CFD computations for DLR F11 (EUROLIFT) using the code HiFUN

Yuvraj Patil, Ravindra K., Nikhil V. Shende, **Balakrishnan N.**

Computational Aerodynamics Laboratory,
Department of Aerospace Engineering
Indian Institute of Science
Bangalore 560 012, Karnataka, India

2nd AIAA CFD High Lift Prediction Workshop, San Diego, CA
June 22–23, 2013

Outline

1. Introduction
2. Grids Used
3. Results
4. Conclusion

Outline

1 Introduction

2 Grids Used

3 Results

4 Conclusion

Tools employed

- Flow computations using HiFUN, a commercial flow solver by S & I Engineering Solutions (SandI) available at CAd Lab.
- A_uns_hex grid (from Boeing) and B_uns_mix grid (from DLR) family provided by the HiLiftPW-2 committee is used.
- Postprocessing is carried out using TECPLOT available at SERC, IISc.

Features of code HIFUN

HIFUN: **HI**gh Resolution **F**low Solver on **UN**structured Meshes

- Unstructured cell centre finite volume methodology.
- Higher order accuracy: linear reconstruction procedure.
- Flux limiting: Venkatakrishnan Limiter.
- Inviscid flux computation: Roe scheme.
- Convergence acceleration: matrix free symmetric Gauss Seidel relaxation procedure.
- The viscous flux discretization: Green–Gauss theorem based diamond path reconstruction.
- Eddy viscosity computation: Spalart Allmaras (Standard) TM.
- Parallelization: MPI.

Outline

1 Introduction

2 Grids Used

3 Results

4 Conclusion

Grid details

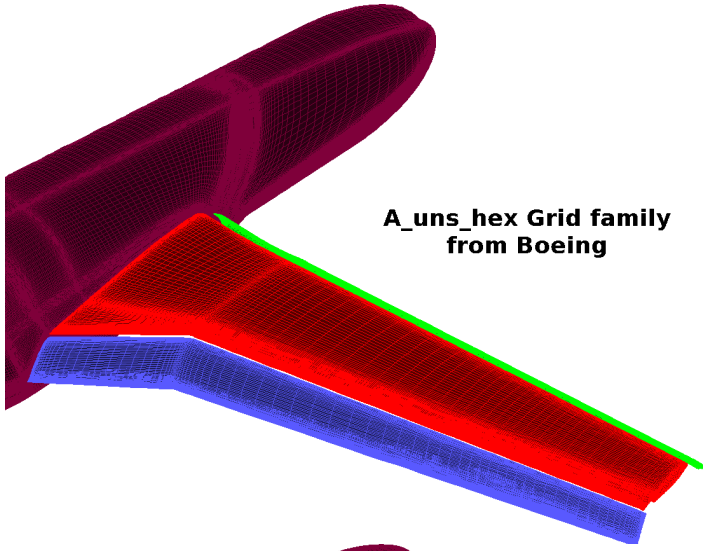
Grid Convergence Study (Case1)

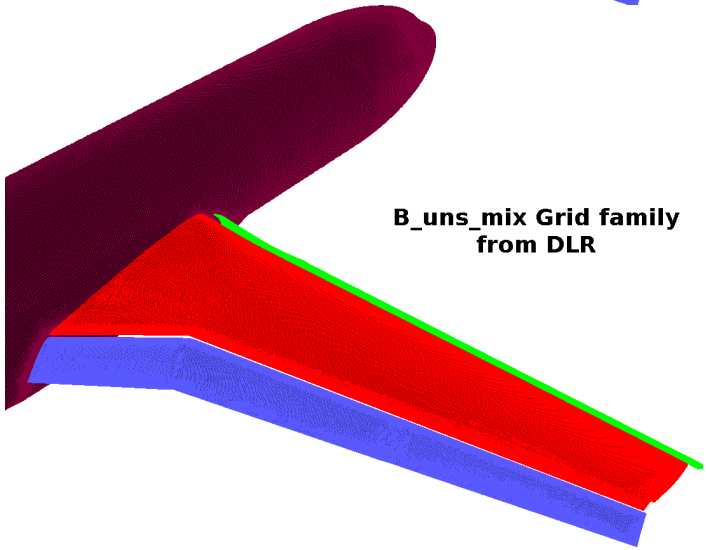
M_∞ = 0.175, Re_∞ = 15.1 million

Grid Family	Type	Size
A_Uns_Hex	Coarse	9,556,725
	Medium	31,998,440
	Fine	100,561,536
B_Uns_mix	Coarse	21,356,048
	Medium	59,066,549
	Fine	165,246,813

Reynolds Number Study (Case2)

Grid Family	Re_∞	Type	Size
B_Uns_mix	1.35 million	Medium	76,972,998
	15.1 million	Medium	73,740,331





Computational details

Hardware & Software

- Computer Platform: Parallel cluster available at CAd Lab
- Processors: Intel(R) Xeon(R) CPU E5-2620 0 @ 2.00GHz
- Number of processor–cores: 192
- Operating system: Linux (Fedora Core 14)
- Compiler: gfortran
- MPI Library: OpenMPI 1.4.3

HiFUN Resource Usage per run on Medium Grid ($\sim$ 77 million), Case2a Config4

- Run Time CPU: About 32 seconds per iteration
- Run Time Wall-Clock: About 40 Hrs (For 4500 iterations)
- Memory Requirements: About 800Mb per million volumes

Outline

1 Introduction

2 Grids Used

3 Results

4 Conclusion

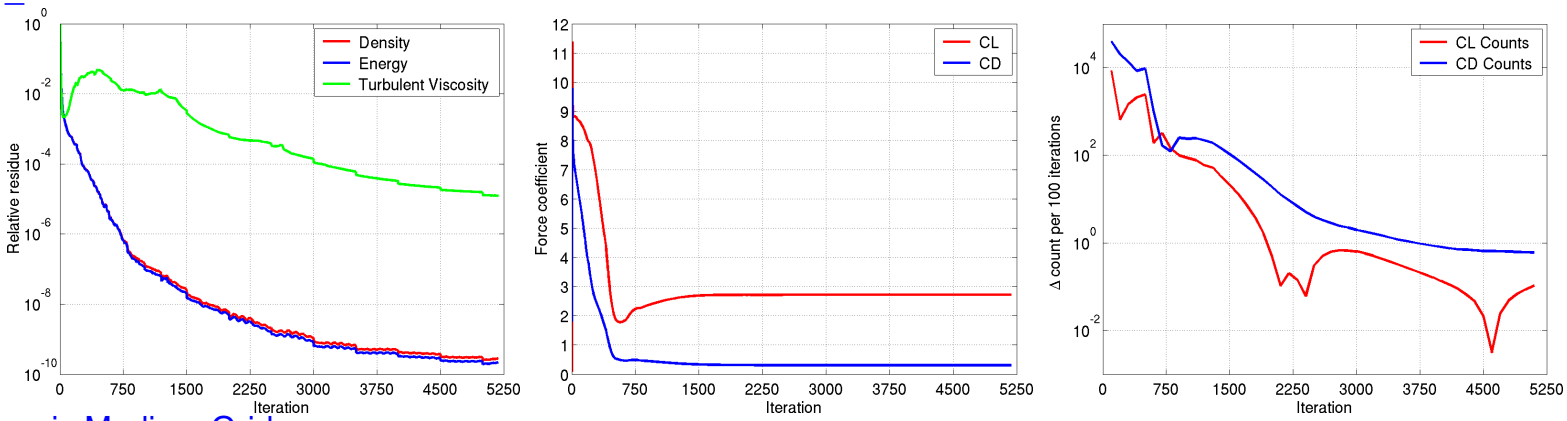
Outline

3 Results
- Solution convergence criterion
- Case 1: Grid convergence study
- Case 2a: Low Reynolds Number Study
- Case 2b: High Reynolds Number Study

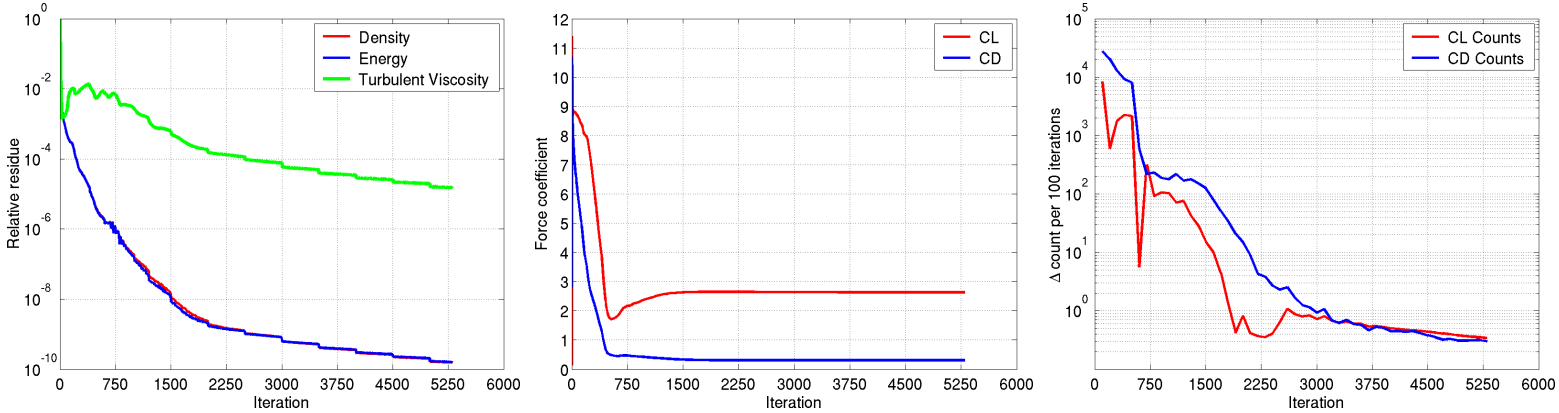
Residue & Force Coefficient Convergence

$M_\infty = 0.175$, $Re_\infty = 15.1$ million, $\alpha = 16$ degree

A_uns_hex Fine Grid



B_uns_mix Medium Grid



- About nine and half decades of fall in relative residue demonstrates robustness of HiFUN.
- Change in lift, drag coefficients between last 100 iterations is less than 1.0 count.

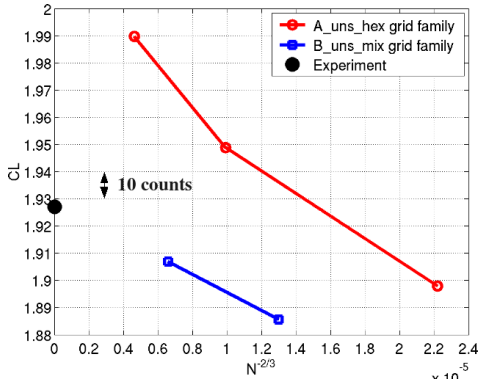
Outline

3 Results
- Solution convergence criterion
- Case 1: Grid convergence study
- Case 2a: Low Reynolds Number Study
- Case 2b: High Reynolds Number Study

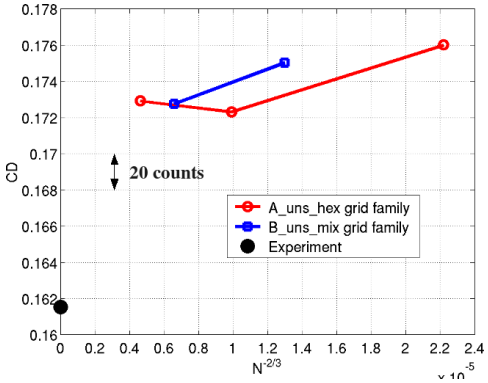
Grid Convergence Study

$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7\&16$ degrees

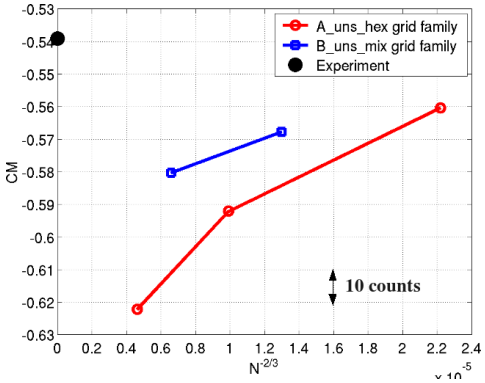
α = 7.0 deg



CL

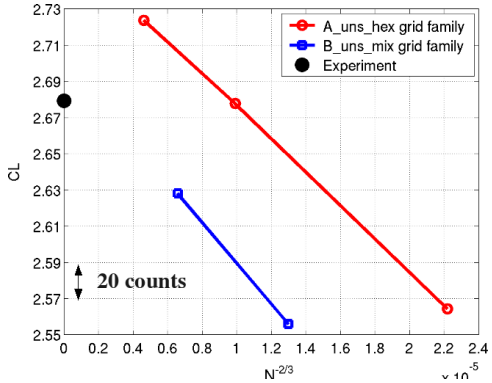


CD

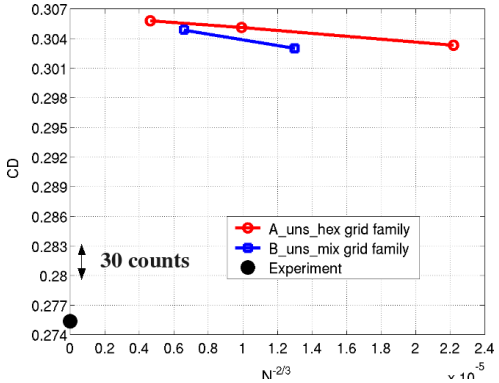


CM

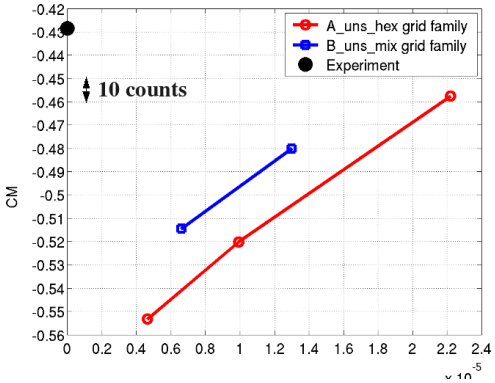
α = 16.0 deg



CL



CD



CM

- 1 CL count = 10^{-3}
- 1 CD count = 10^{-4}
- 1 CM count = 10^{-3}

- Integrated coefficients (on successive grid levels) exhibit tendency to converge to values away from experimental results.

Grid Convergence Study (Case1)

M_∞ = 0.175, Re_∞ = 15.1 million, α = 7 deg.

Grid Family	Type	CL	CD	CM
A_Uns_Hex	Experiment	1.9270	0.1615	-0.5390
	Coarse	1.8979	0.1760	-0.5603
	Medium	1.9488	0.1723	-0.5920
	Fine	1.9897	0.1729	-0.6222
B_Uns_mix	Coarse	1.8857	0.1750	-0.5676
	Medium	1.9069	0.1727	-0.5803

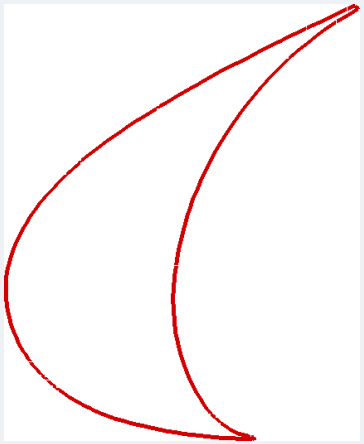
M_∞ = 0.175, Re_∞ = 15.1 million, α = 16 deg.

Grid Family	Type	CL	CD	CM
A_Uns_Hex	Experiment	2.6791	0.2753	-0.4284
	Coarse	2.5643	0.3033	-0.4575
	Medium	2.6777	0.3051	-0.5201
	Fine	2.7238	0.3058	-0.5533
B_Uns_mix	Coarse	2.5559	0.3030	-0.4800
	Medium	2.6281	0.3048	-0.5144

Sectional view of Slat (Case1 Config2)

