ANSYS CFD Study for High-Lift Aircraft Configurations

Krishna Zore, *Application Software Development*

Shoaib Shah, *Senior Software Development*

John Stokes, *Director Software Development*

Bala Sasanapuri, *Lead Technology Specialist*

Patrick Sharkey, *Lead Software Development*

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APA-03, Special Session: High Lift Prediction Using CFD
June 25, 2018

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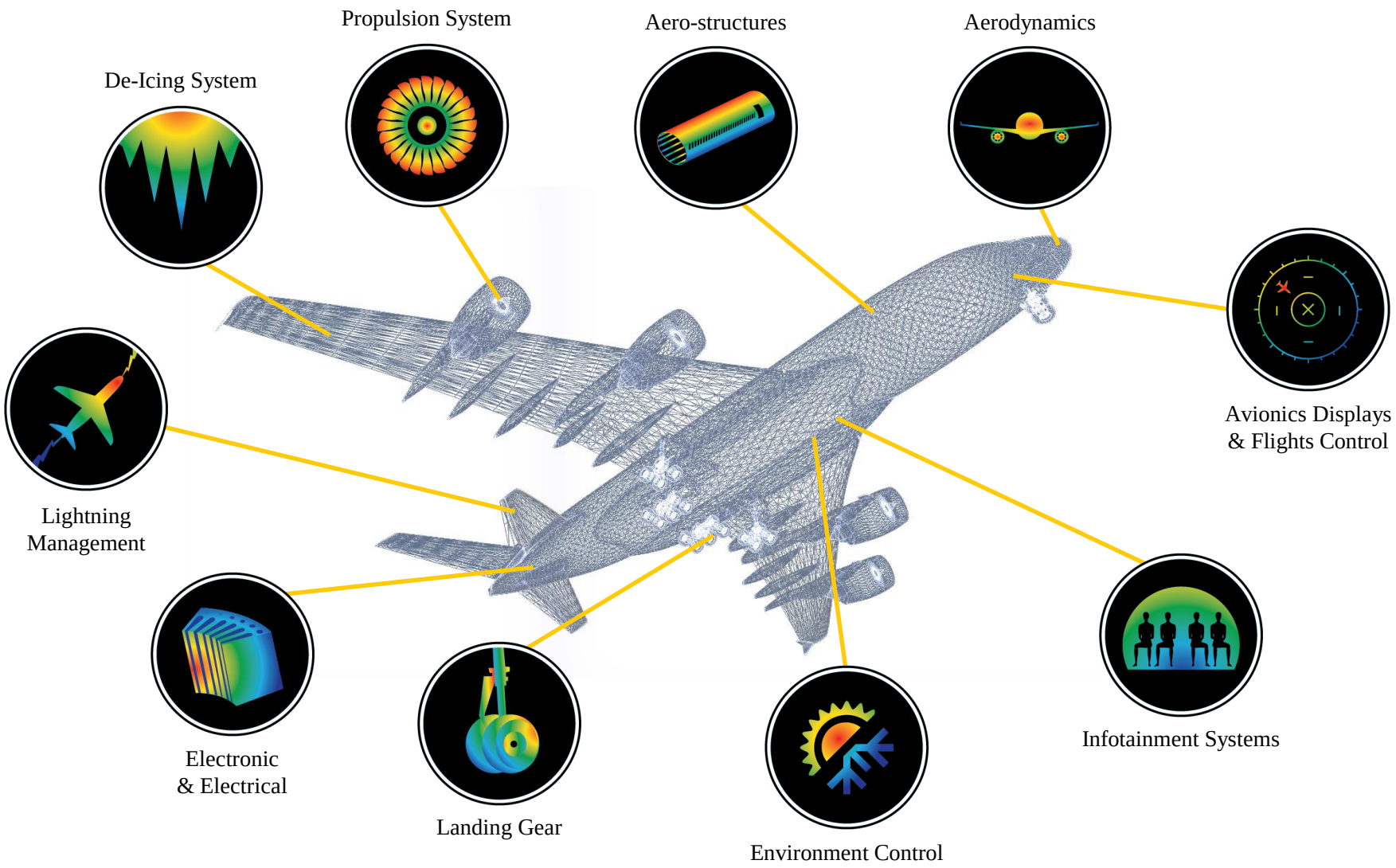
ANSYS – Comprehensive Simulation Platform



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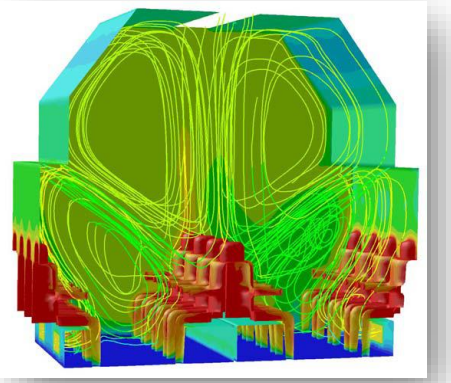
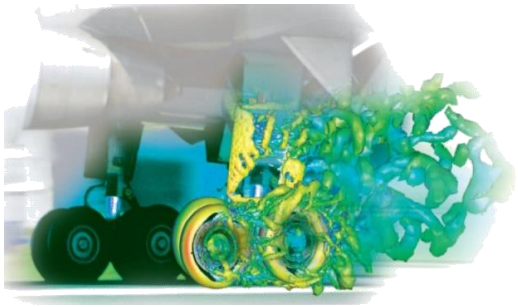
ANSYS CFD Technology

- **Pressure- and density-based coupled solvers**
- **Full range of turbulence models, incl. laminar-turbulent transition**
- **Breadth and depth of physical models**
- **Aerospace & defense application in all areas**
  - **Aerodynamic performance prediction**
  - **Internal and external aero-thermal flow characterization / intake design**
  - **Engine components – compressor, combustor, and turbine**
  - **Fluid-structure interaction**
  - **In-flight icing**
  - **Aerodynamically generated noise**
  - **… and much more**





- **Used in this workshop:**
  - **ANSYS Fluent R18.2 - pressure-based solver with k-ω SST and γ-Re_θ-transition models**

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Content

- **Case 3: 2-D DSMA661 airfoil verification study:**
  - **Results with k-ω SST (a1=0.31 default), k-ω SST (a1=1)**
- **Case 1: HL-CRM Case 1a (Full Gap only) at α = 8, α = 16**
  - **Results with k-ω SST (a1=0.31 default), k-ω SST (a1=1), SST-Transition γ-$R_{e\theta}$ (a1=1)**
  - **Summary**
- **Case 2: JSM including support brackets Case 2a and 2c (with/without nacelle) at sweep of α**
  - **Setting *a1=1*, for the k-ω SST model ?**
  - **Results with k-ω SST (a1=1), SST-Transition γ-$R_{e\theta}$ (a1=1)**
  - **Summary**
- **Questions**

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Summary of Cases

ANSYS Fluent, committee grids, k-ω SST (a1=0.31 default), k-ω SST (a1=1), SST-Transition γ-$R_{e\theta}$ (a1=1)

Case 1	α = 8, α = 16 Fully turbulent, grid study		α = 8, α = 16 Free transition prediction, grid study
1a (full gap)	YES	YES	YES
1b (full gap w adaption)	NO		NO
1c (partial seal)	NO		NO
1d (partial seal w adaption)	NO		NO

Case 2	Polar Fully turbulent	Polar specified transition	Polar Free transition prediction
2a (no nacelle)	YES	NO	YES
2b (no nacelle w adaption)	NO	NO	NO
2c (with nacelle)	YES	NO	YES
2d (with nacelle w adaption)	NO	NO	NO

Case 3	2D Verification study Fully turbulent	
3 (airfoil wake)	YES	YES

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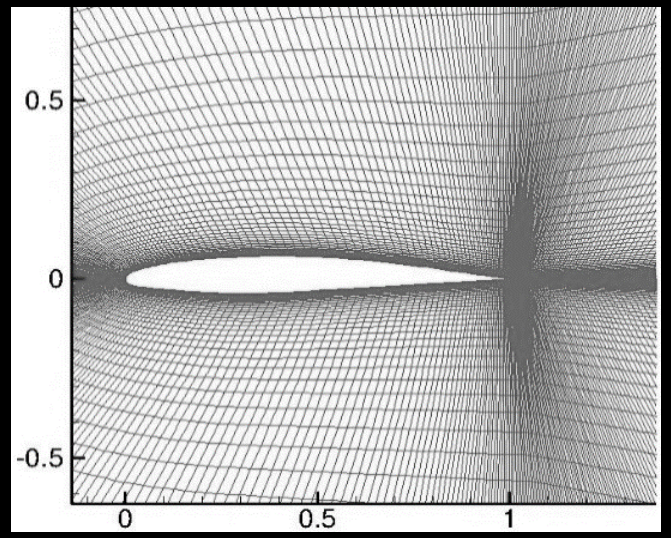
Case 3: 2-D DSMA661 airfoil

k-ω SST (a1=0.31 default) k-ω SST (a1=1)

Case	2D Verification study Fully turbulent	
3 (airfoil wake)	YES	YES



Low Mach number = 0.088, Re = 1.2×10^6 at $\alpha = 0^0$

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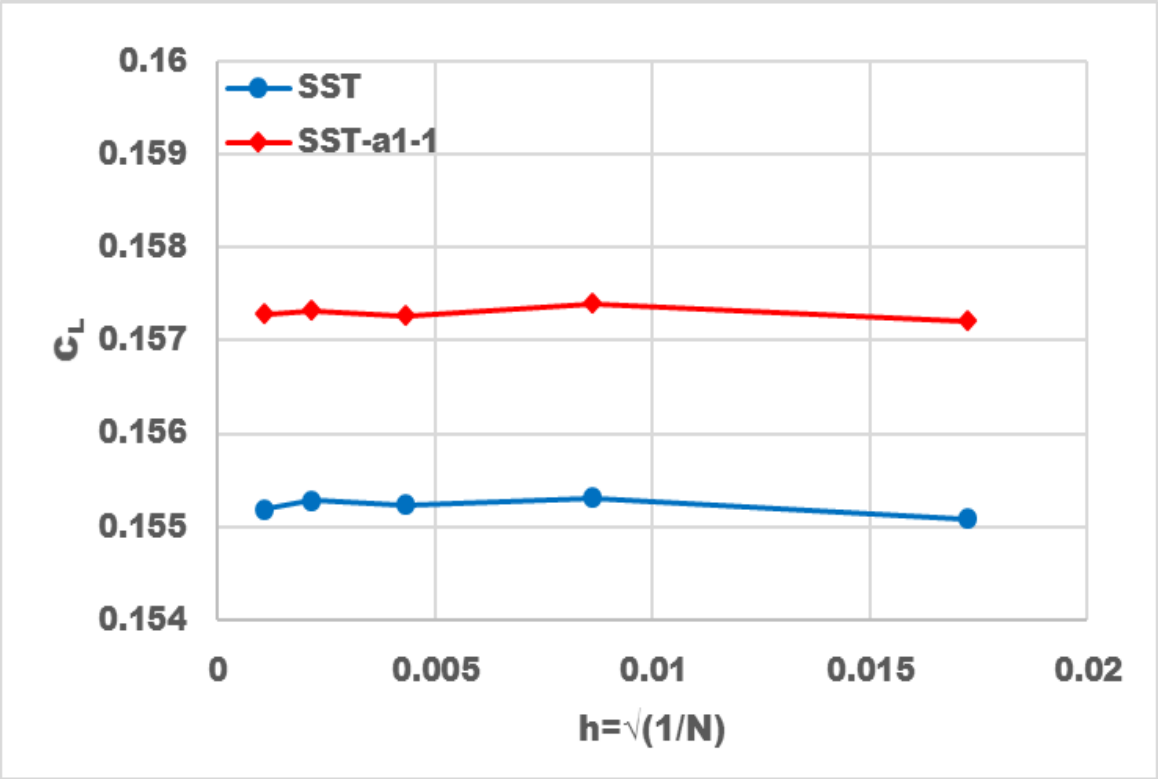
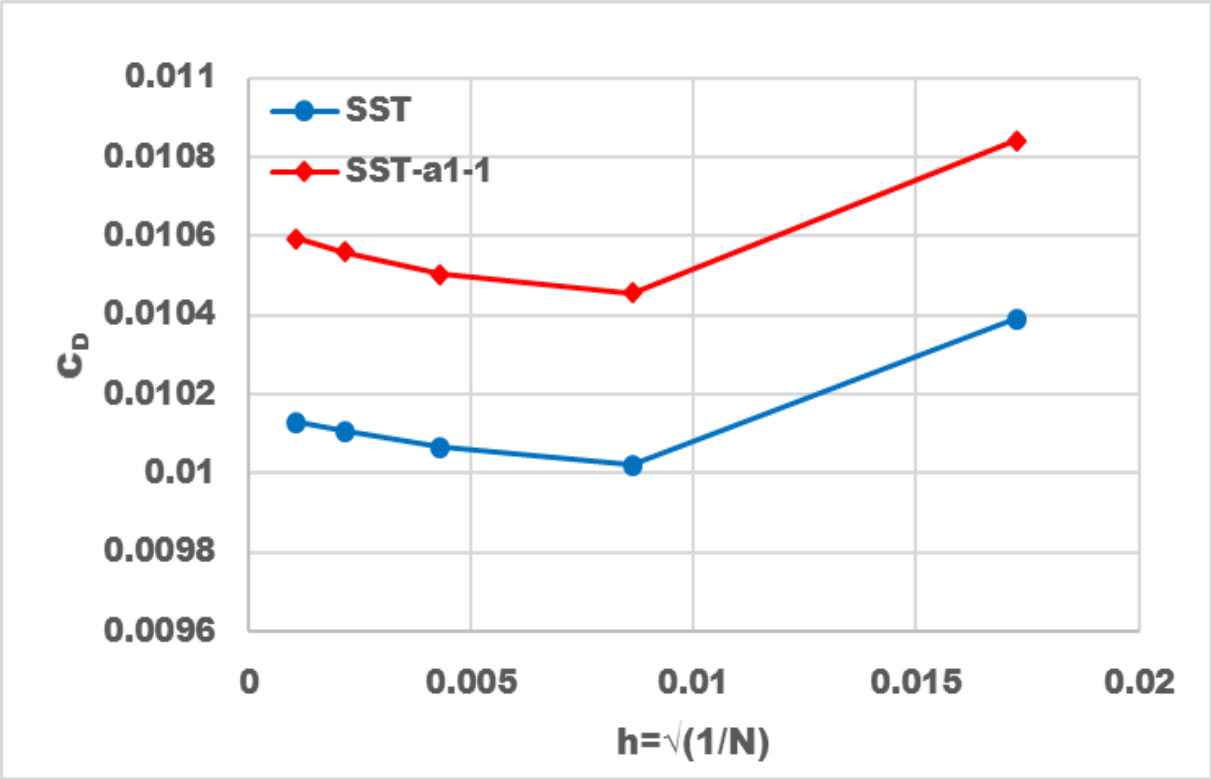
2-D DSMA661 Airfoil - Verification Study Results

Grid convergence





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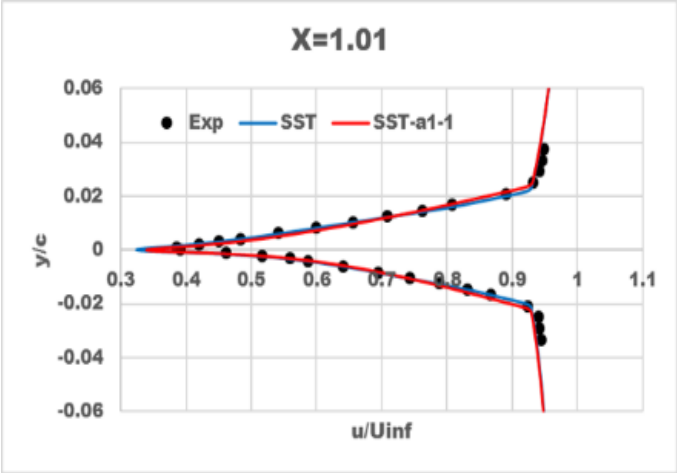
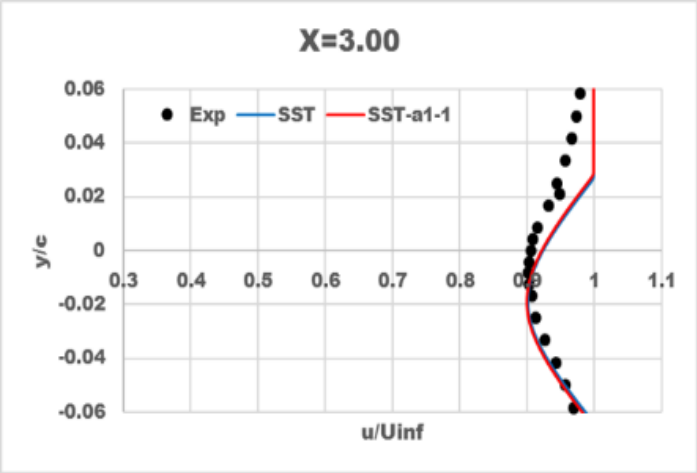
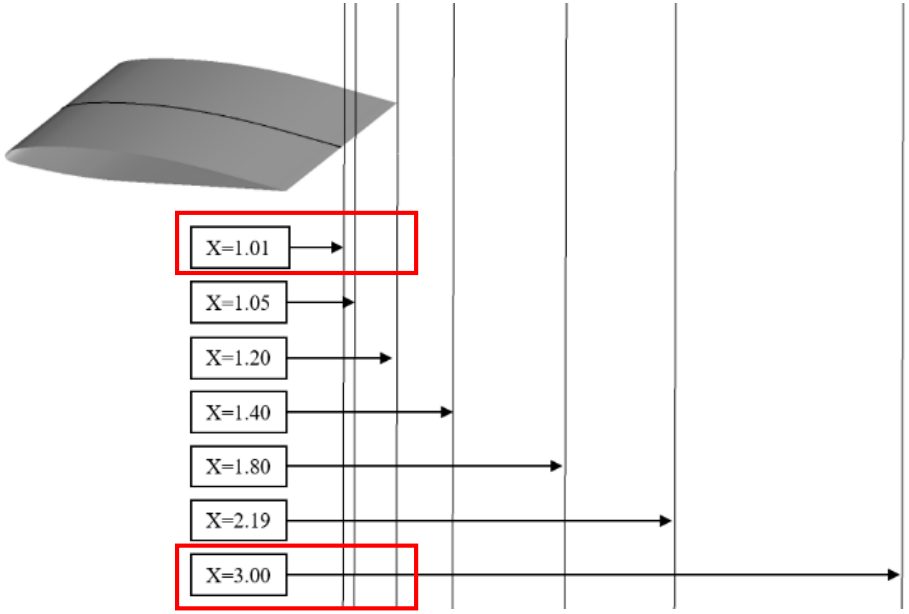
2-D DSMA661 Airfoil - Verification Study Results

Normalized X-Velocity Profiles in Wake Locations

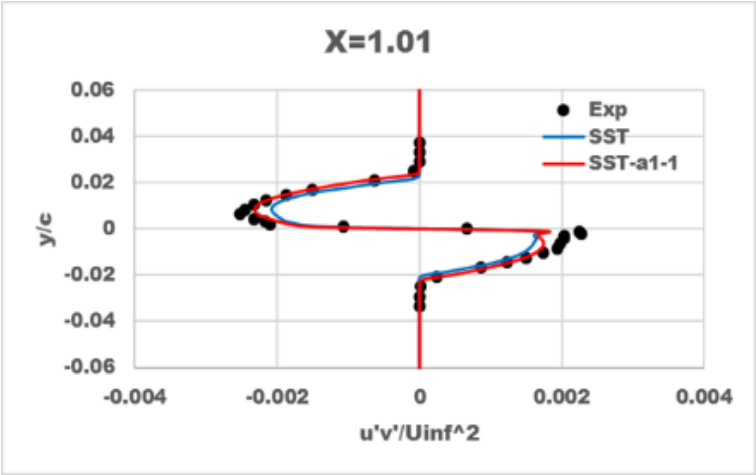


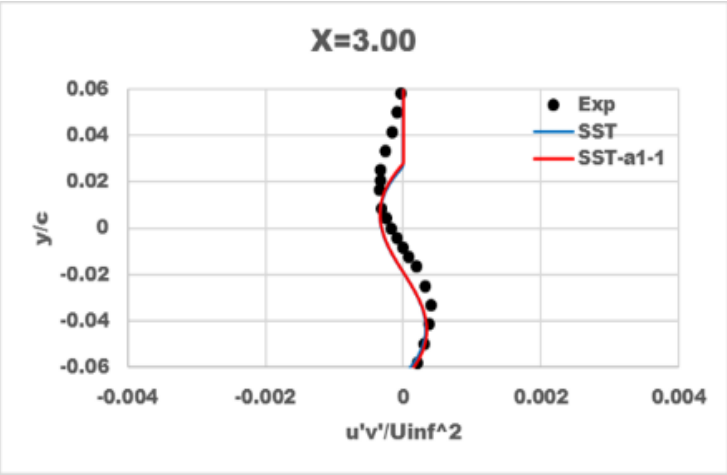




2D Airfoil Near-Wake Locations

Normalized Turbulence Shear Stress Profiles in Wake





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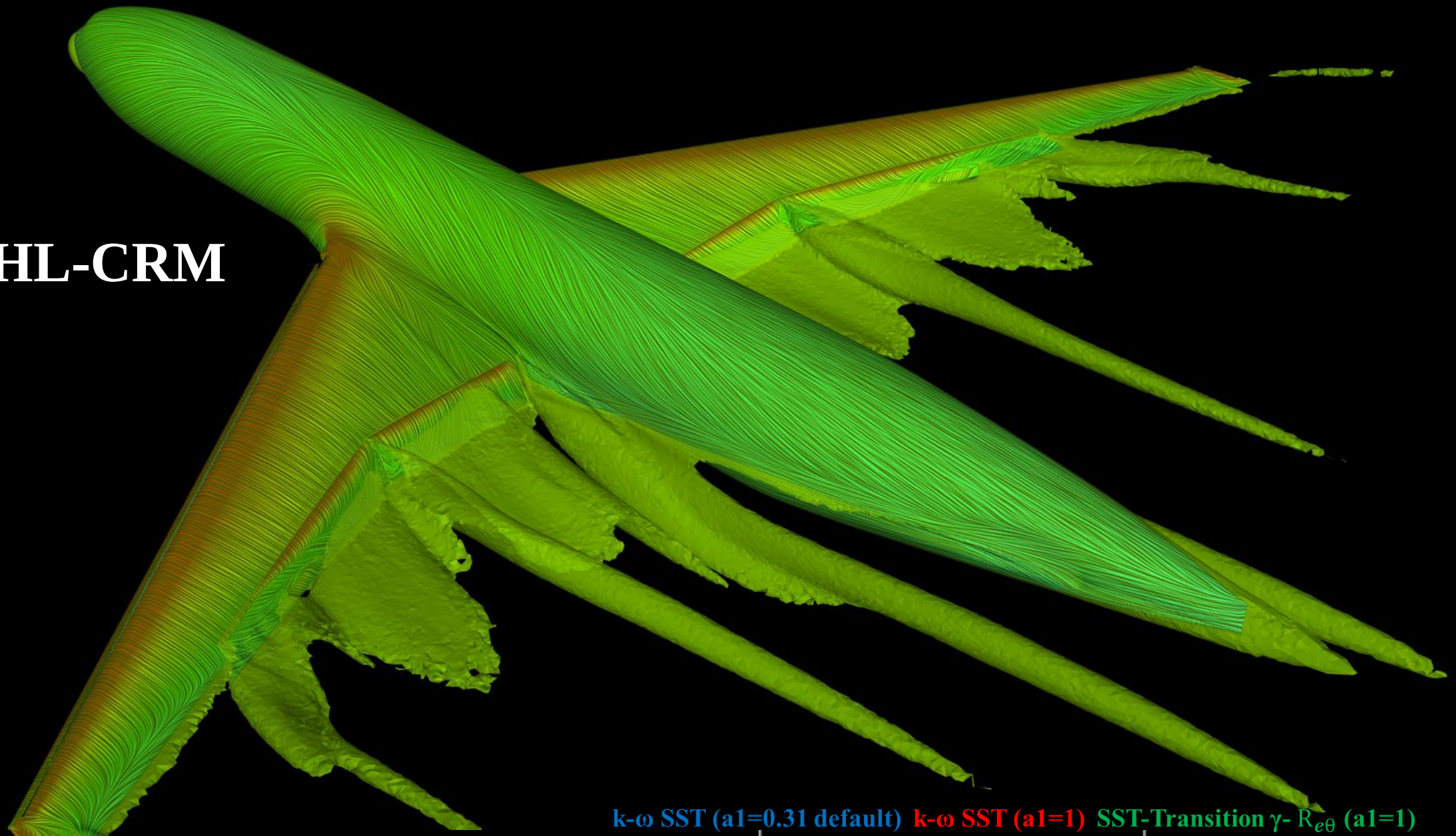
Case 1: HL-CRM



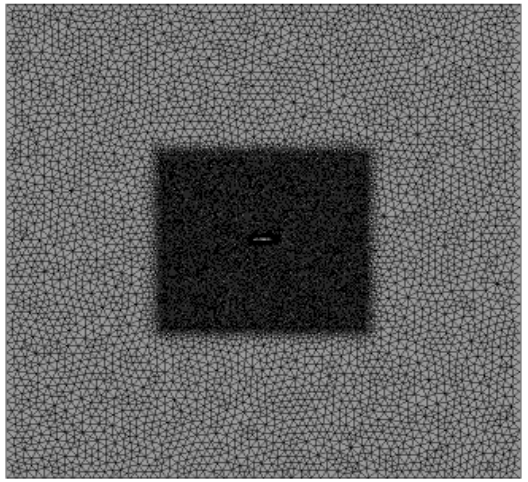
k-ω SST (a1=0.31 default) k-ω SST (a1=1) SST-Transition γ- $R_{e\theta}$ (a1=1)

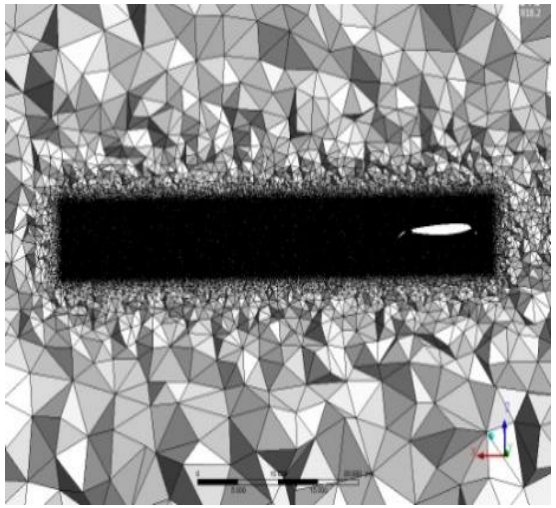
Case	α = 8, α = 16 Fully turbulent, grid study		α = 8, α = 16 Free transition prediction, grid study
1a (full gap)	YES	YES	YES

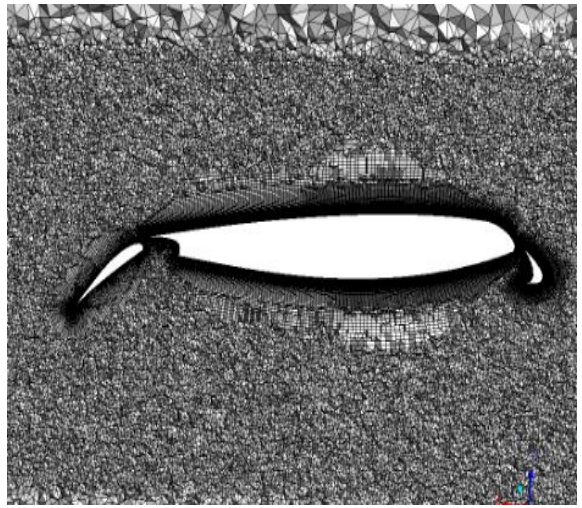
Case 1: HL-CRM Grid Overview

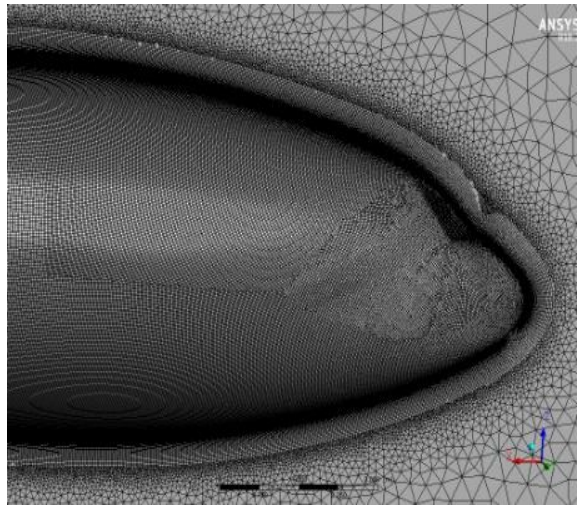
- B3-Pointwise Mesh, Mixed Volume Elements (Hex-Prism-Pyra-Tetra)

Grid resolution level	Number of Nodes	Number of Cells	Y^+ at walls	Initial wall spacing, Δy (normal dist.)	Number of cells on trailing edges
Coarse	10,729,701	18,011,980	1	0.00175"	4
Medium	33,776,063	47,557,044	2/3	0.00117"	8
Fine	84,099,188	118,774,267	4/9	0.00078"	12
Xfine	235,965,224	397,082,470	8/27	0.00052"	16









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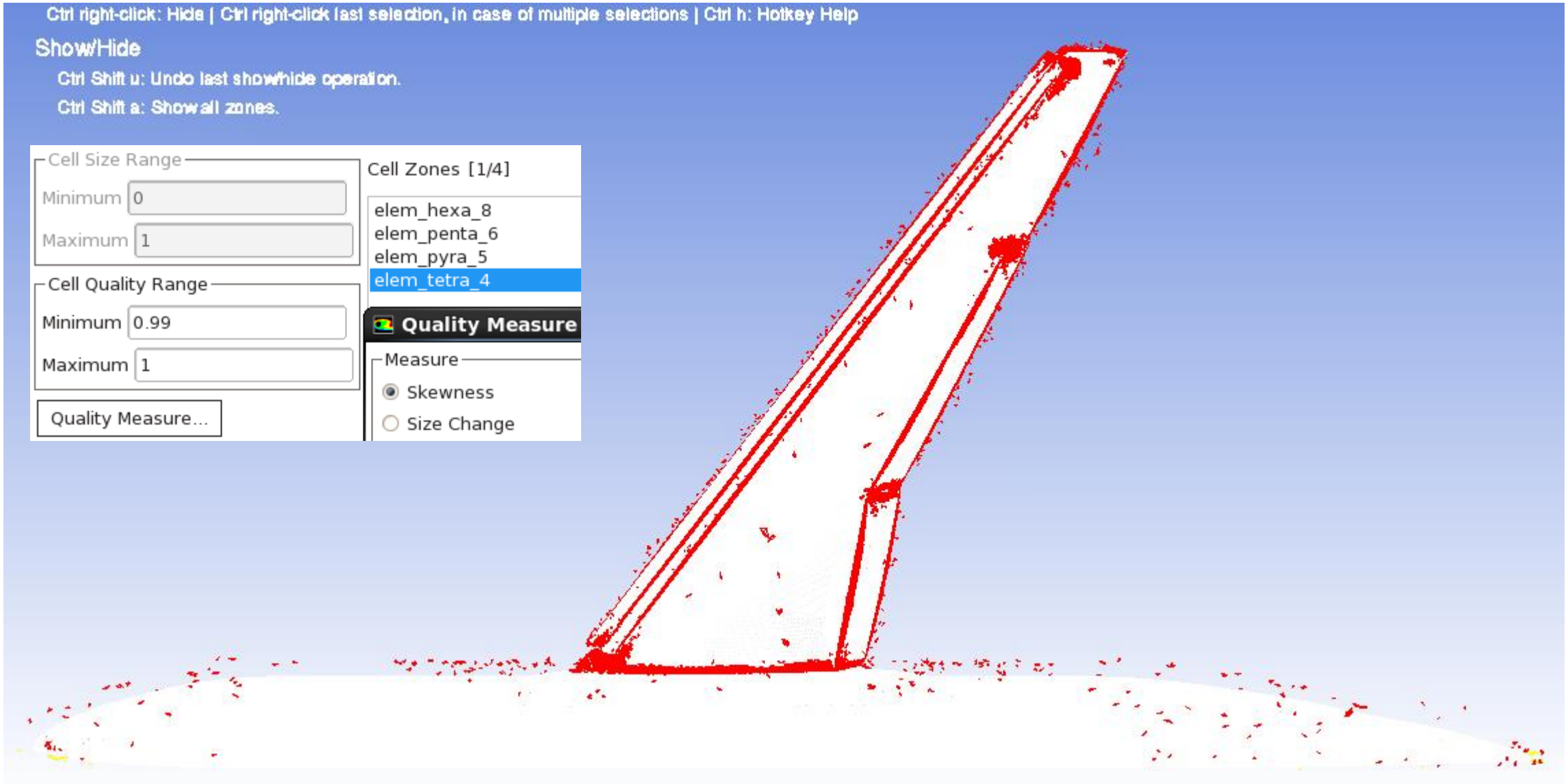
HL-CRM (Fine mesh)

Skewness



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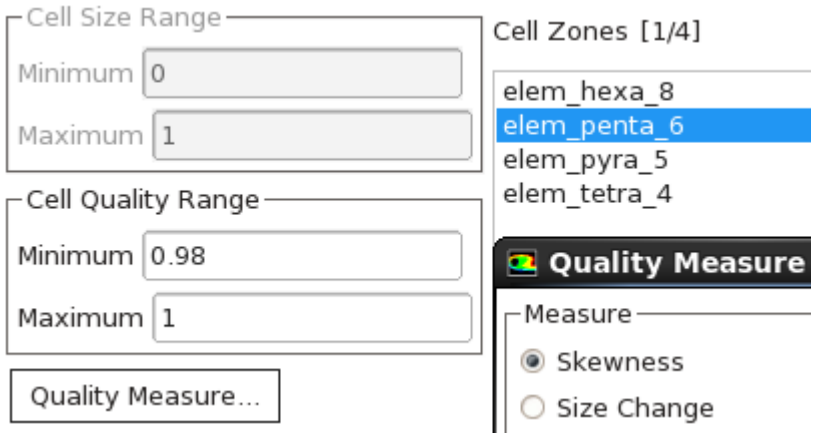
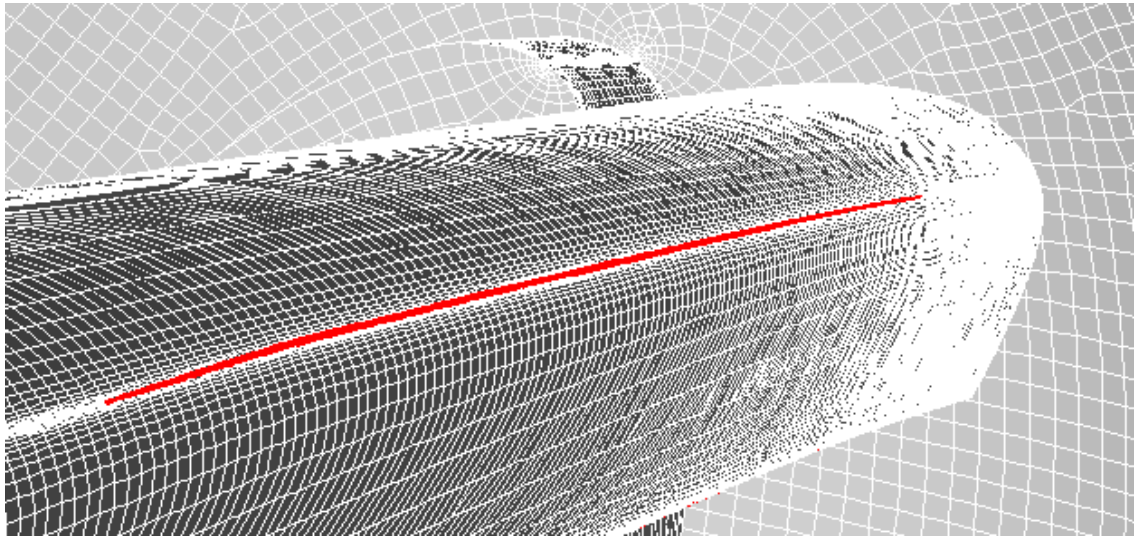
HL-CRM (Fine mesh)

Skewness

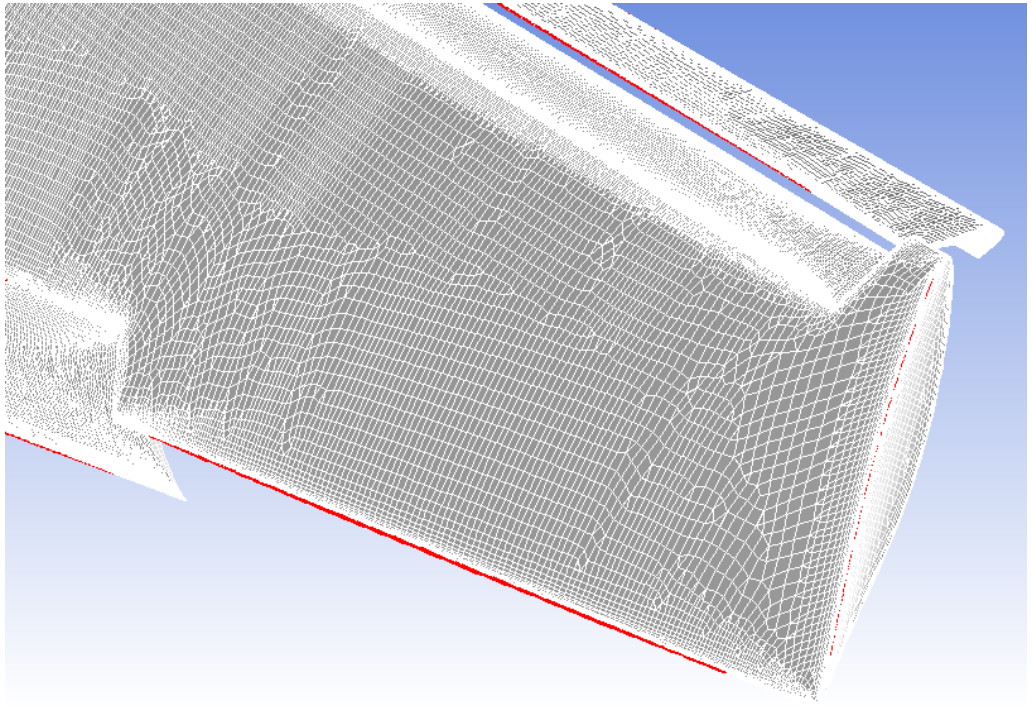




Fluent Meshing Skew

The Fluent Meshing skewness measure is computed as the normalized maximum deviation from the ideal angle at face corners (60 degrees for a tri face or 90 degrees for a quad face) for surface elements, or the normalized maximum deviation from the ideal angle between face normals (for example, 90 degrees for a hexahedral element) for volume elements.

