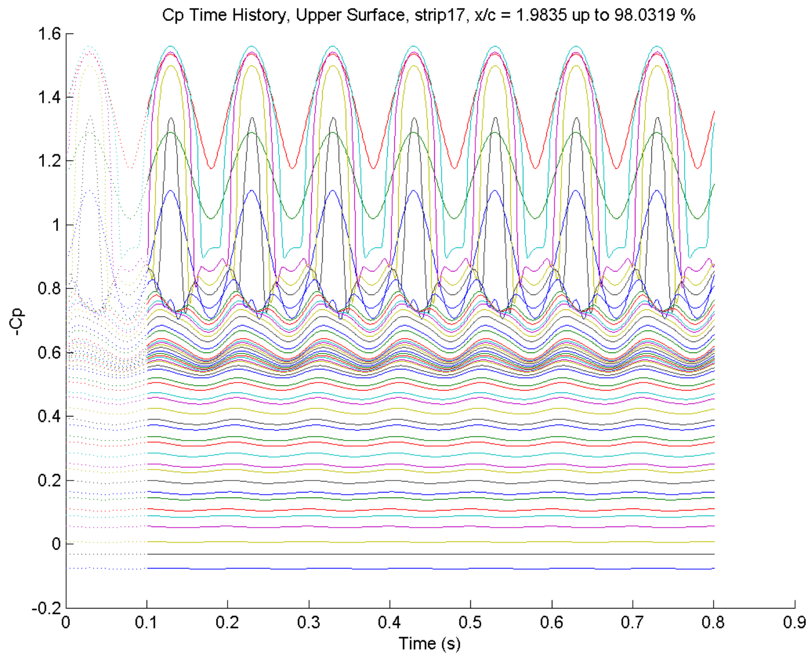




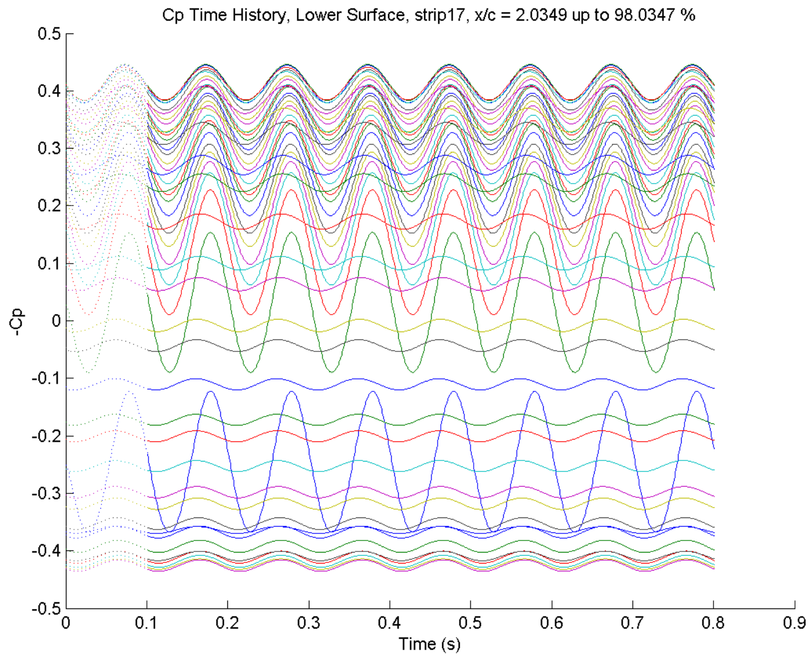
Case 1 – Unsteady Results (Time Histories)

- Strip 60%

- Upper



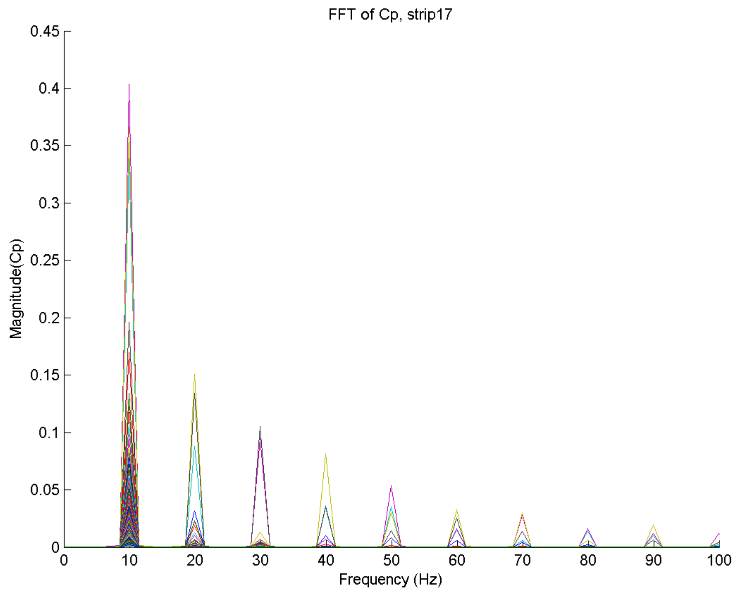
- Lower



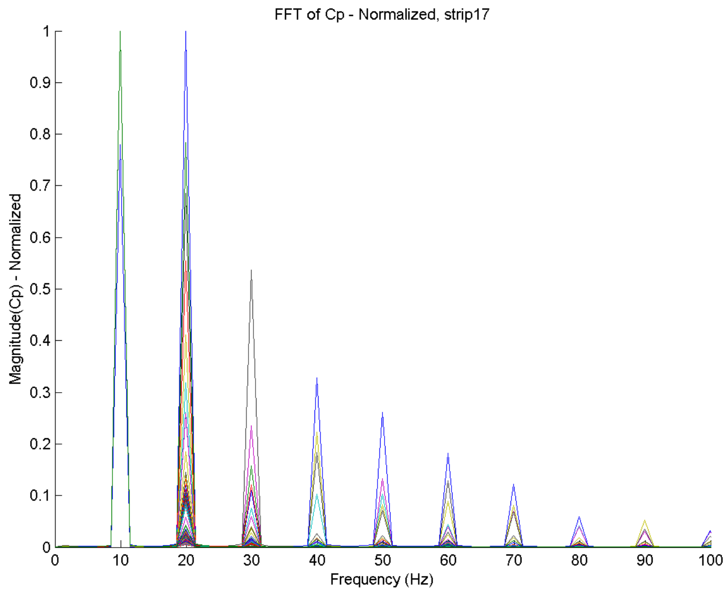
Case 1 – Unsteady Results (Frequency Content)

- Strip 60%

- FFT

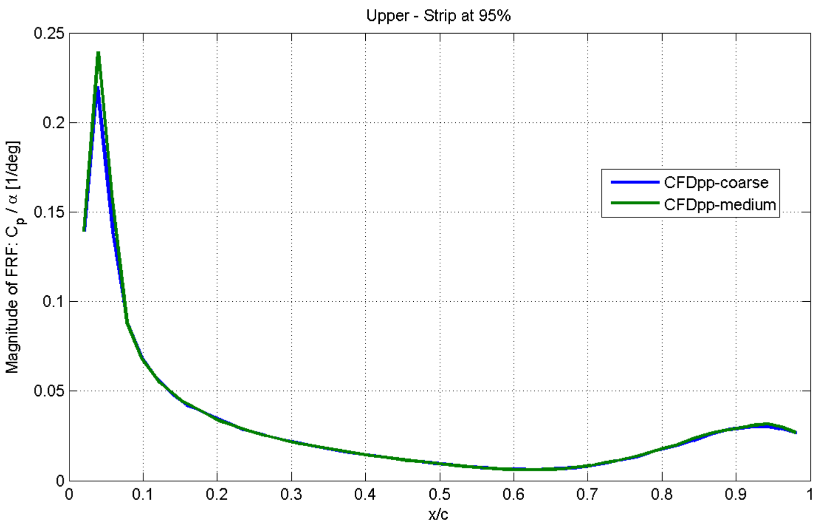


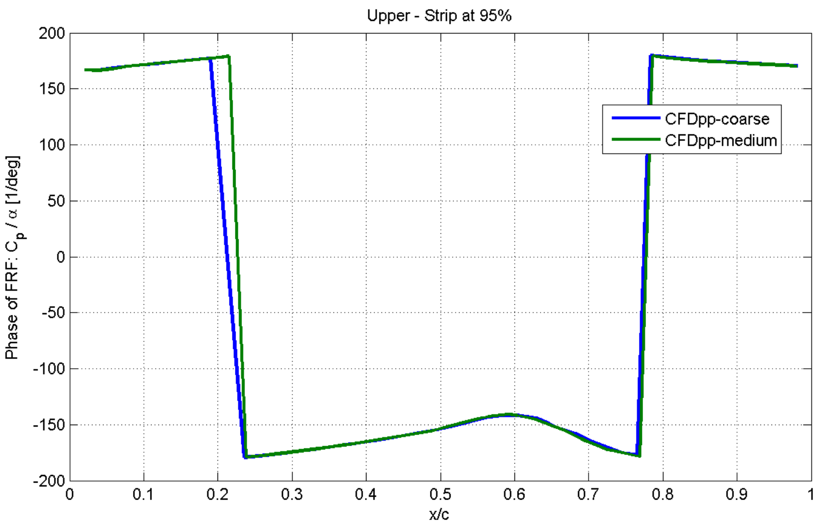
- FFT Normalized
(maximum amplitude of each sensor equal to 1)



Case 1 – Unsteady Results (Mag & Phase)

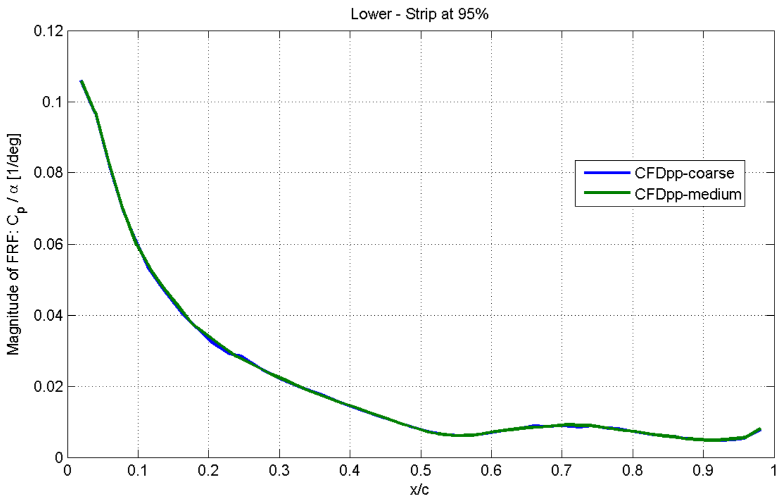
- Upper Side – 95%

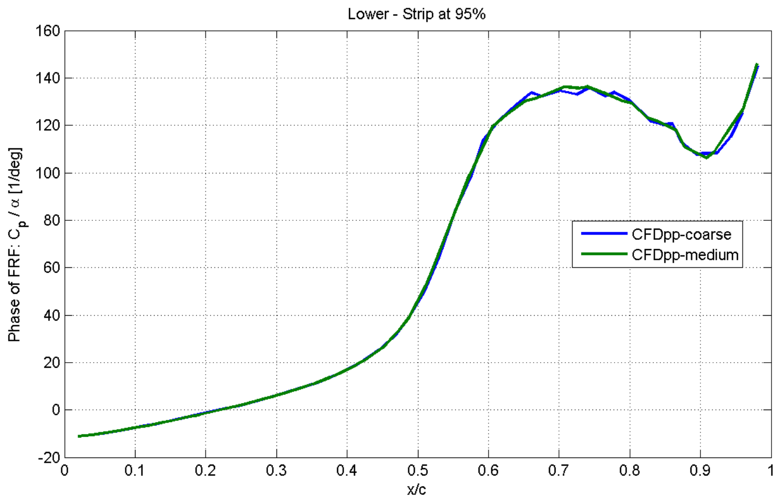




Case 1 – Unsteady Results (Mag & Phase)

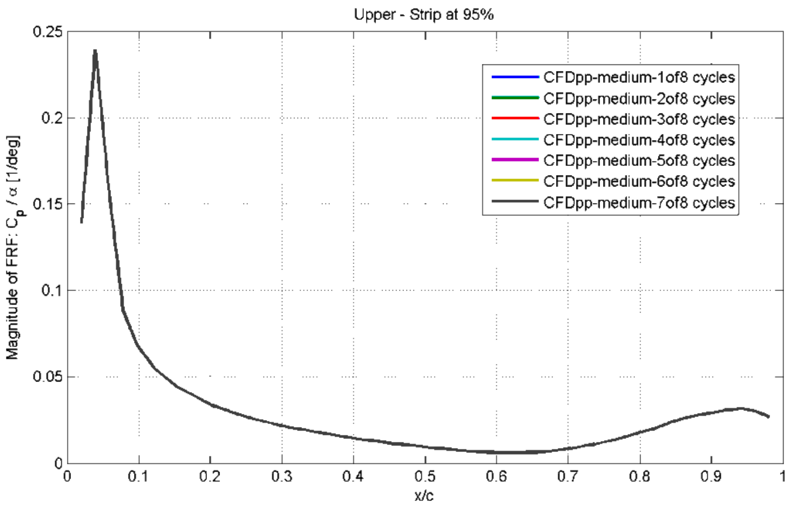
- Lower Side – 95%

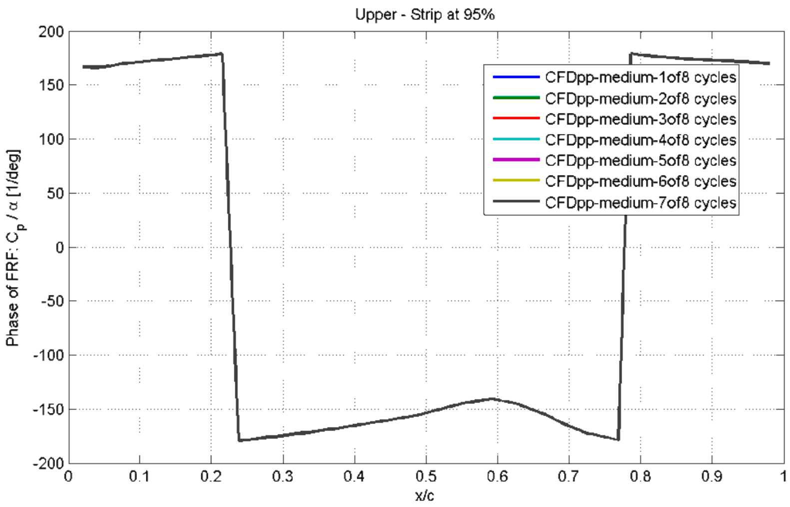




Case 1 – Unsteady Results (Mag & Phase)

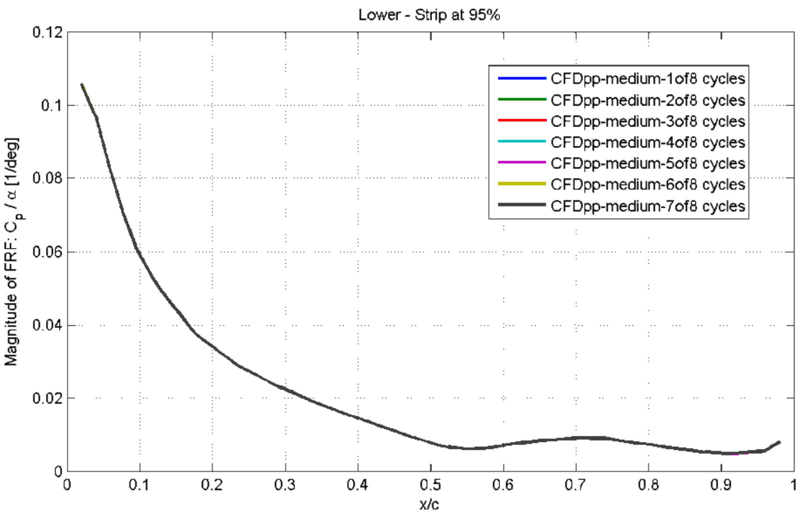
- Effect of Number of Cycles used for FFT - Upper Side – 95%

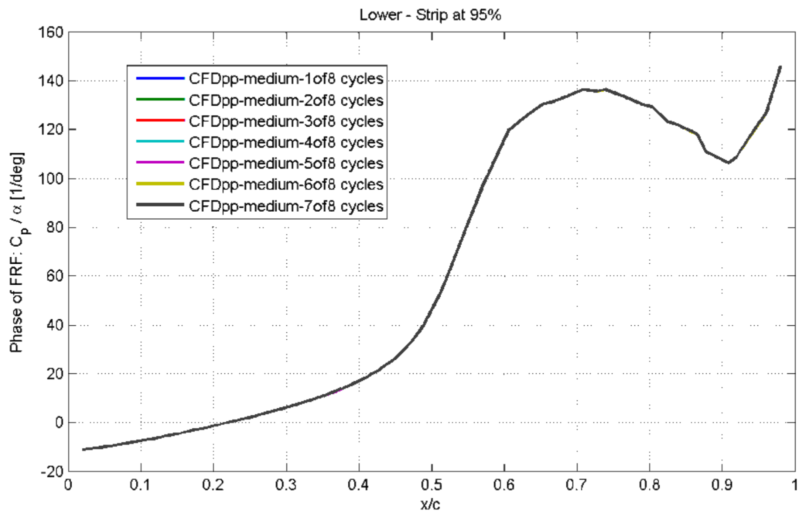




Case 1 – Unsteady Results (Mag & Phase)

- Effect of Number of Cycles used for FFT - Lower Side – 95%

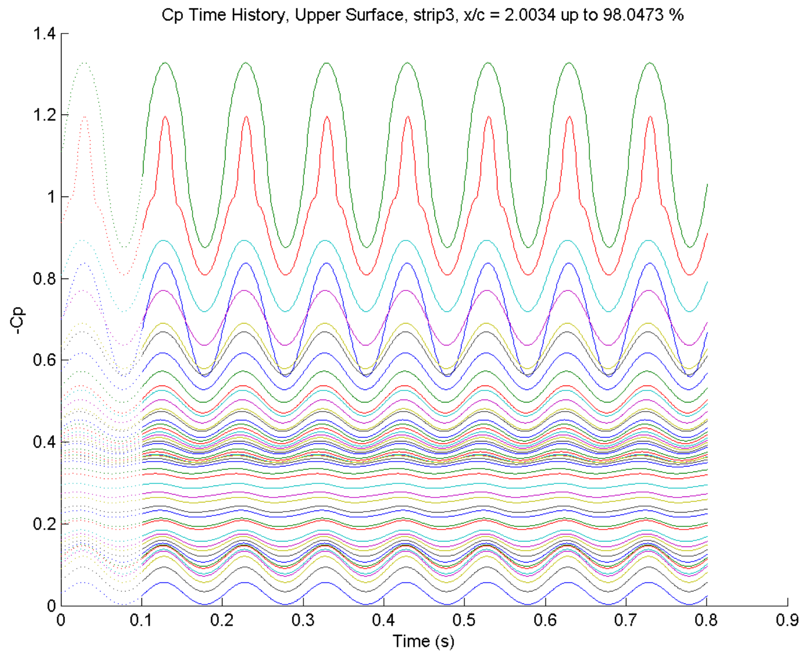




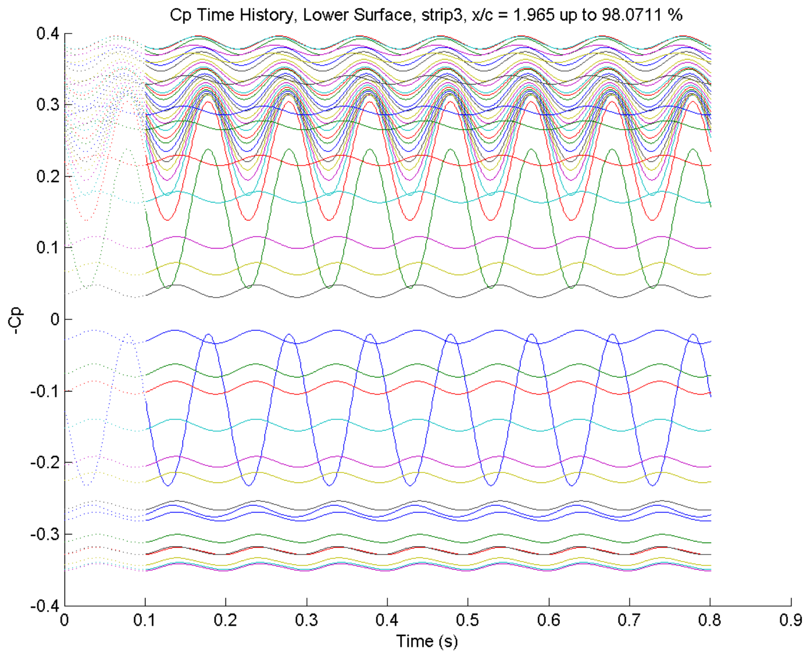
Case 1 – Unsteady Results (Time Histories)