Slat

15%

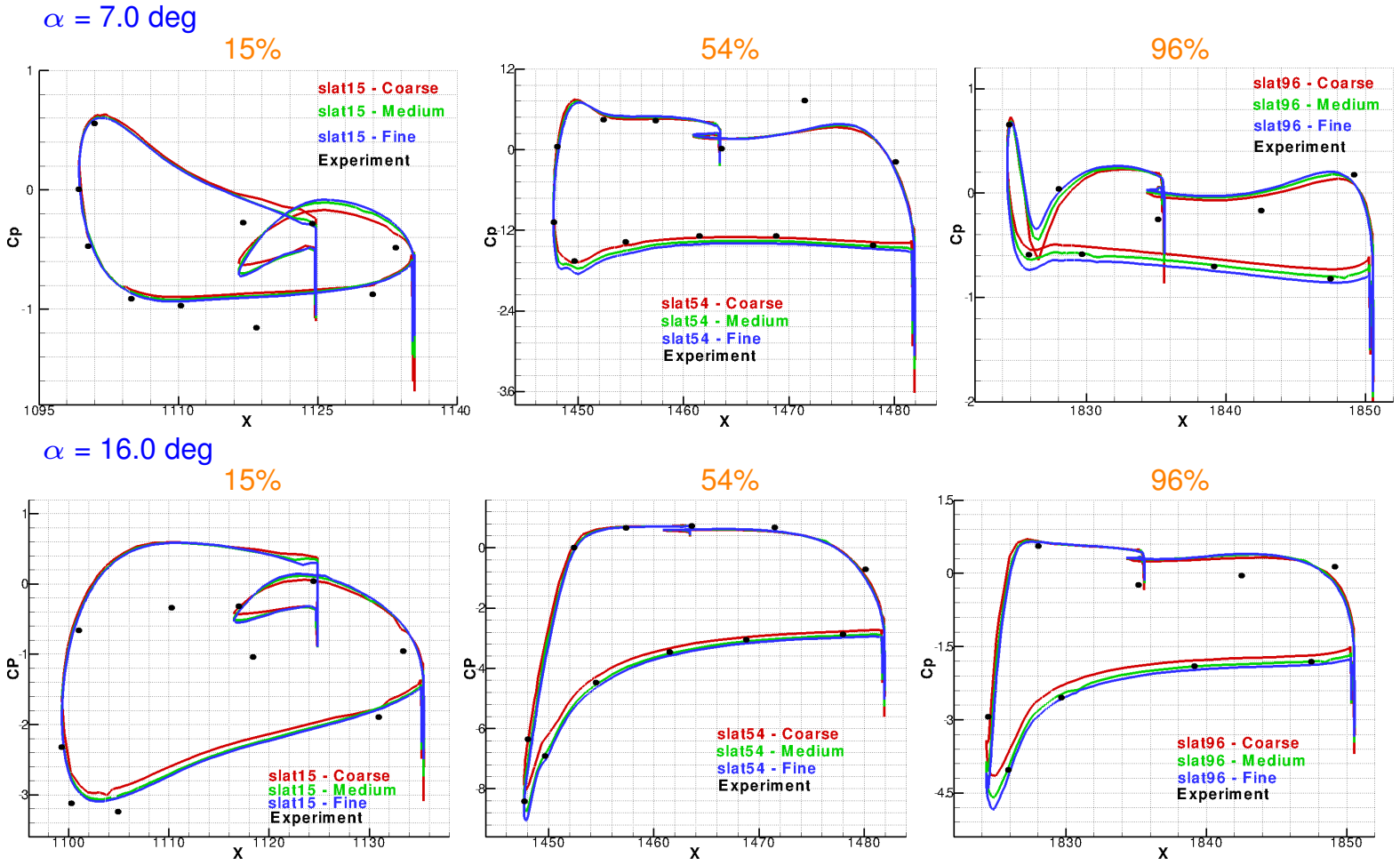


54%

96%

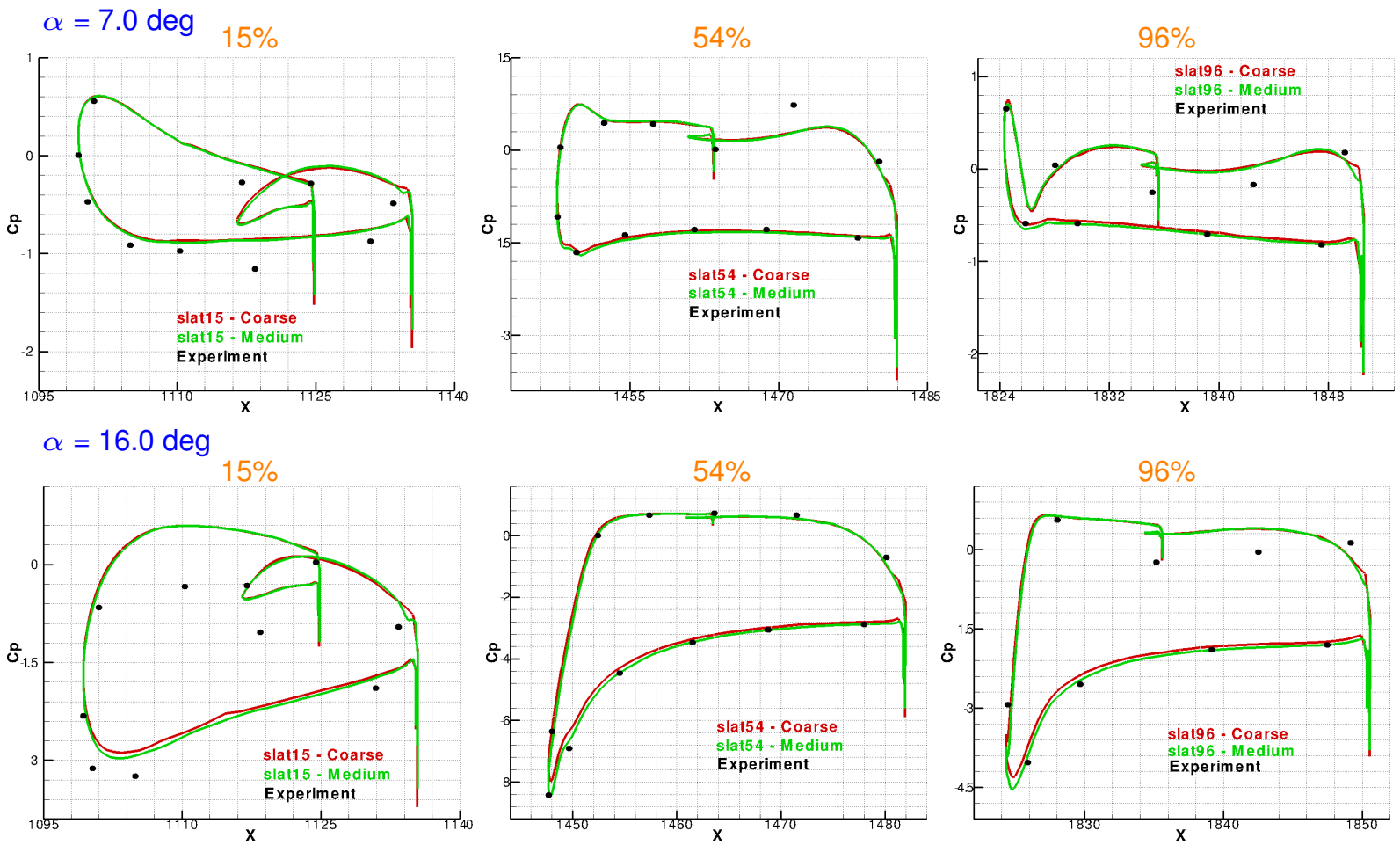
Cp distribution on the Slat (A_uns_hex grid family)

$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7$ & 16 degrees



Cp distribution on the Stat (B_uns_mix grid family)

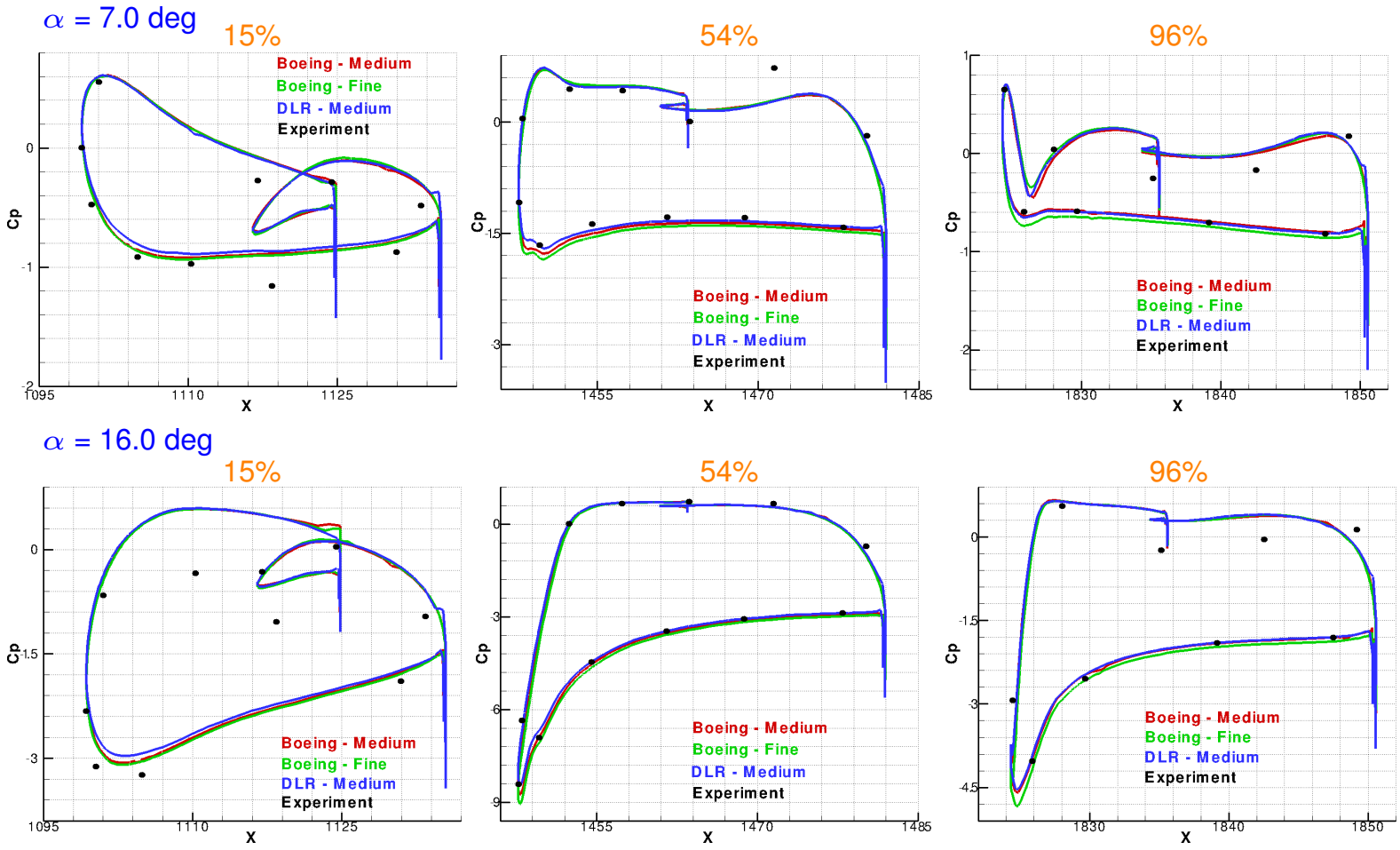
$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7$ & 16 degrees



- With grid refinement, Cp distribution prediction tends towards experimental data.

Cp distribution on the Stat (A_uns_hex & B_uns_mix grid family)

$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7$ & 16 degrees



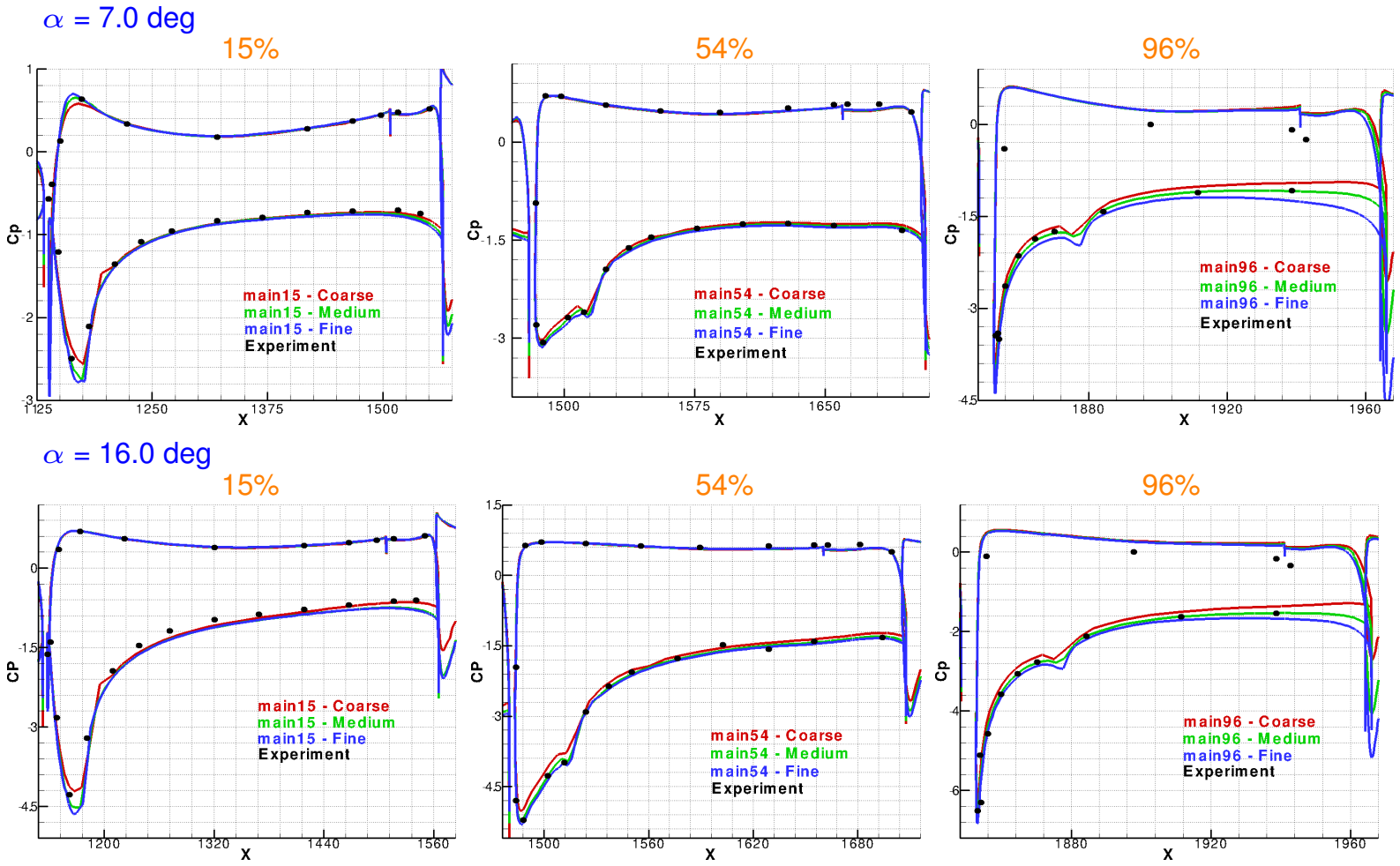
Sectional view of Main (Case1 Config2)

Main

15% 54% 96%

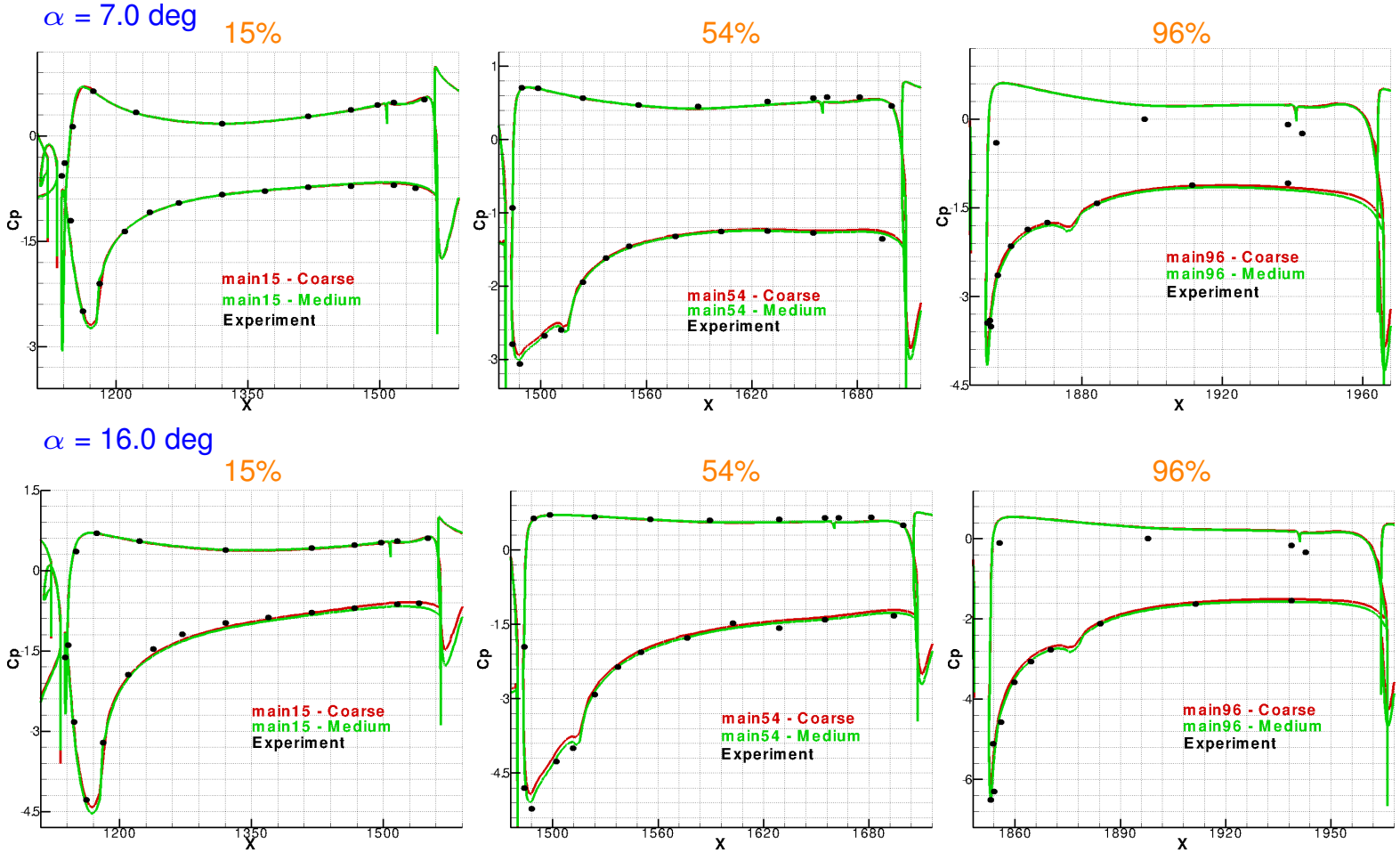
Cp distribution on the Main (A_uns_hex grid family)

$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7$ & 16 degrees



Cp distribution on the Main (B_uns_mix grid family)

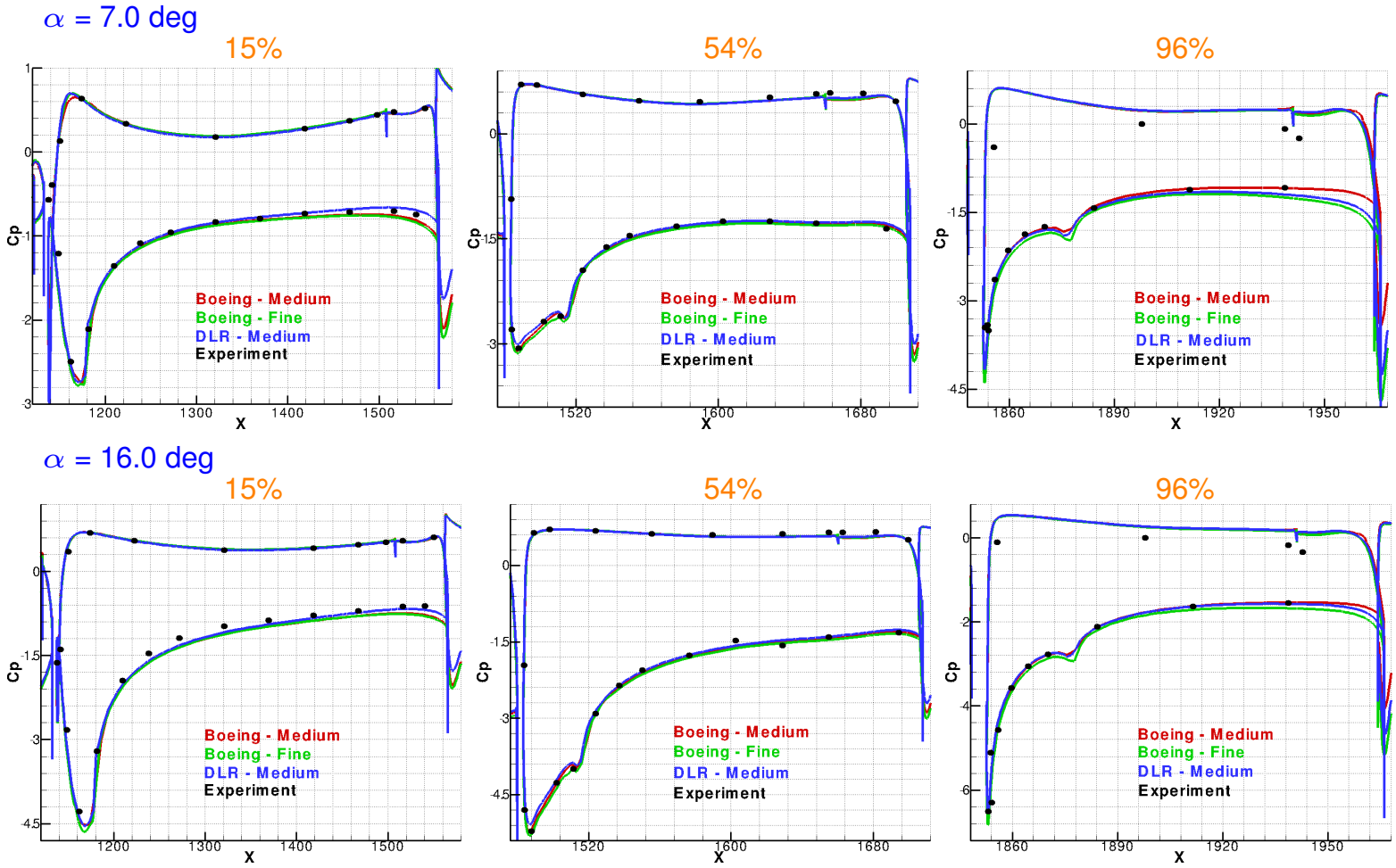
$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7$ & 16 degrees



- With grid refinement, Cp distribution prediction tends towards experimental data.

