Contribution to HiLiftPW-3

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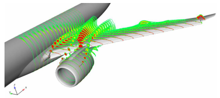
EMBRAER

019

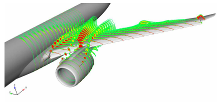
3rd High Lift Prediction Workshop
Denver, CO June 3-4, 2017

Outline



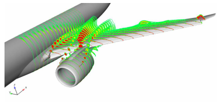
- Description of codes used
- Summary of cases
- Overview of grids used
- Overview of results
  - CRM
  - JSM
- Summary

Summary of code and numerics used



- Simulations performed using 2 codes:
  - CFD++
    - Finite-volume, upwind fluxes and reconstruction algorithms for higher spatial order of accuracy.
    - Time march performed with a point-implicit method and multigrid for convergence acceleration
    - Many turbulence models: used SA with Curvature Correction (CC) and Quadratic Constitutive Relation (QCR)
    - All cases run with restart from previous AOA
    - http://www.metacomptech.com/index.php/features/icfd
  - SU2
    - Finite Volume, 2nd order spatial discretization with Venkatakrishnan limiter and ROE convective numerical method.
    - Time march performed with implicit scheme
    - SA and SST turbulence models, used SA
    - All cases run with restart from previous AOA
    - https://github.com/su2code/SU2/wiki

Summary of cases completed: CRM

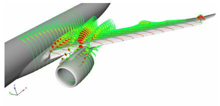


Case	SOLVER	Turb. Model	Workshop		Extra
			Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Full CL x Alpha
			Grids		
1a (full gap)	CFD++	SA-CC-QCR	B2, B3, M5	B2, B3, M5	B2, B3, M5
	SU2	SA	B3	B3	B3
1b (full gap w adaption)	🟥	🟥	🟥	🟥	🟥
	🟥	🟥	🟥	🟥	🟥
1c (partial seal)	CFD++	SA-CC-QCR	B2, B3	B2, B3	B2, B3
	🟥	🟥	🟥	🟥	🟥
1d (partial seal w adaption)	🟥	🟥	🟥	🟥	🟥
	🟥	🟥	🟥 no	🟥 no	🟥

Mean aerodynamic chord (MAC) = 275.8 in (7.0053 m)
Wing semi-span = 1156.75 in (29.38 m)
Reference area of the semi-span model = Sref/2 = 297,360.0 in2 (191.8448m2)
Moment reference center (MRC): x=1325.90 in, y=468.75 in, z=177.95 in
x=33.6779 m, y=11.906 m, z=4.5199 m

Conditions: M=0.20, Rey=3.26E+06
AOAs: 0, 4, 8, 10, 12, 14, 15, 16, 18, 19, 20, 21 and 22°

Summary of cases completed: JSM

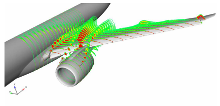


Case	SOLVER	Turb. Model	Workshop		Extra
			Polar, Fully turb	Polar, w/ transition prediction	Other (no slat brackets)
			Grids		
2a (no nacelle)	CFD++	SA-CC-QCR	C2, E	🟥	E_mod
	CFD++	SA	C2	🟥	🟥
	SU2	SA	C2	🟥	🟥
2b (no nacelle w adaption)	🟥	🟥	🟥	🟥	🟥
	🟥	🟥	🟥	🟥	🟥
2c (with nacelle)	CFD++	SA-CC-QCR	C2, E	🟥	E_mod
	SU2	SA	C2	🟥	🟥
2d (with nacelle w adaption)	🟥	🟥	🟥	🟥	🟥
	🟥	🟥	🟥	🟥	🟥

Mean aerodynamic chord (MAC) = 529.2 mm
Wing semi-span = 2300.0 mm
Reference area of the semi-span model = Sref/2 = 1,123,300.0 mm2
Moment reference center (MRC): x=2375.7 mm, y=0.0 mm, z=0.0 mm

Conditions: M=0.17, Rey=1.93E+06
AOAs: 0, 4.36, 8, 10.47, 13, 14.54, 17, 18.58, 19.59, 20.59 and 21.57°

Summary of cases completed:
2D Verification study

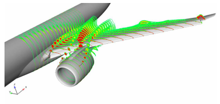


Case	SOLVER	Turb. Model	Workshop	Extra
			2D Verification study	Other
Case 3	CFD++	SA-CC-QCR	Comittee 1, 2, 3, 4, 5	🟥
	CFD++	SA	Comittee 1, 2, 3, 4, 5	🟥
	SU2	SA	Comittee 1, 2, 3, 4, 5	🟥

Mean aerodynamic chord (MAC) = 1.0 m

Conditions: M=0.09, Rey=1.2E+06

Brief overview of grid system(s)

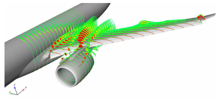


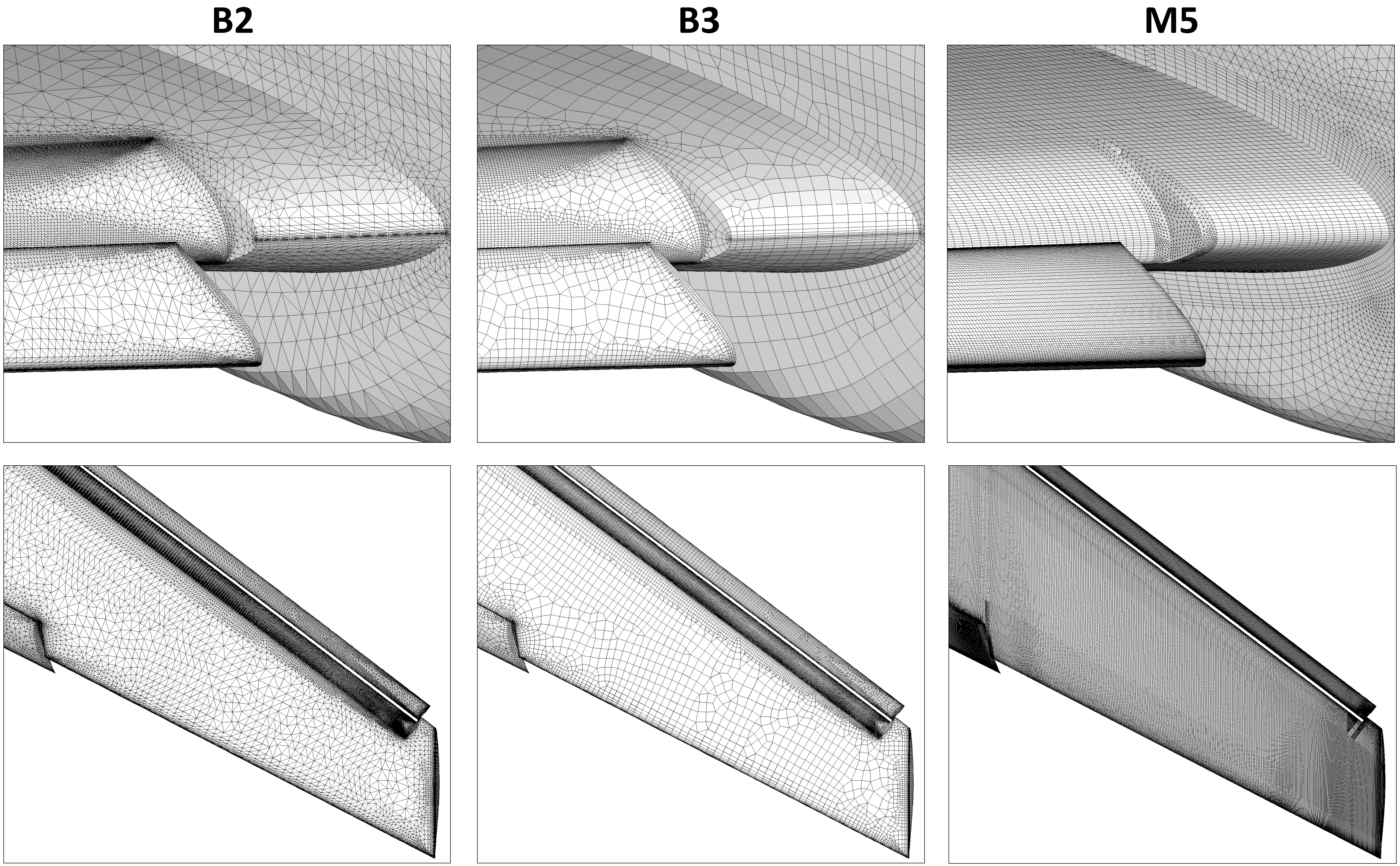
- We used several grid systems
  - CRM B2, B3
  - JSM C2, E
- EMBRAER created its own grid for the CRM geometry
  - More uniform increase in refinement throughout the geometry
  - More refined at the leading edge region
- EMBRAER removed brackets from slat and created a new grid based on mesh family ‘E’ for the JSM geometry

Grid Source	Grid System	Case(s)	Refinement	Problems/Issues/Observations
Committee	**B2**	**1A**	**Coarse, Medium, Fine, Extrafine**	**Extra-fine grid is very large**
	B2	**1C**	**Medium**	
	B3	**1A**	**Coarse, Medium, Fine**	
	B3	**1C**	**Medium**	
	C2	**2A,2C**	**Medium**	
	E	**2A,2C**	**Medium**	
EMBRAER	**M5**	**1A**	**Coarse, Medium, Fine**	**Fine grid is very large**
EMBRAER	**E_mod (*)**	**2A, 2C**	**Medium**	**Similar to mesh_family_E, but without slat brackets**