- Strip 95%

- Upper



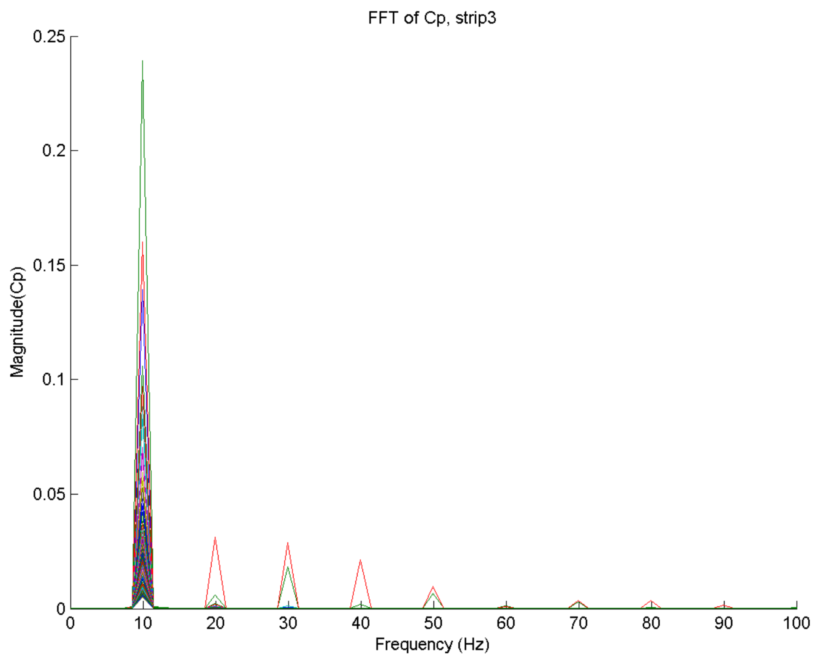
- Lower



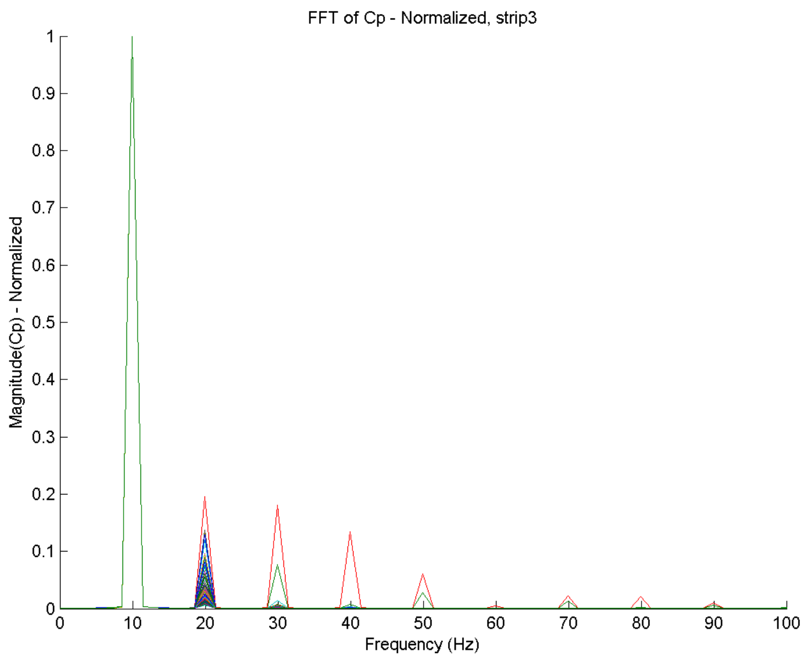
Case 1 – Unsteady Results (Frequency Content)

- Strip 95%

- FFT



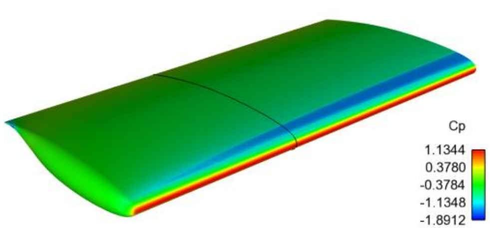
- FFT Normalized
(maximum amplitude of each sensor equal to 1)



Case 2 – Flutter

	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 $f = 10\text{Hz}, \lvert\theta\rvert = 1°$	Flutter	Unforced Unsteady	Forced oscillation $f = 10\text{Hz}, \lvert\theta\rvert = 1°$	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

FSI (Fluid Structure Iteraction) → DYNAMIC AEROELASTIC RESPONSE



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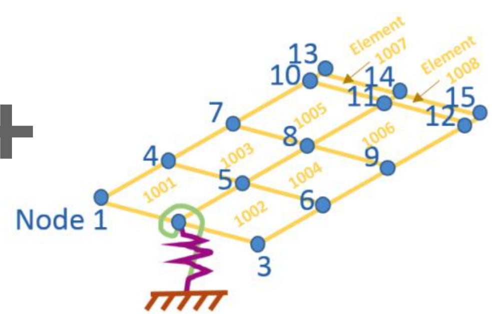

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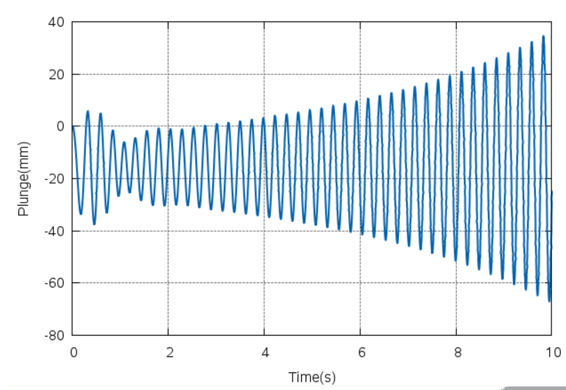


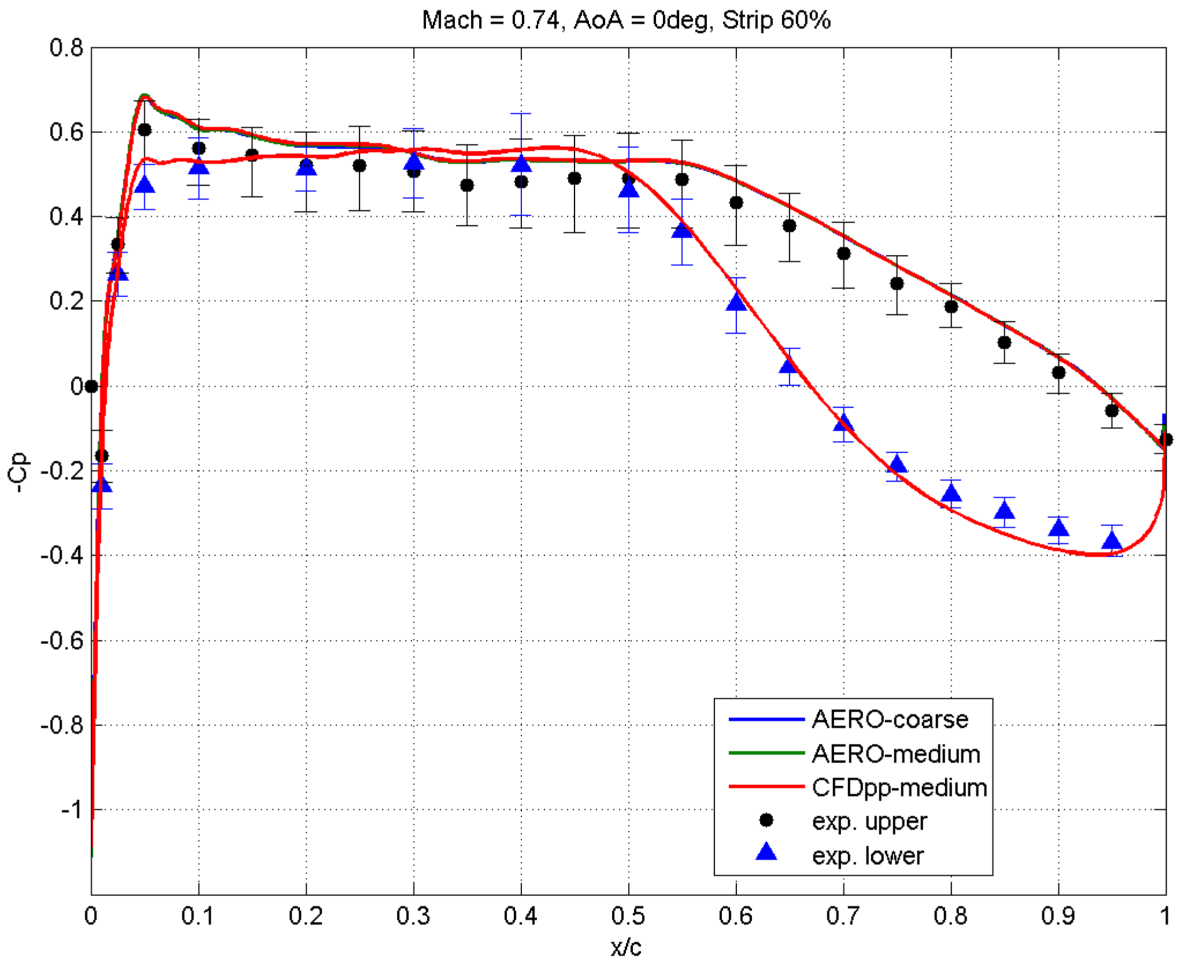
Case 2 – Setup

- **CFD++ (MetacompTech) – Steady rigid**
  Meshes: Mixed node based (medium)
  Solver: Compressible Navier-Stokes
  Turbulence Model: k-omega SST

- **Aero (CMSoft) - Steady Rigid, Static Aeroelastic and Flutter**
  Meshes: Mixed node based (coarse, medium)
  Solver: Compressible Navier-Stokes
  Newton-Krylov
  Modal Approach
  Fluid-structure staggered solution coupling (2nd order)
  Turbulence Model: SA-fv3
  Time Step: 0.001s
  Simulation Time: 10 s