Cp distribution on the Main (A_uns_hex & B_uns_mix grid family)

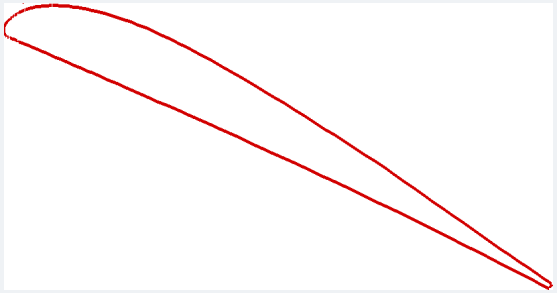
$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7$ & 16 degrees



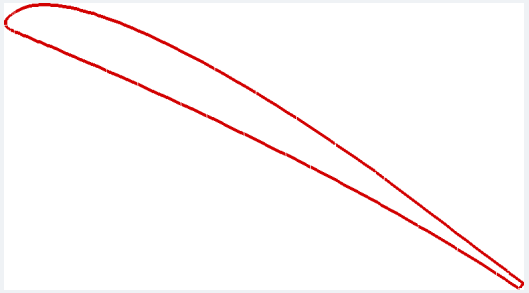
Sectional view of Flap (Case1 Config2)

Flap

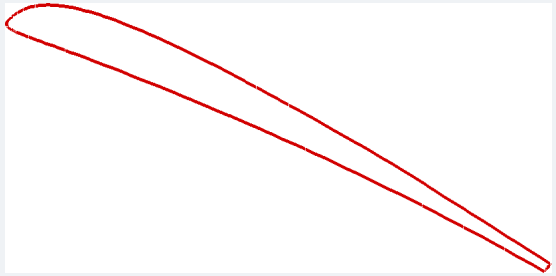
15%



54%

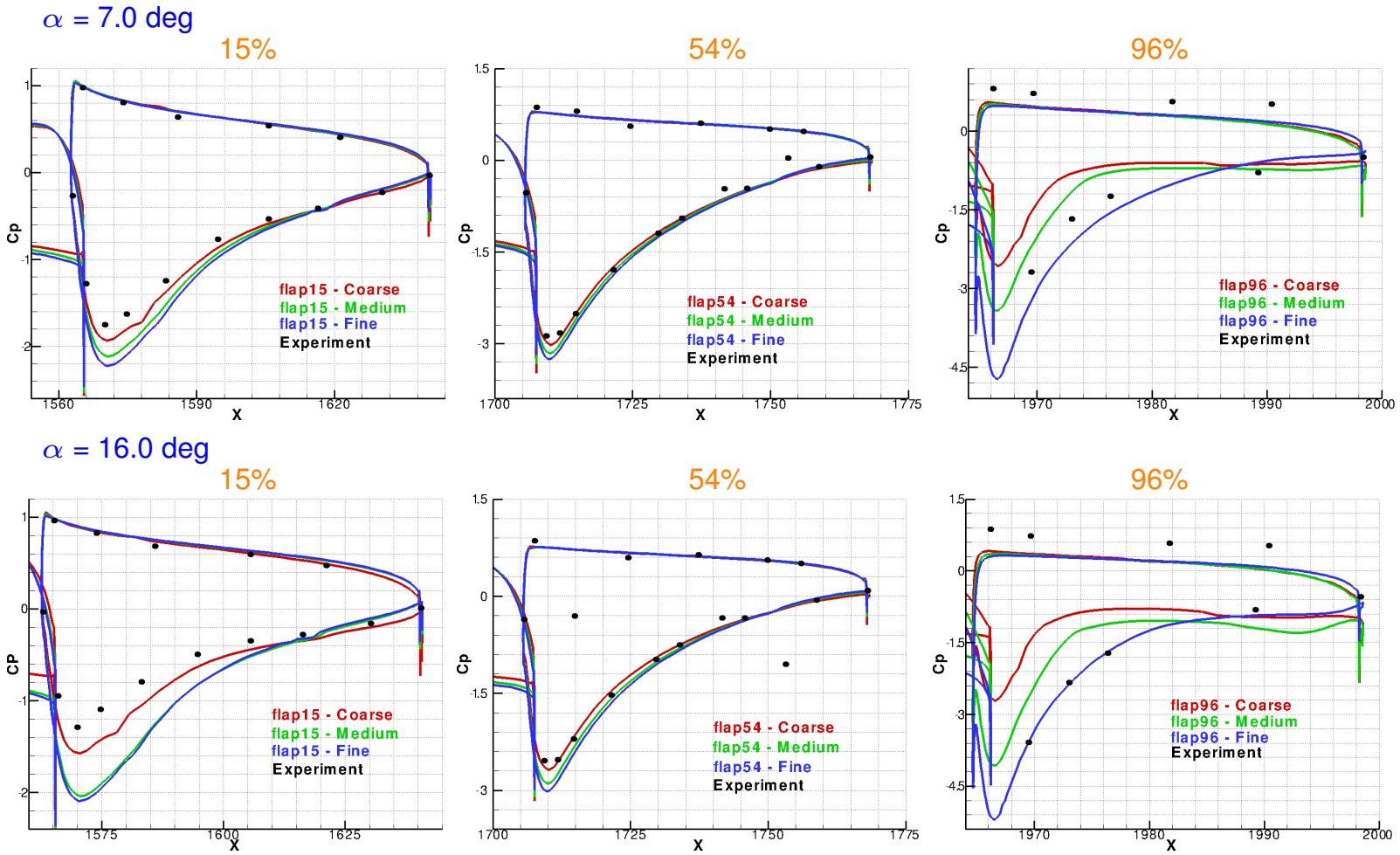


96%



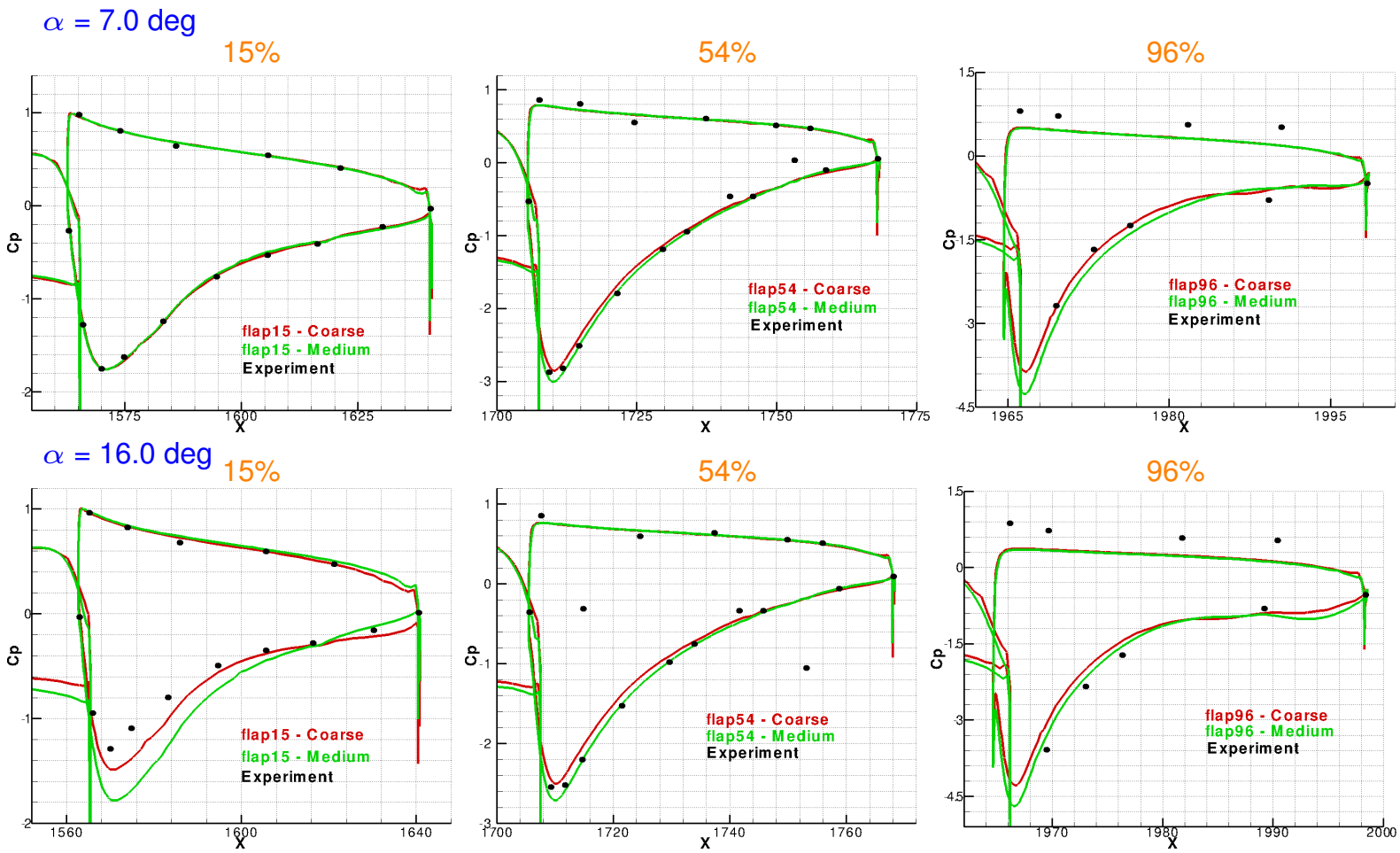
Cp distribution on the Flap (A_uns_hex grid family)

$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7$ & 16 degrees



Cp distribution on the Flap (B_uns_mix grid family)

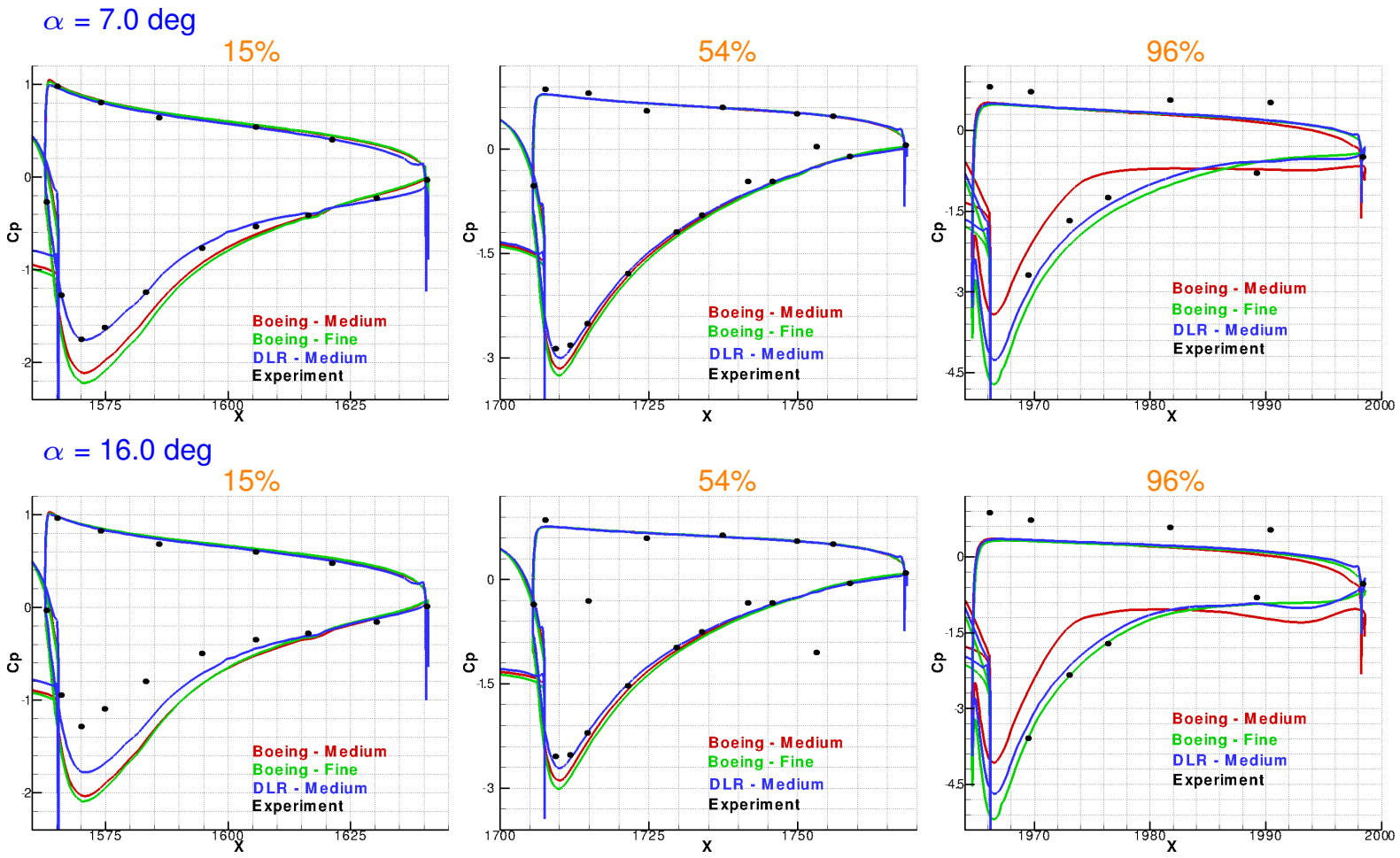
$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7$ & 16 degrees



- With grid refinement, Cp distribution prediction tends towards experimental data.

Cp distribution on the Flap (A_uns_hex & B_uns_mix grid family)

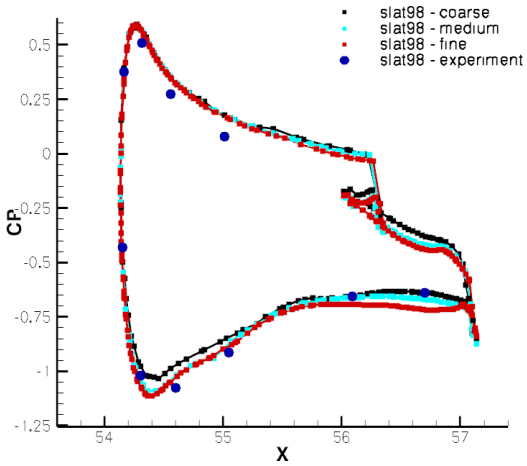
$M_\infty = 0.175$, $Re_\infty = 15.10$ million, $\alpha = 7$ & 16 degrees



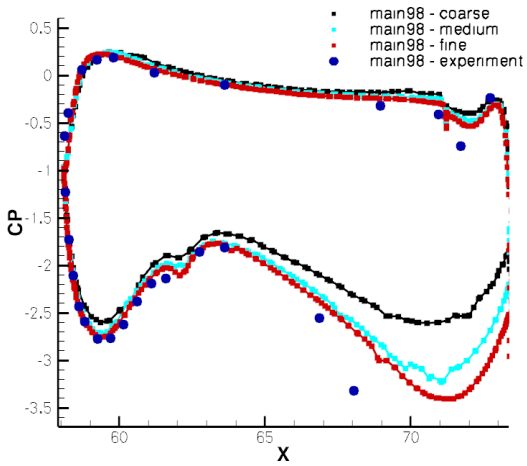
Cp comparison at wing tip for Nasa Trapwing & DLR F11