(*) Thanks to ANSA, which provided the E grid for modifications

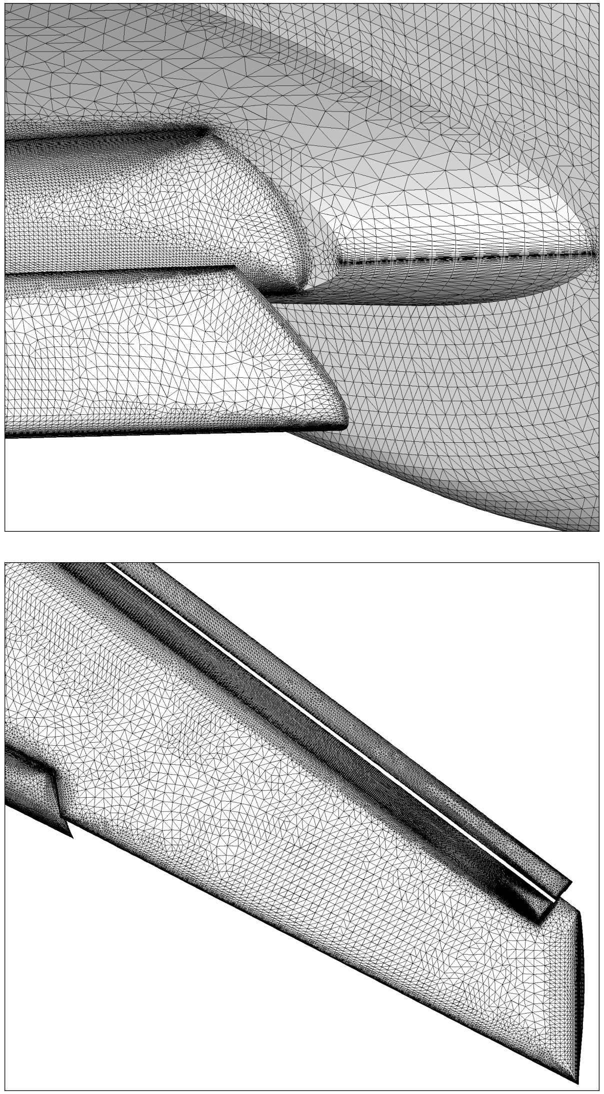
Grid comparison (coarse): B2, B3, M5



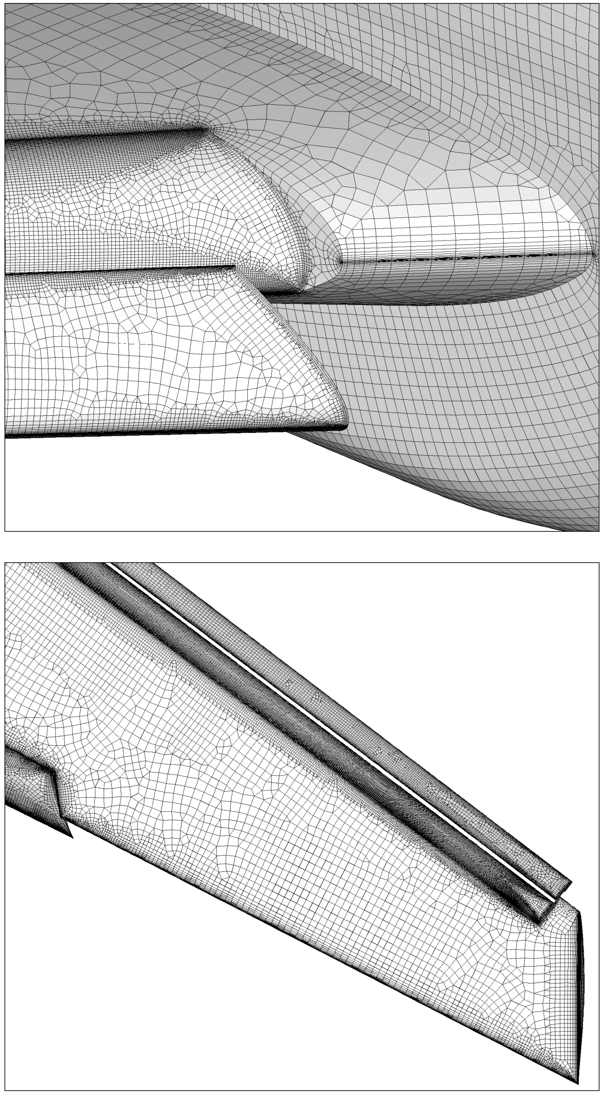


Grid comparison (medium): B2, B3, M5

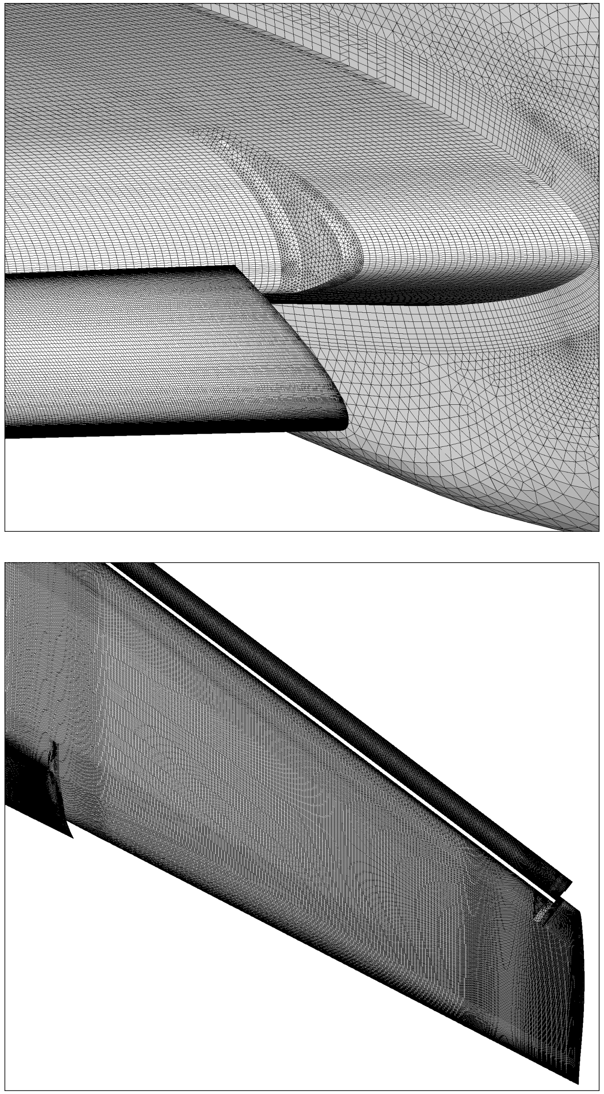
B2



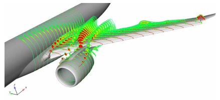
B3



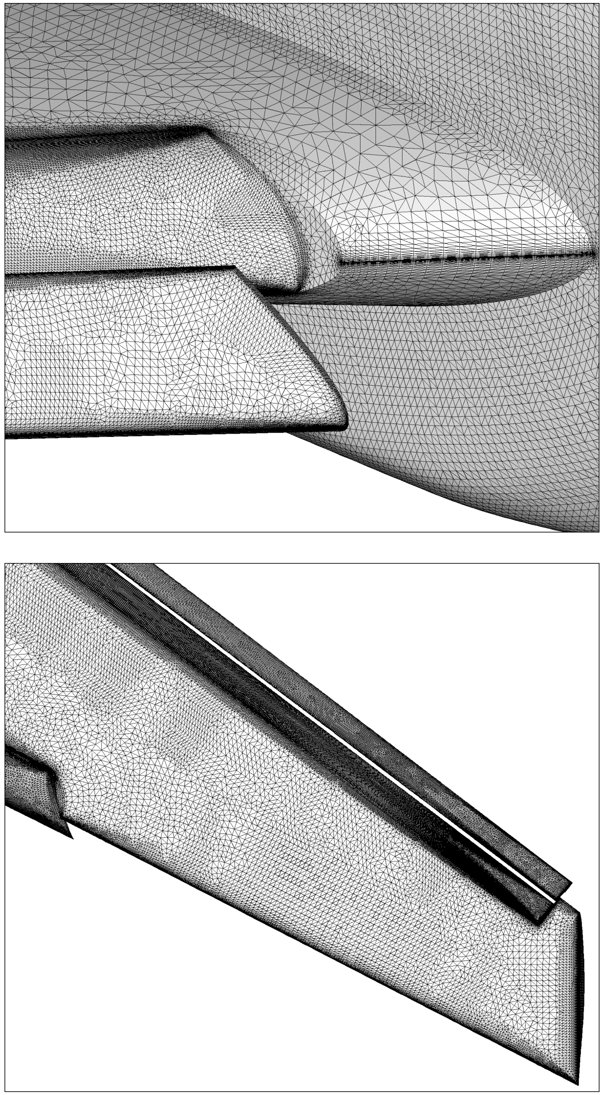
M5



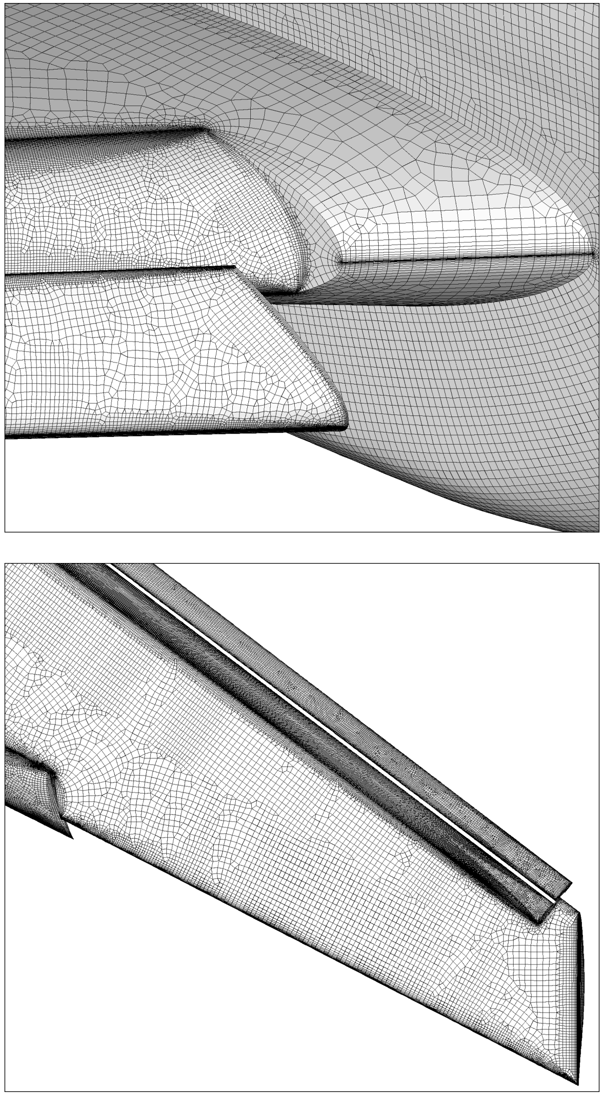
Grid comparison (fine): B2, B3, M5



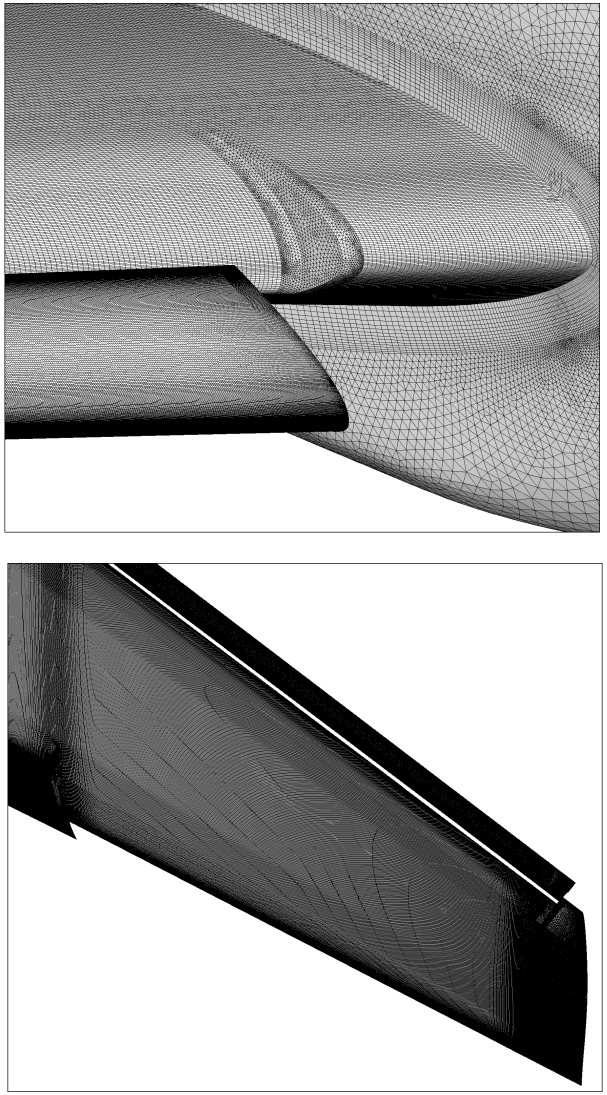
B2



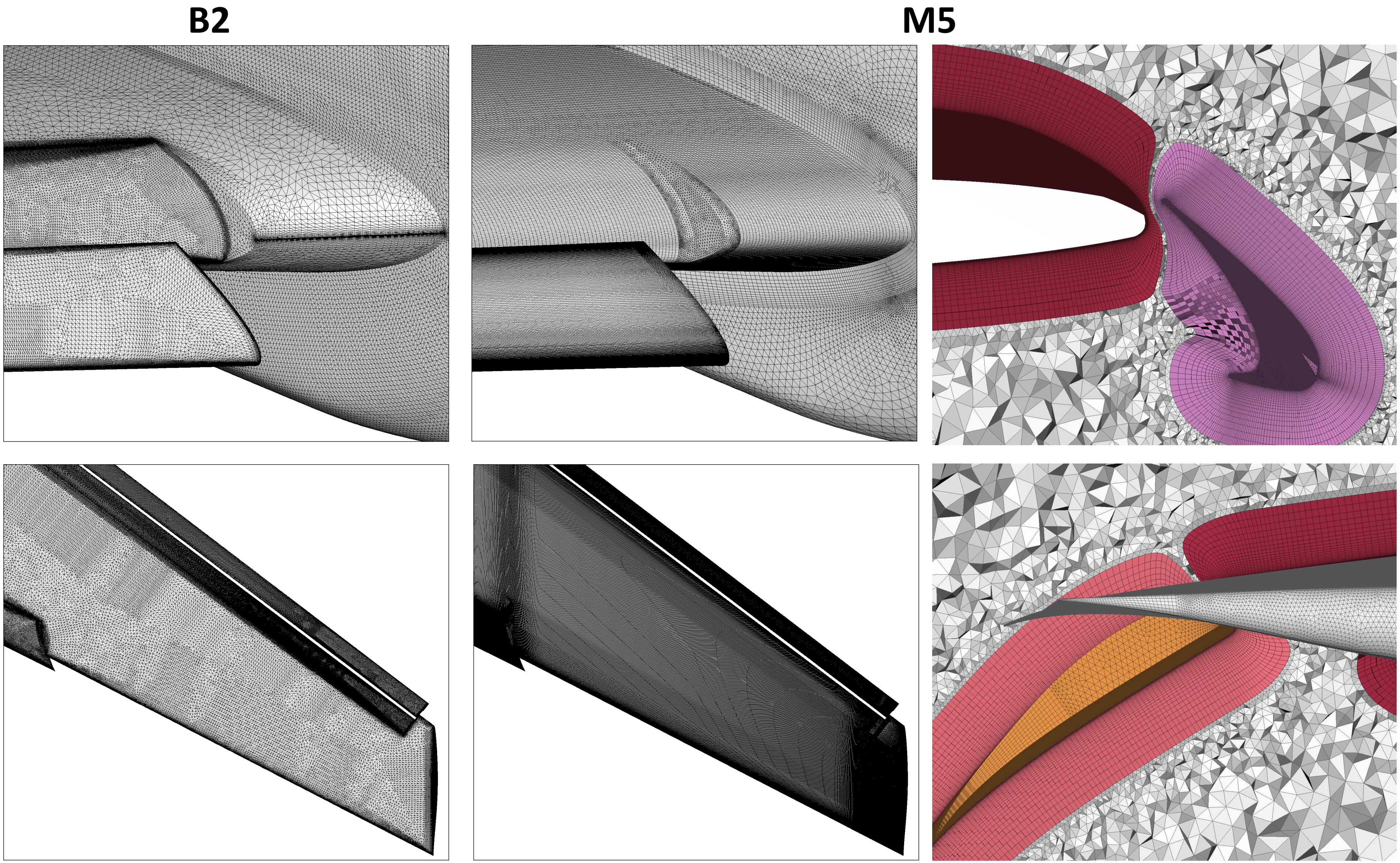
B3



M5

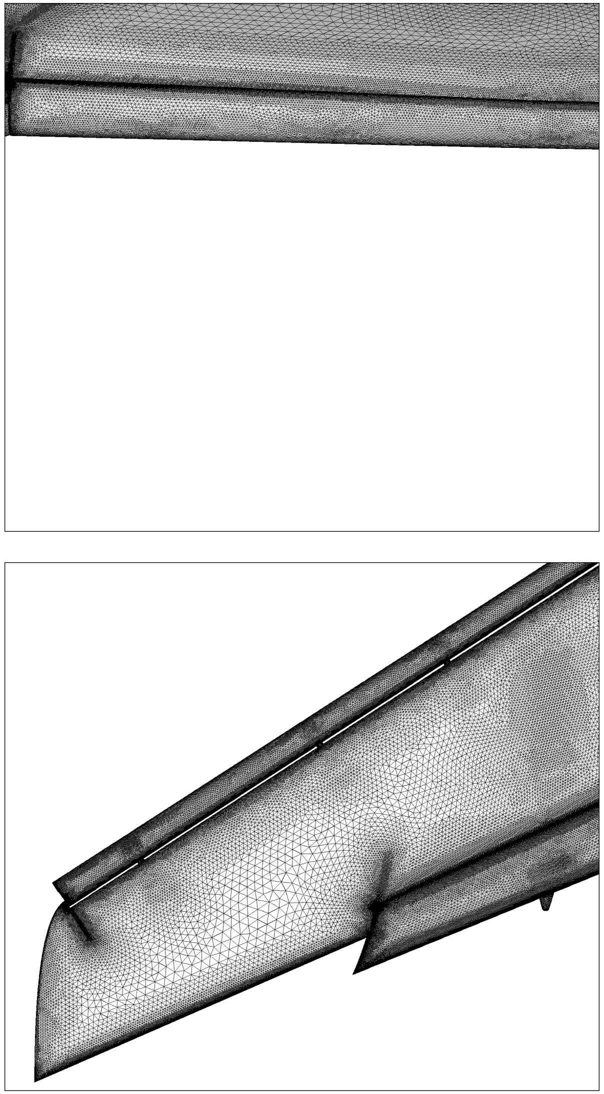


Grid comparison: extrafine B2, fine M5

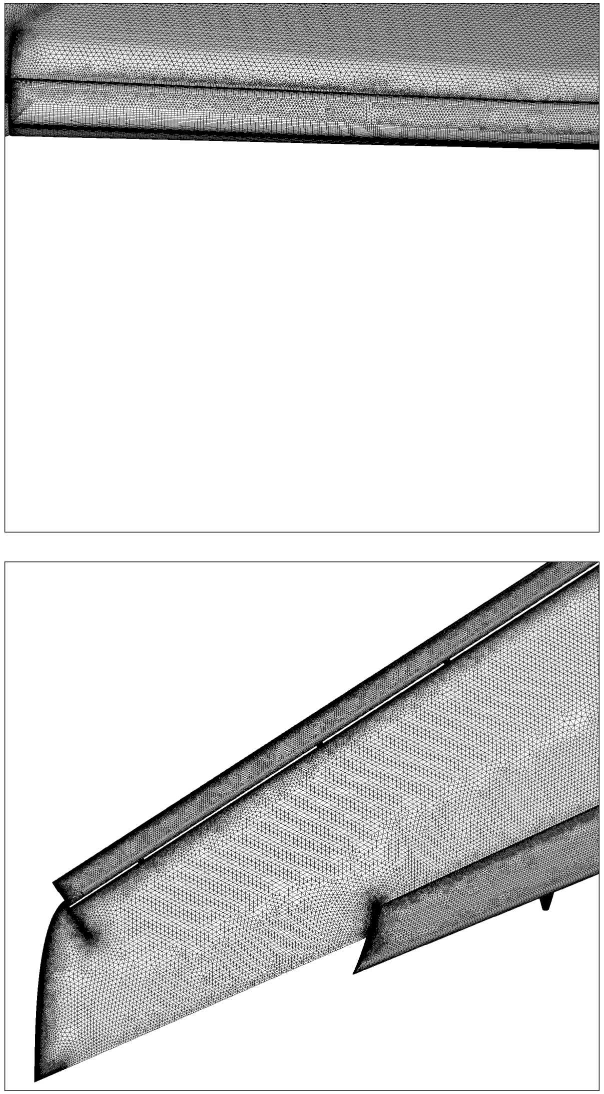


Grid comparison (PyNa Off): C2, E

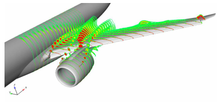
C2



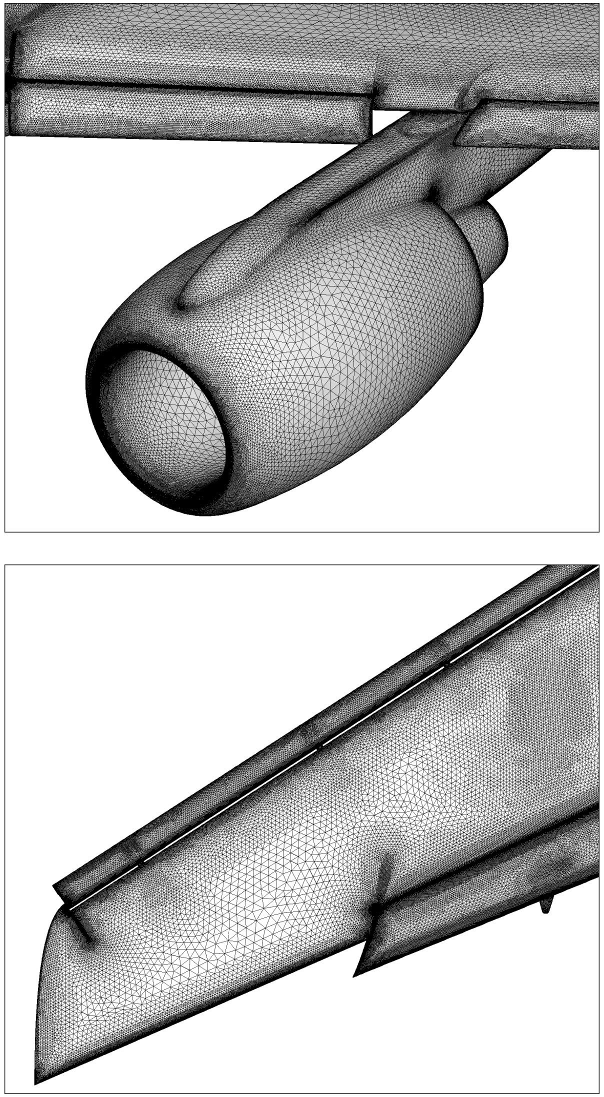
E



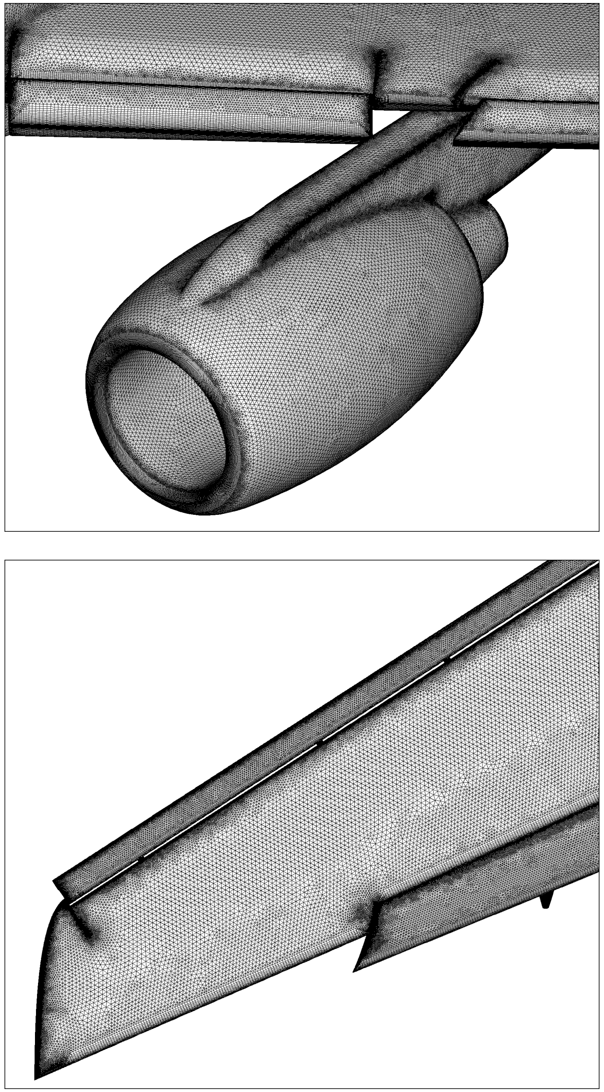
Grid comparison (PyNa On): C2, E



C2



E



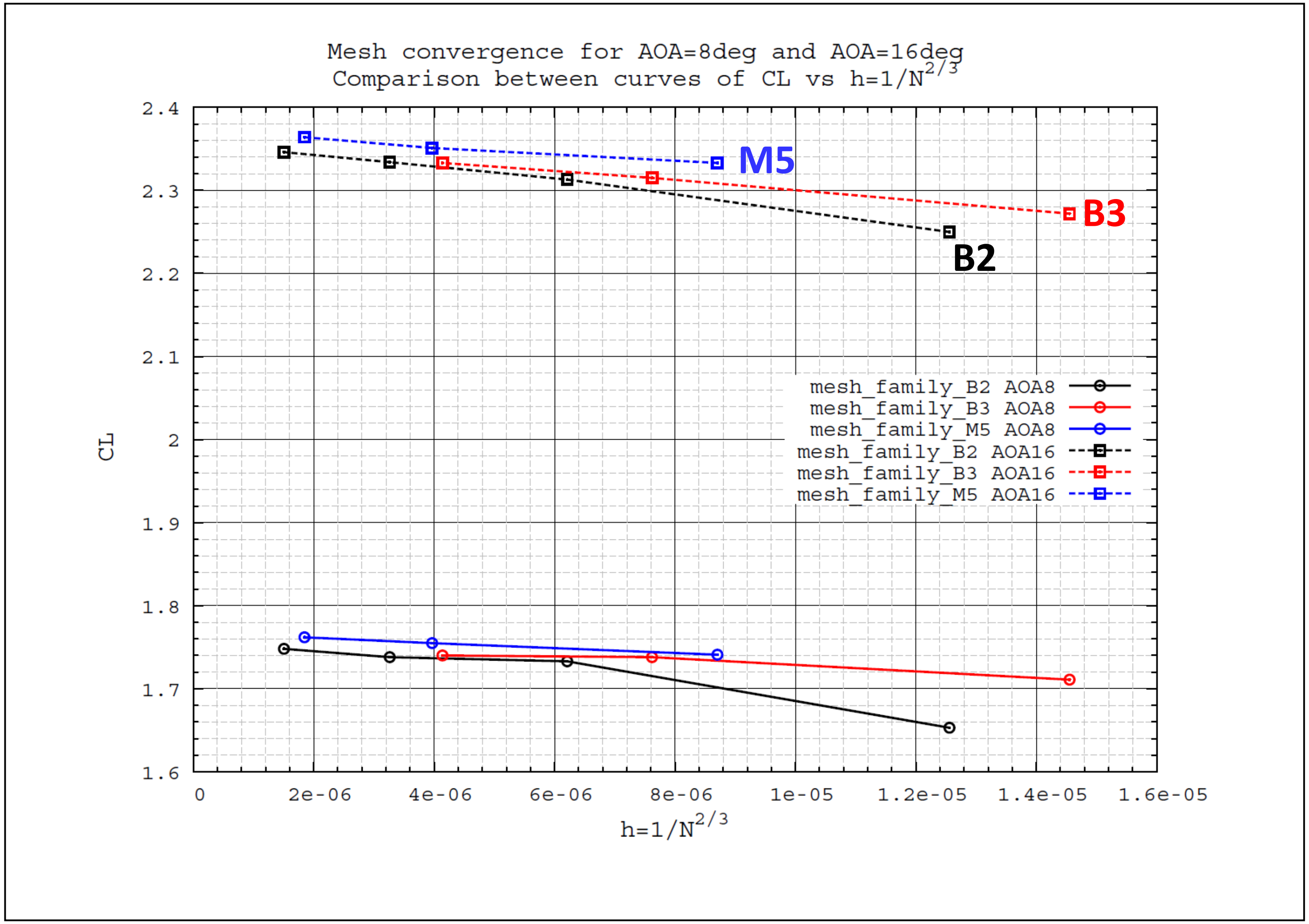
HL-CRM results

M=0.20

Rey=3.26E+06

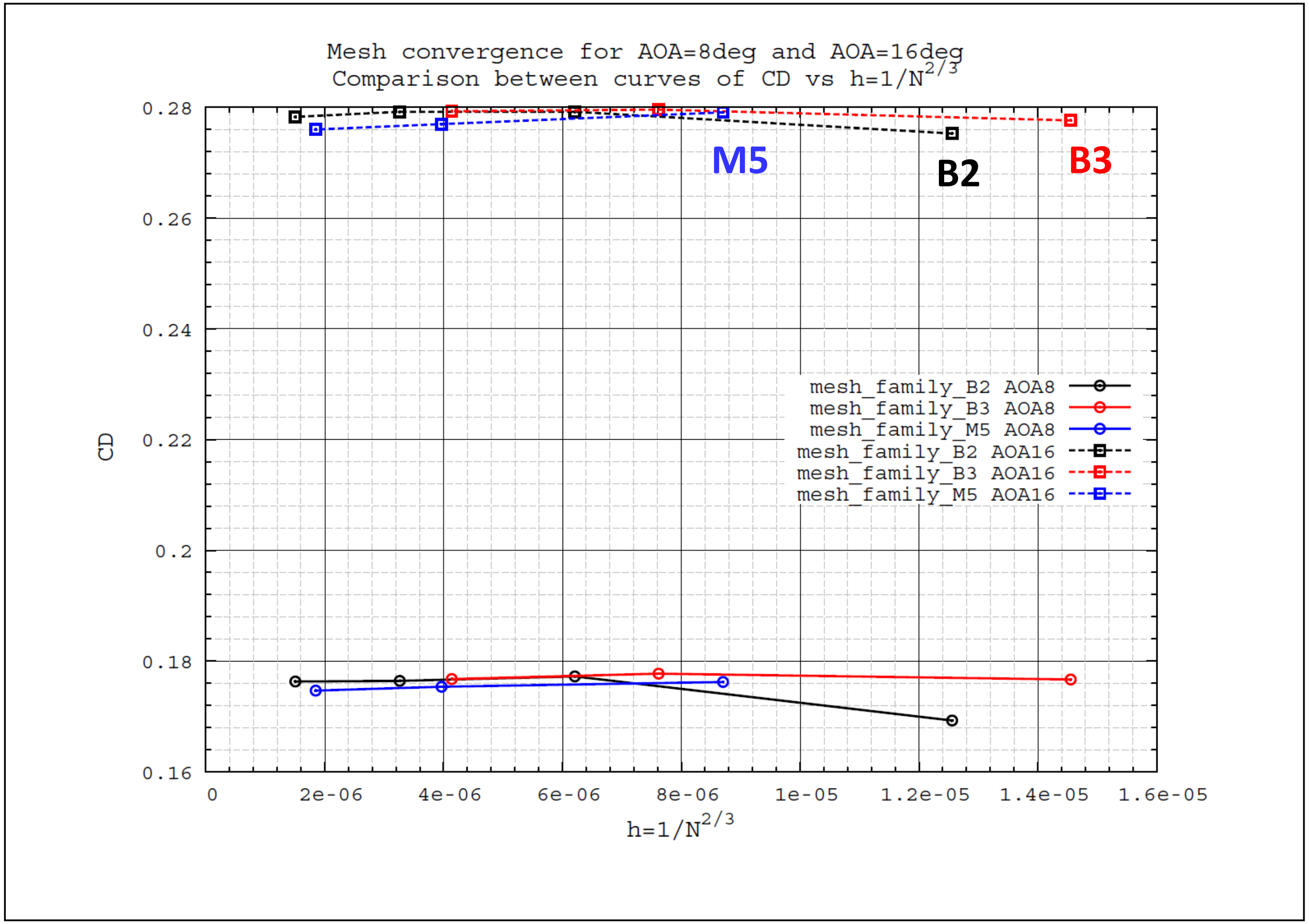
HL-CRM results – grid convergence – CFD++

Grids B2, B3, M5



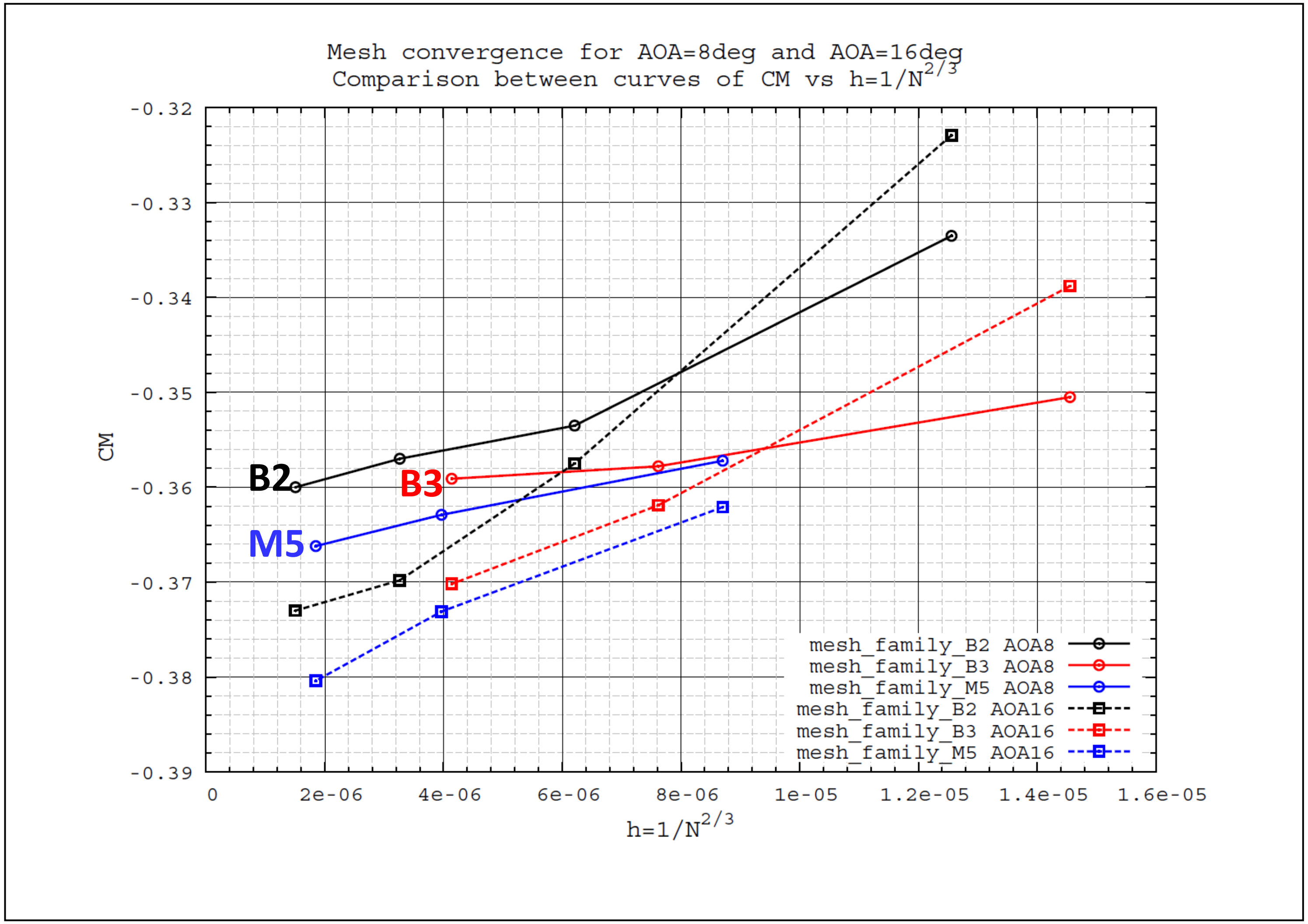
HL-CRM results – grid convergence – CFD++

Grids B2, B3, M5



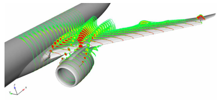
HL-CRM results – grid convergence – CFD++

Grids B2, B3, M5

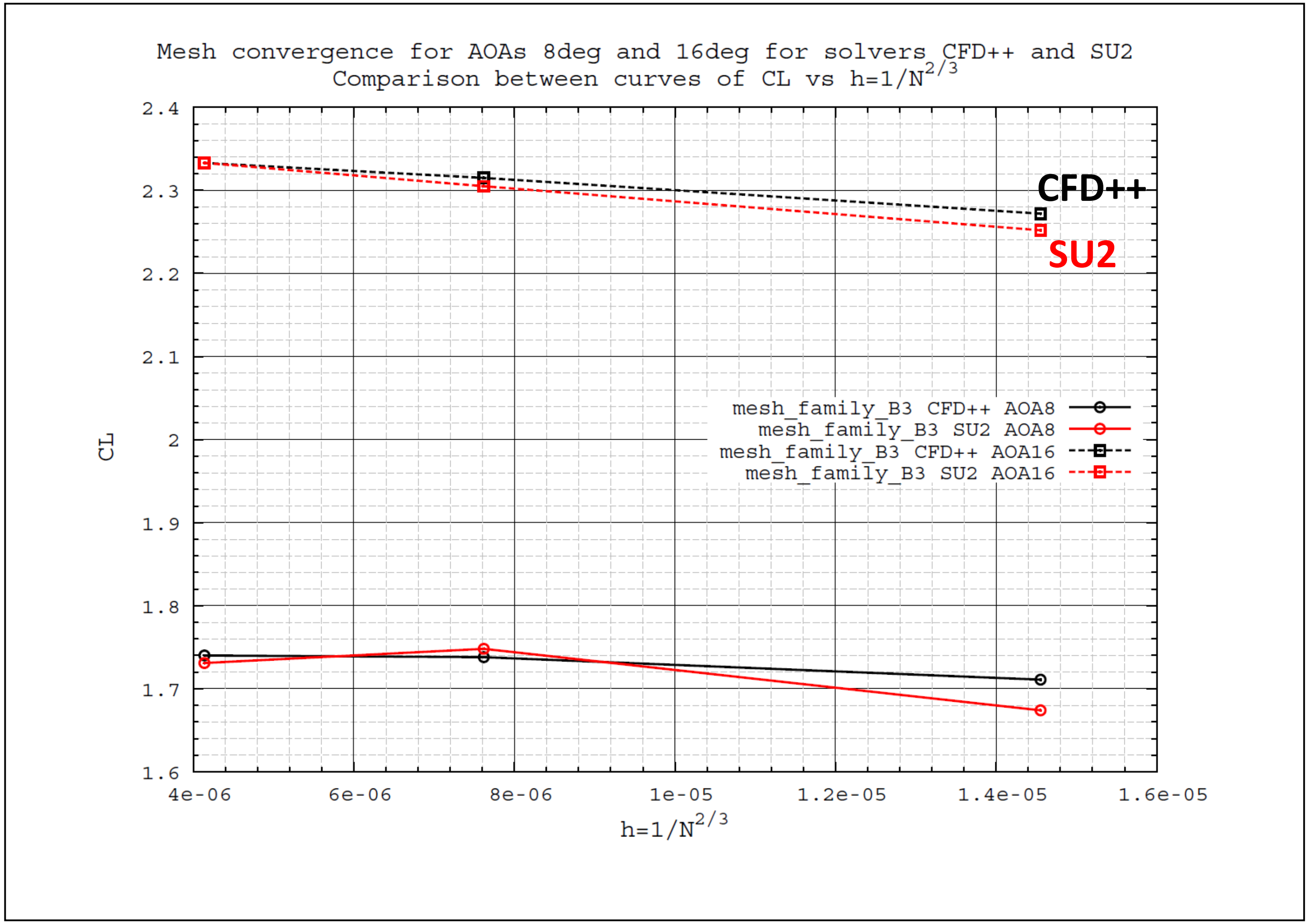


Flow separation position and extent strongly affect CM

HL-CRM results – grid convergence – CFD++ x SU2

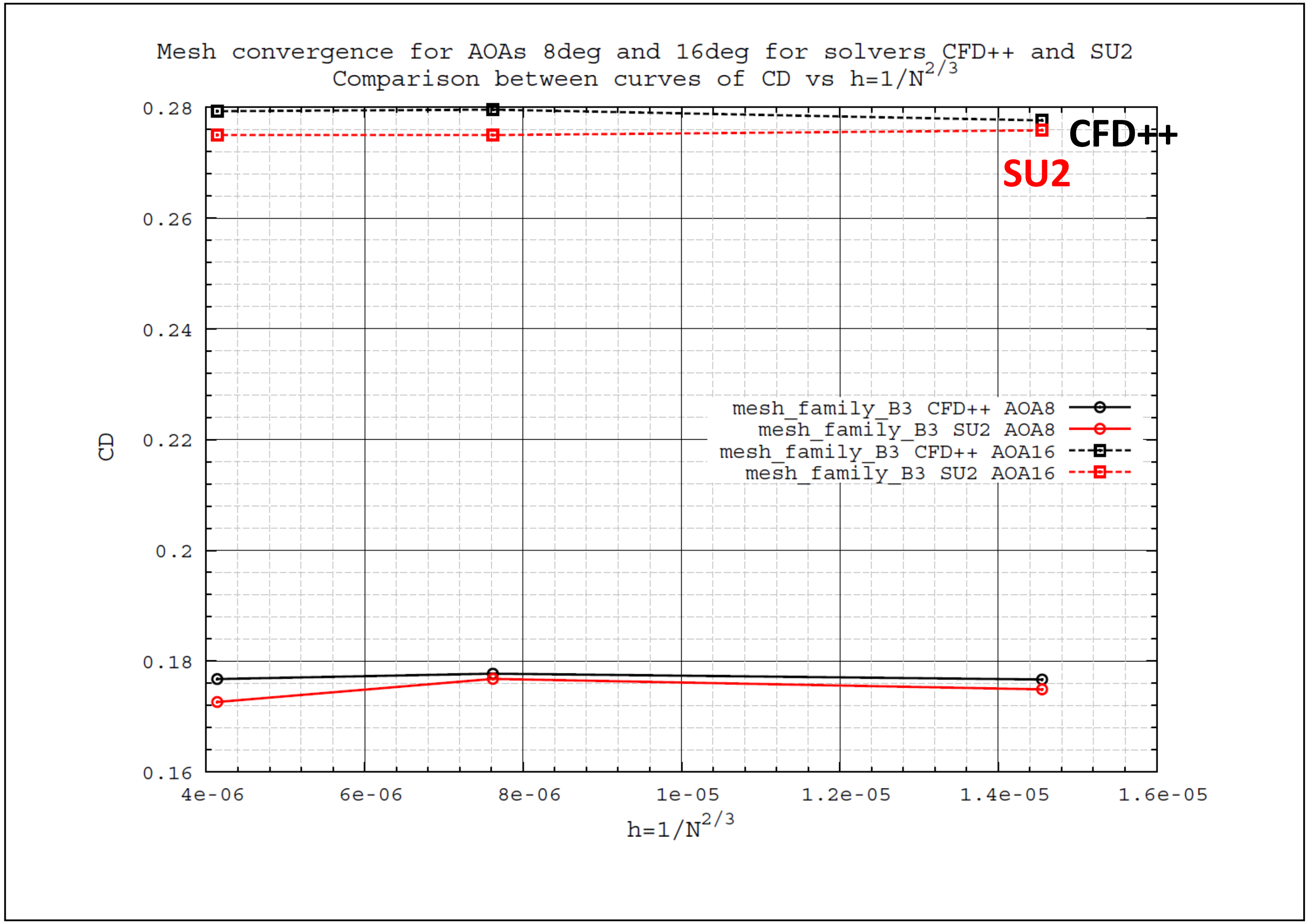


Grid B3



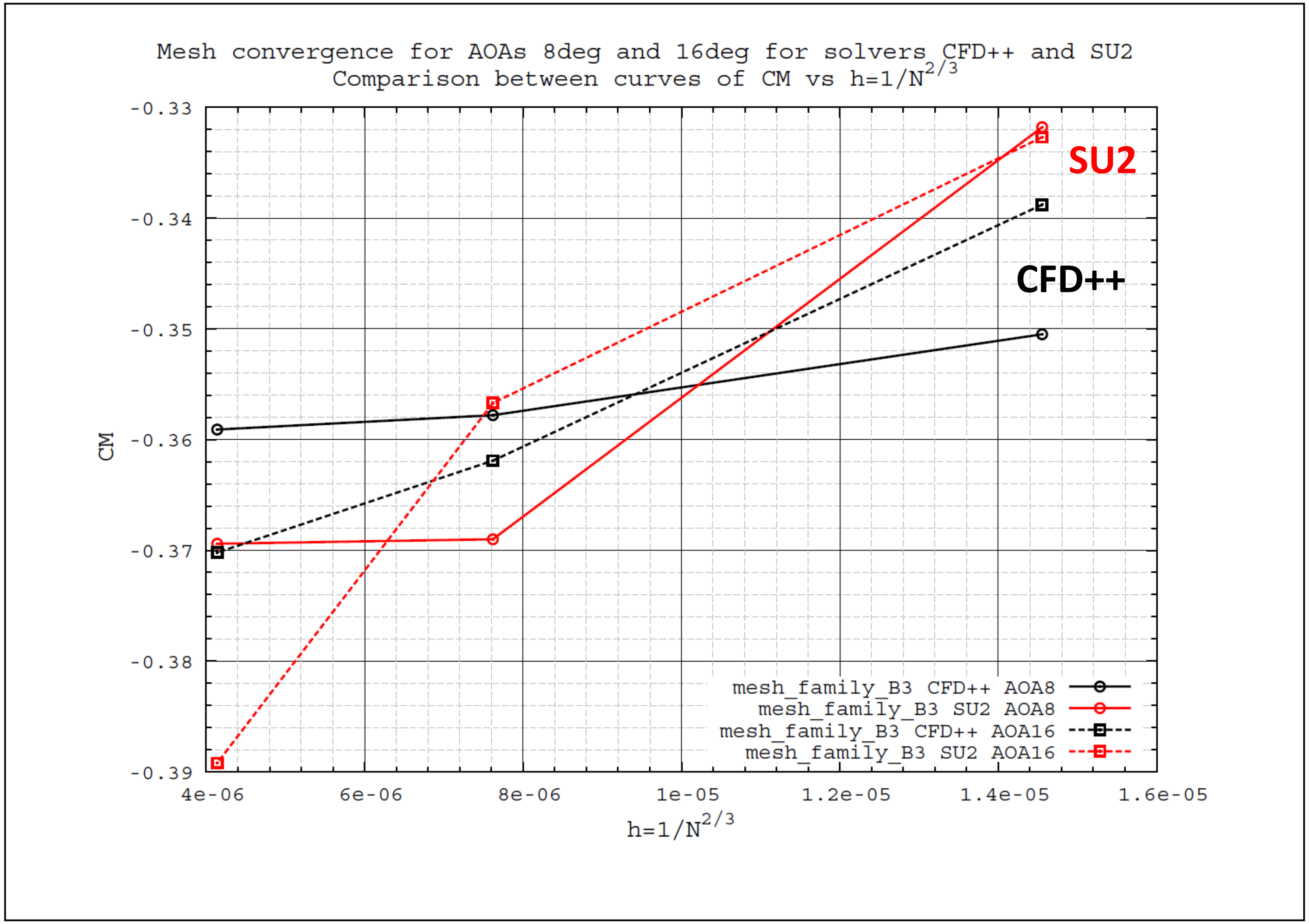
HL-CRM results – grid convergence – CFD++ x SU2