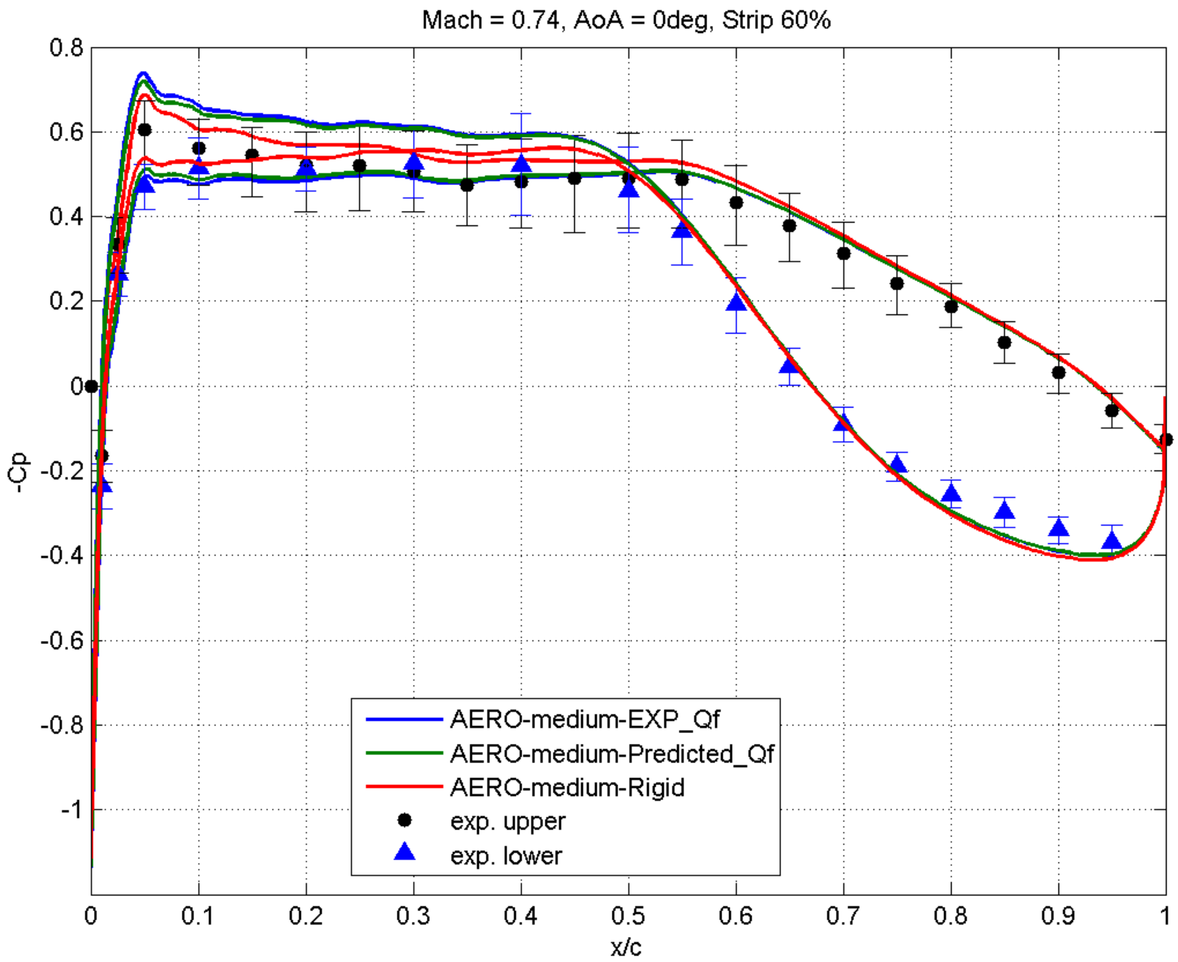
Case 2 – Steady Results

- Strip 60% - Rigid



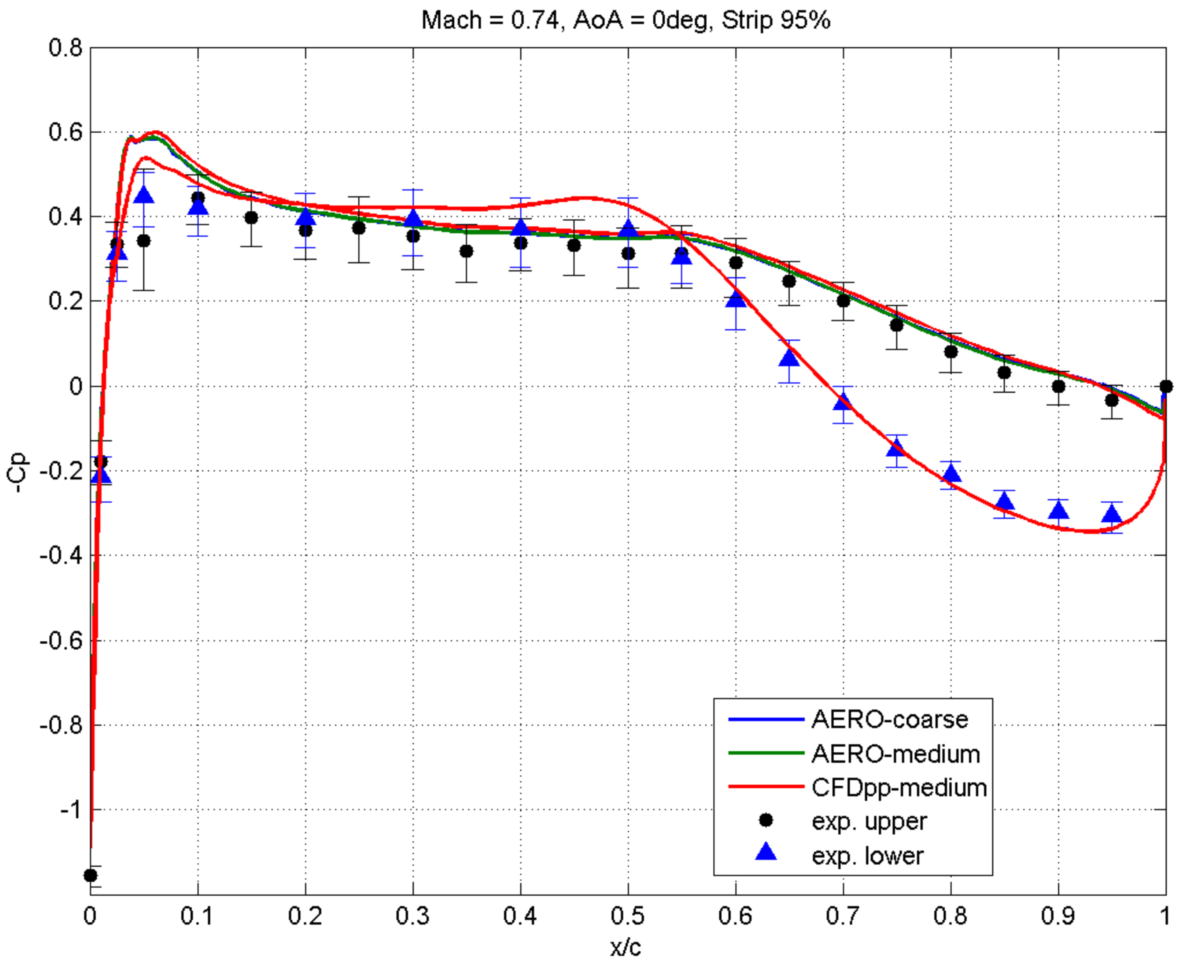
Case 2 – Steady Results

- Strip 60% - Static Aeroelastic



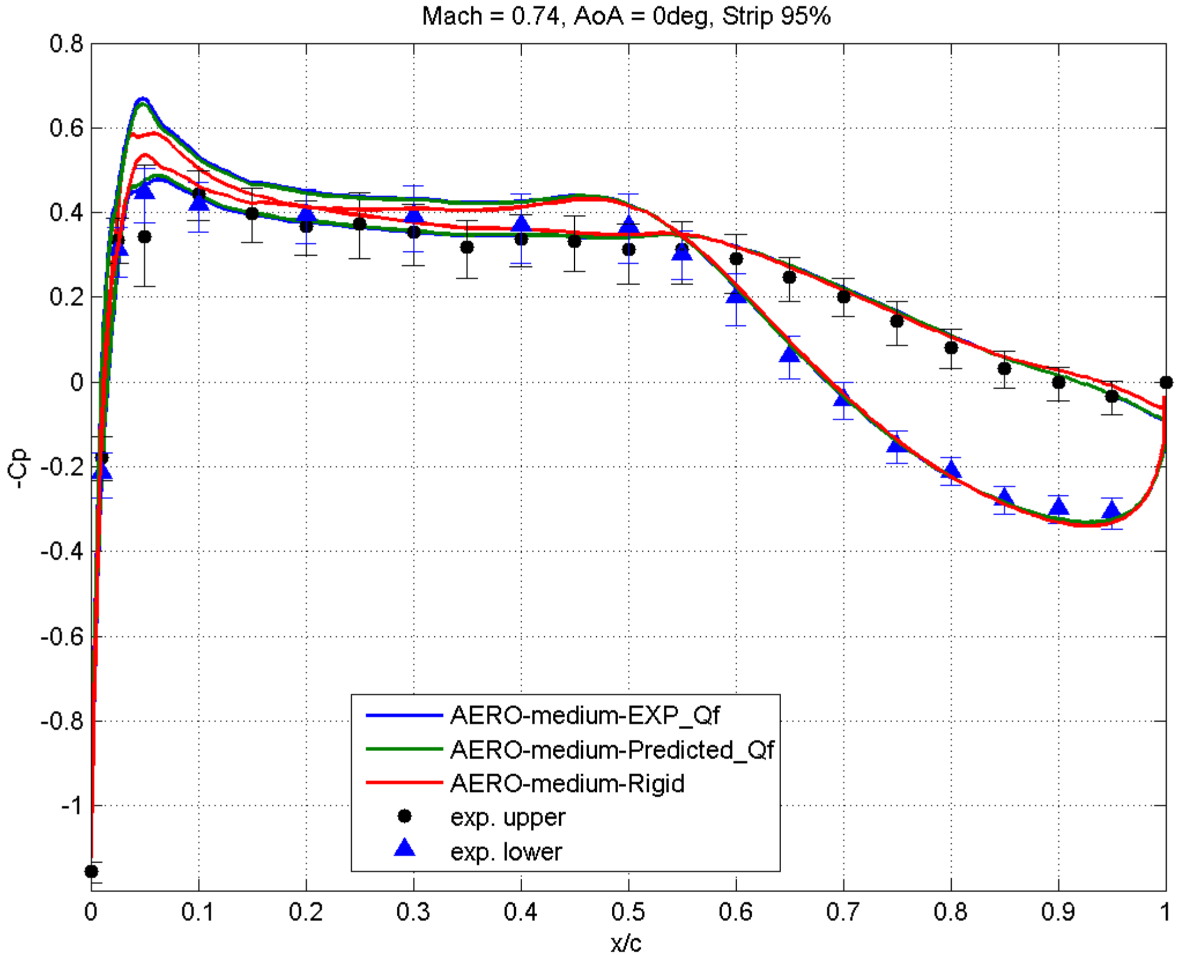
Case 2 – Steady Results

- Strip 95% - Rigid



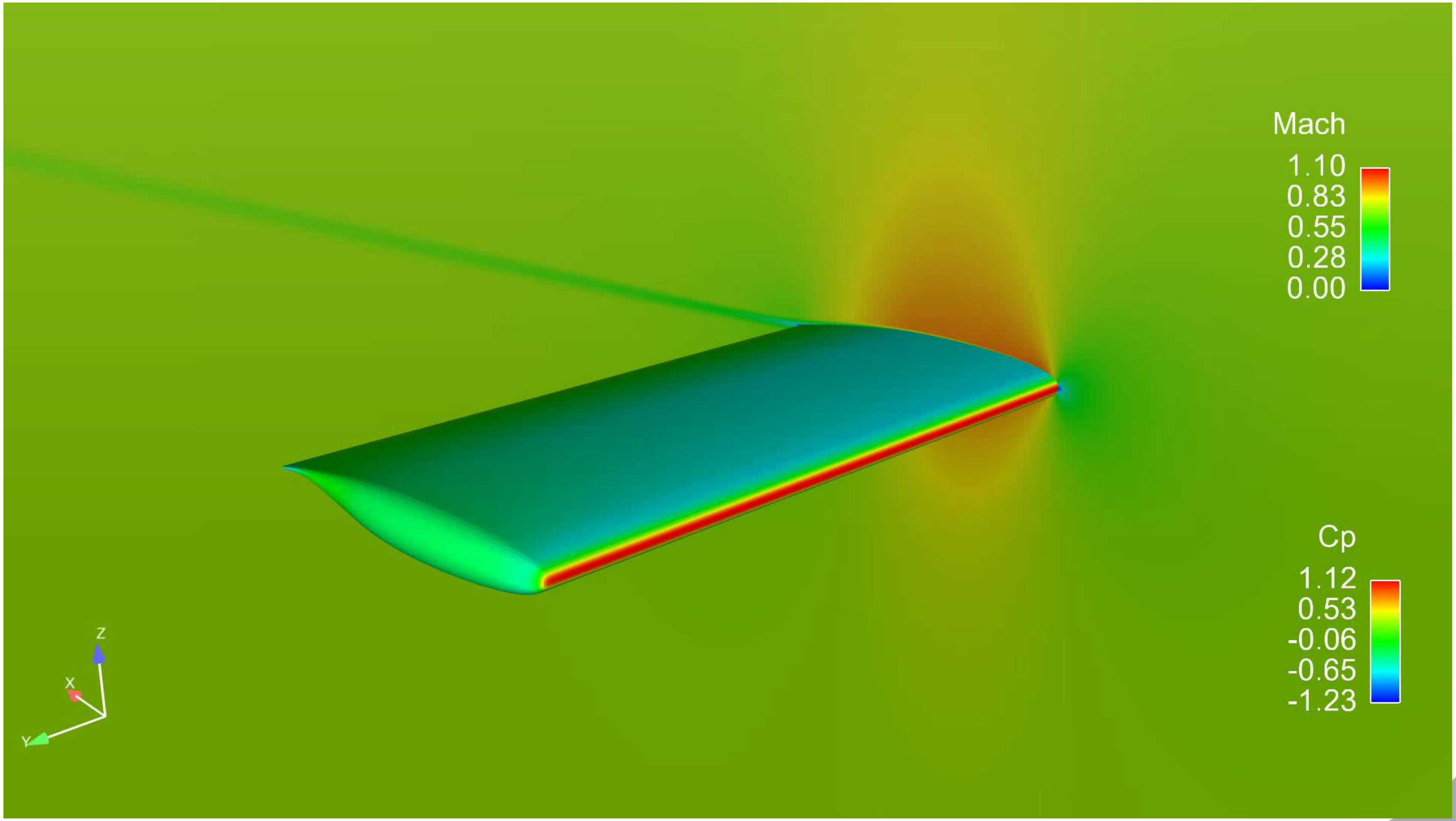
Case 2 – Steady Results

- Strip 95% - Static Aeroelastic



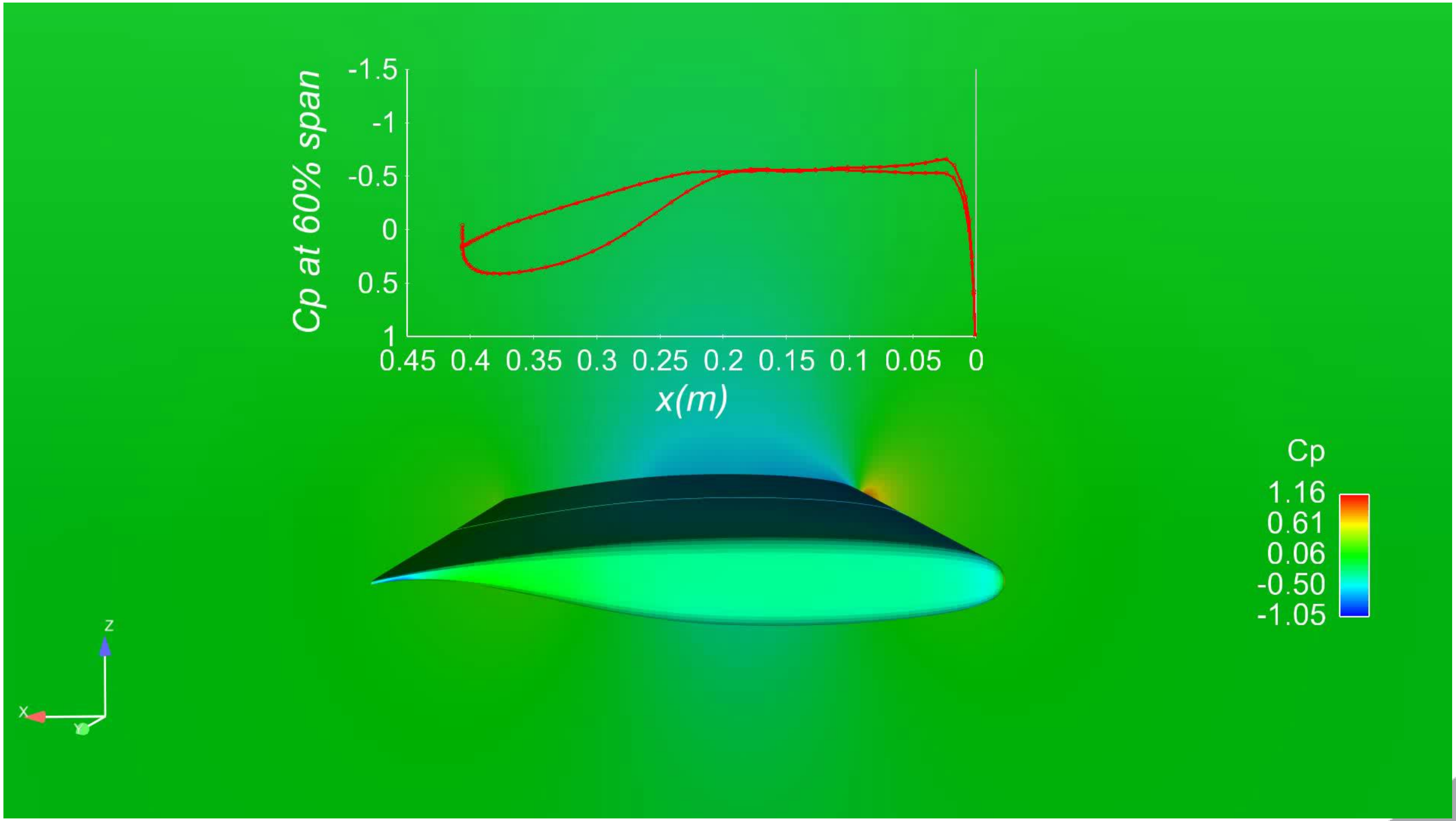
Case 2 – Flutter

Mach = 0.74, Re = 4.45E6 , Initial Condition α = 0° (Steady State Solution)



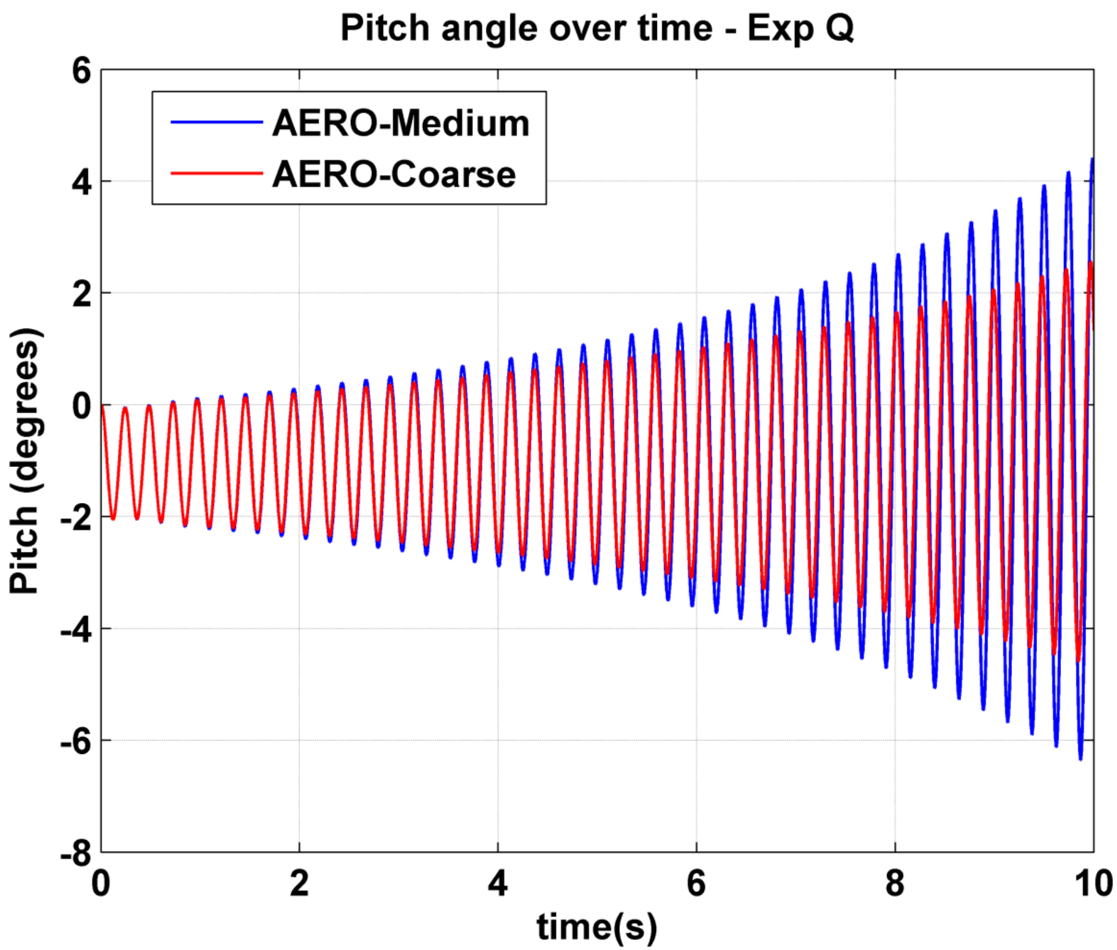
Case 2 – Flutter

Mach = 0.74, Re = 4.45E6 , Initial Condition α = 0° (Steady State Solution)



Case 2 – Flutter - NS

Mach = 0.74, Re = 4.45E6 , q = 168.8 psf ,Initial Condition α = 0° (Steady State Solution)



Coarse Mesh

Frequency: 4.1111 Hz

Damping: -0.005077
192 CPU (191CFD+1FEM)
~56 h CPU Wall time Coarse

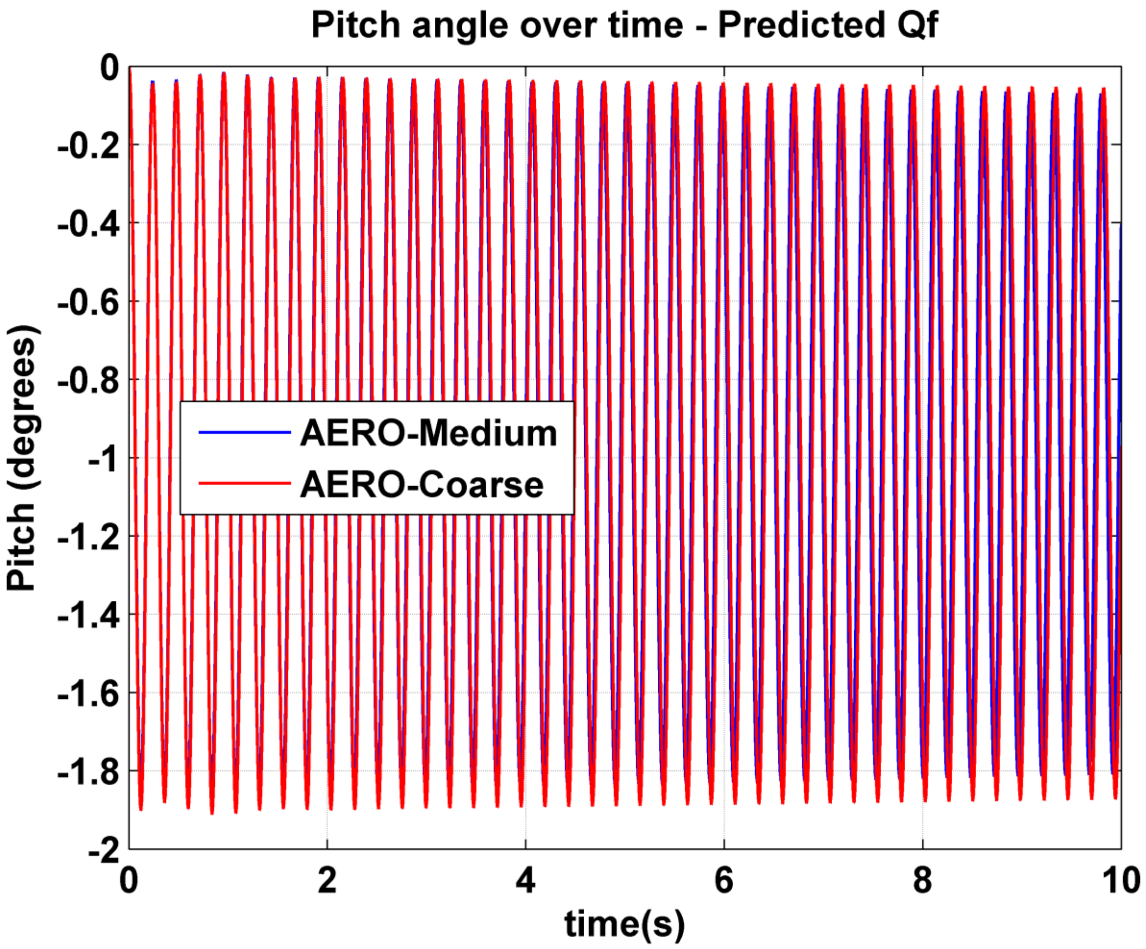
Medium Mesh

Frequency: 4.1003 Hz

Damping: -0.0068149
382 CPU (381CFD+1FEM)
~130 h CPU Wall time Medium

Case 2 – Flutter - NS

Mach = 0.74, Initial Condition α = 0° (Steady State Solution for each dynamic pressure)



Coarse Mesh

160.8 psf

Frequency: 4.1745 Hz

Damping: 0.000139

Medium Mesh

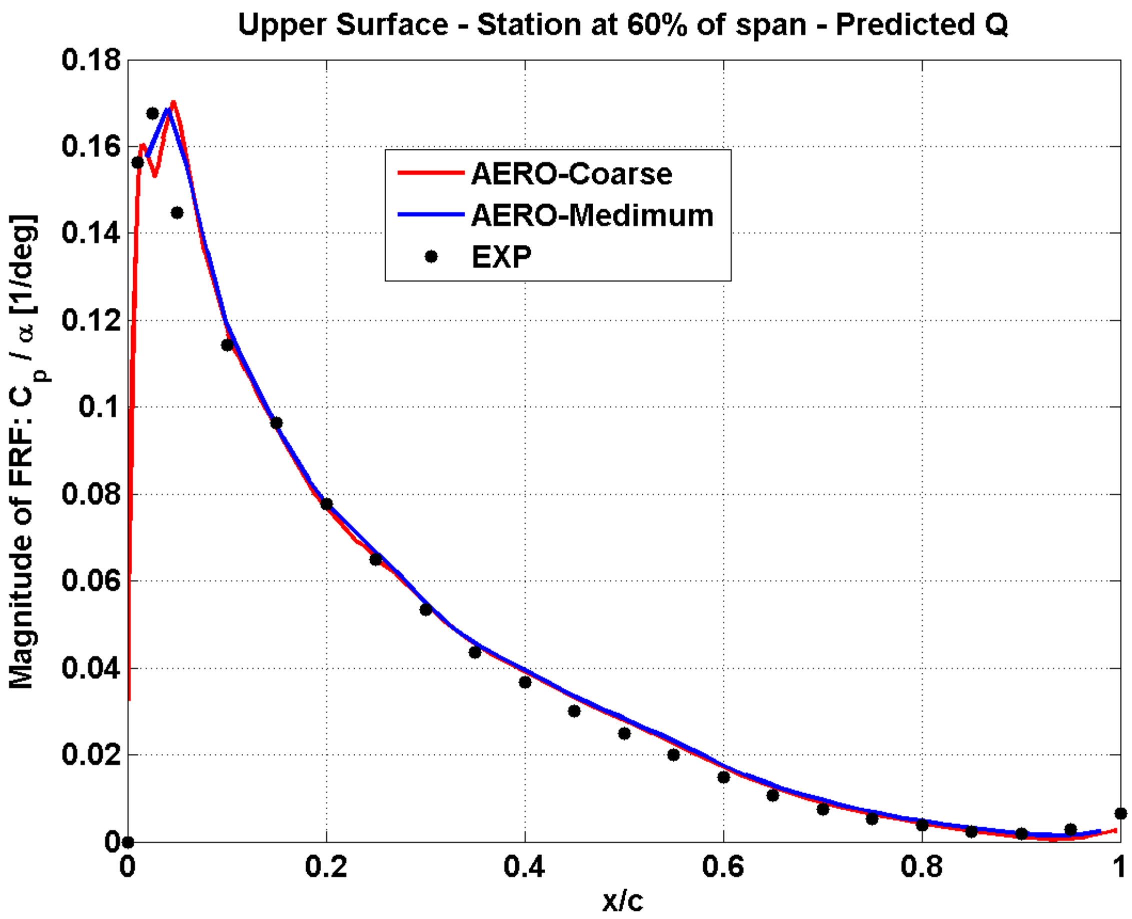
158.6 psf

Frequency: 4.1851 Hz

Damping: 0.0002266

Case 2 – Flutter - NS

Mach = 0.74, Initial Condition α = 0° (Steady State Solution for each dynamic pressure)



Coarse Mesh

160.8 psf

Frequency: 4.1745 Hz

Damping: 0.000139

Medium Mesh

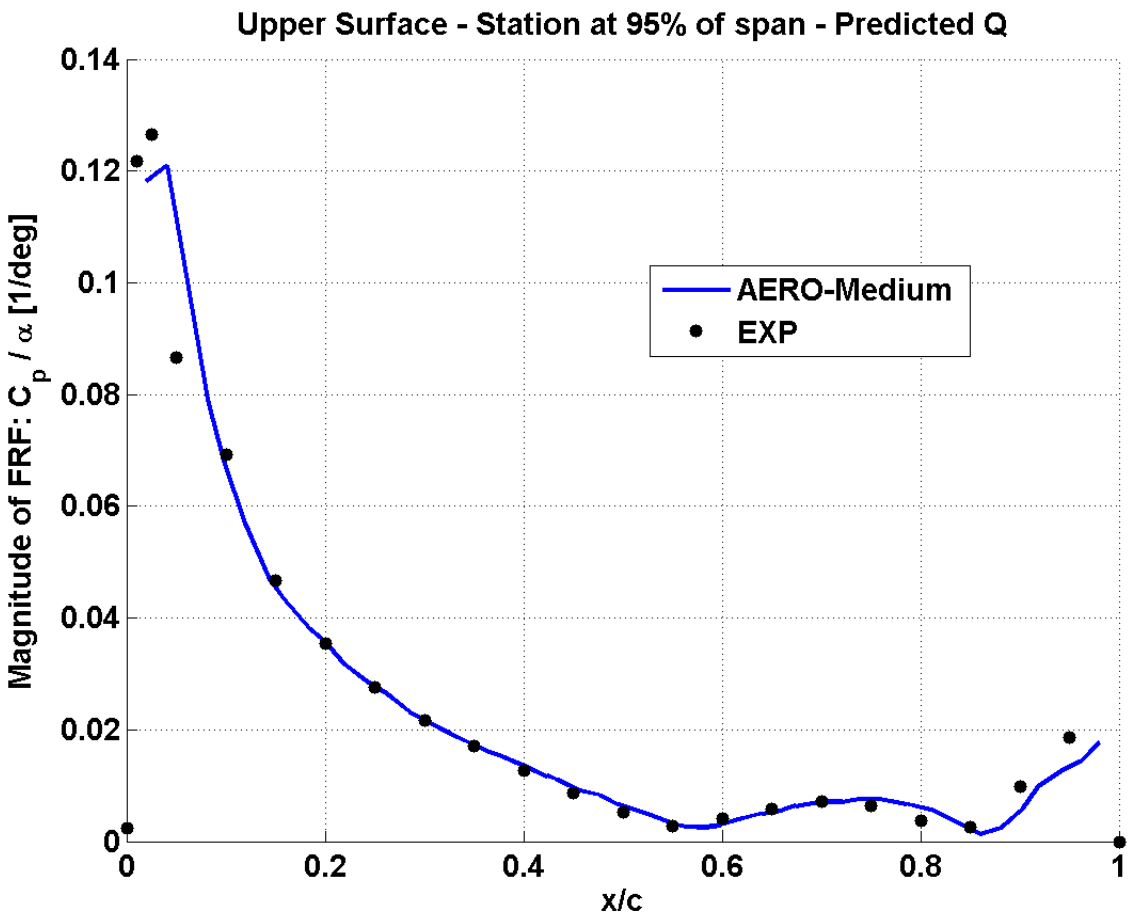
158.6 psf

Frequency: 4.1851 Hz

Damping: 0.0002266

Case 2 – Flutter - NS

Mach = 0.74, Initial Condition α = 0° (Steady State Solution for each dynamic pressure)