A value of 0 indicates the best quality element while a value of 1 indicates a degenerate element.



Note: high skewness cells are on stretched cells at LE & TE

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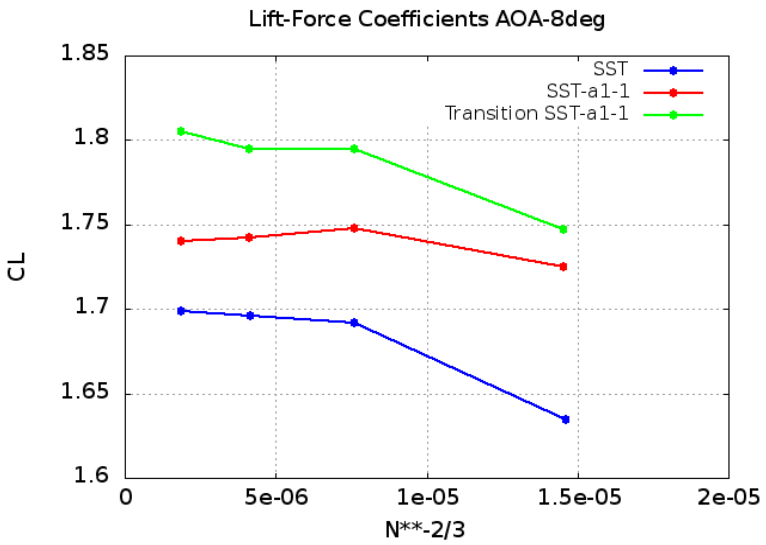
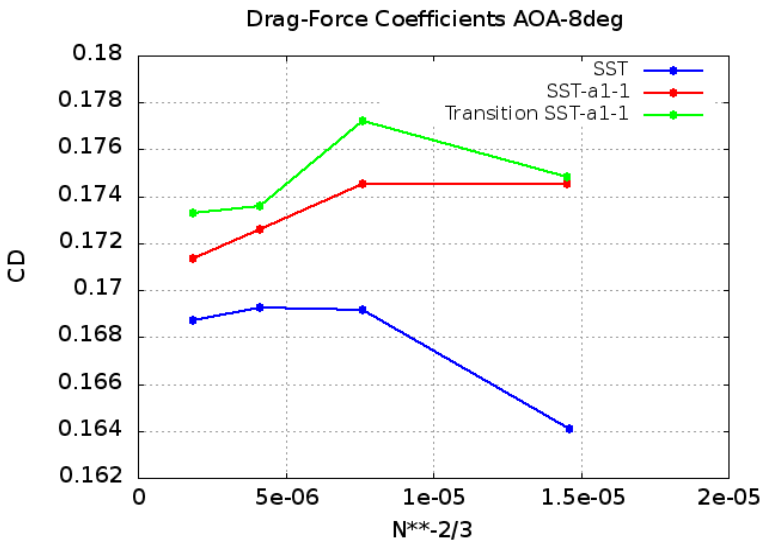
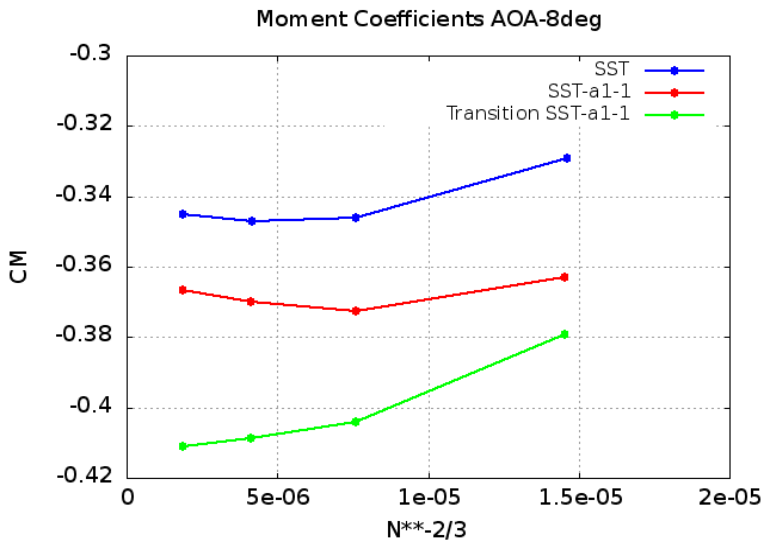
Case 1a: HL-CRM Results

Grid convergence

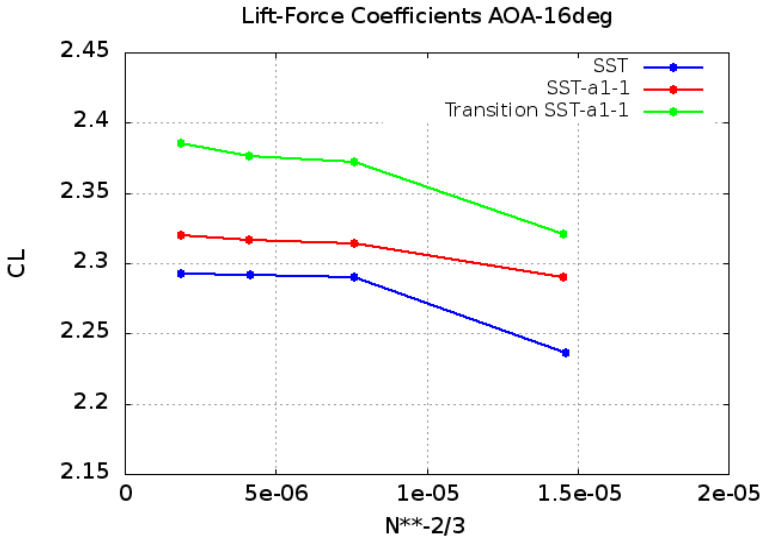
$\alpha = 8^0$

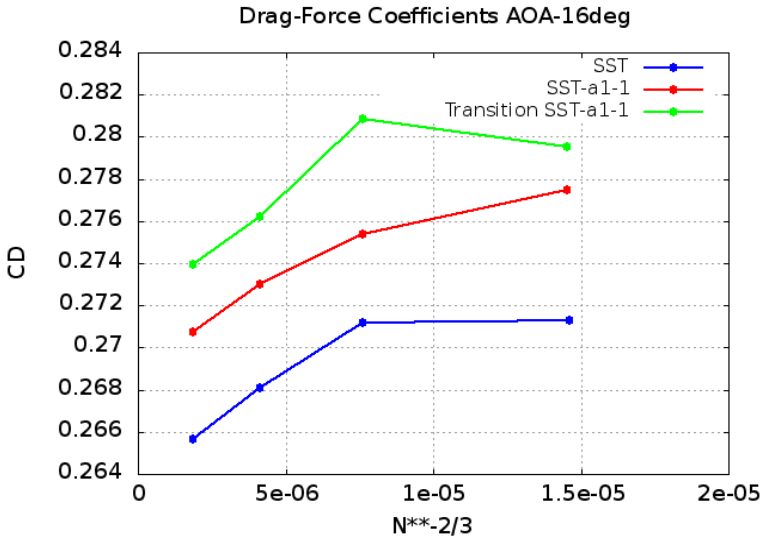


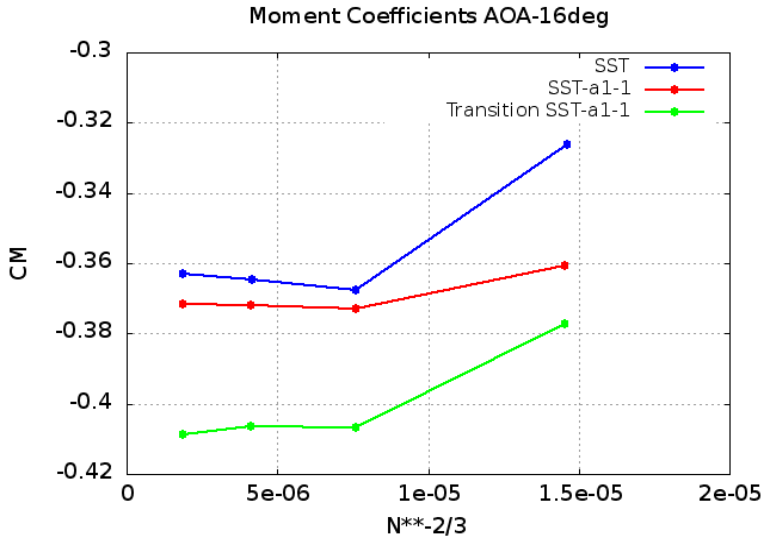




$\alpha = 16^0$







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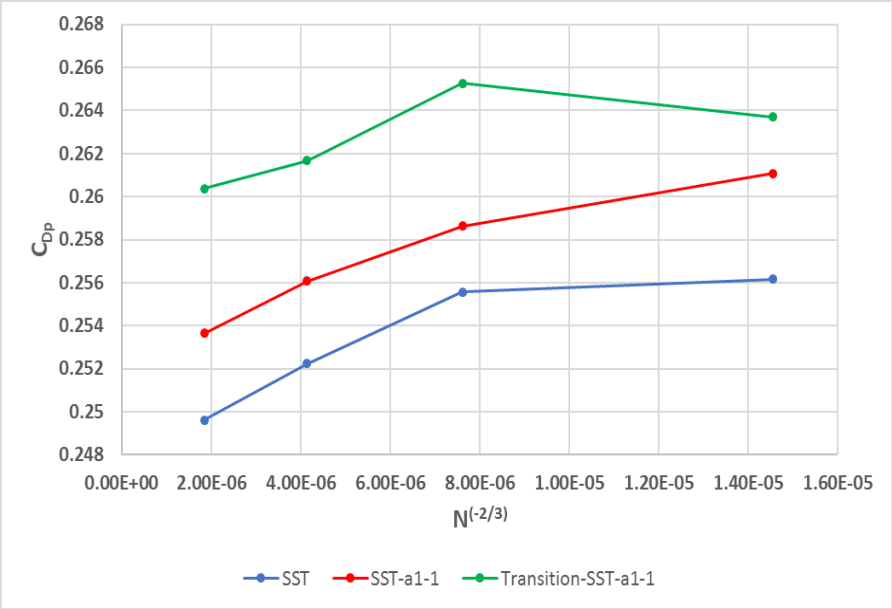
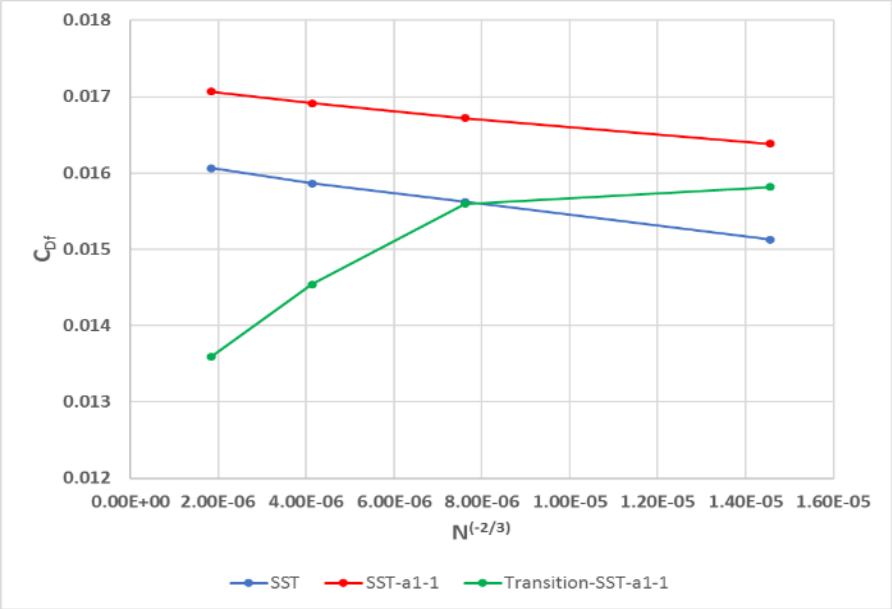
Case 1a: HL-CRM Results

$\alpha = 16^0$

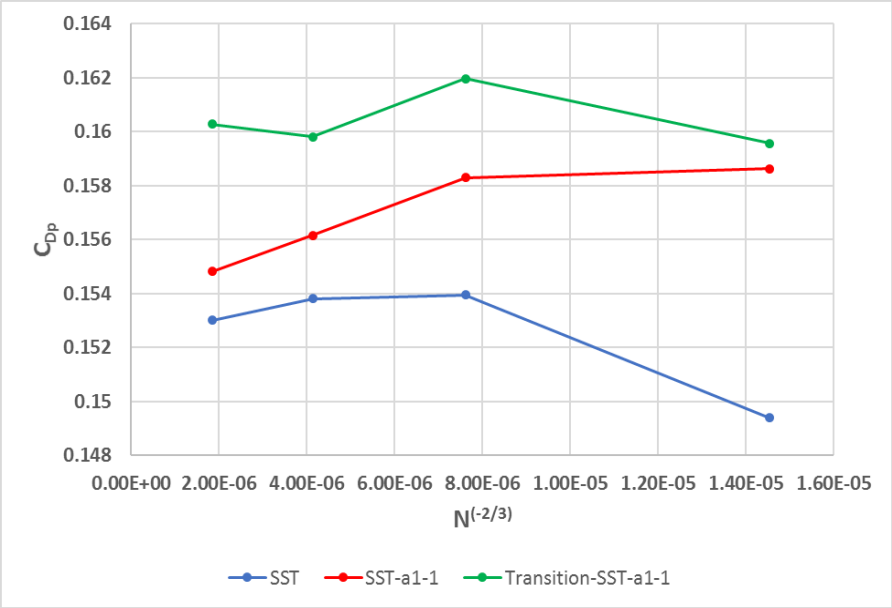


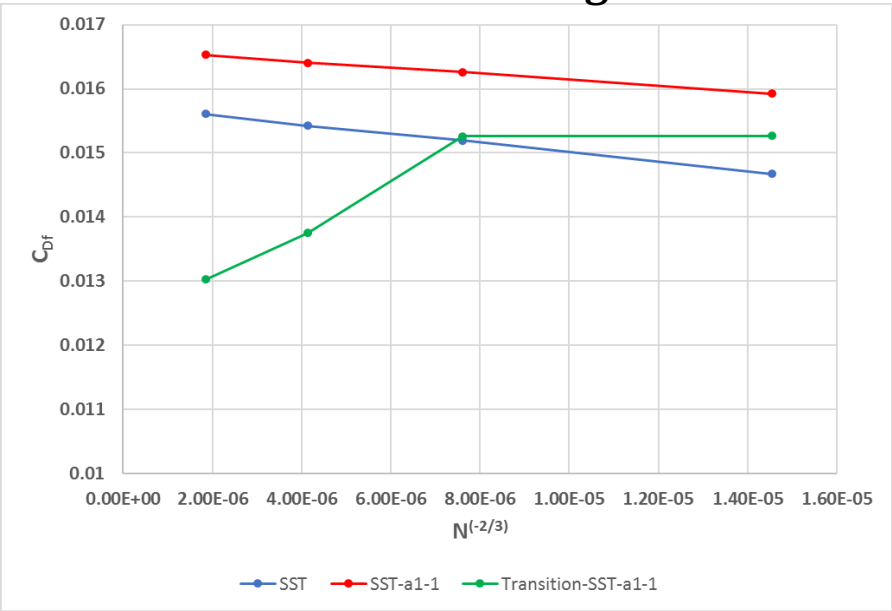


Pressure Drag

Viscous Drag

$\alpha = 8^0$





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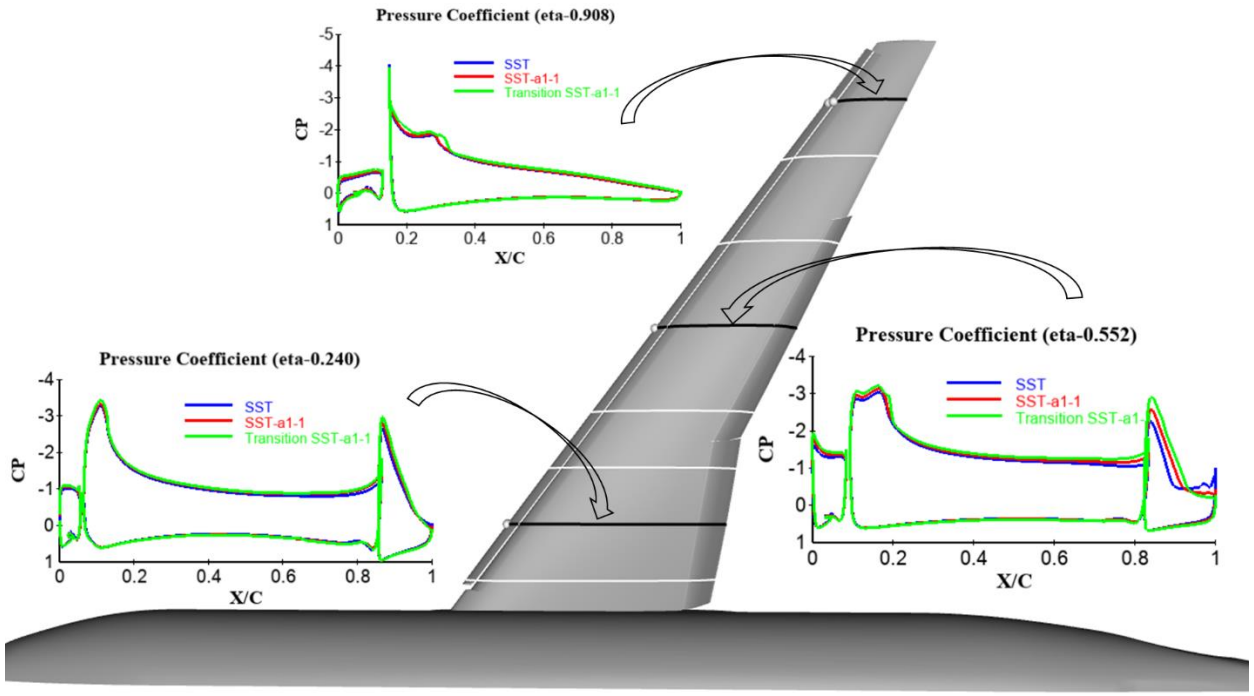
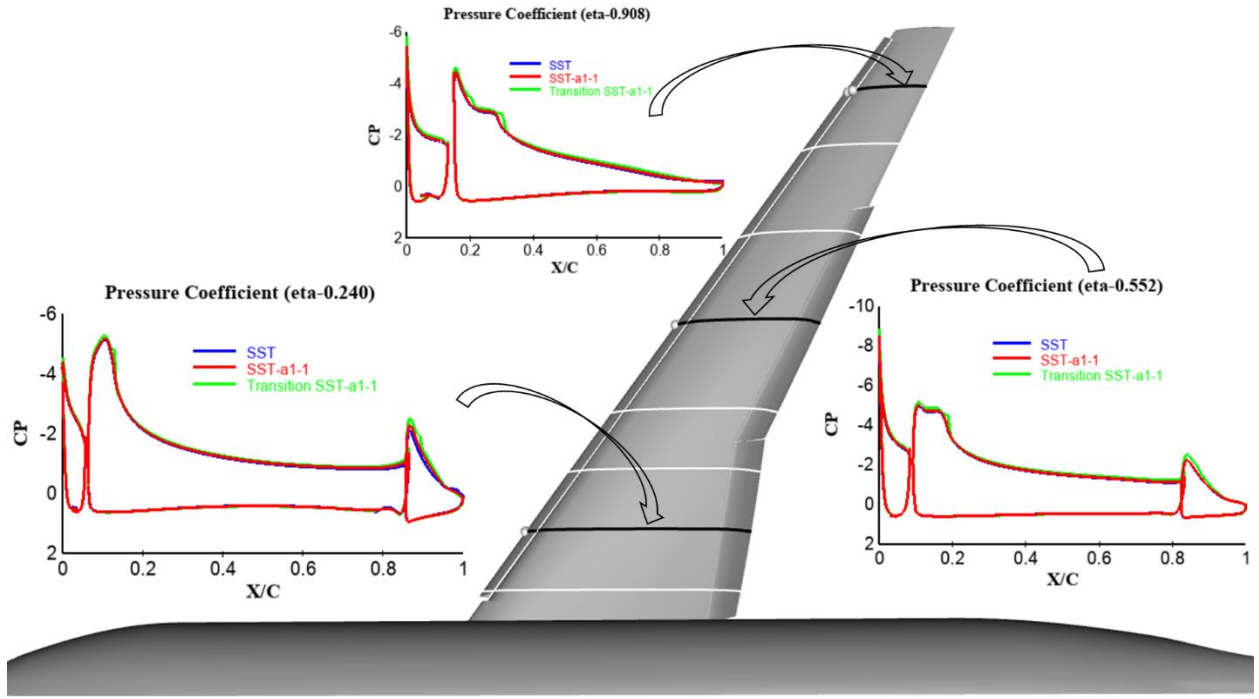
Case 1a : HL-CRM Results

Pressure coefficient plots

α = 8⁰



α = 16⁰



C_p Plots (*xfine* mesh level) - *k-ω SST (a1=0.31 default)*, *k-ω SST (a1=1)*, *SST-Transition γ-$R_{e\theta}$ (a1=1)* models

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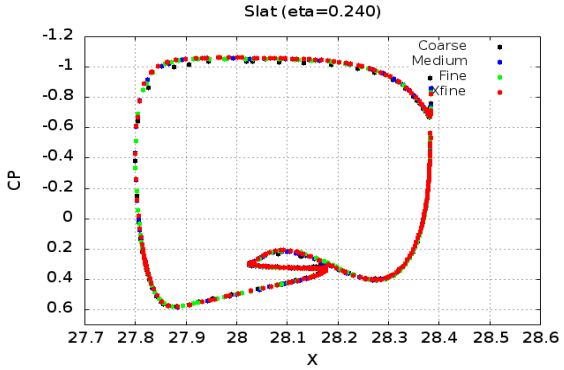
Case 1a : HL-CRM Results

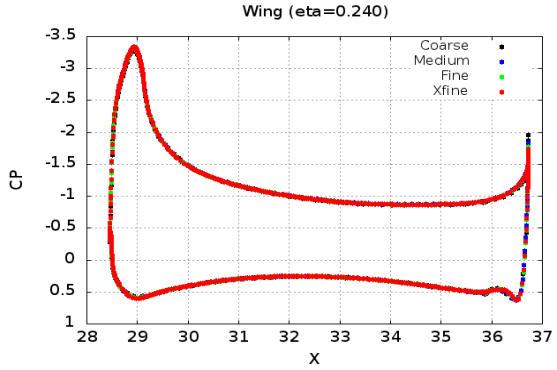
Pressure coefficient plots, grid convergence, k-ω SST (a1=1)

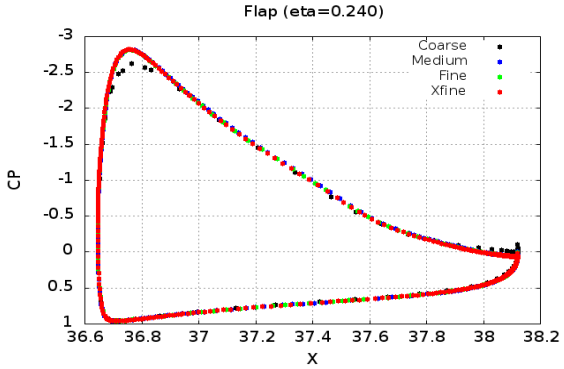
$\alpha = 8^0$

Slat | **Wing** | **Flap**

y = 277.5







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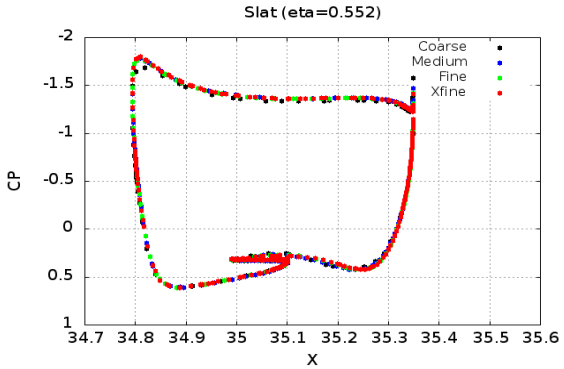

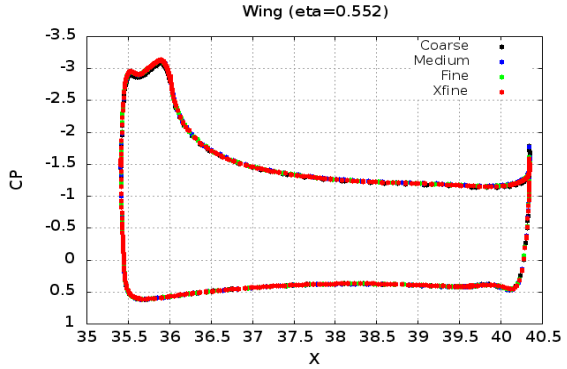

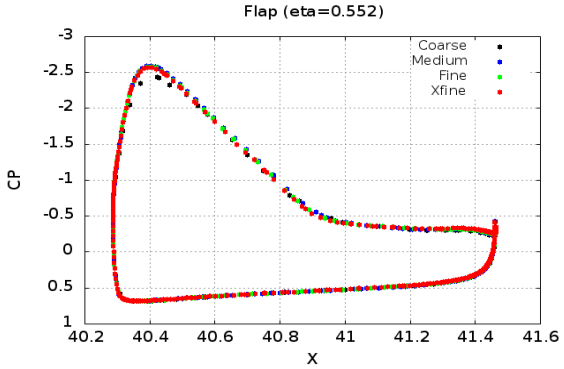

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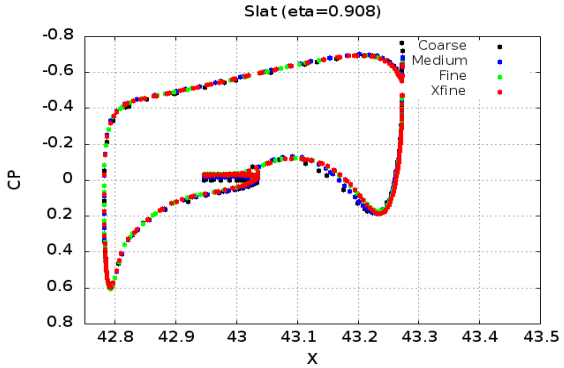

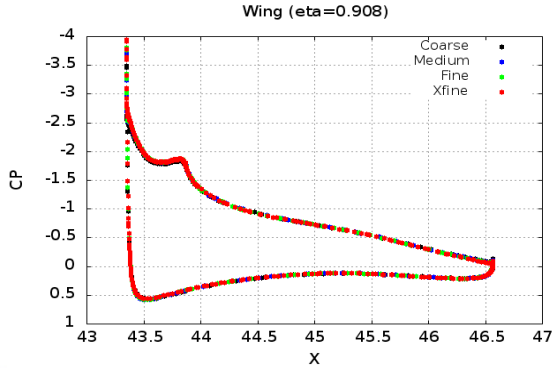

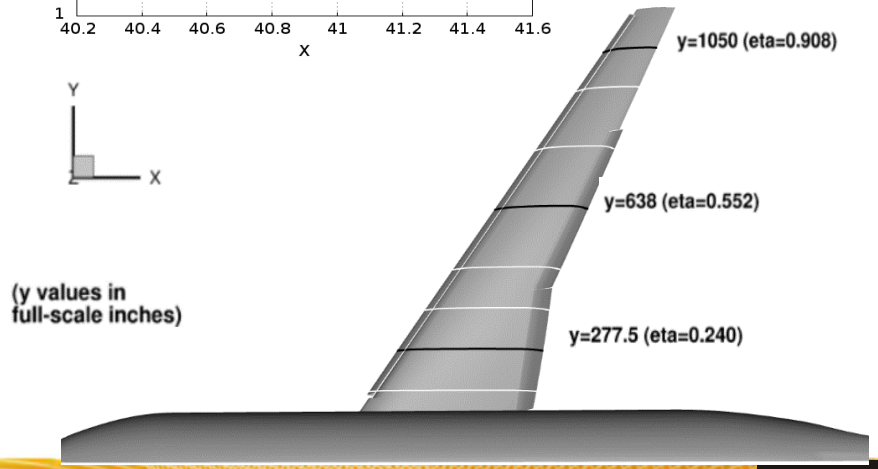

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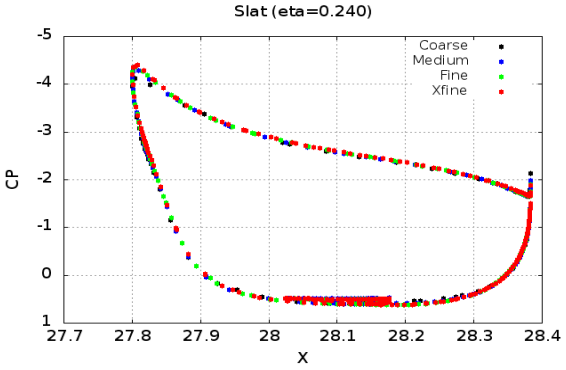
Case 1a : HL-CRM Results

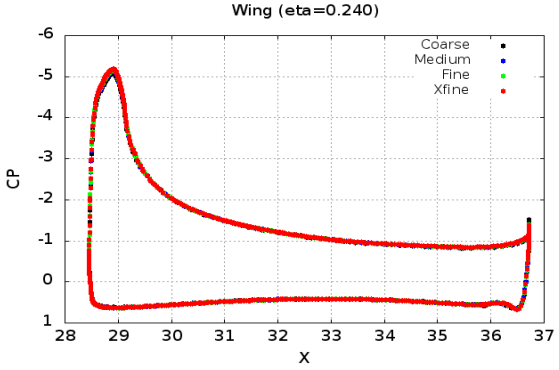
Pressure coefficient plots, grid convergence, k-ω SST (a1=1)

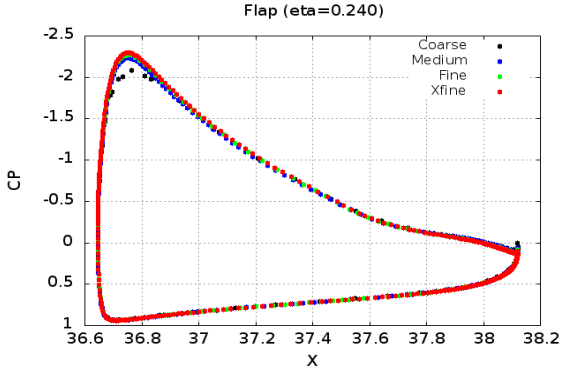
α = 16⁰

Slat | **Wing** | **Flap**

y = 277.5







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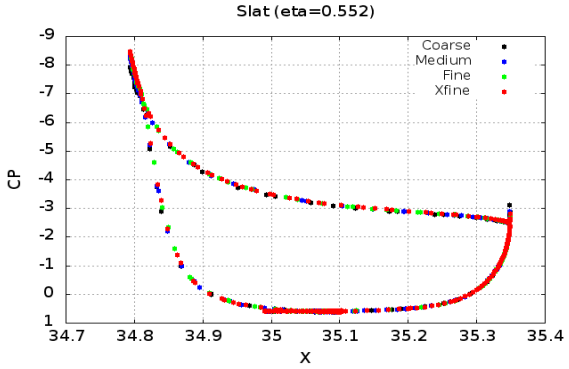
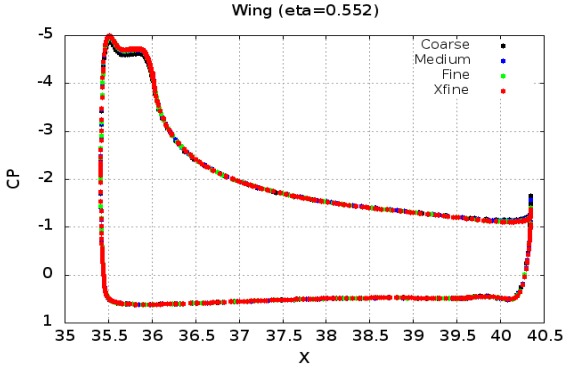
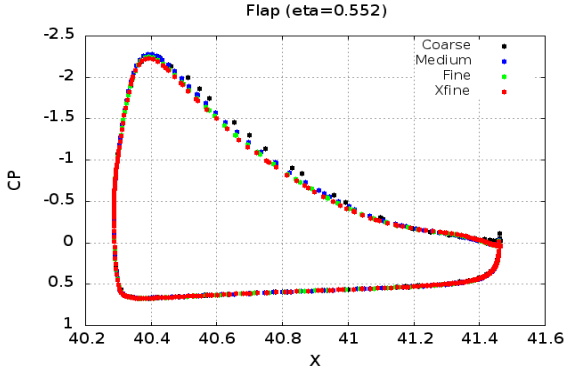
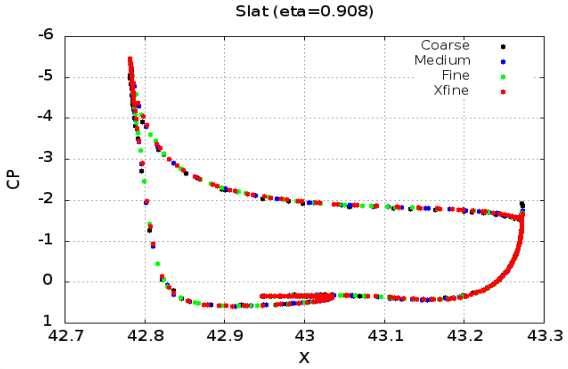
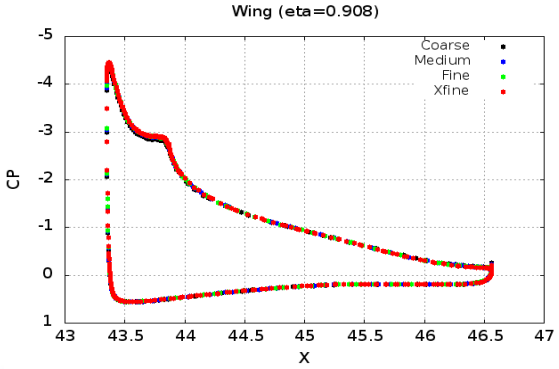