Nasa Trapwing: α = 13.0 deg, 98% of span

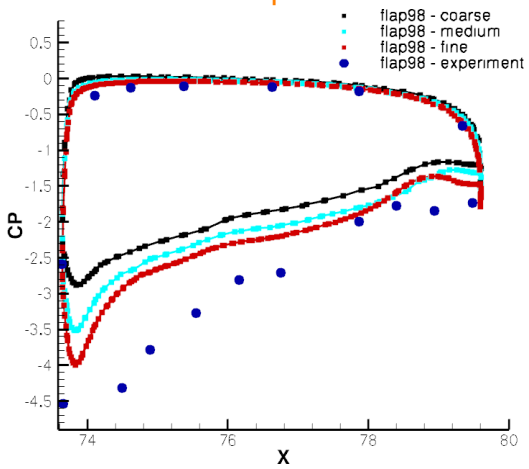
Slat



Main

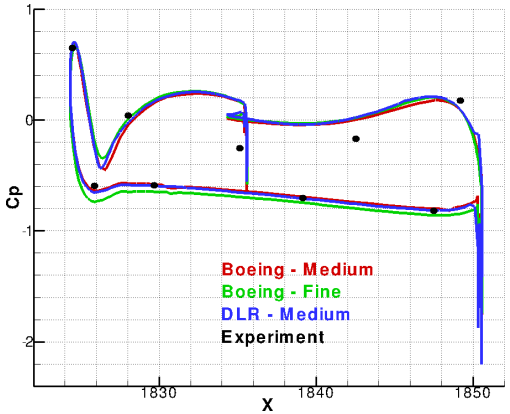


Flap

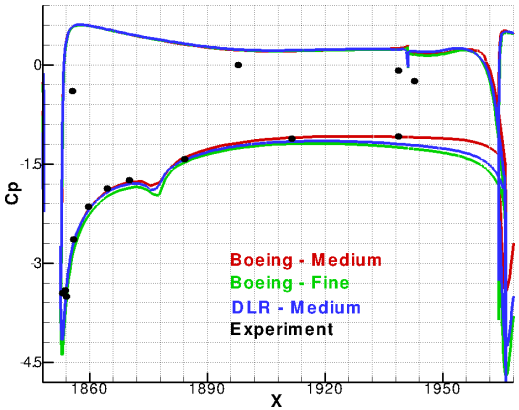


DLR F11, Eurolift: α = 7.0 deg, 96% of span

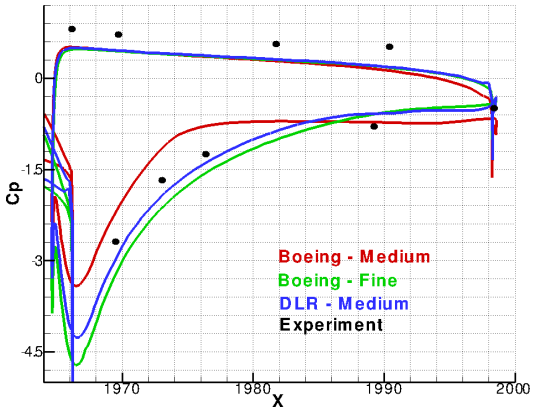
Slat



Main



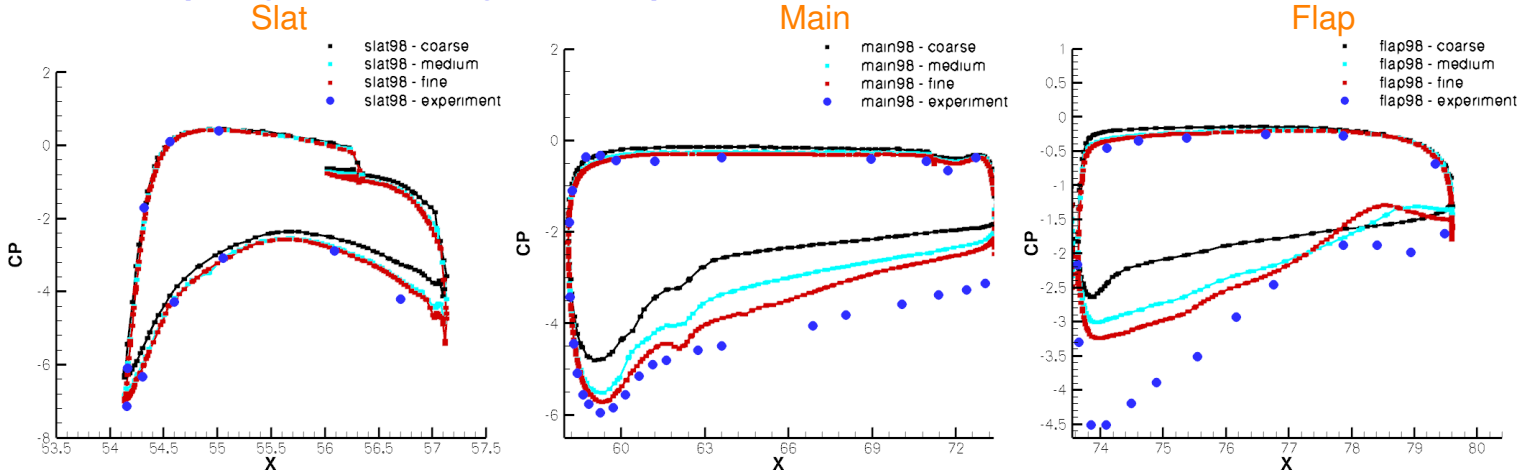
Flap



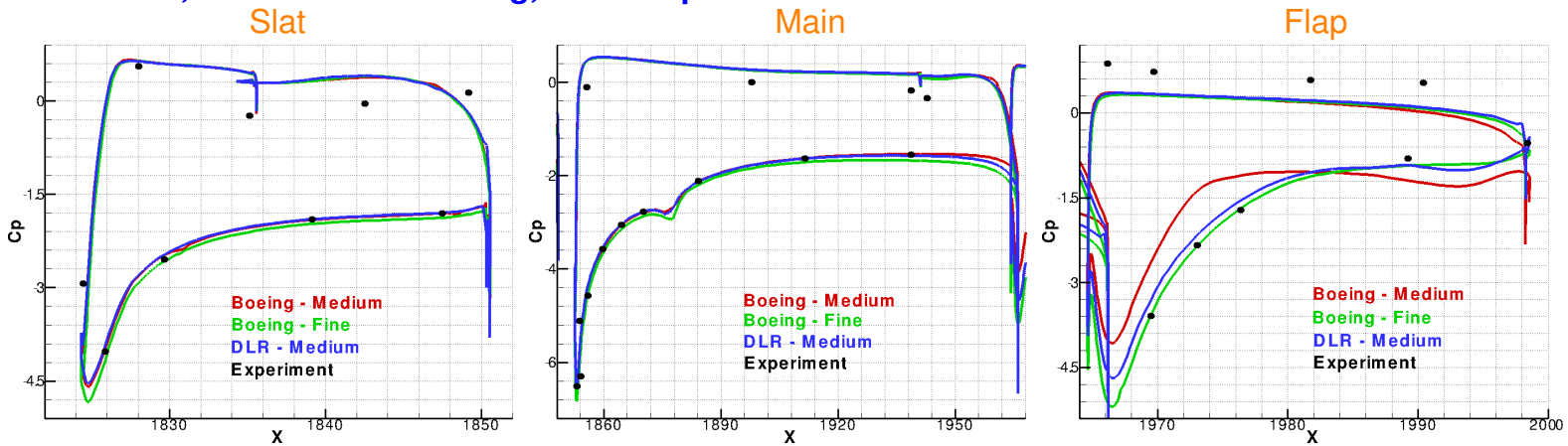
- Cp distribution prediction at wing tip is better on DLR F11 compared to that on Nasa Trapwing.

Cp comparison at wing tip for Nasa Trapwing & DLR F11

Nasa Trapwing: α = 28.0 deg, 98% of span



DLR F11, Eurolift: α = 16.0 deg, 96% of span



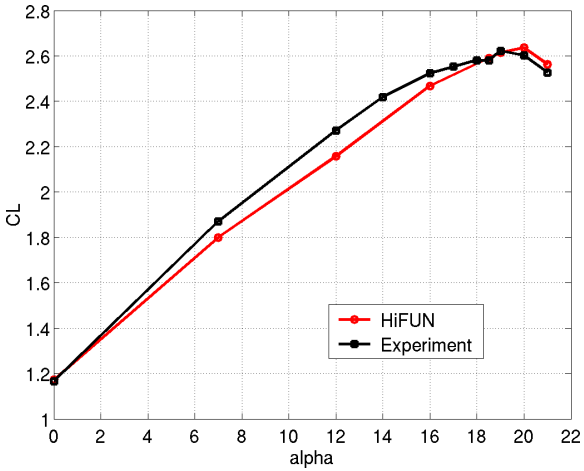
- Cp distribution prediction at wing tip is better on DLR F11 compared to that on Nasa Trapwing.

Outline

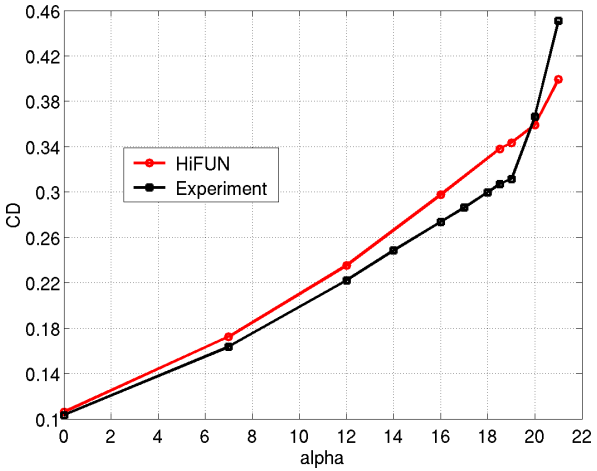
3 Results
- Solution convergence criterion
- Case 1: Grid convergence study
- Case 2a: Low Reynolds Number Study
- Case 2b: High Reynolds Number Study

Force & Moment v.s α (Case2a Config4, B_uns_mix medium grid)

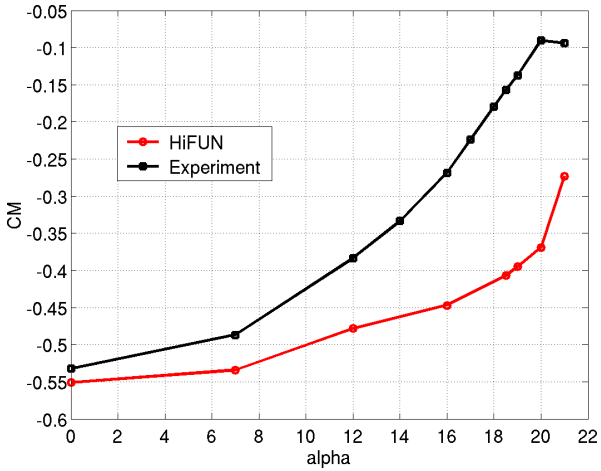
$M_\infty = 0.175$, $Re_\infty = 1.35$ million



CL vs α



CD vs α



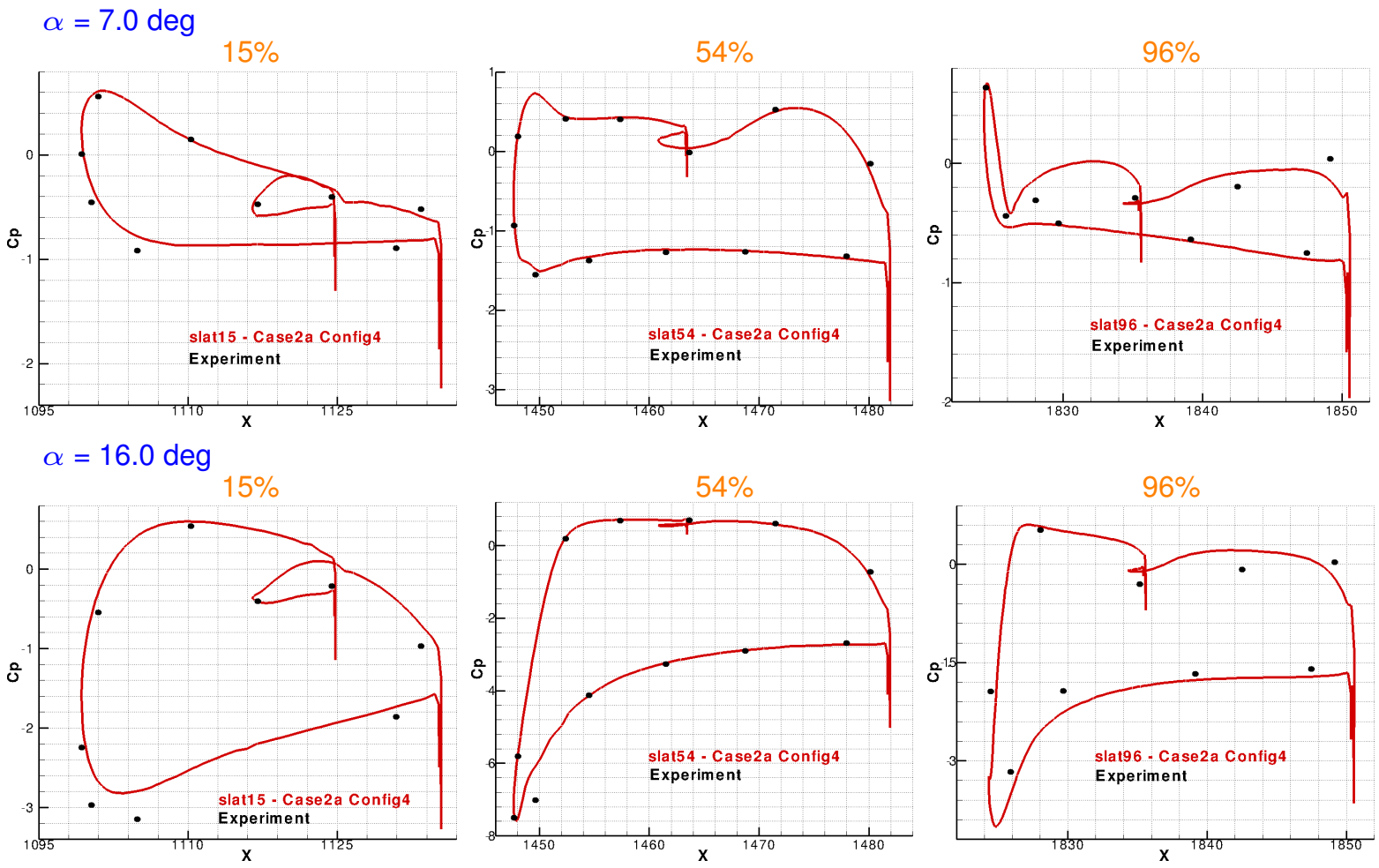
CM vs α

α	Δ CL count	Δ CD count	Δ CM count
7	71.5	-88.2	47.2
12	113.2	-131.2	94.3
16	55.8	-236.67	198.2
19	8.9	-319.1	257.8

- Under prediction of CL for all alphas compared to experiment.
- Over prediction of α_{max} by 1.0 degree.
- Drag prediction is marginally higher for all alphas compared to experiment.
- Deviation of predicted pitching moment from experiment increases with alpha.

Cp distribution on the Slat (Case2a Config4)

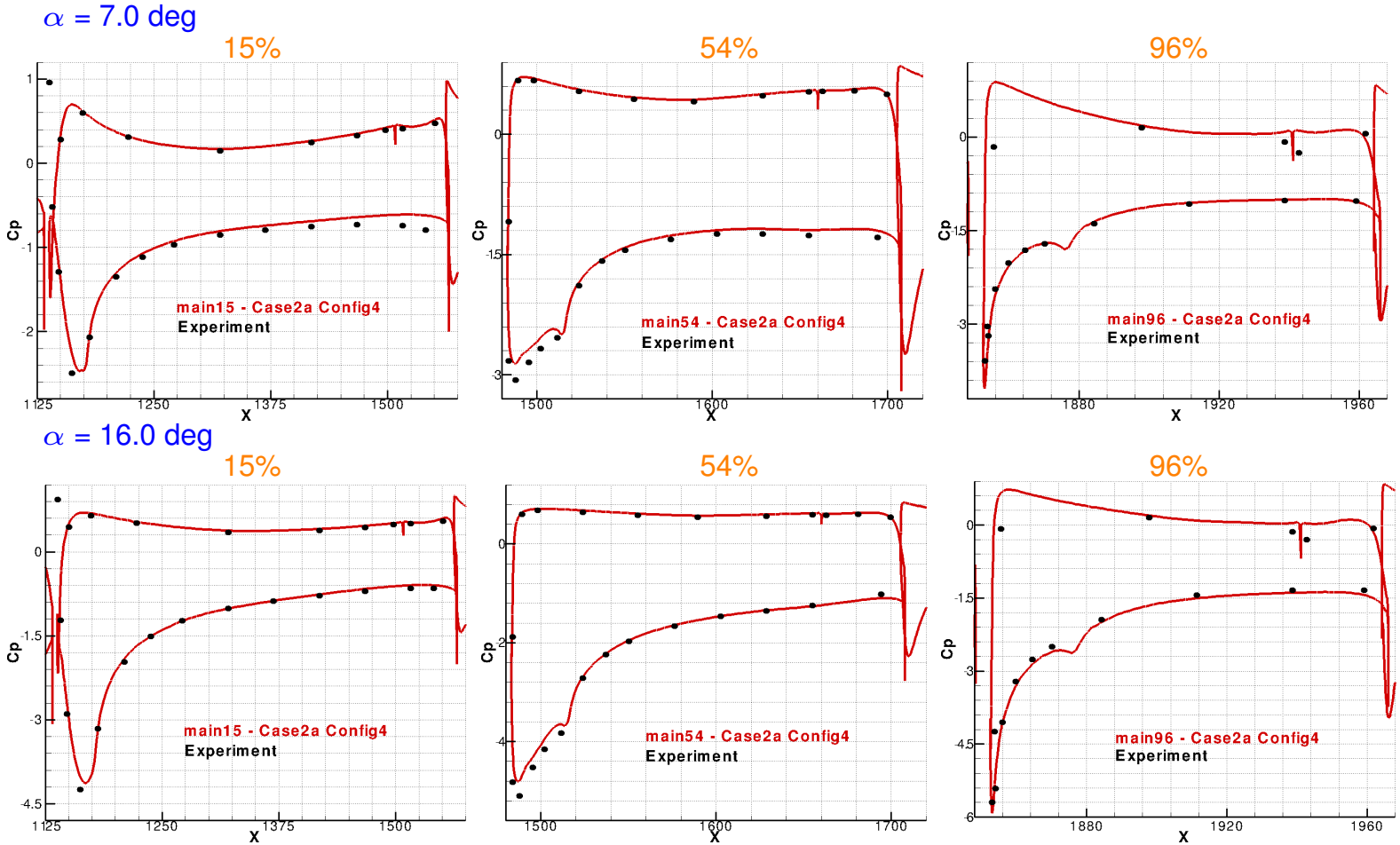
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, $\alpha = 7$ & 16 degrees



- Good match between CFD and experiment.

Cp distribution on the Main (Case2a Config4)

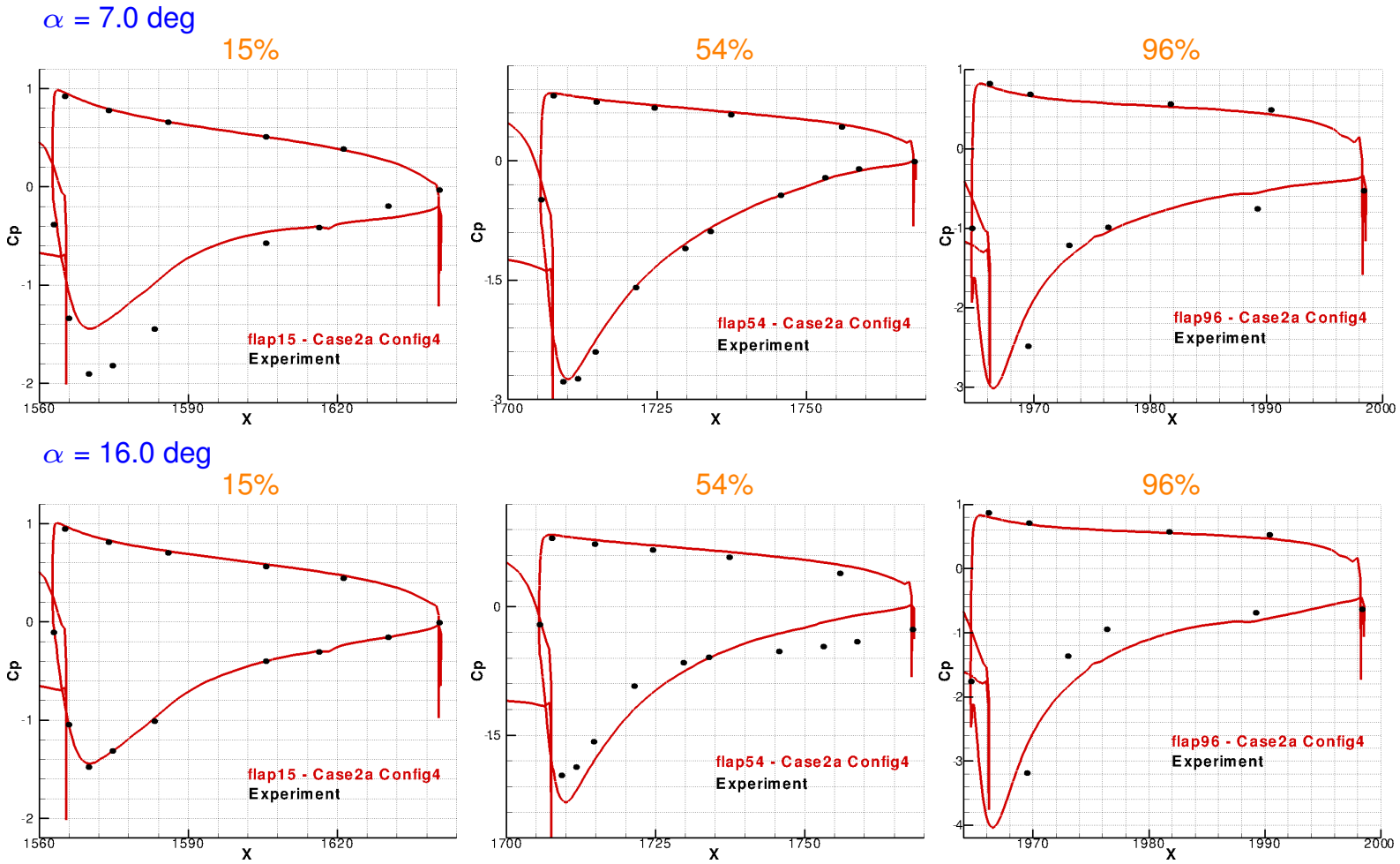
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, $\alpha = 7$ & 16 degrees



- Predicted Cp distribution compares well with experiment.