Grid B3



HL-CRM results – grid convergence – CFD++ x SU2

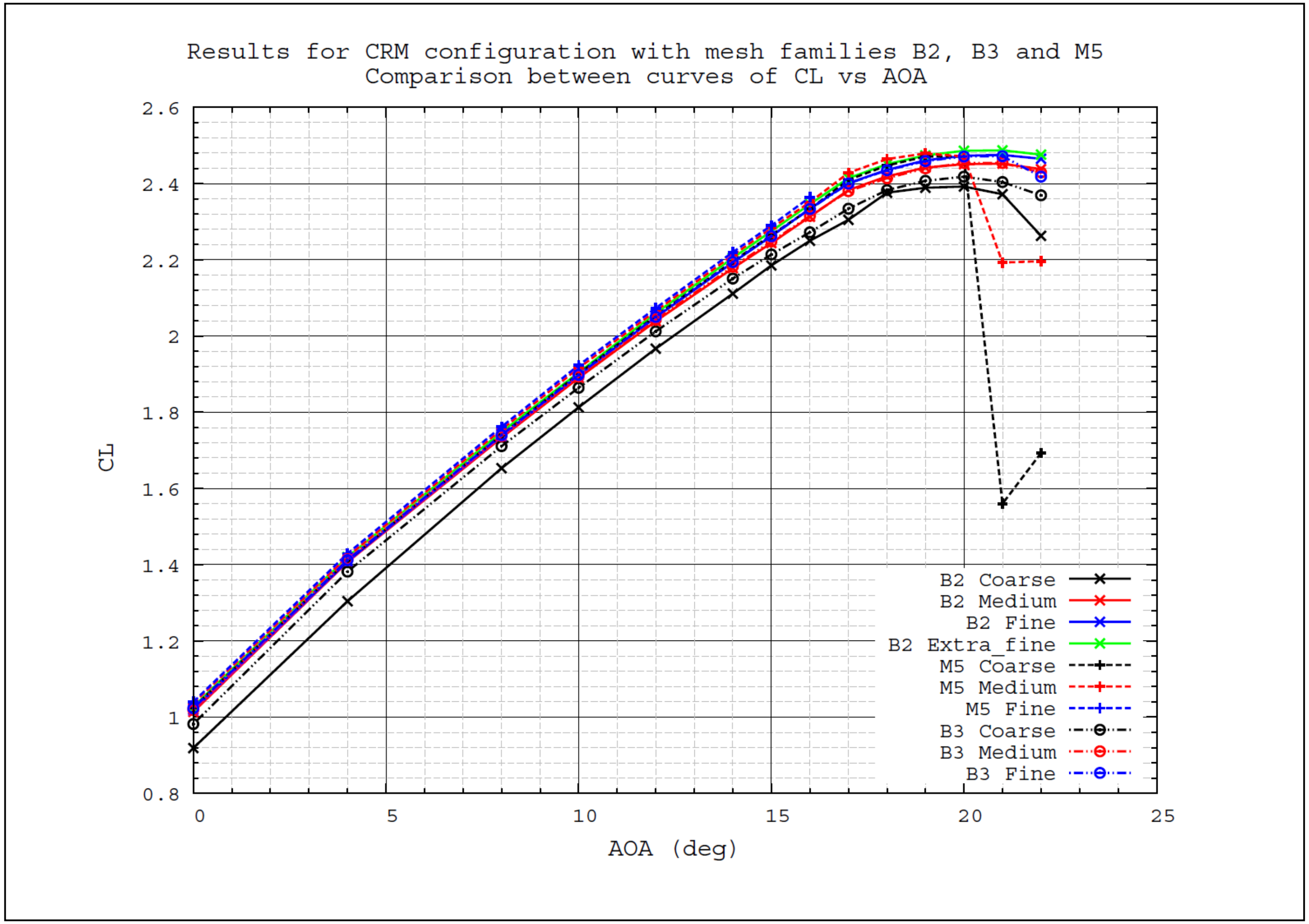
Grid B3



Flow separation position and extent strongly affect CM

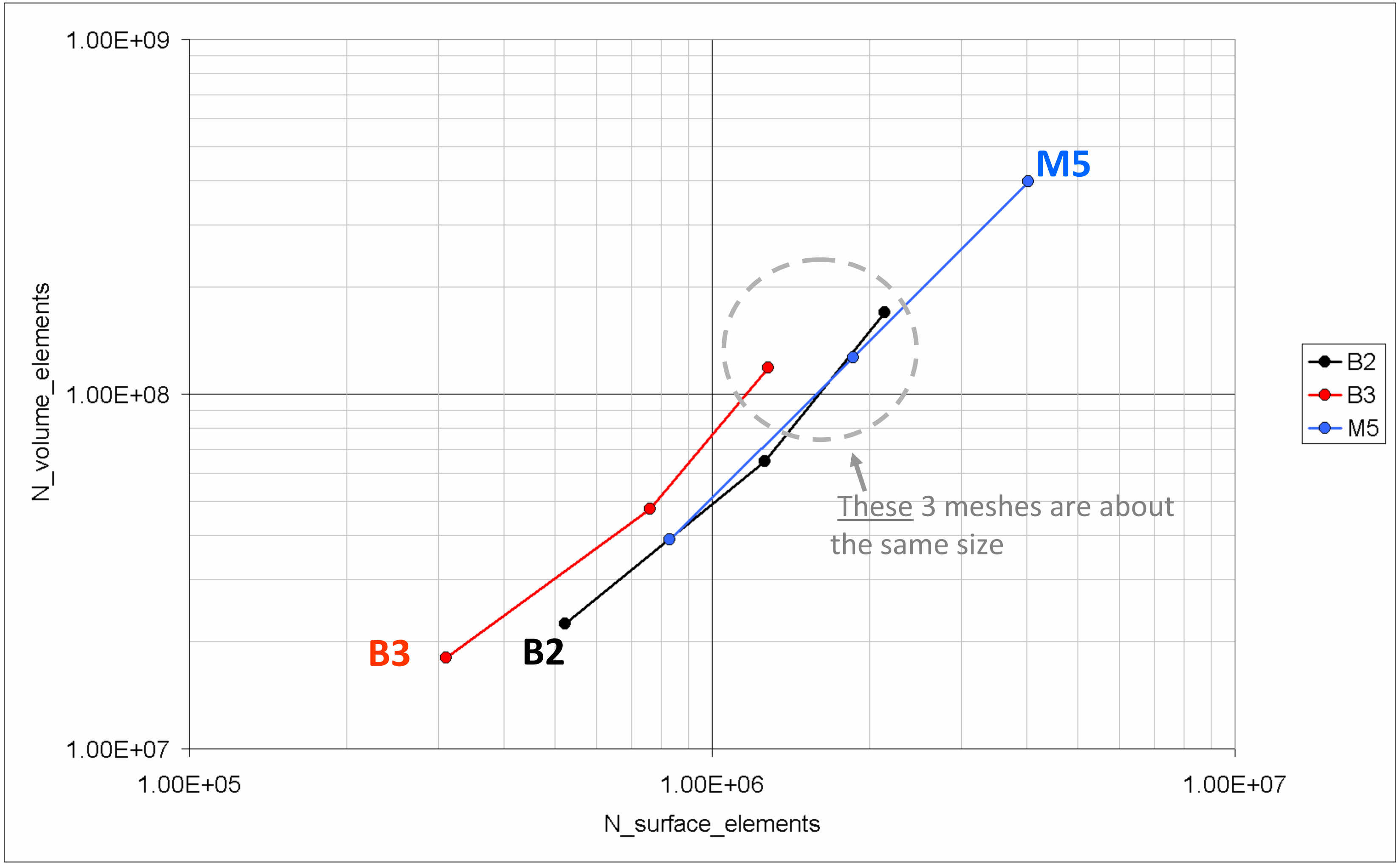
HL-CRM results – coefficients – CFD++

Grids B2, B3, M5



Grid comparison: B2, B3, M5

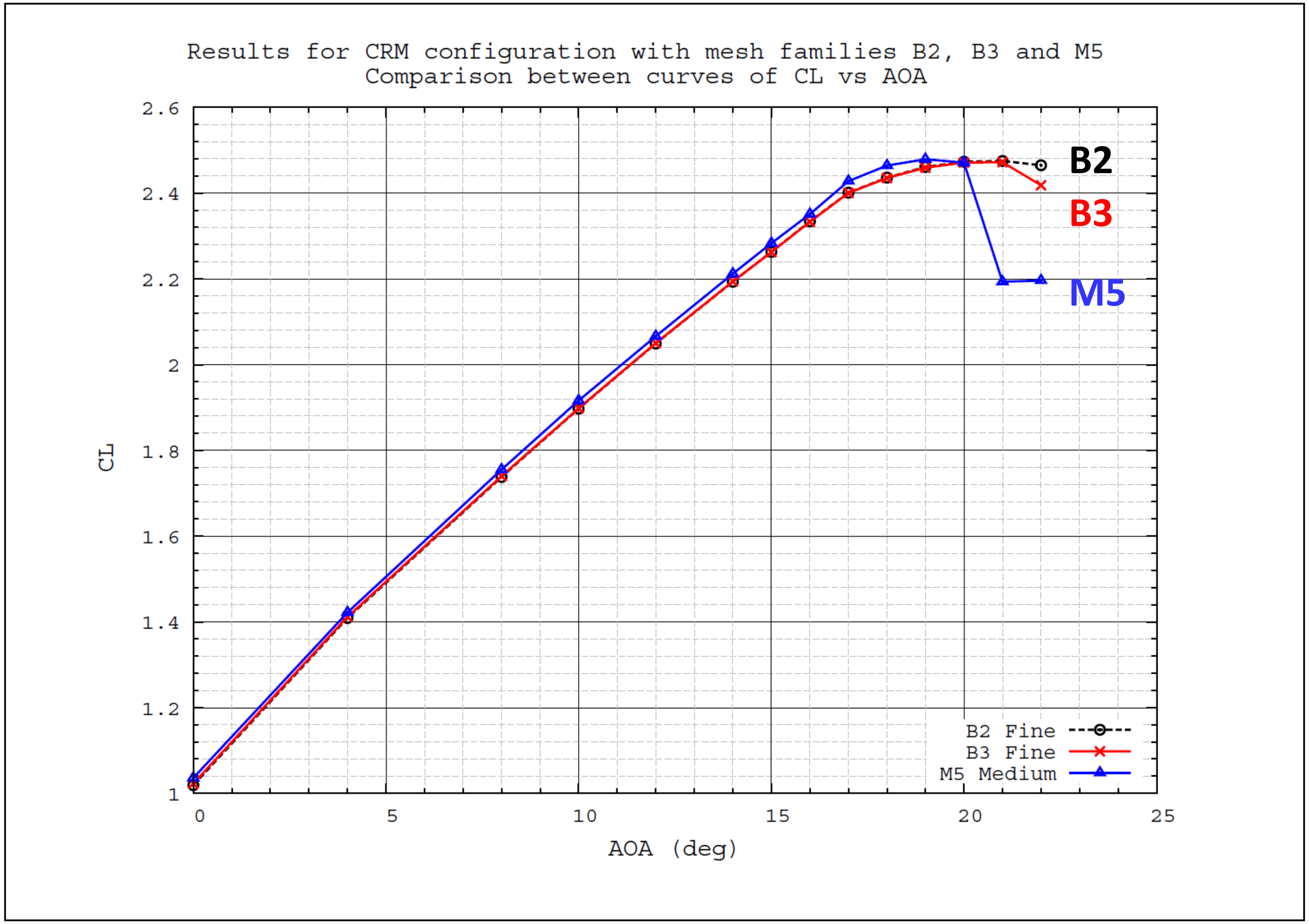
B2 (fine) **B3 (fine)** **M5 (Medium)**



These 3 meshes are about the same size

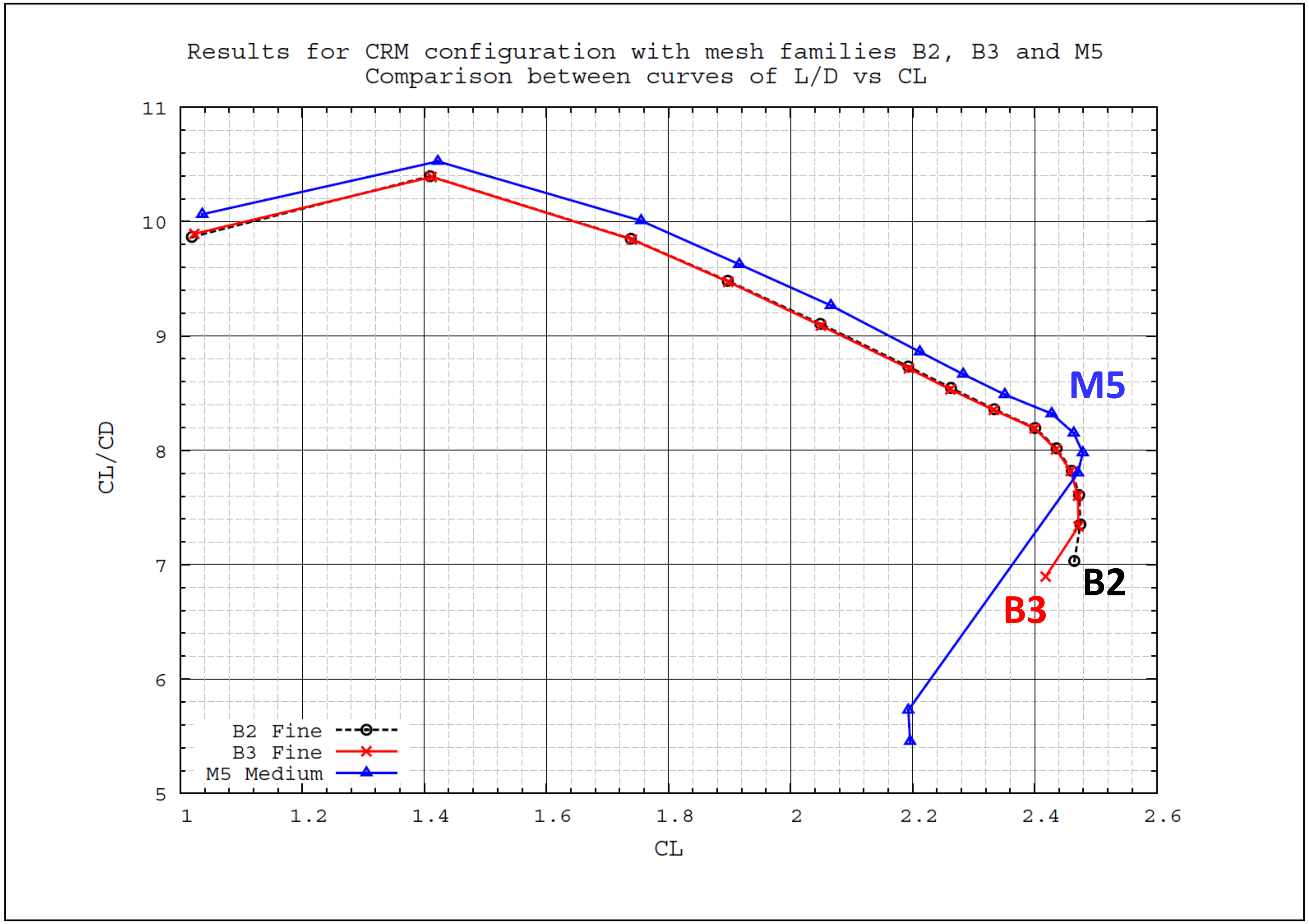
HL-CRM results – coefficients – CFD++

Grids B2, B3, M5

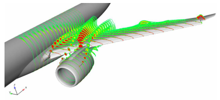


HL-CRM results – coefficients – CFD++

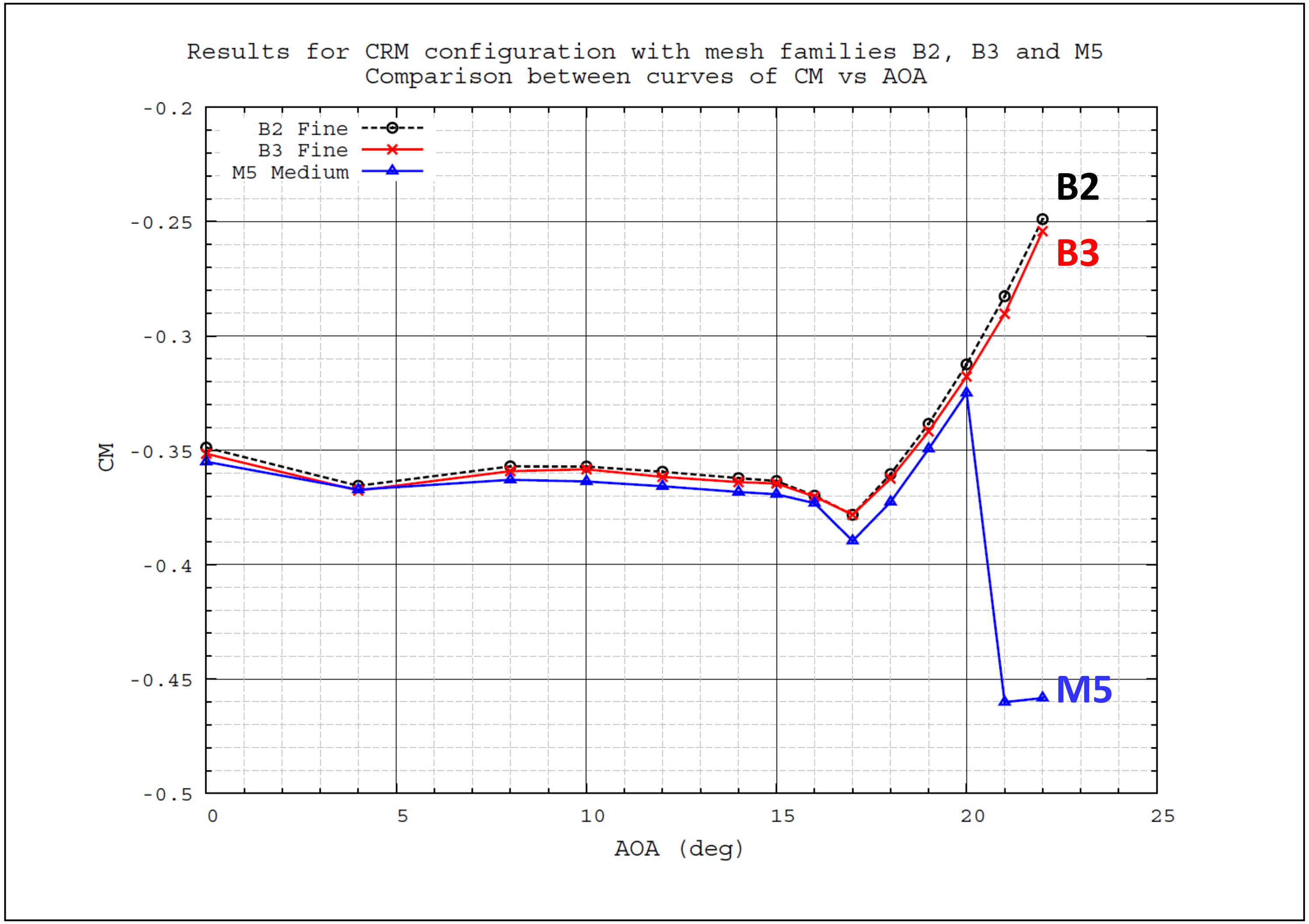
Grids B2, B3, M5



HL-CRM results – coefficients – CFD++

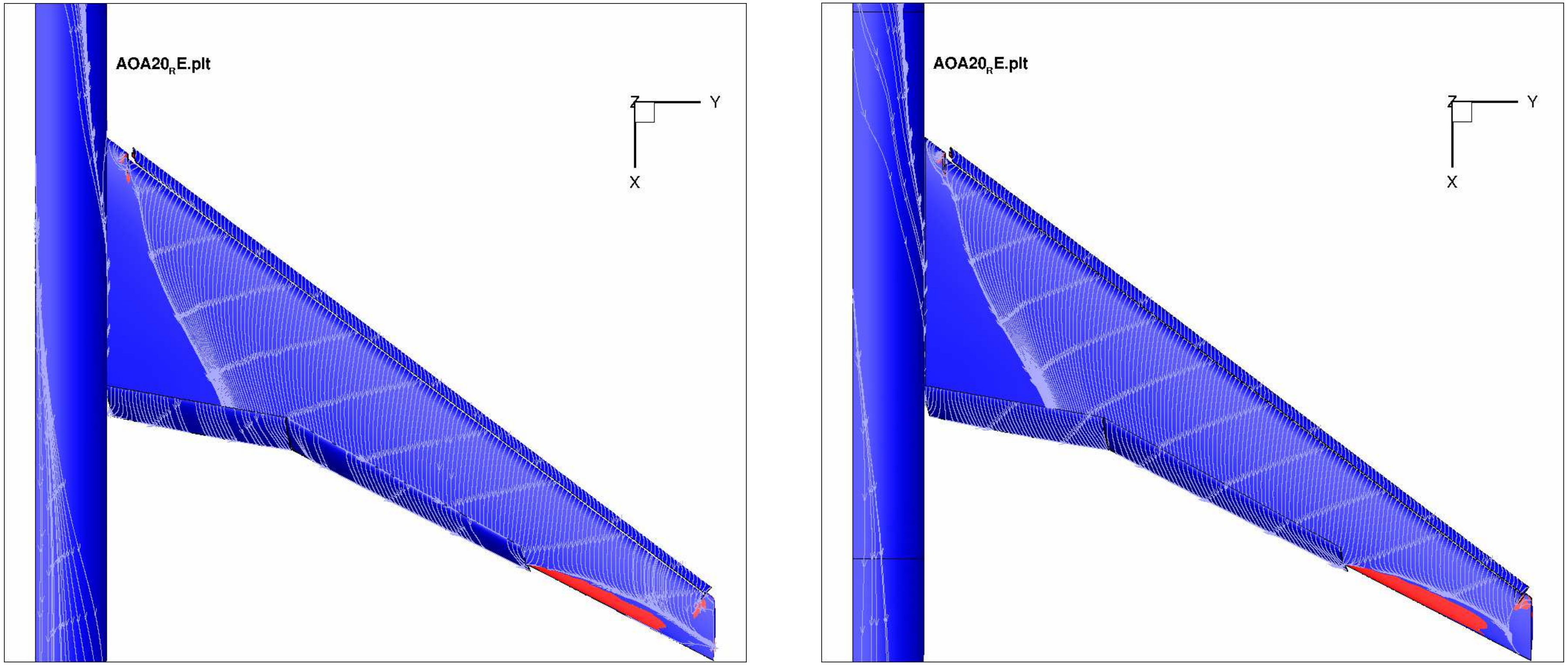


Grids B2, B3, M5

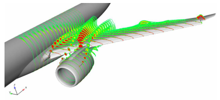


HL-CRM results – 20° – CFD++

Grids B2 fine x M5 medium

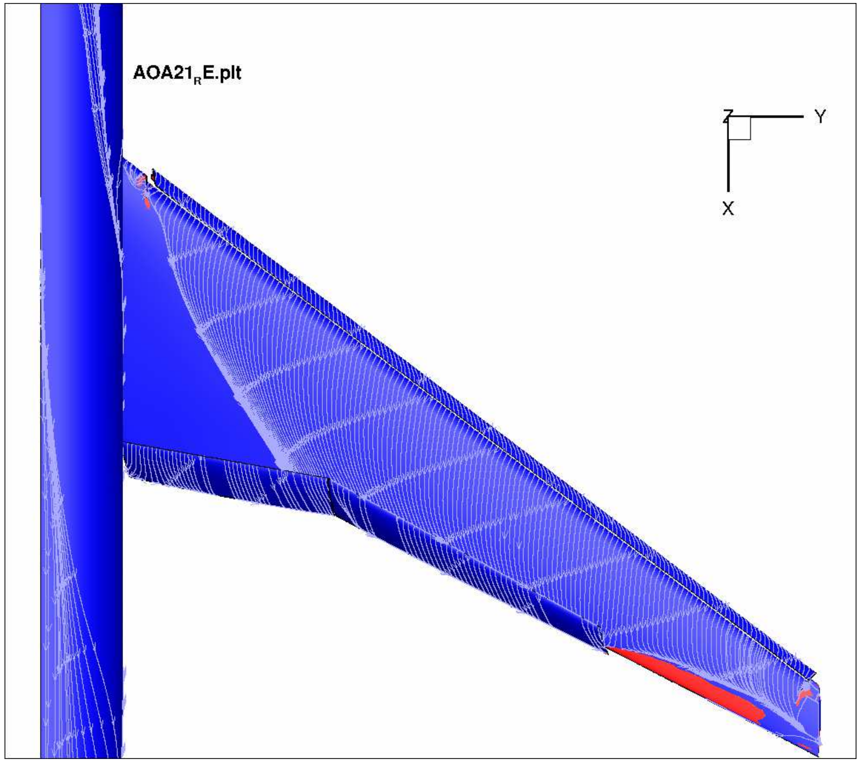


HL-CRM results – 21° – CFD++

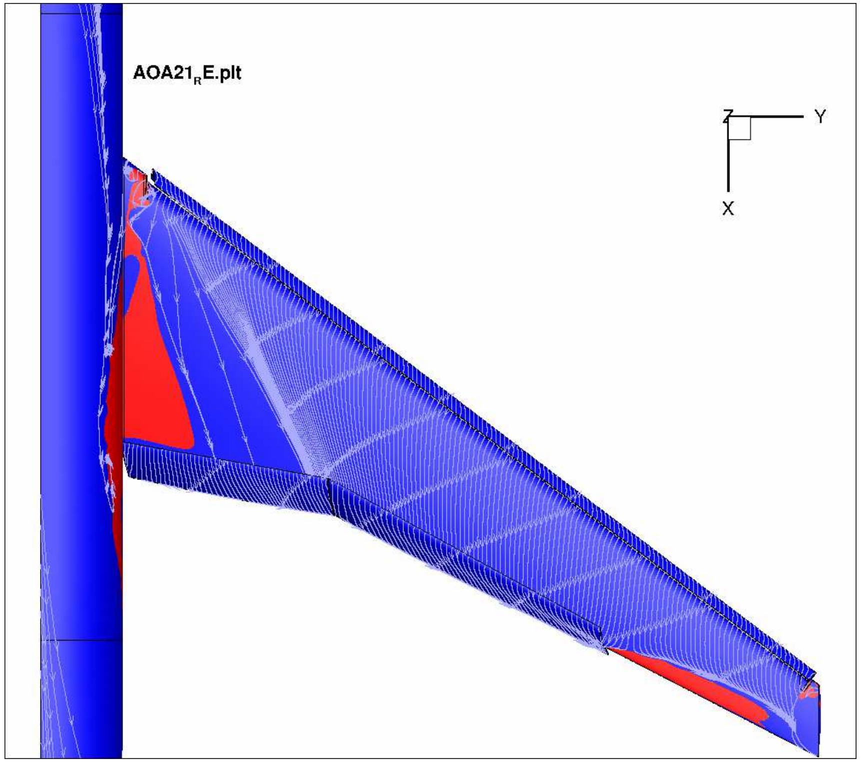


Grids B2 fine x M5 medium

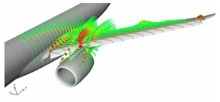
B2

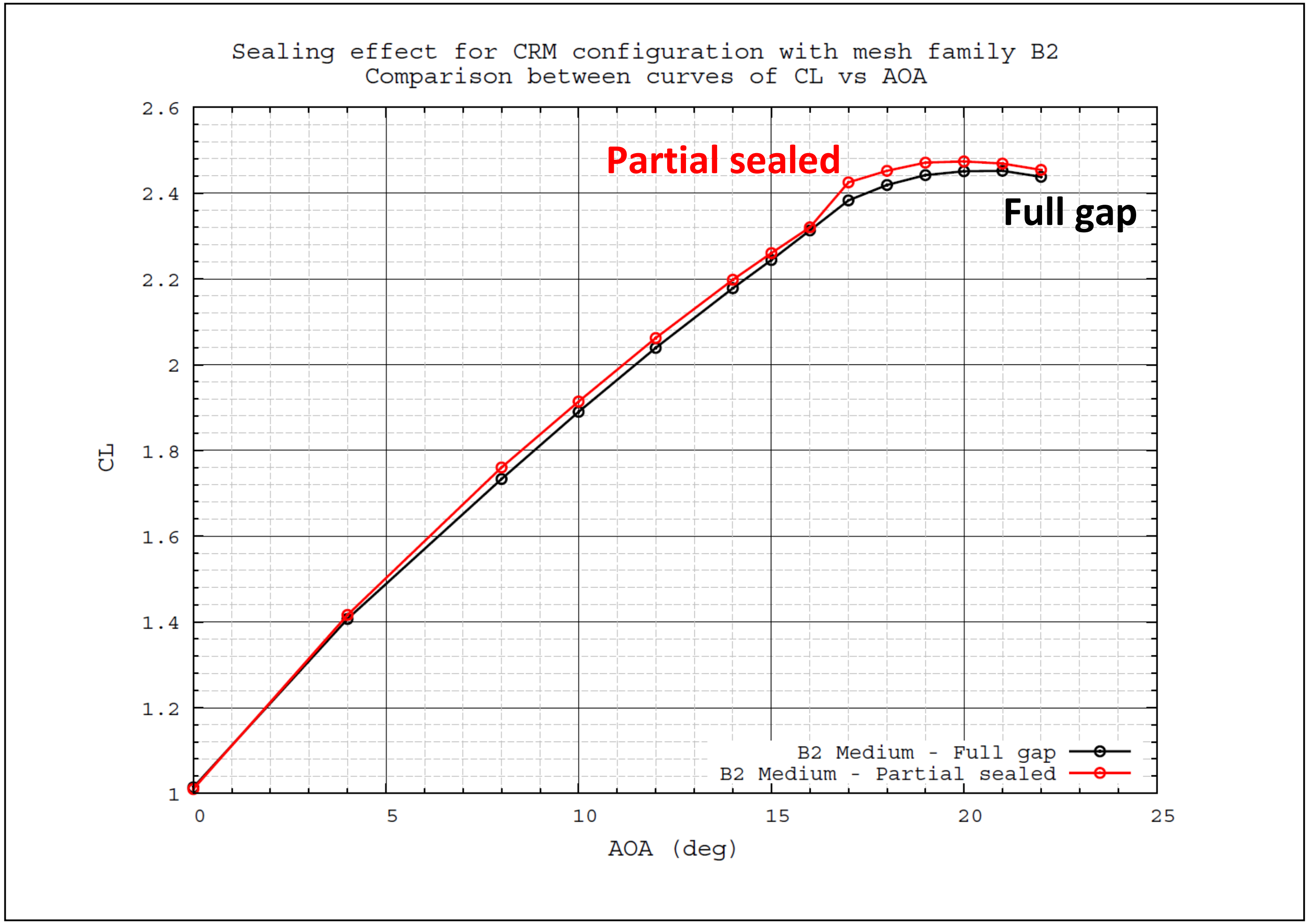


M5

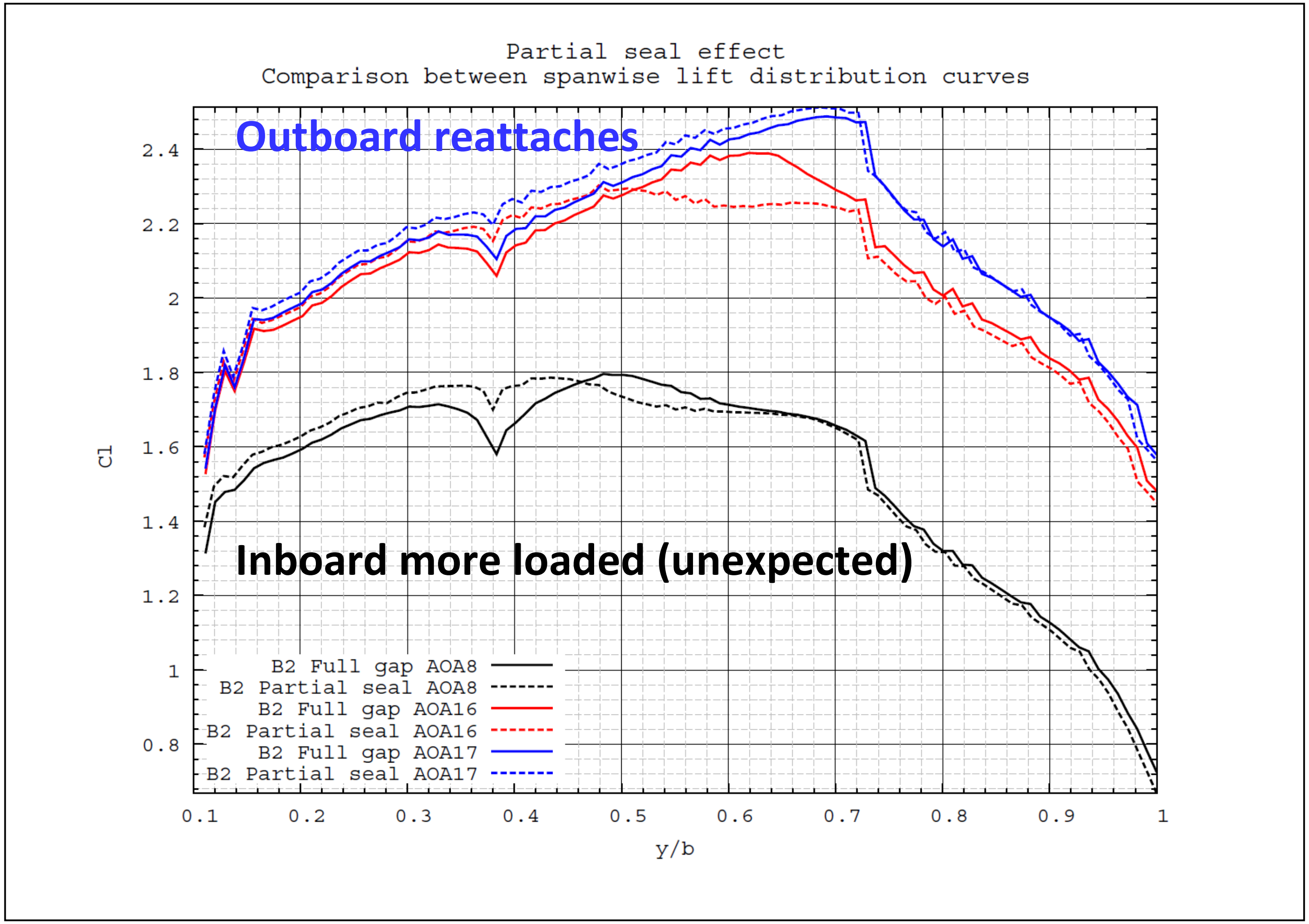


HL-CRM results – partial sealed x full gap

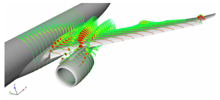




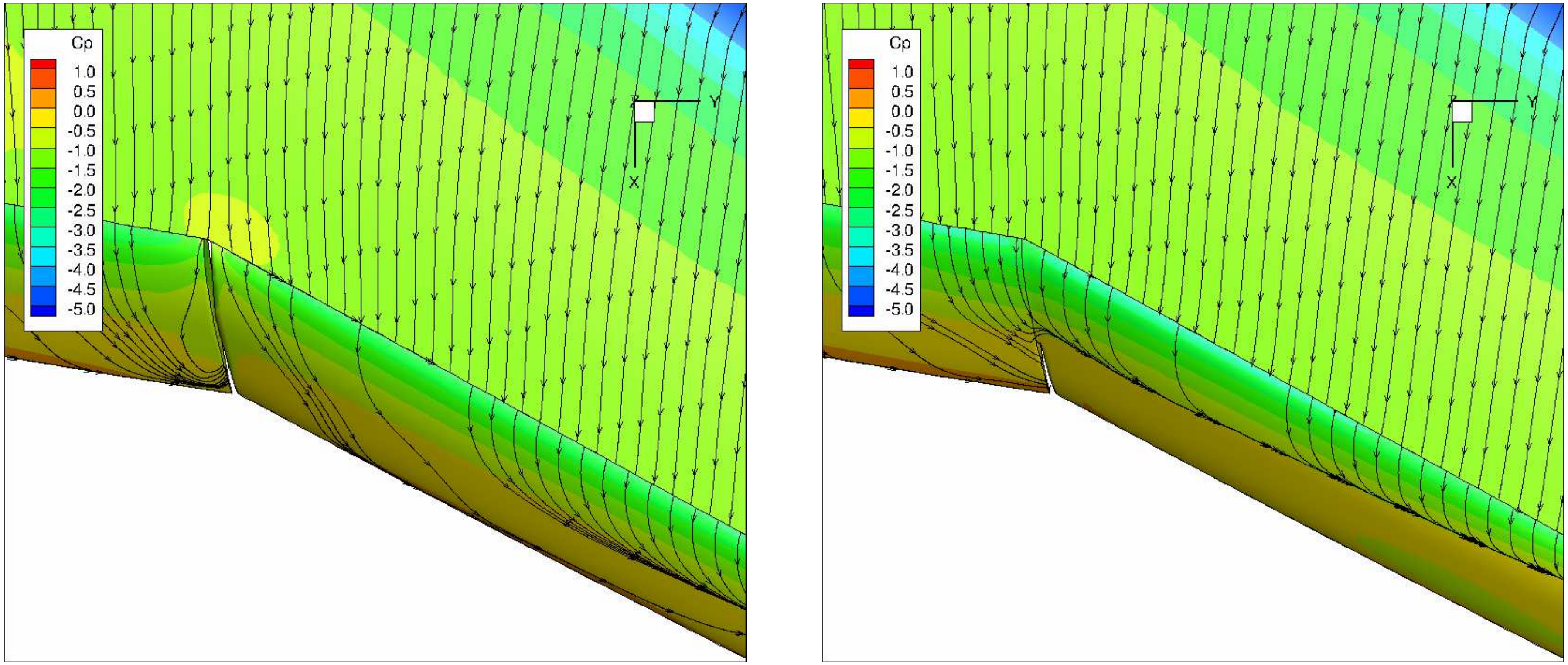
HL-CRM results – sealed gap x non-sealed – cl x span



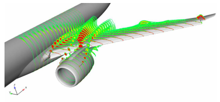
HL-CRM results – partial sealed x full gap – flow visualization



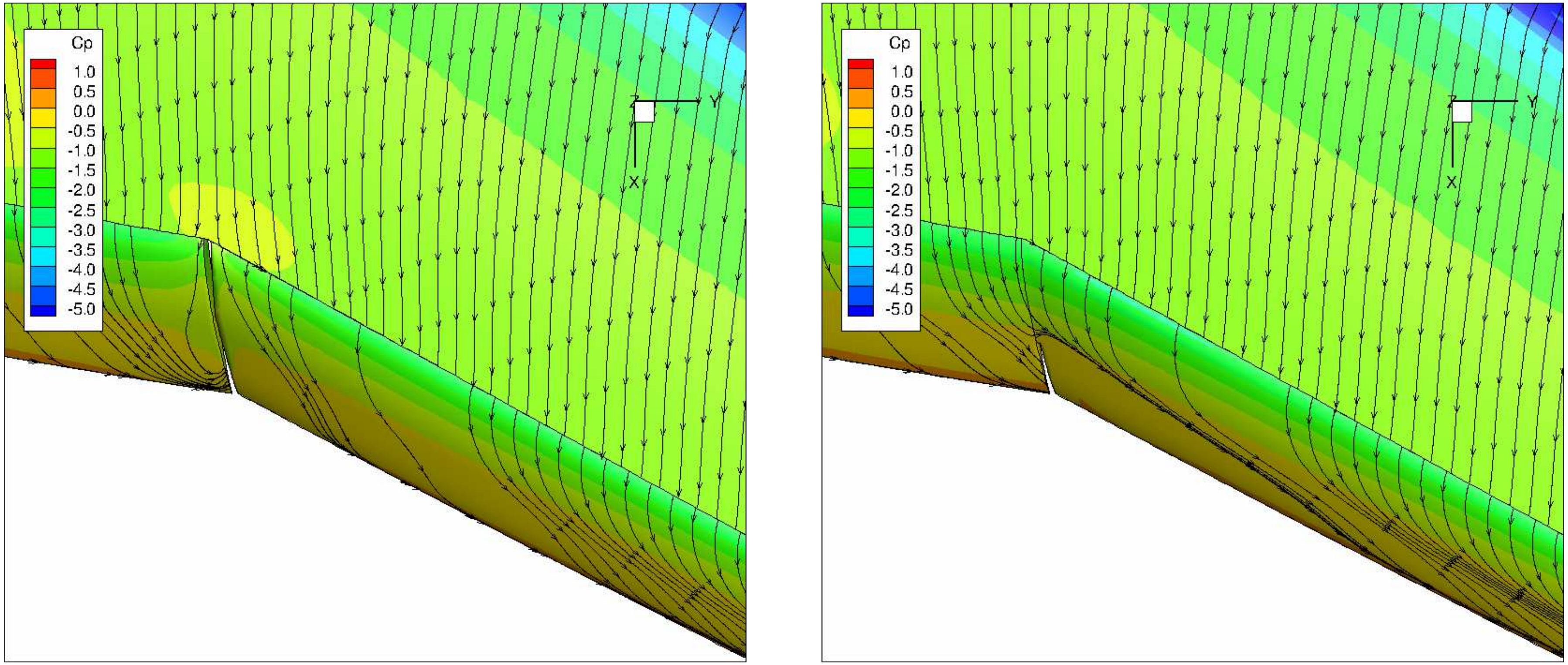
AOA=16°



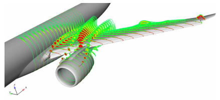
HL-CRM results – sealed gap x non-sealed – flow visualization



AOA=17°



Brief overview of HL-CRM results



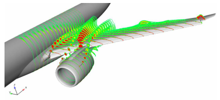
- Grid convergence
  - Grid M5 seems to converge to a lower value of CD and more negative CM (due to a smaller flow separation on flap)
    - Uniform surface grid distribution
  - Results are reasonably converged for CL and CD but not for CM
- Coefficients
  - Grids B2 and B3 (Fine mesh) yield virtually the same results for CL and CD, with grid B3 having less elements
  - Grid M5 captured an inboard stall at 20°, while grids B2 and B3 captured outboard stall
- Partial seal
  - The partial seal caused an increase in loading in the inboard panel but increased flow separation in the outboard panel for alphas smaller than 16°
  - After 16°, the seal increased loading over the full span, with increase in CLMax
  - Overall, the seal increases CL, CM (more negative) and L/D ratio