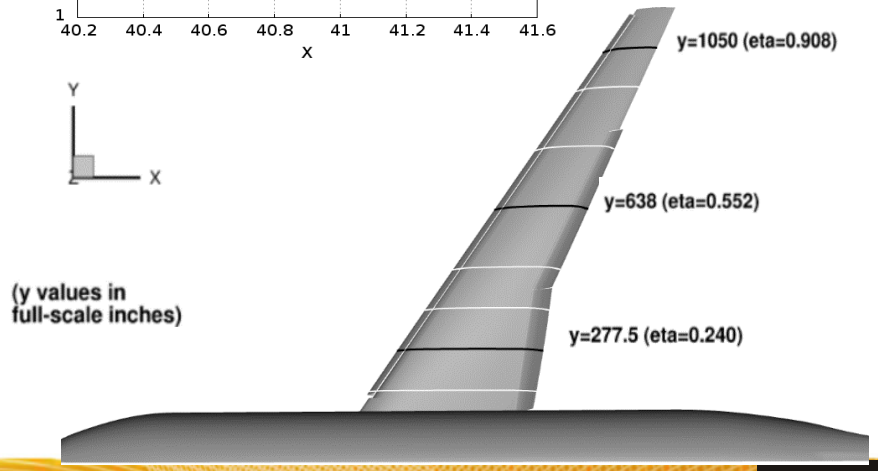




y = 1050







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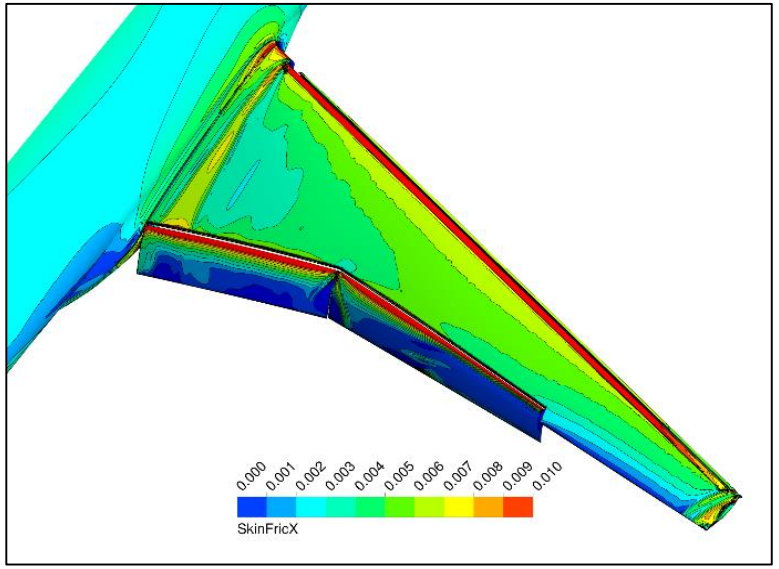
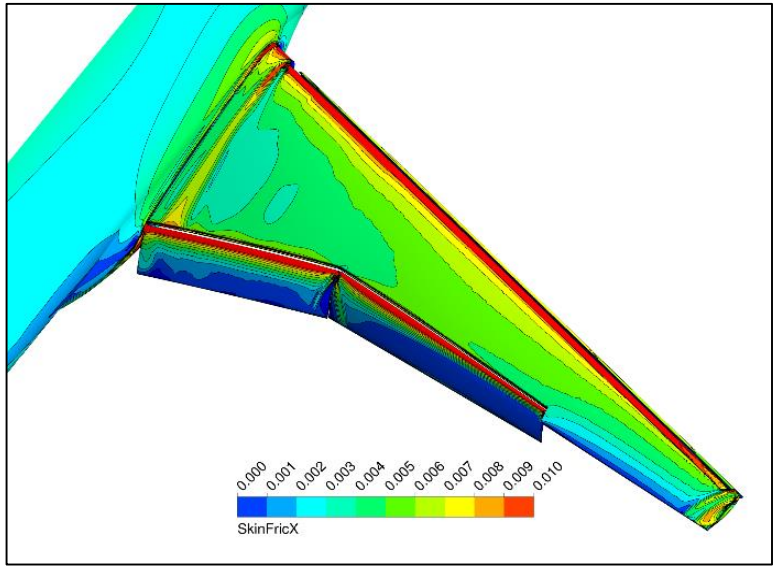
Case 1a : HL-CRM Results

Skin-friction coefficient contours (*xfine* mesh level) - turbulence model comparison

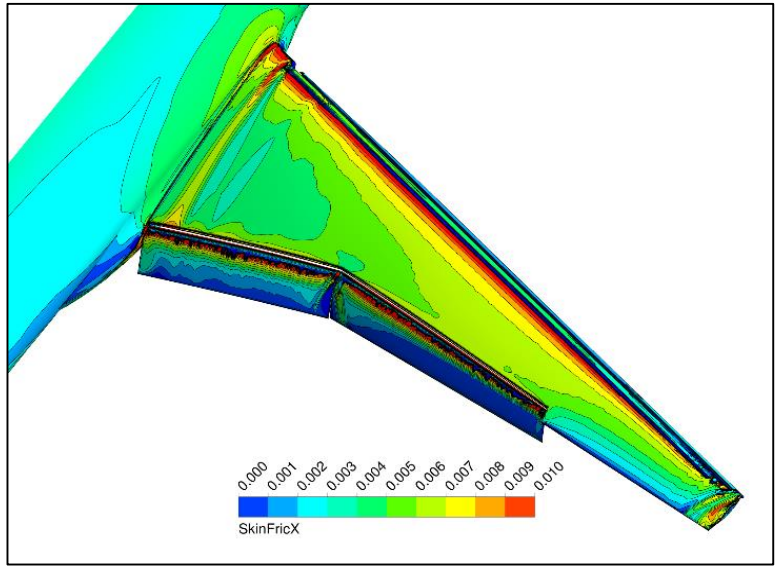
α = 8⁰



k-ω SST (a1=0.31 default)

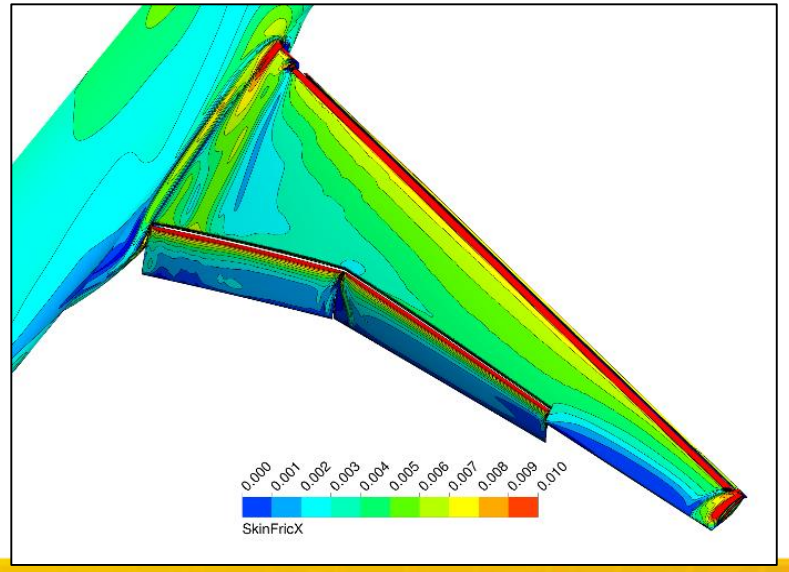


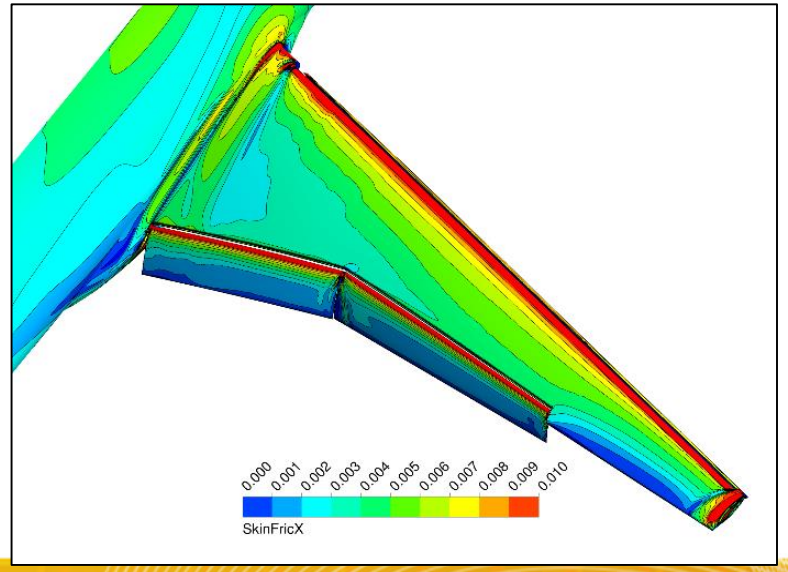
k-ω SST (a1=1)

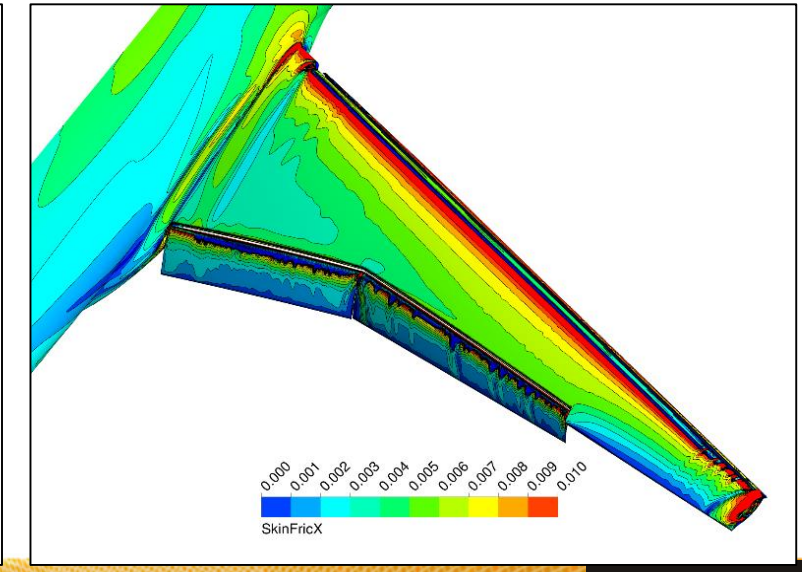


SST-Transition γ-$R_{e\theta}$ (a1=1)

α = 16⁰







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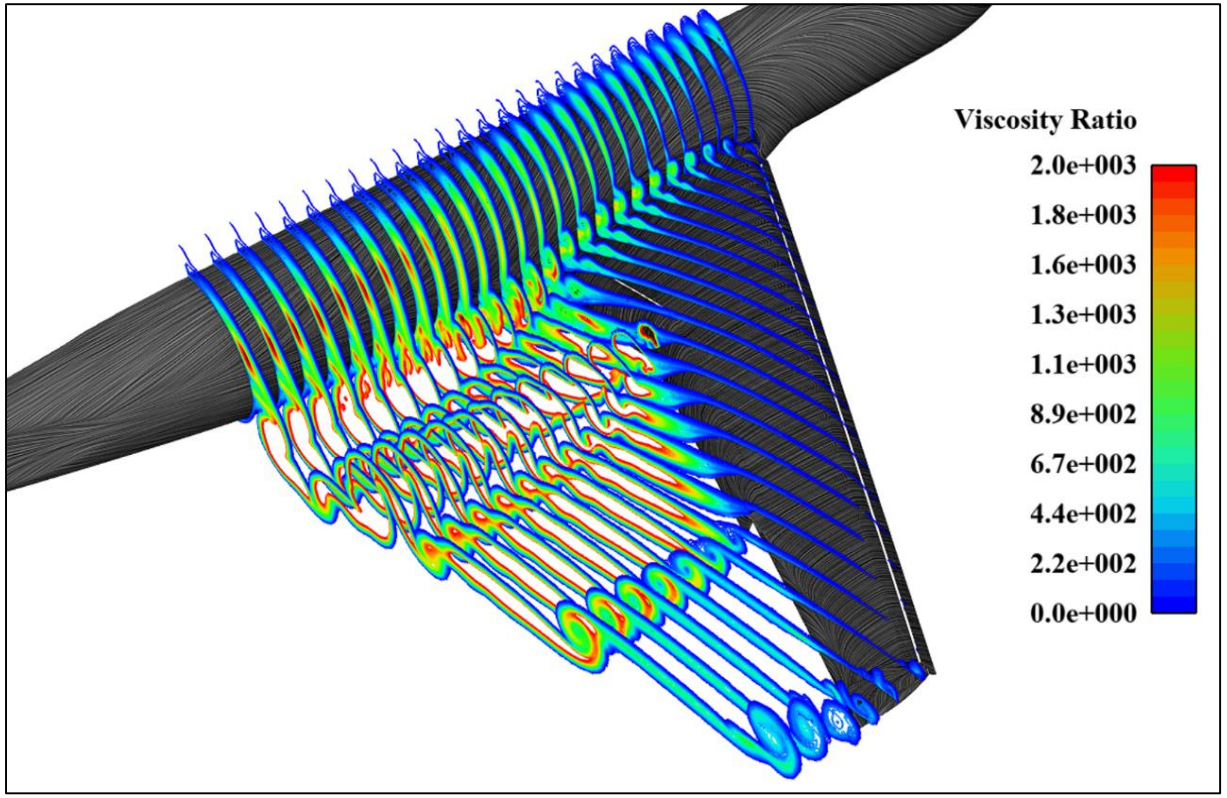
Case 1a : HL-CRM Results

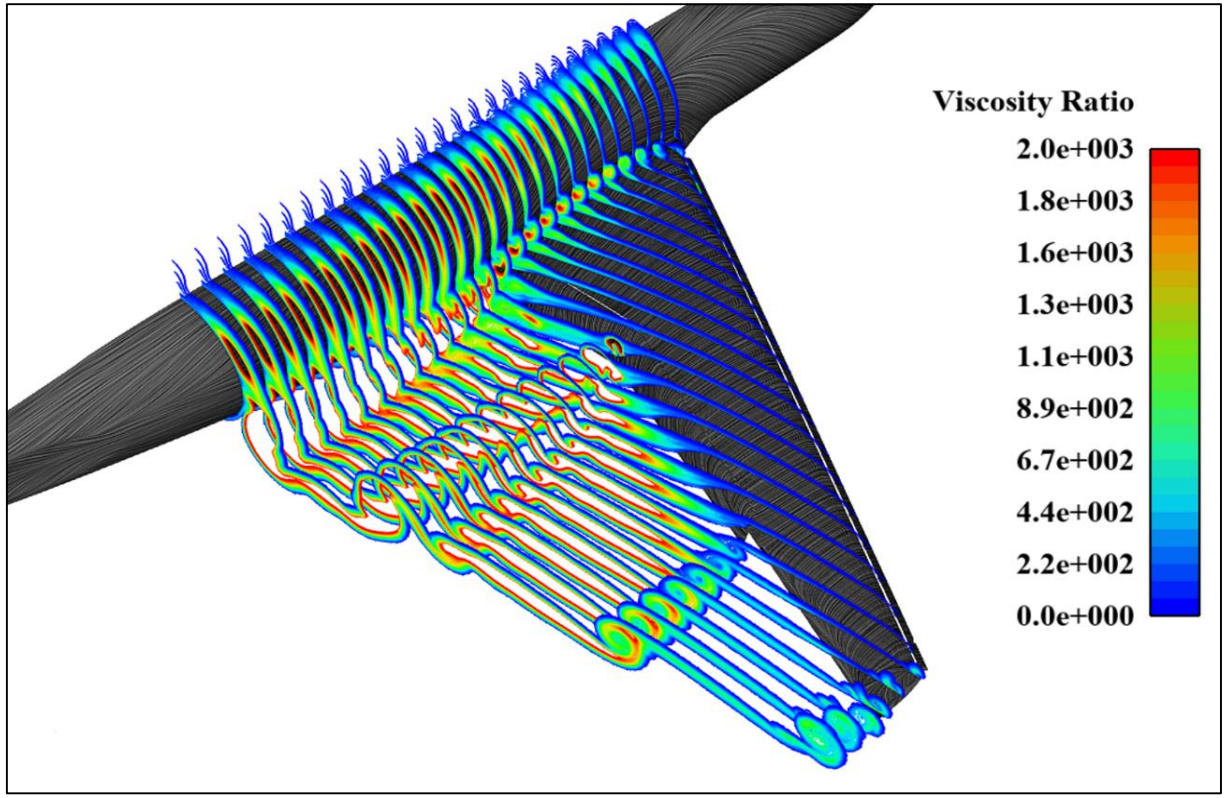
Eddy viscosity ratio contours (*xfine* mesh level)

$\alpha = 16^0$

k-ω SST (a1=0.31 default)



k-ω SST (a1=1)



Eddy Viscosity Ratio Contour Comparison - *k-ω SST (a1=0.31 default)* and *k-ω SST (a1=1)*

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Summary Case 1: HL-CRM

- The *k-ω SST* model constant *a1* was modified from its default *a1=0.31* to *a1=1*, based on the observation that, this modification largely avoided an early loss of lift for these high-lift configurations compared with experiments.
- The HL-CRM grid sensitivity computations were performed with three different *k-ω SST* turbulence model variants at angles of attack $\alpha = 8^0$ and $\alpha = 16^0$: *k-ω SST (default)*, *k-ω SST (a1=1)*, and *SST-Transition* γ-$R_{e\theta}$ *(a1=1)*.
- The maximum C_L differences between the "baseline" *(medium mesh)* and the *xfine* mesh observed were less than 1% while the C_D showed much larger drag count differences. In general, lift results showed less sensitivity to mesh density whereas larger relative differences were observed for drag.
- The most important contributor to drag was found to be the pressure drag, and grid independence for drag was not achieved. Further **grid refinement** is deemed necessary in key locations: wake regions, wake/boundary layer interaction of high-lift devices, wing-tip vortices, gaps, SOB junctions, coves etc.
- Comparisons of C_p distributions at multiple span-wise locations showed differences between the models, particularly close to the leading edge of the multi-element high lift system. All three model variants produce similar flow solutions for this "clean" high lift system configuration (without slat supports and FTFs).
- The higher drag when using *a1=1* (due to the increased eddy viscosity levels) appears to be compensated by the increased lift (by the resultant delayed separation as compared to *k-ω SST (default)*).

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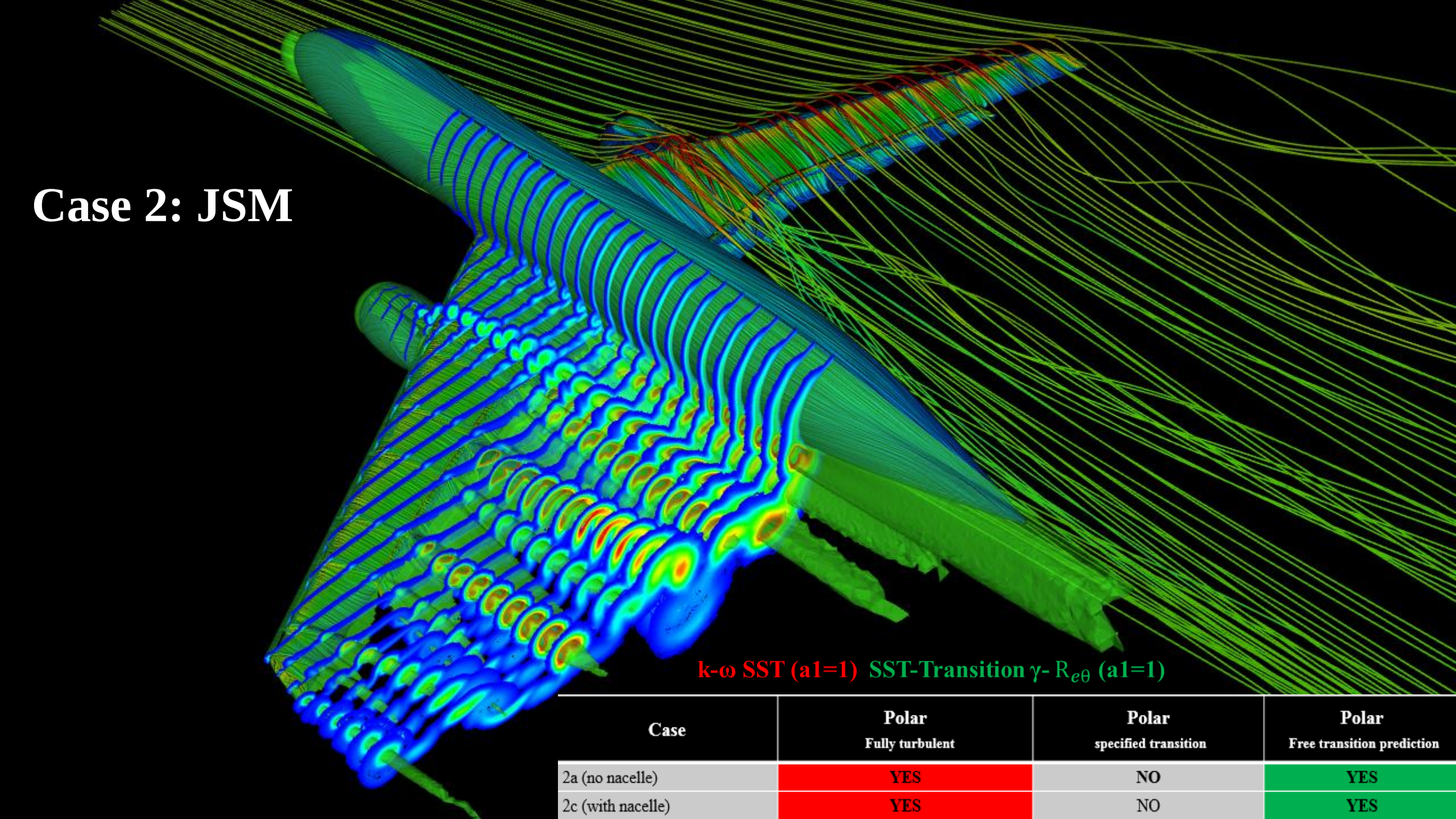
Case 2: JSM

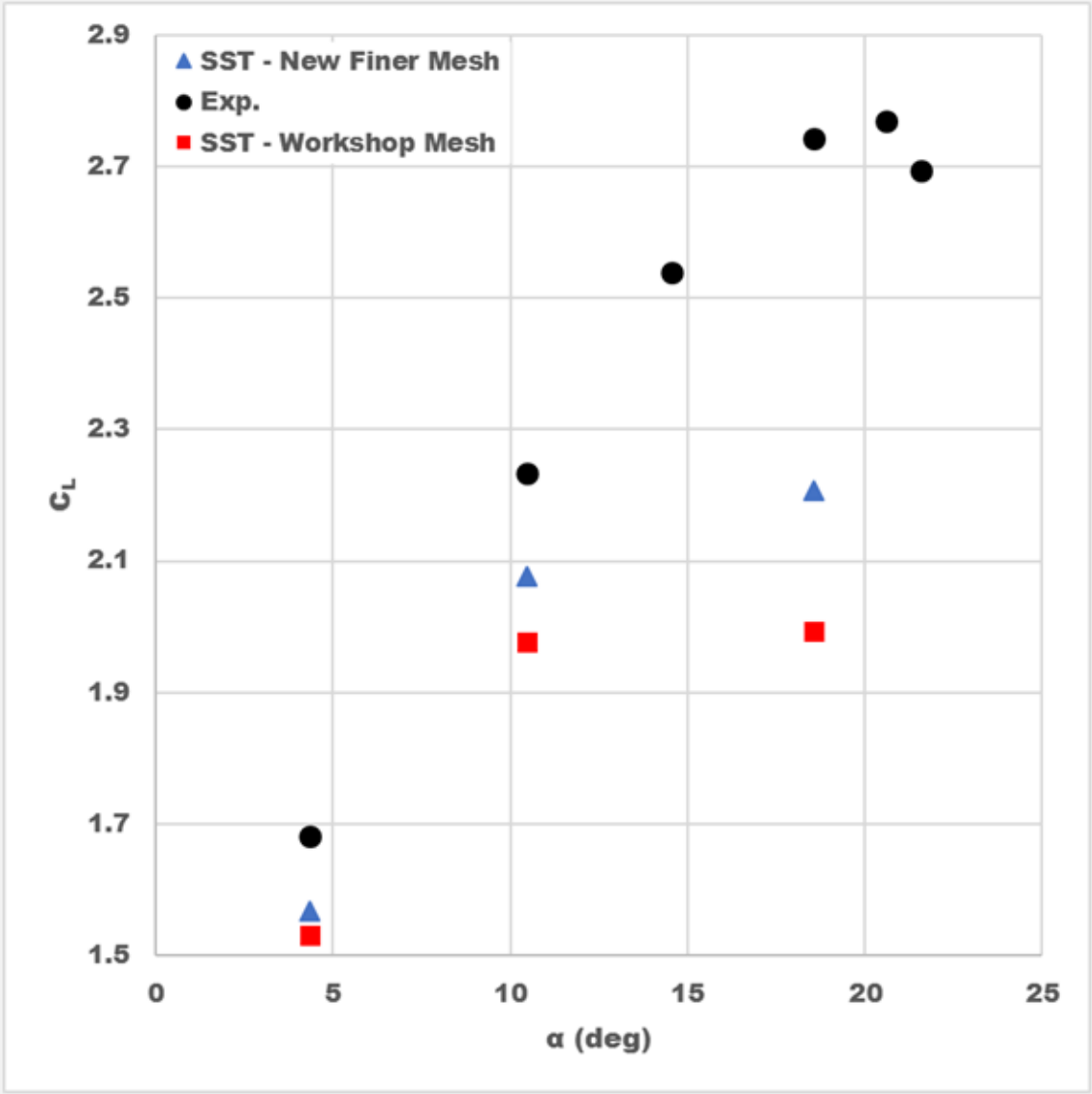


k-ω SST (a1=1) SST-Transition γ- $R_{e\theta}$ (a1=1)

Case	Polar Fully turbulent	Polar specified transition	Polar Free transition prediction
2a (no nacelle)	YES	NO	YES
2c (with nacelle)	YES	NO	YES

a1 =1 coefficient

- **Early onset of separation when using the *default* SST model**
  - **It is also possible that further mesh refinement is needed and could yield improved results**
- **"*a1=1* results in delayed separation for adverse pressure gradient flow predictions"[1]**
- **Systematic investigation of the performance of the SST model on high-lift configurations is needed**



[1]*Hiroshi Kato, Keiichi Ishiko, and Akira Yoshizawa. "Optimization of Parameter Values in the Turbulence Model Aided by Data Assimilation", AIAA Journal, Vol. 54, No. 5 (2016), pp. 1512-1523.*

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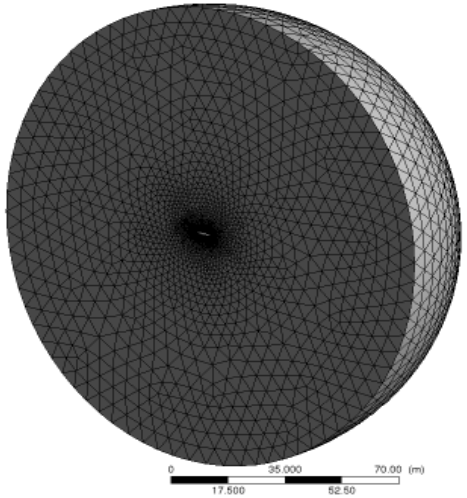
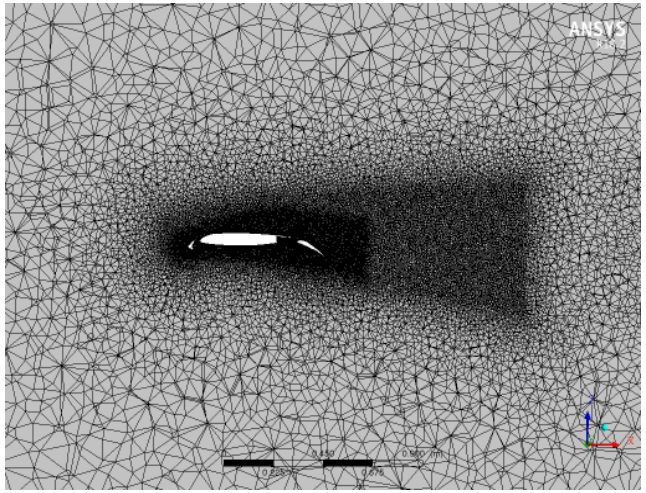
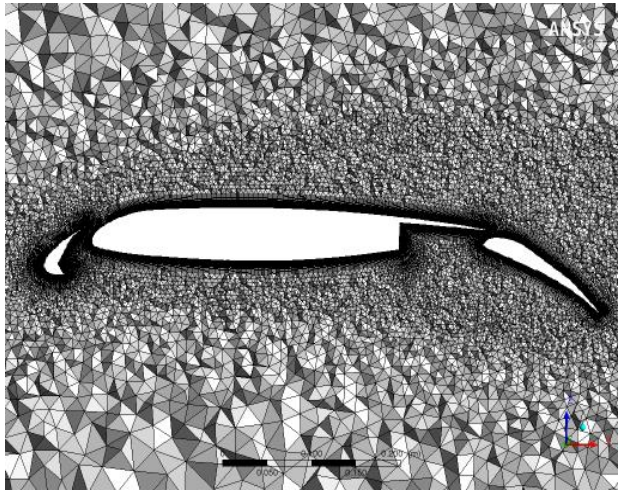
Case 2: JSM Grid Overview

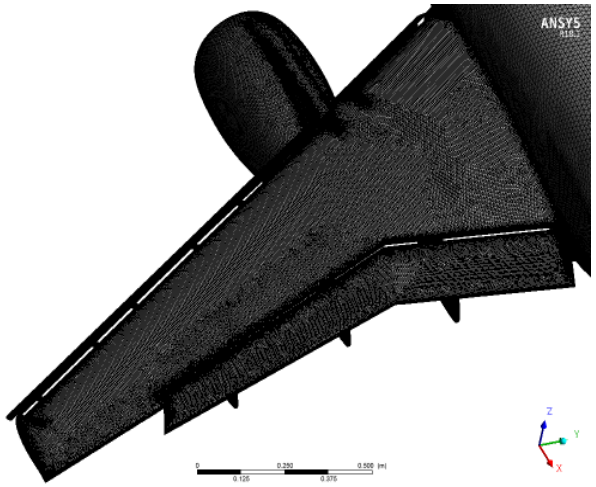
- Case 2a, 2c: 030-ANSA Mesh, Mixed Volume Elements (Prism-Pyra-Tetra)

JAXA JSM Configuration	Grid resolution level	Number of Nodes	Number of Cells	Y^+ at walls	Initial wall spacing, Δy (normal dist.)	Number of cells on trailing edges
Wing-body	Fine	82,818,156	165,022,648	4/9	0.00242 mm	12
Wing-body-nacelle-pylon	Fine	94,648,886	189,408,926	4/9	0.00242 mm	12









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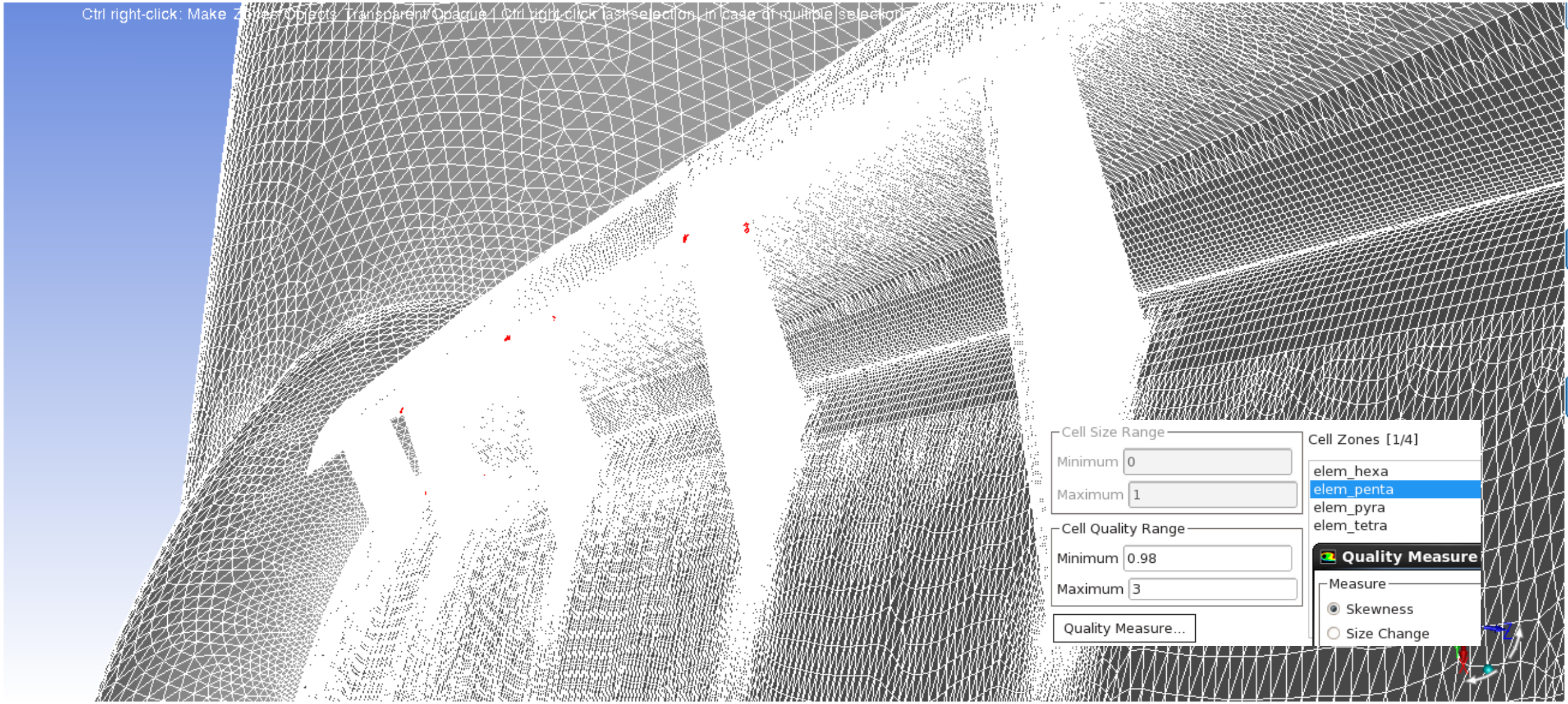
JAXA (Fine mesh)

Skewness



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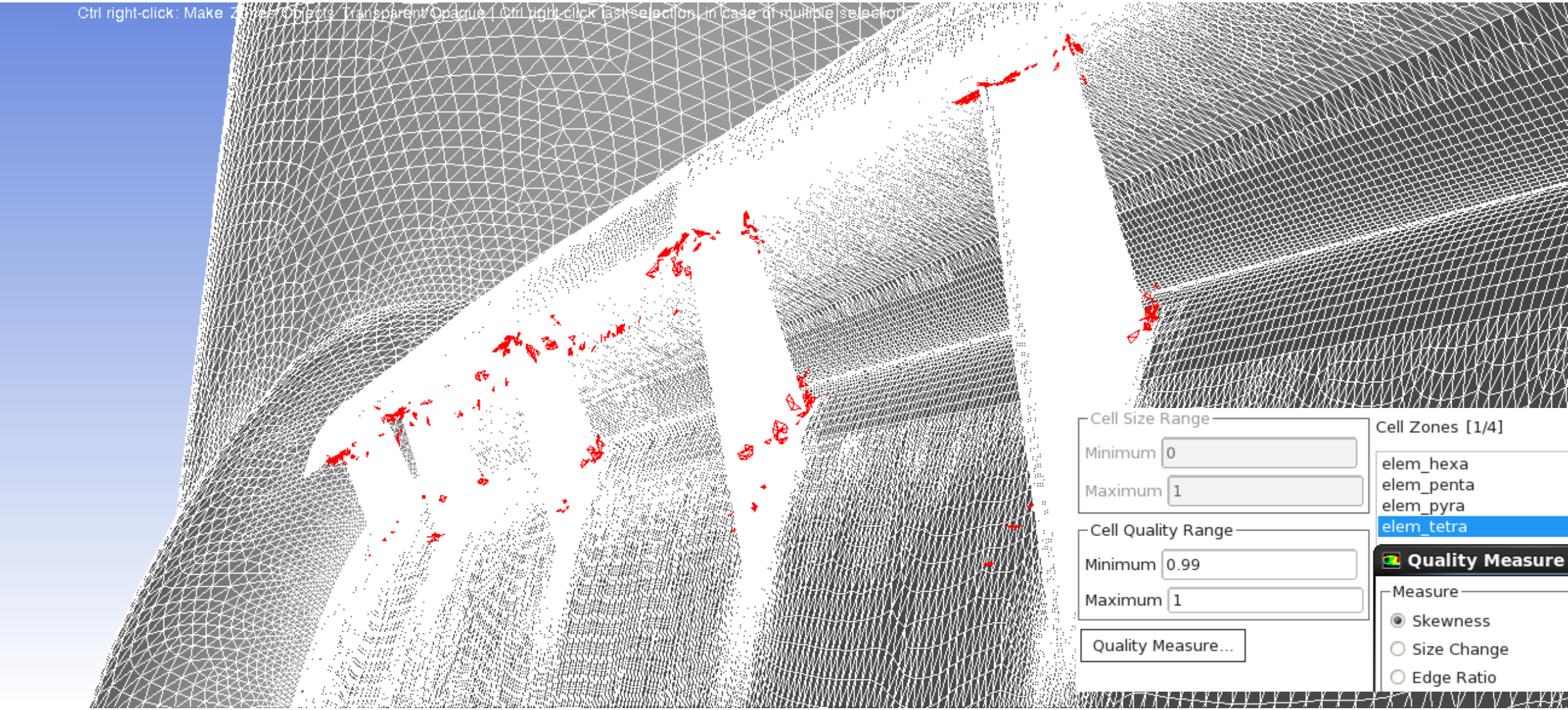
JAXA (Fine mesh)