Coarse Mesh

160.8 psf

Frequency: 4.1745 Hz

Damping: 0.000139

Medium Mesh

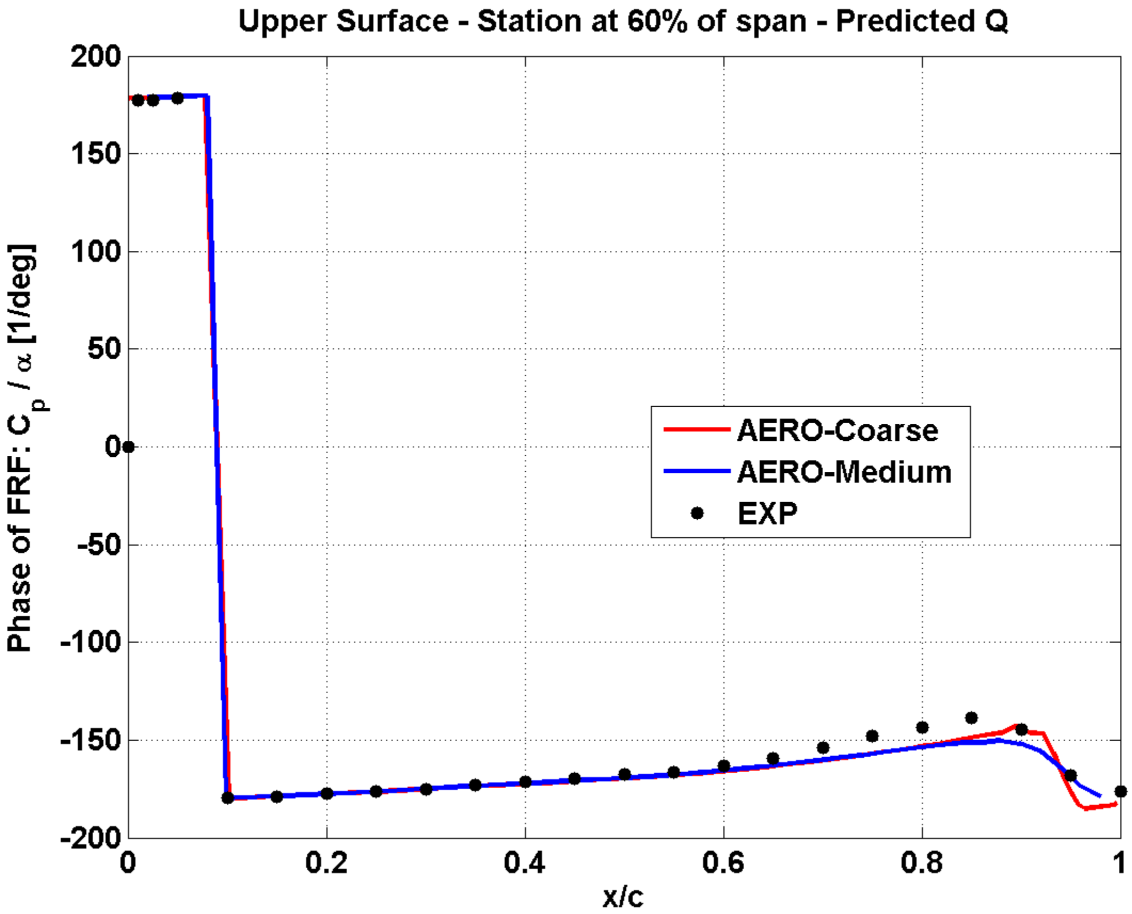
158.6 psf

Frequency: 4.1851 Hz

Damping: 0.0002266

Case 2 – Flutter - NS

Mach = 0.74, Initial Condition α = 0° (Steady State Solution for each dynamic pressure)



Coarse Mesh

160.8 psf

Frequency: 4.1745 Hz

Damping: 0.000139

Medium Mesh

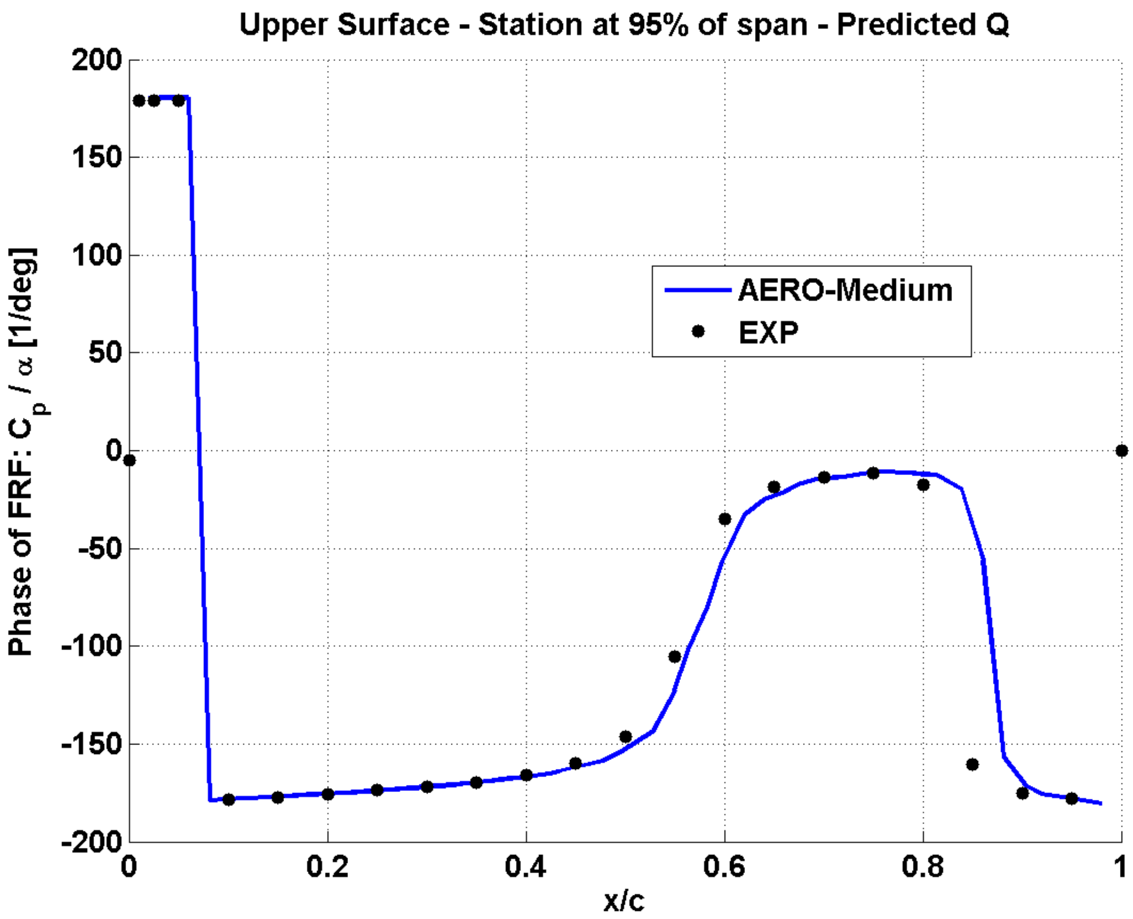
158.6 psf

Frequency: 4.1851 Hz

Damping: 0.0002266

Case 2 – Flutter - NS

Mach = 0.74, Initial Condition α = 0° (Steady State Solution for each dynamic pressure)



Coarse Mesh

160.8 psf

Frequency: 4.1745 Hz

Damping: 0.000139

Medium Mesh

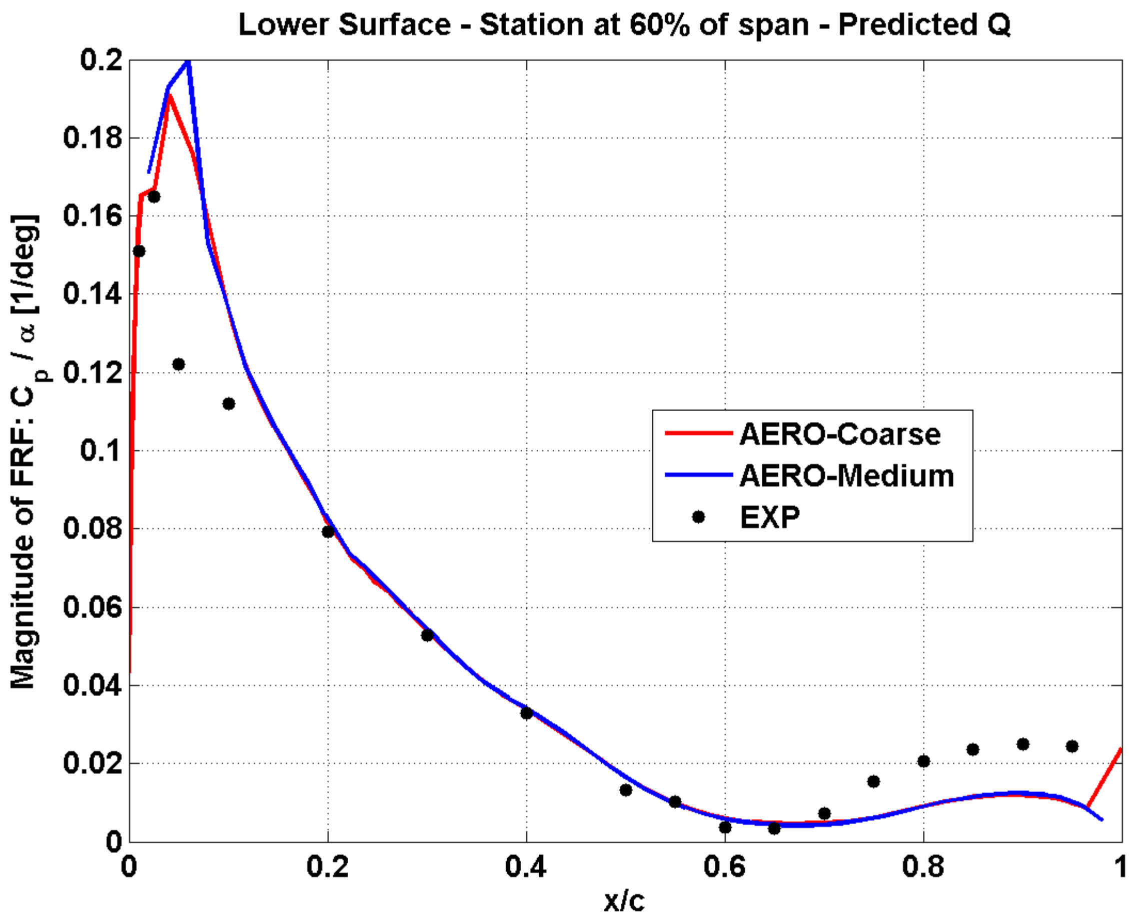
158.6 psf

Frequency: 4.1851 Hz

Damping: 0.0002266

Case 2 – Flutter - NS

Mach = 0.74, Initial Condition α = 0° (Steady State Solution for each dynamic pressure)



Coarse Mesh

160.8 psf

Frequency: 4.1745 Hz

Damping: 0.000139

Medium Mesh

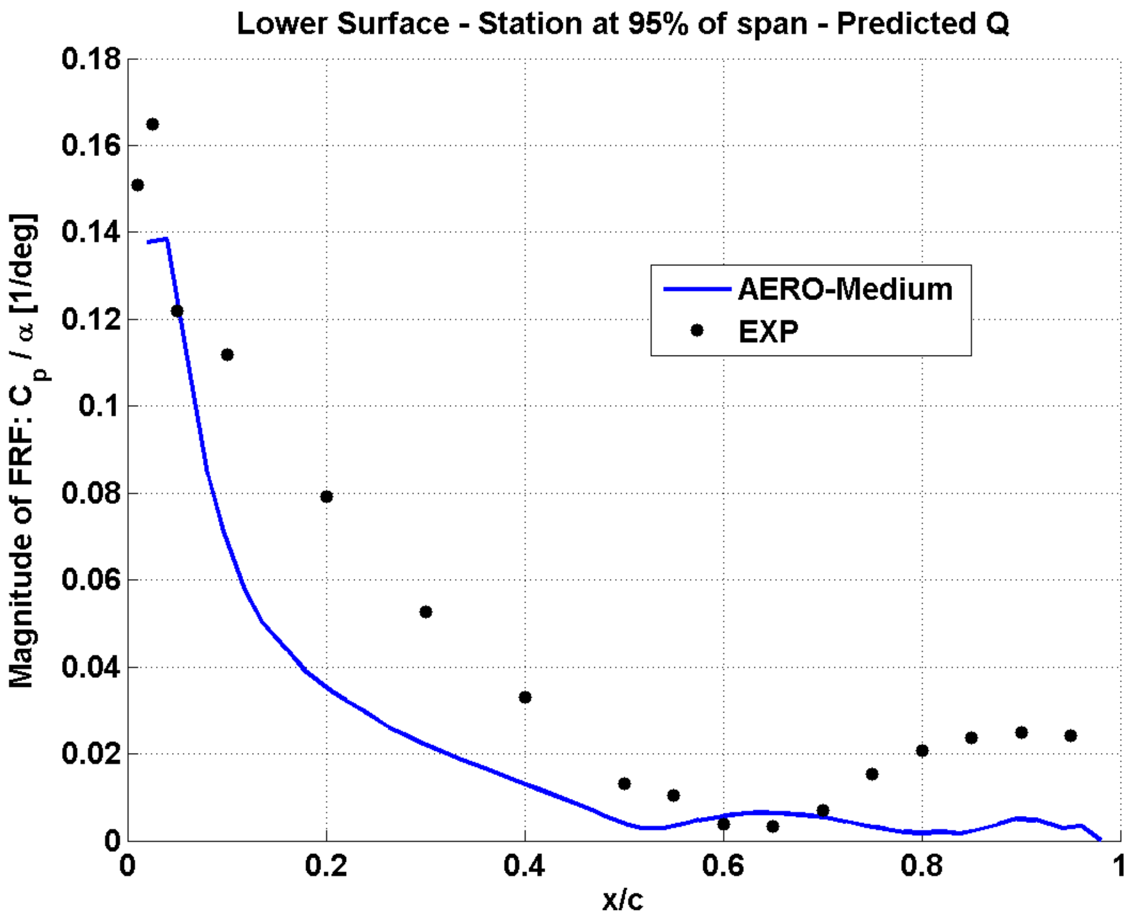
158.6 psf

Frequency: 4.1851 Hz

Damping: 0.0002266

Case 2 – Flutter - NS

Mach = 0.74, Initial Condition α = 0° (Steady State Solution for each dynamic pressure)



Coarse Mesh

160.8 psf

Frequency: 4.1745 Hz

Damping: 0.000139

Medium Mesh

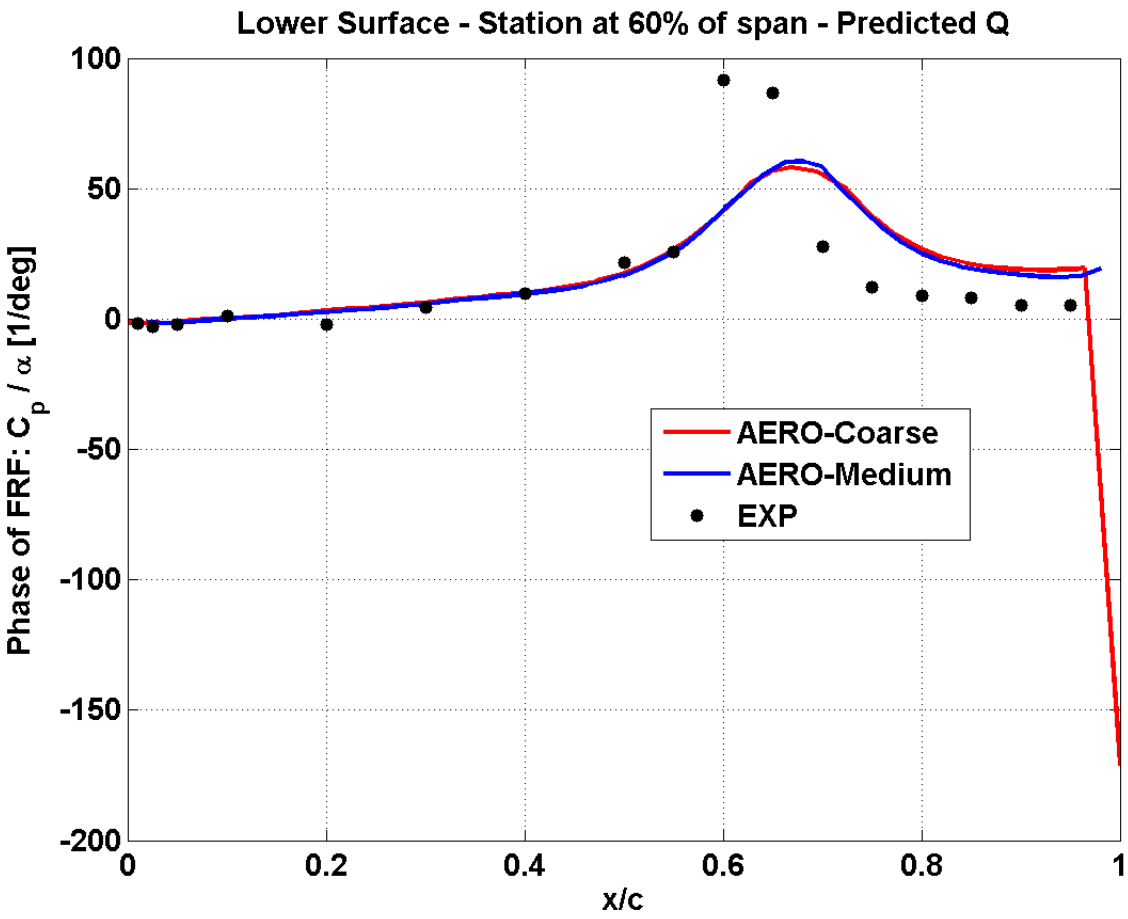
158.6 psf

Frequency: 4.1851 Hz

Damping: 0.0002266

Case 2 – Flutter - NS

Mach = 0.74, Initial Condition α = 0° (Steady State Solution for each dynamic pressure)



Coarse Mesh

160.8 psf

Frequency: 4.1745 Hz

Damping: 0.000139

Medium Mesh

158.6 psf

Frequency: 4.1851 Hz

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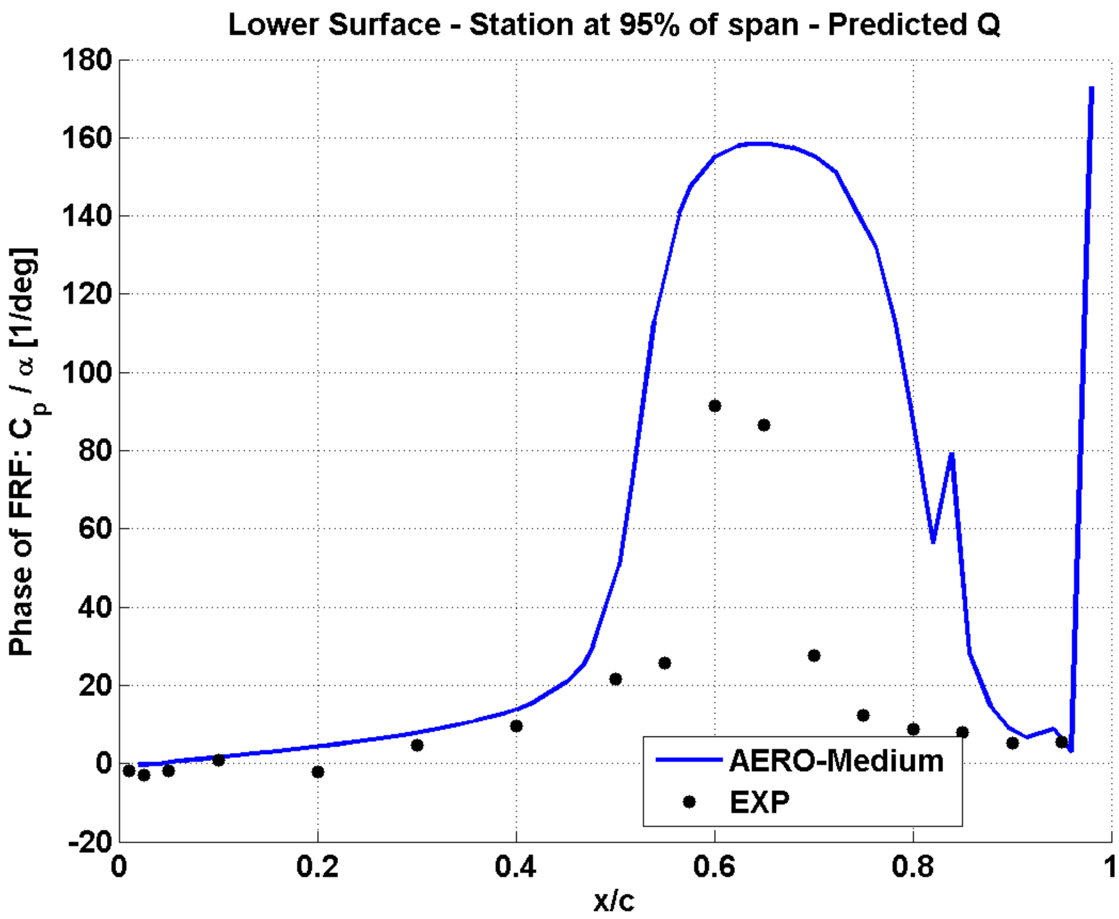
Case 2 – Flutter - NS