Cp distribution on the Flap (Case2a Config4)

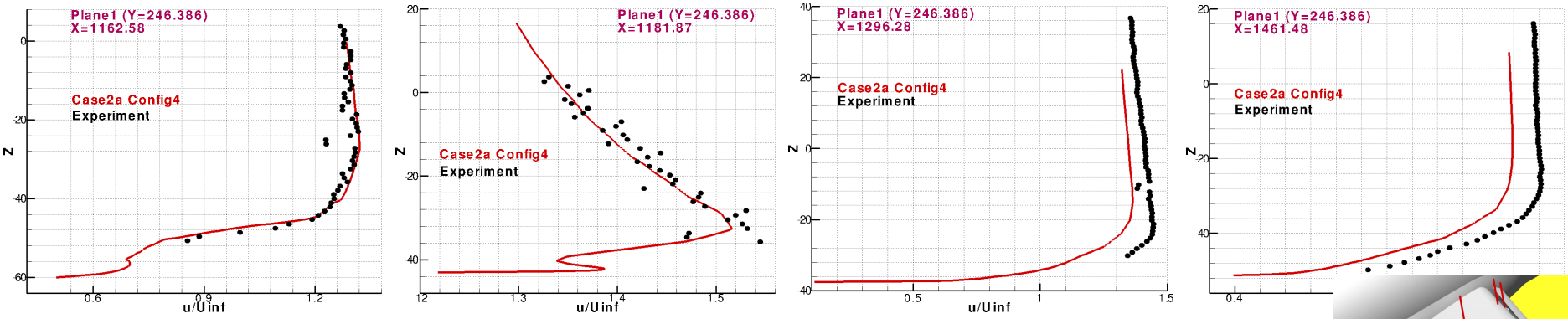
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, $\alpha = 7$ & 16 degrees



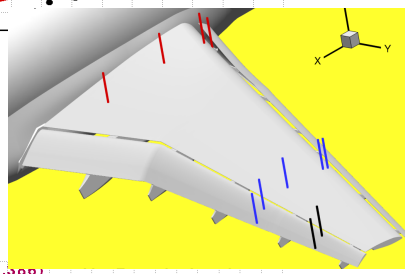
u/U_{inf} profiles on Main Element **Plane 1**: Y = 246.386 (Case2a Config4)

$M_\infty = 0.175$, $Re_\infty = 1.35$ million, α **= 7 deg**

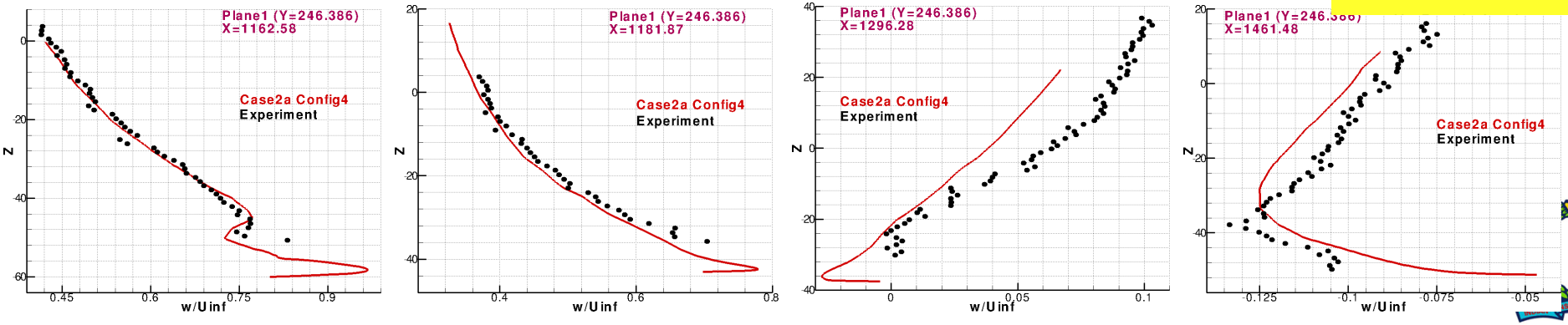
Location 1 | Location 2 | Location 3 | Location 4



u/U_{inf}



Location 1 | Location 2 | Location 3 | Location 4

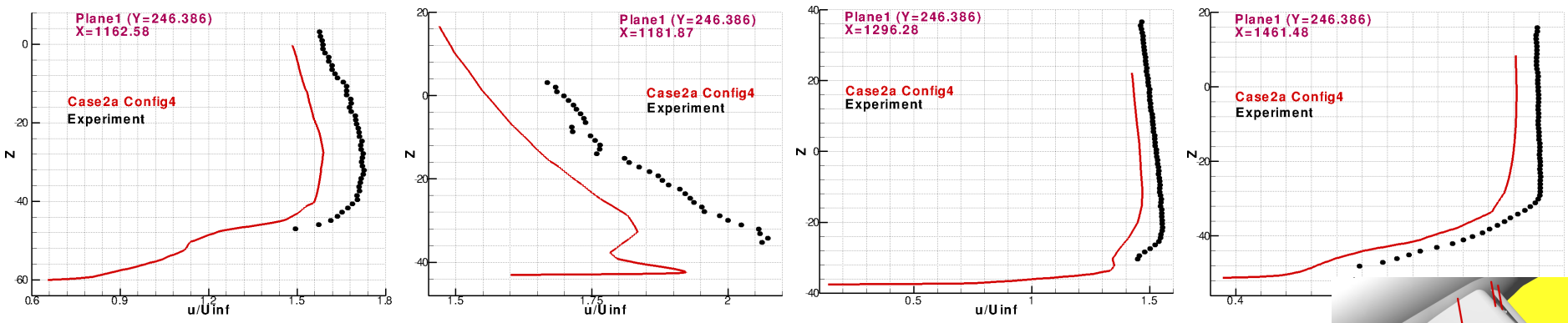


w/U_{inf}

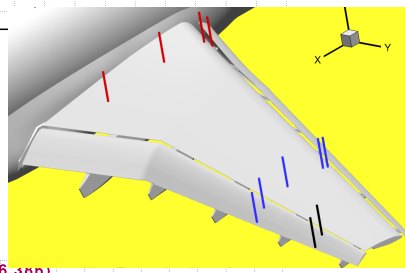
u/U_{inf} profiles on Main Element **Plane 1**: Y = 246.386 (Case2a Config4)

$M_\infty = 0.175$, $Re_\infty = 1.35$ million, α **= 18.5 deg**

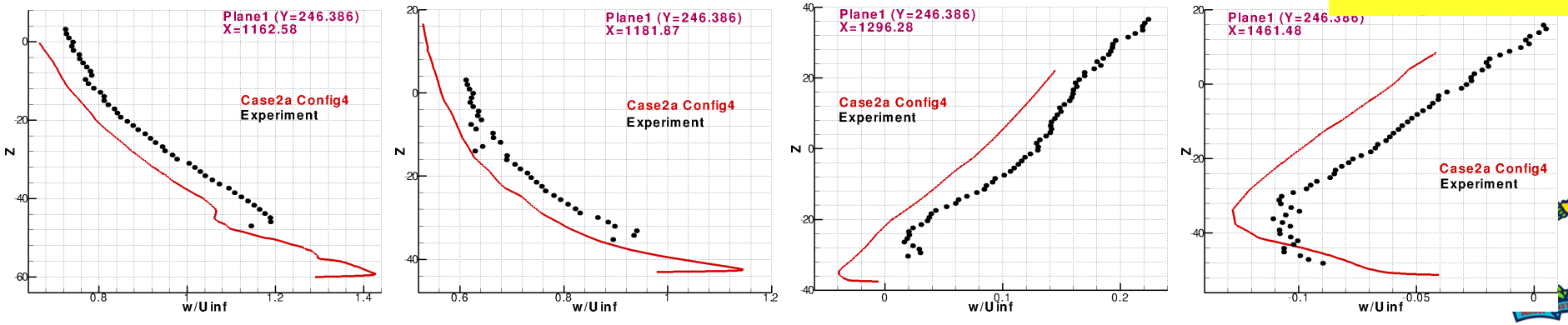
Location 1 | Location 2 | Location 3 | Location 4



u/U_{inf}



Location 1 | Location 2 | Location 3 | Location 4

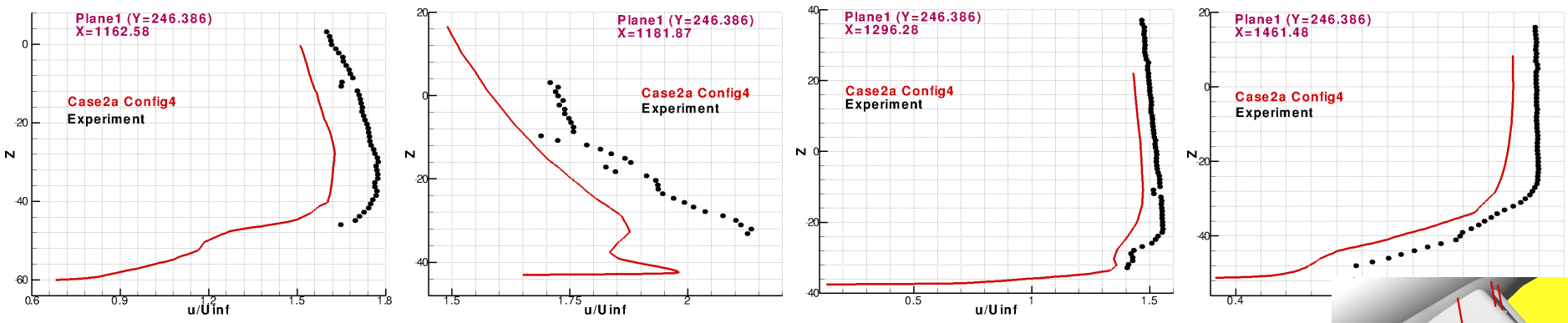


w/U_{inf}

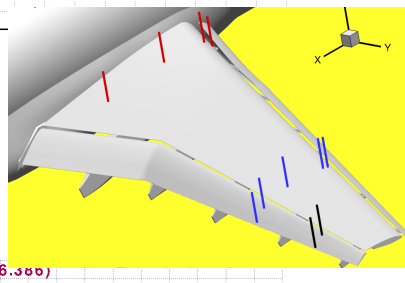
u/U_{inf} profiles on Main Element **Plane 1**: Y = 246.386 (Case2a Config4)

$M_\infty = 0.175$, $Re_\infty = 1.35$ million, α **= 21.0 deg**

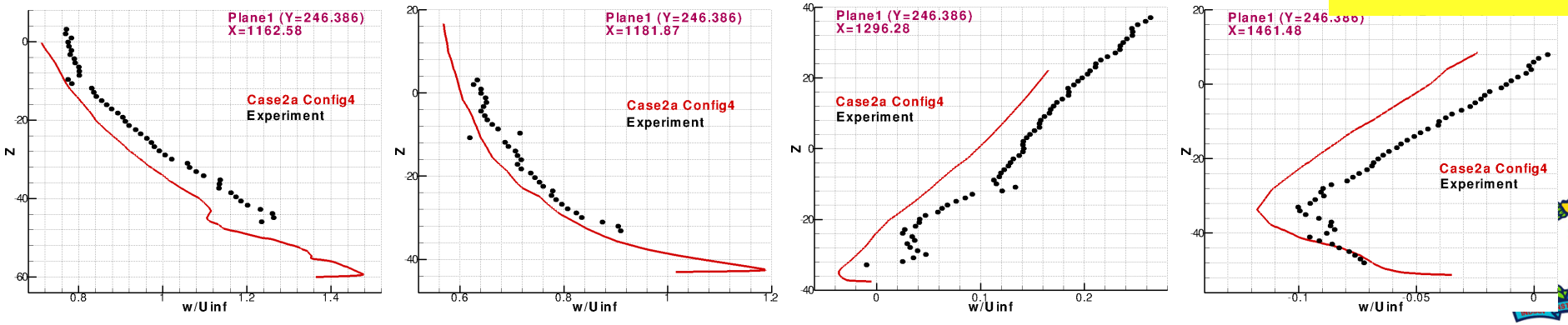
Location 1 | Location 2 | Location 3 | Location 4



u/U_{inf}



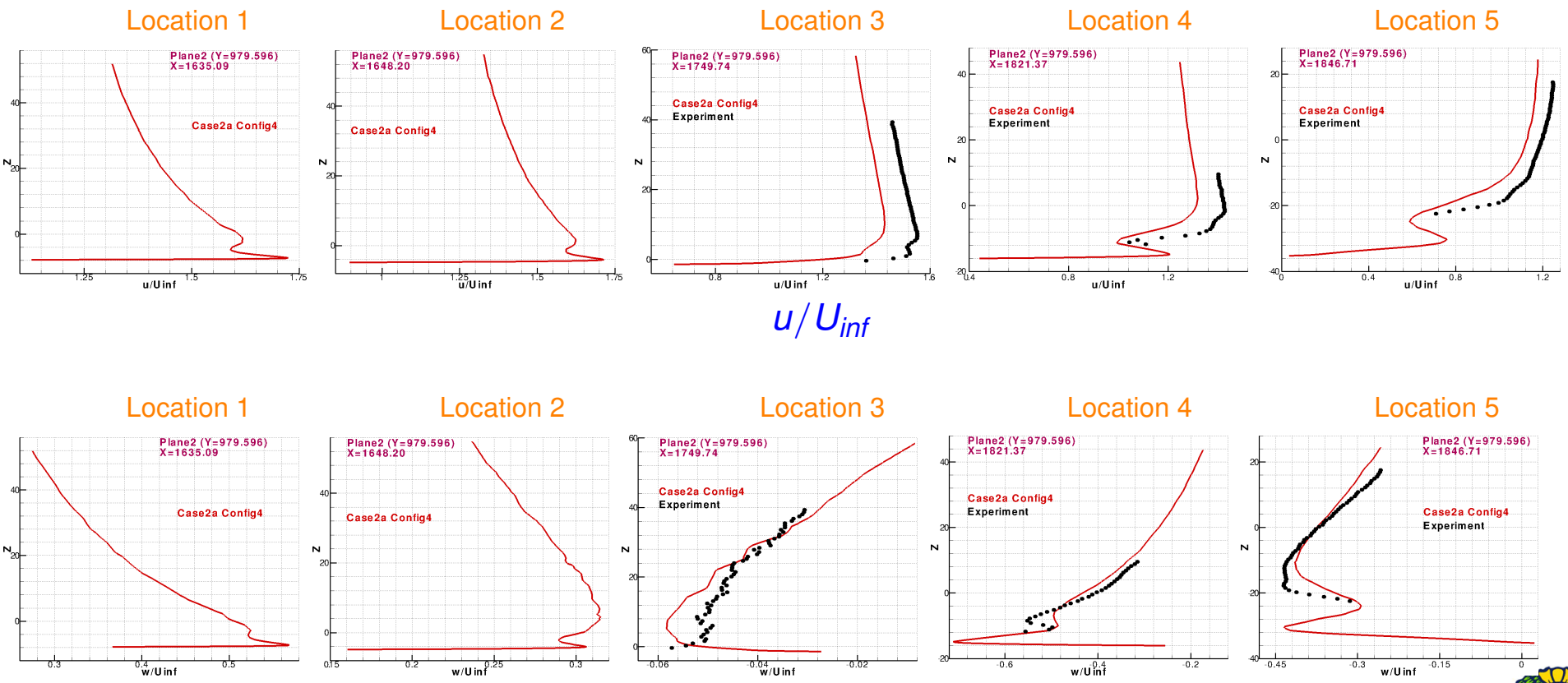
Location 1 | Location 2 | Location 3 | Location 4



w/U_{inf}

u/U_{inf} profiles on Main and Flap, **Plane 2**: Y = 979.596 (Case2a Config4)

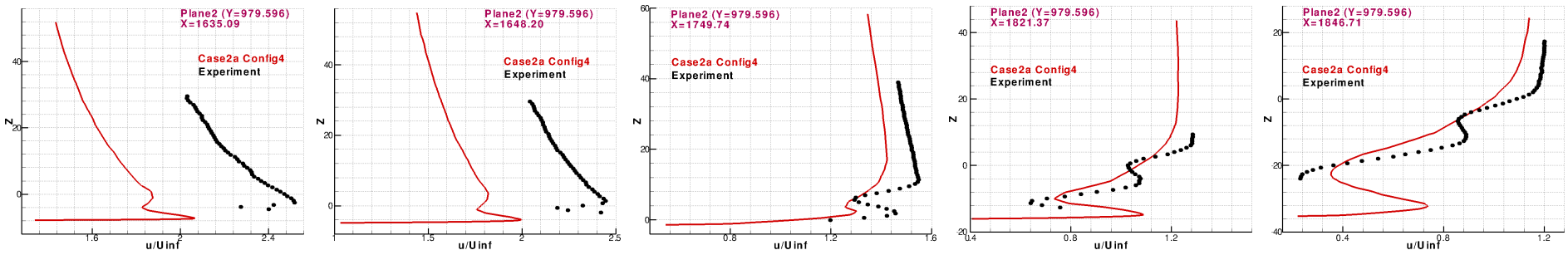
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, α **= 7 deg**



u/U_{inf} profiles on Main and Flap, **Plane 2**: Y = 979.596 (Case2a Config4)

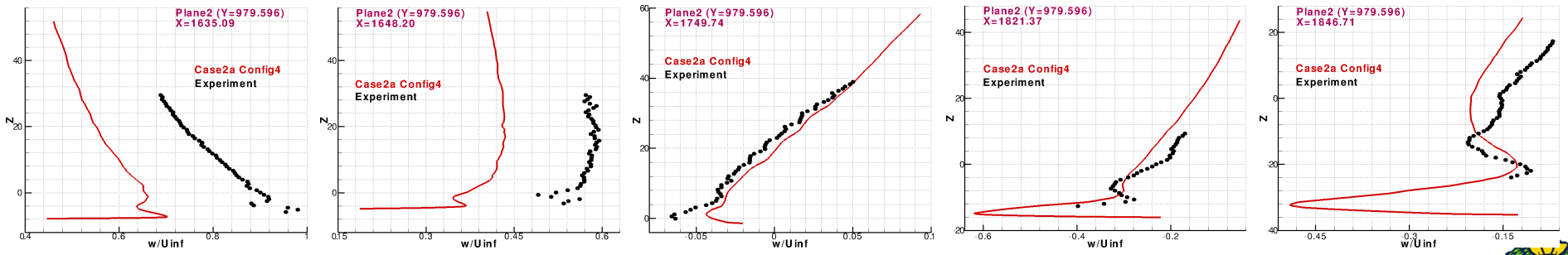
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, α **= 18.5 deg**