JSM results

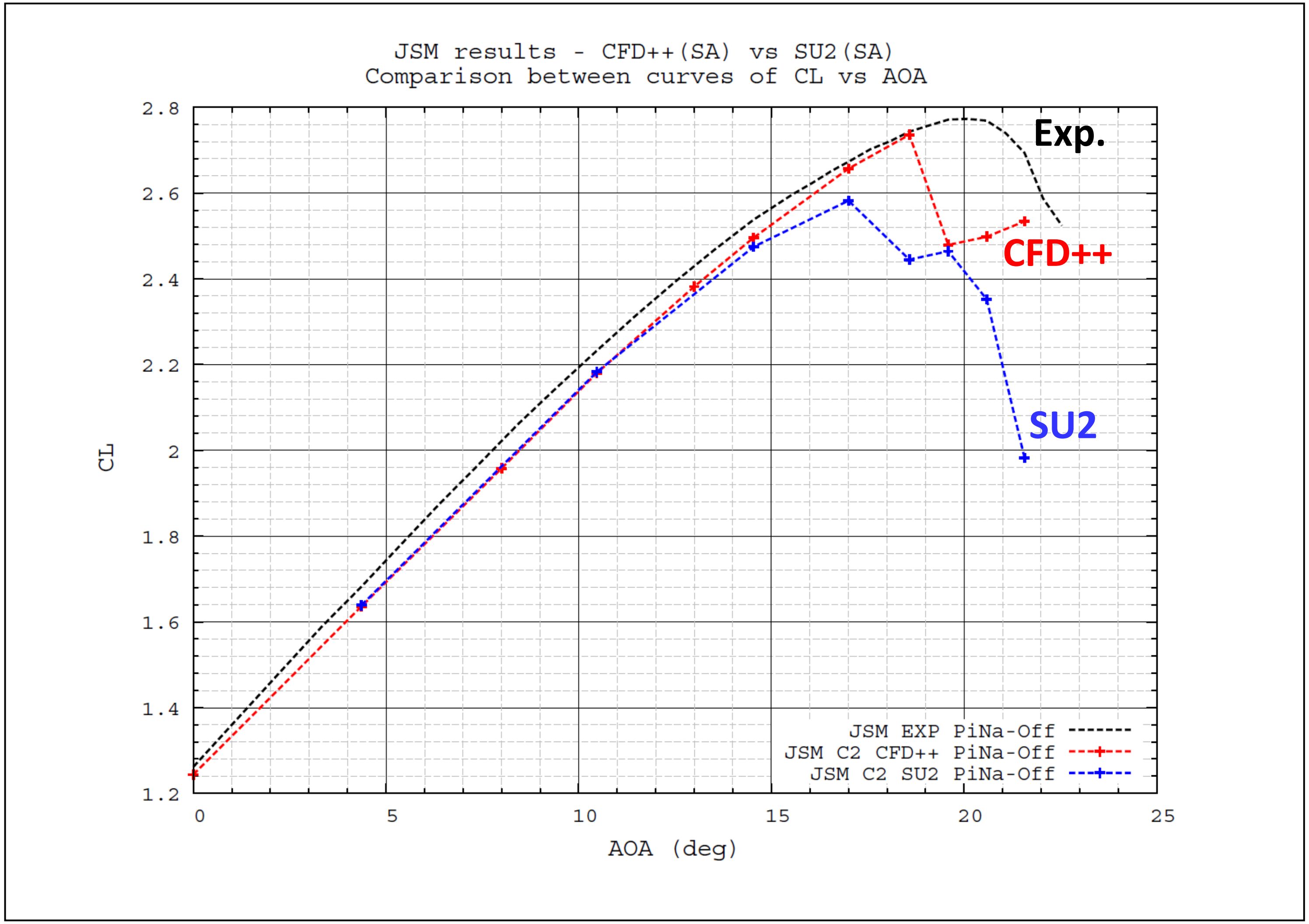
M=0.17

Rey=1.93E+06

JSM results – CFD++ x SU2 (mesh family C2)



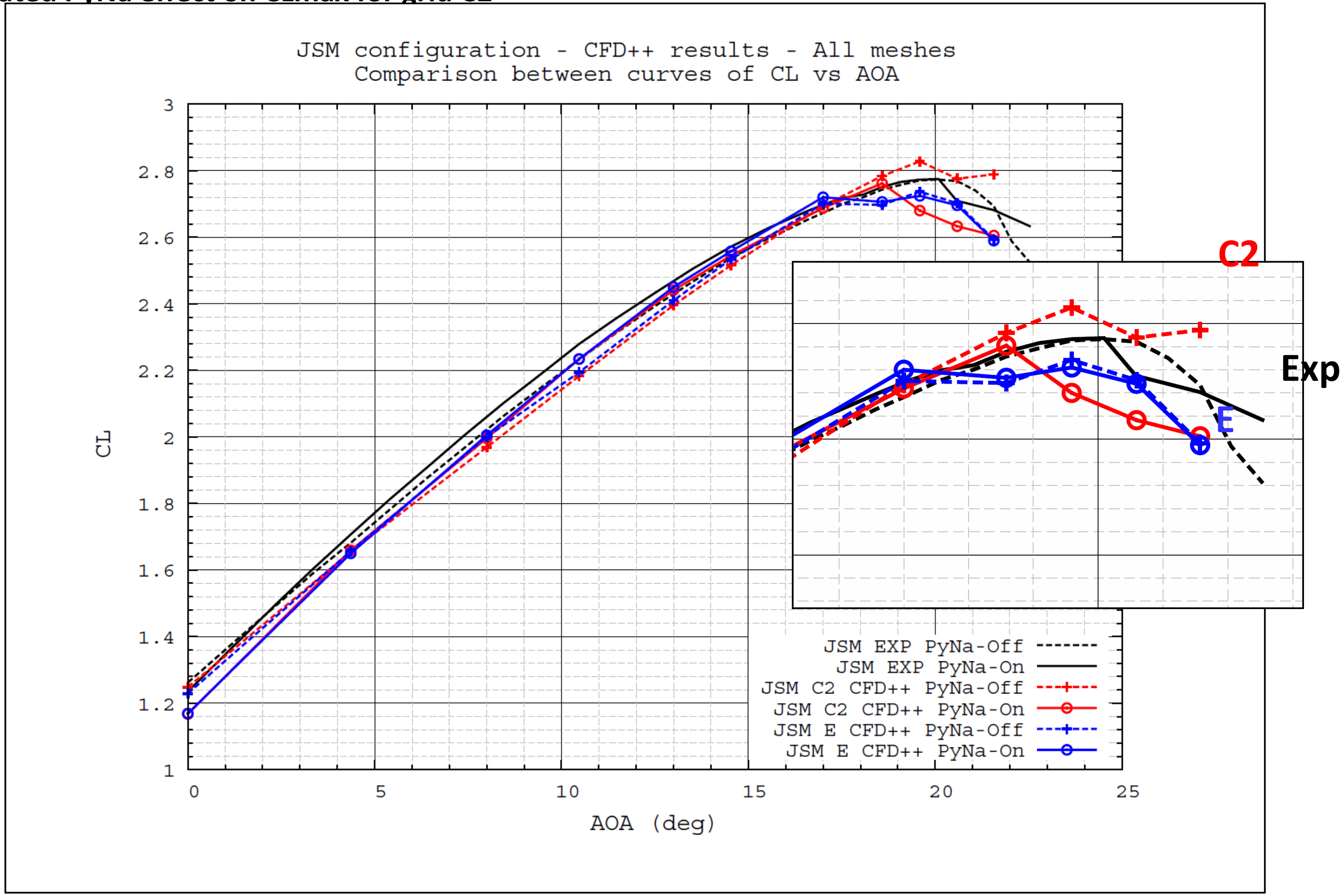
SU2: SA
CFD++: SA



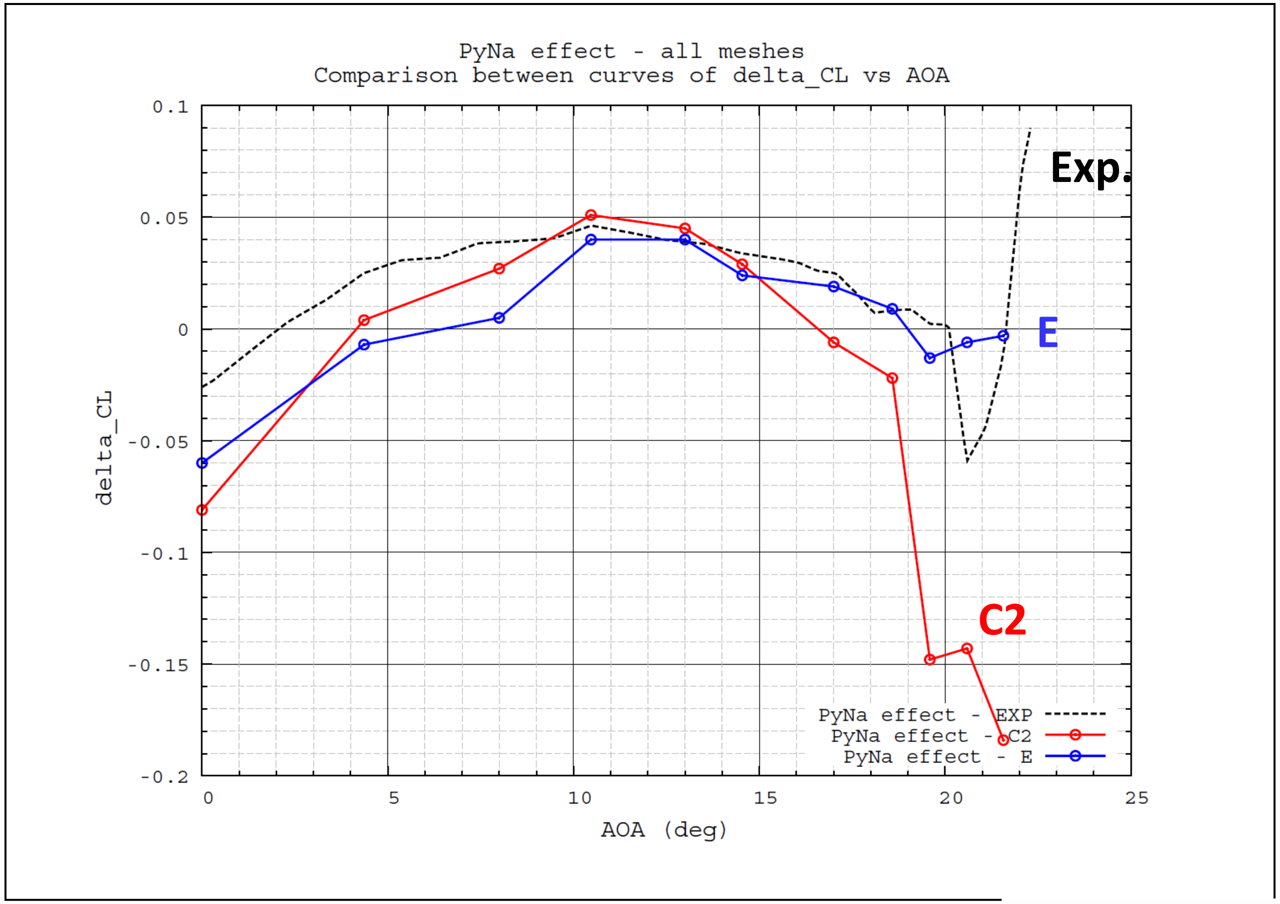
JSM results – PyNaOn x PyNaOff

Non-monotone behavior of CL near stall region for grid E

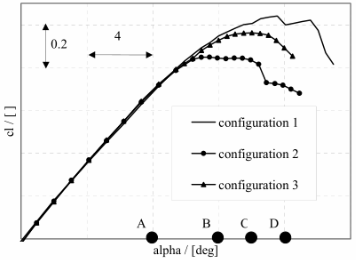
Exaggerated PyNa effect on CLmax for grid C2



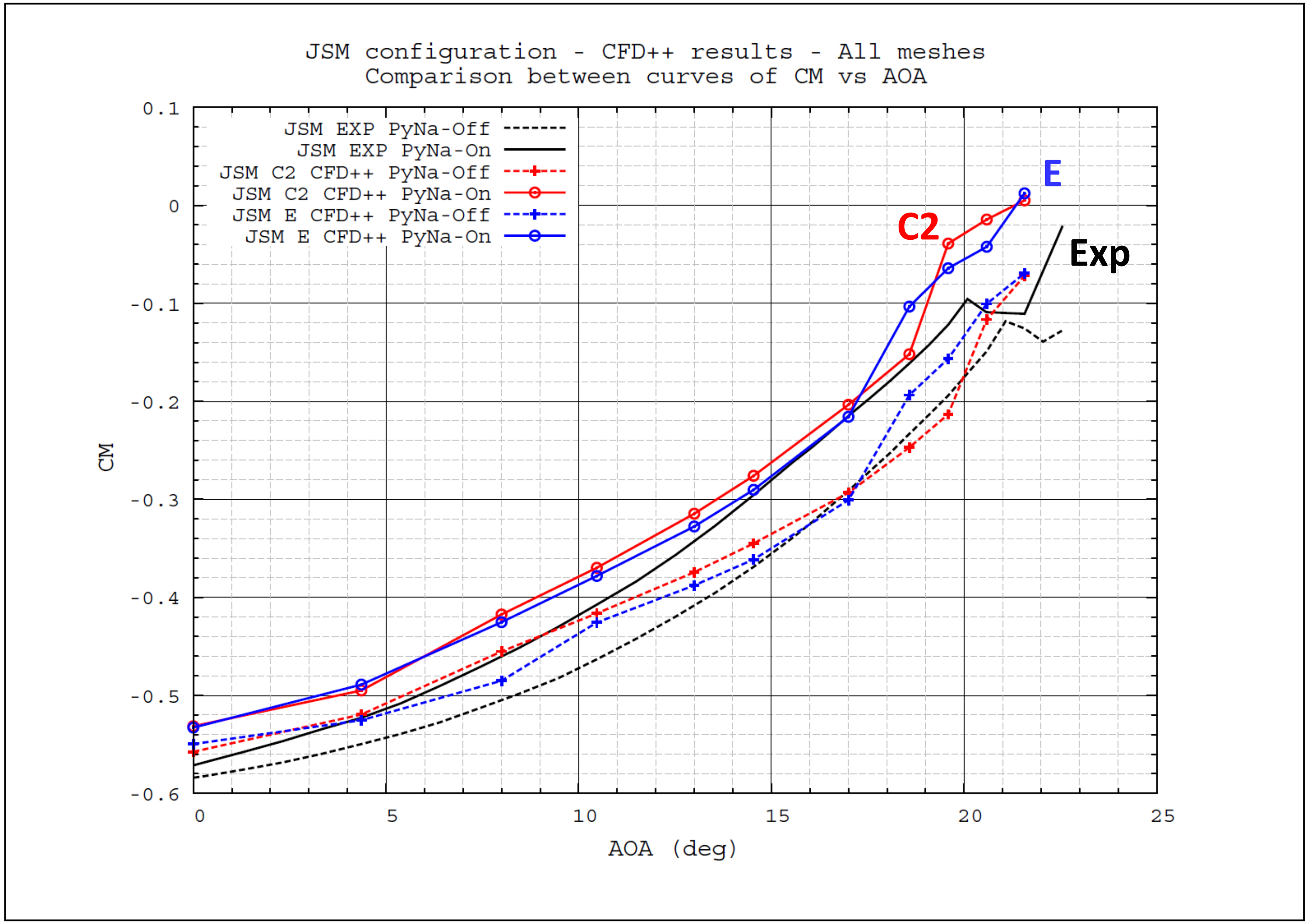
JSM results – DPyNaOn - PyNaOff



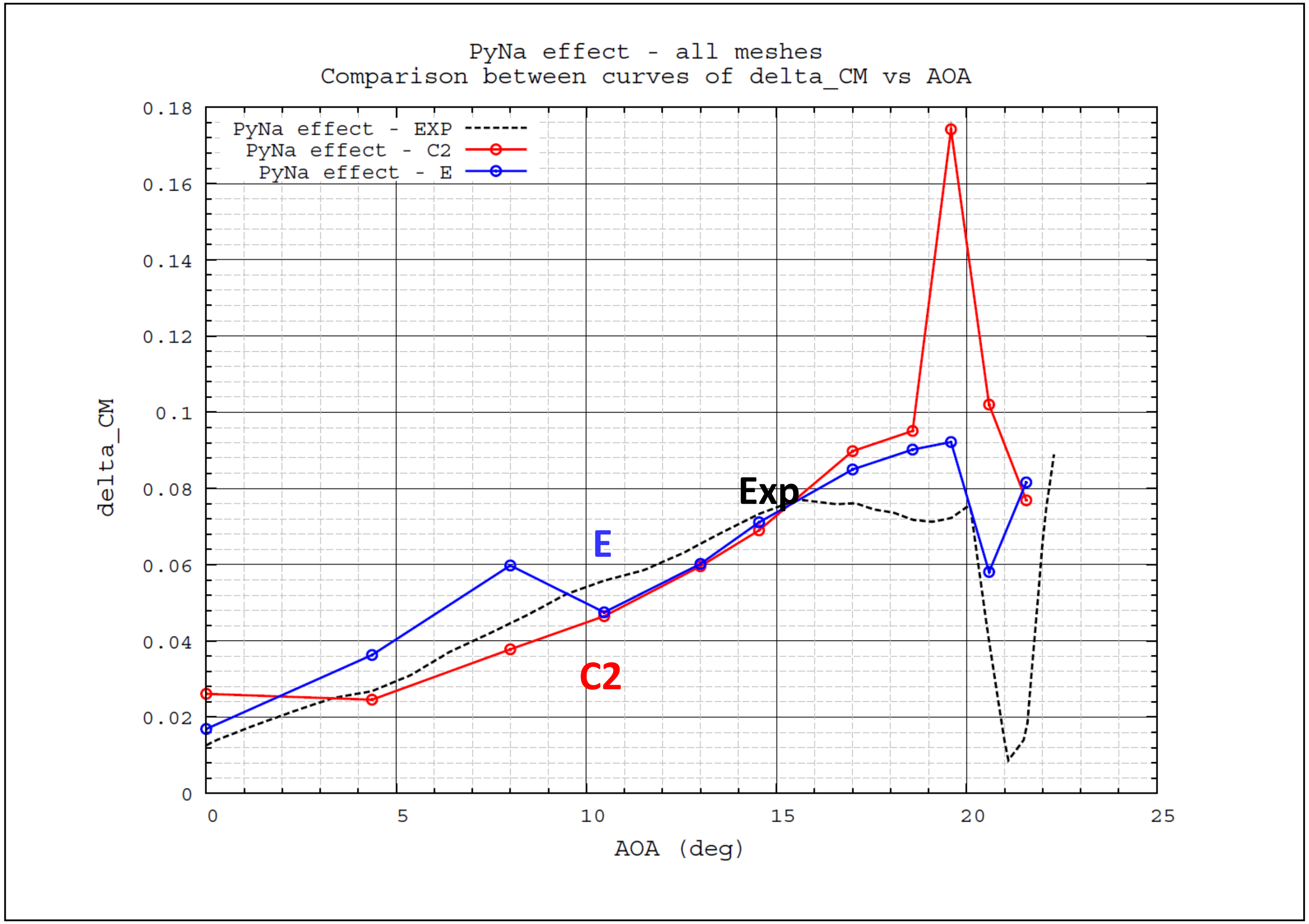
- **Captured small DCLmax**
  - **AIAA 2007-4298, Low Speed High Lift Validation Tests within the European Project EUROLIFT II, Quix H, Schulz M, Quest J, Rudnik R, Schröder A**
  - **The pylon-nacele can have much larger effects depending on the geometry**



JSM results – PyNaOn x PyNaOff

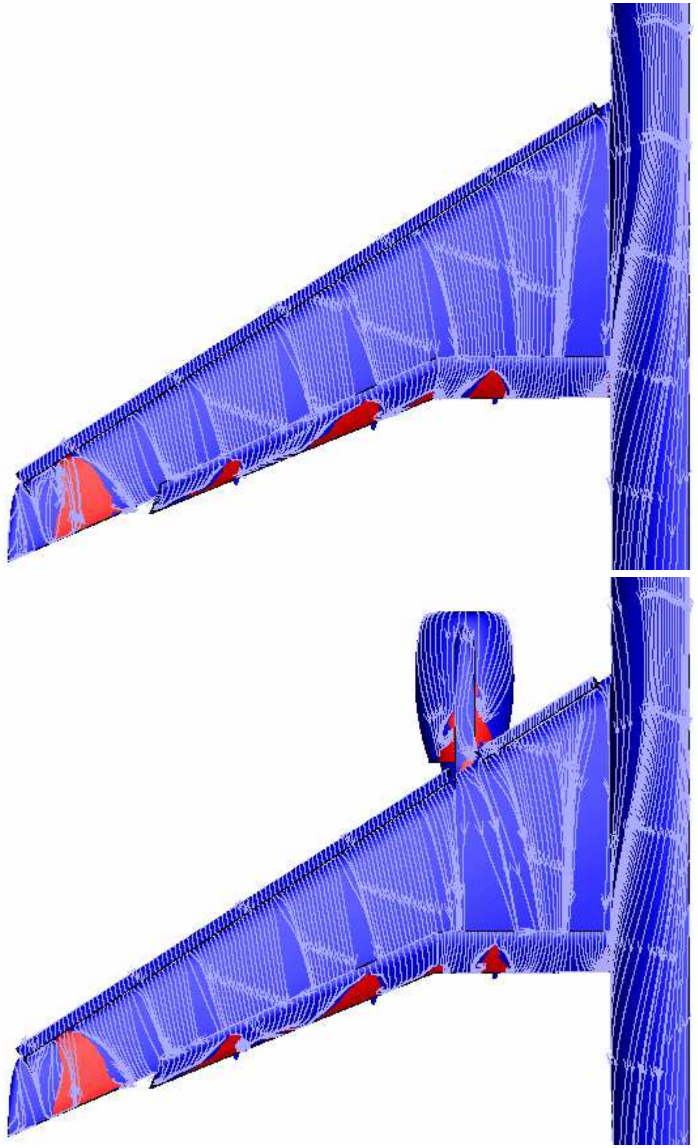


JSM results – PyNaOn x PyNaOff

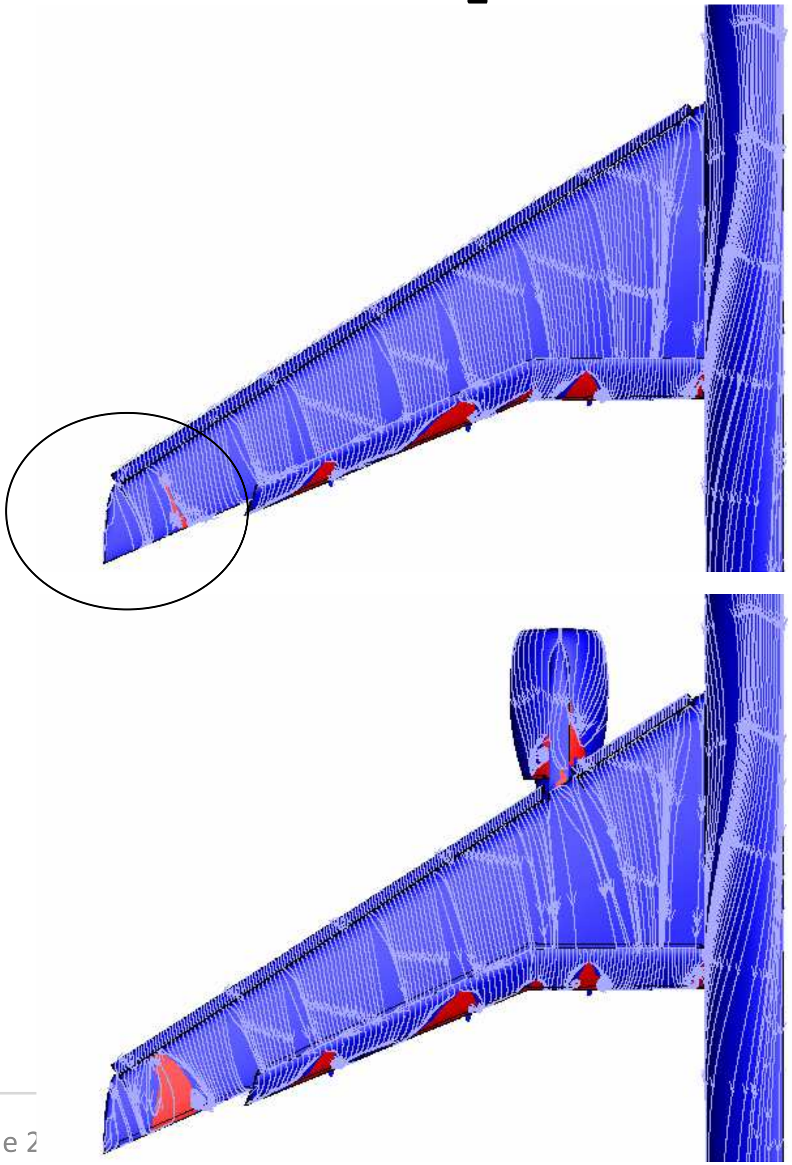


JSM results – PyNaOn x PyNaOff – 8°

C2

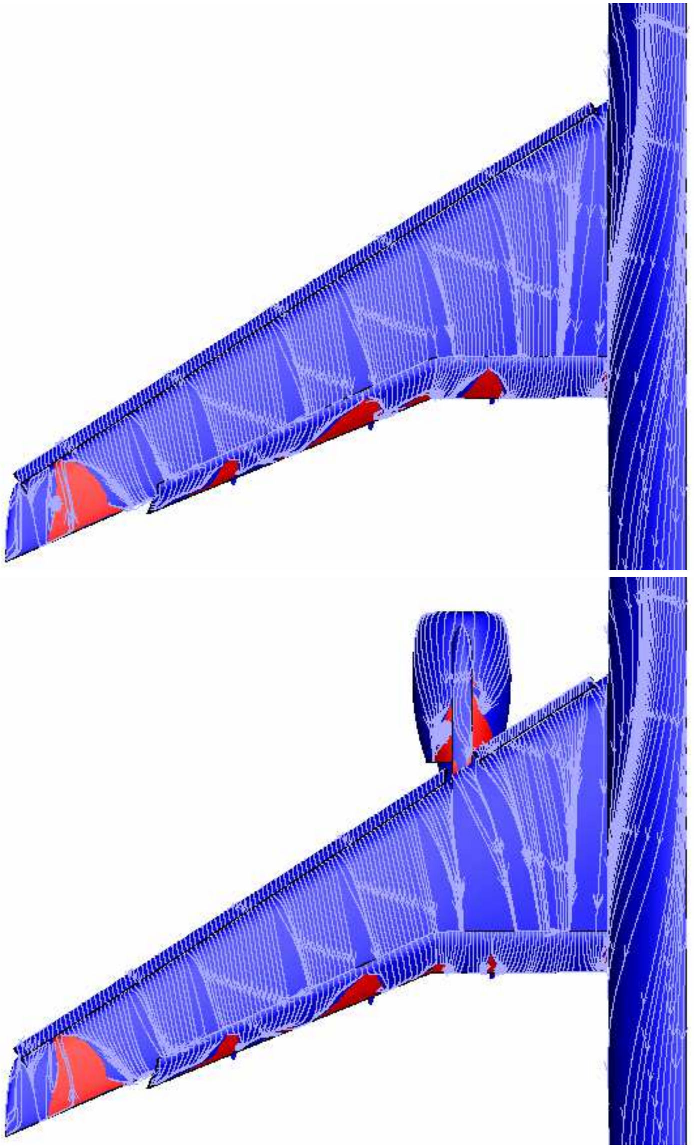


E



JSM results – PyNaOn x PyNaOff – 10°

C2



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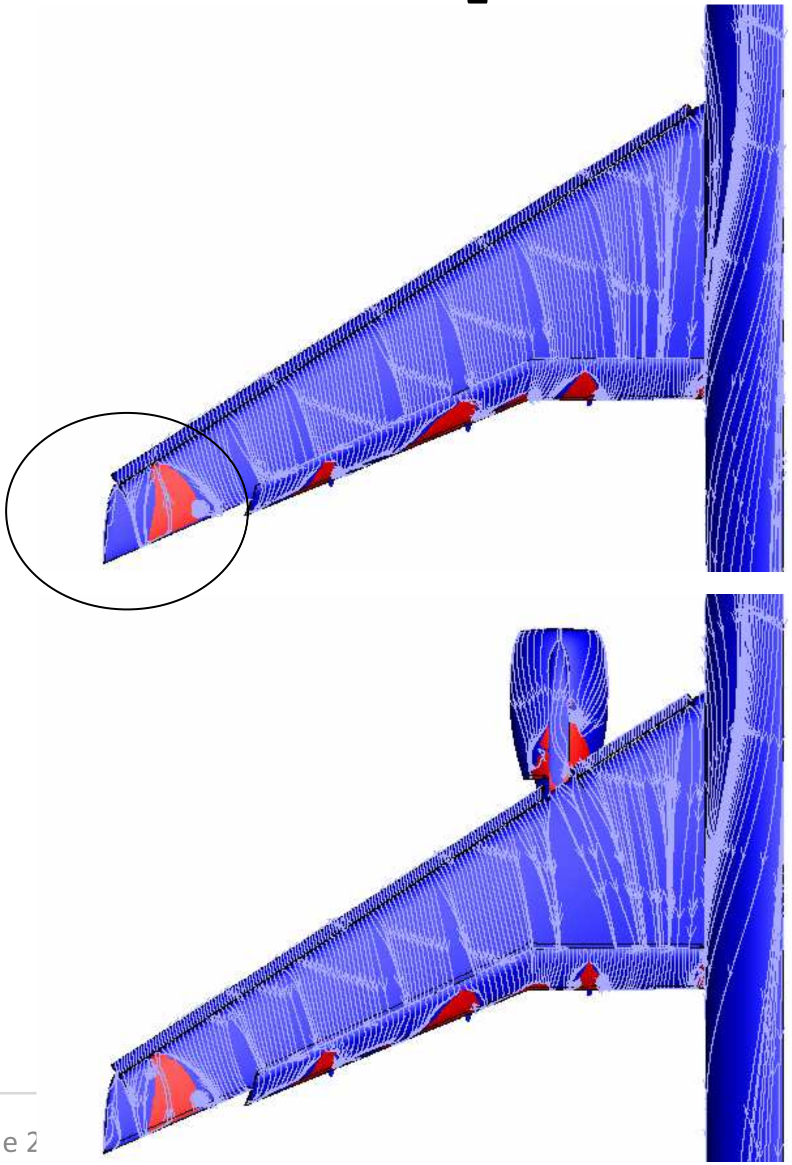
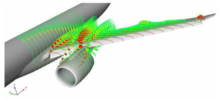
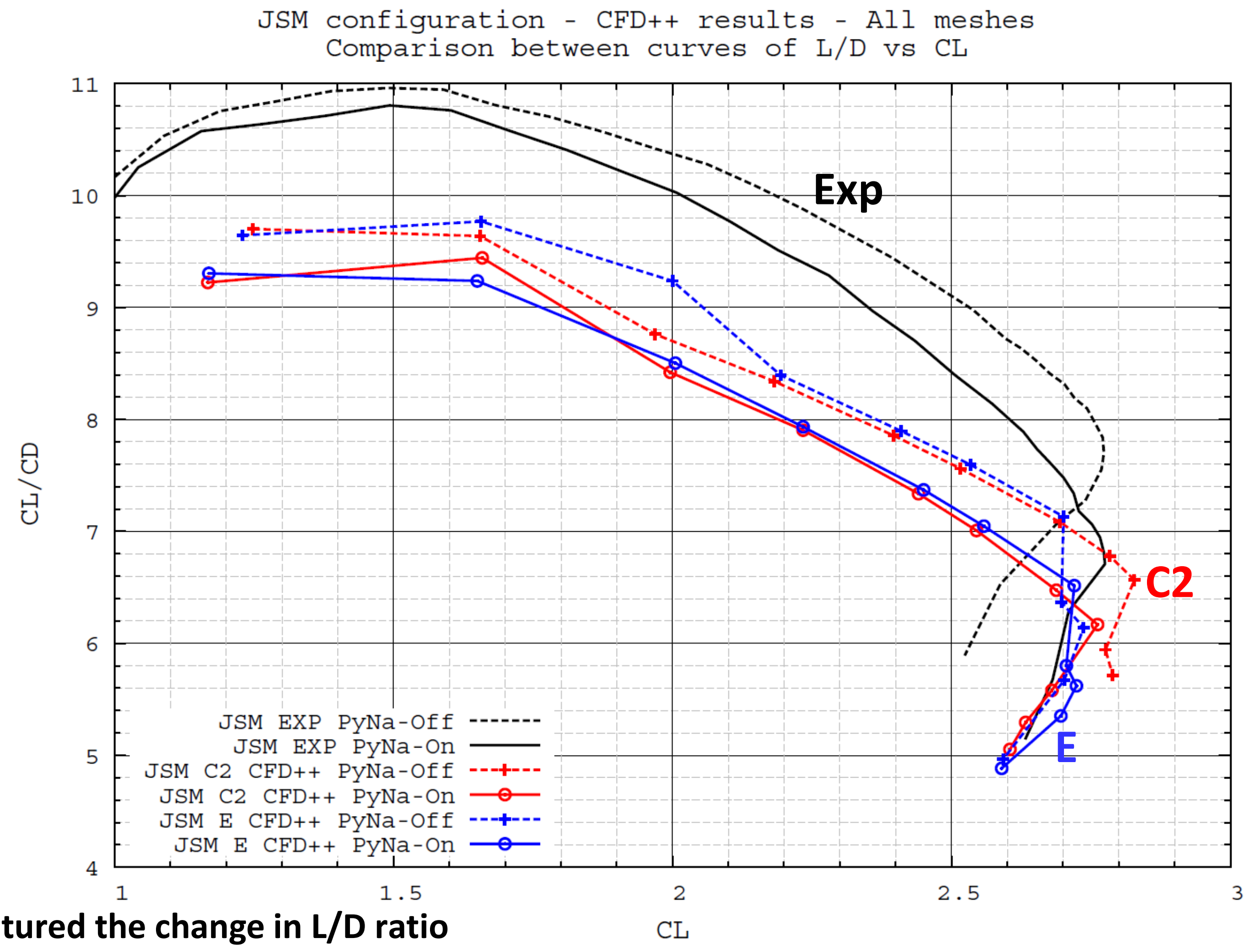