Mach = 0.74, Initial Condition α = 0° (Steady State Solution for each dynamic pressure)



Coarse Mesh

160.8 psf

Frequency: 4.1745 Hz

Damping: 0.000139

Medium Mesh

158.6 psf

Frequency: 4.1851 Hz

Damping: 0.0002266

Case 2 – Flutter - NS

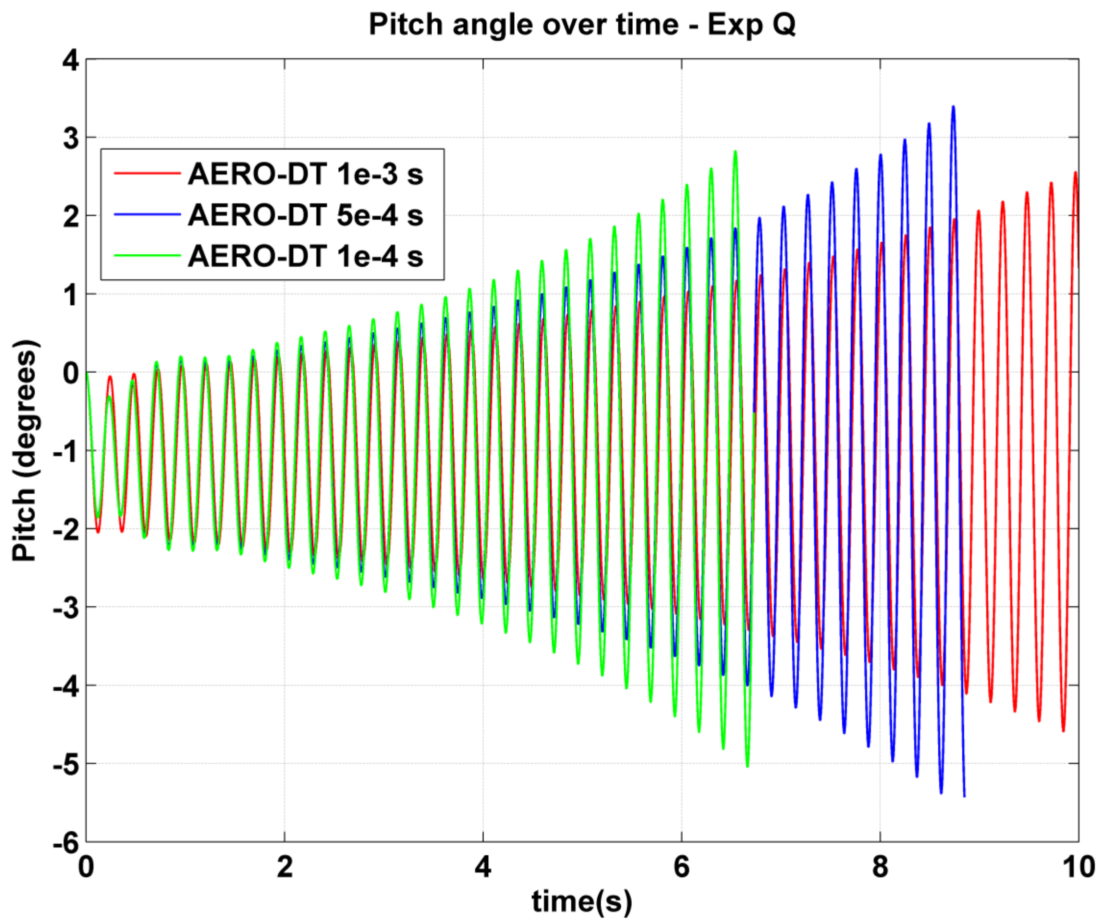
Time-step influence

DT (s)	Q(psf)	Freq_Pitch(Hz)	Damping_Pitch
1.00E-03	169	4.1111	-0.0050777
5.00E-04	169	4.1102	-0.0068922
1.00E-04	169	4.1159	-0.0084011

Coarse mesh only.

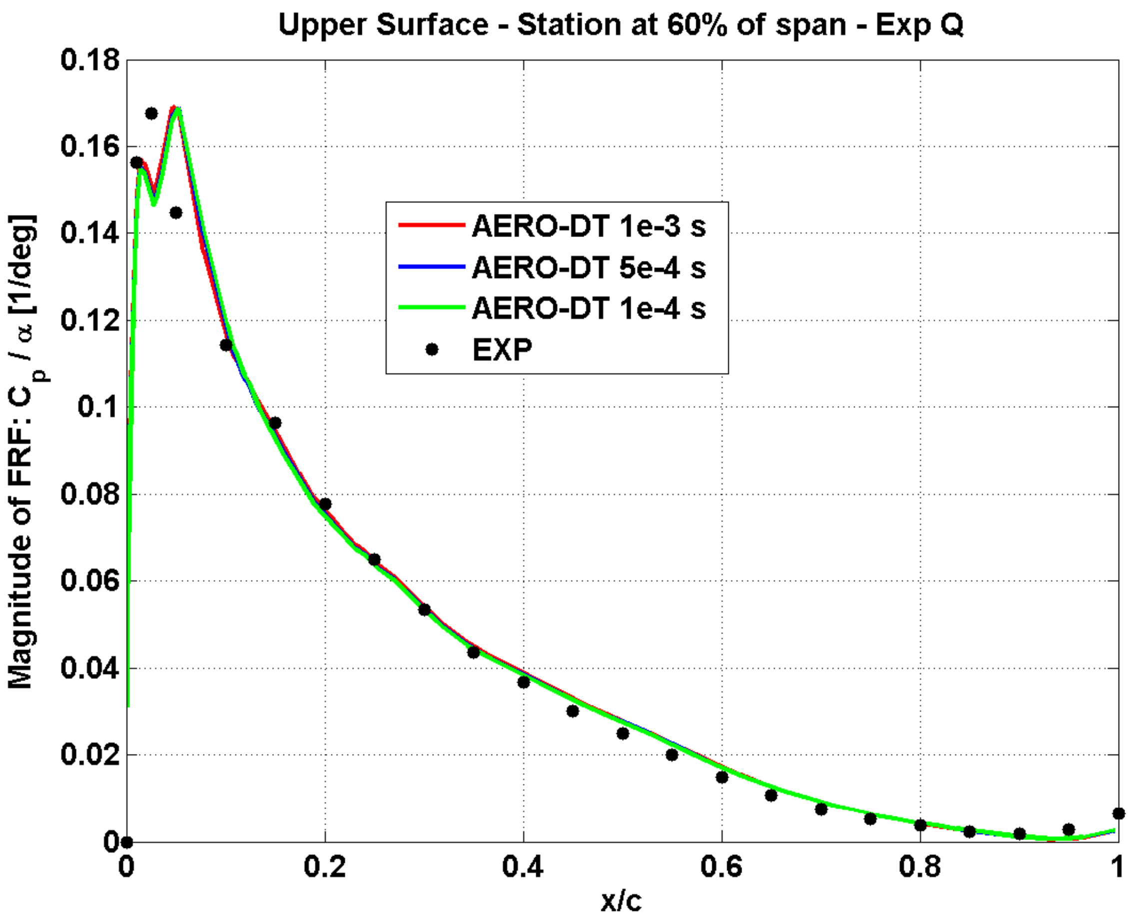
Case 2 – Flutter - NS

Time-step influence



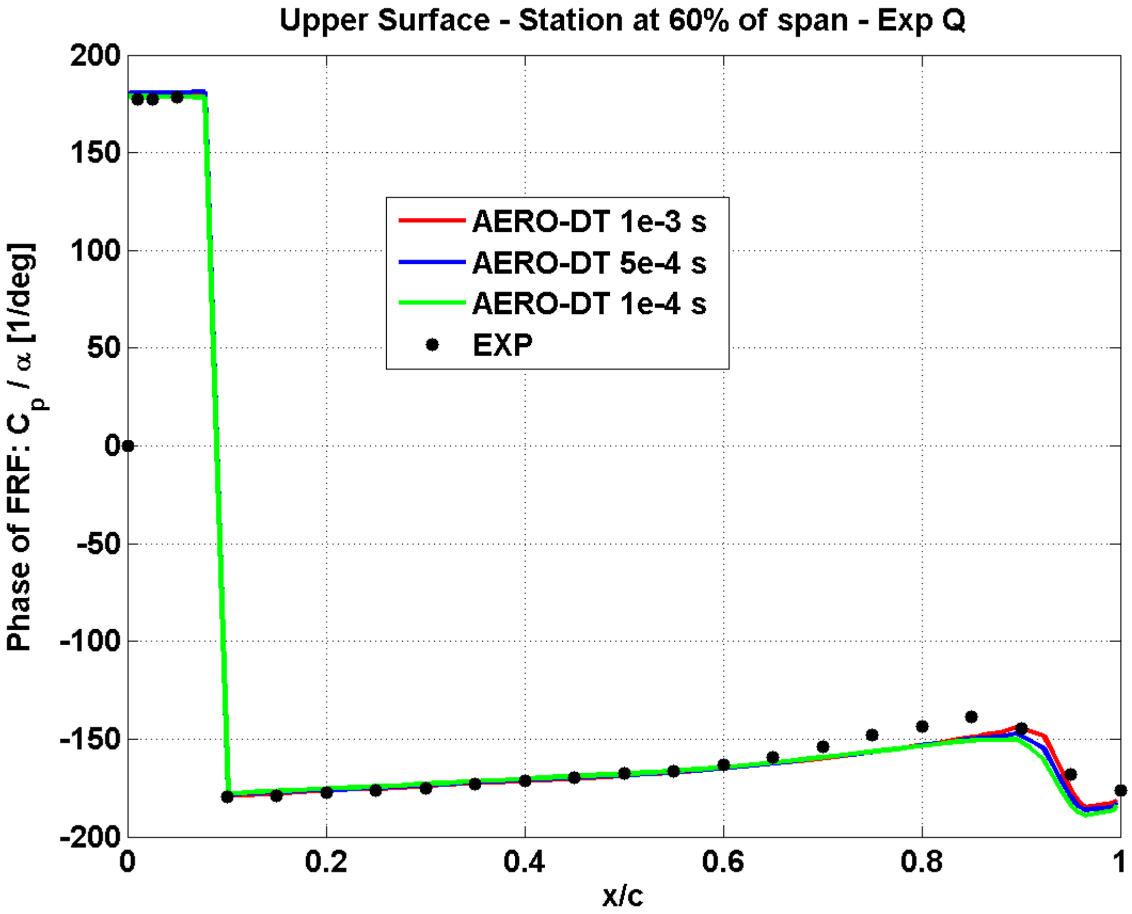
Case 2 – Flutter - NS

Time-step influence



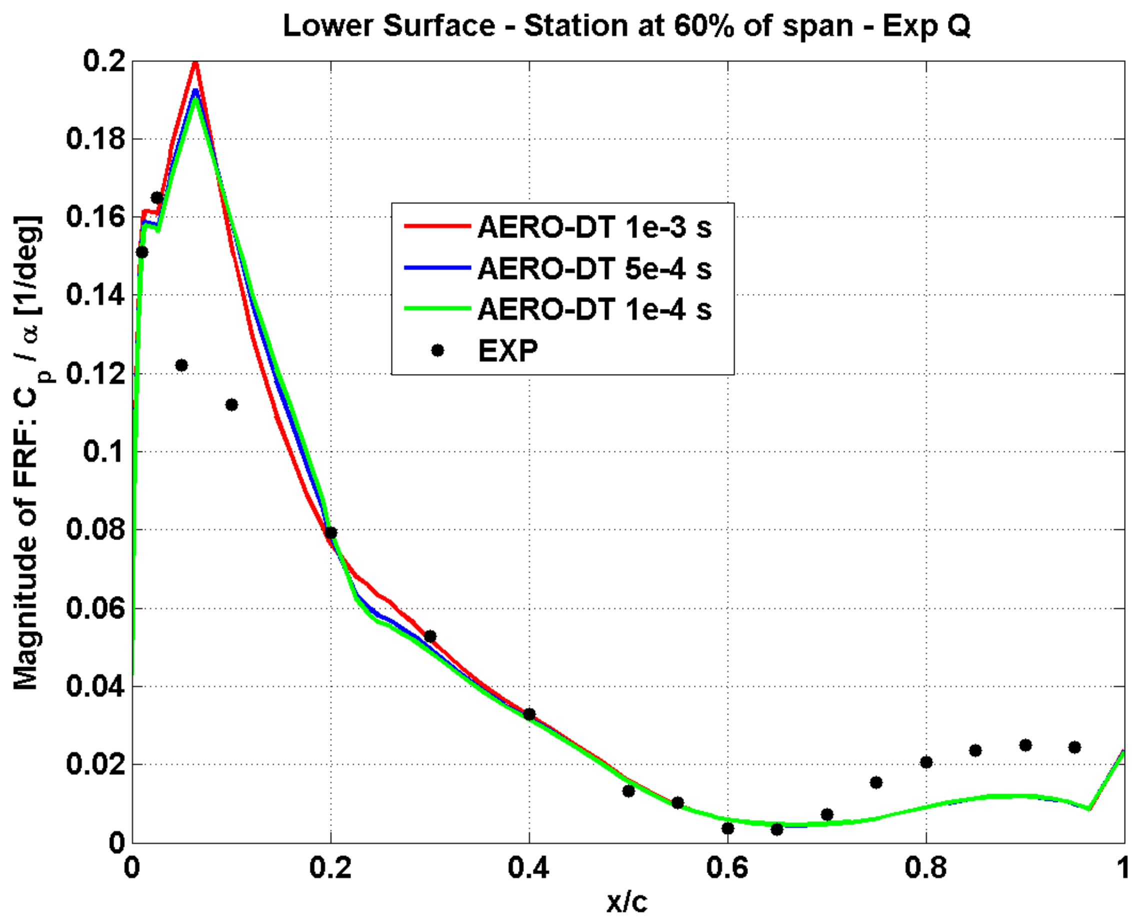
Case 2 – Flutter - NS

Time-step influence



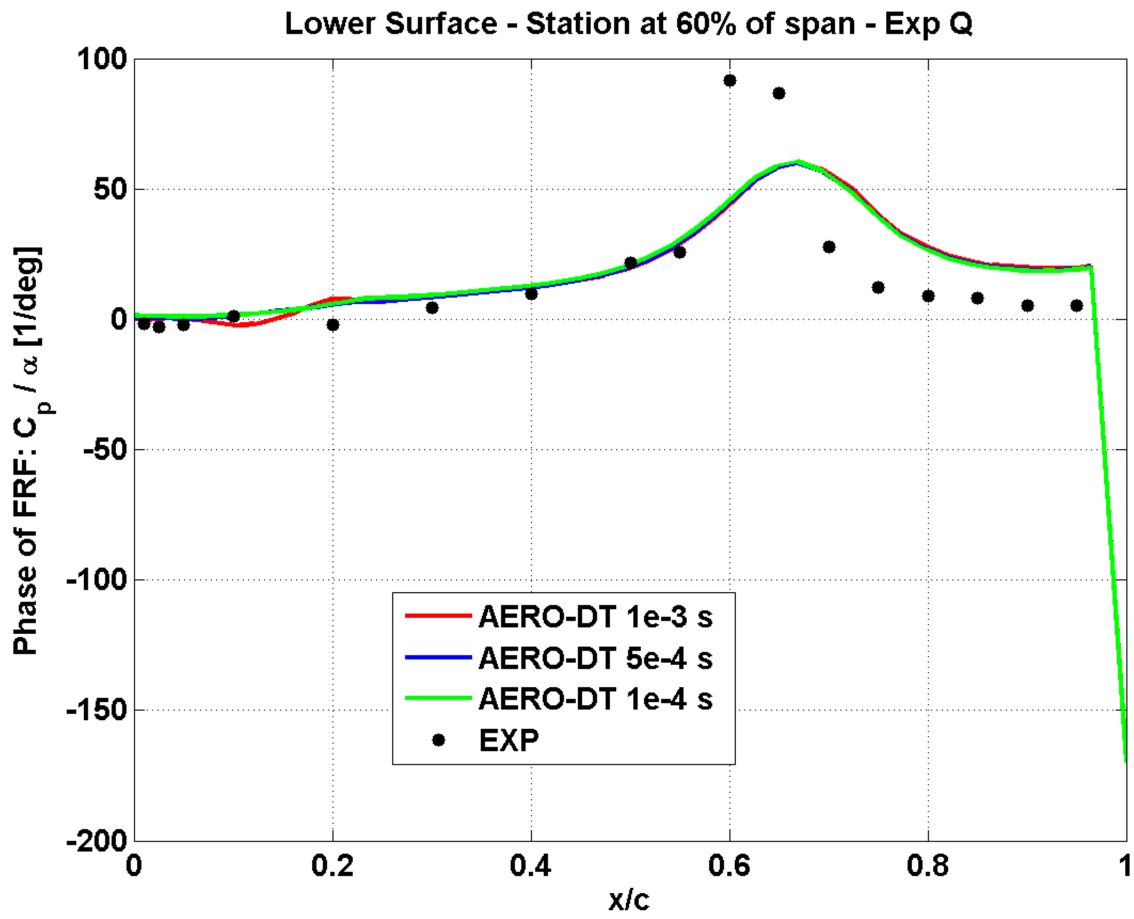
Case 2 – Flutter - NS

Time-step influence



Case 2 – Flutter - NS

Time-step influence



Case 3

	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 = 10Hz, $\|\theta\|$=1°	Flutter	Unforced Unsteady	Forced oscillation f = 10Hz, $\|\theta\|$=1°	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 3 – Summary of Results

- Only CFD++ used for this case
- Coarse and Medium Meshes employed

STEADY Runs:

- Coarse mesh converged to steady state
- Medium mesh did not, oscillations in coefficients shown in next slide

UNSTEADY Unforced Runs:

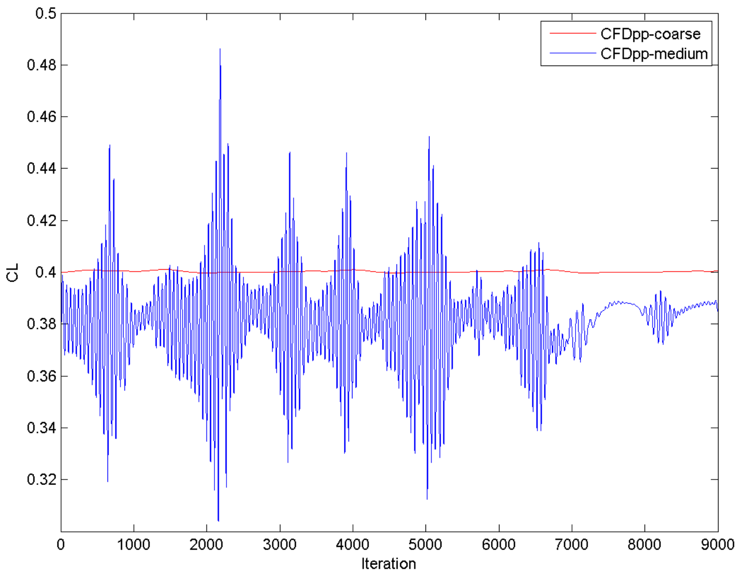
- Both meshes were able to capture shock movement
- Sensors present frequency content in a broad range

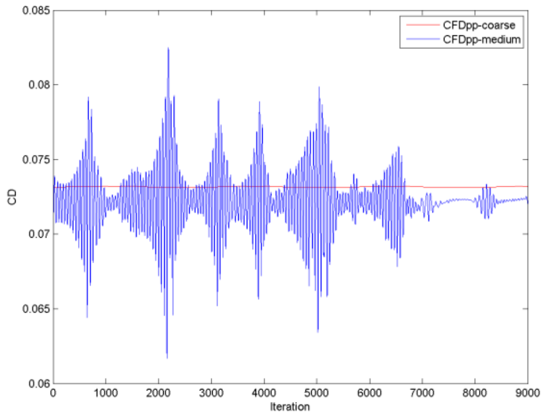
UNSTEADY Forced Runs:

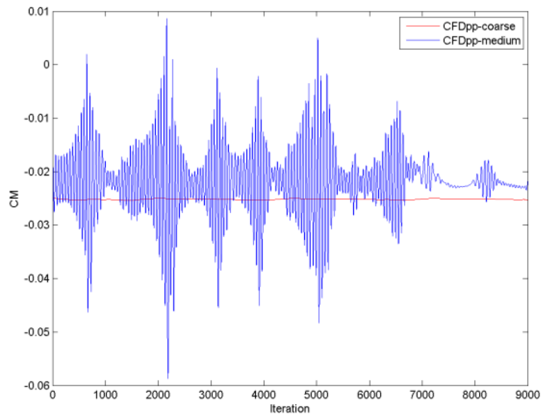
- Mesh refinement affect amplitude at peak regions
- Choice at number of points for FFT has some effect on upper surface

Case 3 – Steady Results

- CL, CD, CM



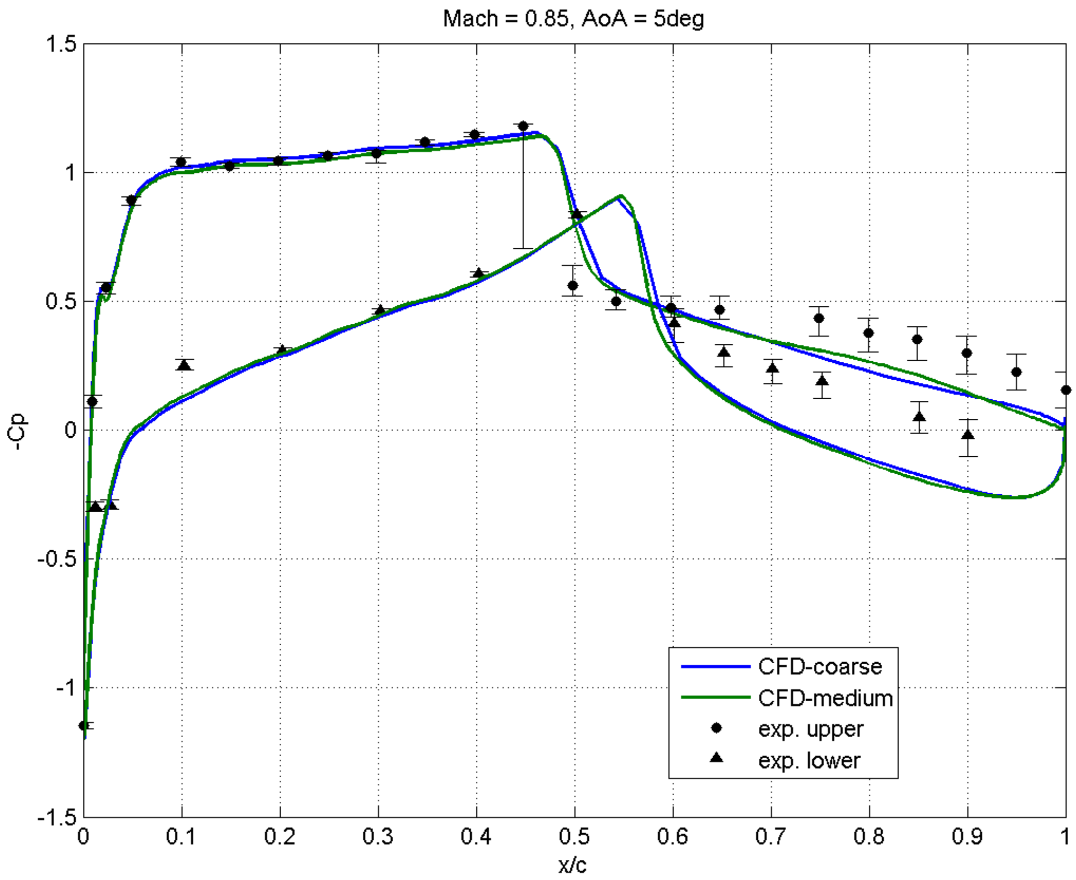




EMBRAER

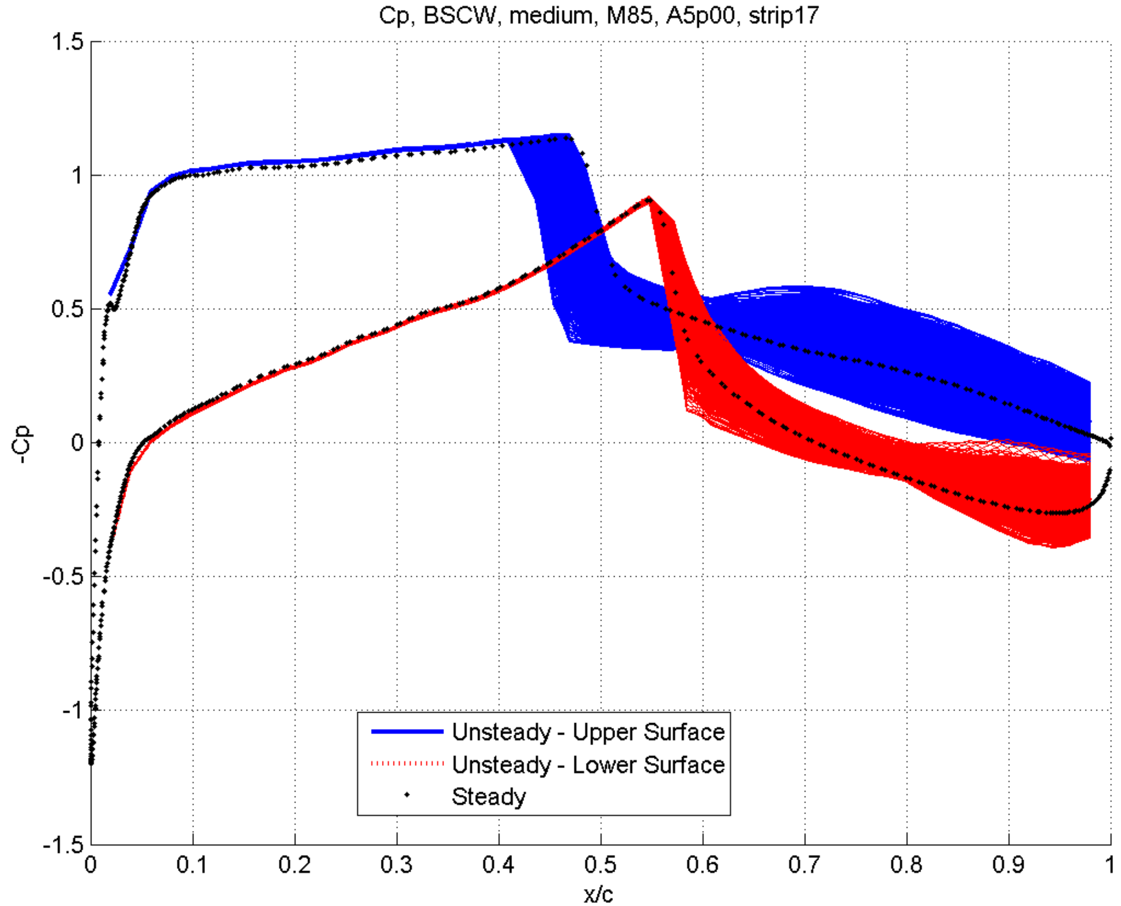
Case 3 – Steady Results

- Strip 60% - last iteration



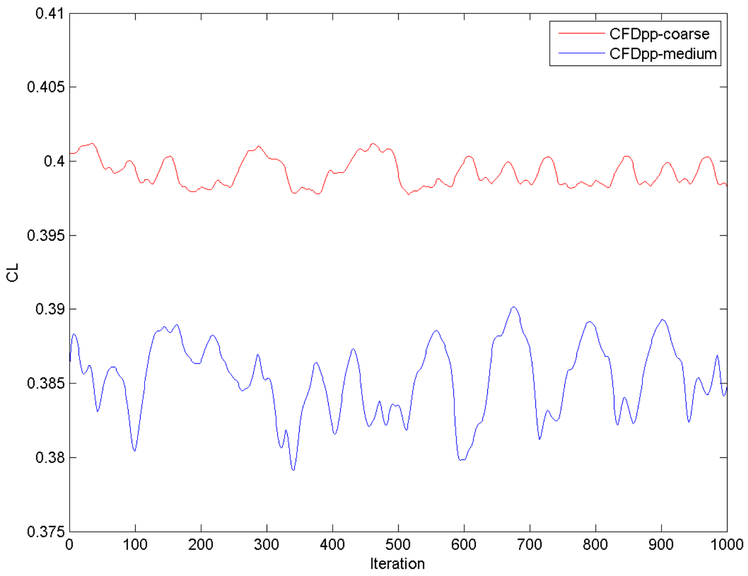
Case 3 – Steady Results

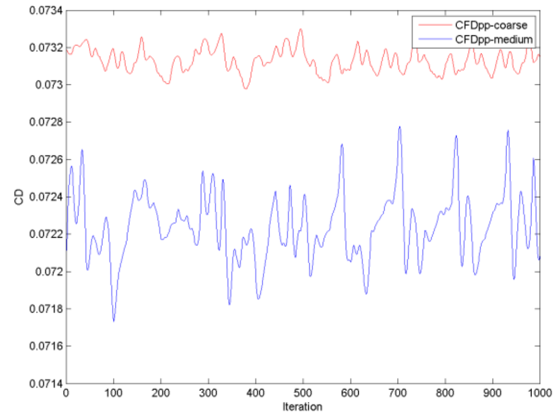
- Strip 60% - medium mesh - all data

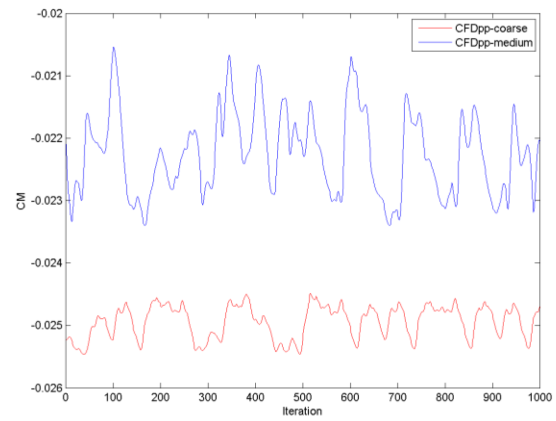


Case 3 – Unsteady Unforced Results

- CL, CD, CM

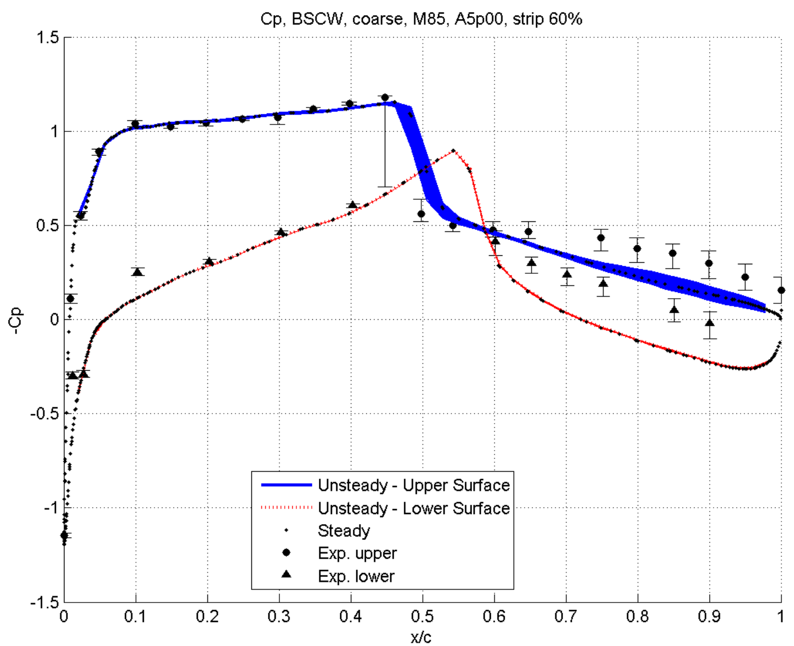




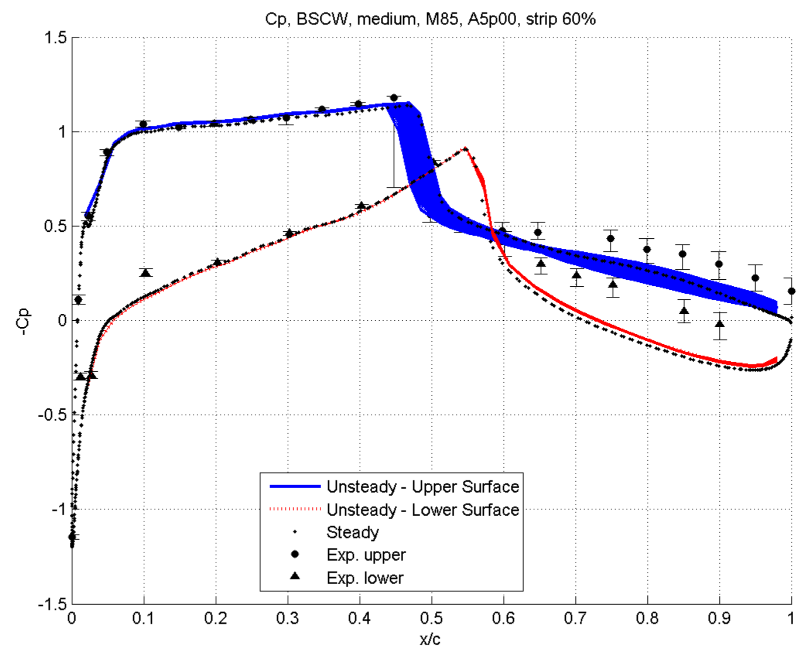


Case 3 – Unsteady Unforced Results

- Coarse



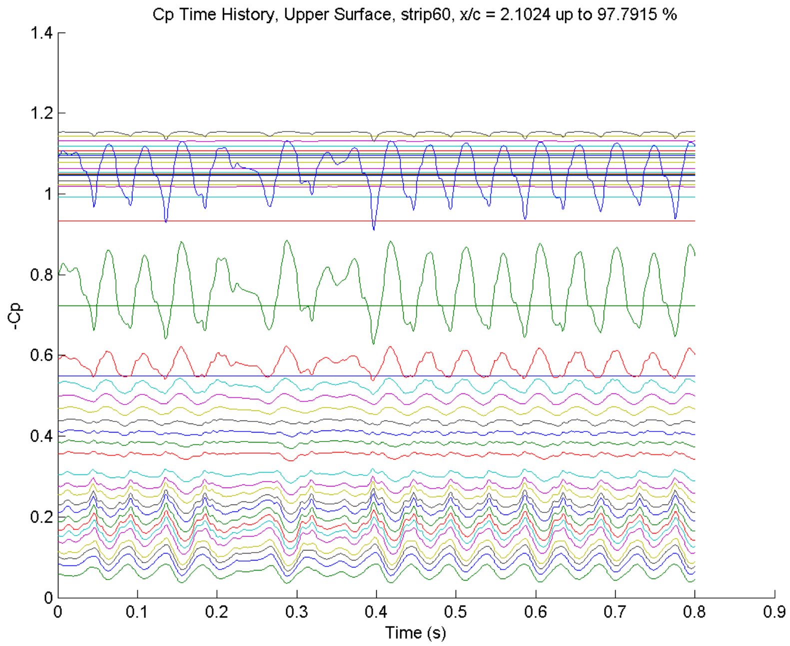
- Medium



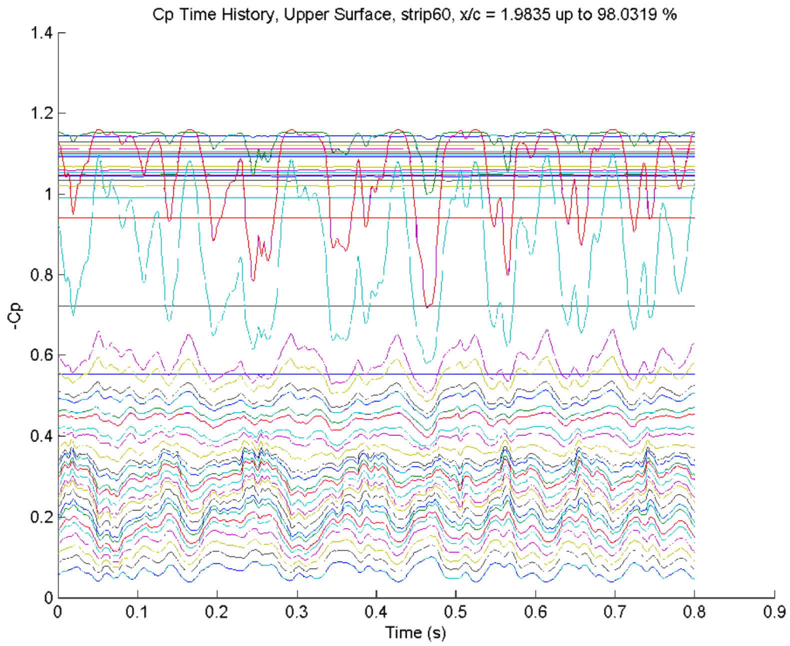
Case 3 – Unsteady Unforced Results

- Upper Side – 60%

- Coarse



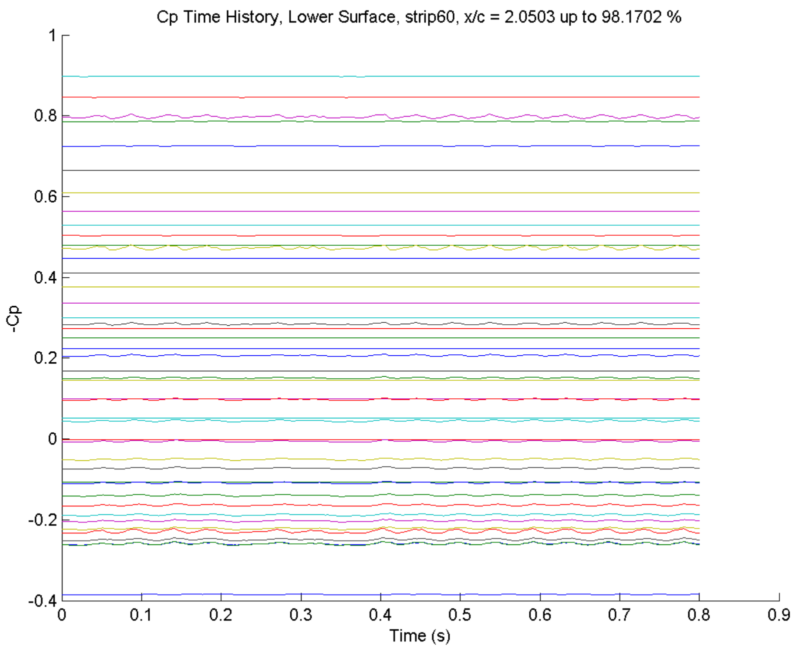
- Medium



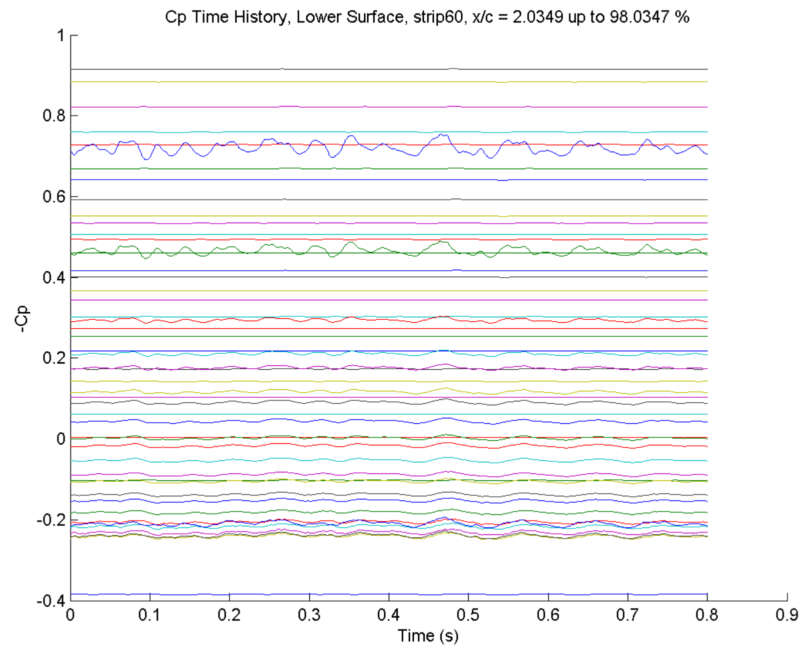
Case 3 – Unsteady Unforced Results

- Lower Side – 60%

- Coarse



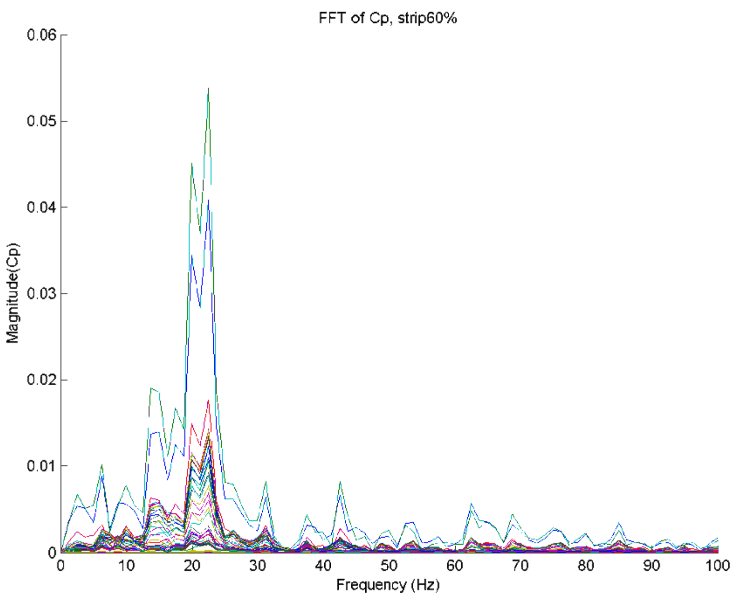
- Medium



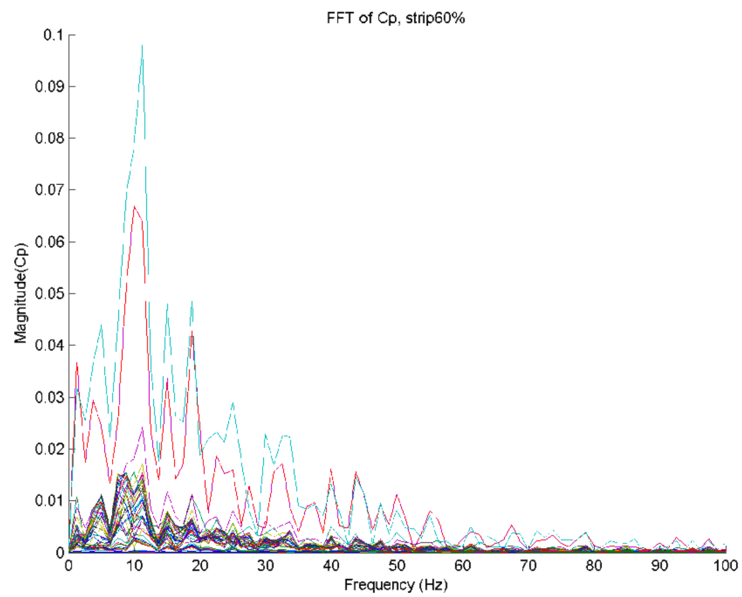
Case 3 – Unsteady Unforced Results