Skewness



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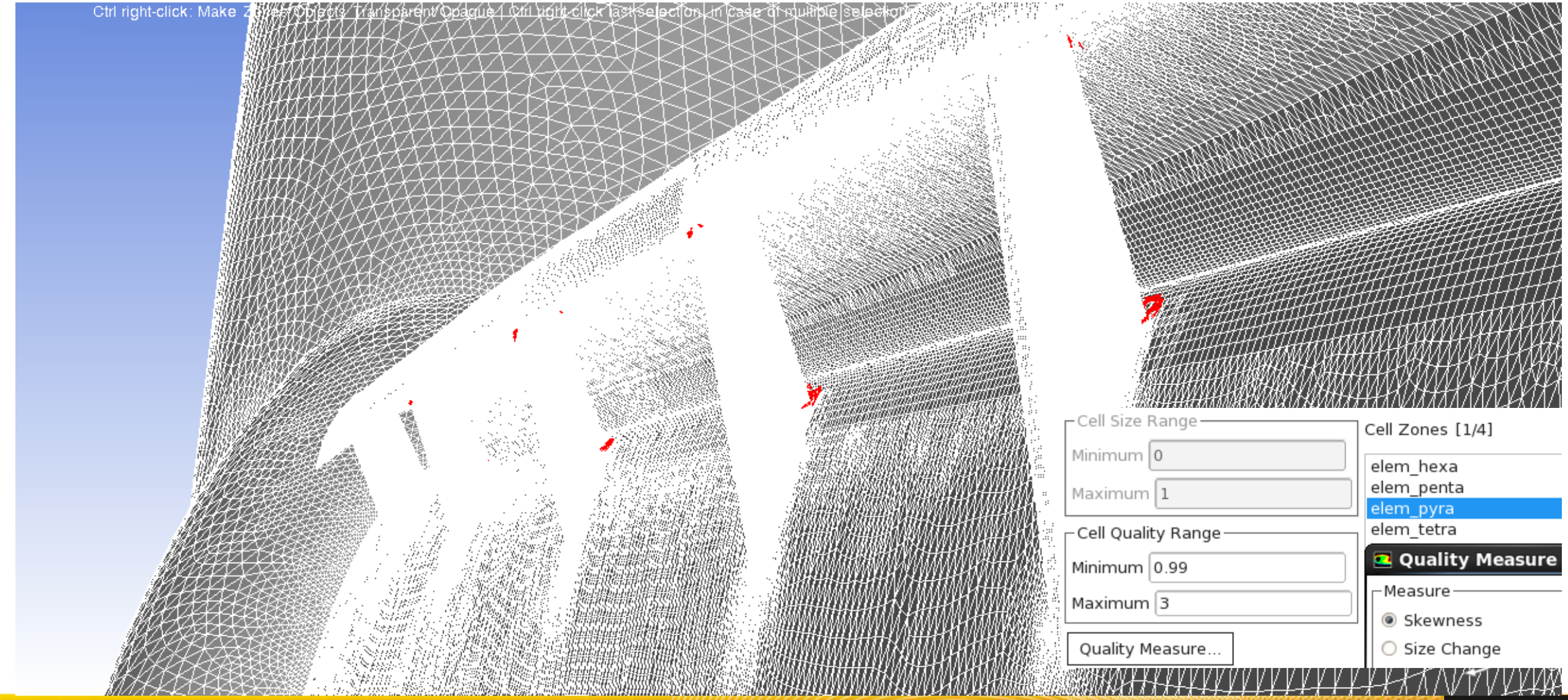
JAXA (Fine mesh)

Skewness



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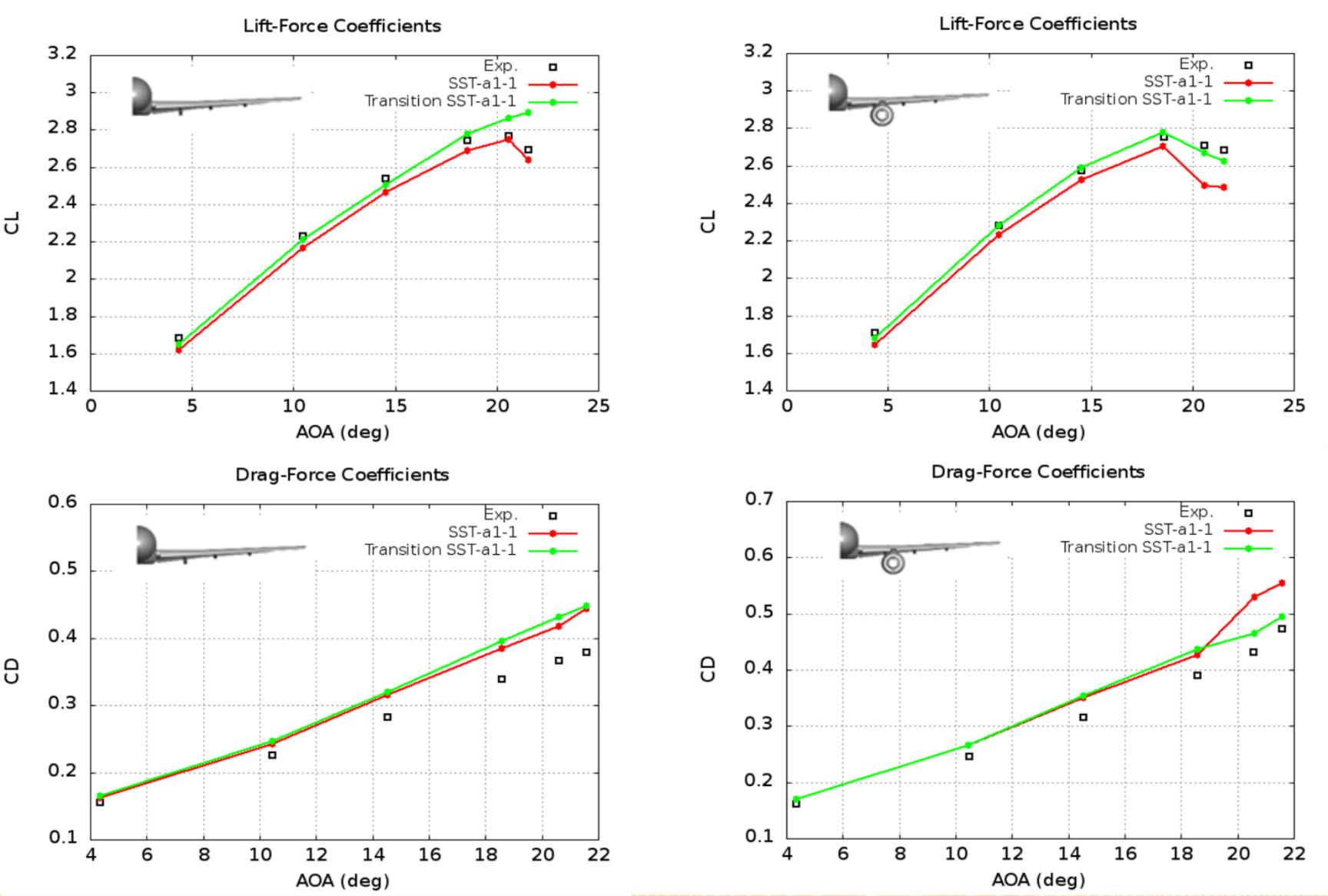
Case 2 : JSM Results

Integral force coefficients plots (*fine* mesh level) - k-ω SST (a1=1), SST-Transition γ-$R_{e\theta}$ (a1=1)



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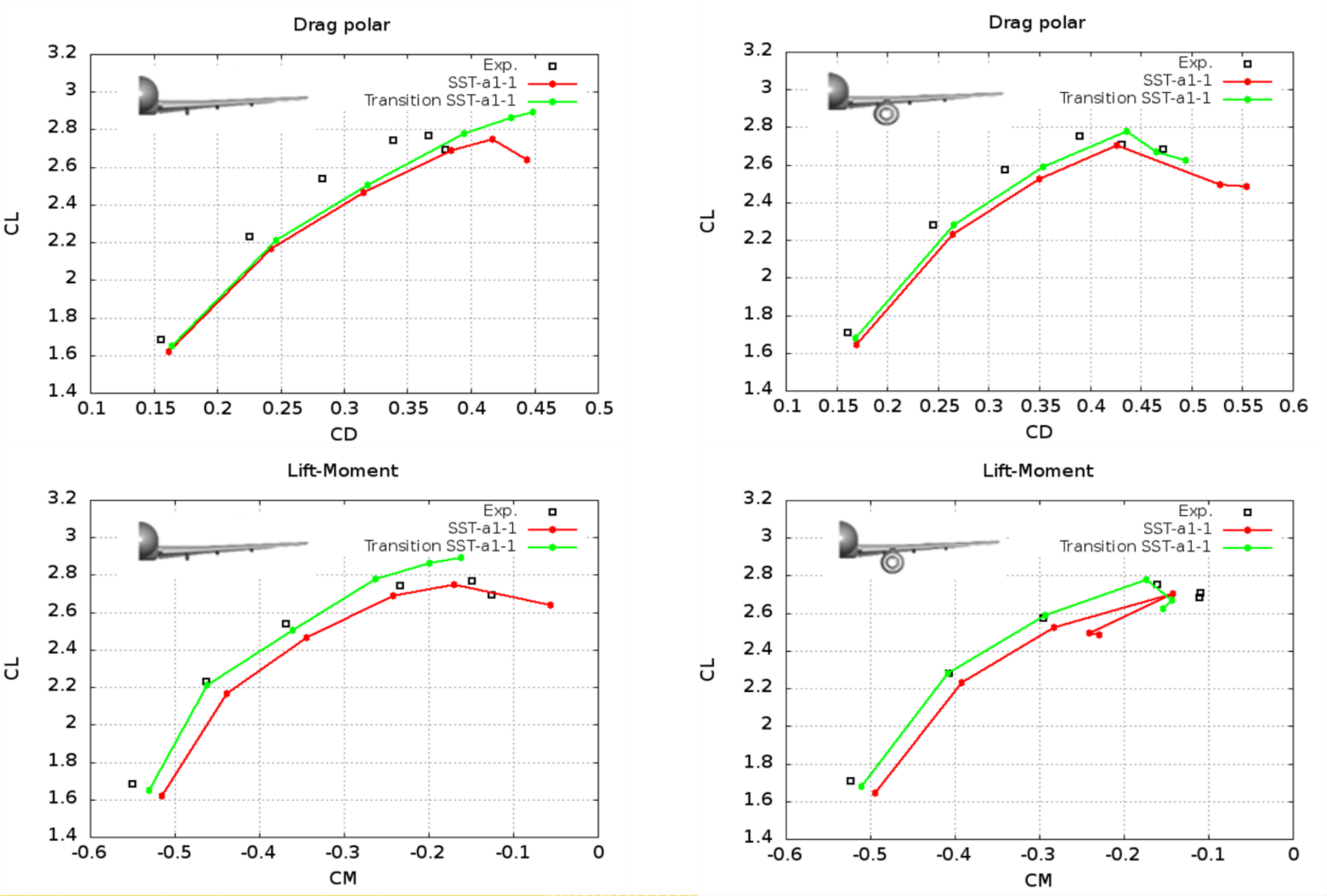
Case 2 : JSM Results

Drag polar & lift-moment plots (*fine* mesh level) - k-ω SST (a1=1), SST-Transition γ-$R_{e\theta}$ (a1=1)



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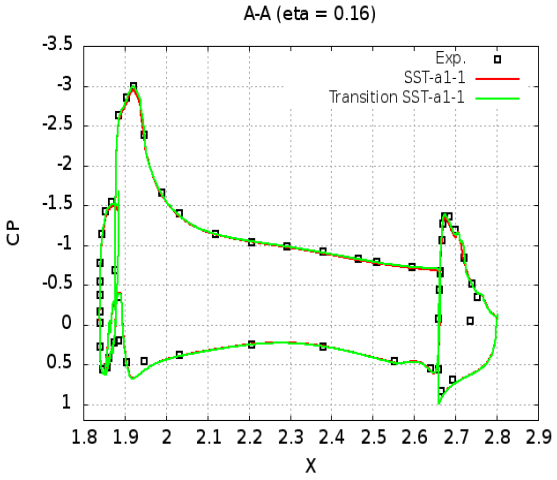
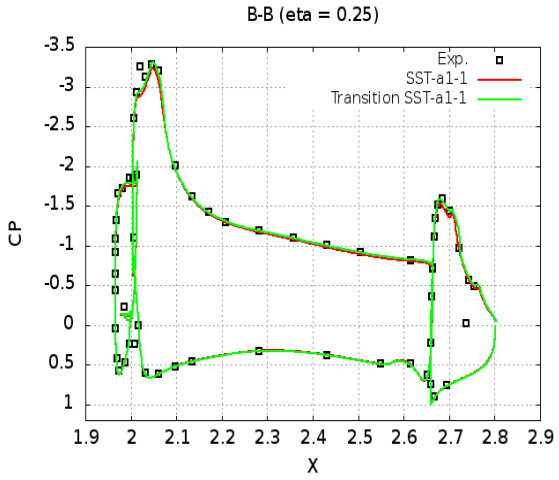
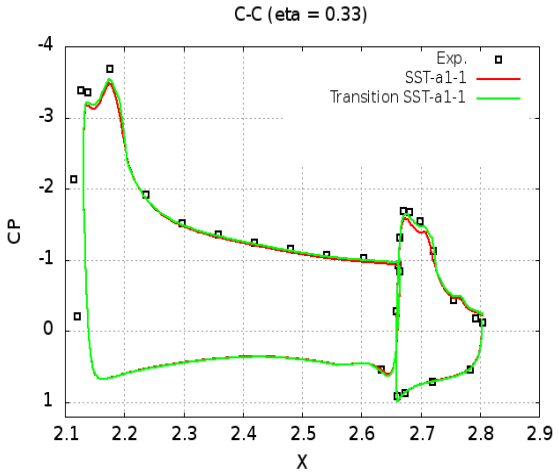
Case 2a: JSM Results

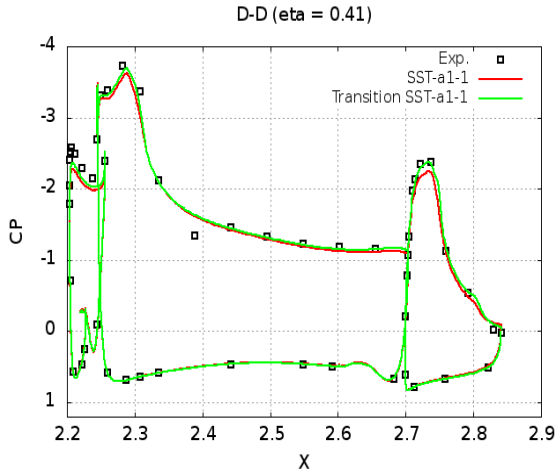
Pressure coefficient plots, *fine* mesh level - **JSM-WB**

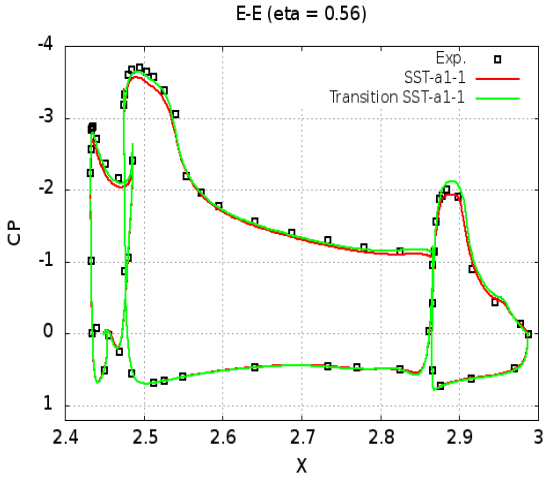
$\alpha = 10.47^0$

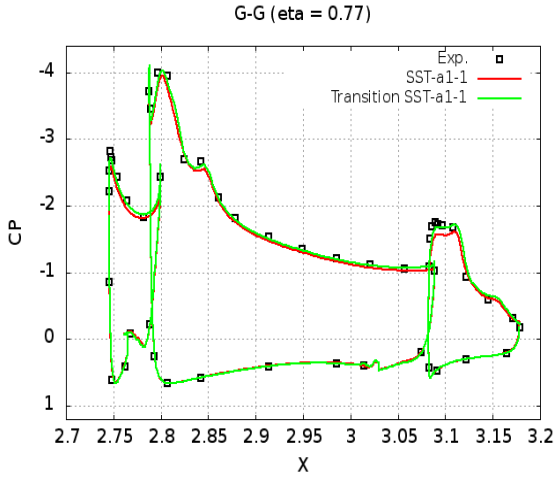


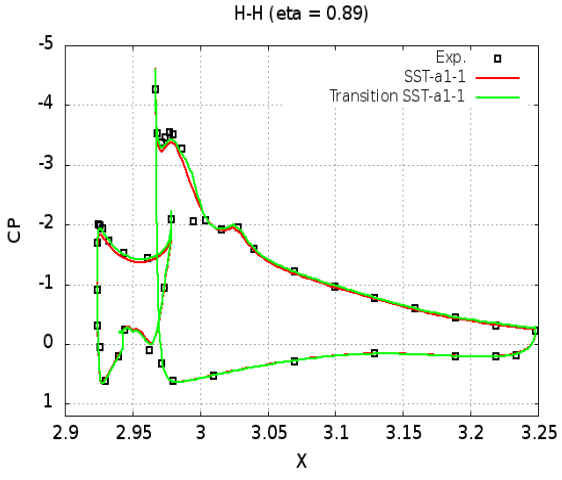


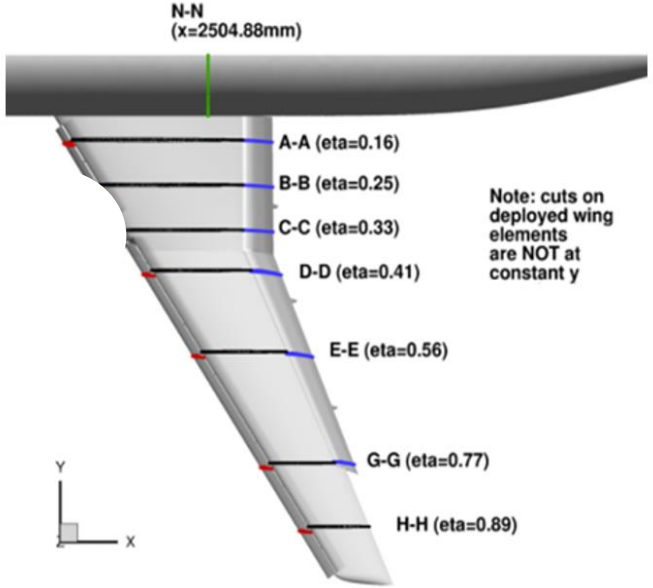












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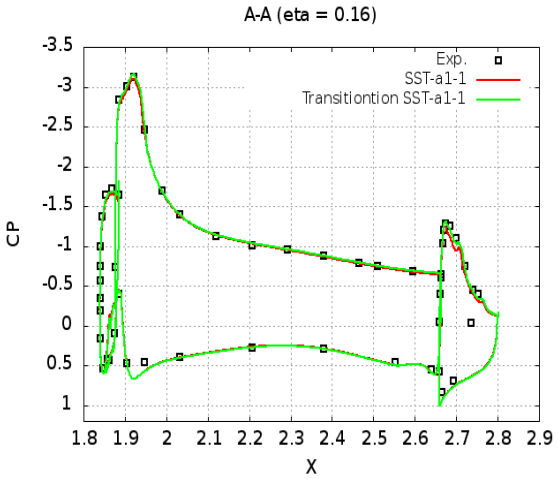
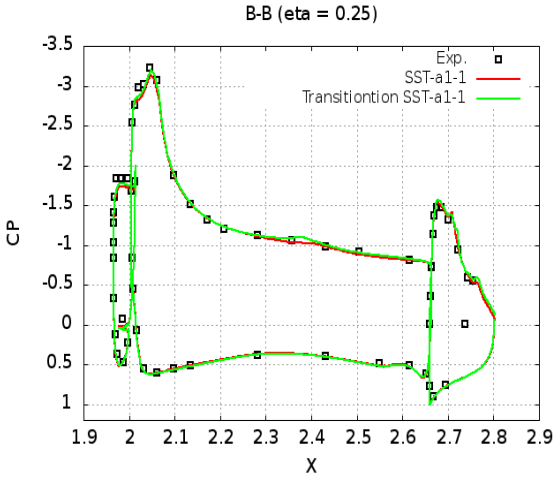
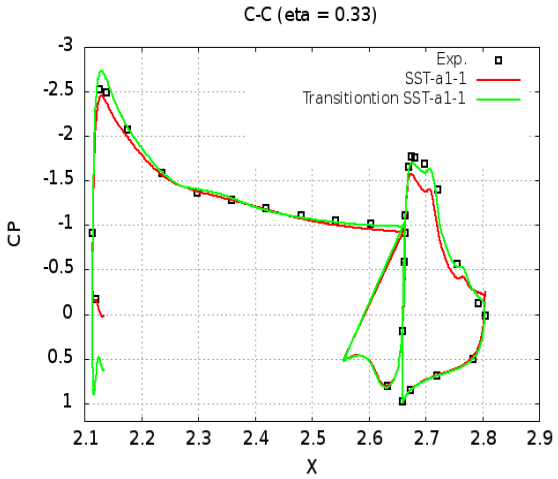
Case 2c: JSM Results

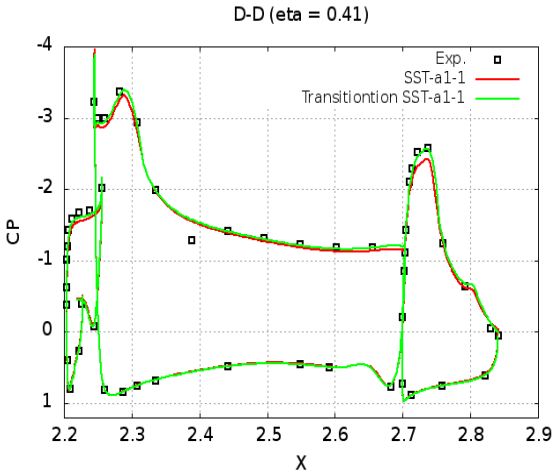
Pressure coefficient plots, *fine* mesh level - **JSM-WBNP**

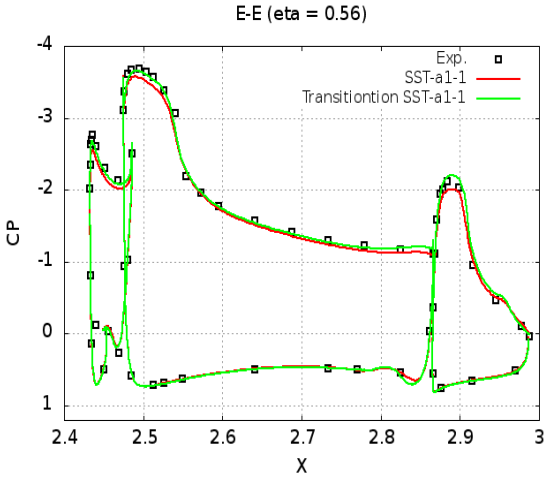
$\alpha = 10.47^0$

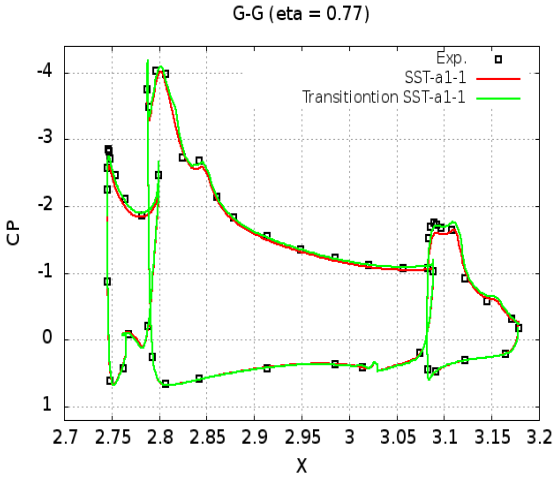


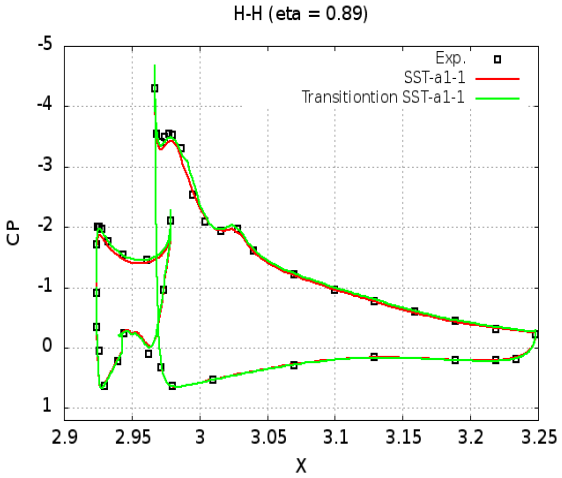


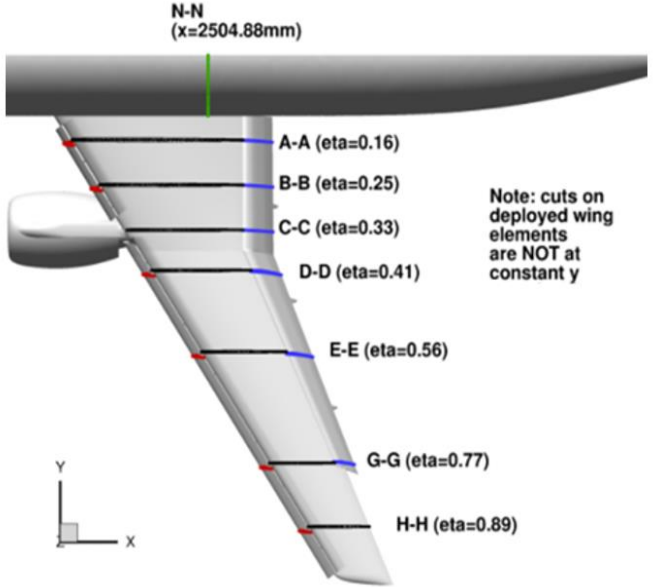












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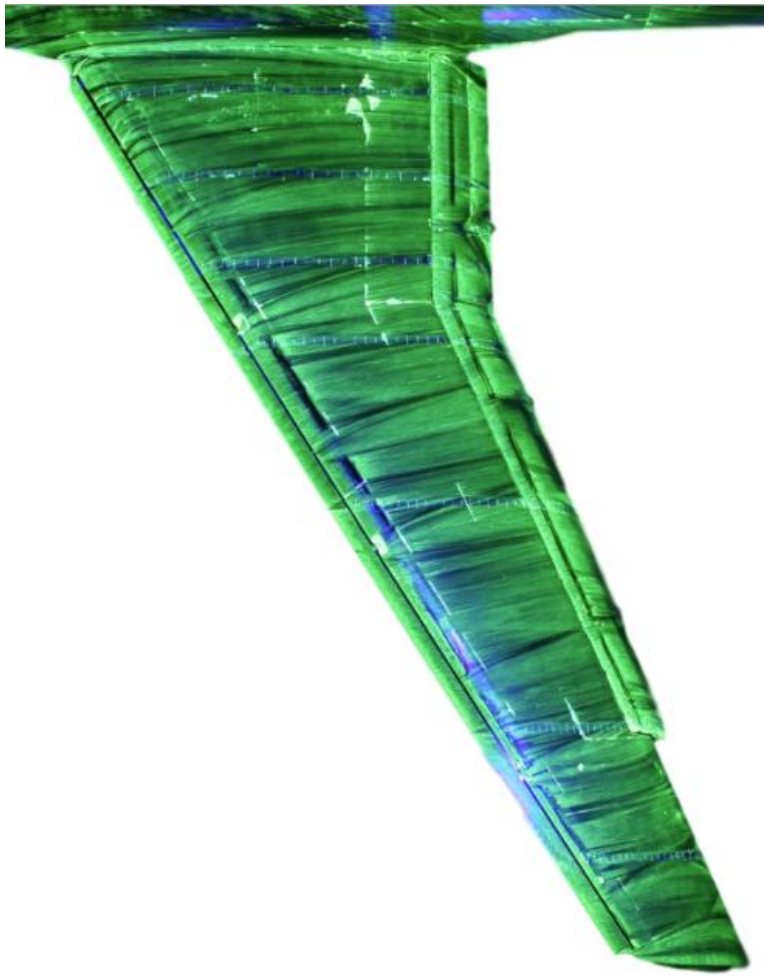
Case 2a: JSM Results

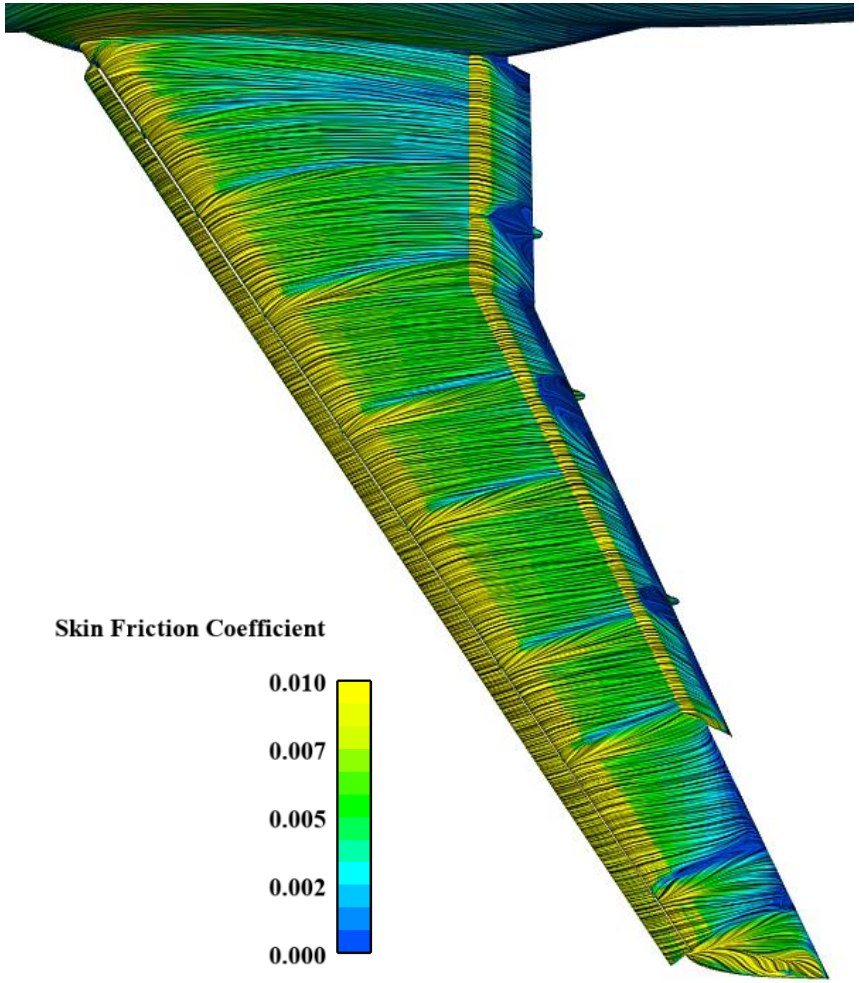
Oil flow visualization, fine mesh - JSM-WB

$\alpha = 10.47^0$

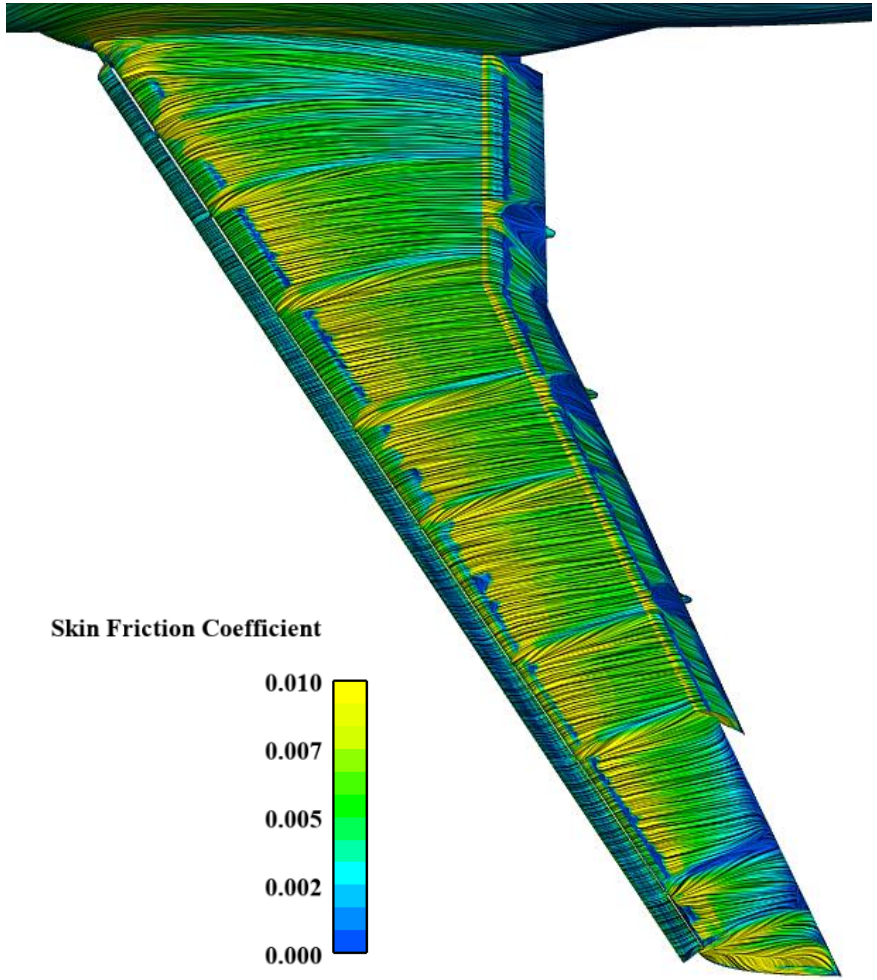
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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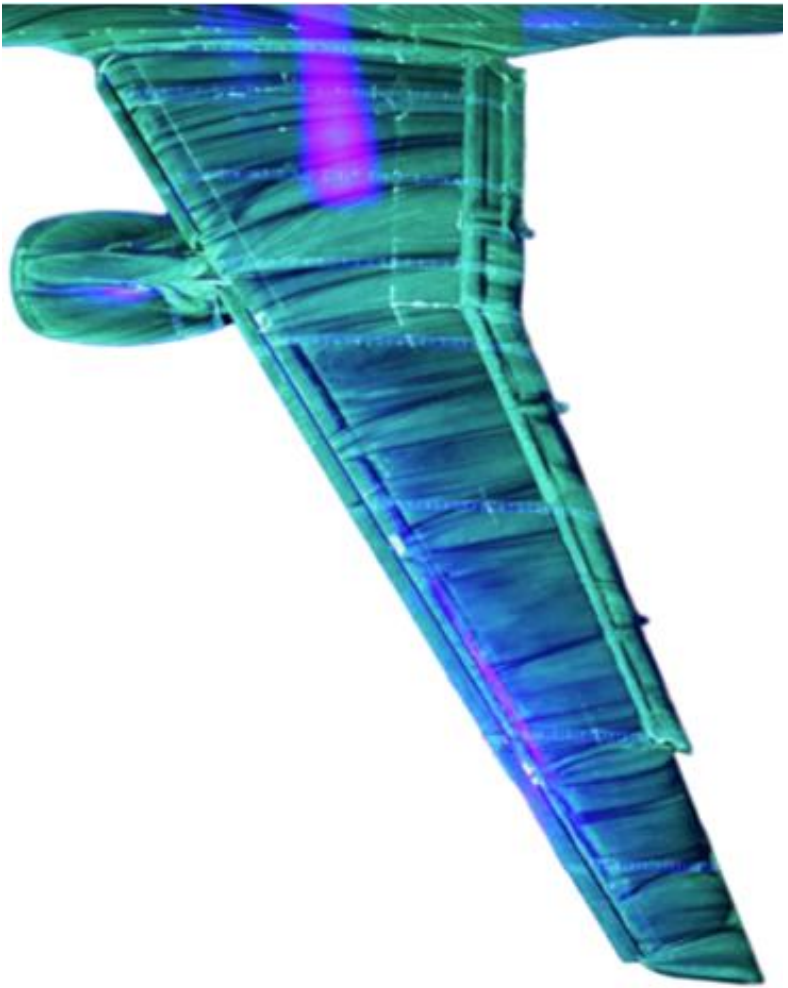
Case 2c : JSM Results