Location 1 Location 2 Location 3 Location 4 Location 5



u/U_{inf}

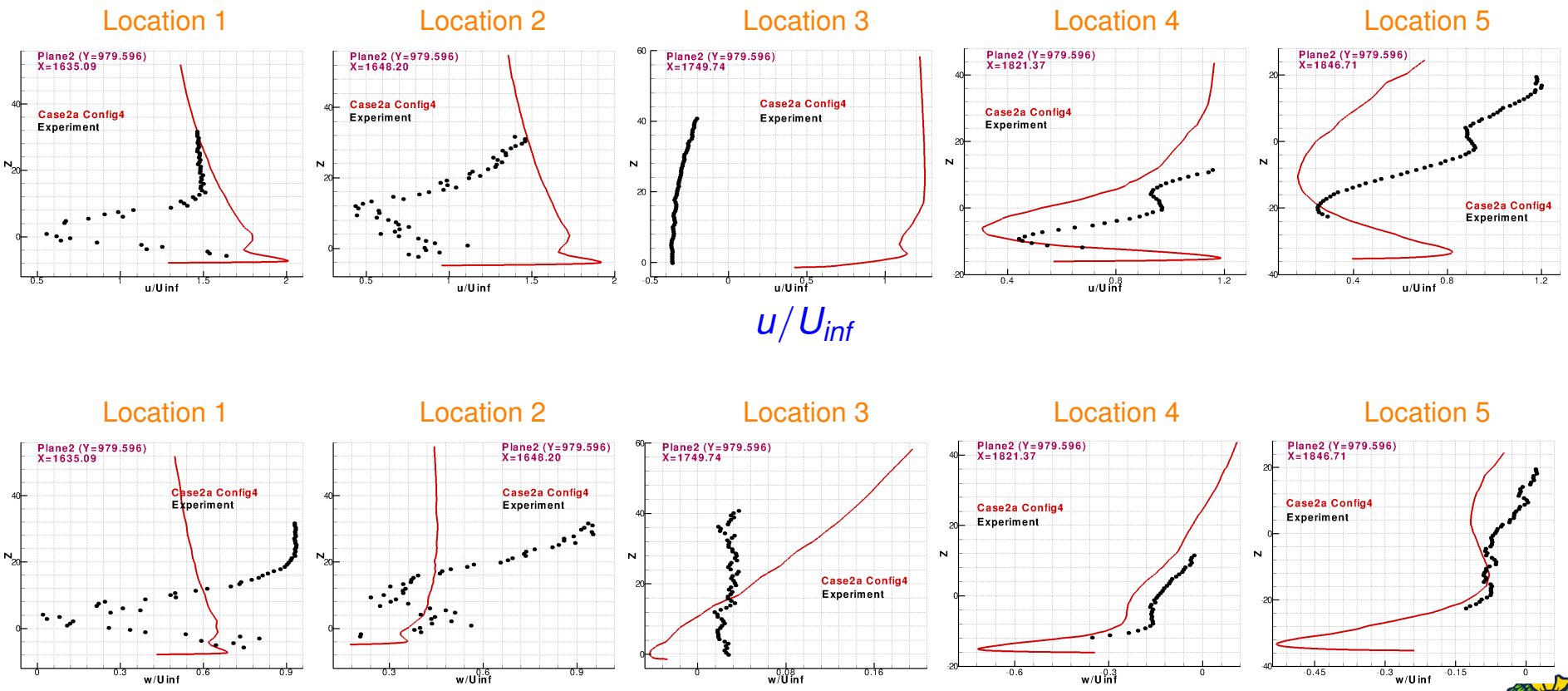
Location 1 Location 2 Location 3 Location 4 Location 5



w/U_{inf}

u/U_{inf} profiles on Main and Flap, **Plane 2**: Y = 979.596 (Case2a Config4)

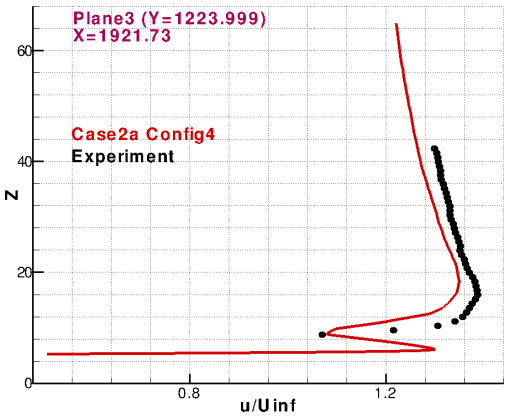
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, α **= 21.0 deg**



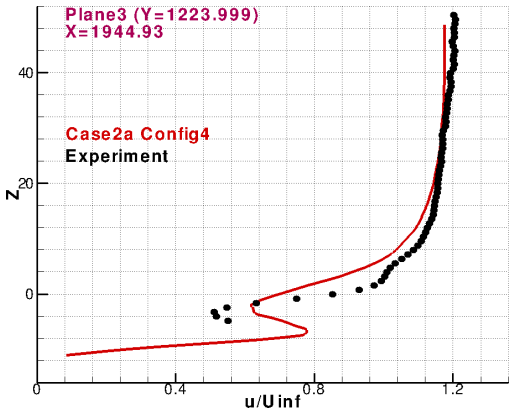
Velocity profiles on Main and Flap, **Plane 3**: Y = 1223.999 (Case2a Config4)

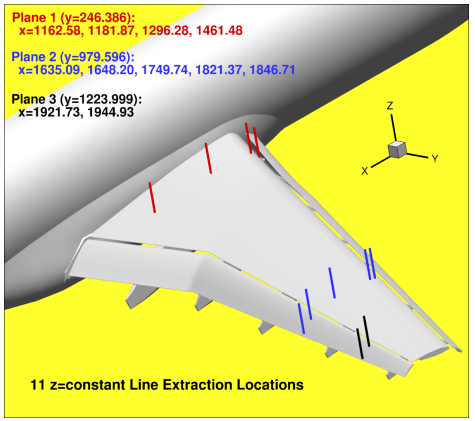
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, α **= 7 deg**

Location 1



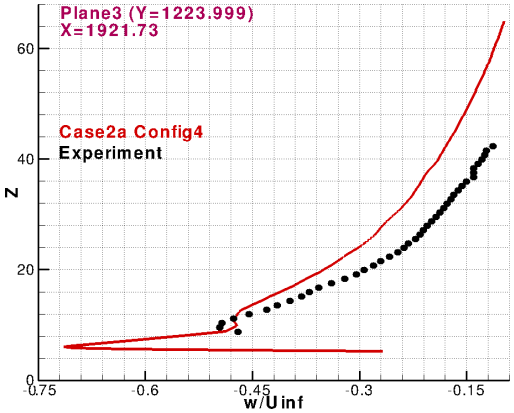
Location 2



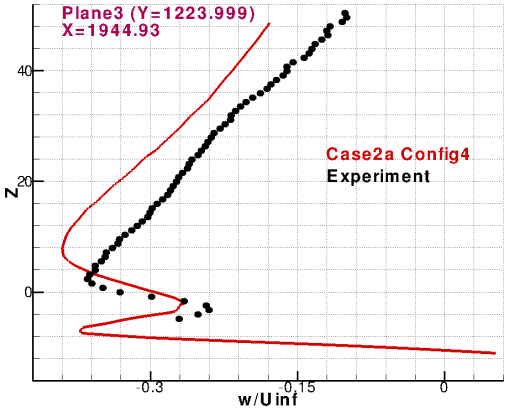


u/U_{inf}

Location 1



Location 2

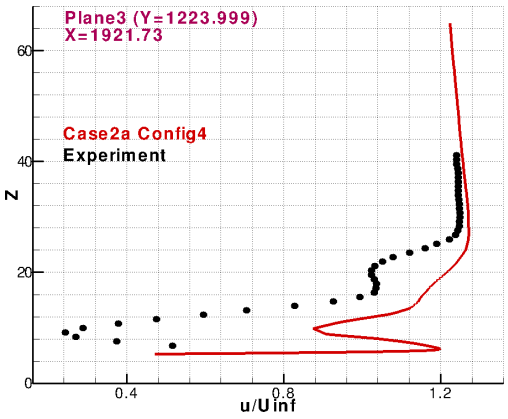


w/U_{inf}

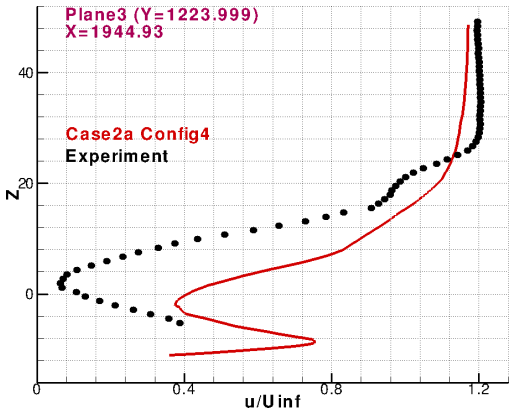
Velocity profiles on Main and Flap, **Plane 3**: Y = 1223.999 (Case2a Config4)

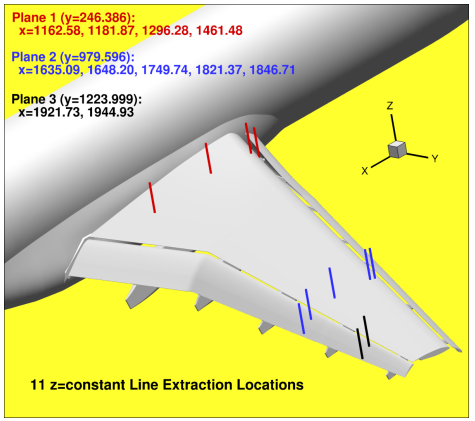
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, α **= 18.5 deg**

Location 1



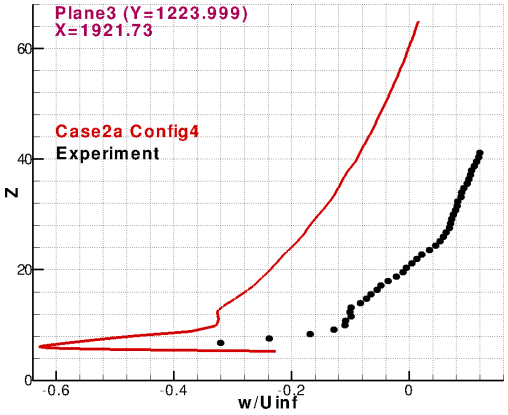
Location 2



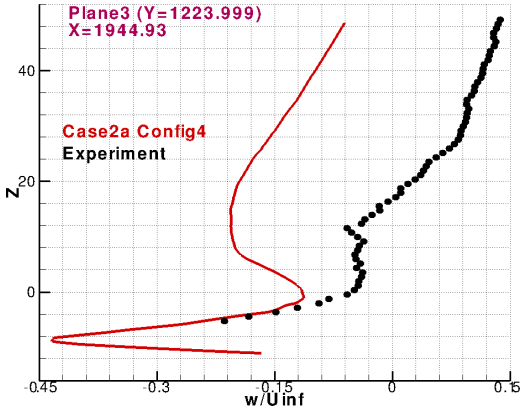


u/U_{inf}

Location 1



Location 2

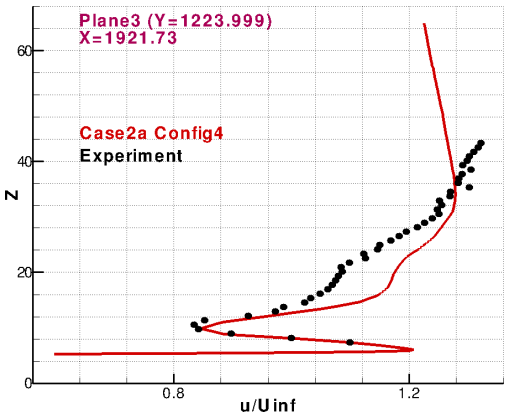


w/U_{inf}

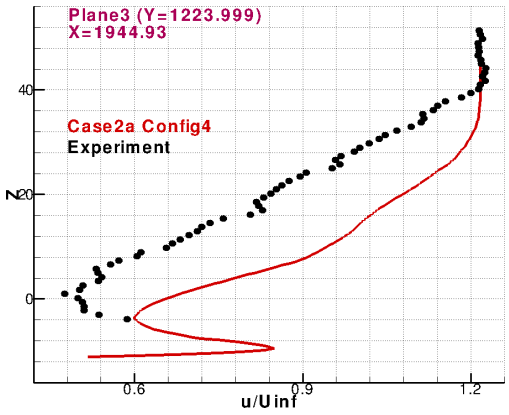
Velocity profiles on Main and Flap, **Plane 3**: Y = 1223.999 (Case2a Config4)

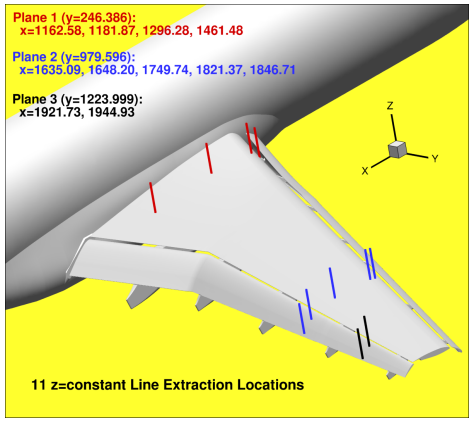
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, α **= 21 deg**

Location 1



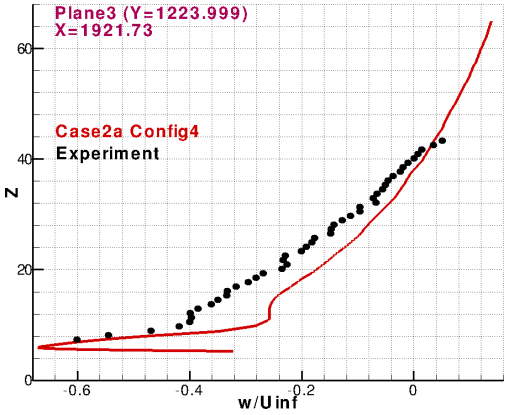
Location 2



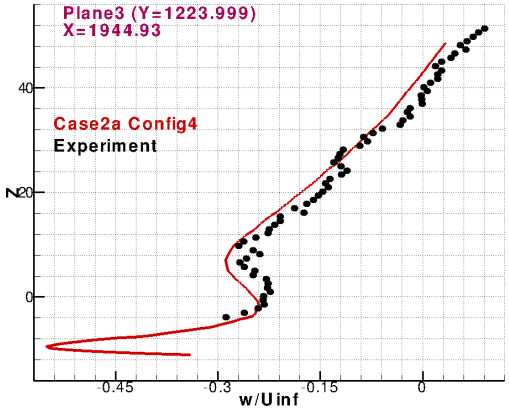


u/U_{inf}

Location 1



Location 2



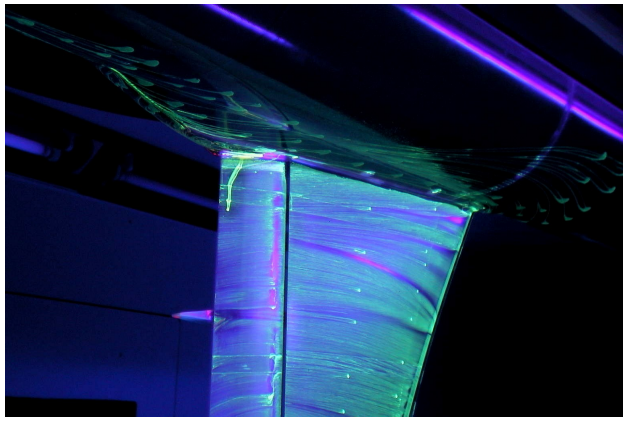
w/U_{inf}

Surface Streamlines (Case2a Config4)

$M_\infty = 0.175$, $Re_\infty = 1.35$ million, $\alpha = 7$ degree

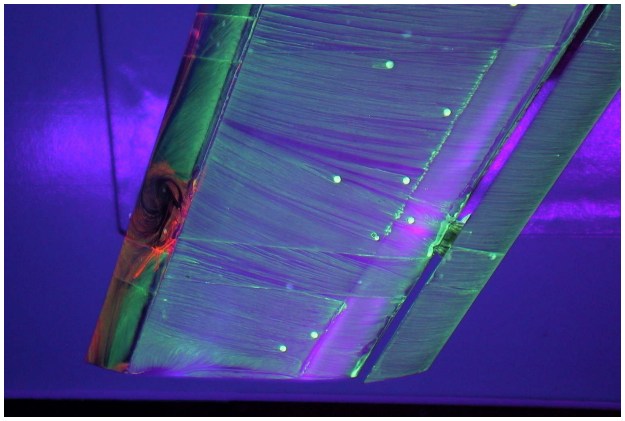
Experiment: Oil flow images

Wing-body junction

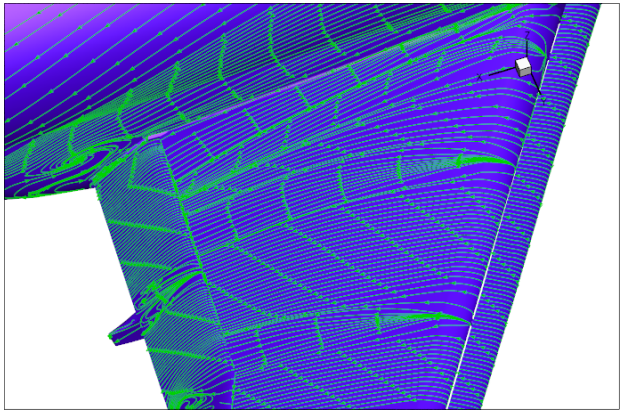


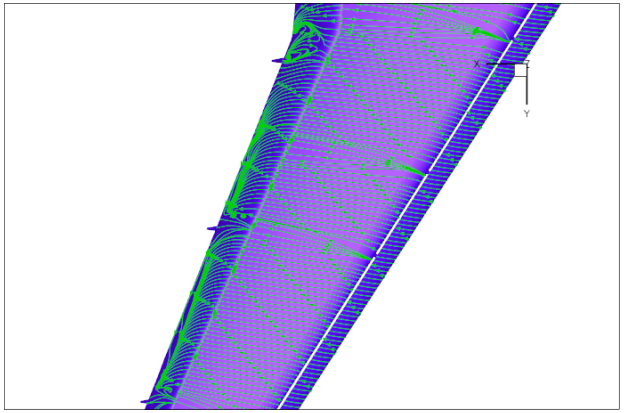
Midspan kink

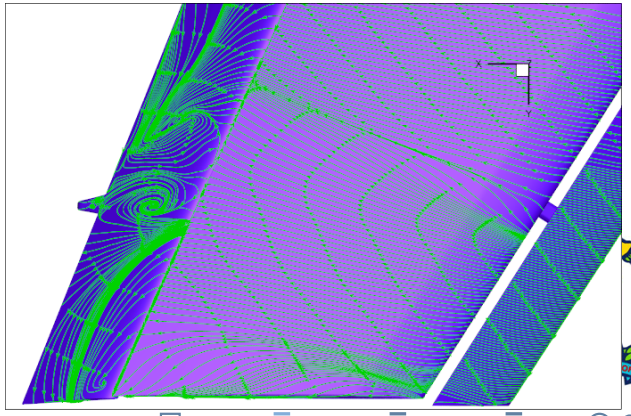
Wing tip



HiFUN: Surface streamlines





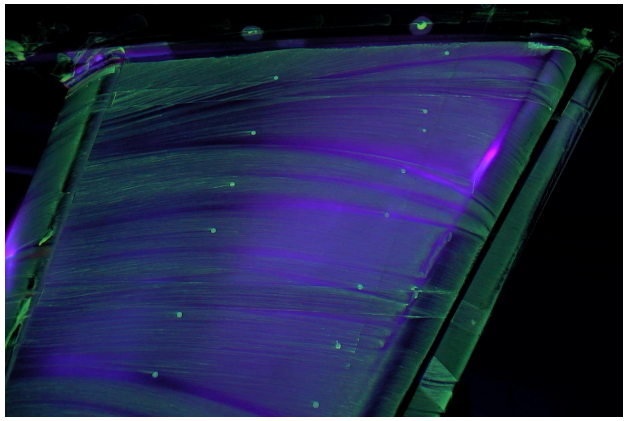


Surface Streamlines (Case2a Config4)