JSM results – PyNaOn x PyNaOff

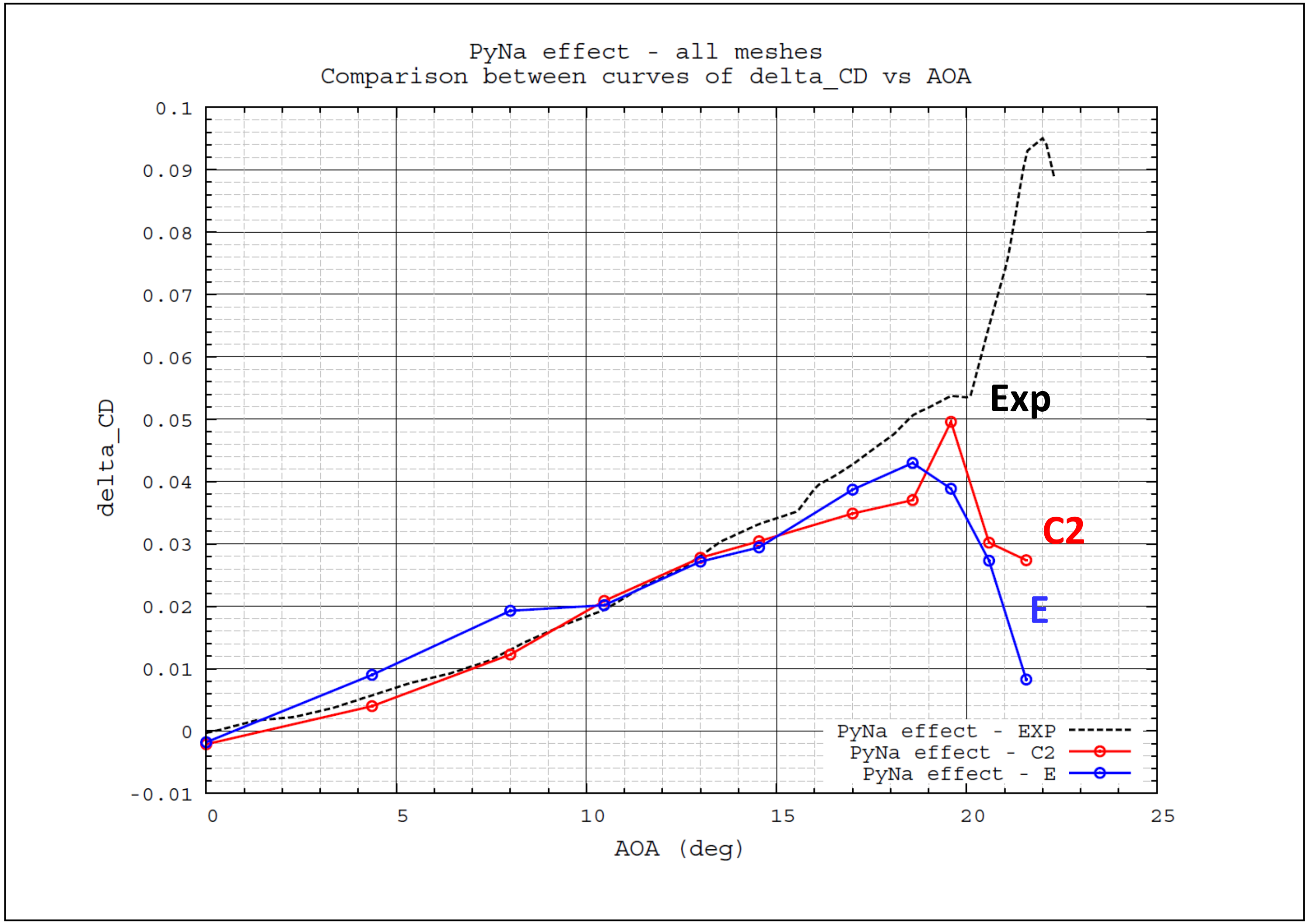




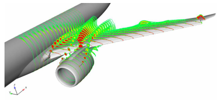
Captured the change in L/D ratio

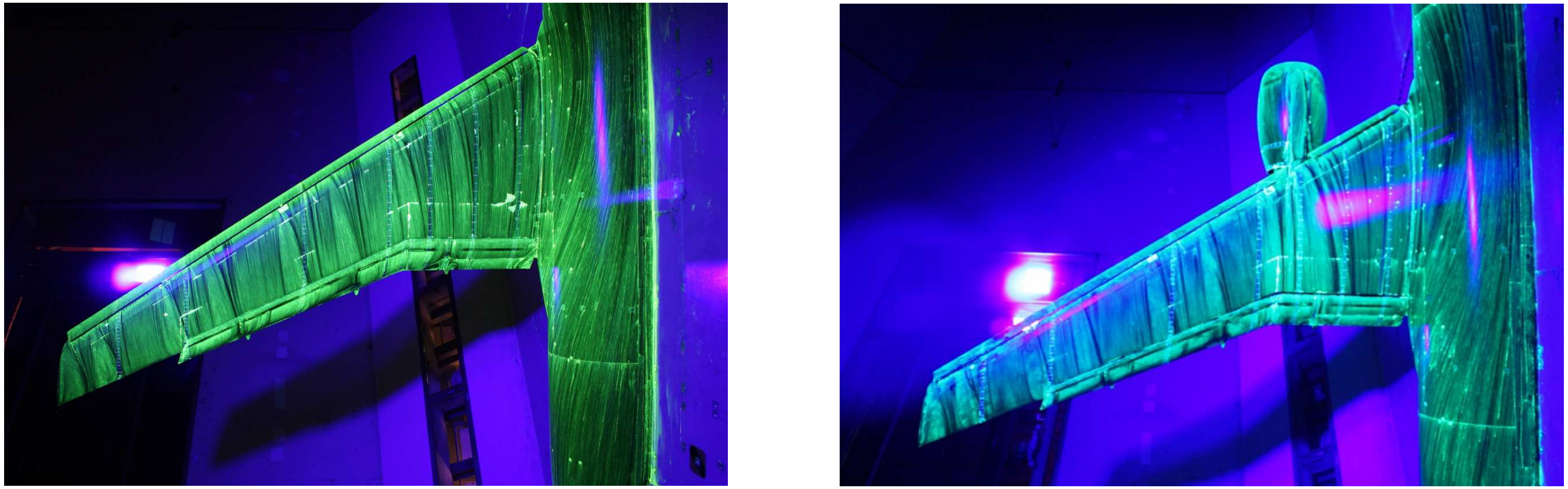
Overall poor comparison

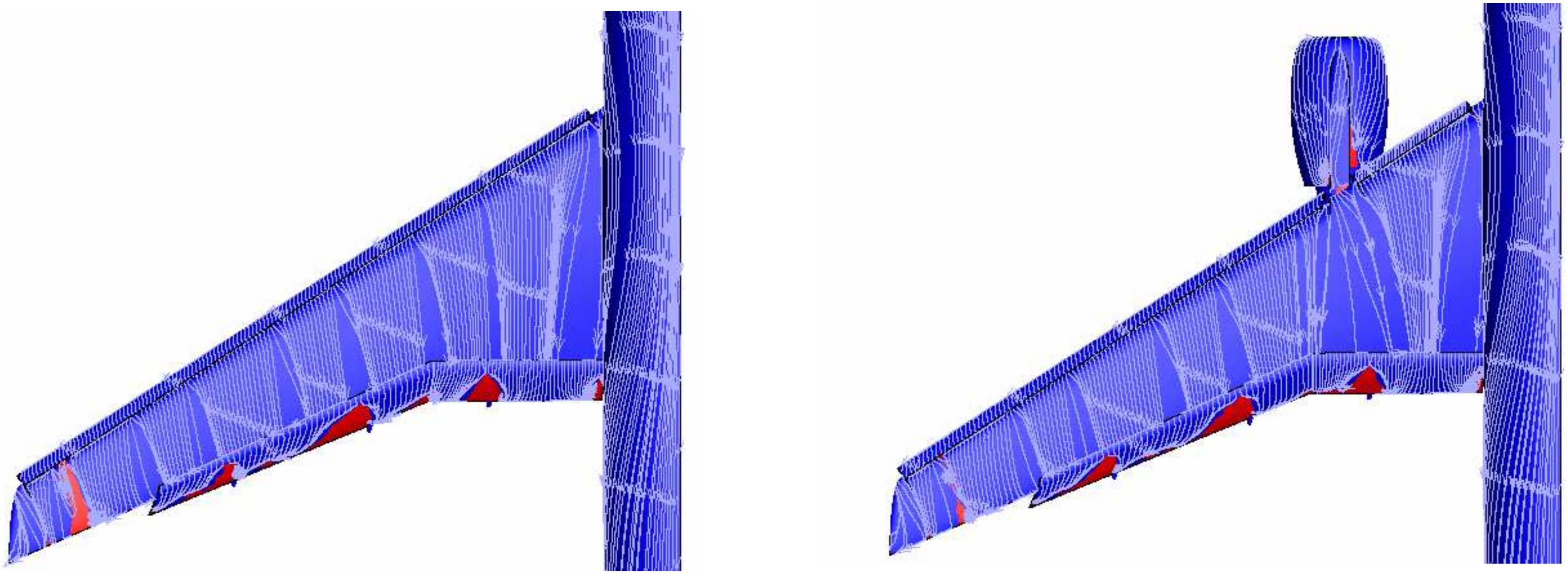
JSM results – PyNaOn x PyNaOff



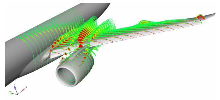
JSM results – C2 – PyNaOn x PyNaOff – 4.36°

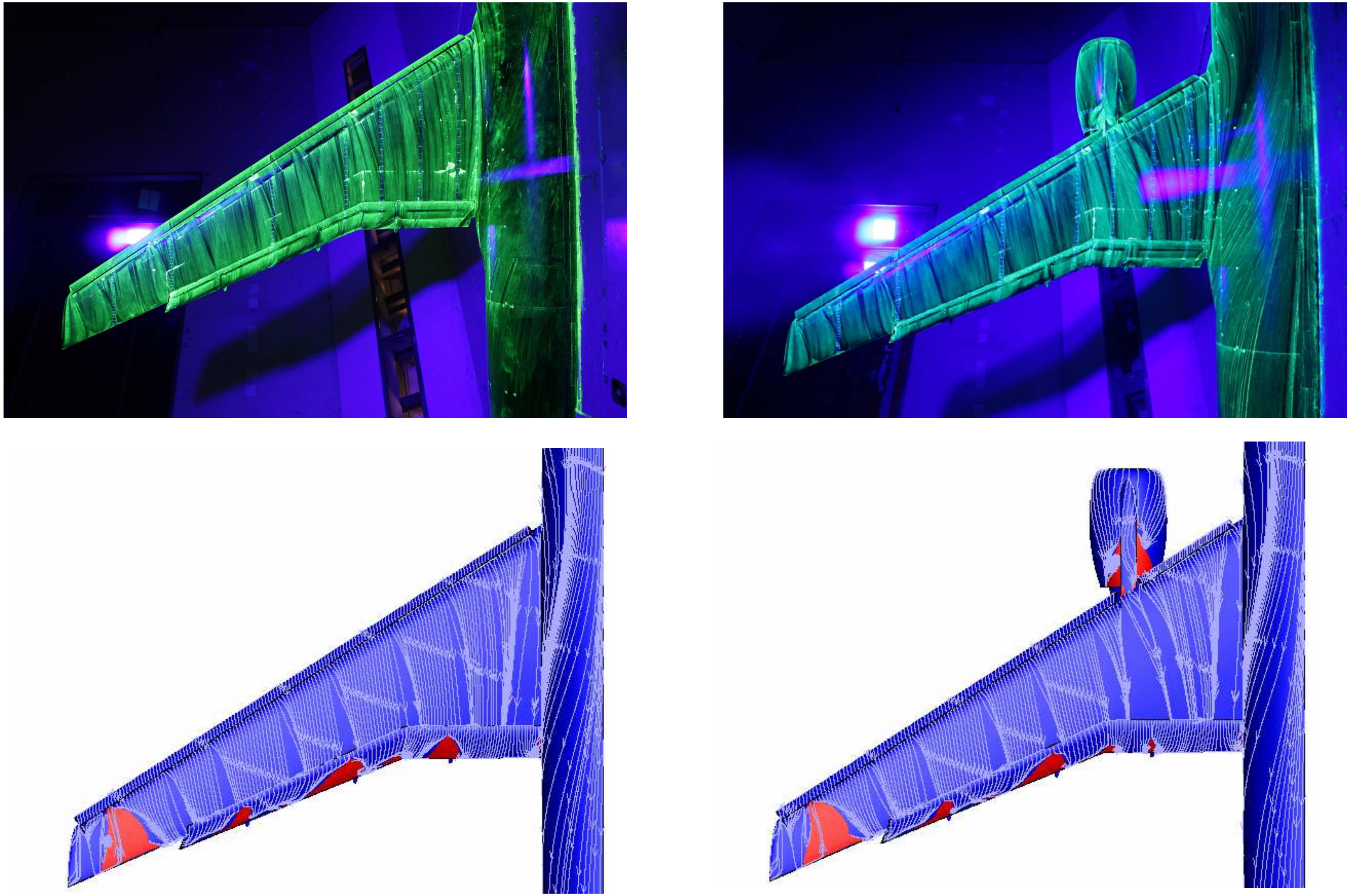




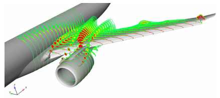


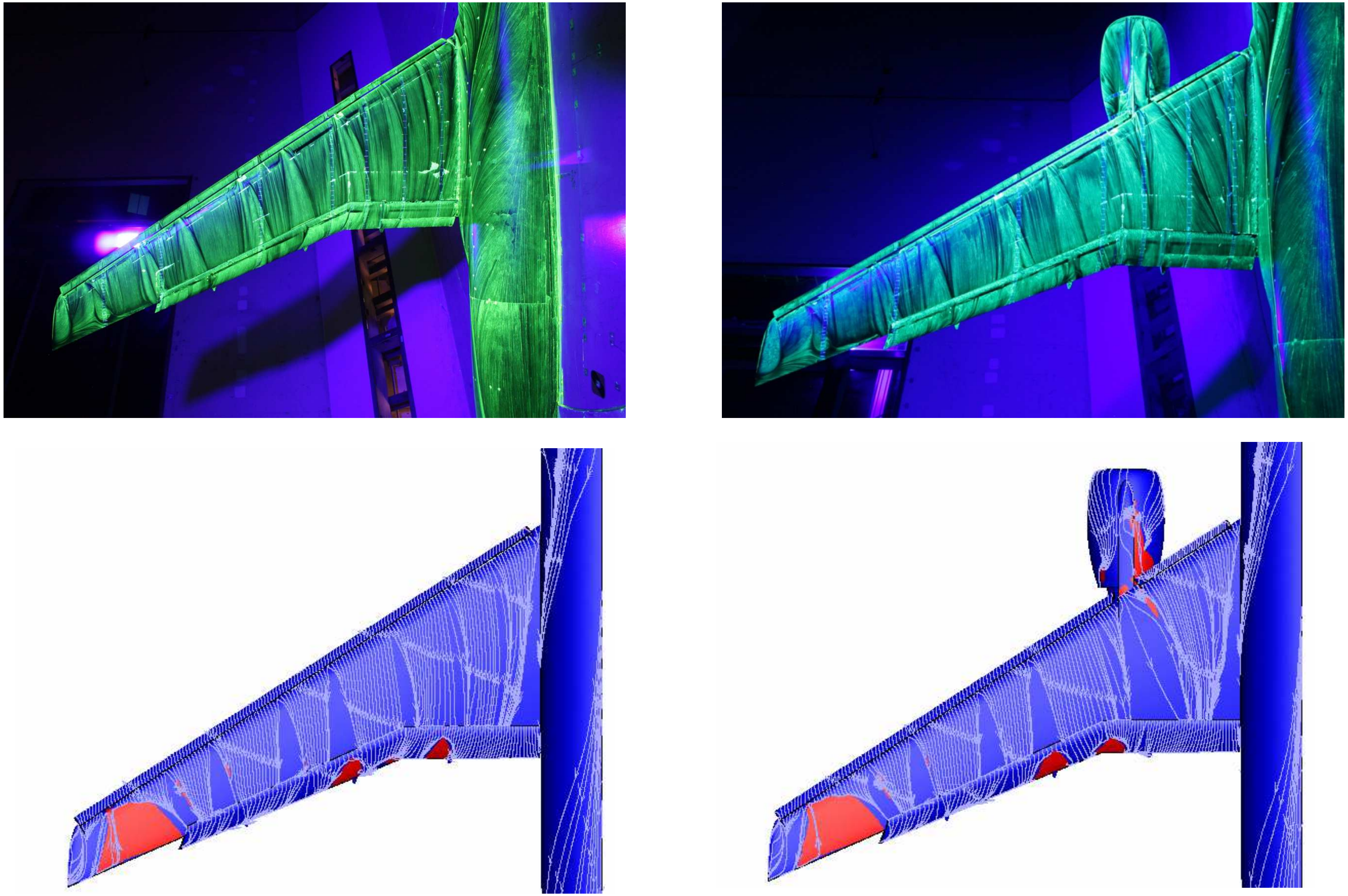
JSM results – C2 – PyNaOn x PyNaOff – 10.47°



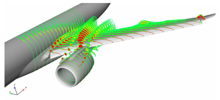


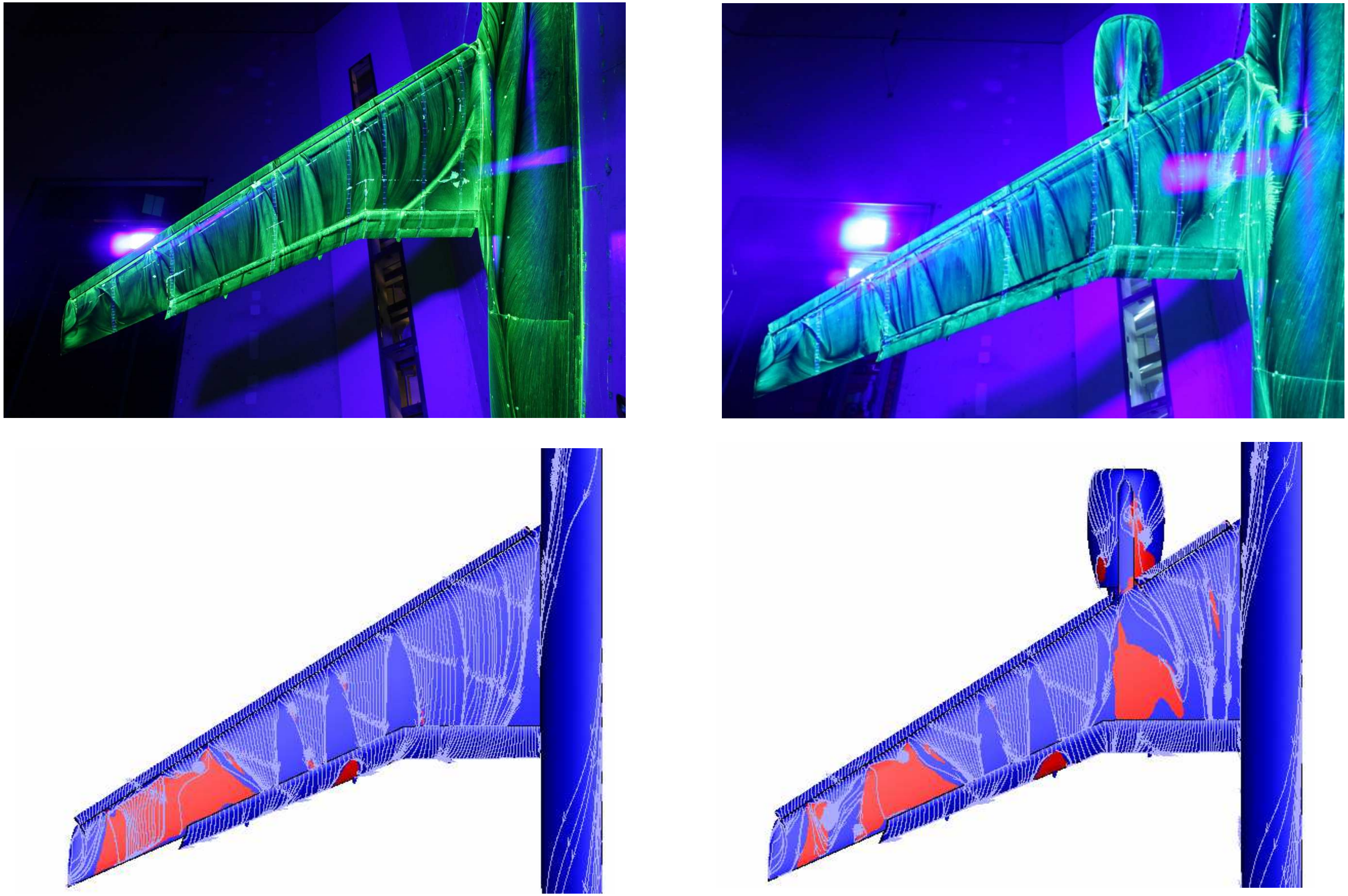
JSM results – C2 – PyNaOn x PyNaOff – 18.58°