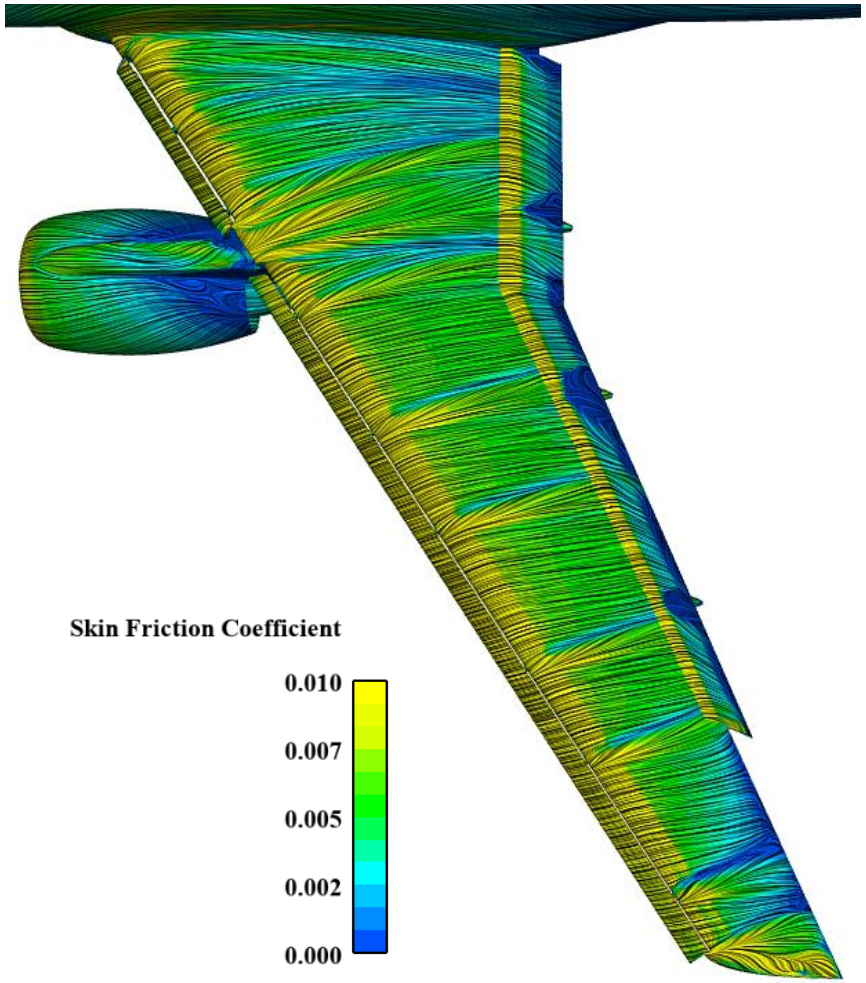
Oil flow visualization, fine mesh - JSM-WBNP

$\alpha = 10.47^0$

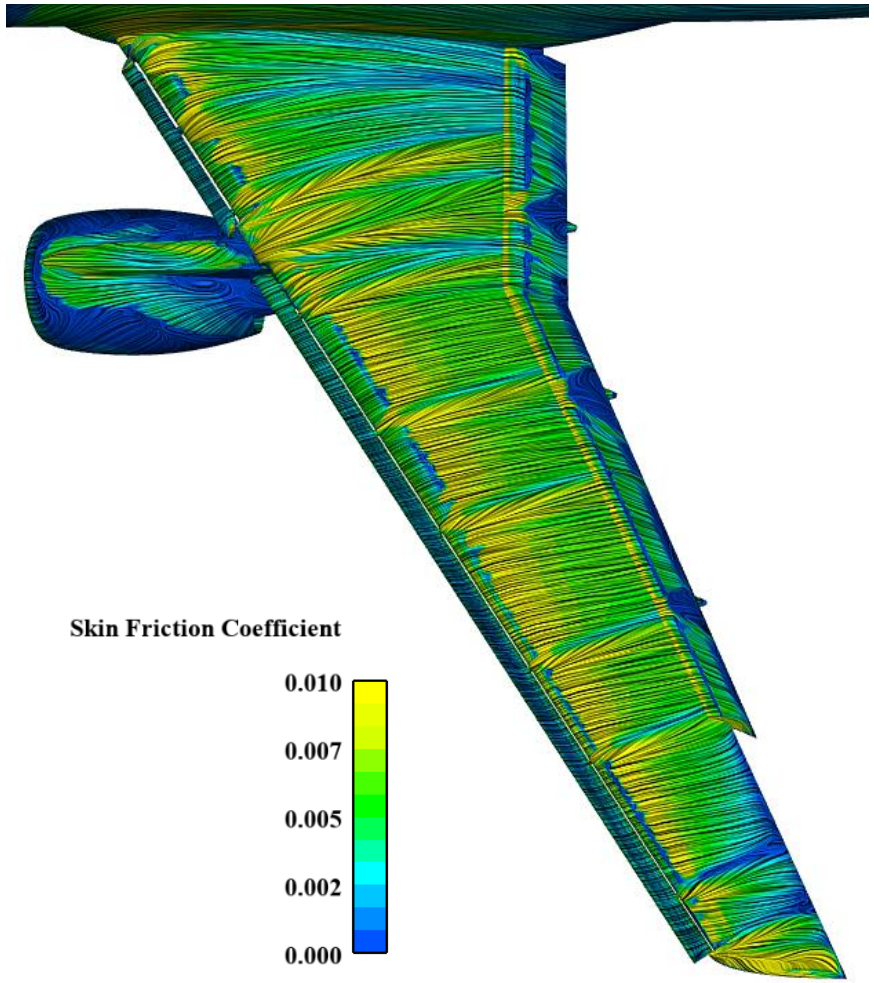
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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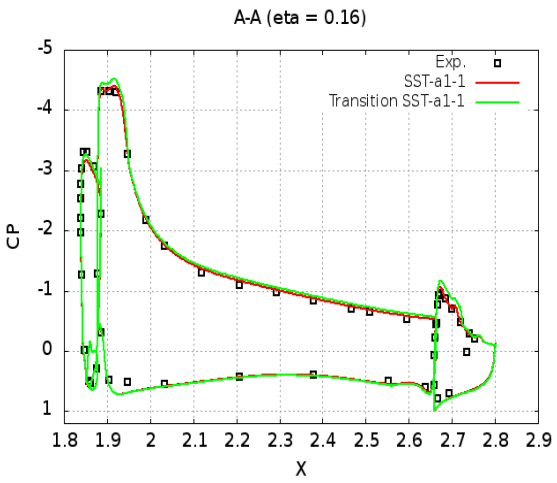
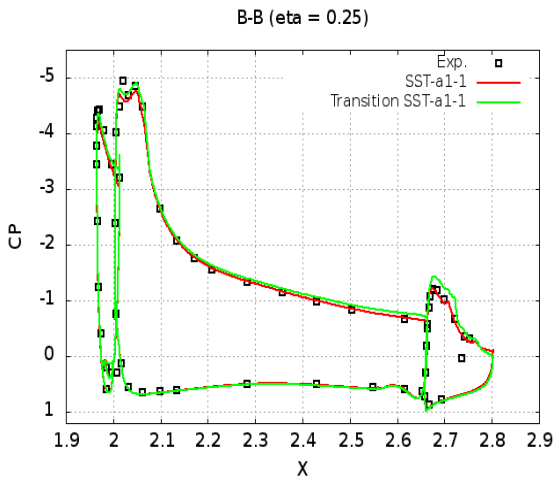
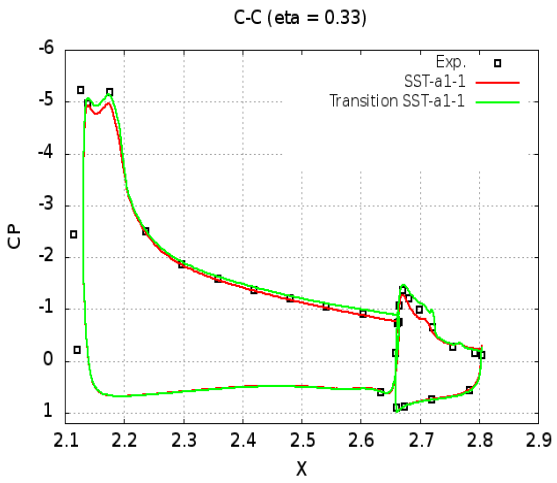
Case 2a: JSM Results

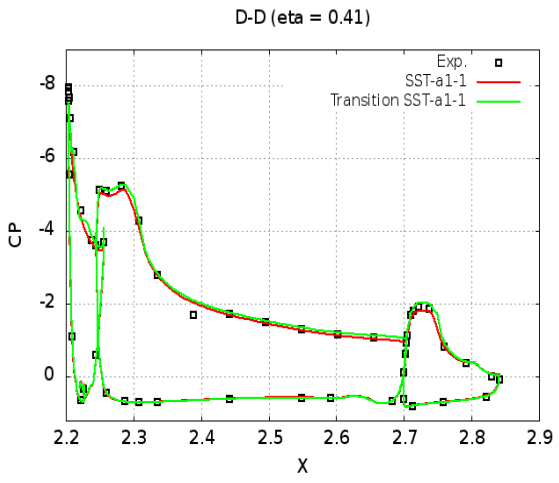
Pressure coefficient plots, *fine* mesh level - JSM-WB

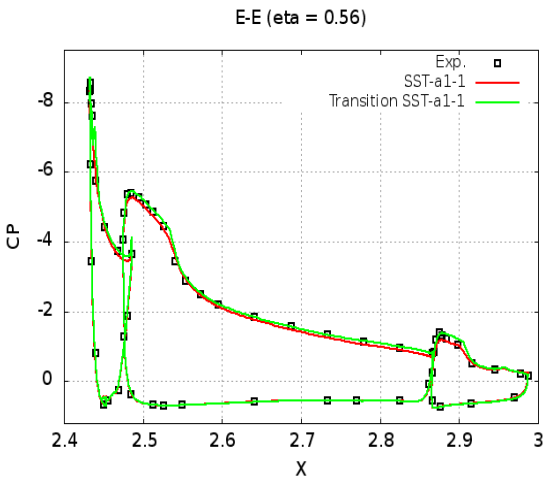
$\alpha = 18.58^0$

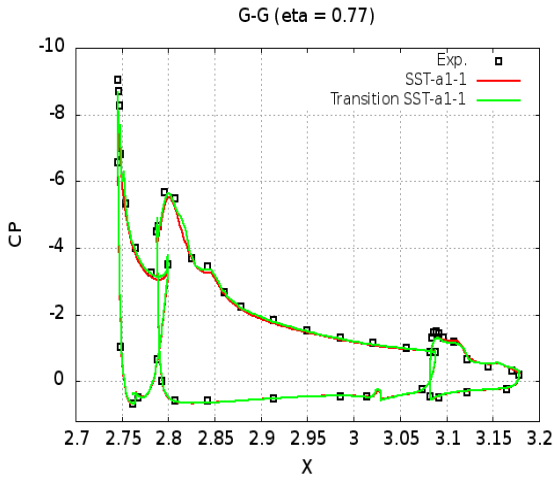


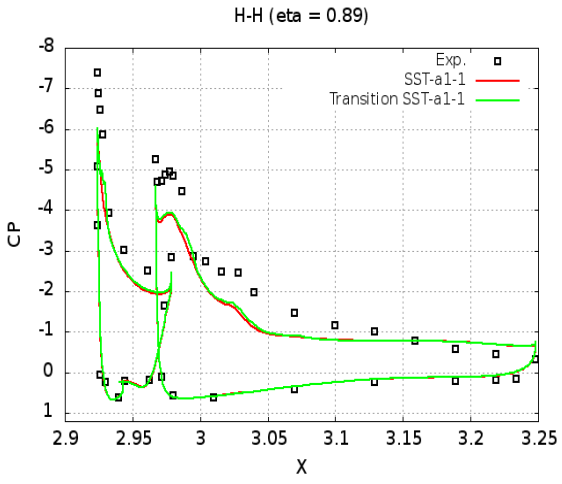


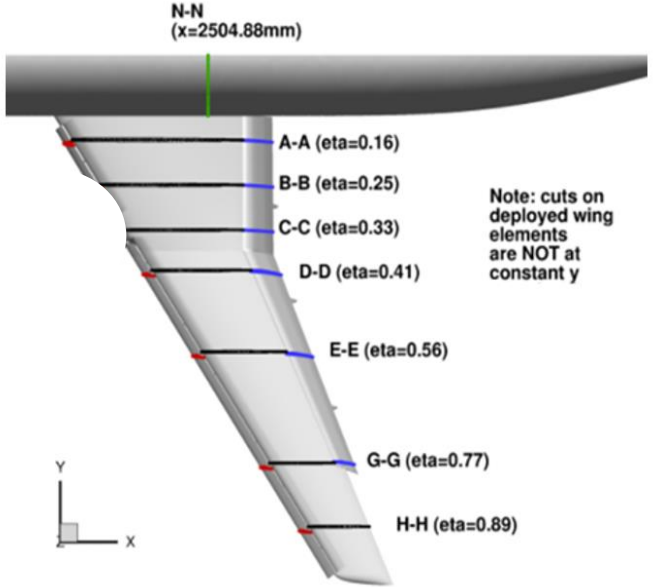












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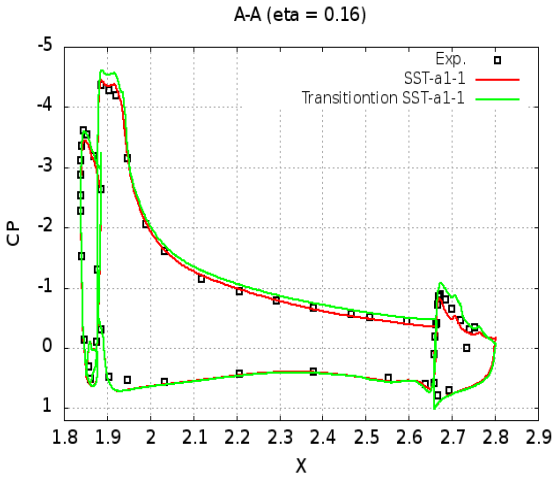
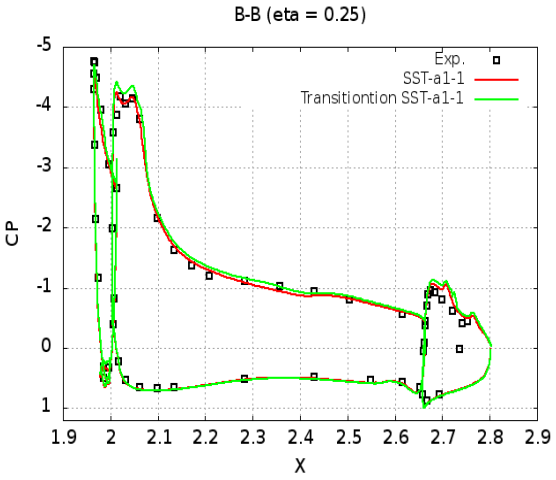
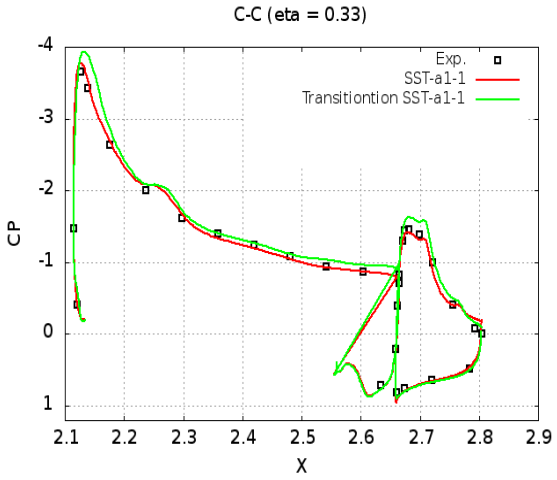
Case 2c: JSM Results

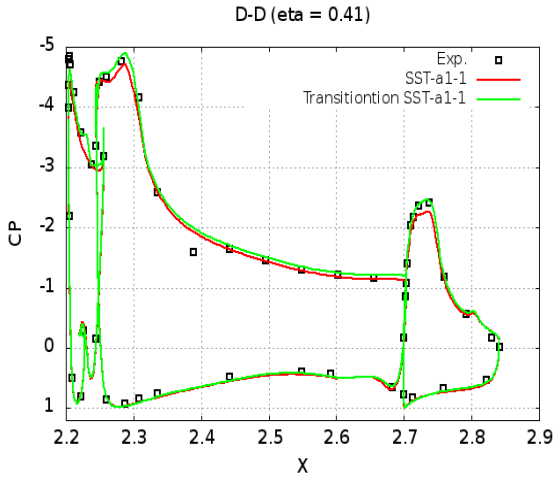
Pressure coefficient plots, *fine* mesh level - **JSM-WBNP**

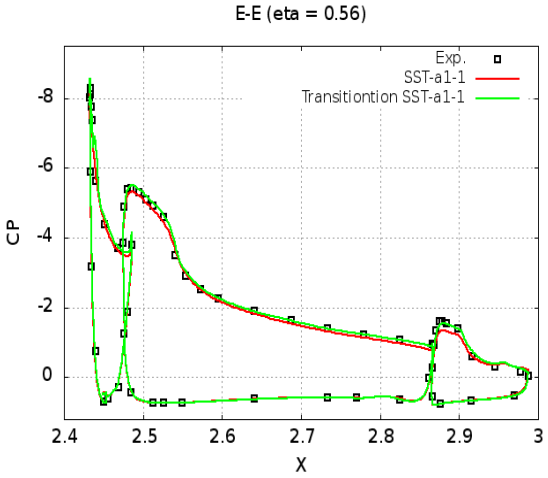
$\alpha = 18.58^0$

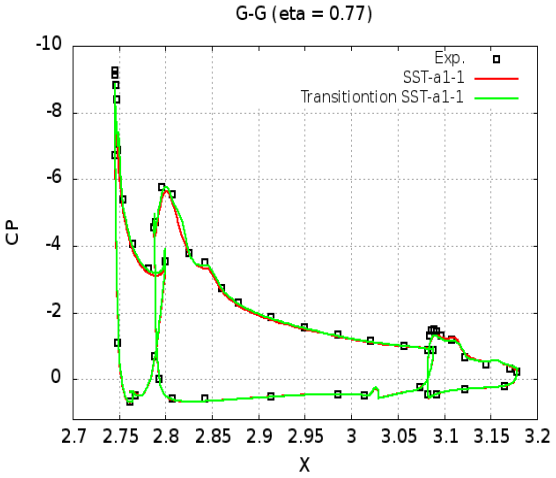


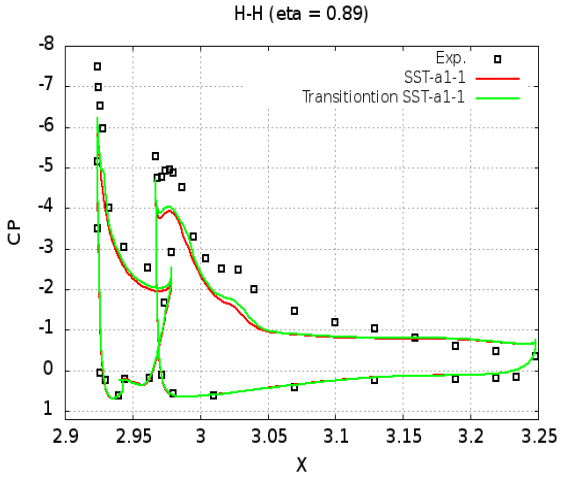


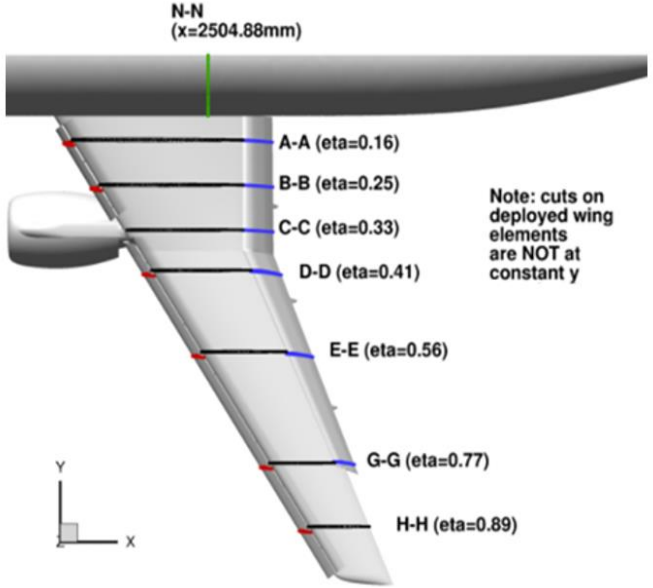












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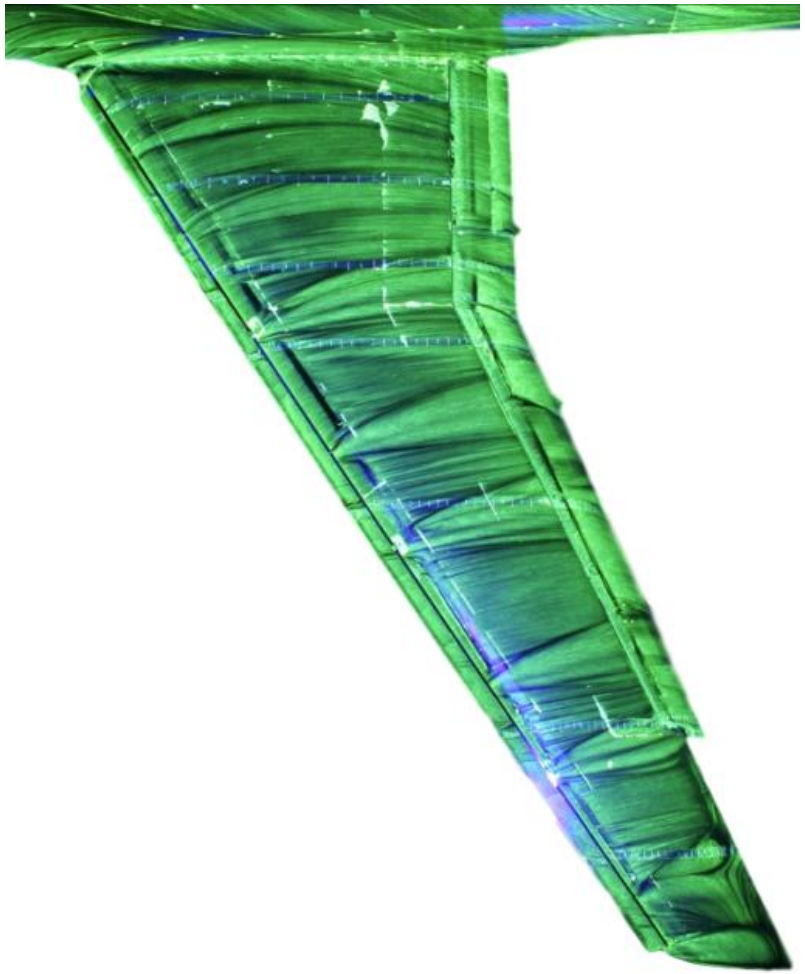
Case 2a : JSM Results

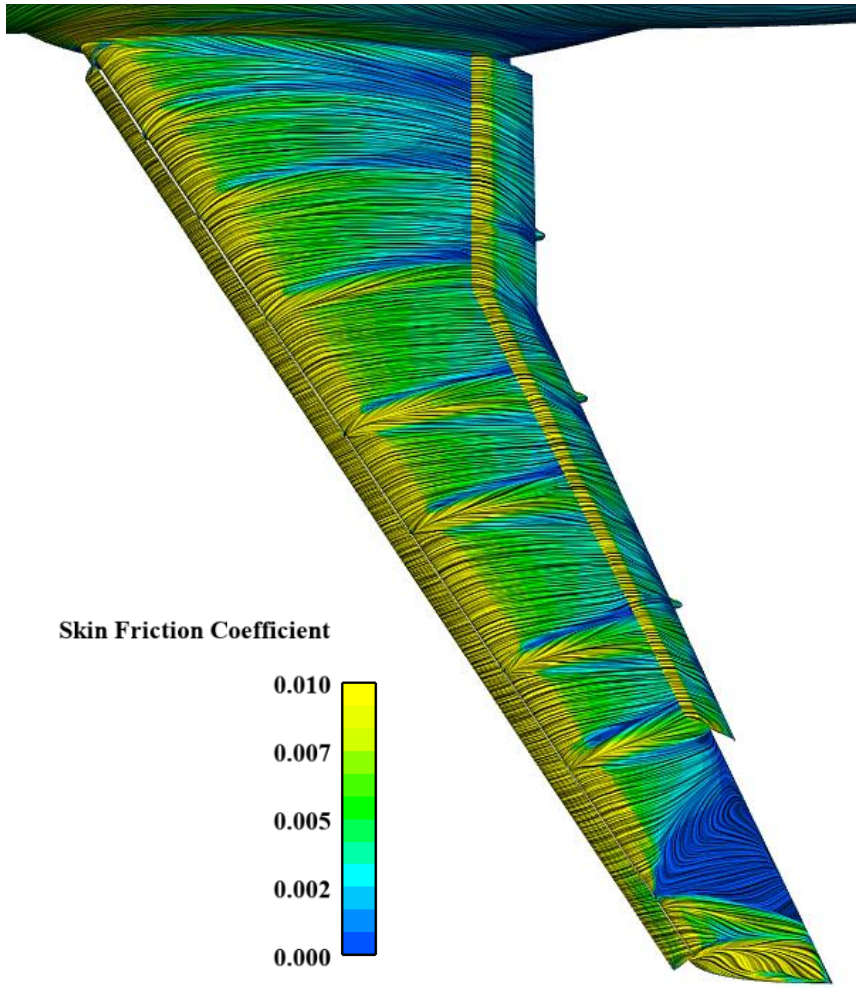
Oil flow visualization, fine mesh - JSM-WB

$\alpha = 18.58^0$

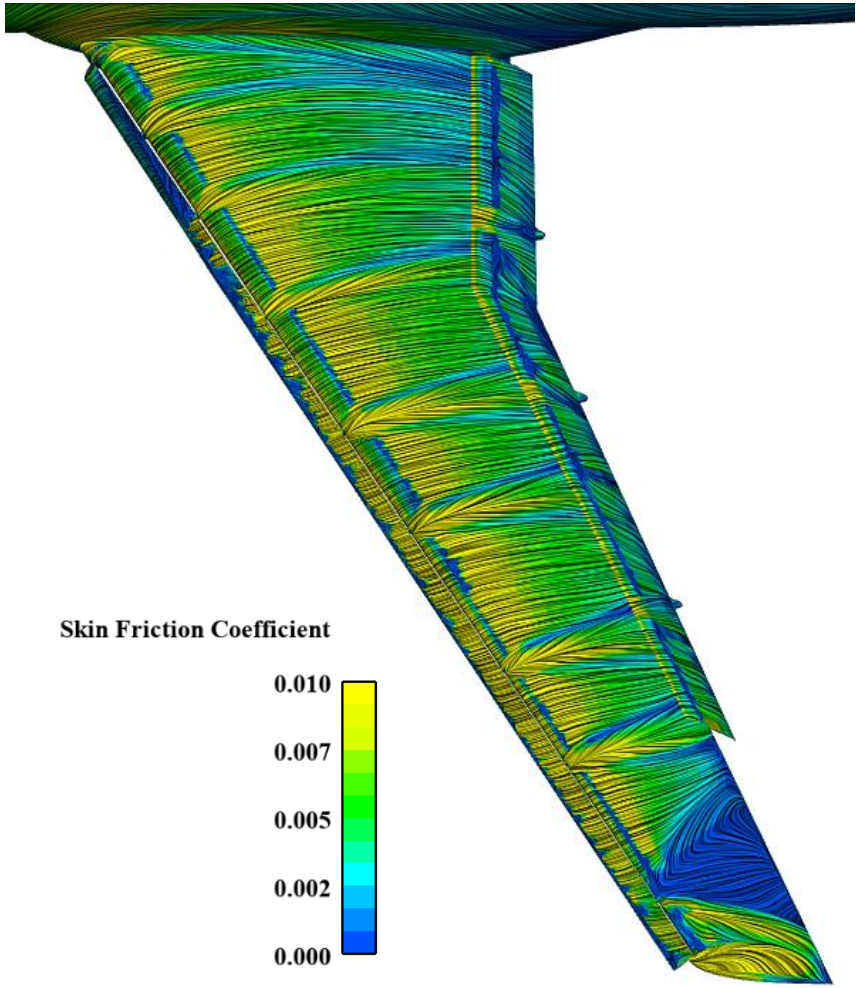
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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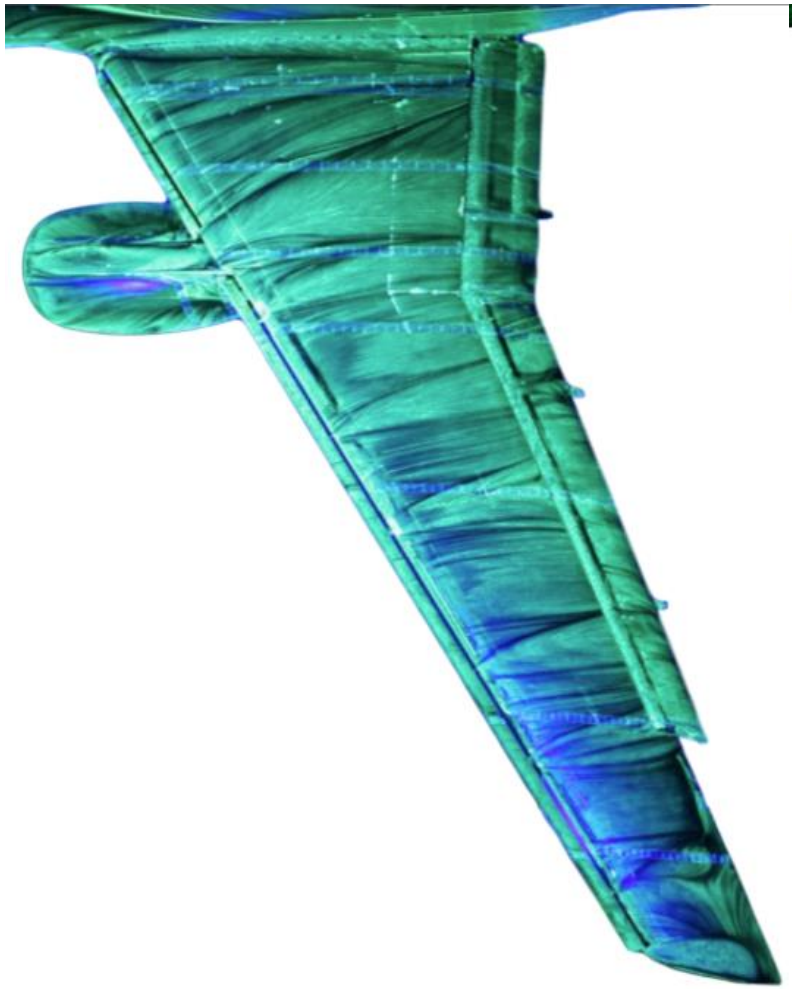
Case 2c : JSM Results

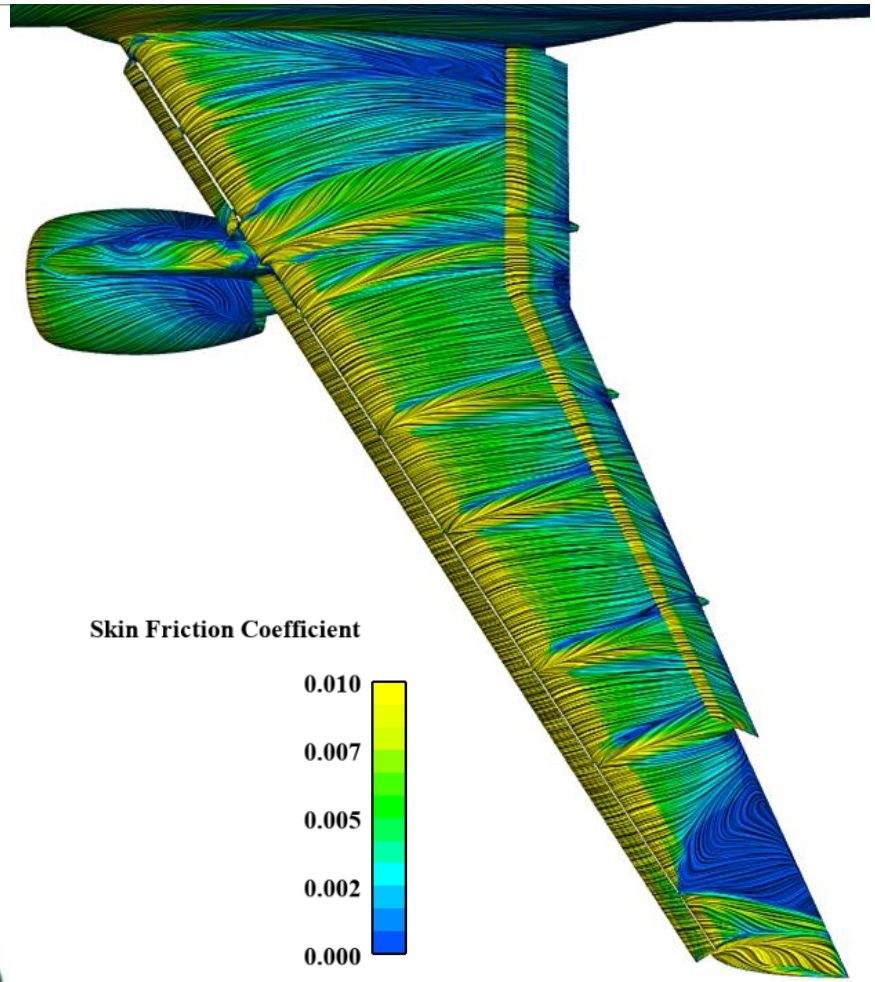
Oil flow visualization, fine mesh - JSM-WBNP