- Upper Side – 60%

- Coarse



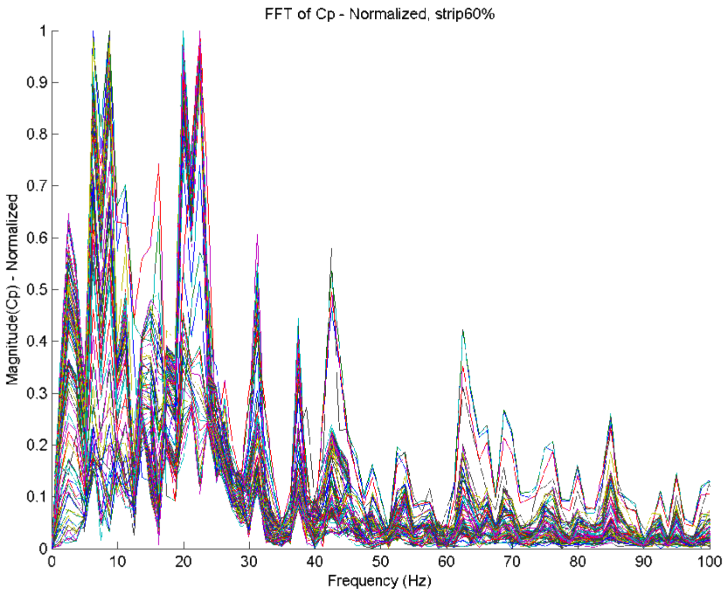
- Medium



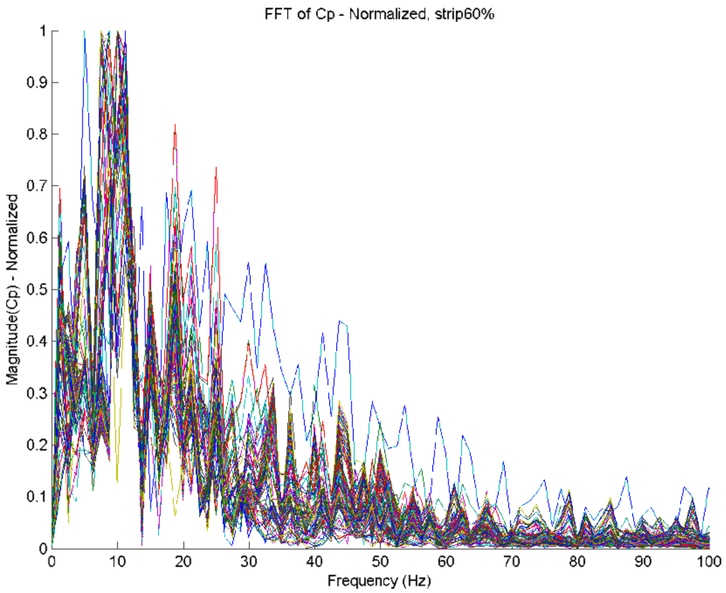
Case 3 – Unsteady Unforced Results

- Upper Side – 60%
- FFTs normalized to make maximum amplitude of each sensor equal to unity.

- Coarse

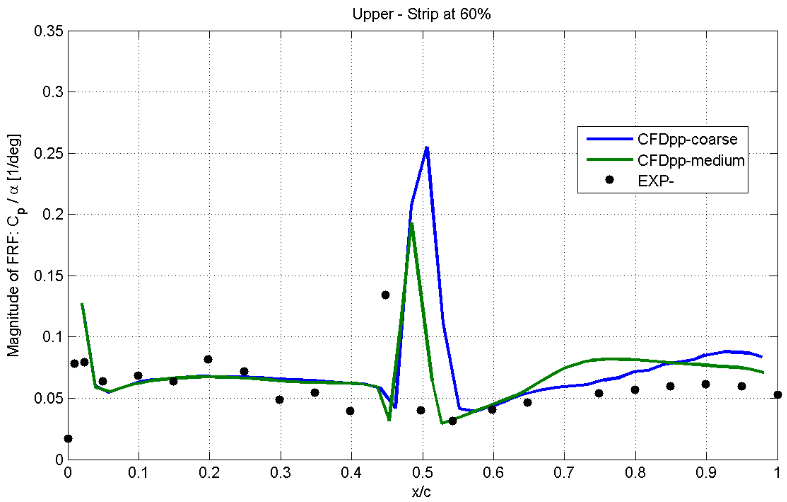


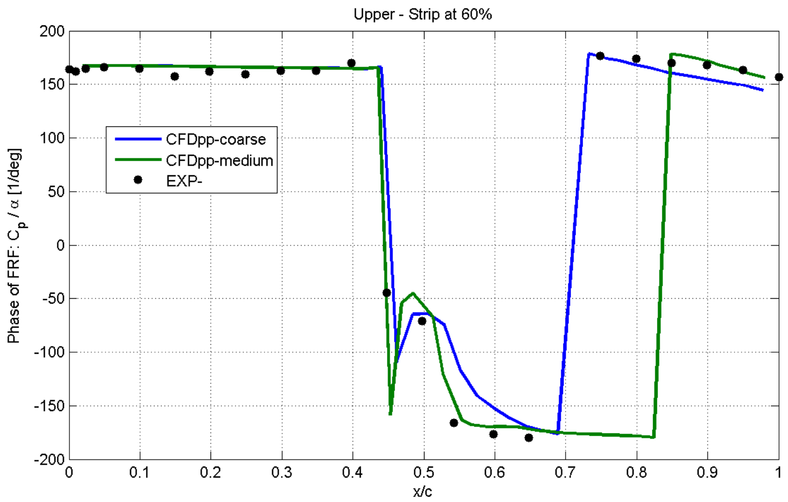
- Medium



Case 3 – Forced Results

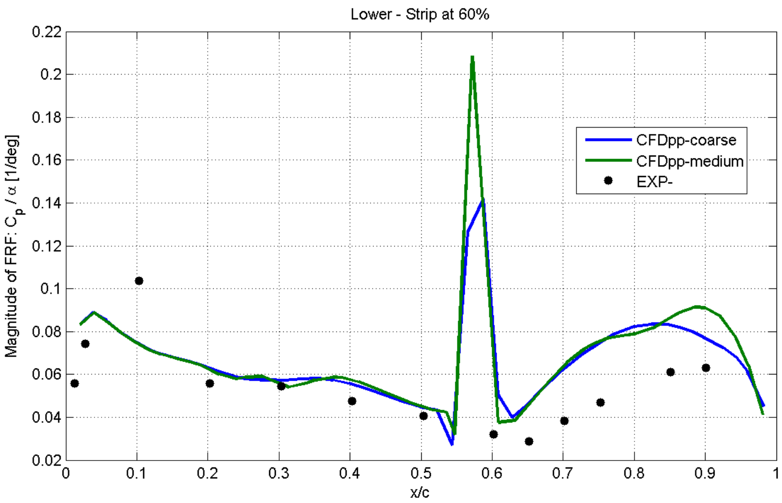
- Upper Side – 60%

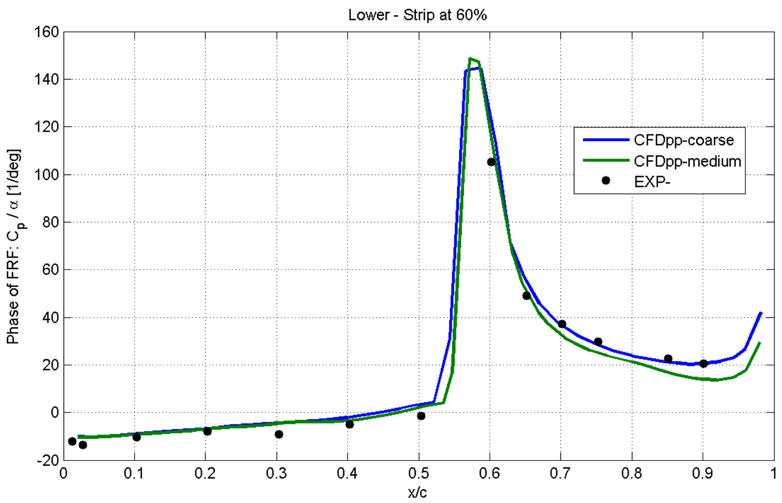




Case 3 – Forced Results

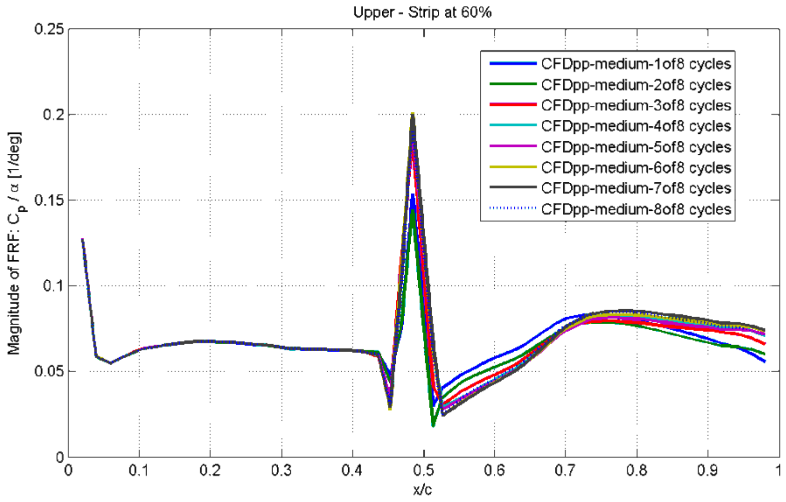
- Lower Side – 60%

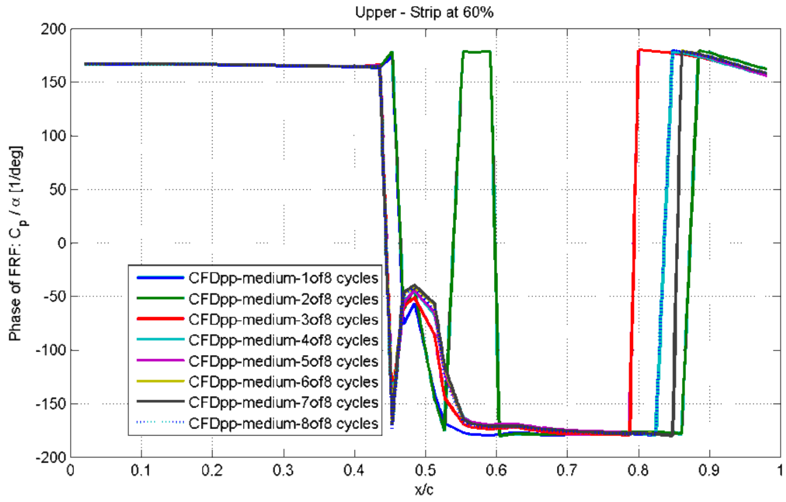




Case 3 – Forced Results

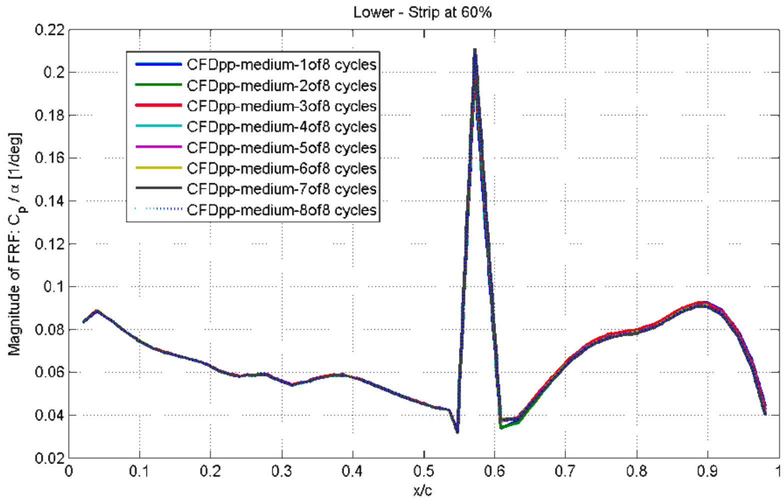
- Effect of Number of Cycles used for FFT - Upper Side – 60%

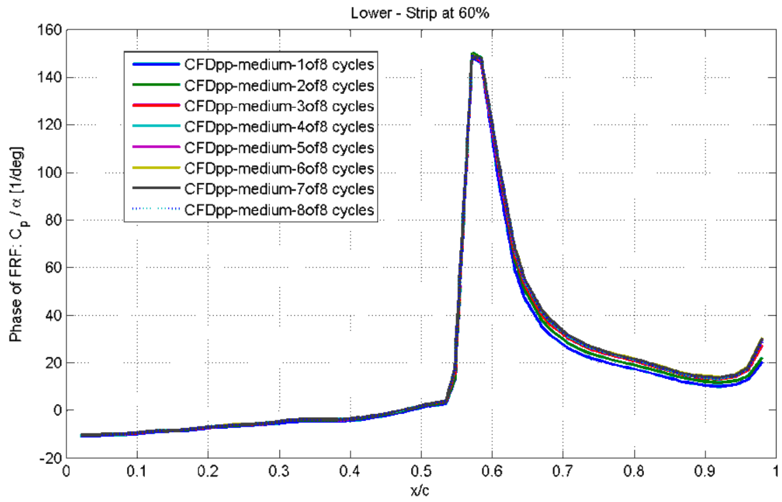




Case 3 – Forced Results

- Effect of Number of Cycles used for FFT - Lower Side – 60%



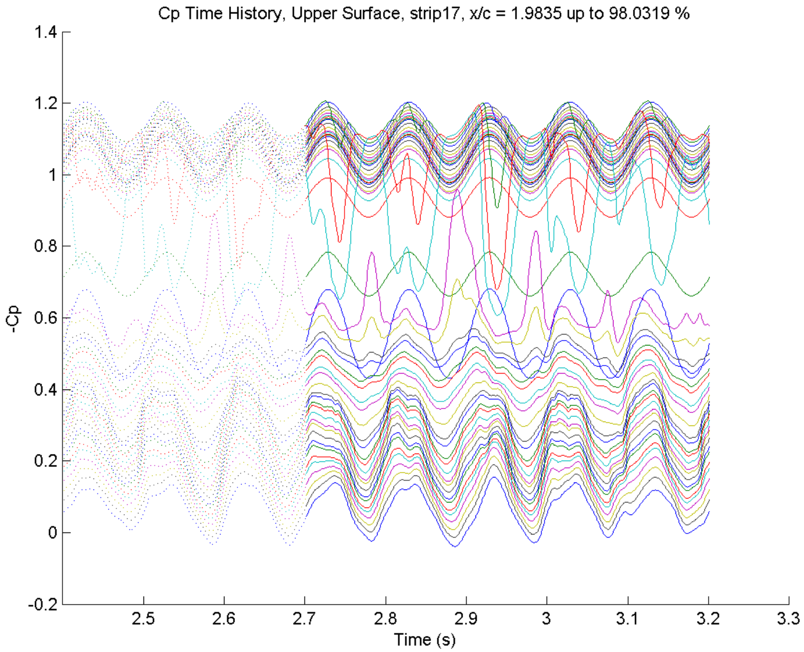


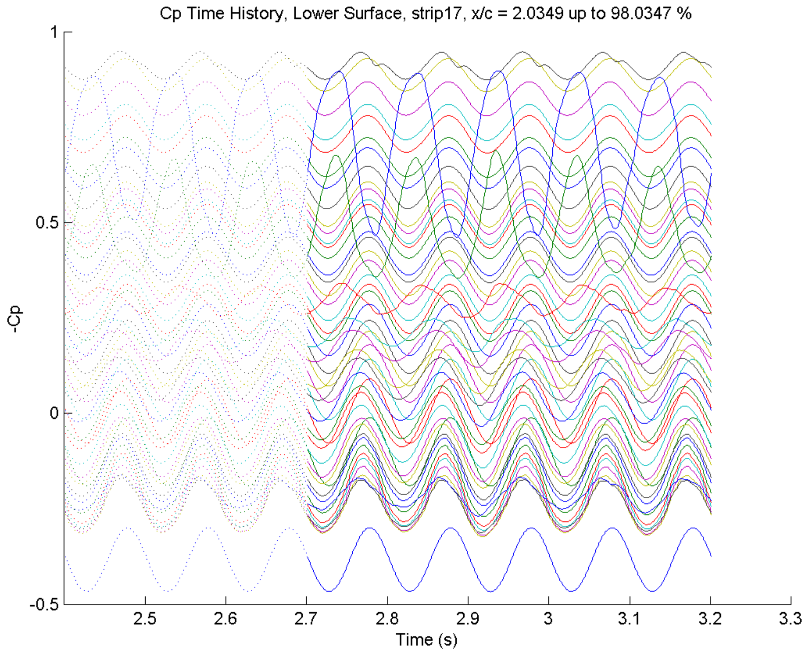
Case 3 – Forced Results (Time Histories)

- Strip 60%

- Upper

- Lower

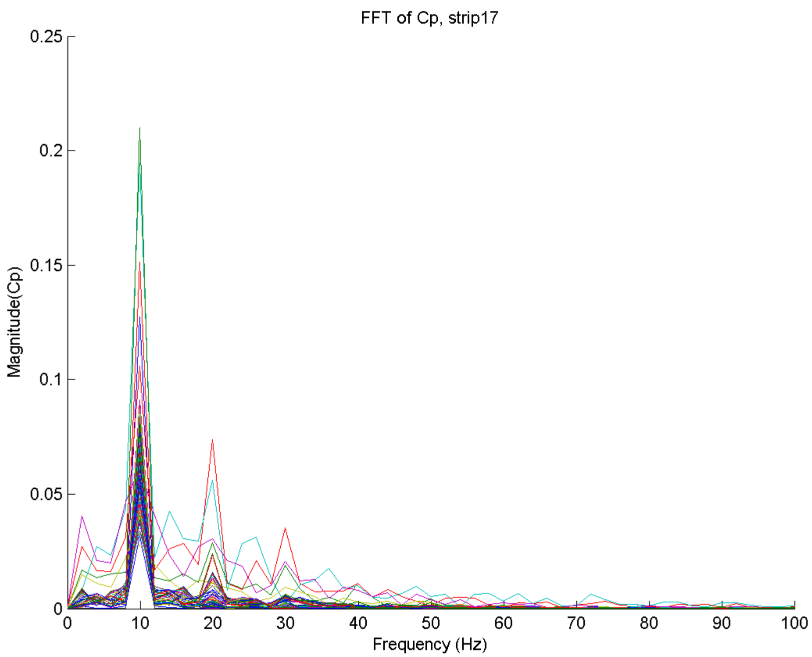




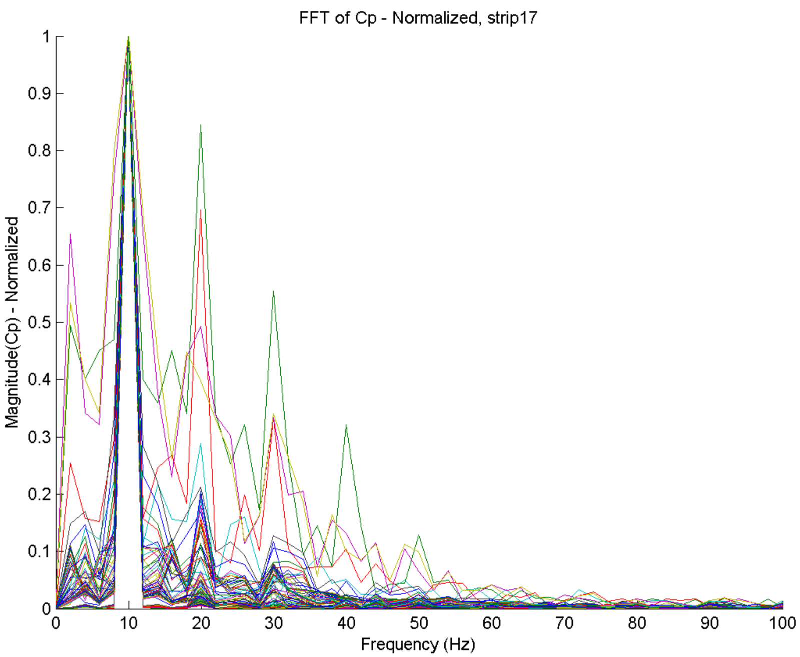
Case 3 – Forced Results (Frequency Content)