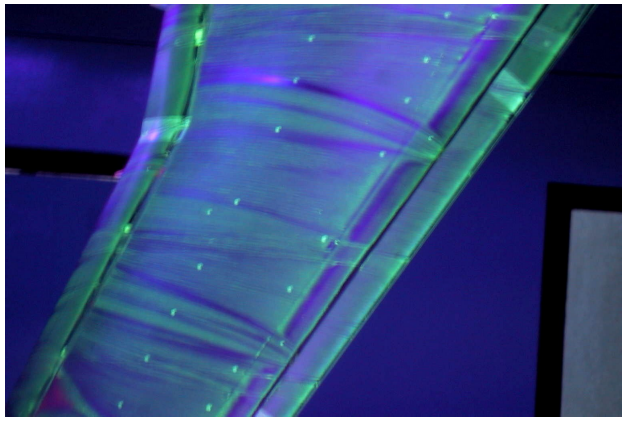
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, $\alpha = 18.5$ degree

Experiment: Oil flow images

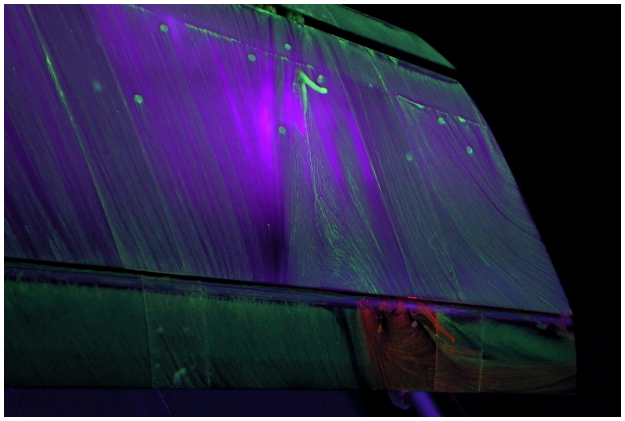
Wing-body junction



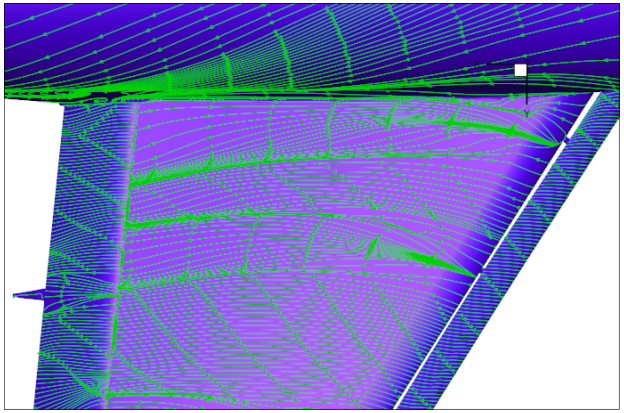
Midspan kink

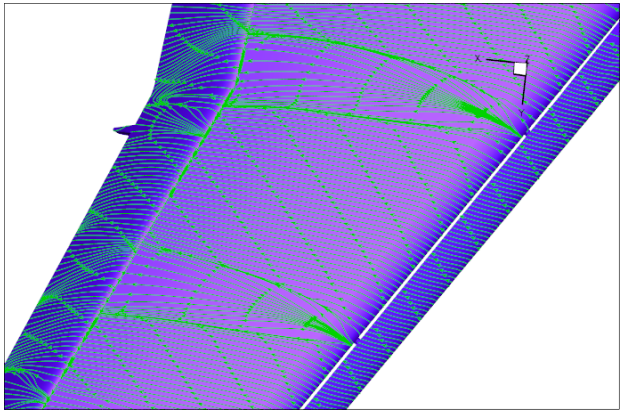


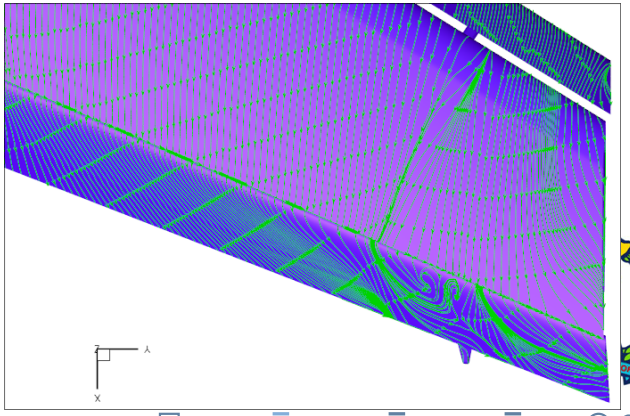
Wing tip



HiFUN: Surface streamlines





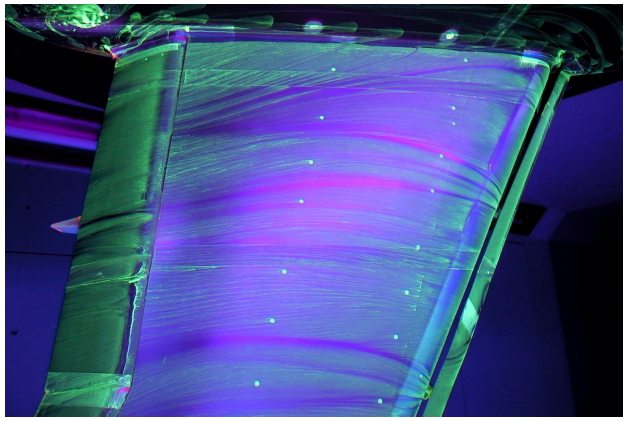


Surface Streamlines (Case2a Config4)

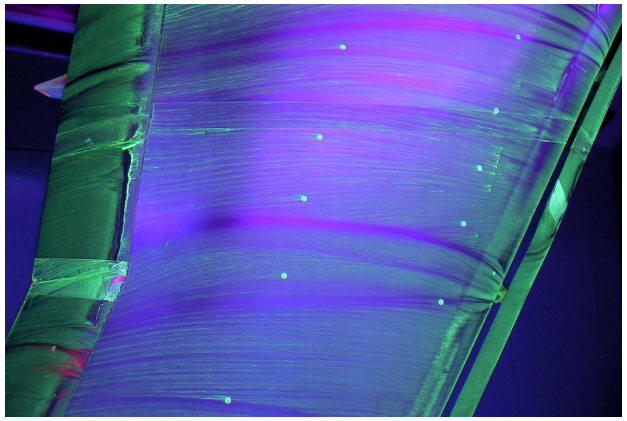
$M_\infty = 0.175$, $Re_\infty = 1.35$ million, $\alpha = 21$ degree

Experiment: Oil flow images

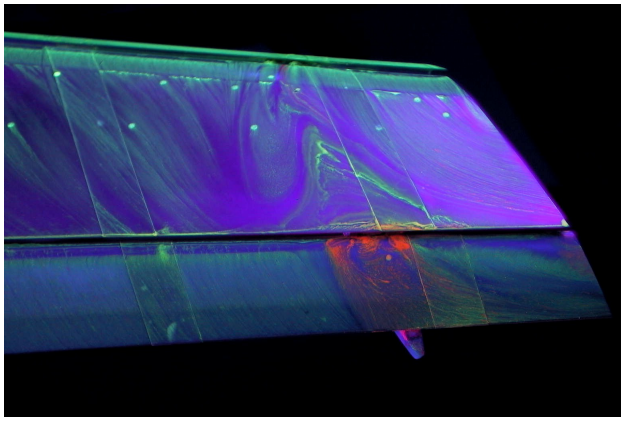
Wing-body junction



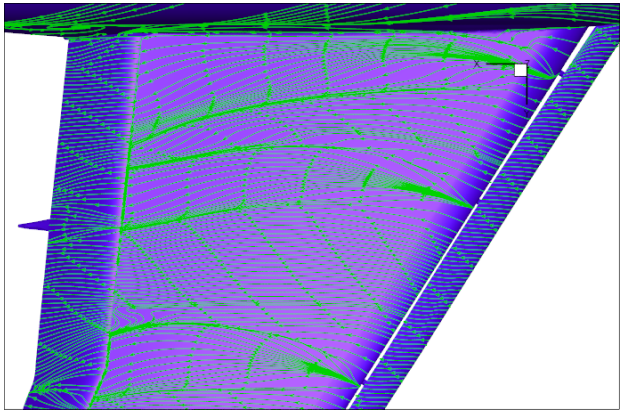
Midspan kink

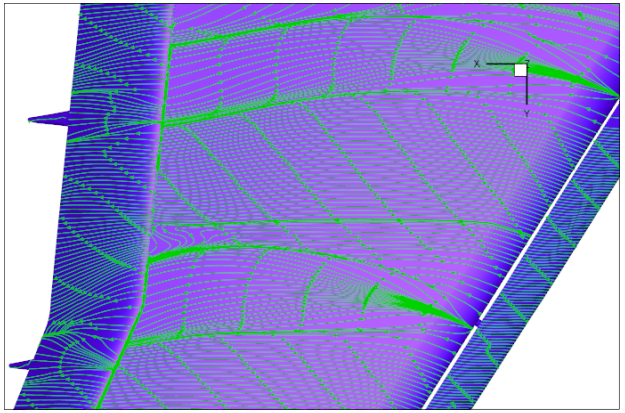


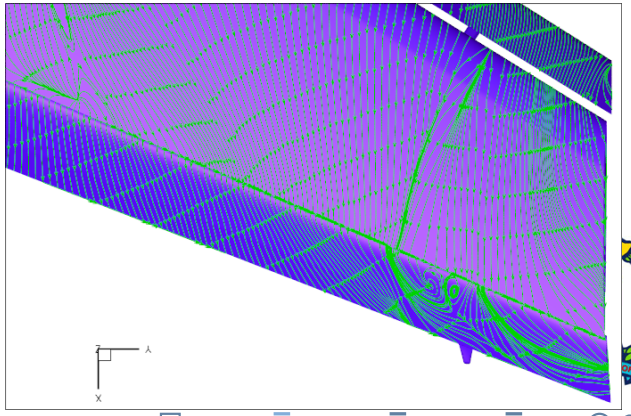
Wing tip



HiFUN: Surface streamlines





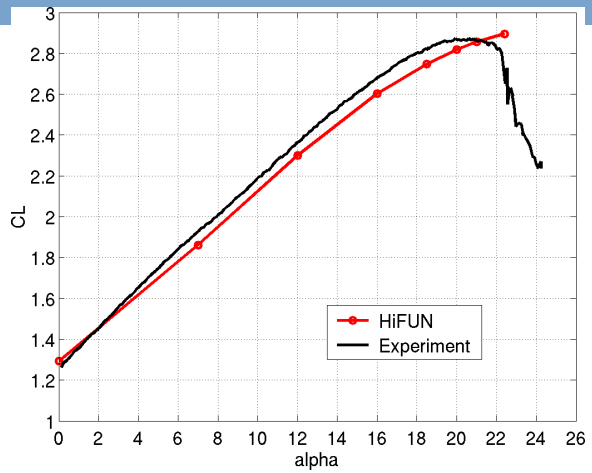


Outline

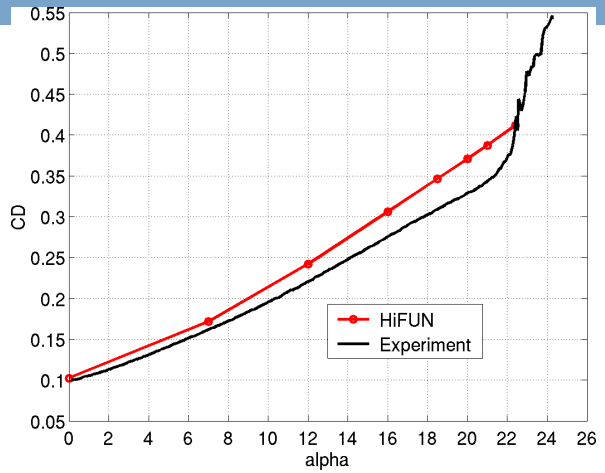
3 Results
- Solution convergence criterion
- Case 1: Grid convergence study
- Case 2a: Low Reynolds Number Study
- Case 2b: High Reynolds Number Study

Force & Moment v.s α (Case2b Config4, B_uns_mix medium grid)

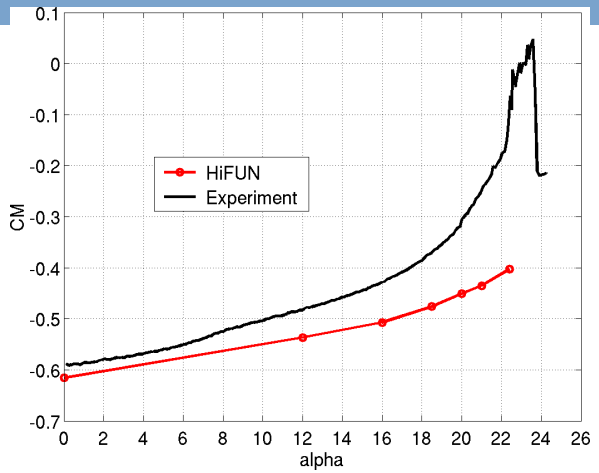
$M_\infty = 0.175$, $Re_\infty = 15.1$ million



CL vs α



CD vs α



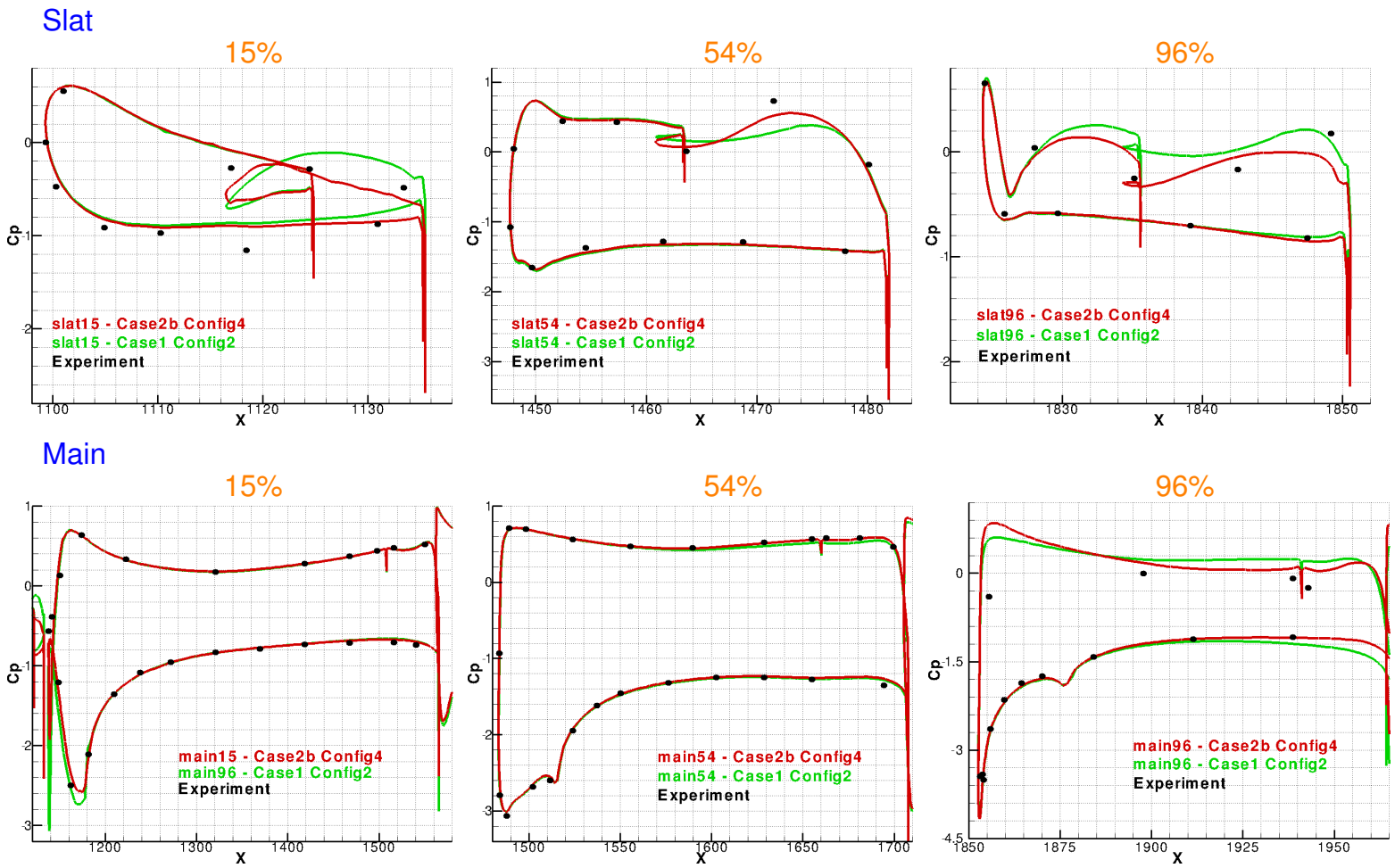
CM vs α

α	Δ CL count	Δ CD count	Δ CM count
7	69.4	-98.2	40.7
12	64.2	-217	53.5
16	76.2	-306.4	78.8
20	46.9	-415.3	146.2

- Overall, forces and moments prediction is better compared to that at low Reynolds number.
- Under prediction of CL for all alphas compared to experiment.
- There is a tendency to over predict α_{max} and CL_{max}.
- Drag prediction is marginally higher for all alphas compared to experiment.
- Deviation of predicted pitching moment from experiment increases with alpha.