$\alpha = 18.58^0$

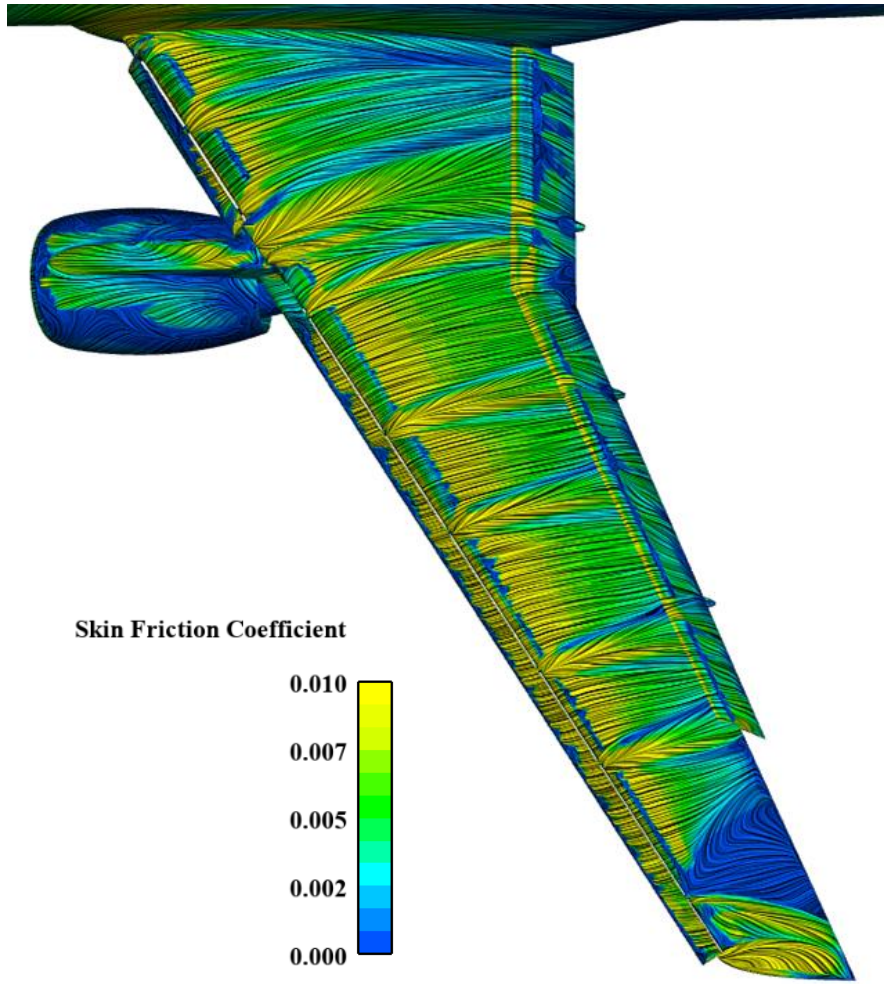
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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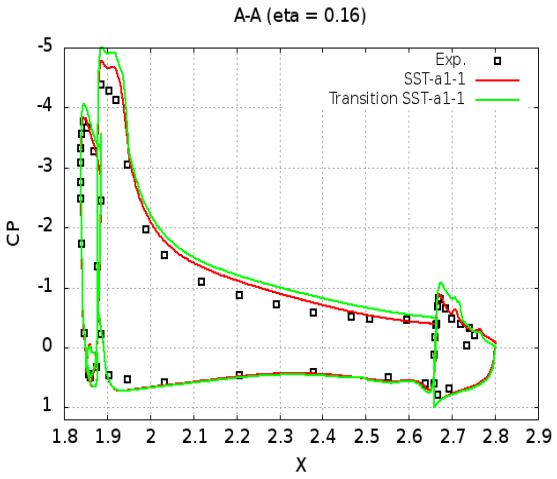
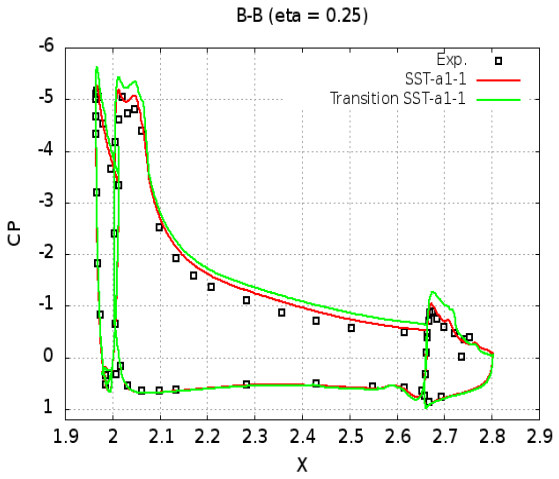
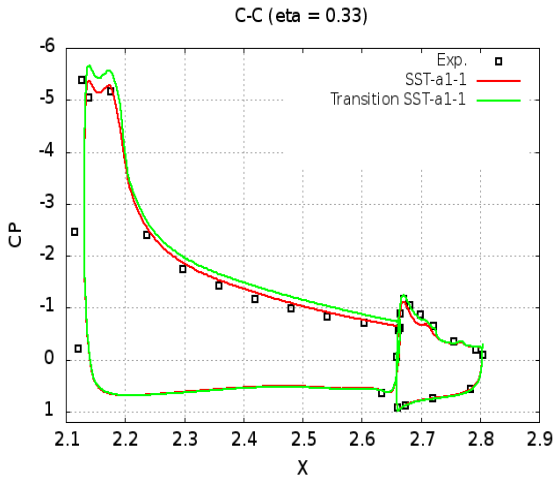
Case 2a: JSM Results

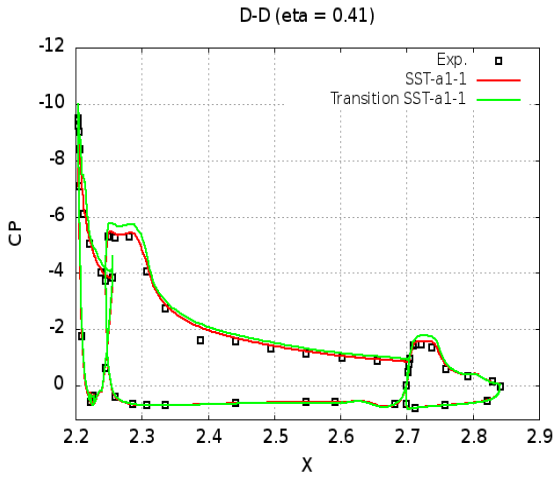
Pressure coefficient plots, *fine* mesh level - JSM-WB

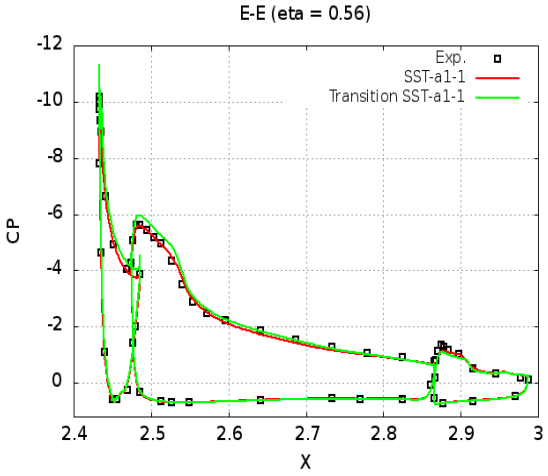
$\alpha = 21.57^0$

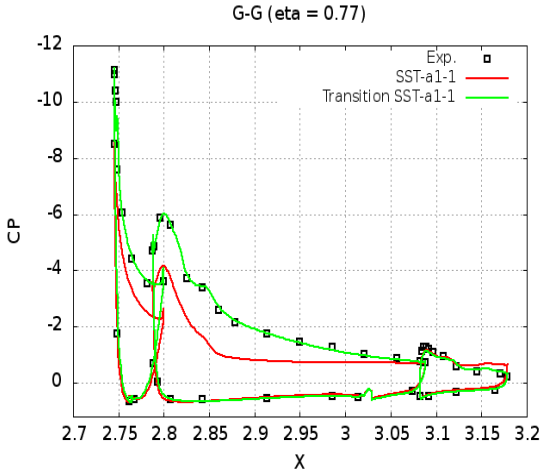


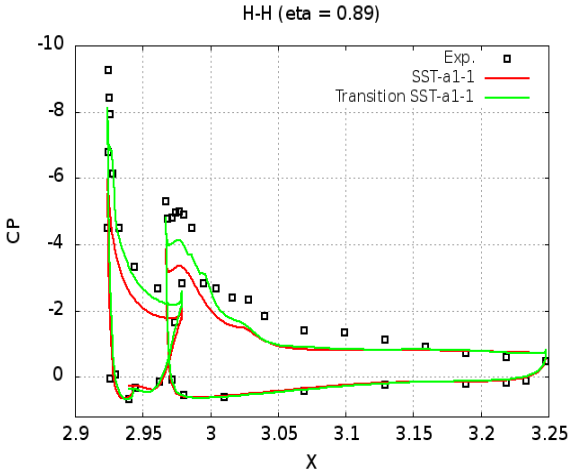


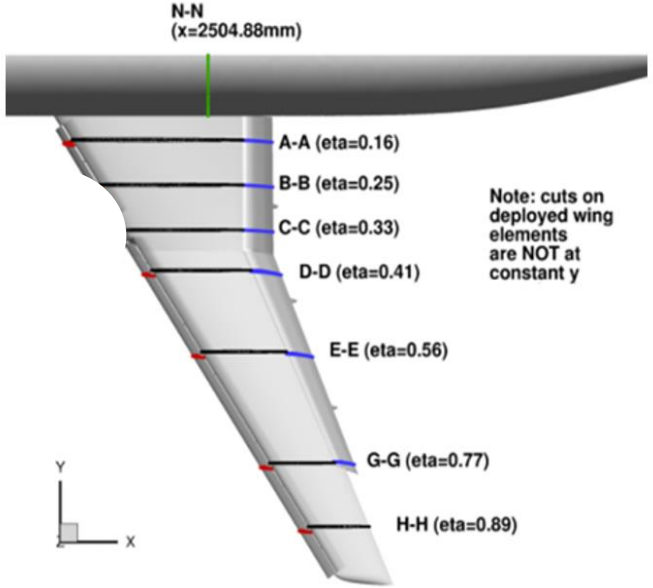












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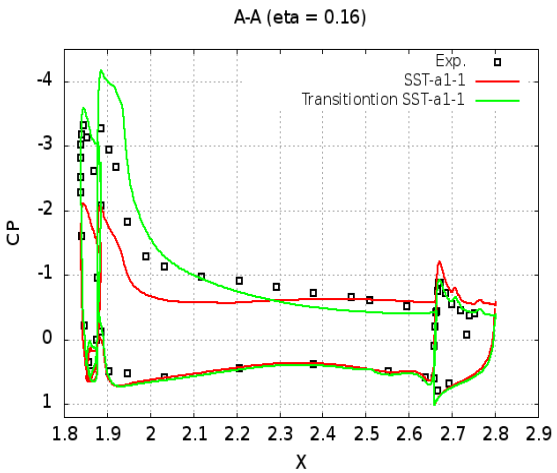
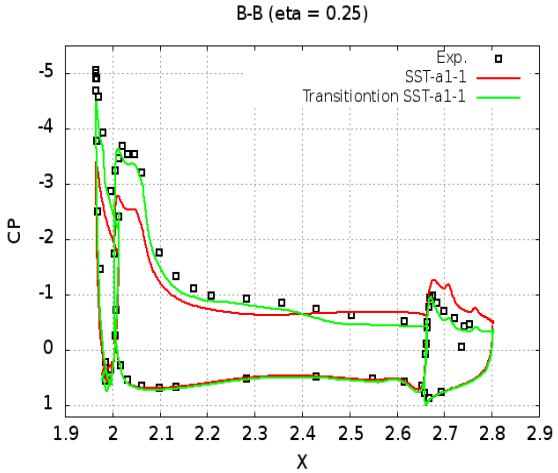
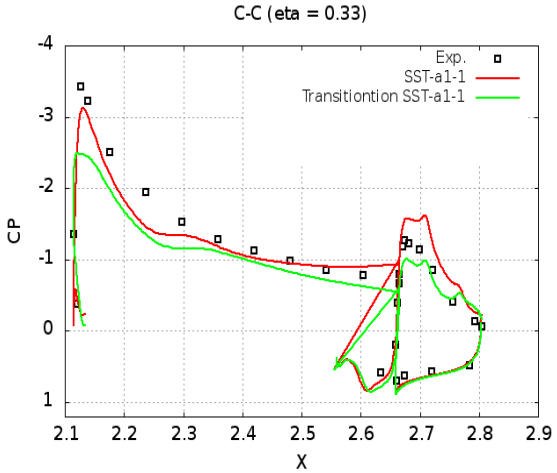
Case 2c: JSM Results

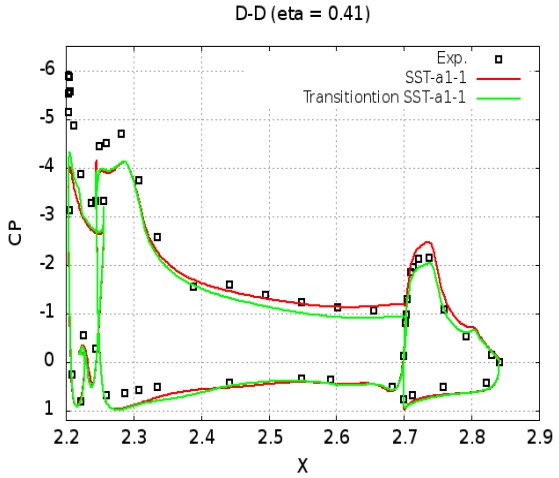
Pressure coefficient plots, *fine* mesh level - JSM-WBNP

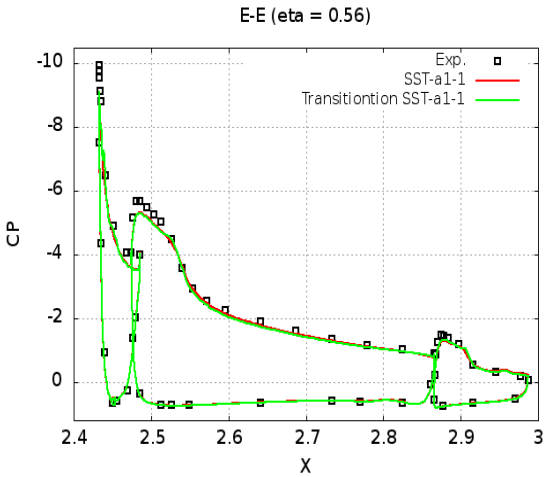
$\alpha = 21.57^0$

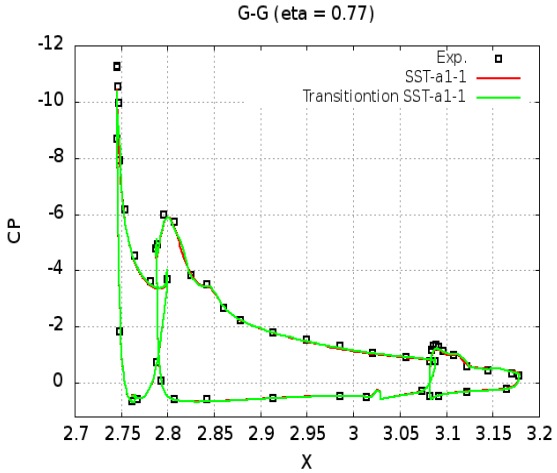


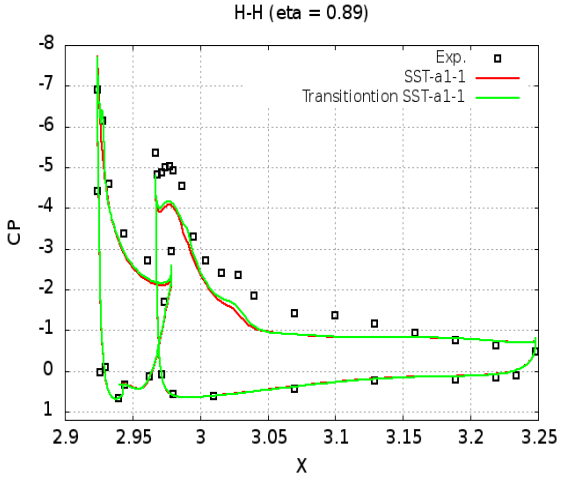


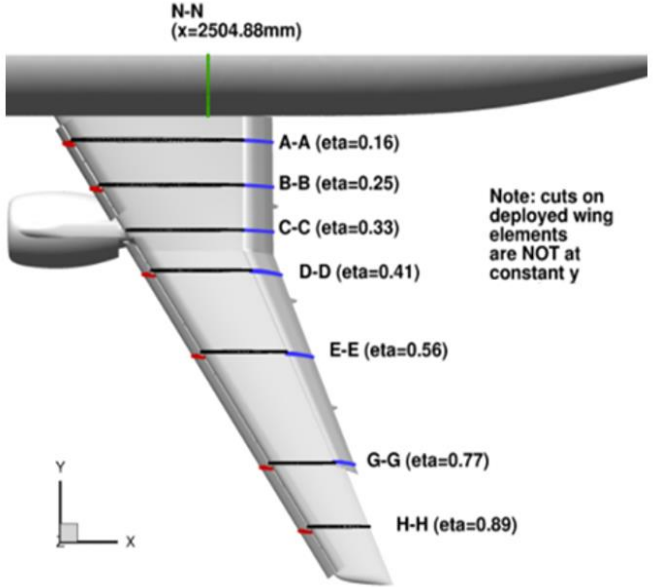












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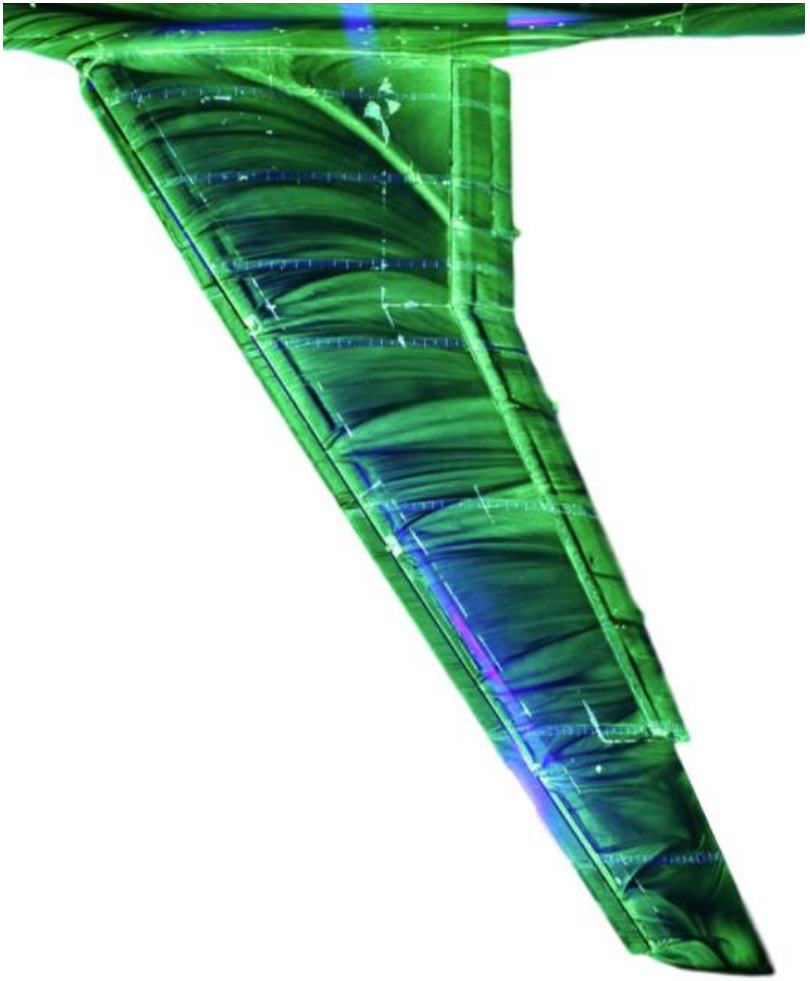
Case 2 : JSM Results

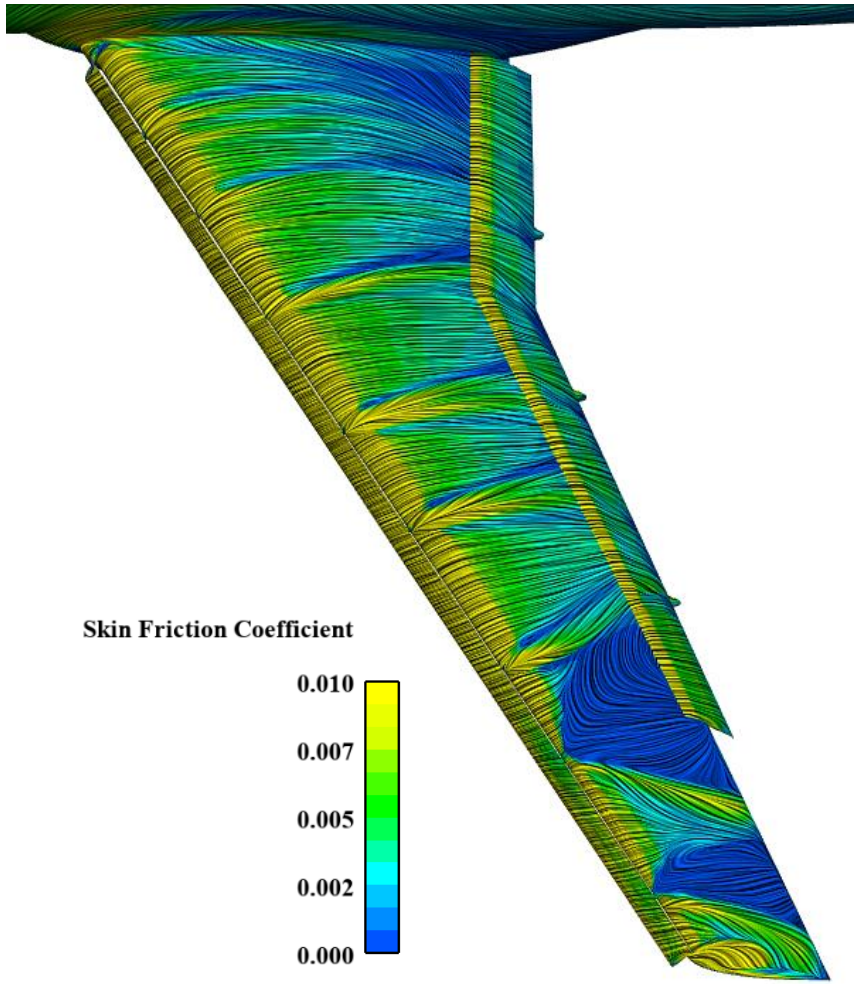
Oil flow visualization, fine mesh - JSM-WB

$\alpha = 21.57^0$

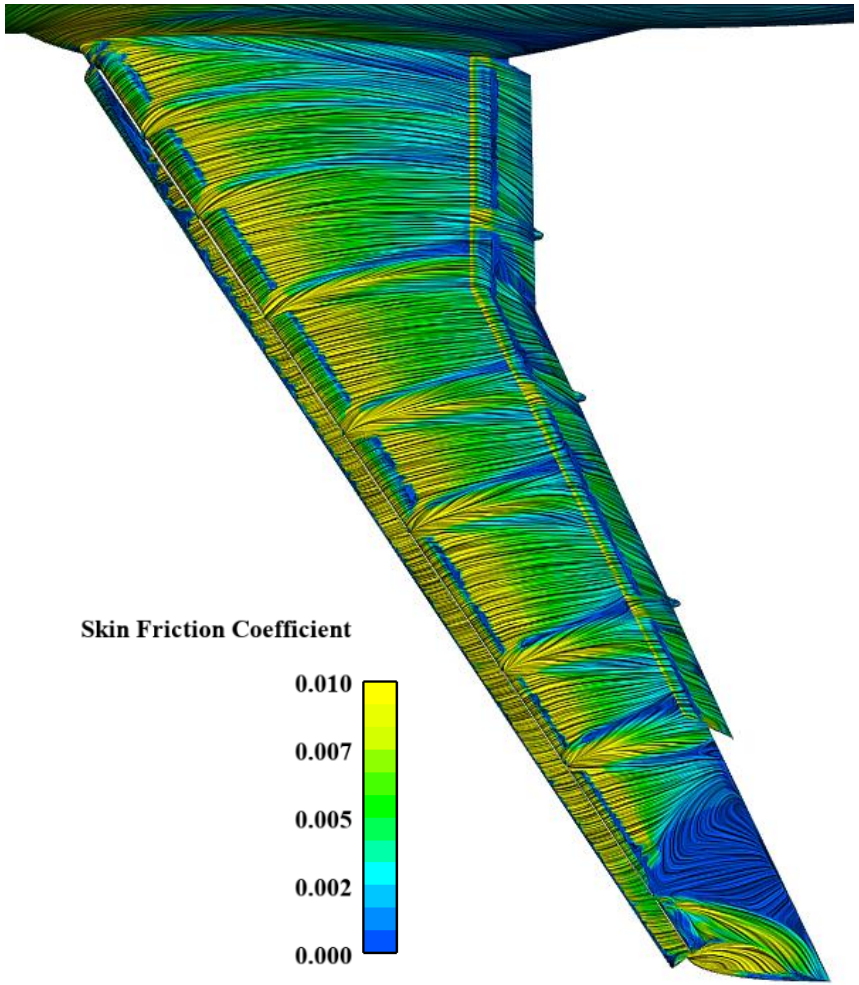
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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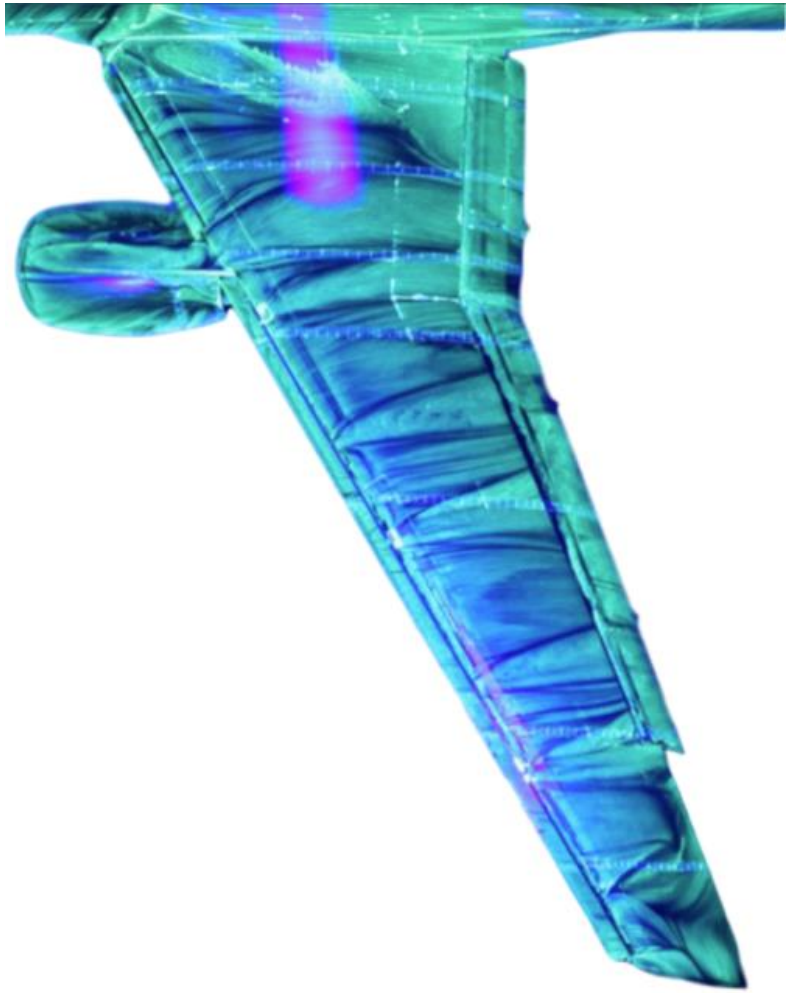
Case 2 : JSM Results

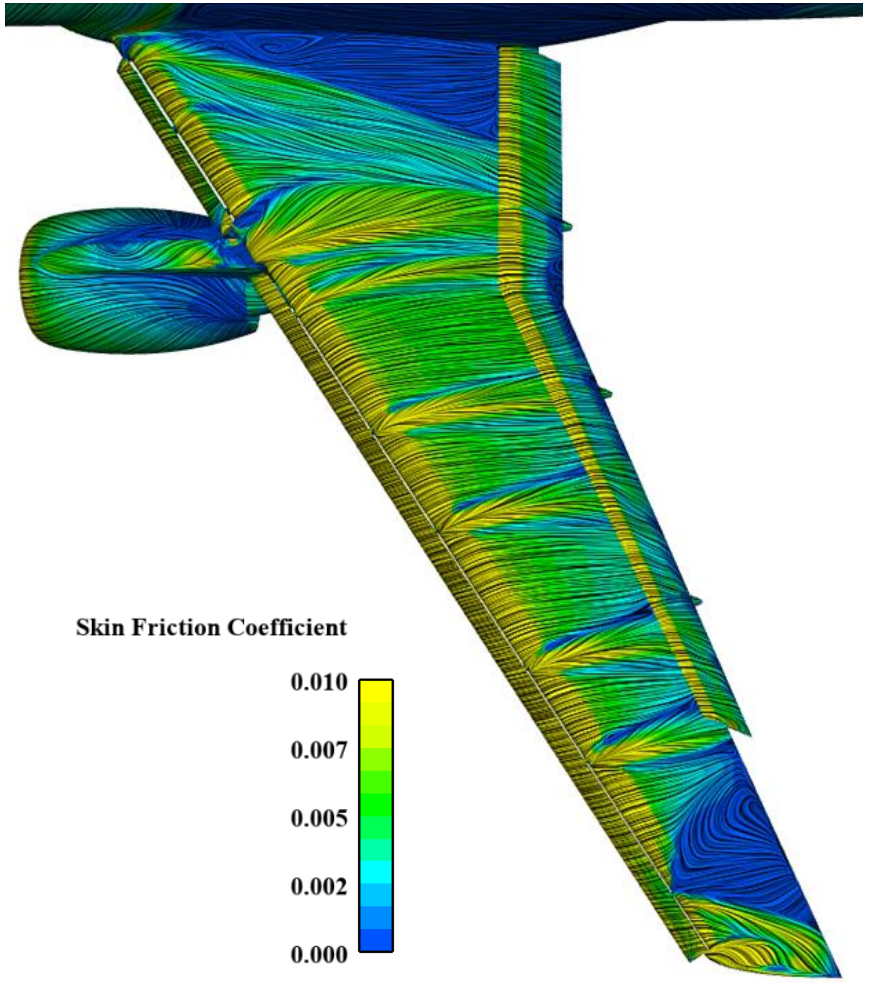
Oil flow visualization, fine mesh - JSM-WBNP

$\alpha = 21.57^0$

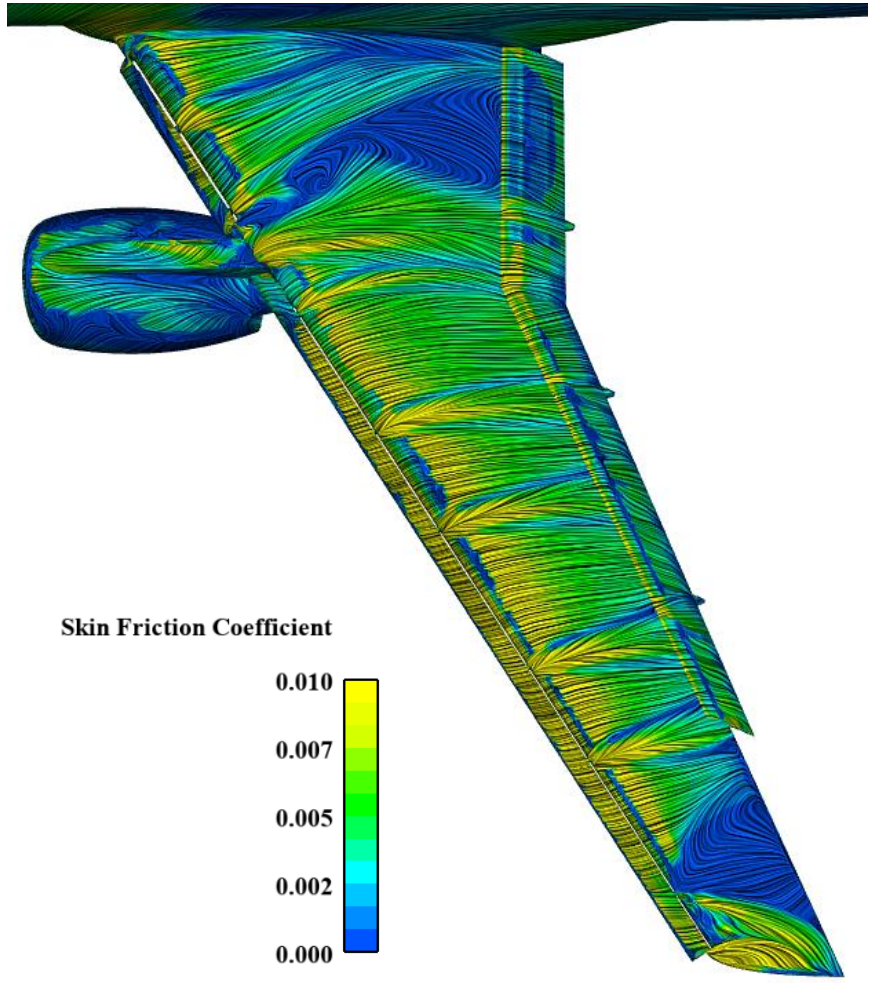
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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Summary Case 2: JSM

- The JSM model was simulated with and without nacelle pylon. Each was run with a workshop provided *fine* level mesh using *SST-Transition* γ-$R_{e\theta}$ *(a1=1)* and *k-ω SST (a1=1)* at six angles of attack (α).
- For JSM-WB, both the computational results with *SST-Transition* γ-$R_{e\theta}$ *(a1=1)* and *k-ω SST (a1=1)* show good agreement with the experiment data, with the *k-ω SST (a1=1)* giving better predictions of stall angle of attack and C_{Lmax} when compared to experiment. For JSM-WBNP, both models predict the critical angle of attack and consistent with the experiment. In general, though the *SST-Transition* γ-$R_{e\theta}$ *(a1=1)* gives a better prediction of C_L over a wider range of α.
- Large differences between wind tunnel and computational results were observed for drag in both cases, especially with increasing angles of attack.
- These differences are believed to be primarily due to **insufficient grid resolution, grid quality, grid element type** in key flow regions with complex flow structures, such as high-lift device trailing edge wakes, support bracket wakes, wing-body junction flow, slat and flap cove vortices, flap and wing tip vortices and any other secondary spiral vortices.
- The inherent limitation of linear eddy-viscosity turbulence models which neglect the non-linear effects of turbulent, secondary and swirling flows may also be a contributing factor.
- Computational surface flow patterns on the high-lift system, that included the slat tracks and FTFs, showed qualitatively good agreement with experimental oil flow visualizations.
- Results show that laminar-turbulent transition has a significant and important effect (hence considered here in this study), as also seen by the china clay visualizations from the experiments, and therefore needs to be correctly accounted for.

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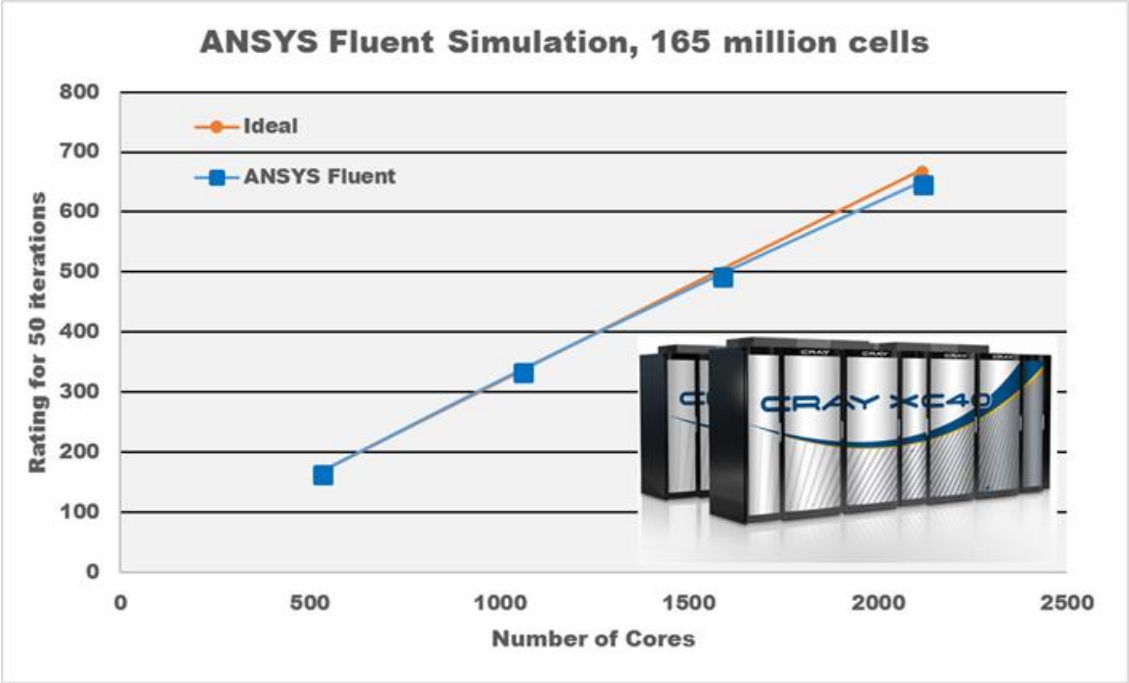
Acknowledgements

- David Whitaker from CRAY
- Florian Menter and Boris Makarov from ANSYS



Fluent Scalability on CRAY XC Series Supercomputers

The Cray XC system offers excellent parallel performance for ANSYS Fluent, with continued scaling to more than 2,000 cores for ~165-million-cell simulation. Cray and ANSYS are committed to delivering high performance computing capabilities that quickly bring aerospace applications to new heights of simulation fidelity. This project is just one example of how ANSYS and Cray collaborate to build robust solutions for a broad set of engineering simulations.