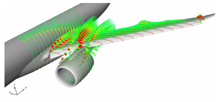


JSM results – C2 – PyNaOn x PyNaOff – 21.57°





JSM results –PyNaOff – 4.36°

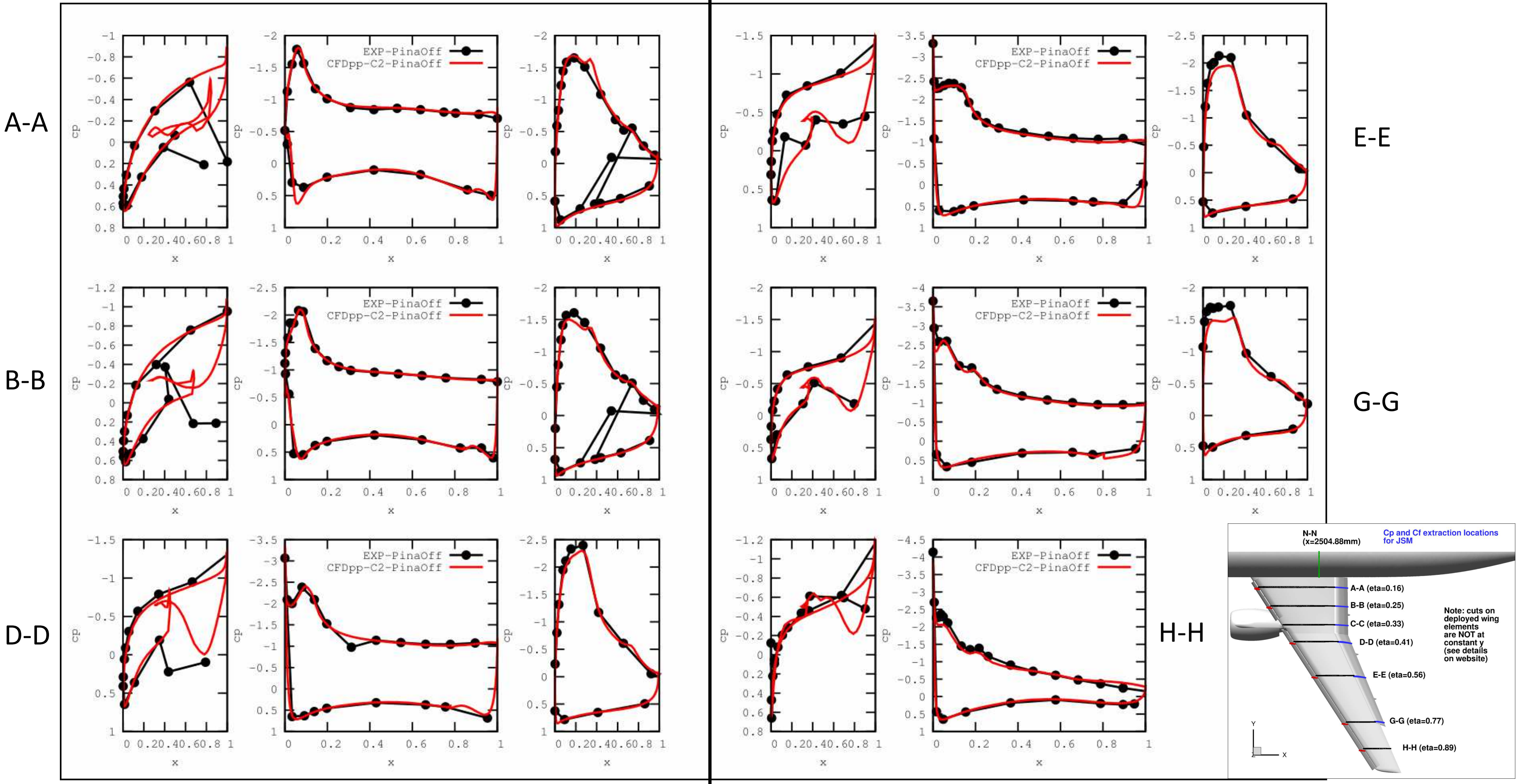


INBOARD SECTIONS

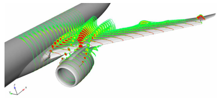
SLAT WING FLAP

OUTBOARD SECTIONS

SLAT WING FLAP



JSM results –PyNaOff – 10.47°

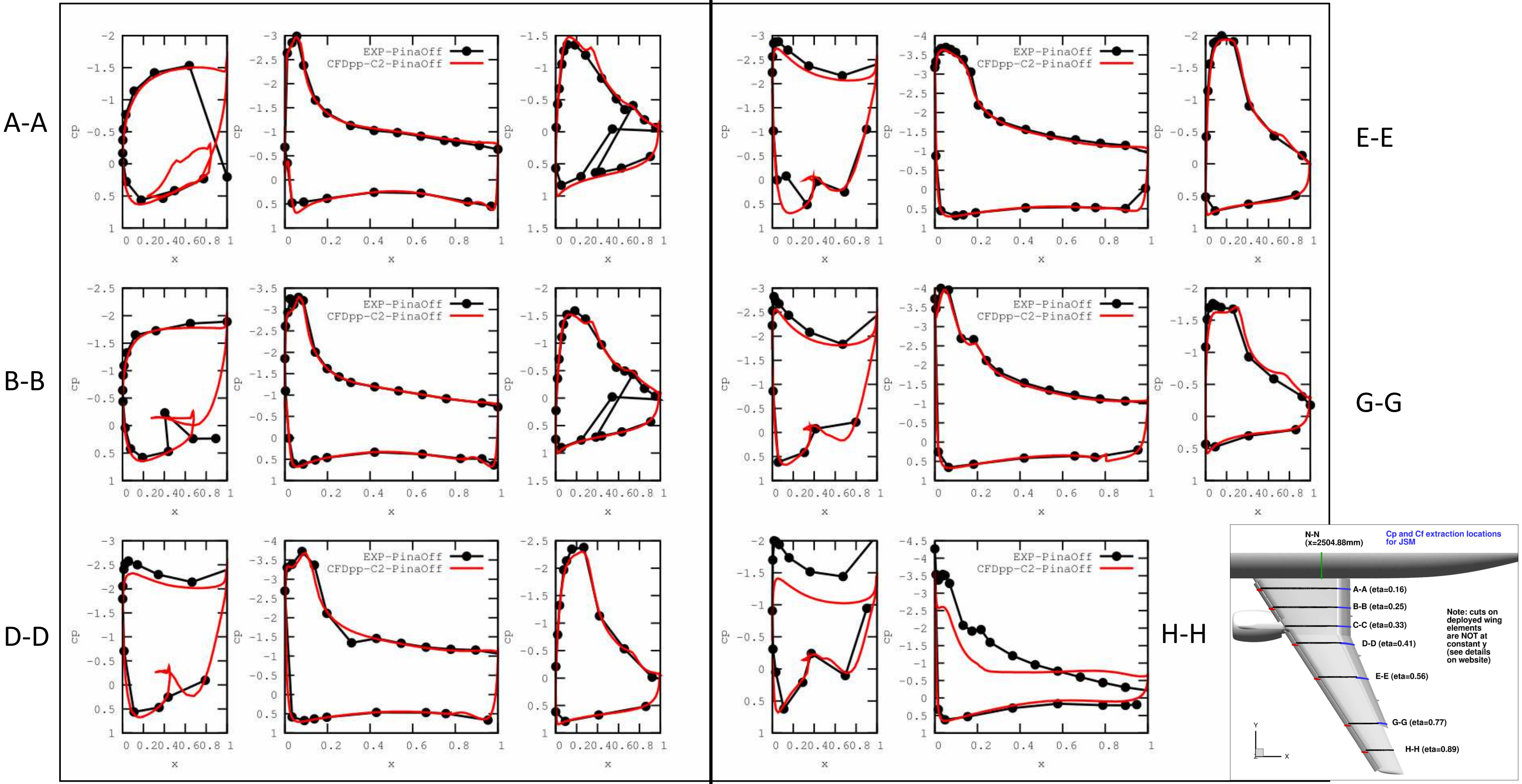


INBOARD SECTIONS

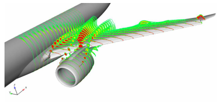
SLAT WING FLAP

OUTBOARD SECTIONS

SLAT WING FLAP



JSM results –PyNaOff – 18.58°

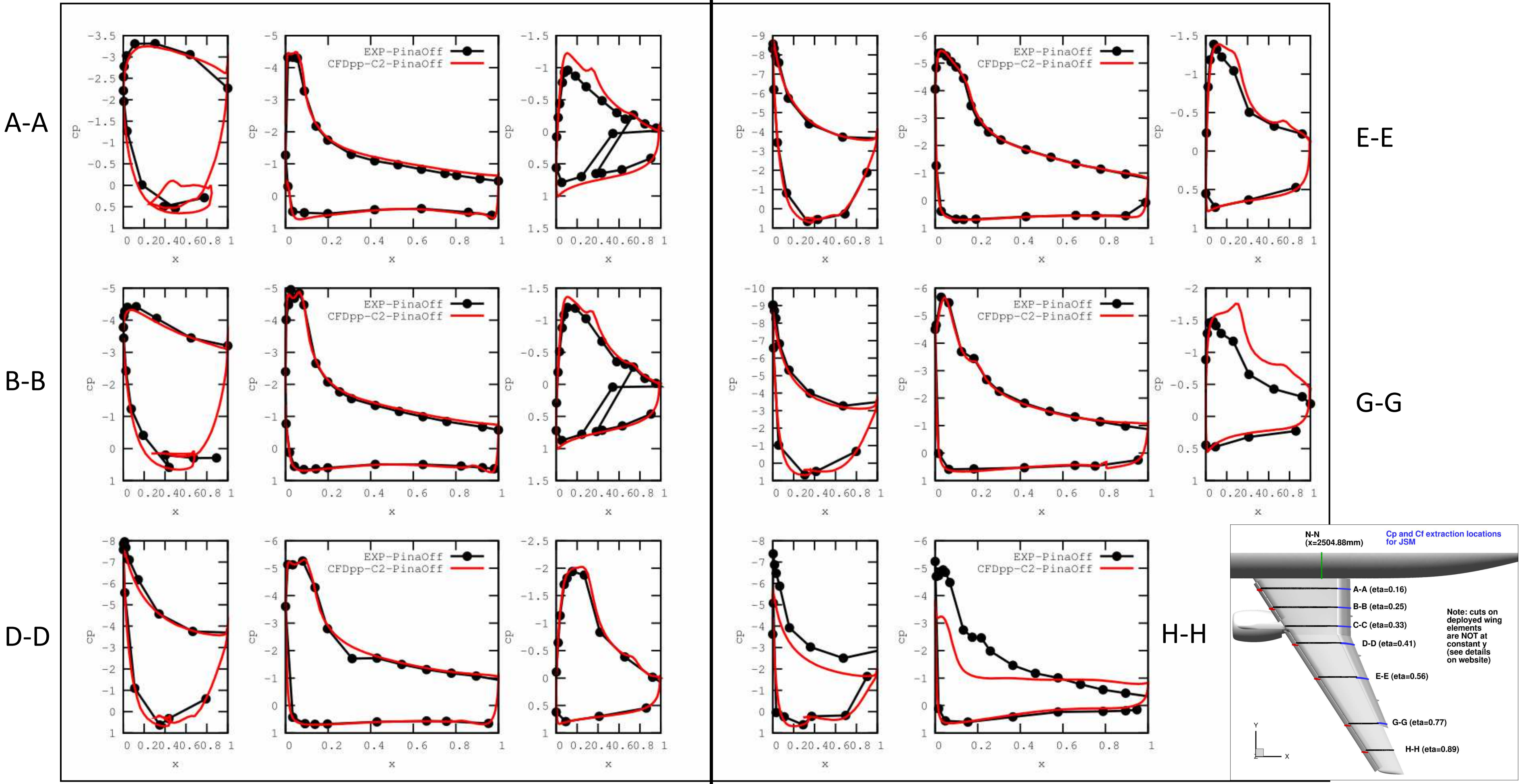


INBOARD SECTIONS

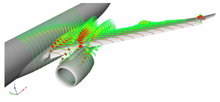
SLAT WING FLAP

OUTBOARD SECTIONS

SLAT WING FLAP



JSM results –PyNaOff – 21.57°



INBOARD SECTIONS

SLAT WING FLAP

OUTBOARD SECTIONS

SLAT WING FLAP

A-A

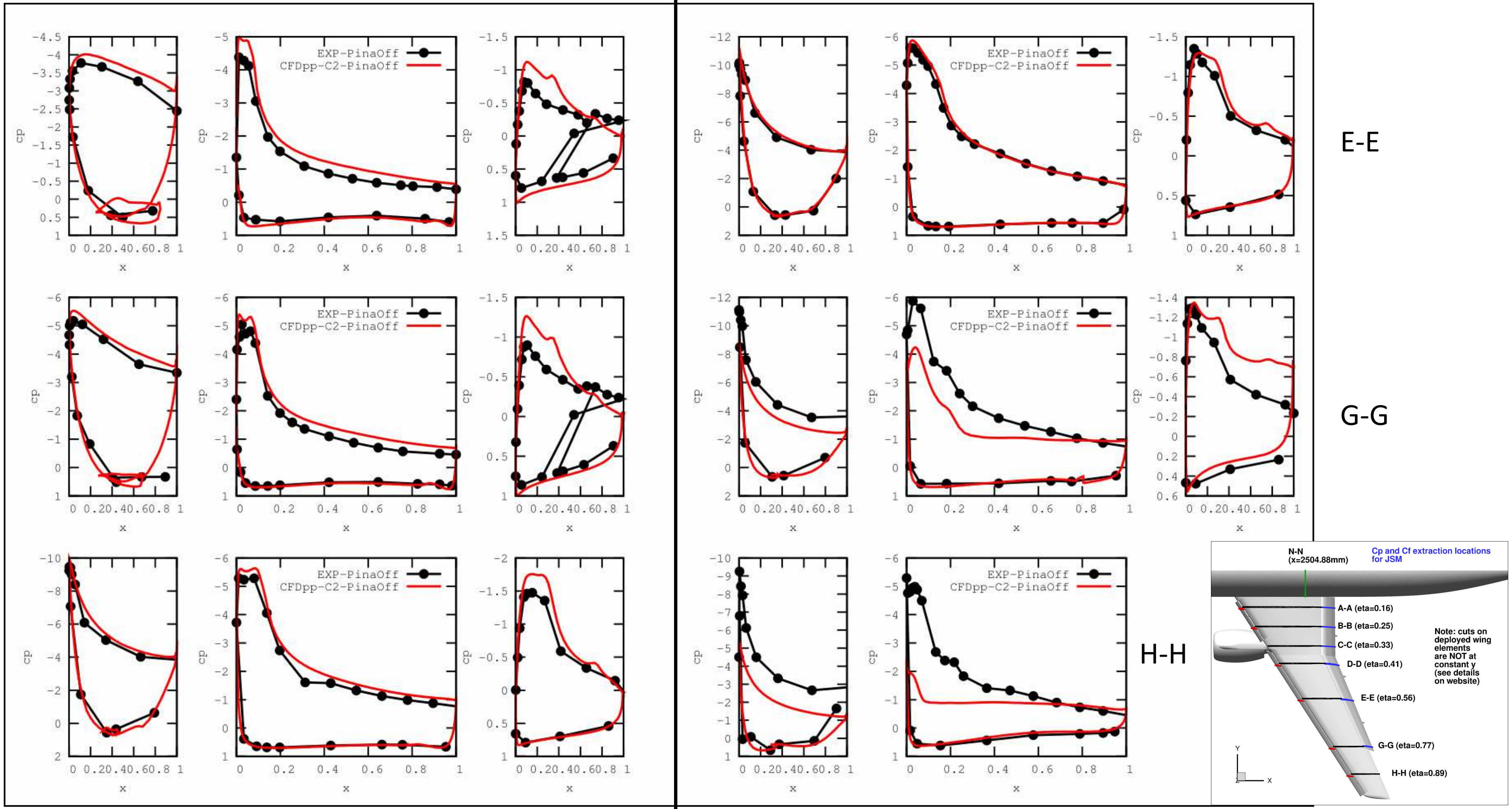
B-B

D-D

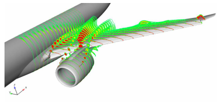
E-E

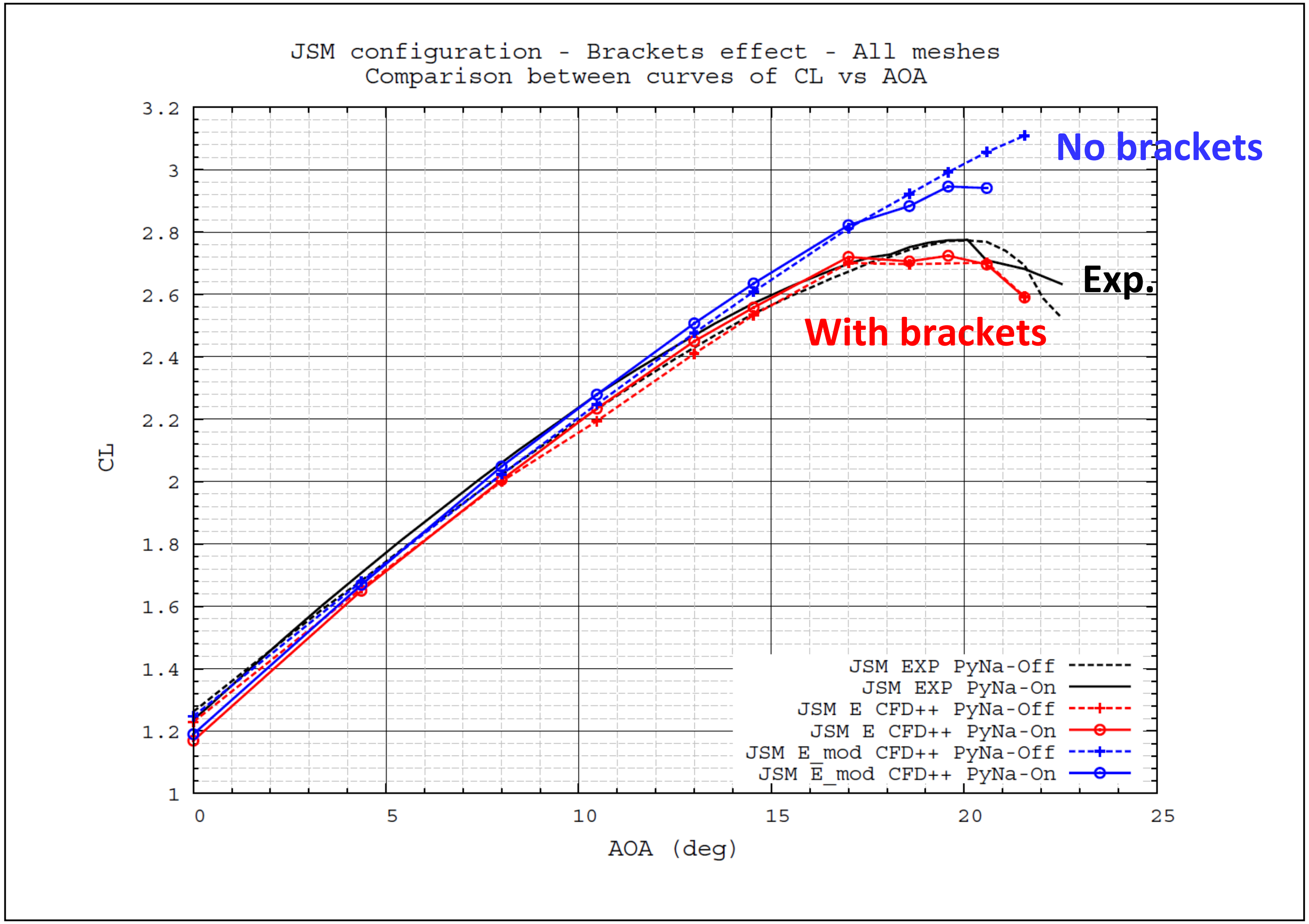
G-G

H-H

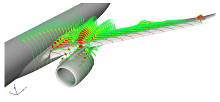


JSM results – Slat brackets effect



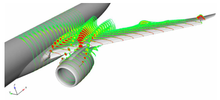


Brief overview of JSM results

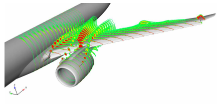


- CFD++ x SU2
  - Embraer needs to improve its setup for using SU2 for high-lift simulations
- Coefficients & surface streamlines
  - Both grids employed, C2 and E, yielded good results for DCL, DCD and DCM
  - CL/CD ratio did not compare well to experiment
    - Peniche effect on aspect ratio?
  - Behavior of CL near stall could be improved
    - Stall starts on the inboard panel for experiment while CFD predicts stall starting on the outboard panel
      - Slat brackets effect seems a little exaggerated at high AOA
      - However, results without slat brackets were not representative of experiment

Summary

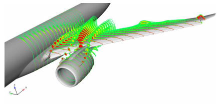


- Although a lot of improvements have happened in the past, high-lift flow prediction is still difficult
- Processing capabilities and enhancements in mesh generation allowed an increase in geometry fidelity, such as including slat and flap brackets as well as wind tunnel walls
  - Where to refine, how much to refine, how to circumvent grid generator crashes still exist
- Another challenge seems to remain the accurate prediction of flow separation in terms of position and extent
  - Flow physics (transition, unsteady vs steady etc.)
  - Turbulence modeling



THANK YOU!

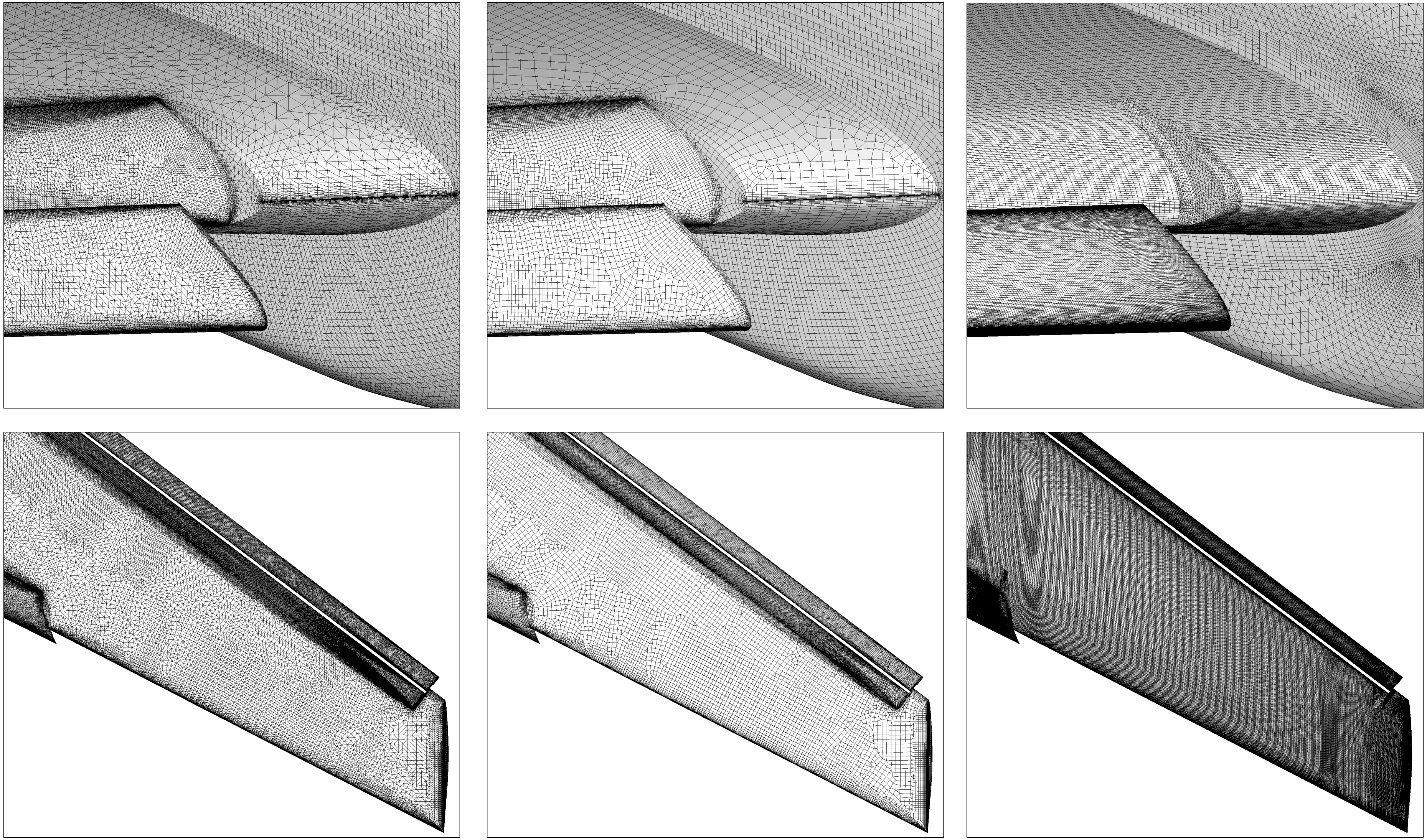
QUESTIONS?