- Strip 60%

- FFT

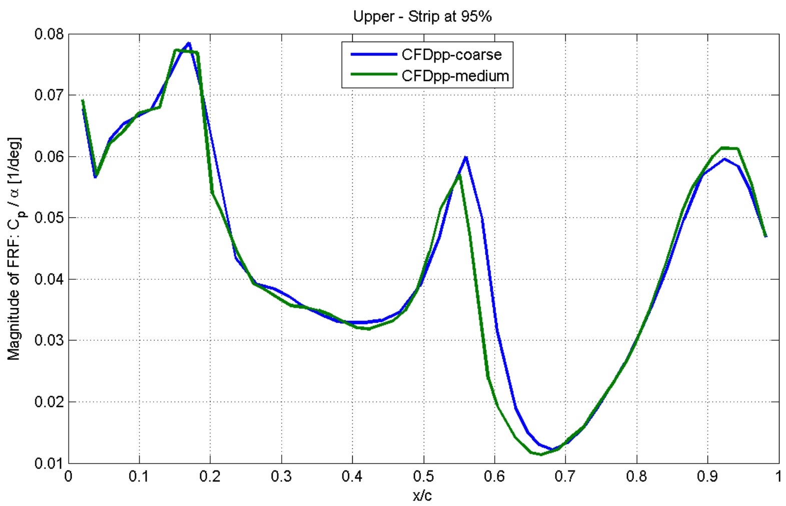


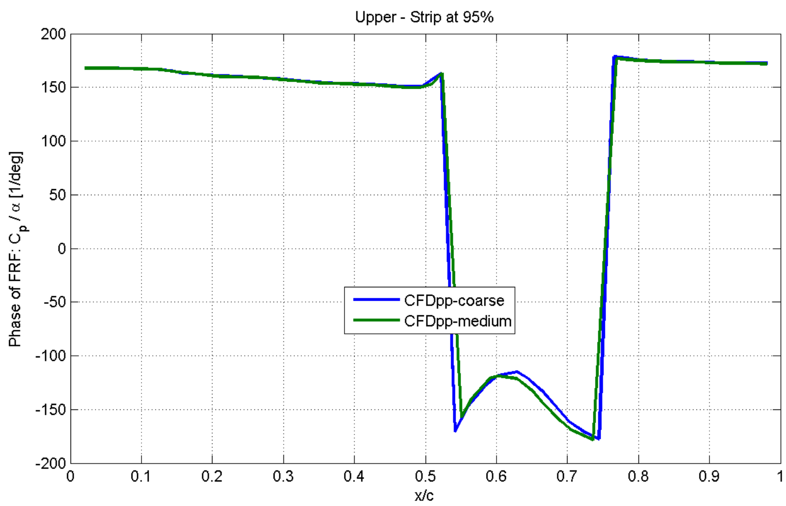
- FFT Normalized
(maximum amplitude of each sensor equal to 1)



Case 3 – Forced Results

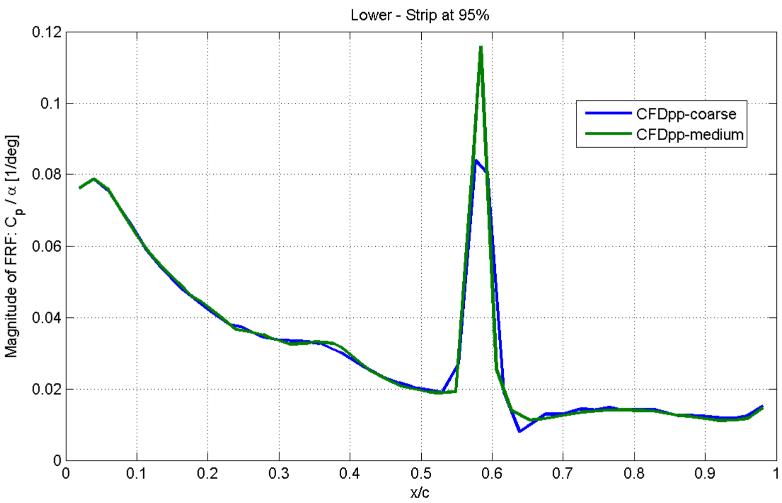
- Upper Side – 95%

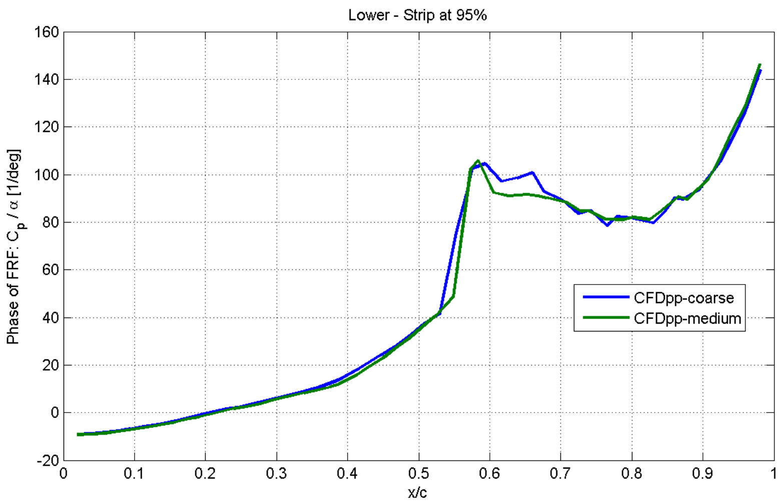




Case 3 – Forced Results

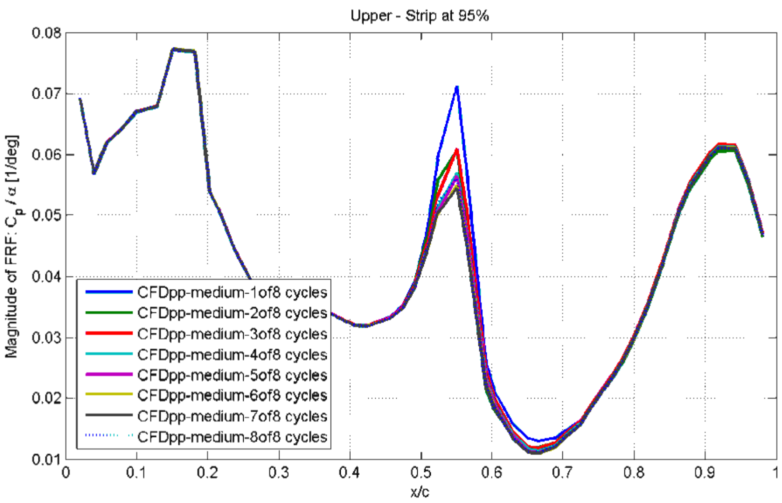
- Lower Side – 95%

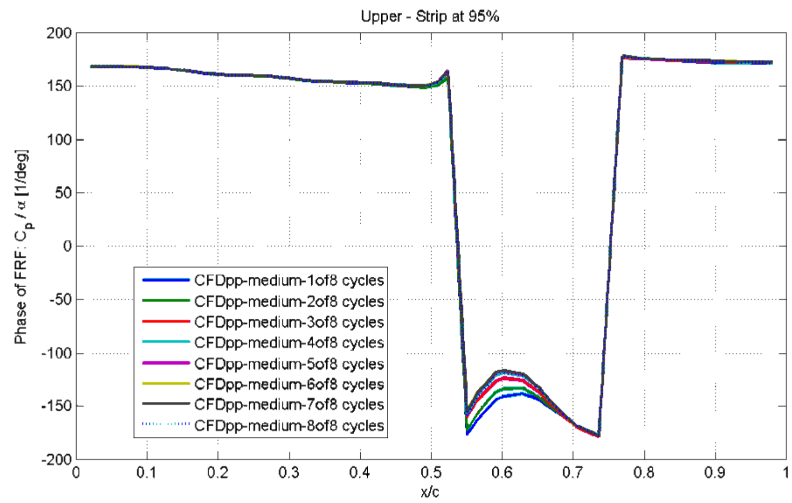




Case 3 – Forced Results

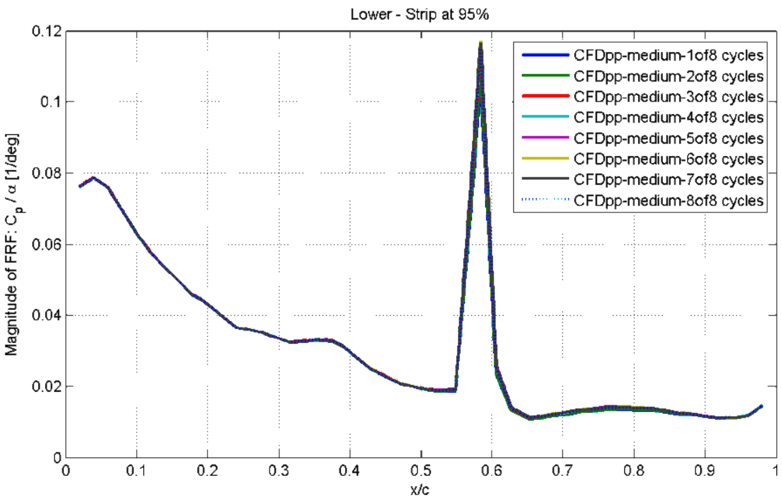
- Effect of Number of Cycles used for FFT - Upper Side – 95%

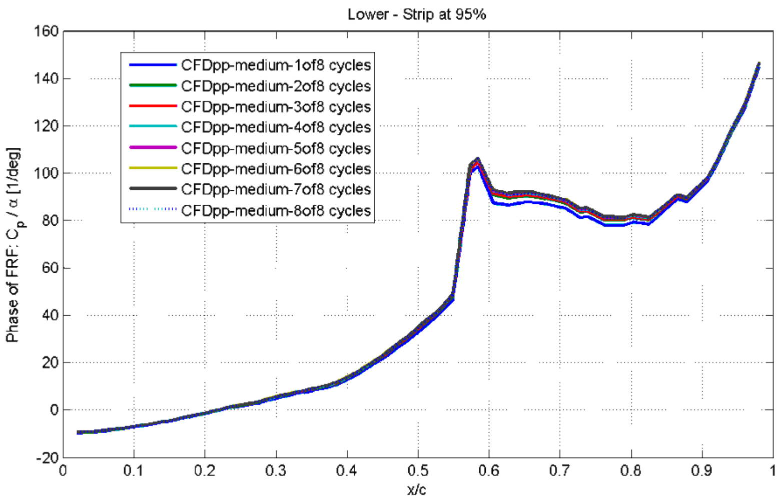




Case 3 – Forced Results

- Effect of Number of Cycles used for FFT - Lower Side – 95%

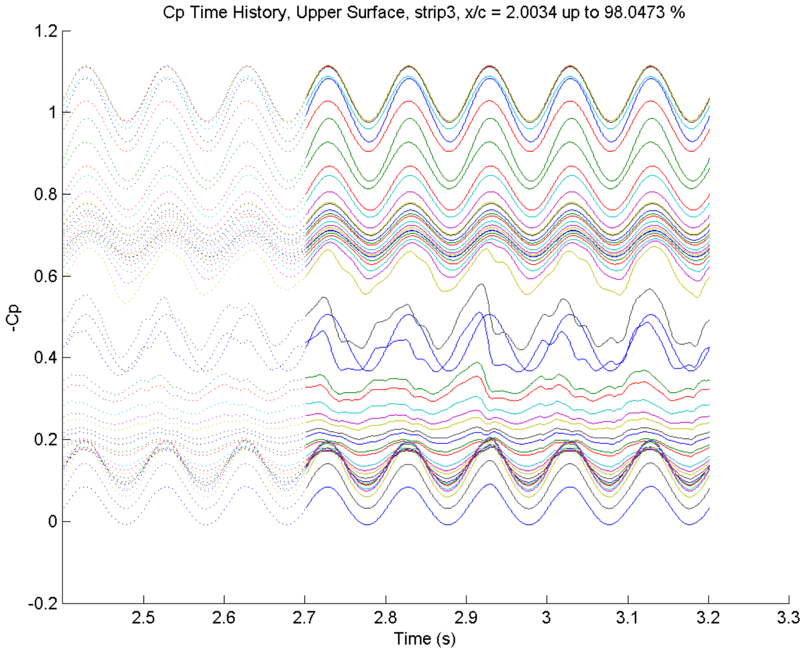




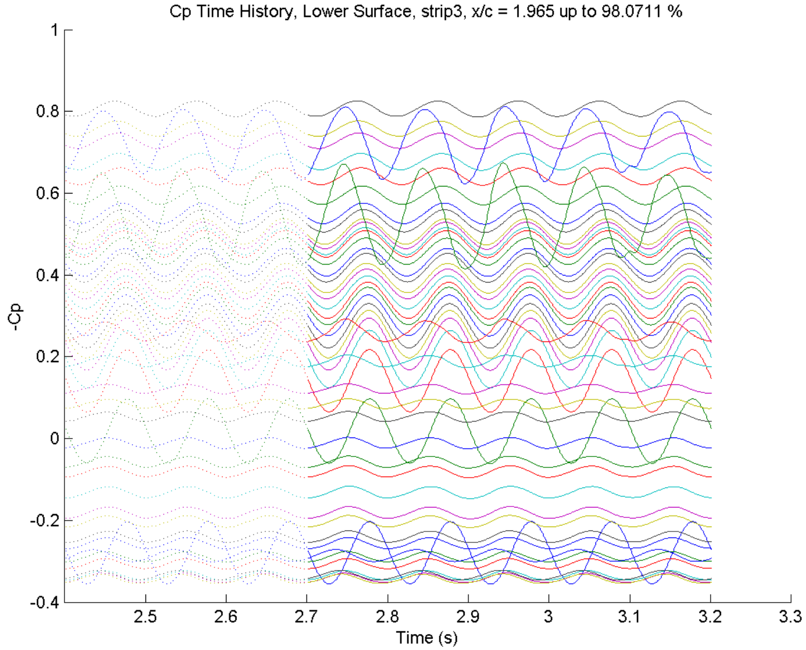
Case 3 – Forced Results (Time Histories)

- Strip 95%

- Upper



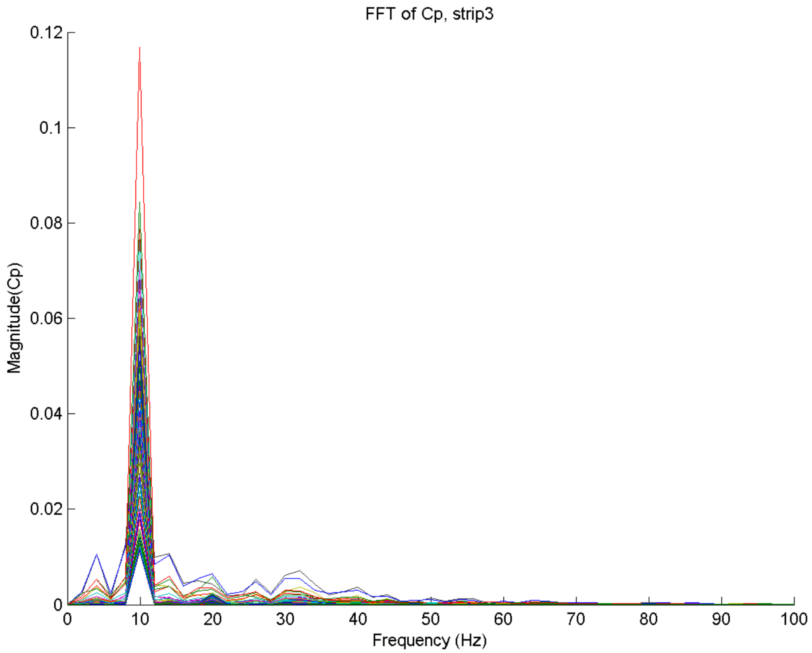
- Lower



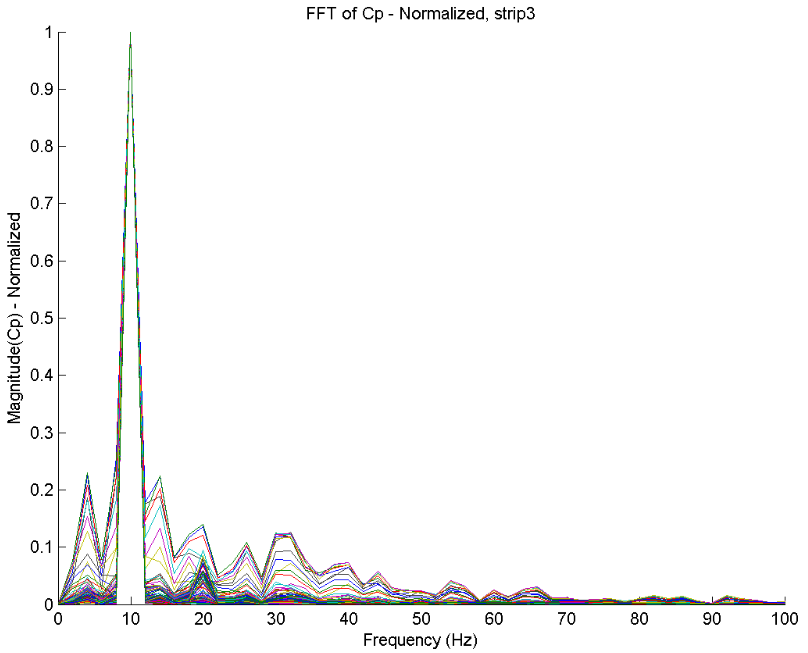
Case 3 – Forced Results (Frequency Content)

- Strip 95%

- FFT



- FFT Normalized
(maximum amplitude of each sensor equal to 1)



Conclusions and suggestions

1. The unsteady aerodynamics were well represented by both CFD codes for case 1, with the same phase issues despite the turbulence modeling, flux constructions, limiters and time schemes differences between codes.

2. While attached, the flow exhibited linear behavior, which explain good results for flutter velocity obtained with linear methods and Euler simulations for case 2;

3. The insertion of a small amount of structural damping would make the viscous resutls better for flutter velocity, increasing it.

4. The flutter results are sensible to mesh and time-step refinements. More analysis are needed to clarify if it is a fluid solver or fluid-strucuture coupling.

Conclusions and suggestions

5. Case 3 is still very challenging. It is hard to distiguish between physical and numerical oscillations. Unsteadyness can be affected by the forced movement, promoting tunning of pressure oscillations with the imposed displacement. Flutter analysis in this regime can be tougth, as the system is naturally unstable and will be probably in a LCO due to shock oscillation and flow detachements;

6. Time-step paramentric studies are expensive due to large CPU time, specially for flutter, where a large total simulation time is needed.

7. Maybe a 2D configuration would be usefull to parametric study in deeper detail the mesh and time-step depence in a cheaper way, pushing the codes to the real limit of accuracy. Obviously, all the flow features of interest must be present.

8. Positioning mesh nodes exactly over the experimental Cp stations (60 and 95%) would facilitate the numerical analysis, as no cuts or interpolations would be needed;

Conclusions and suggestions

9. The participants could colaborate to unify the post processing scripts prior to data submission. This would make the life of the person responsible to put all results together a little bit easier and facilitates the information exchange between participants during the telecons and the workshop;

10. Propose for the AePW-3 a collaborative initiative to design a common reasearch model for aeroelastic studies, using the tools applied to the first and second workshops. It can be used to clarify the objectives for further development and future of the workshop. This can attract more experimental people too.

11. Thanks the AePW-2 organizing committee to make this event possible and really open to all interested in aeroelasticity and related disciplines.