Cray XC40 system combines the advantages of its Aries™ interconnect and Dragonfly network topology, Intel® Xeon® processors, integrated storage solutions, and major enhancements to the Cray Linux® Environment and programming environment. The Cray XC40 supercomputer is a groundbreaking architecture upgradable to 100 petaflops per system.

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Thank you !

Questions ?

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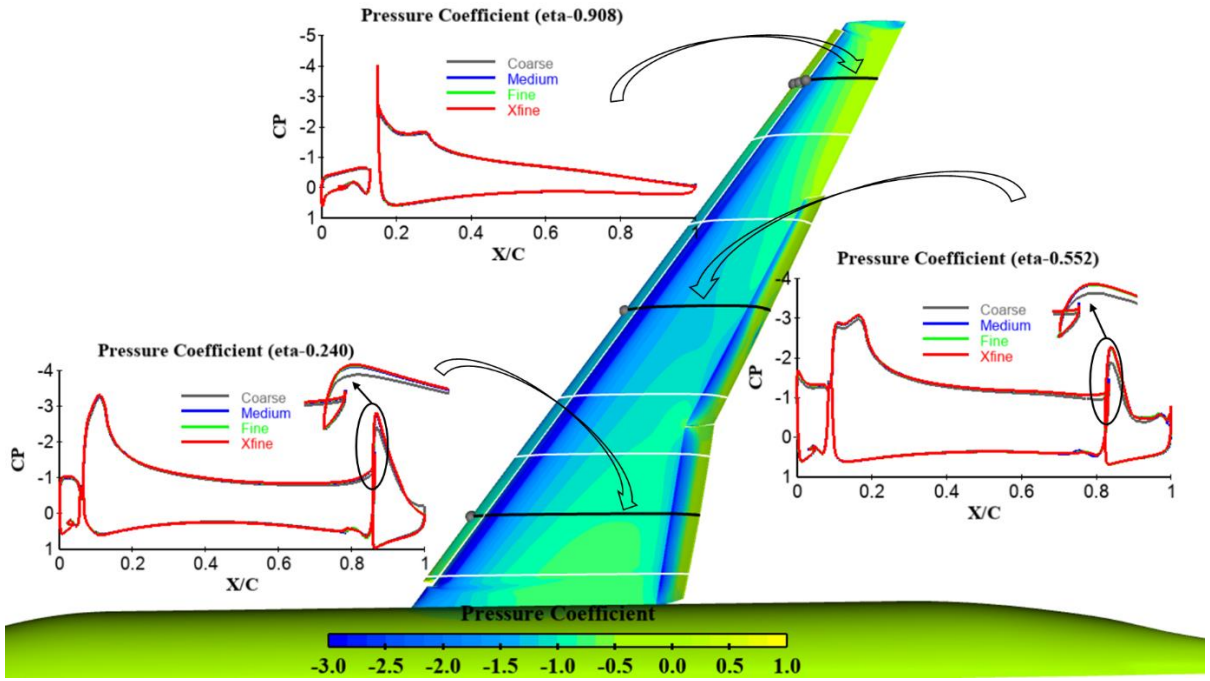
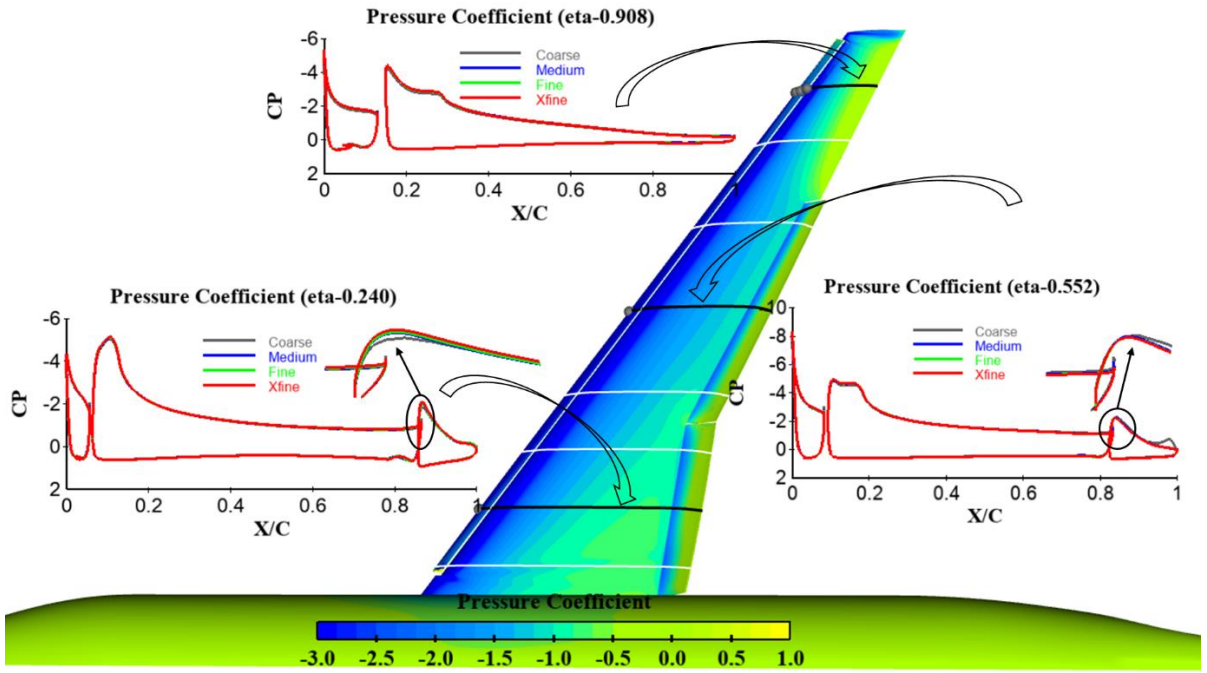
Appendix

Case 1: HL-CRM



$\alpha = 8^0$



$\alpha = 16^0$

C_p Contours on Xfine Mesh and C_p 2-D plots on Coarse, Medium, Fine and Xfine Meshes – *k-ω SST (a1 = default).*

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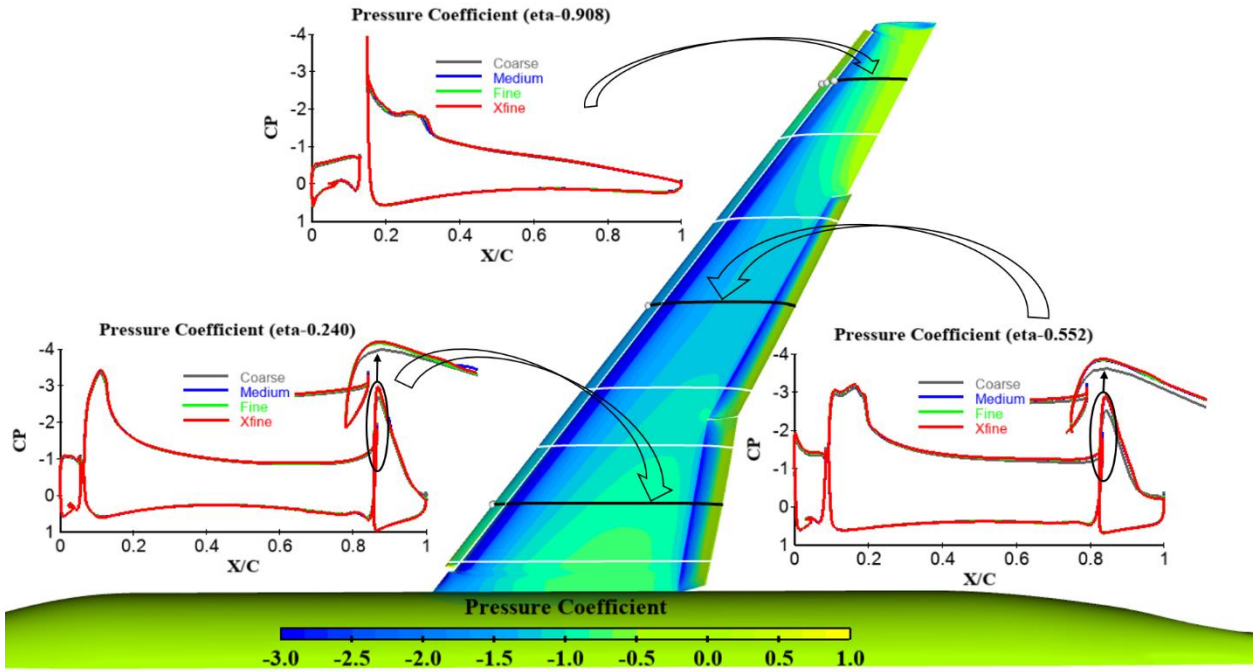
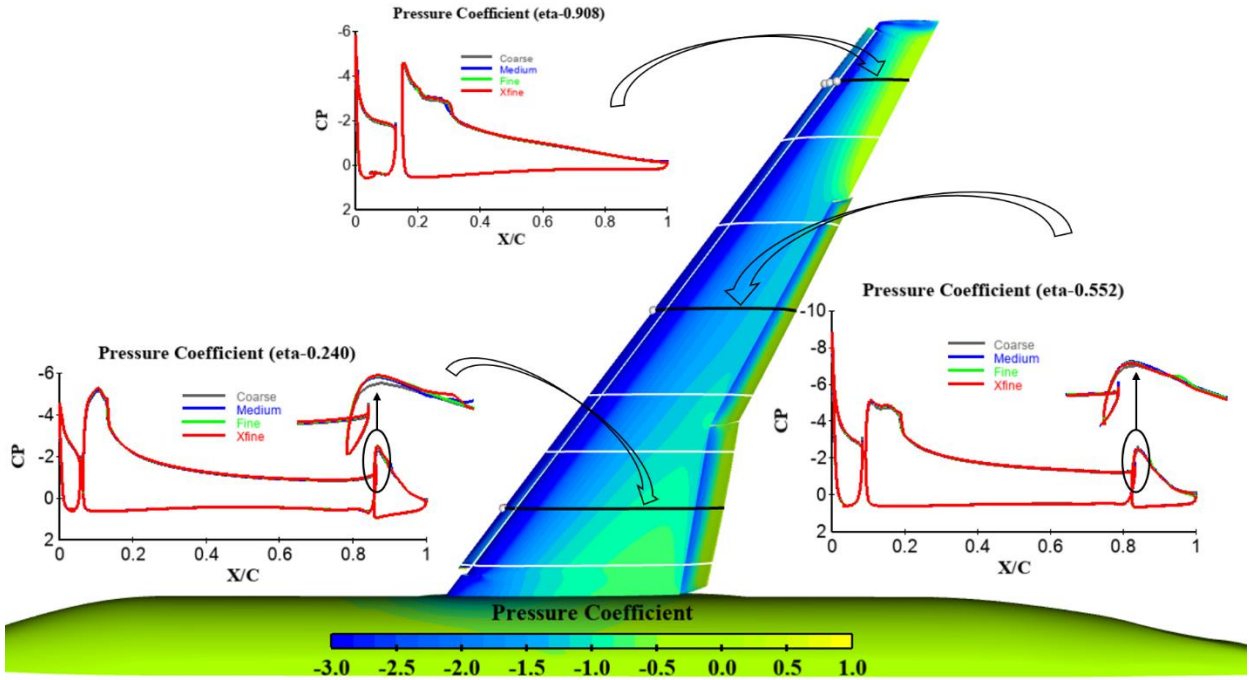
Appendix

Case 1: HL-CRM



α = 8^0



α = 16^0

C_p Contours on Xfine Mesh and C_p 2-D plots on Coarse, Medium, Fine and Xfine Meshes – *SST-Transition* γ-$R_{e\theta}$ *(a1=1).*

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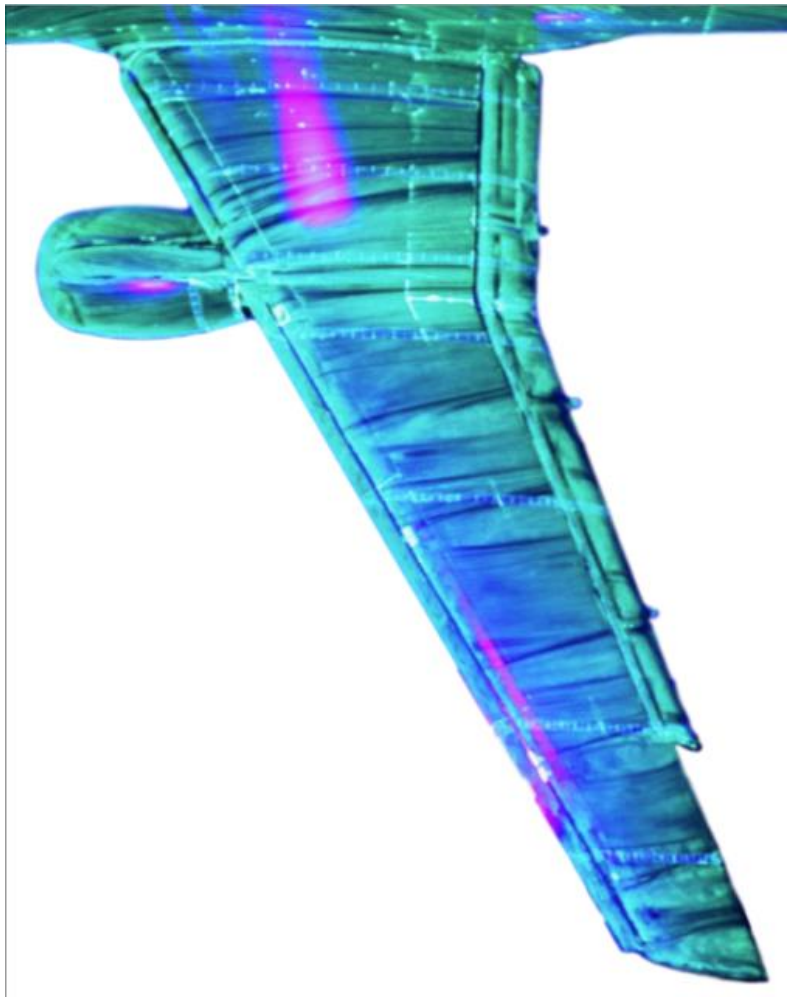
Appendix

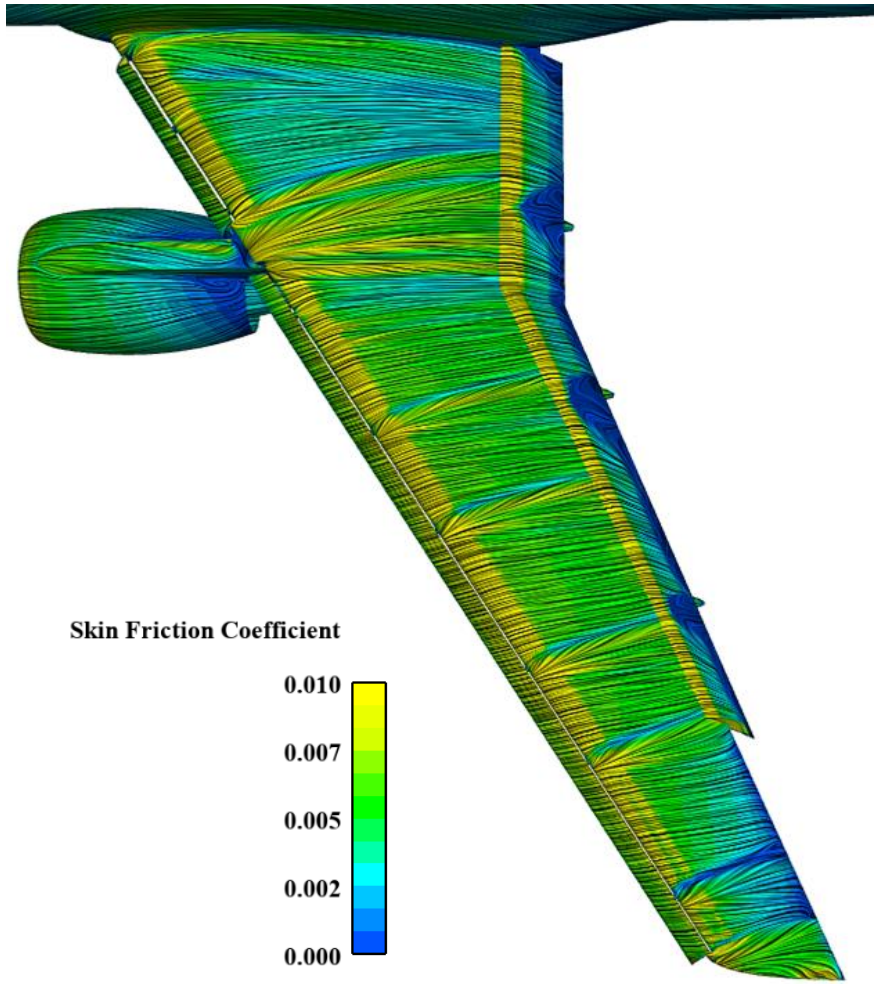
Case 2: JSM-WBNP $\boldsymbol{\alpha = 4.36^0}$

Oil flow visualization, fine mesh

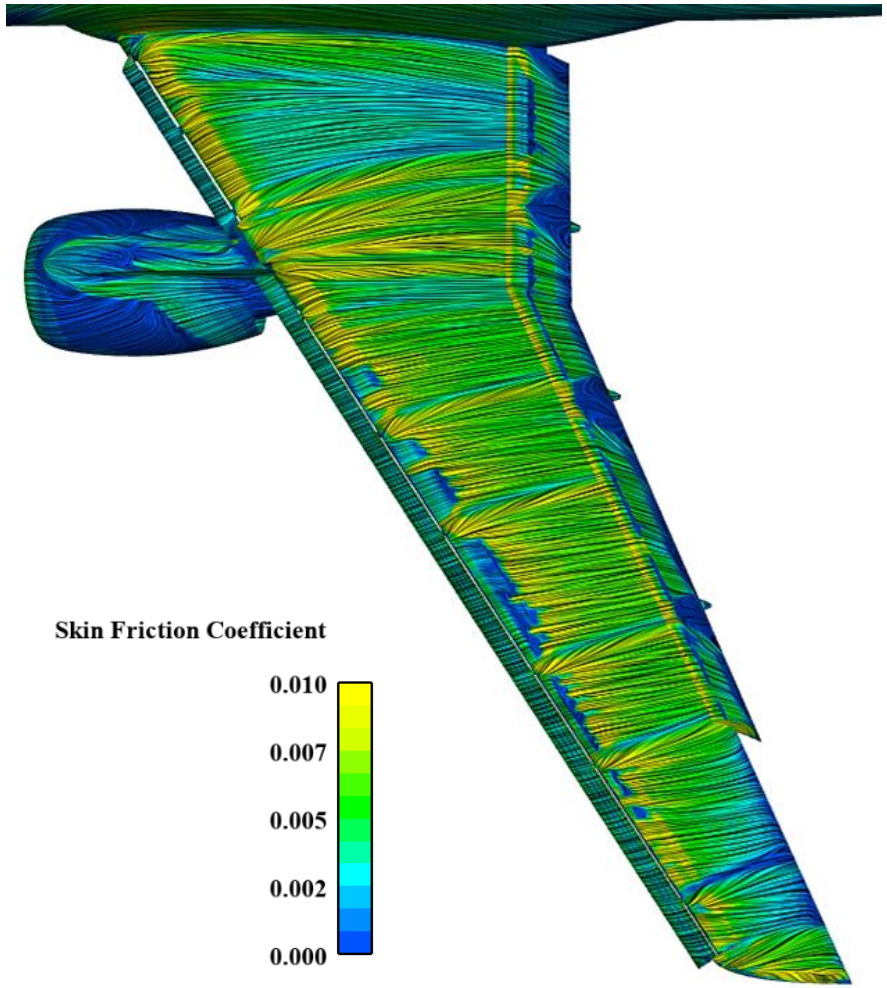
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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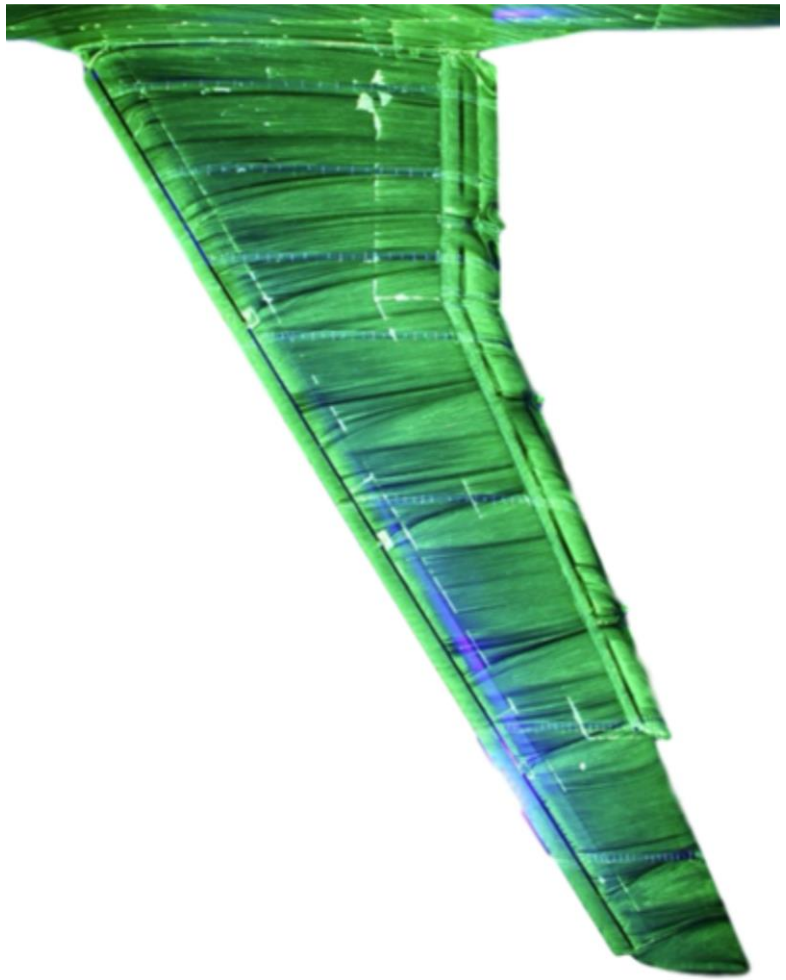
Appendix

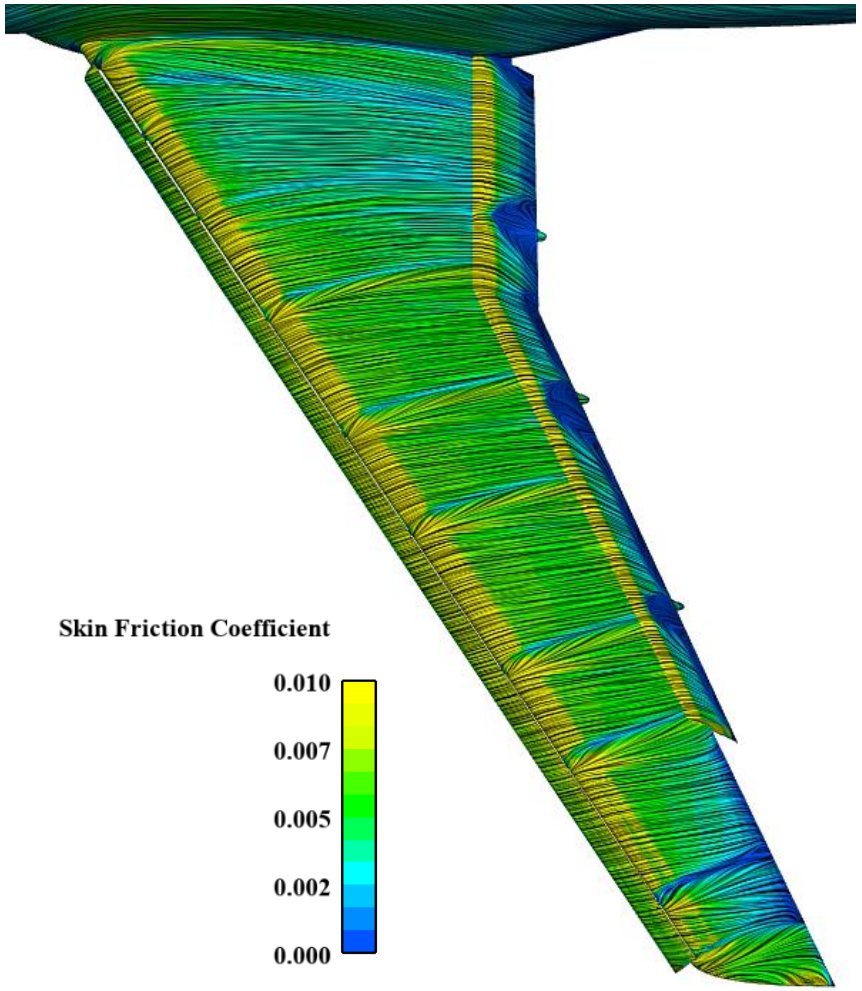
Case 2: JSM-WB $\alpha = 4.36^0$

Oil flow visualization, fine mesh

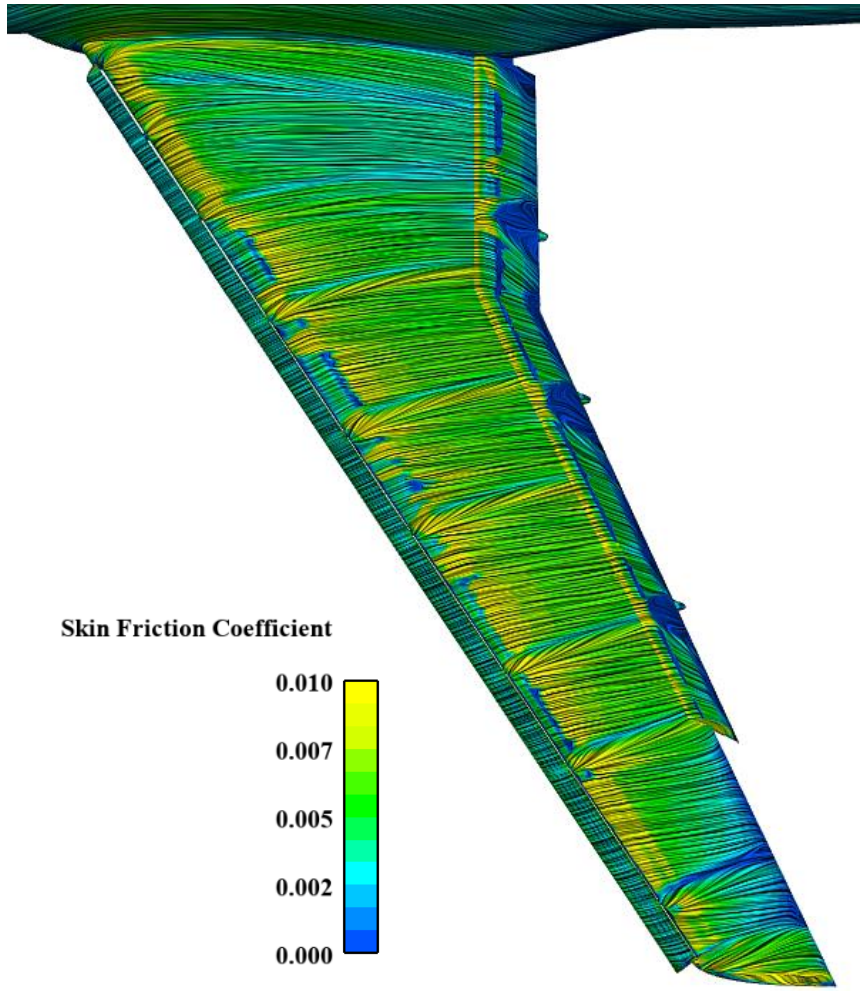
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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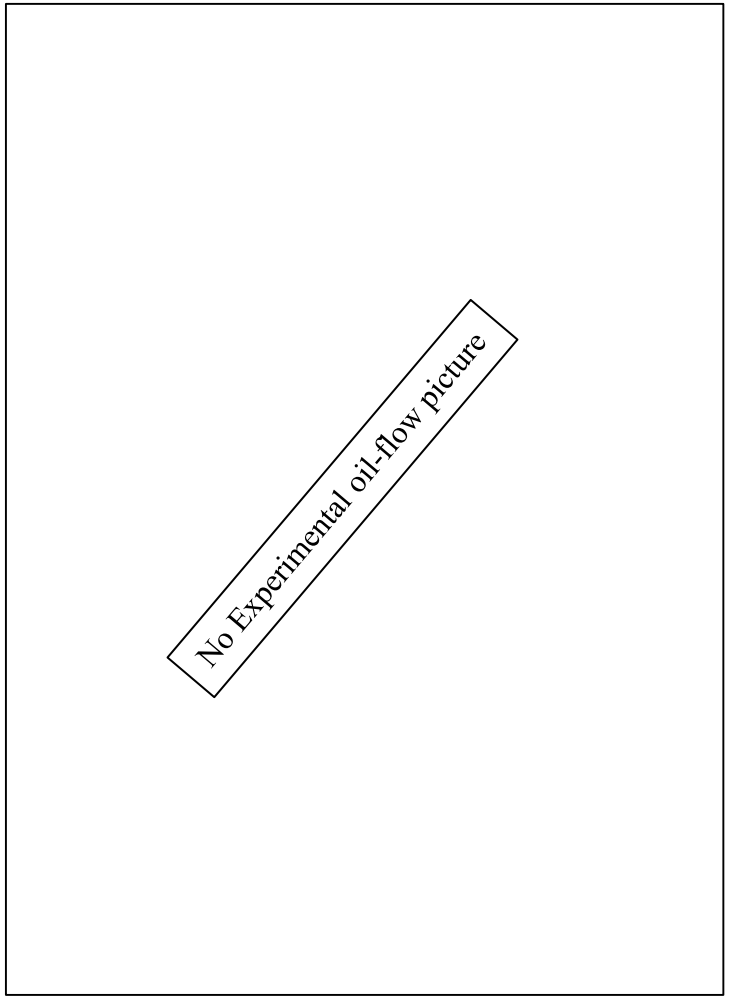
Appendix

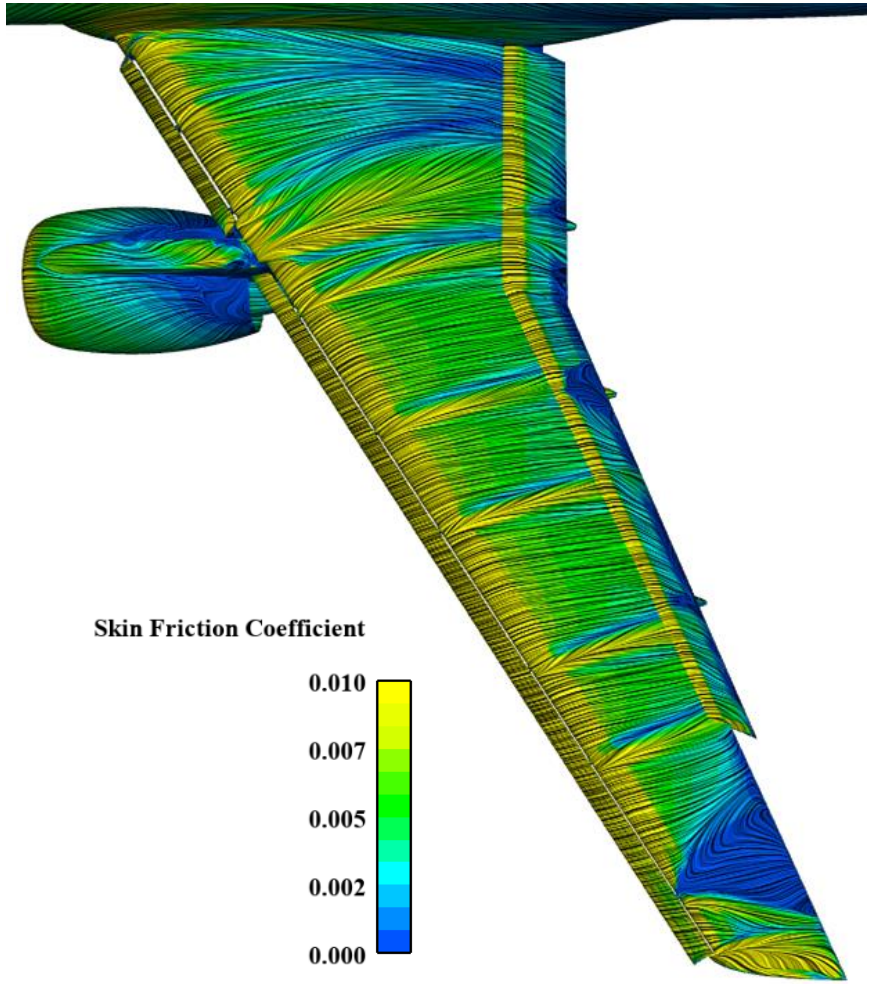
Case 2: JSM-WBNP $\boldsymbol{\alpha = 14.54^0}$

Oil flow visualization, fine mesh

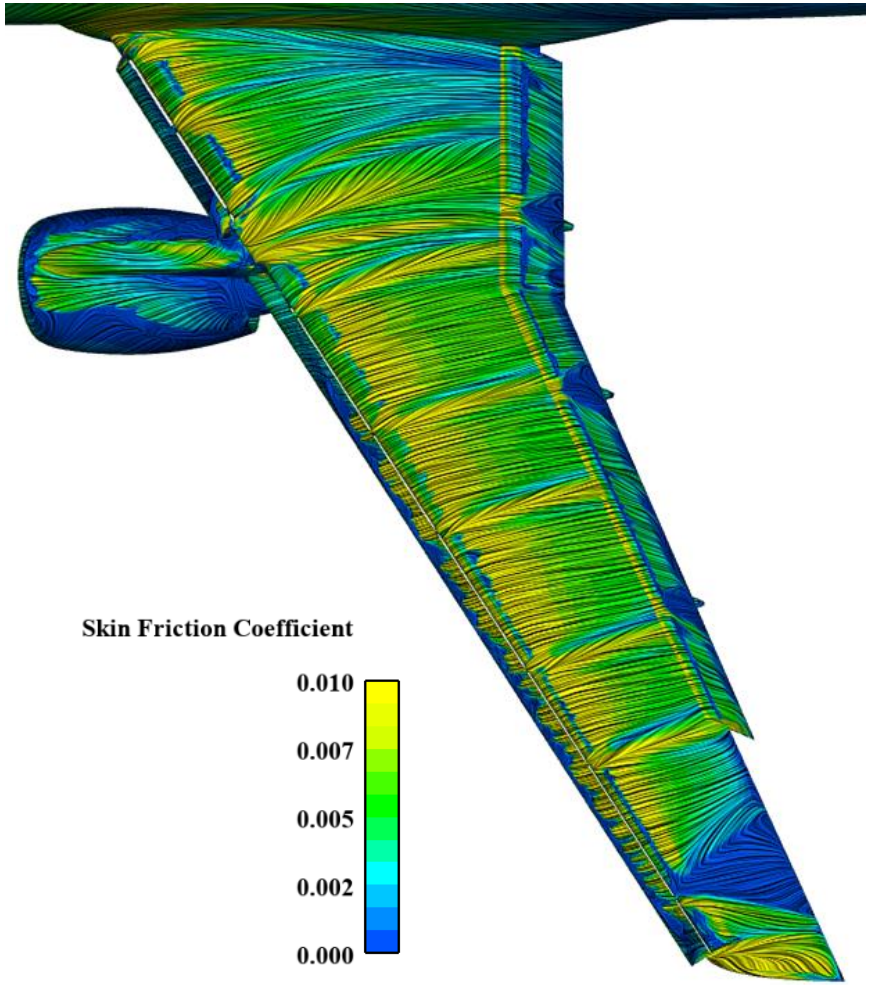
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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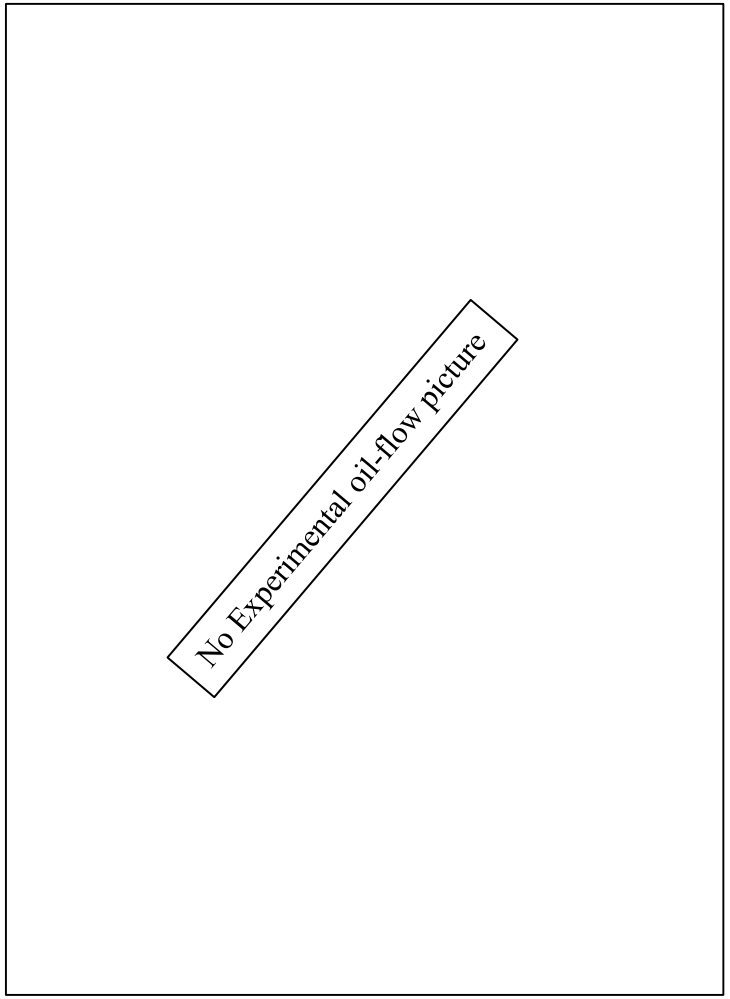
Appendix