CRM – APPENDIX

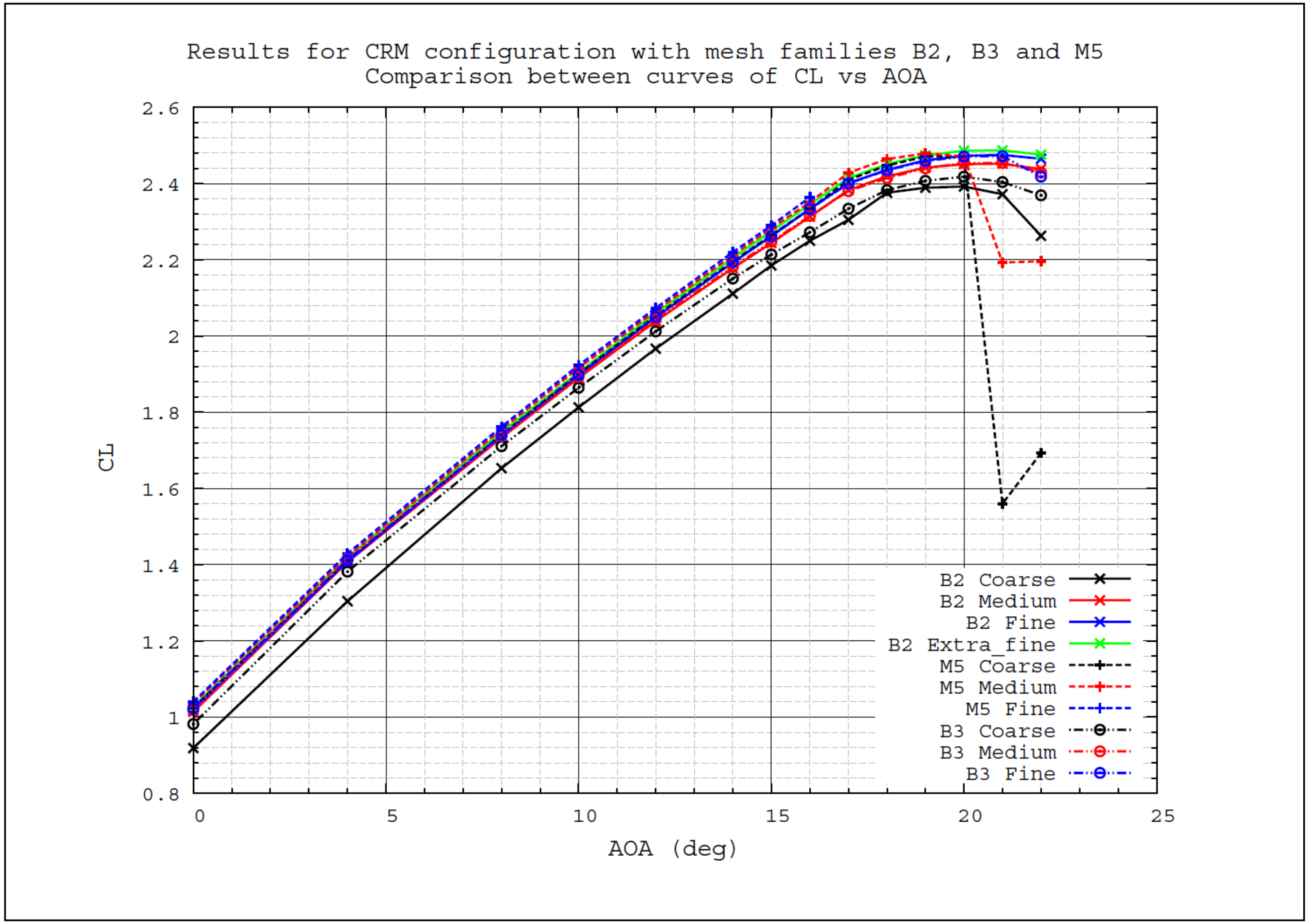
Grid comparison: B2, B3, M5

B2 (fine) **B3 (fine)** **M5 (Medium)**

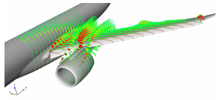


HL-CRM results – coefficients – CFD++

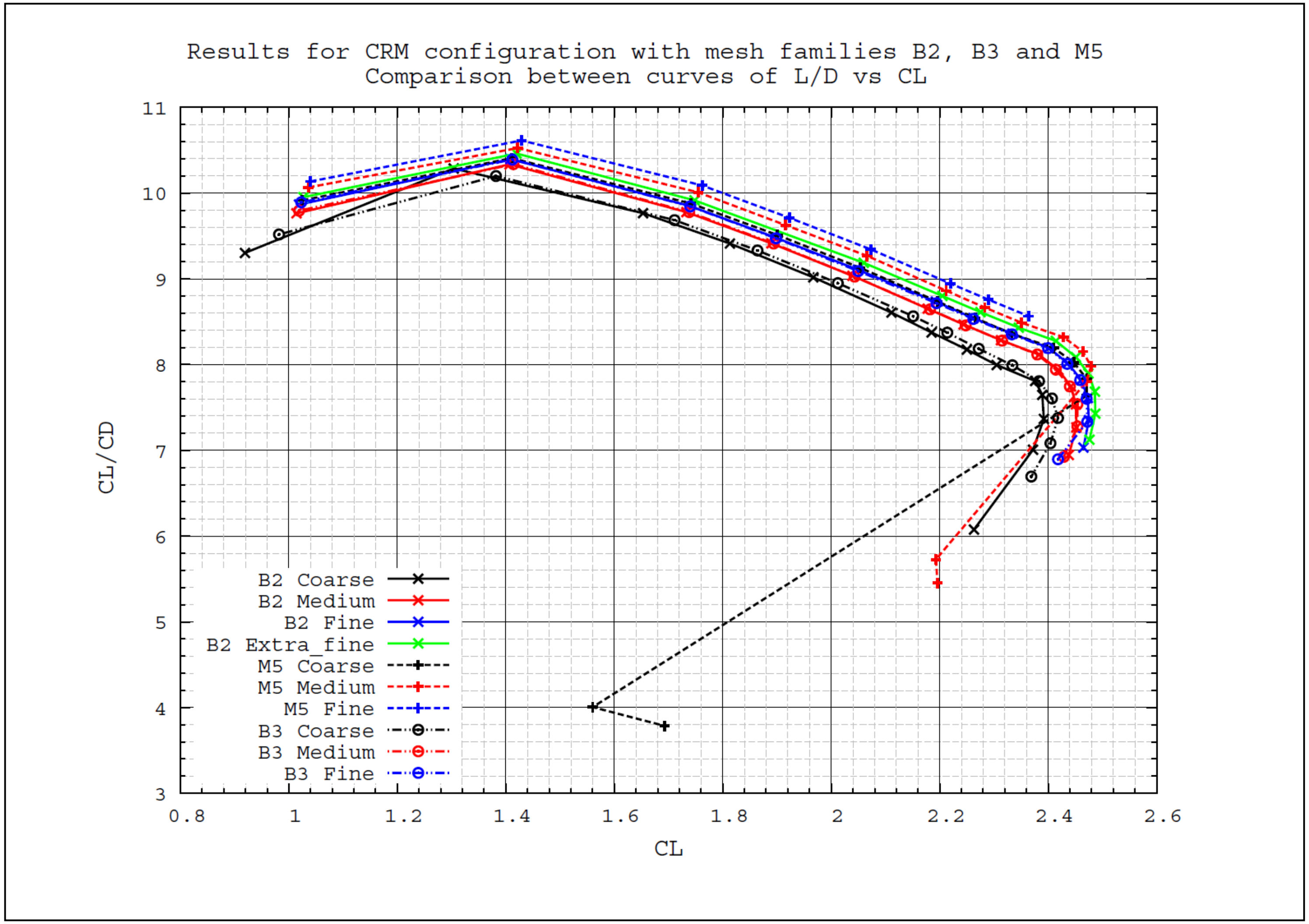
Grids B2, B3, M5



HL-CRM results – coefficients – CFD++

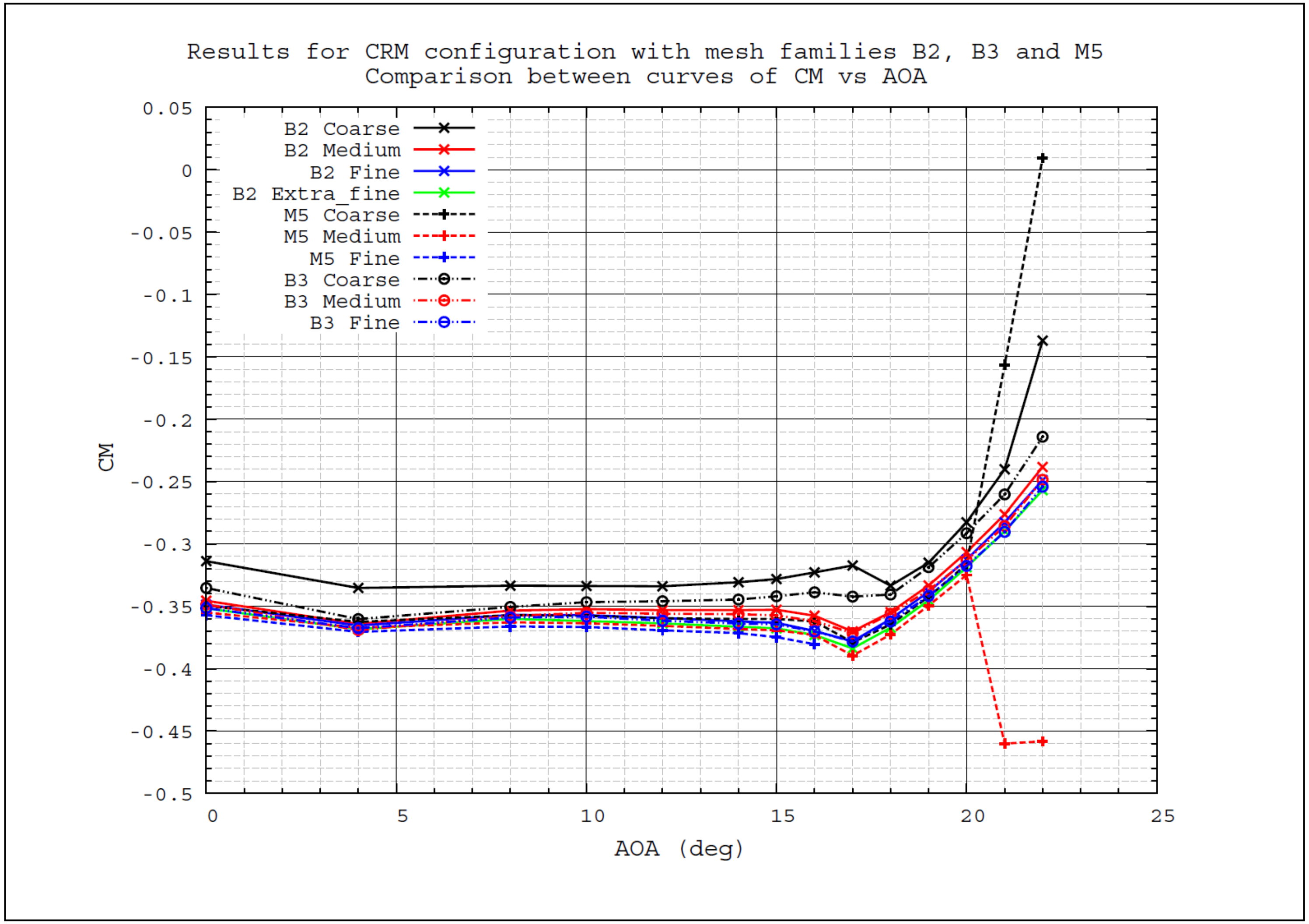


Grids B2, B3, M5

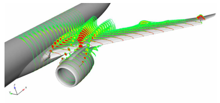


HL-CRM results – coefficients – CFD++

Grids B2, B3, M5

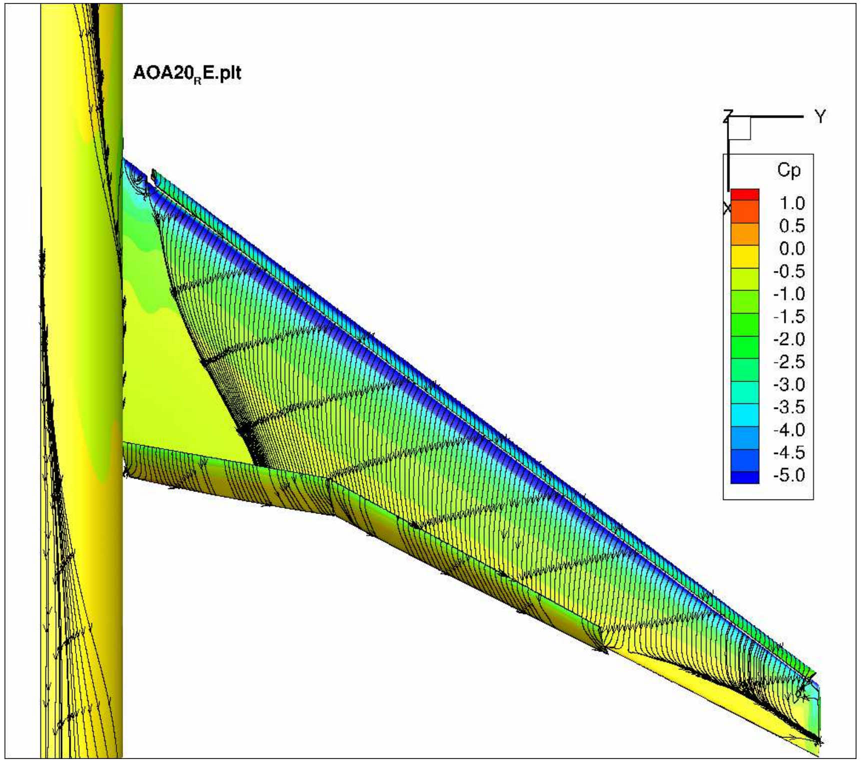


HL-CRM results – 20° – CFD++

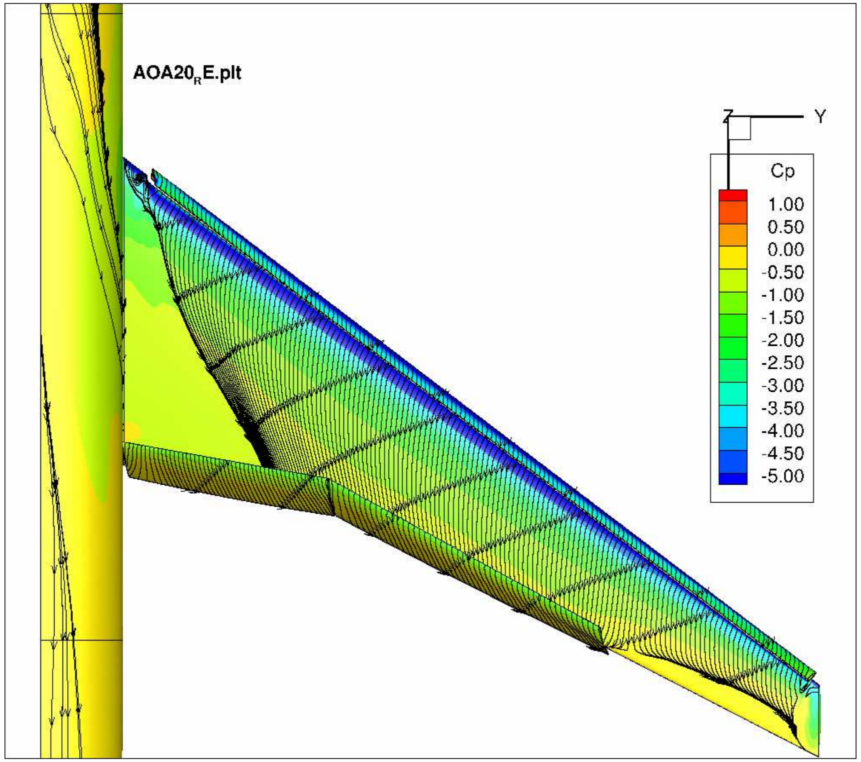


Grids B2 fine x M5 medium

B2



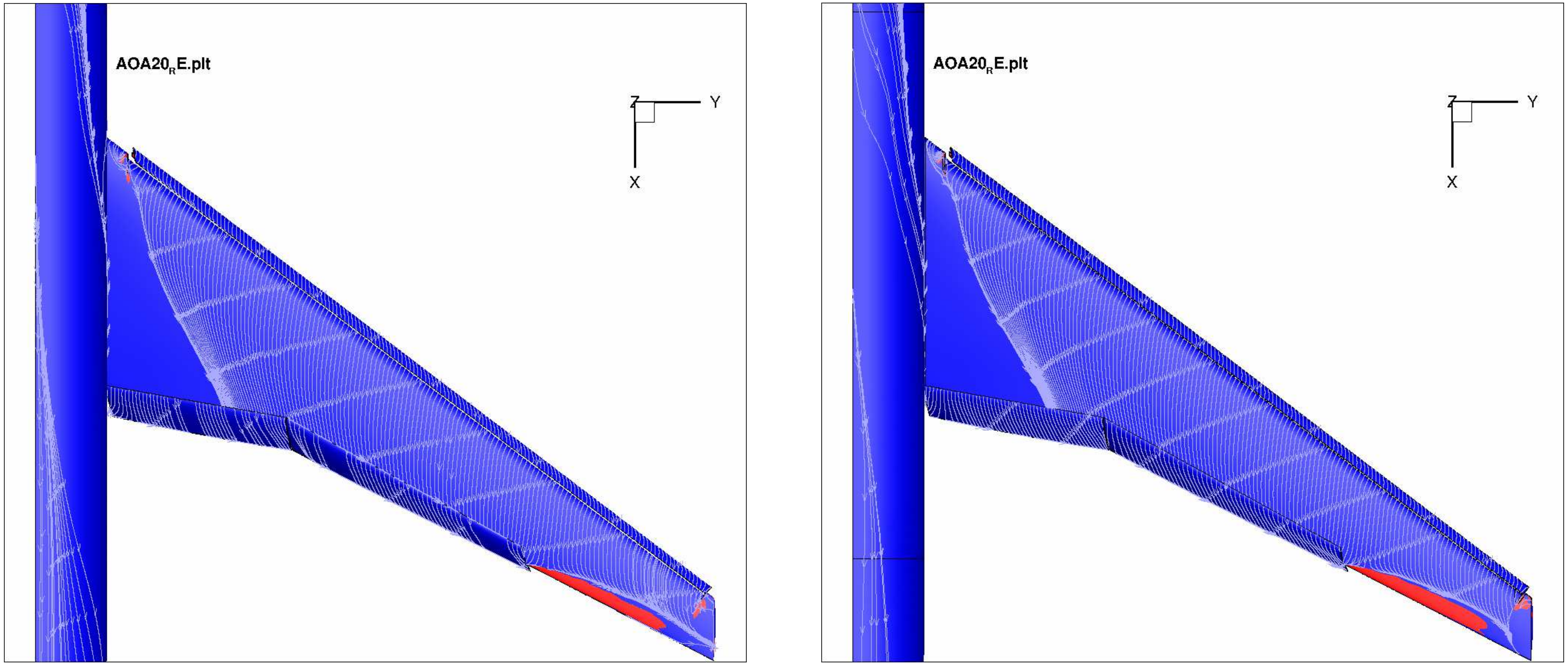
M5



HL-CRM results – 20° – CFD++

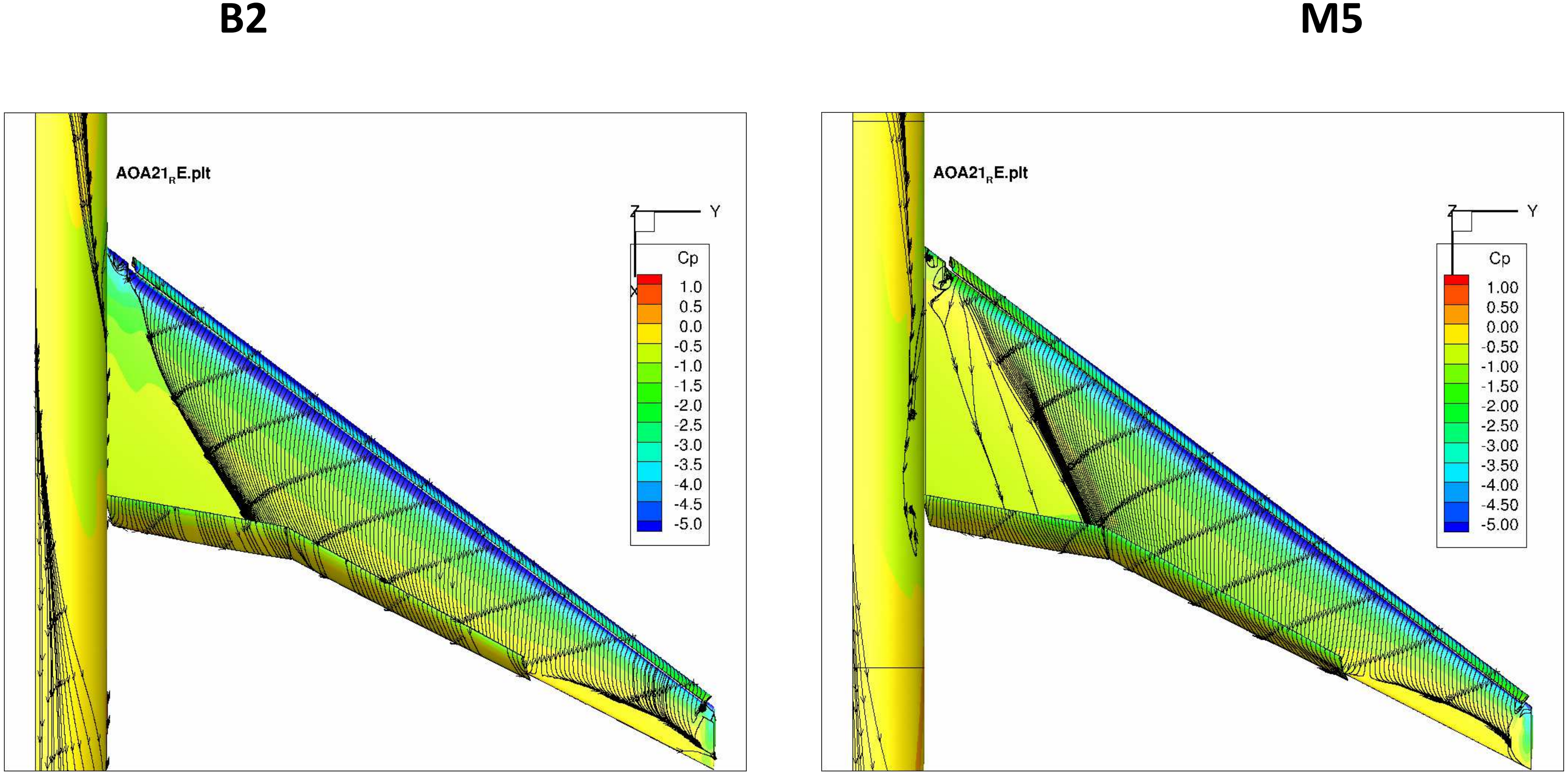
Grids B2 fine x M5 medium

B2 **M5**



HL-CRM results – 21° – CFD++

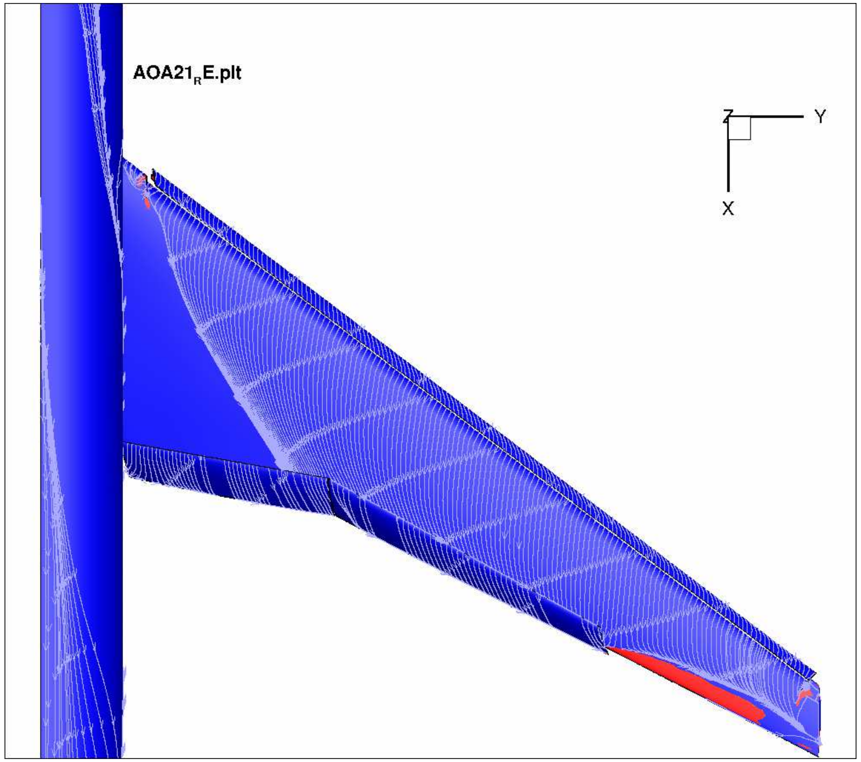
Grids B2 fine x M5 medium



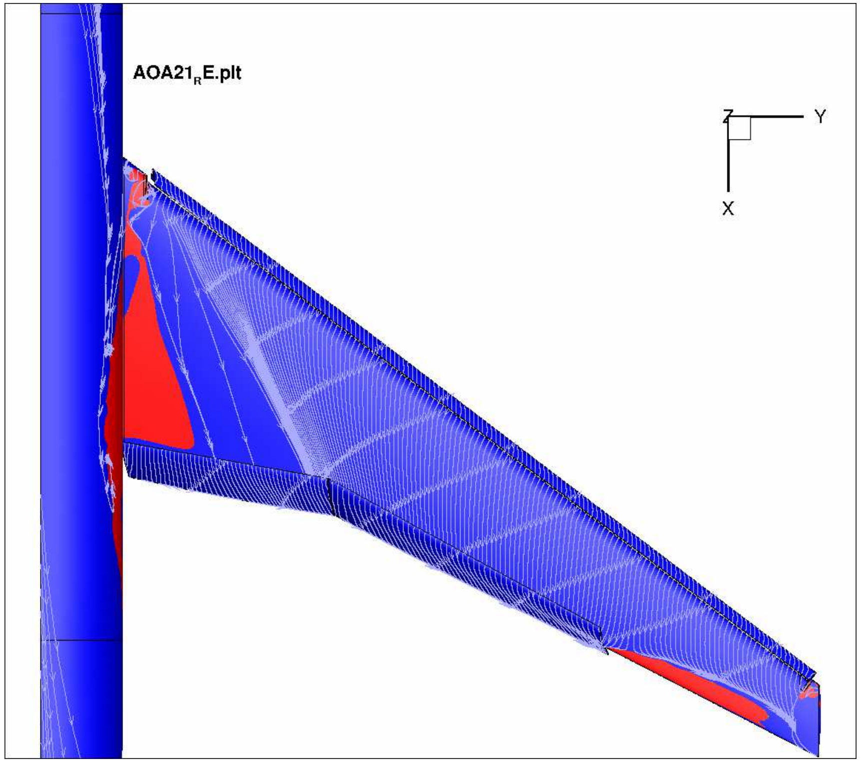
HL-CRM results – 21° – CFD++

Grids B2 fine x M5 medium

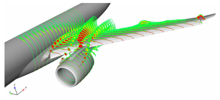
B2



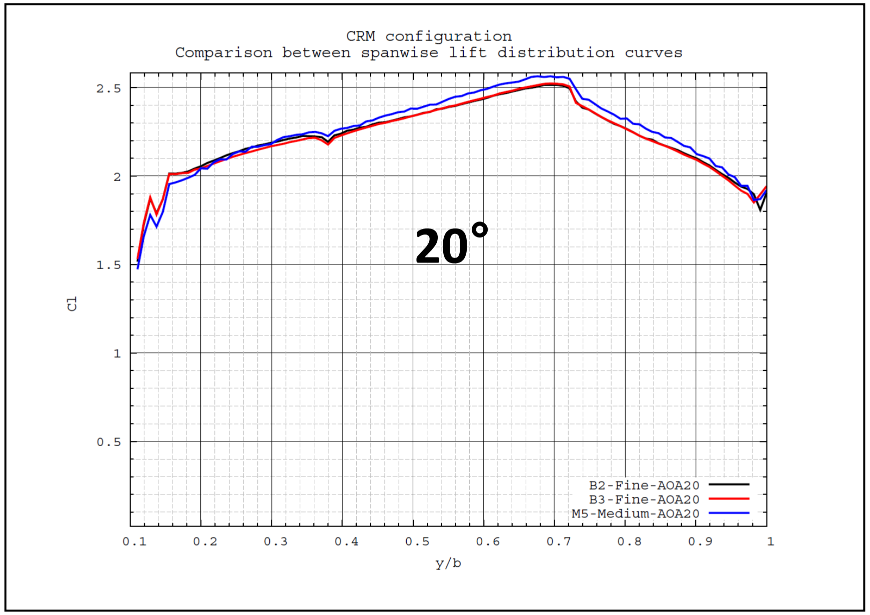
M5

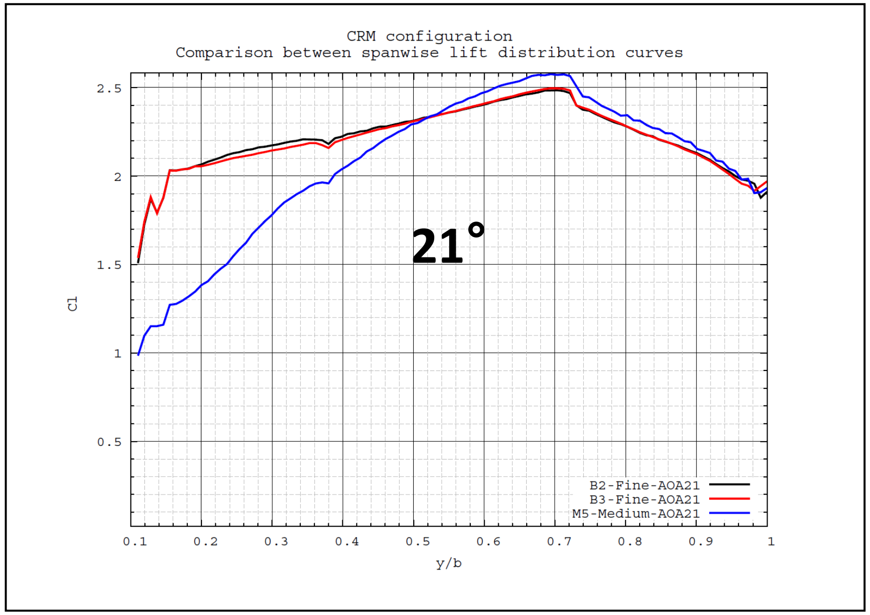


HL-CRM results – 21° – CFD++

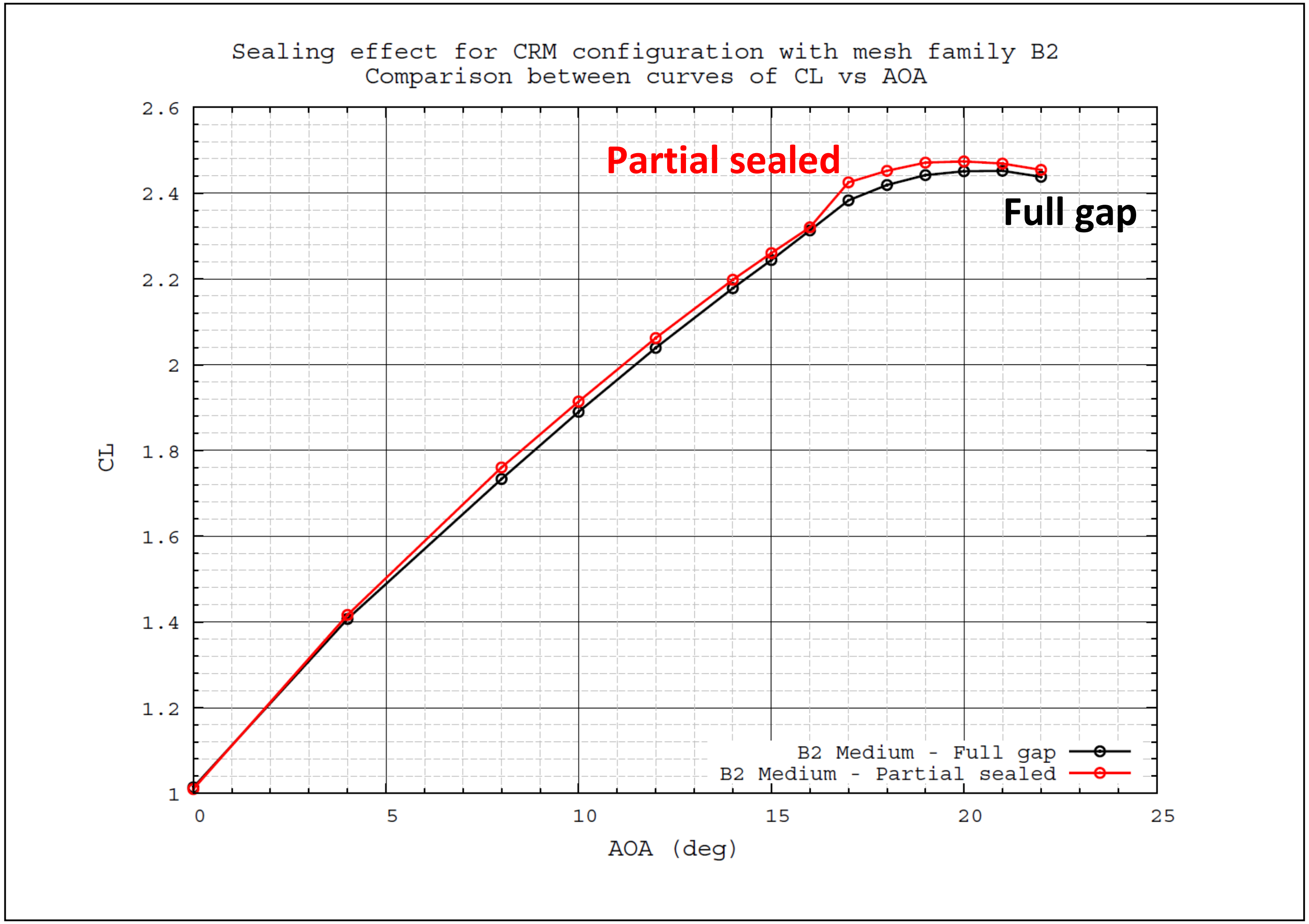


Grids B2 fine x M5 medium

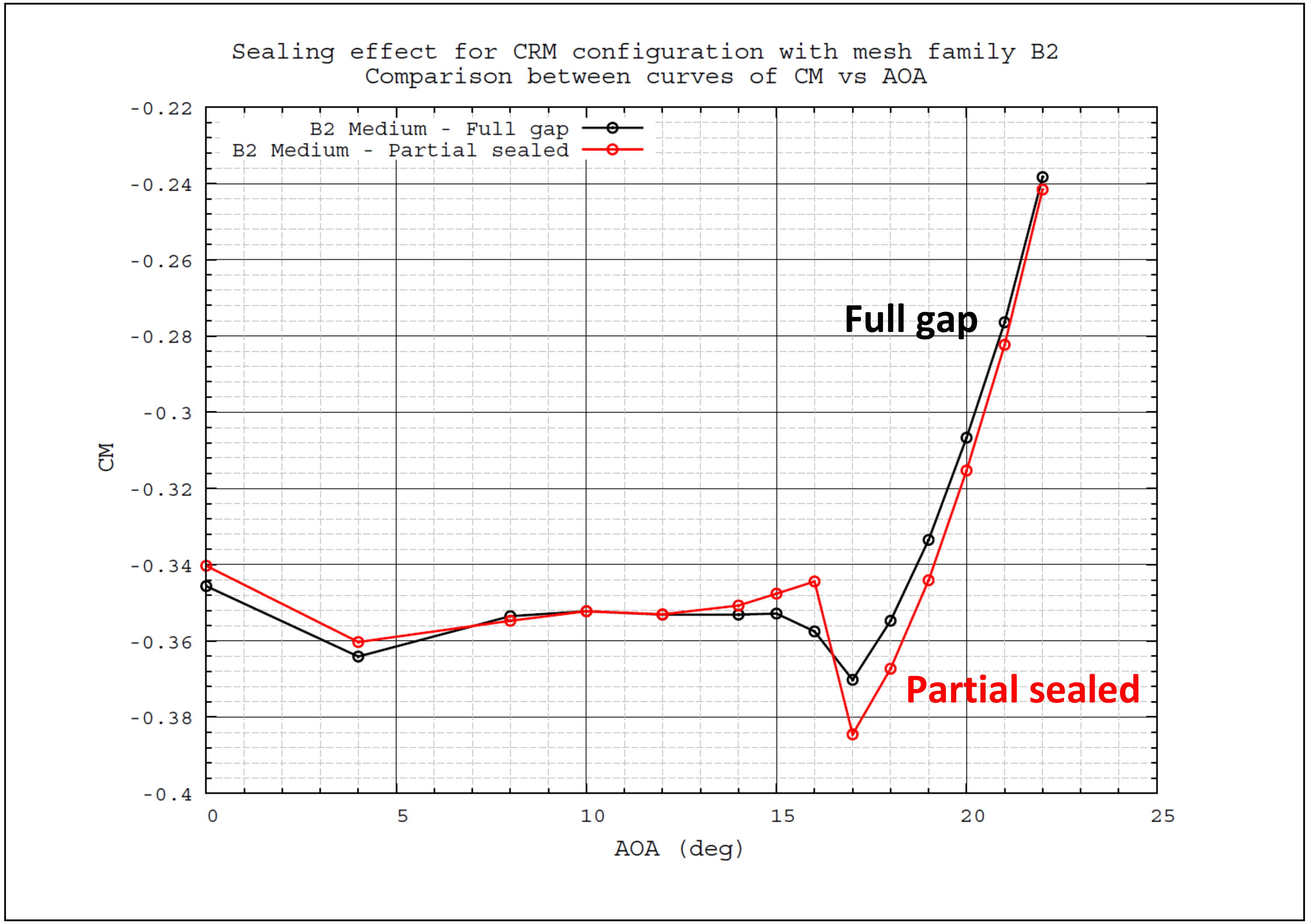




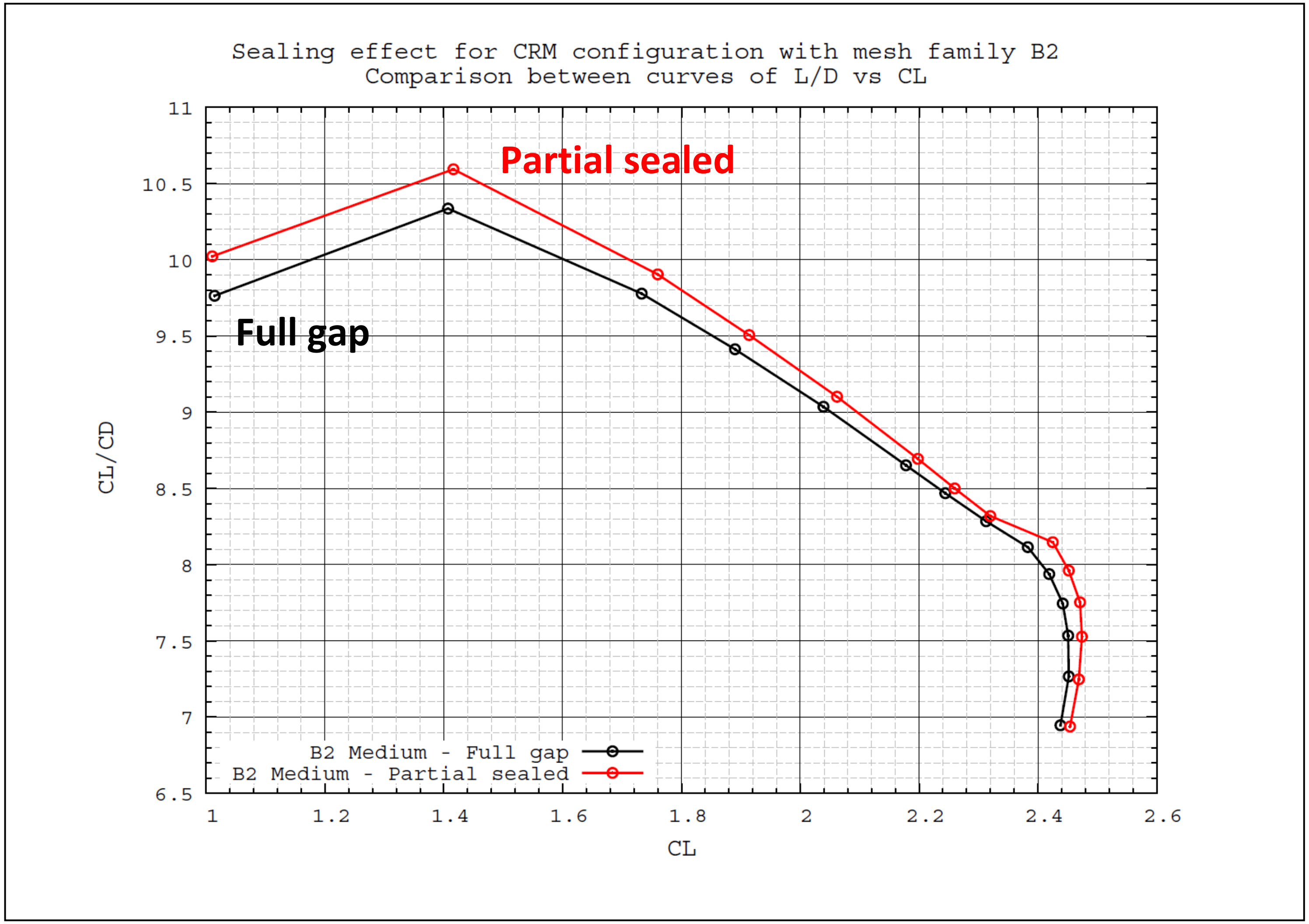
HL-CRM results – sealed gap x non-sealed

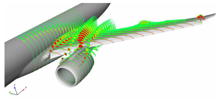


HL-CRM results – sealed gap x non-sealed



HL-CRM results – sealed gap x non-sealed



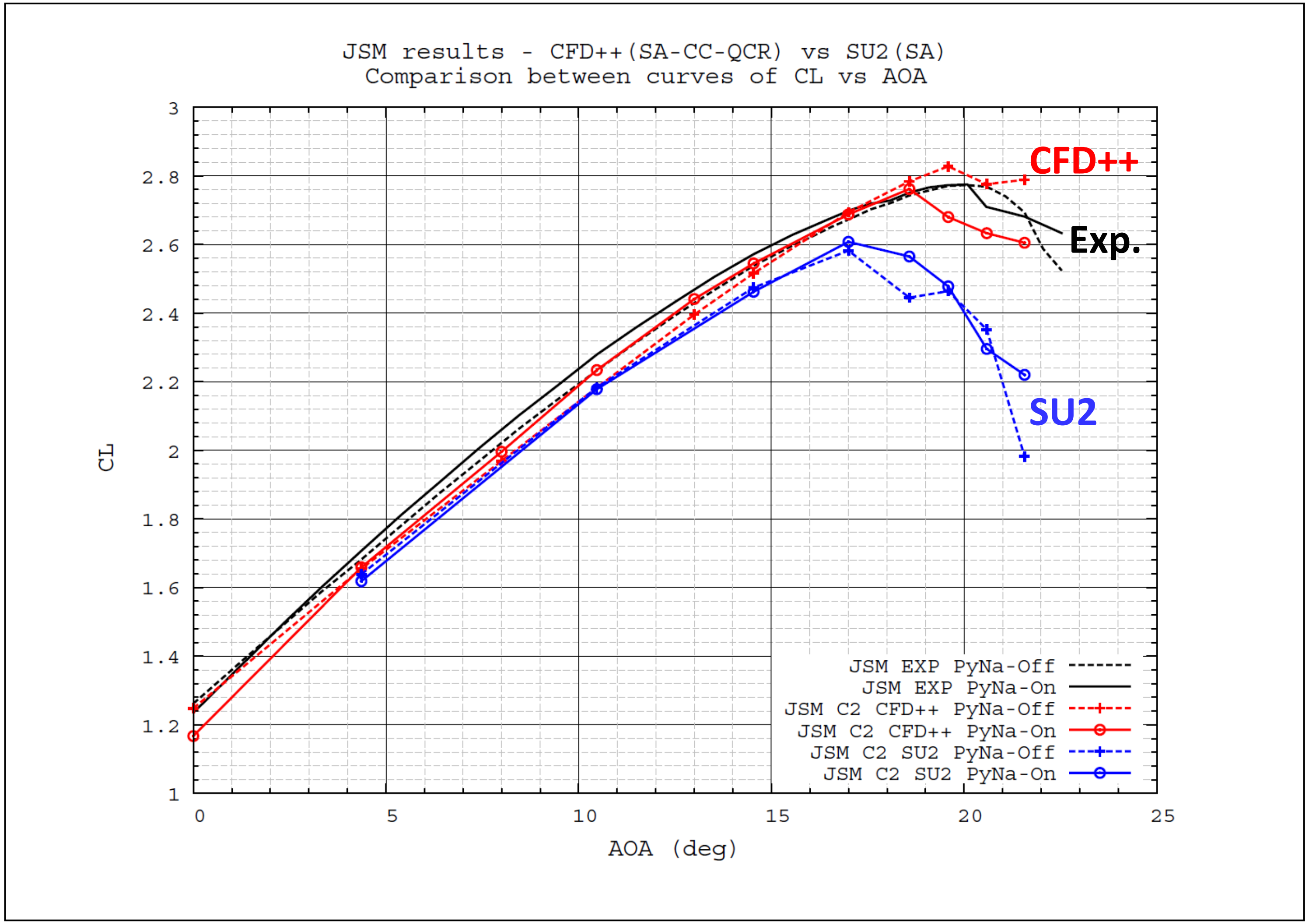


JSM – APPENDIX

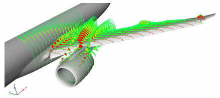
JSM results – CFD++ x SU2

SU2: SA

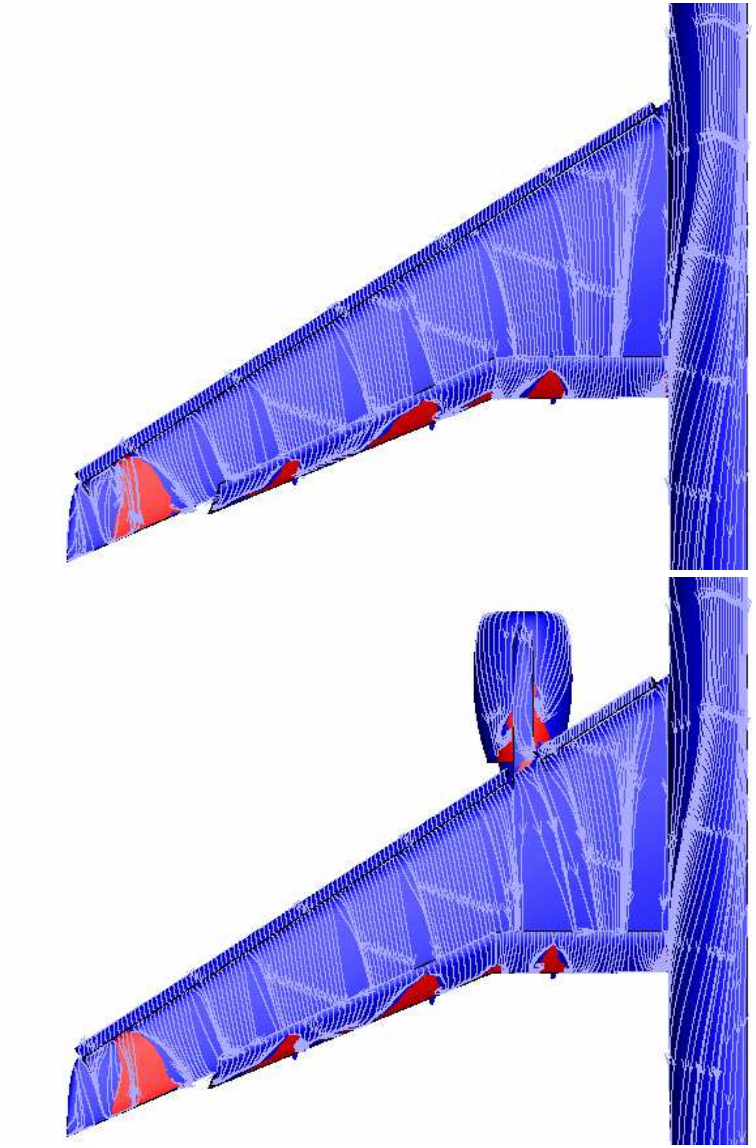
CFD++: SA-CC-QCR



JSM results – PyNaOn x PyNaOff – 8°



C2



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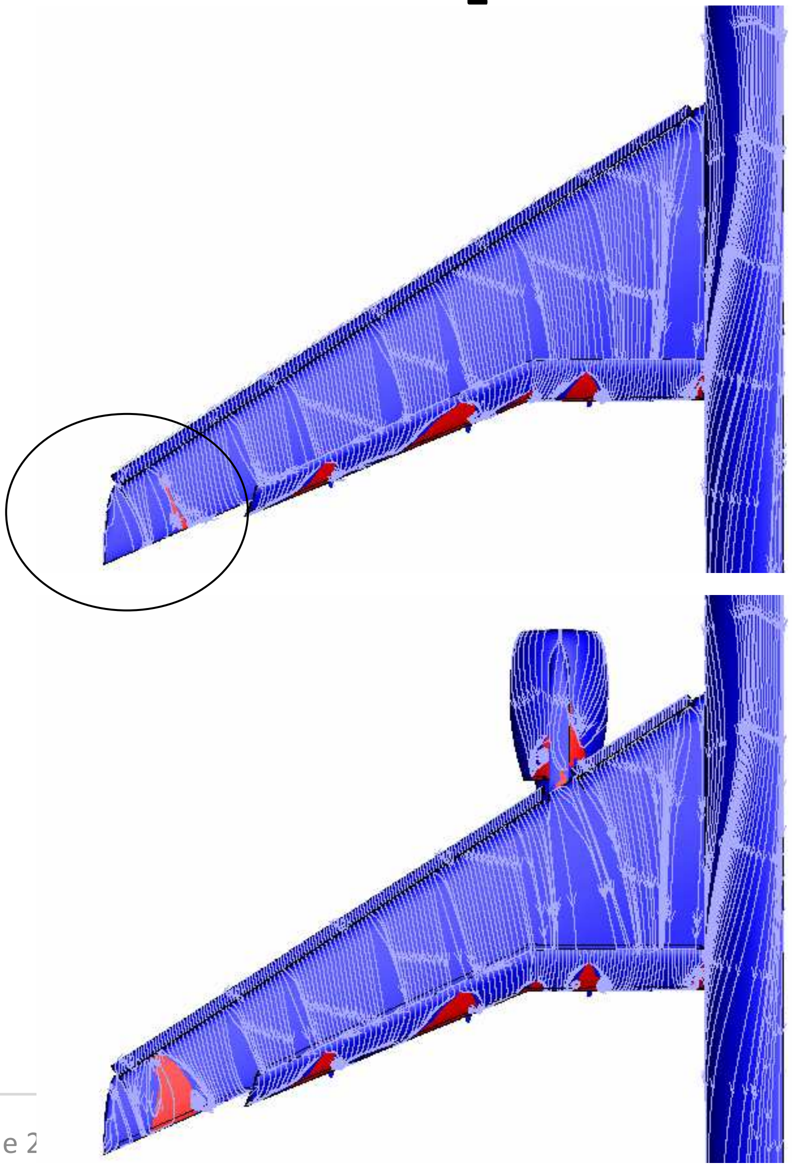
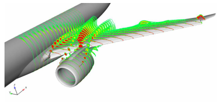
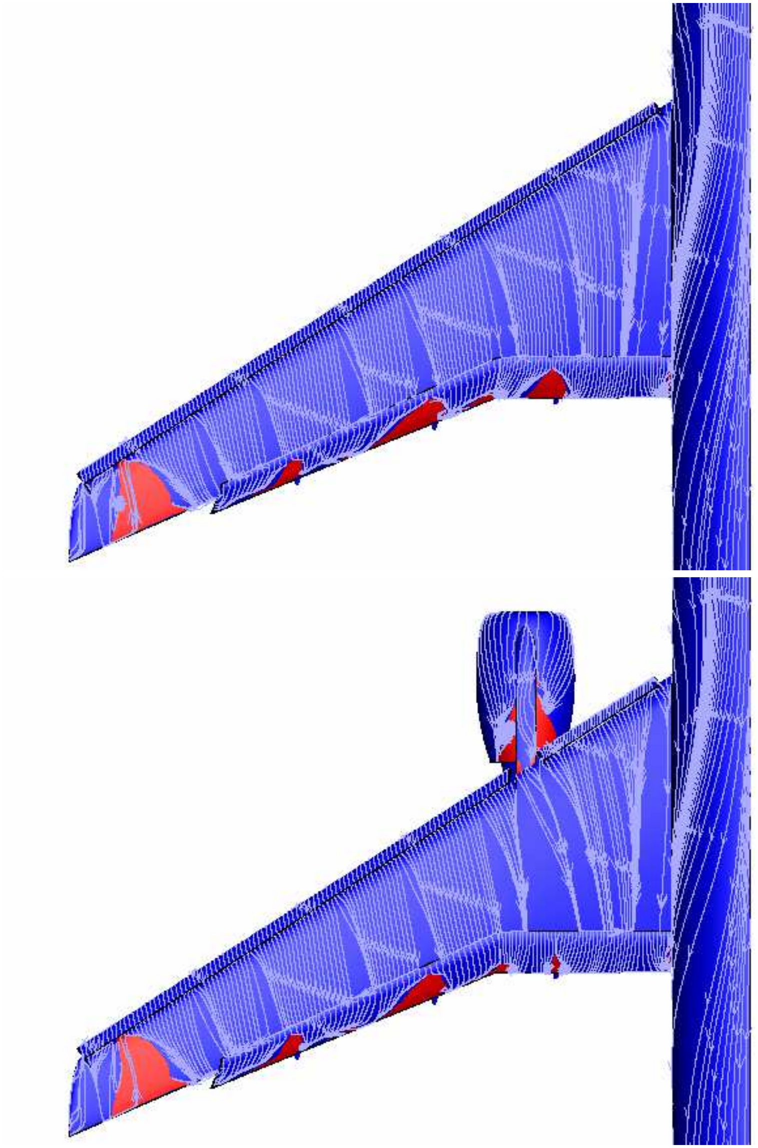