Cp distribution on the Slat & Main (Case2b Config4)

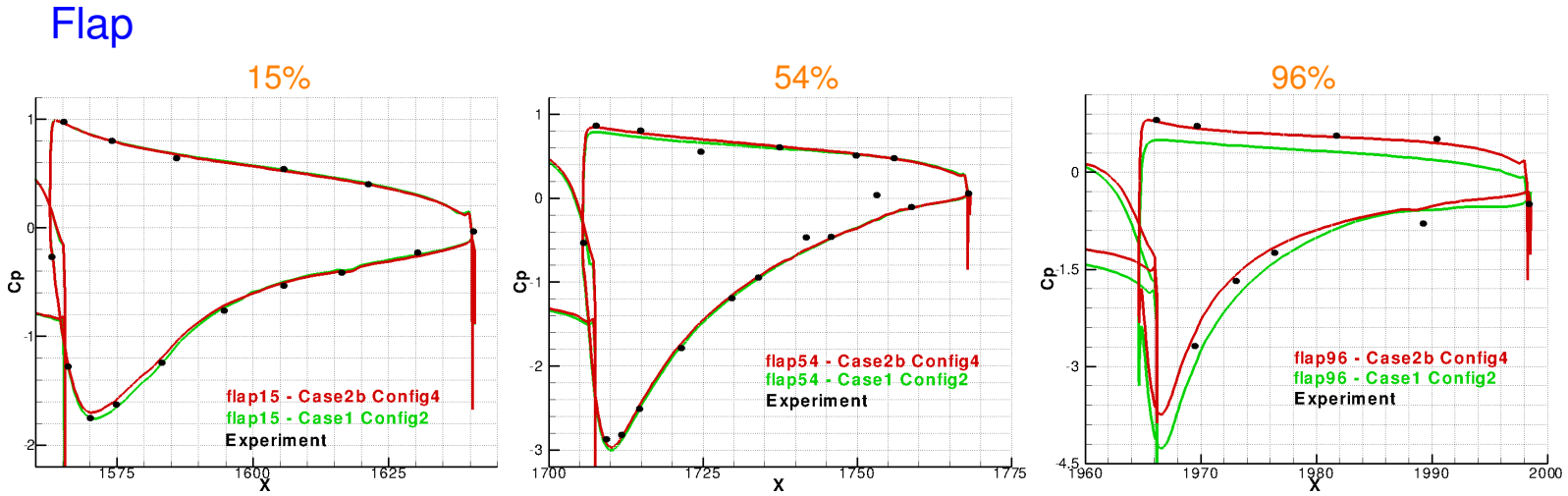
$M_\infty = 0.175$, $Re_\infty = 15.1$ million, $\alpha = 7$ degree



- Cp distribution prediction improves with inclusion of support tracks.

Cp distribution on the Flap (Case2b Config4)

$M_\infty = 0.175$, $Re_\infty = 15.1$ million, $\alpha = 7$ degree

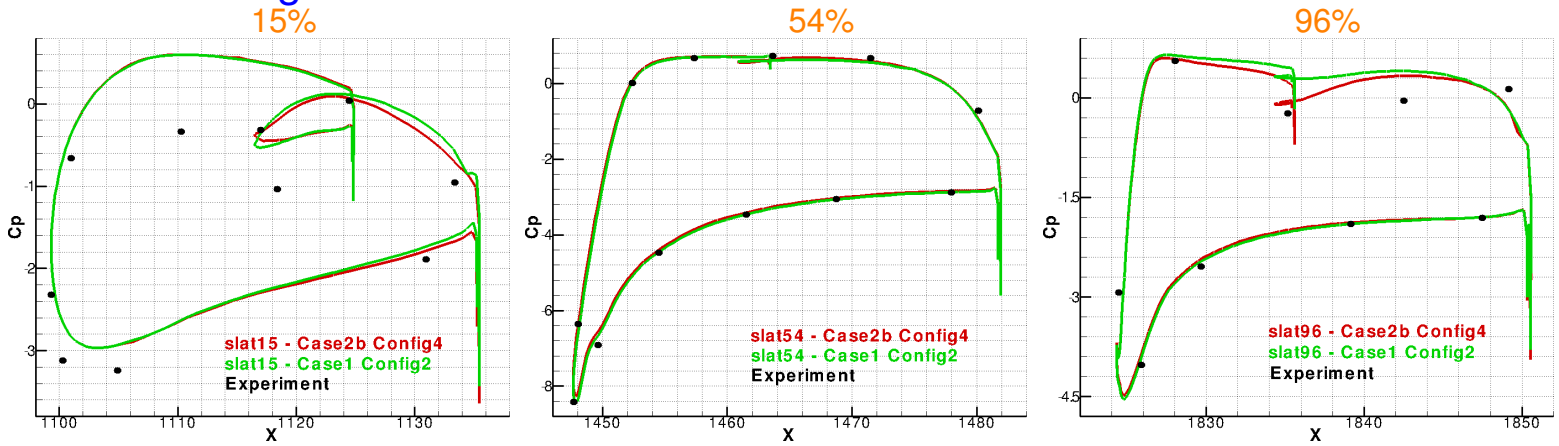


- Cp distribution prediction improves with inclusion of support tracks, especially at flap tip.

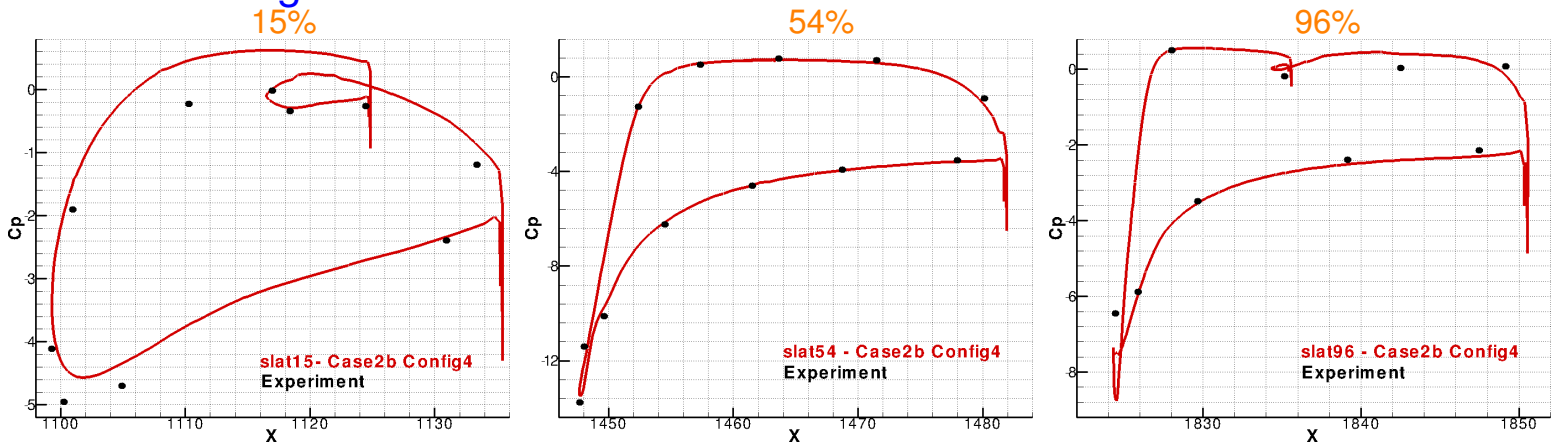
Cp distribution on the Slat (Case2b Config4)

$M_\infty = 0.175$, $Re_\infty = 15.1$ million, $\alpha = 16$ & 21 degrees

α = 16.0 deg



α = 21.0 deg

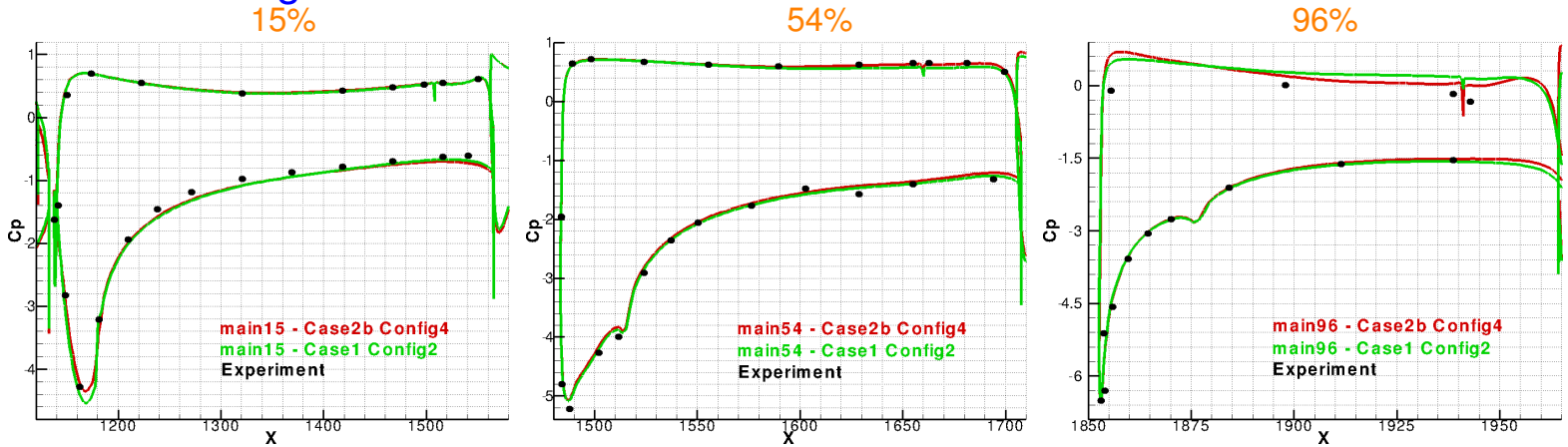


- Better Cp distribution prediction with support tracks.

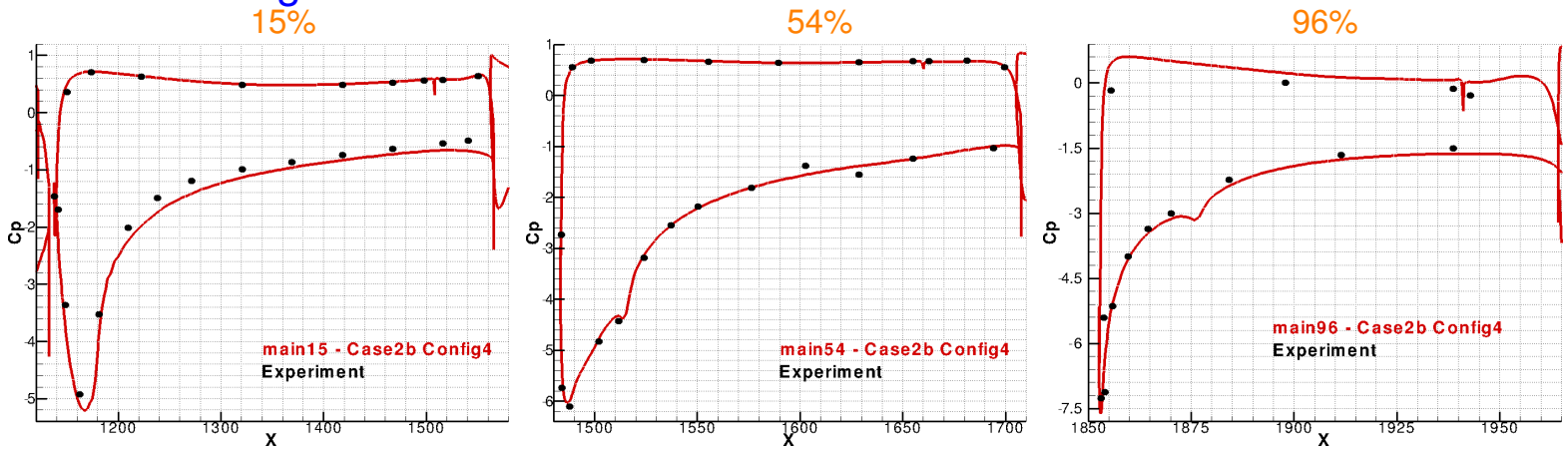
Cp distribution on the Main (Case2b Config4)

$M_\infty = 0.175$, $Re_\infty = 15.1$ million, $\alpha = 16$ & 21 degrees

α = 16.0 deg



α = 21.0 deg

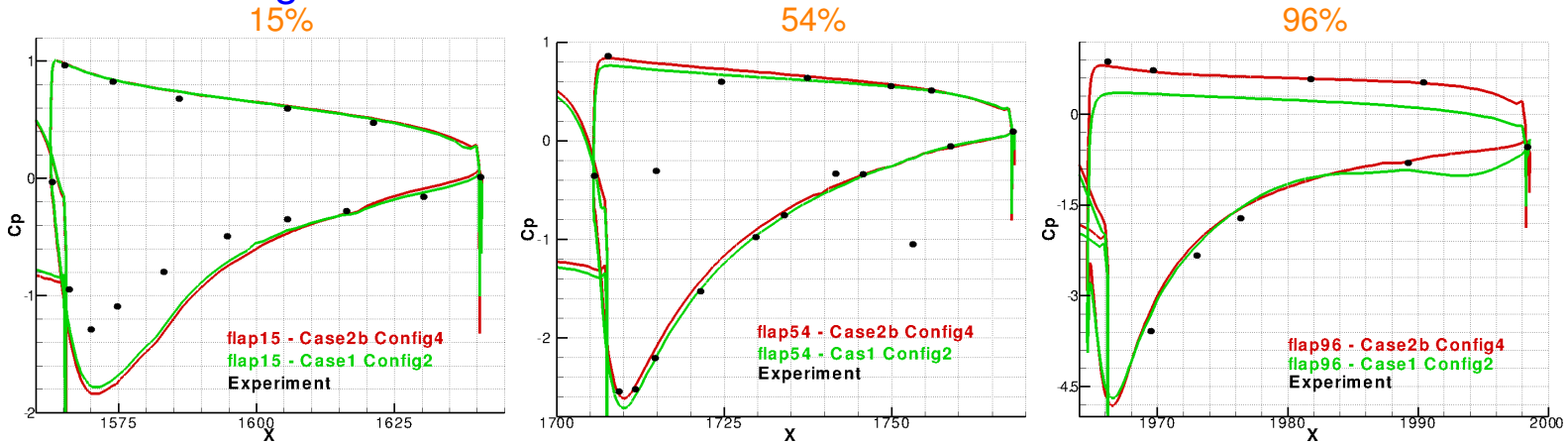


- Cp distribution prediction improves with inclusion of support tracks.

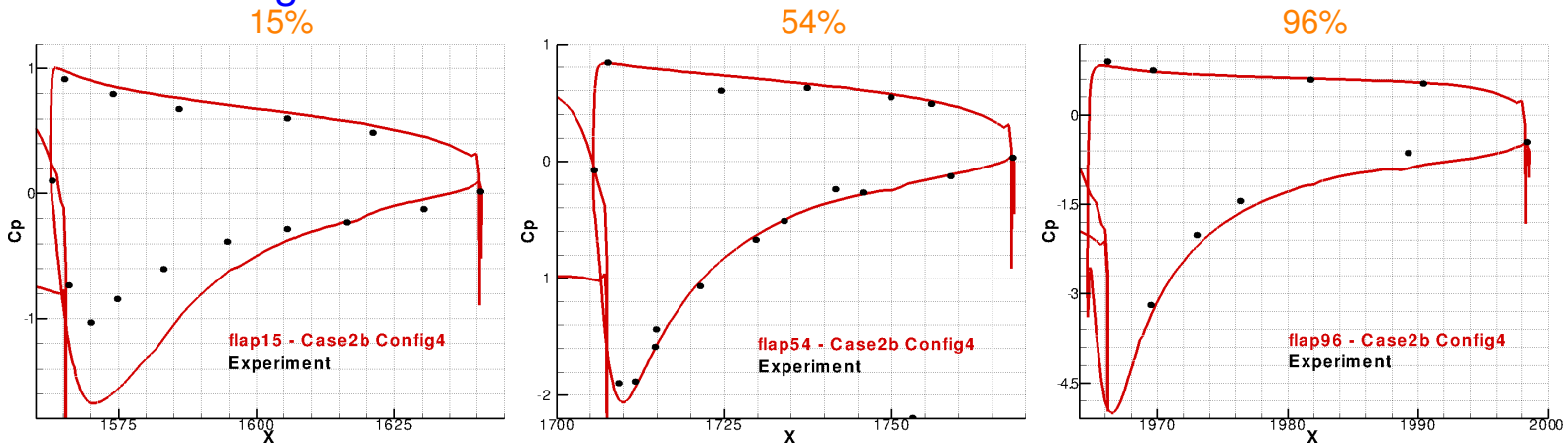
Cp distribution on the Flap (Case2b Config4)

$M_\infty = 0.175$, $Re_\infty = 15.1$ million, $\alpha = 16$ & 21 degrees

α = 16.0 deg



α = 21.0 deg



- Cp distribution prediction improves with inclusion of support tracks, especially at flap tip.

Outline

1 Introduction

2 Grids Used

3 Results

4 Conclusion

Concluding remarks

Conclusions

- In the present work, results of RANS computations for DLR F11 (EUROLIFT) using the code HIFUN are presented.
- A_uns_hex grid and B_uns_mix grid family provided by the HiLiftPW-2 committee is used.

Concluding remarks

Case 1: Grid convergence study

- On A_uns_hex grid:
  - Predicted CL, CD and CM on successive finer grids tends to converge to values different from experiment.
  - Overall Cp comparison with experiment is good, but with successive finer grids, Cp distribution tends to deviate from experiment.
- On B_uns_mix grid:
  - Other than CL, for successive finer grids CD and CM tends to deviate from experimental value.
  - Cp distribution compares really well with the experiment. Suction peaks are well captured and with successive finer grids, Cp distribution tends towards experimental data.
- Cp distribution prediction on the suction side of DLR F11 is much better than that on Nasa Trapwing near wing tip, especially on flap.

Case 2a: Low Reynolds number study

- Forces & moments:
  - Under prediction of CL for all alphas compared to experiment.
  - Over prediction of α_{max} by 1 degree.
  - Drag prediction is marginally higher for all alphas compared to experiment.
  - Deviation of predicted pitching moment from experiment increases with alpha.
- Overall Cp distribution compares well with experimental data on all the elements.
- From our experience, velocity profile prediction on DLR F11 has been better compared to that on Nasa Trapwing.
- Surface streamlines:
  - Overall very good comparison of surface streamlines with oil flow patterns. The large flow separation bubble near flap tip region for the three alpha's considered are well predicted.
  - Flow separation due to presence of support tracks on the main and flap are well predicted.

Concluding remarks

Case 2b: High Reynolds number study

- Forces & moments:
  - Overall, forces and moments prediction is better compared to that at low Reynolds number.
  - Under prediction of CL for all alphas compared to experiment.
  - There is a tendency to over predict α_{max} and CL_{max}.
  - Drag prediction is marginally higher for all alphas compared to experiment.
  - Deviation of predicted pitching moment from experiment increases with alpha.
- Cp distribution compares very well with experiments. With support tracks the Cp distribution prediction improves considerably.

Thank you

Thank you

- Yuvraj Patil: patil.yuvi@gmail.com
- Ravindra K.: deepu.ravindra@gmail.com
- Nikhil Vijay Shende: nikvijay@aero.iisc.ernet.in
- N. Balakrishnan: nbalak@aero.iis.ernet.in