JSM results – PyNaOn x PyNaOff – 10°



C2



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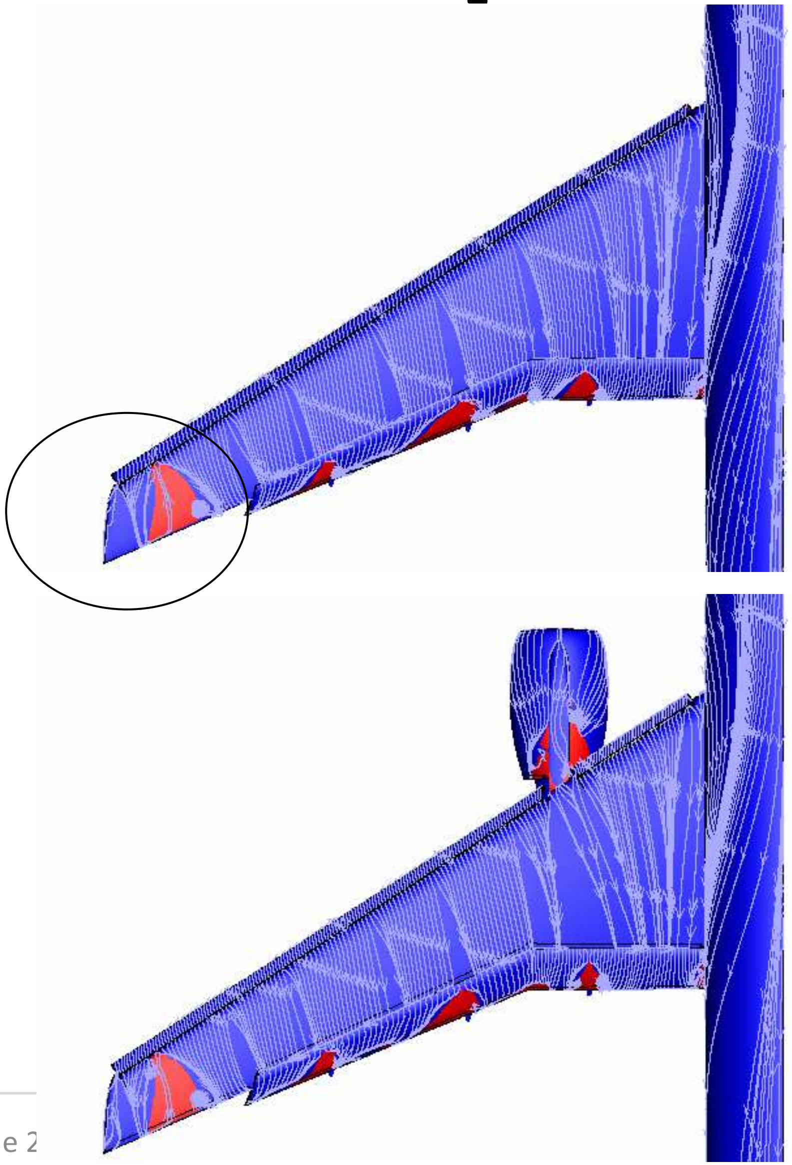
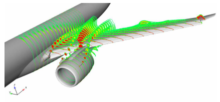
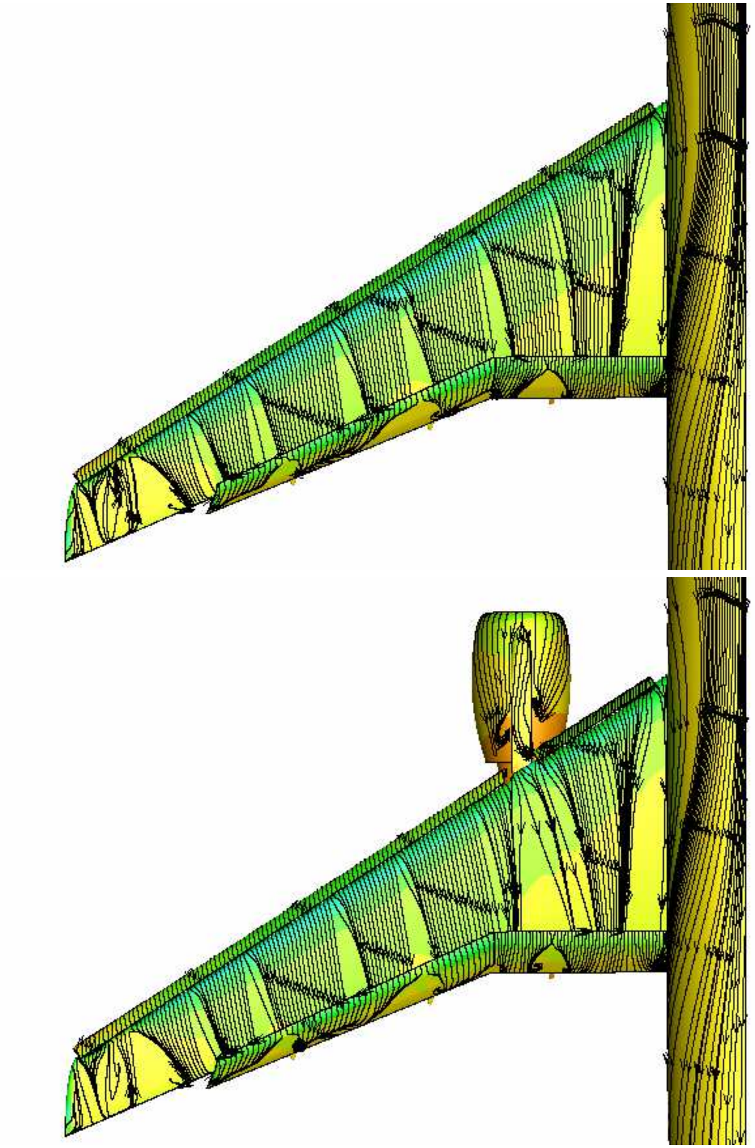


JSM results – PyNaOn x PyNaOff – 8°



C2



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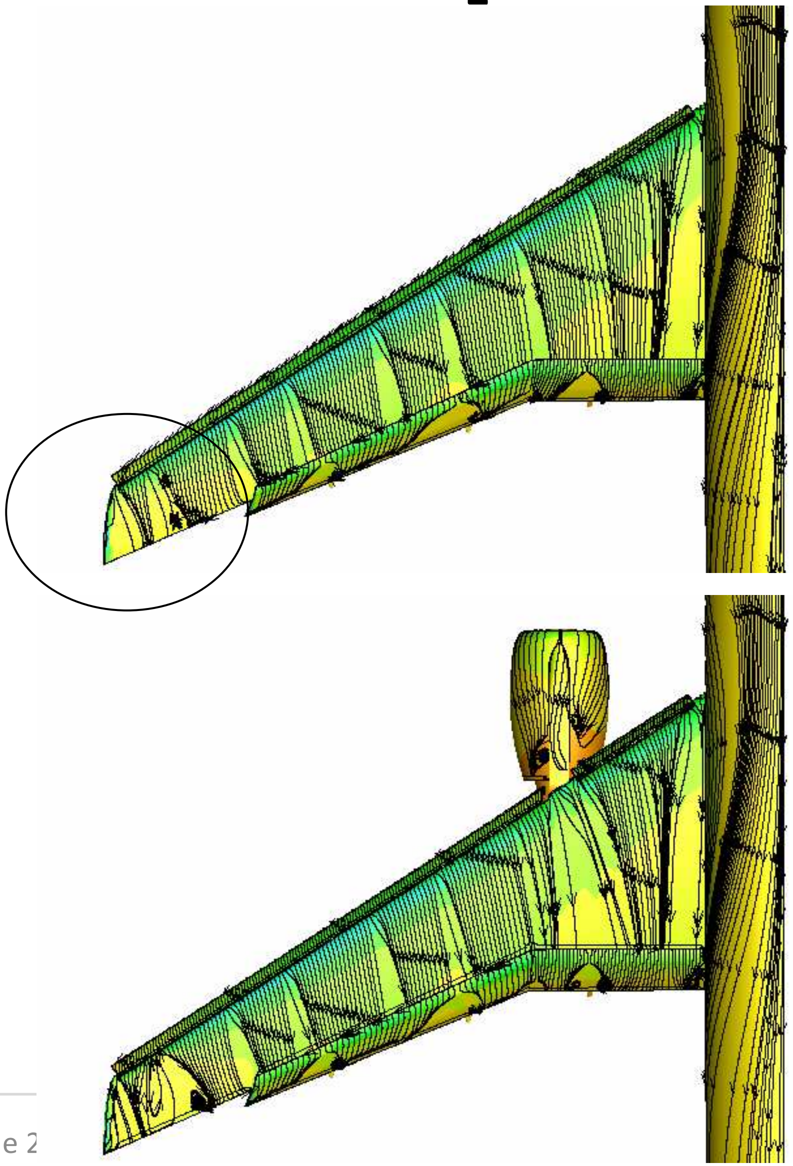
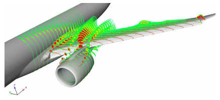
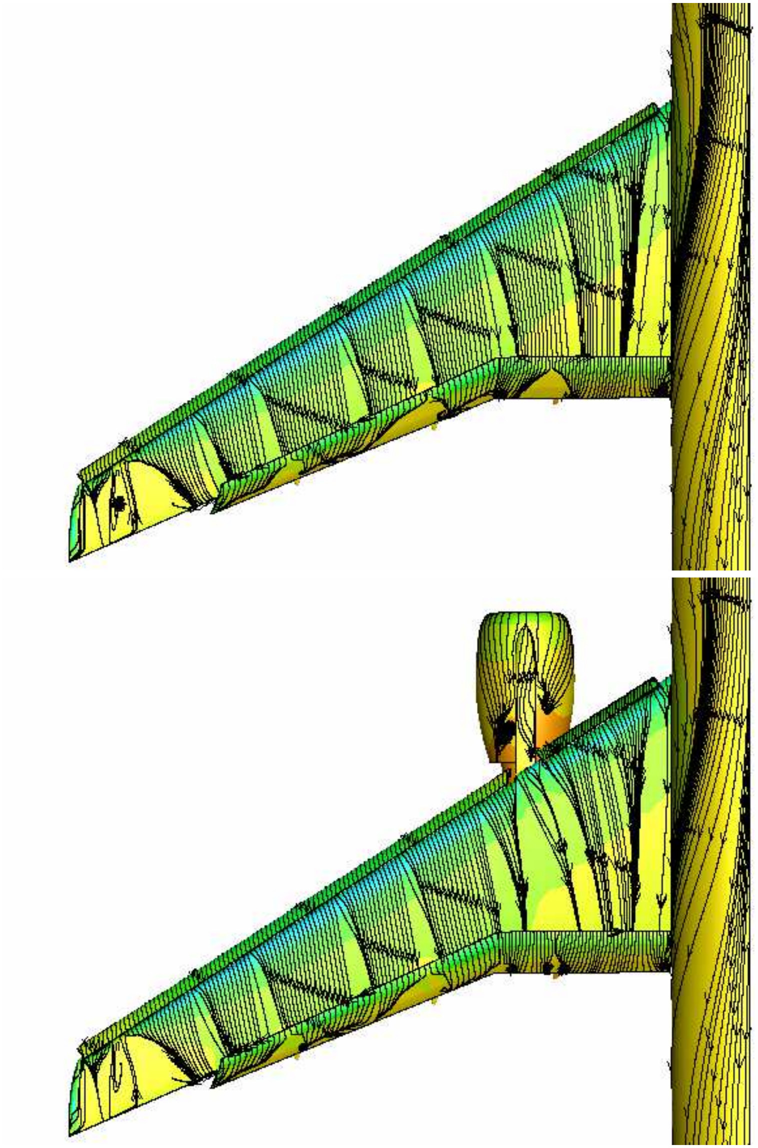


JSM results – PyNaOn x PyNaOff – 10°



C2



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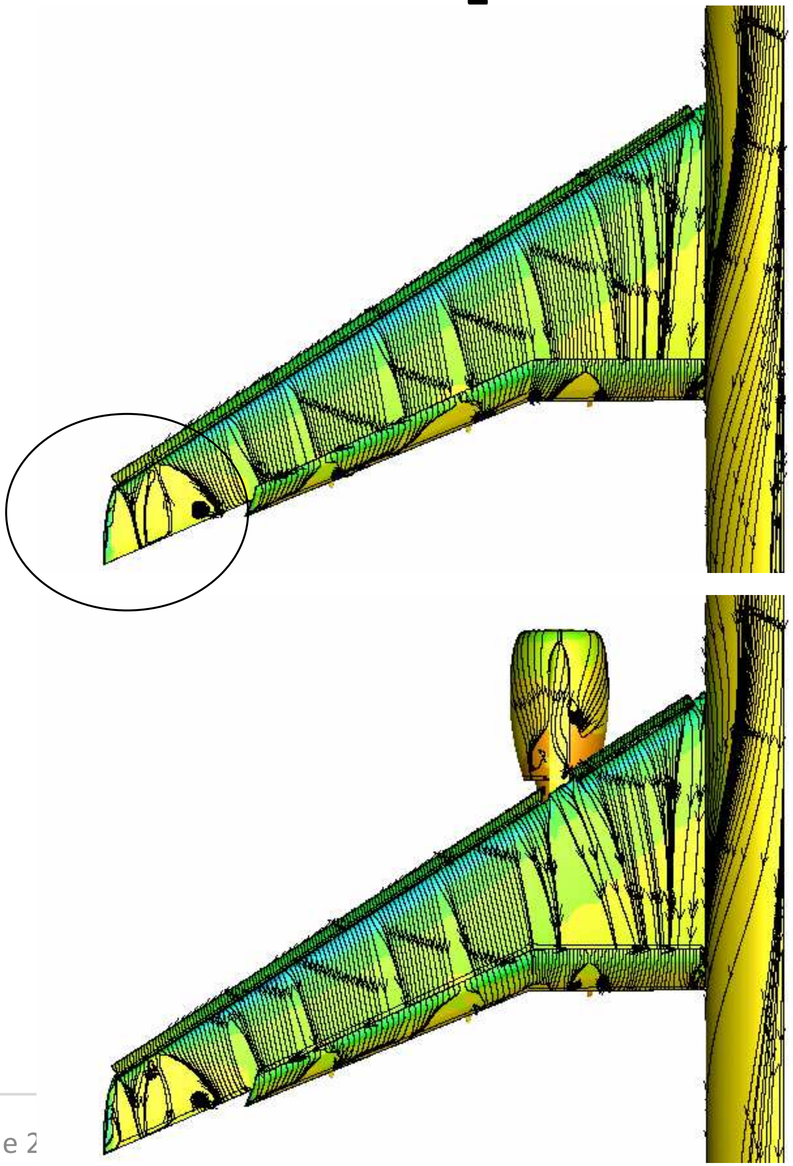
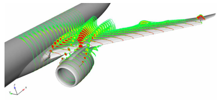
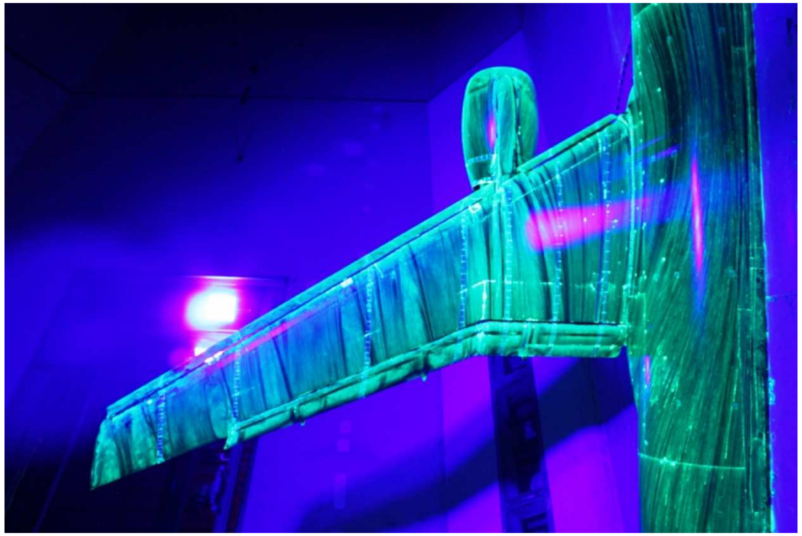
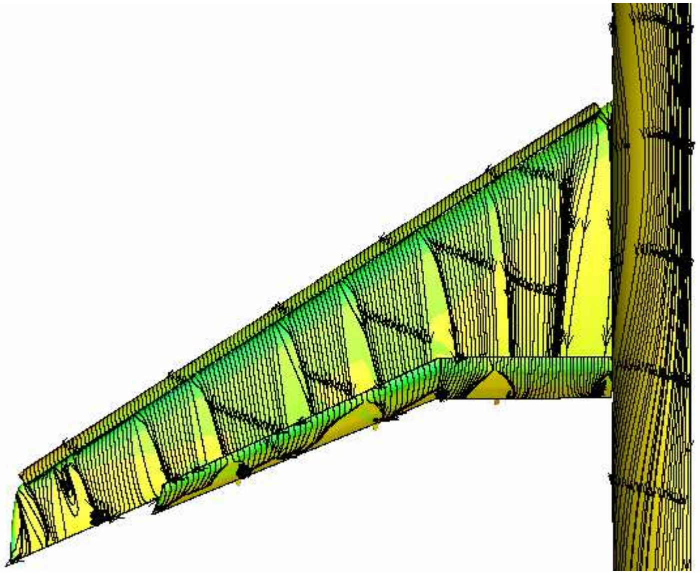
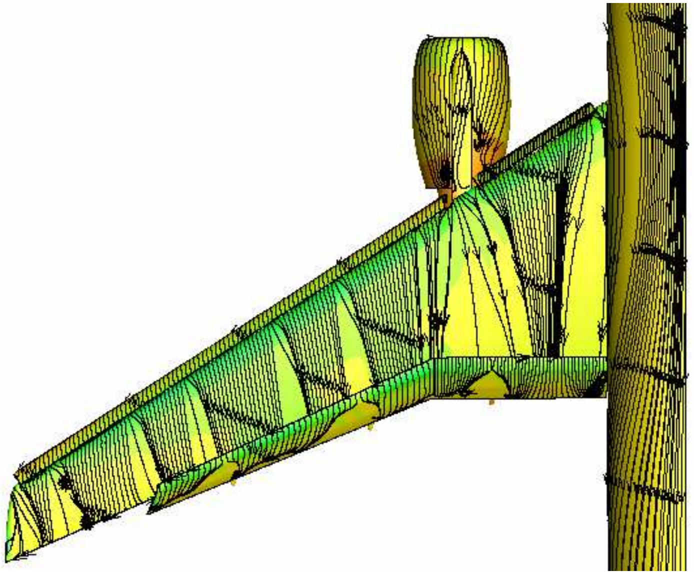


JSM results – C2 – PyNaOn x PyNaOff – 4°

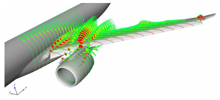


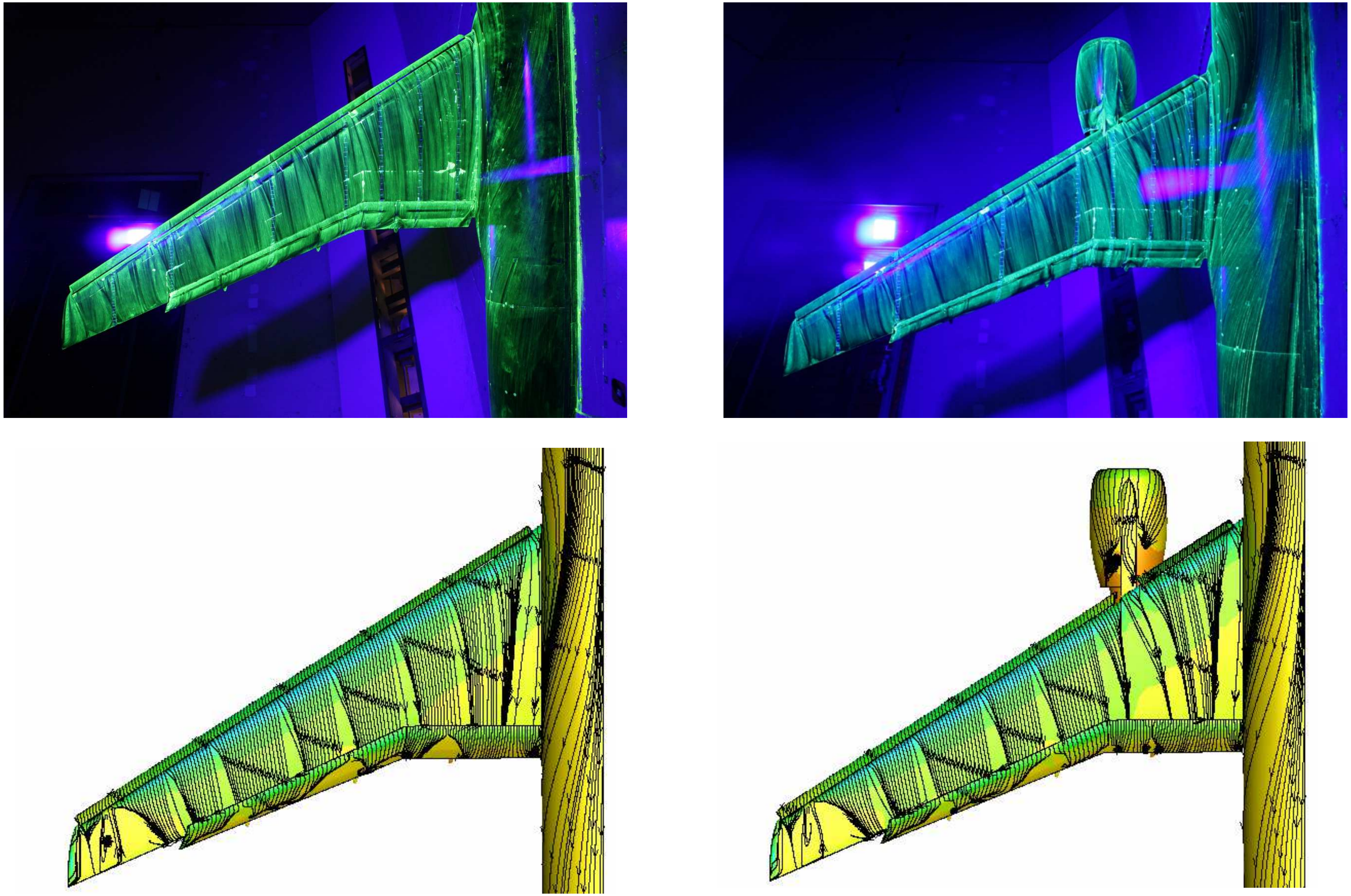




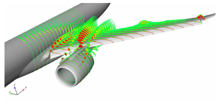


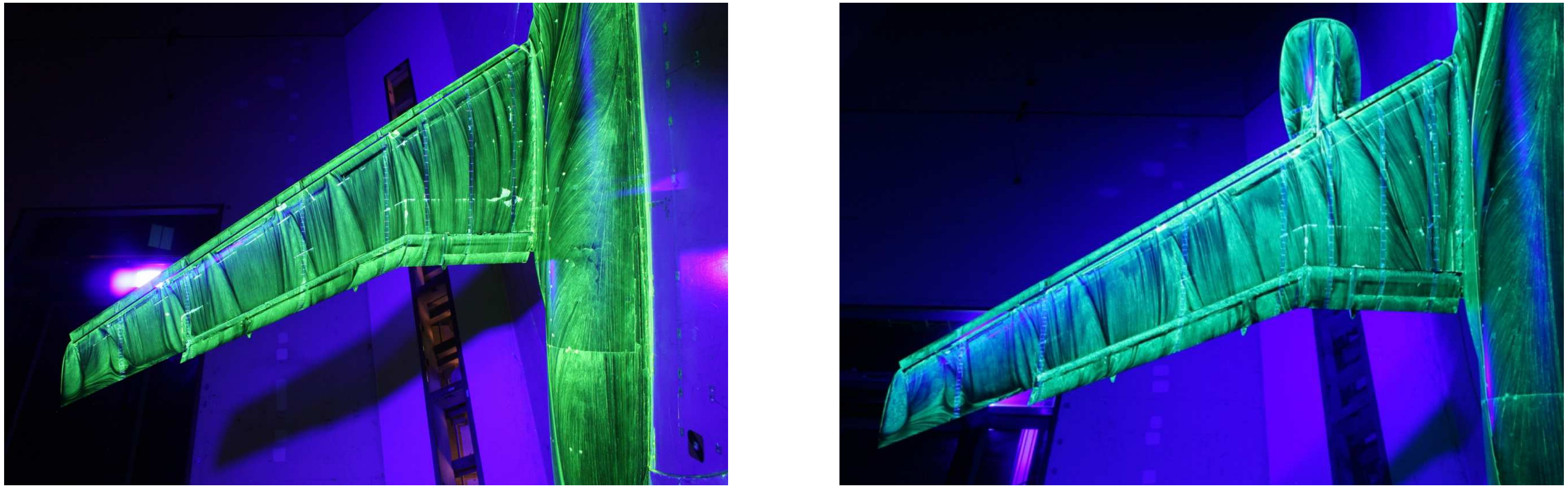
JSM results – C2 – PyNaOn x PyNaOff – 10°

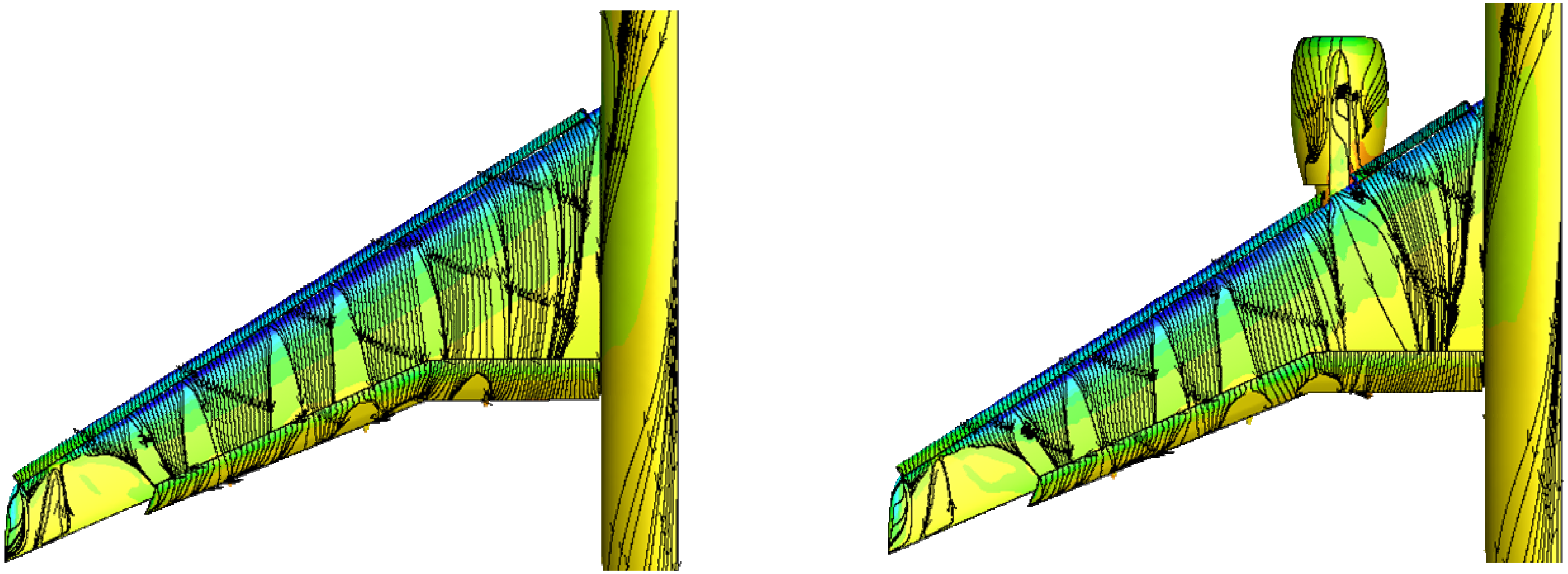




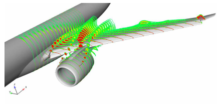
JSM results – C2 – PyNaOn x PyNaOff – 18°

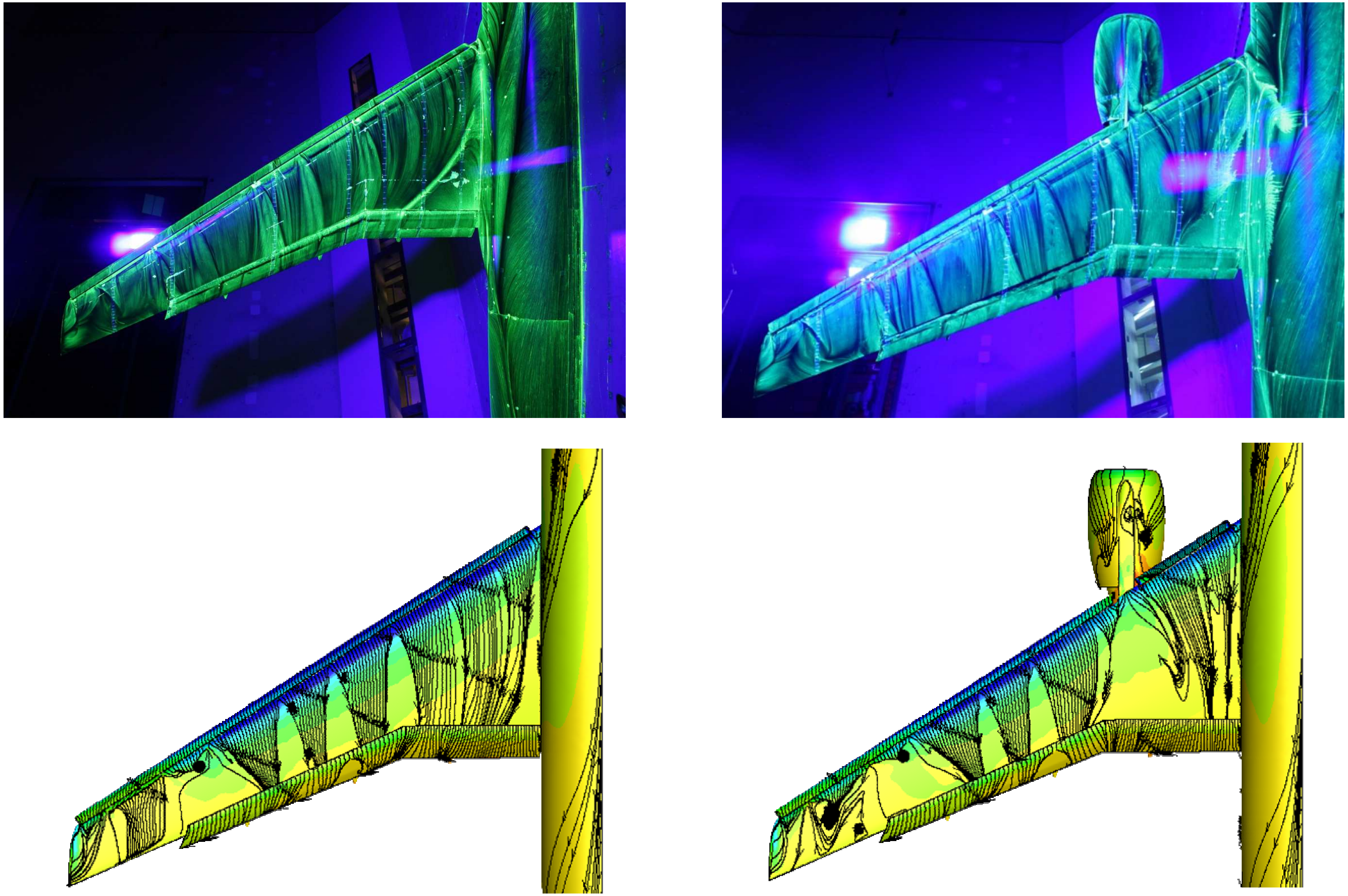


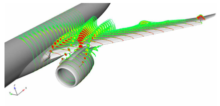




JSM results – C2 – PyNaOn x PyNaOff – 21°

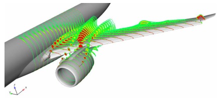






Case 3 – APPENDIX

Turbulence model verification study results



- Observed differences in coefficients between
  - SA
  - SA-CC-QCR
- Small differences in CL and CDviscous
  - 0.0015 in CL
  - 0.0003 in CD