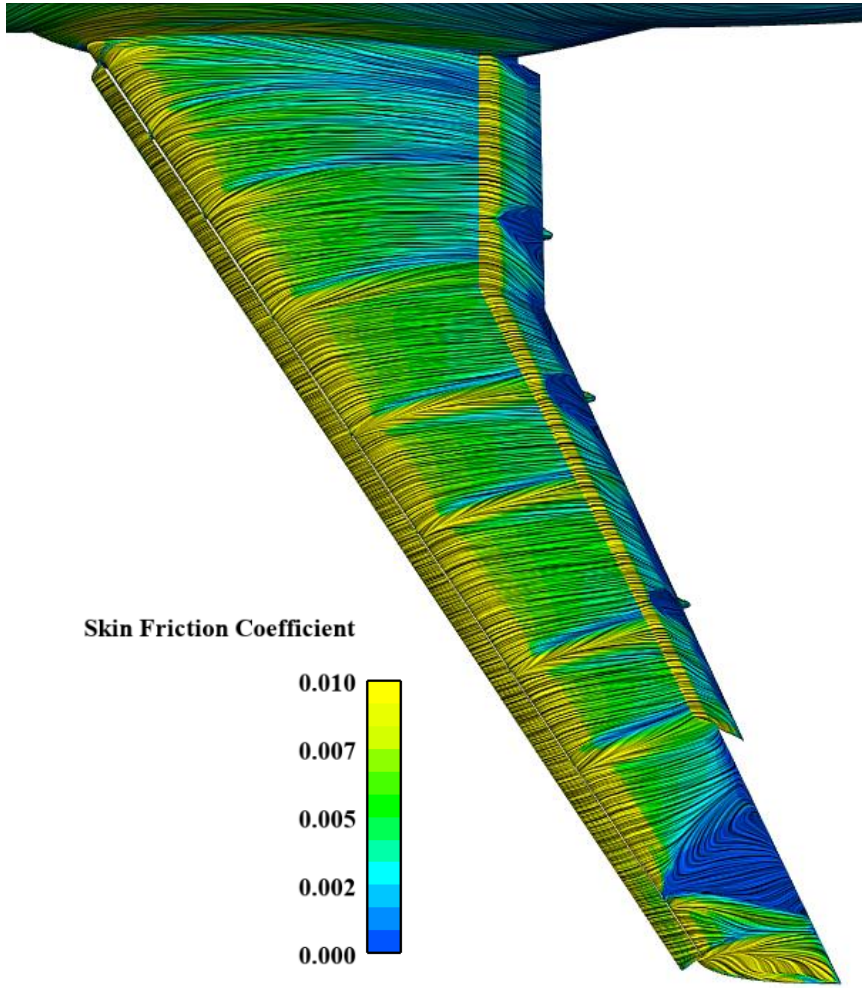
Case 2: JSM-WB $\boldsymbol{\alpha = 14.54^0}$

Oil flow visualization, fine mesh

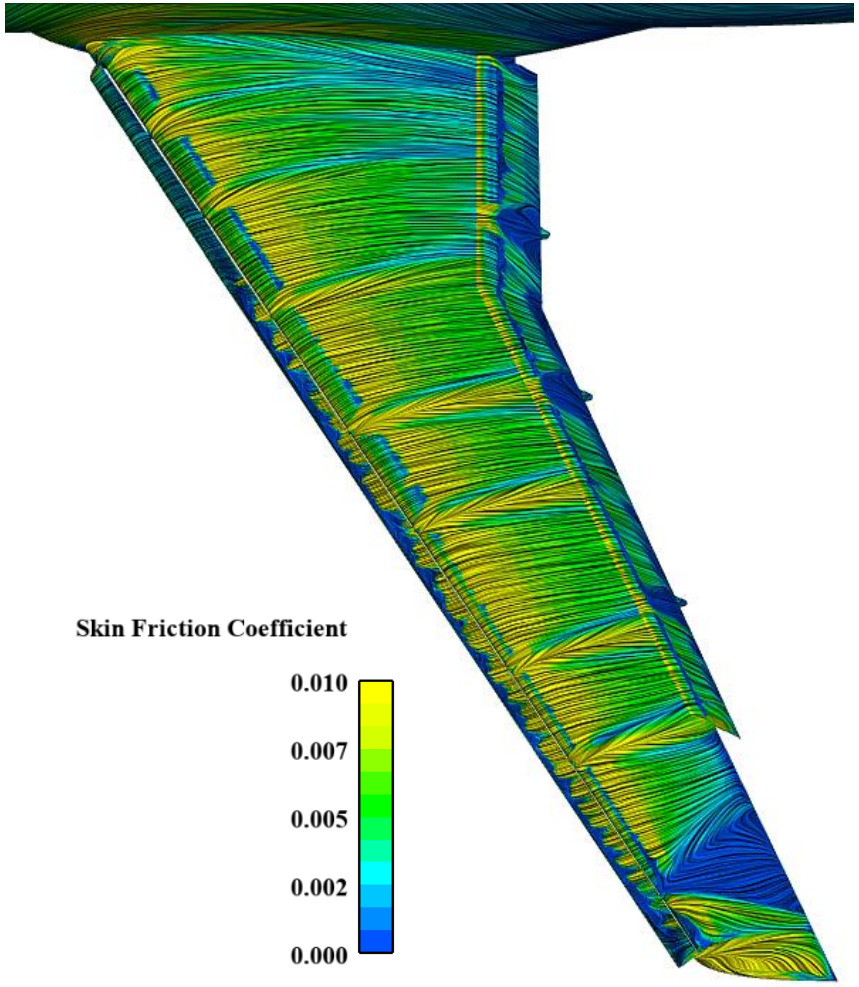
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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Appendix

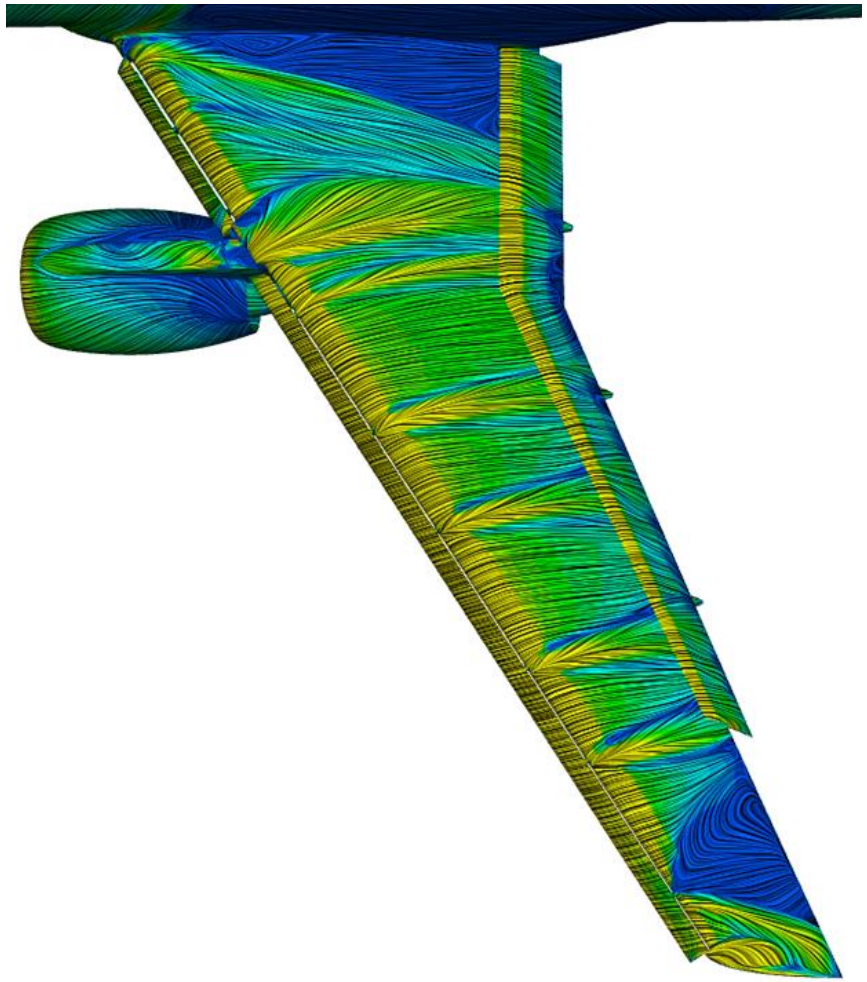
Case 2: JSM-WBNP $\boldsymbol{\alpha = 20.59^0}$

Oil flow visualization, fine mesh

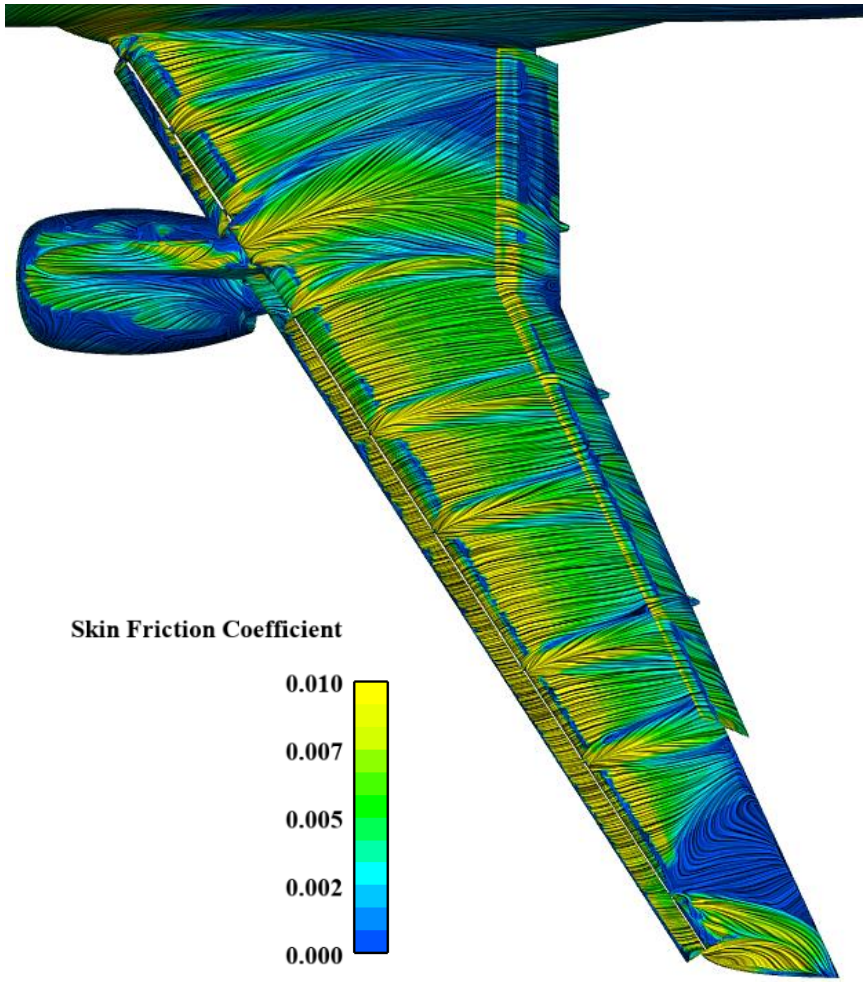
Experimental Oil Flow

No Experimental oil-flow picture

k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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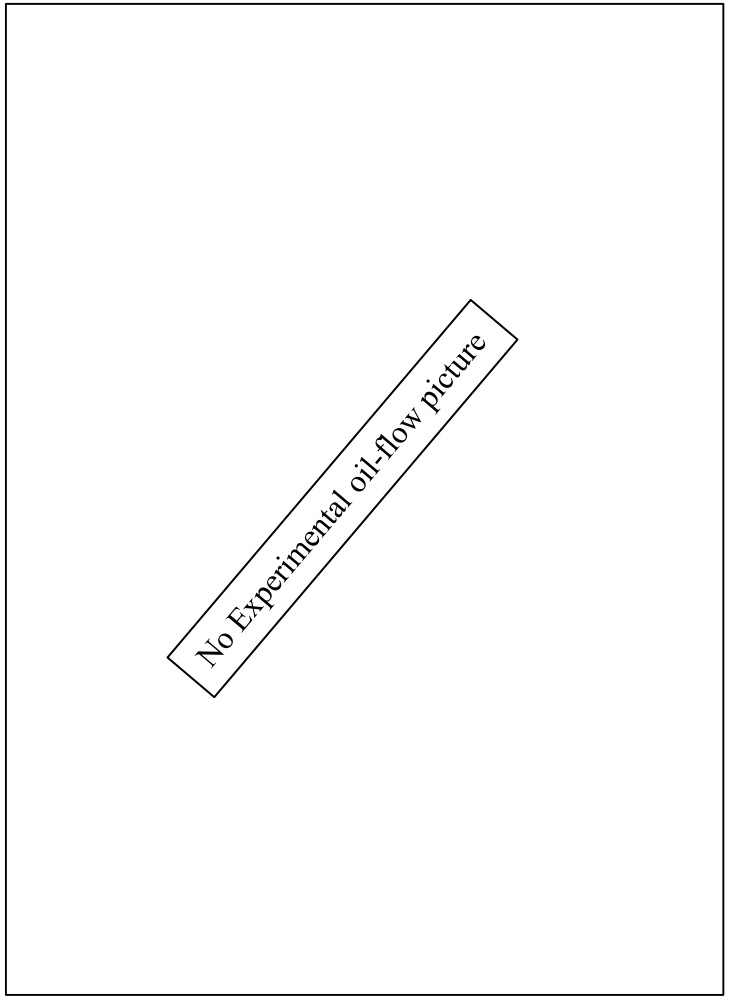
Appendix

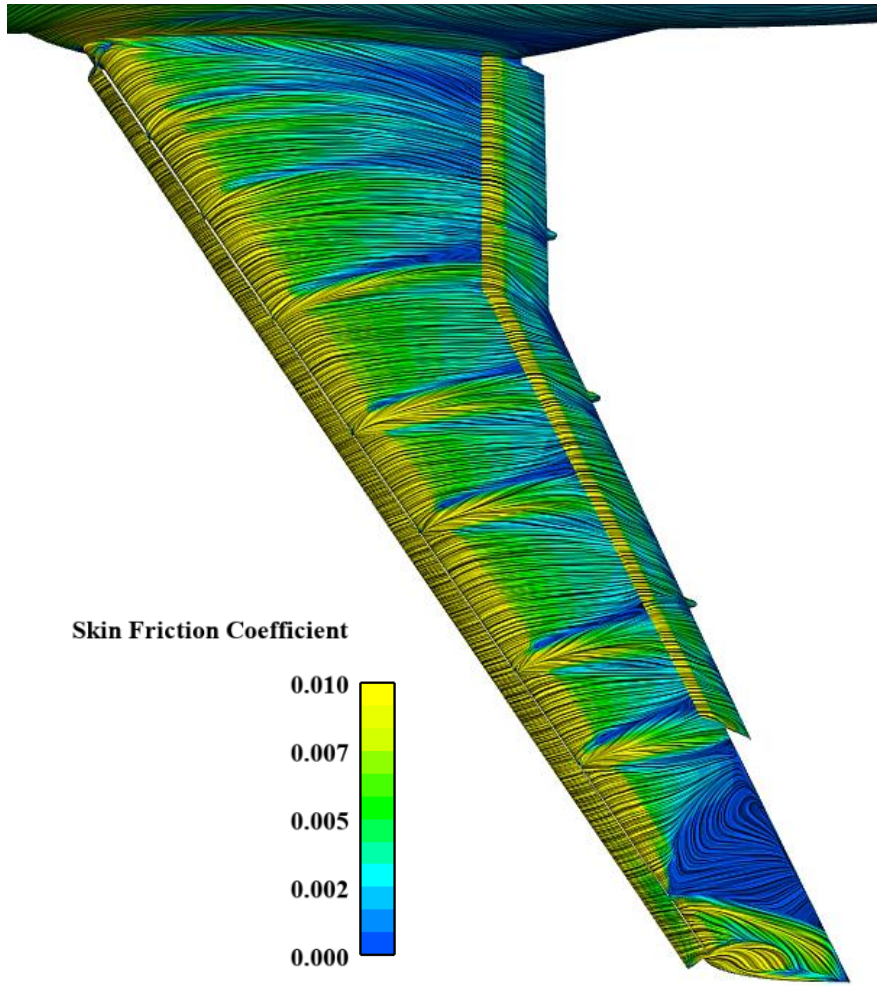
Case 2: JSM-WB $\alpha = 20.59^0$

Oil flow visualization, fine mesh

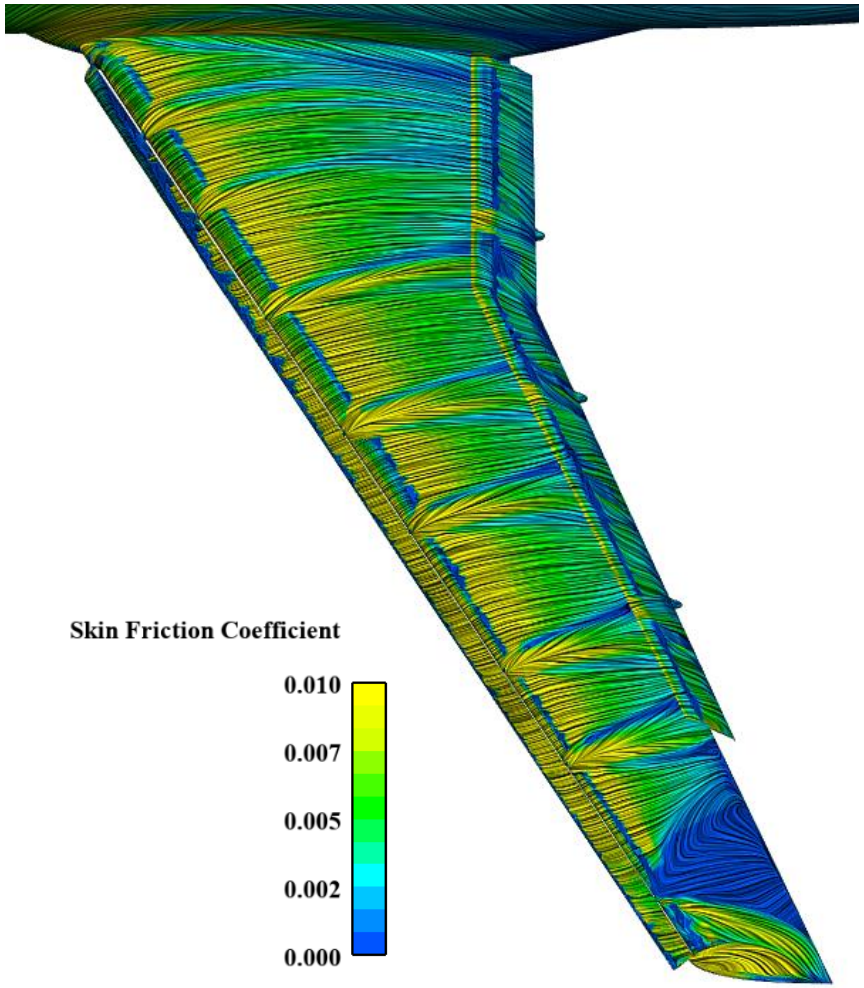
Experimental Oil Flow



k-ω SST (a1=1)



SST-Transition γ-$R_{e\theta}$ (a1=1)



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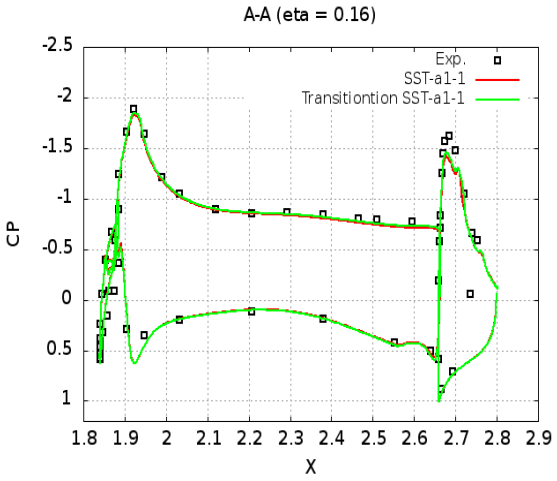
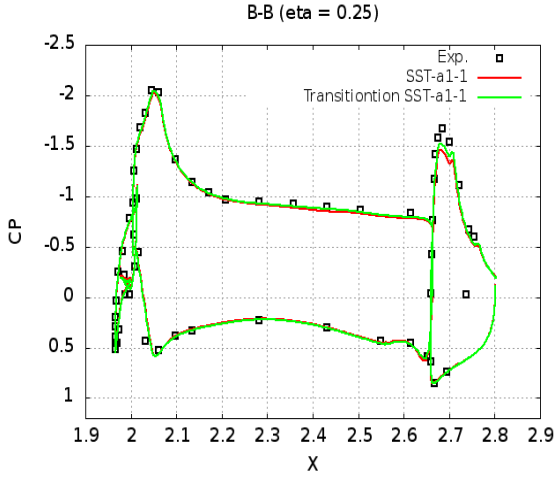
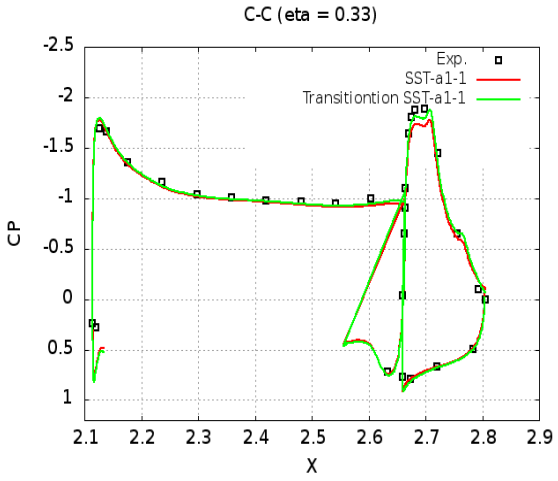
Appendix

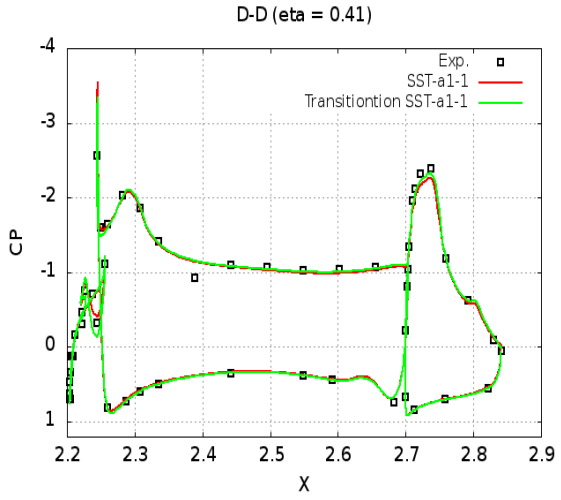
Case 2: JSM-WBNP $\alpha = 4.36^0$

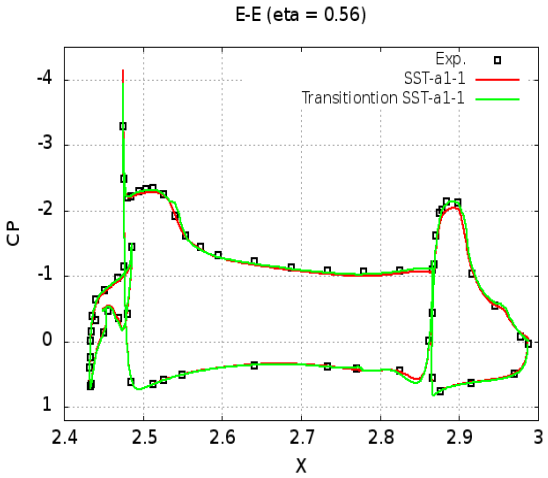
Pressure coefficient plots, fine mesh

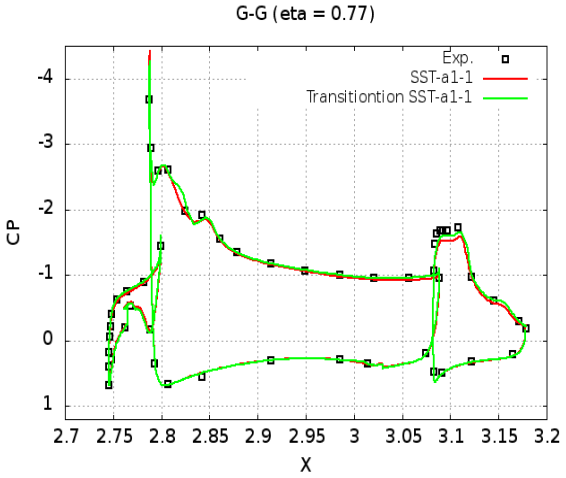


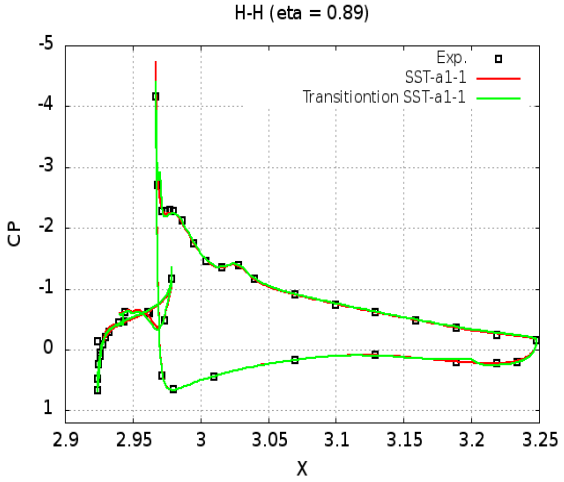


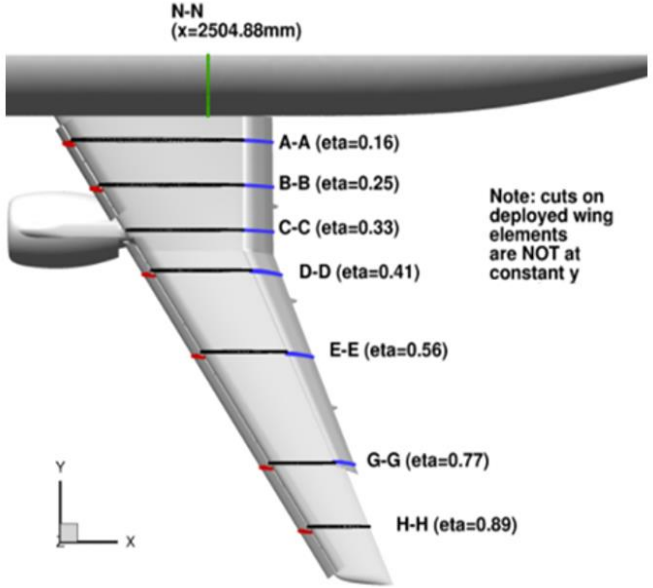












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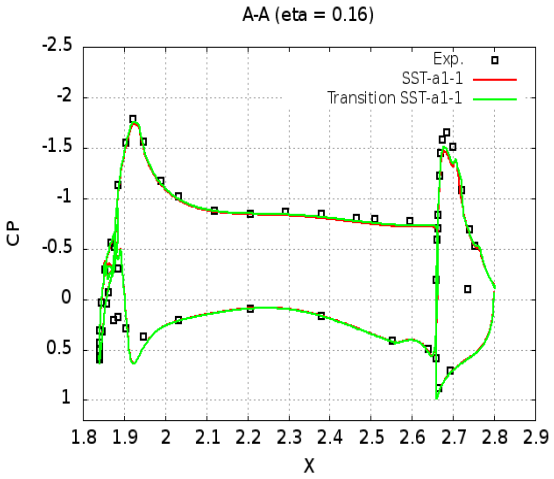
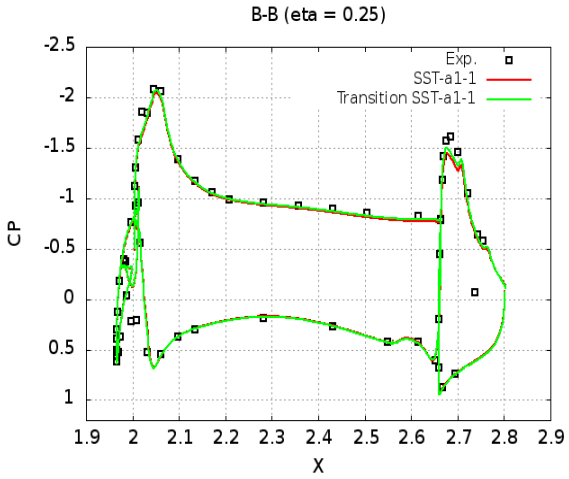
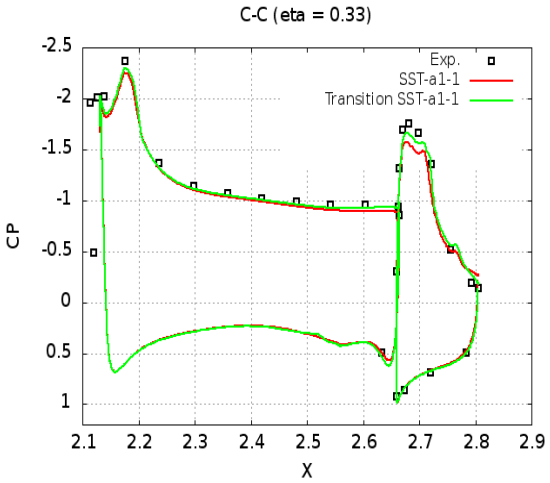
Appendix

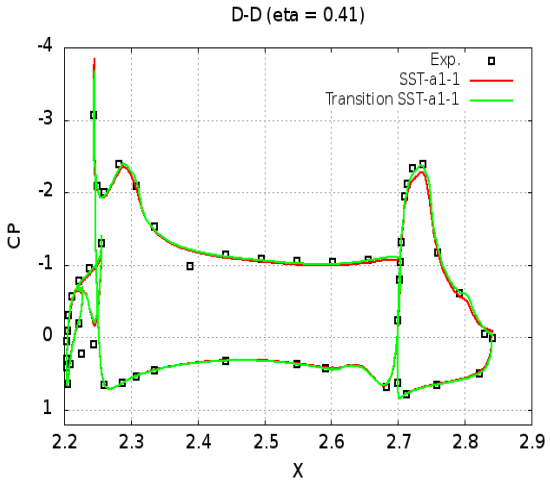
Case 2: JSM-WB $\alpha = 4.36^0$

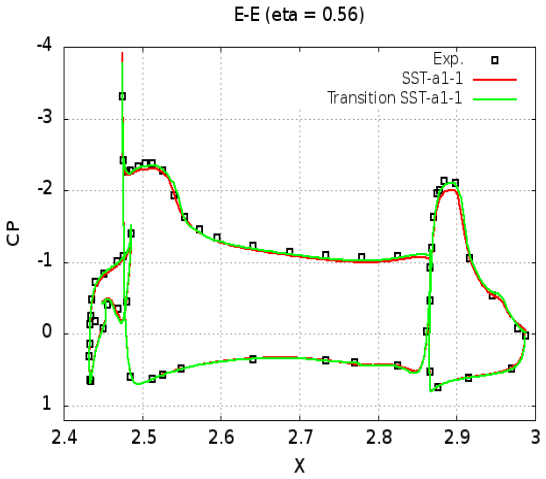
Pressure coefficient plots, fine mesh

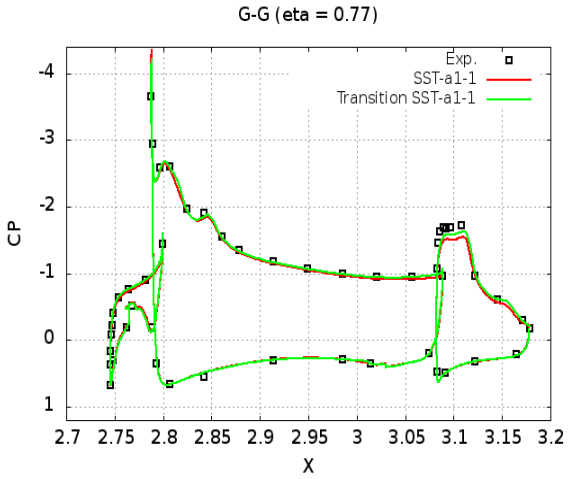


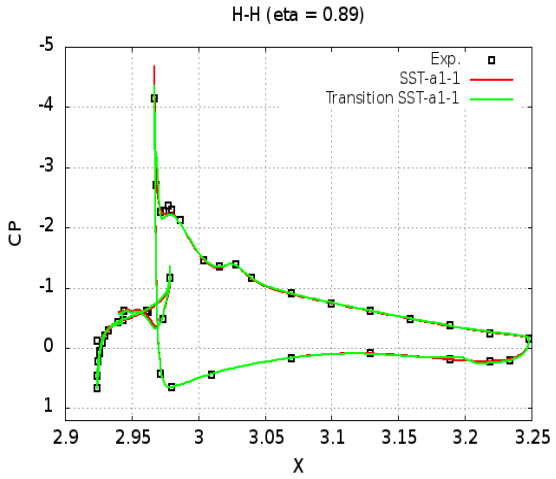


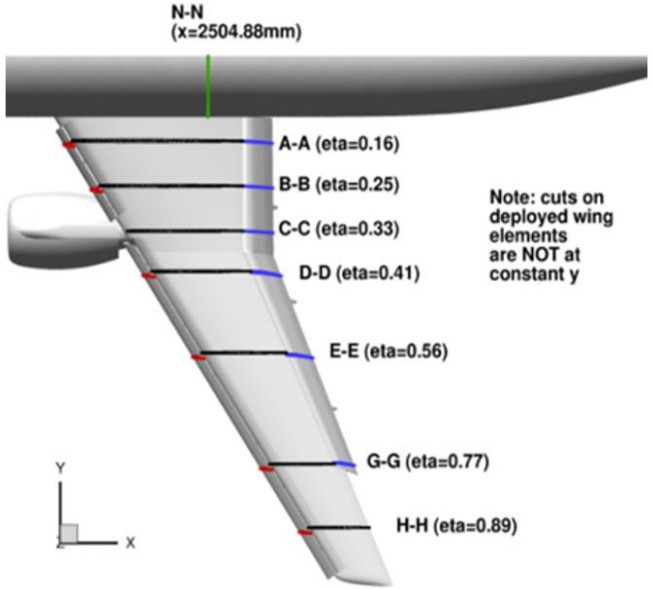












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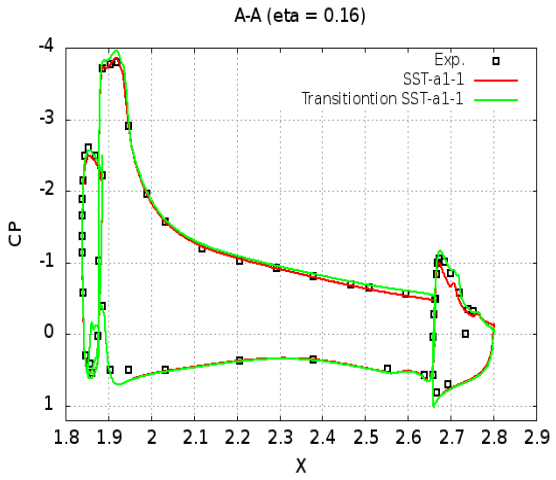
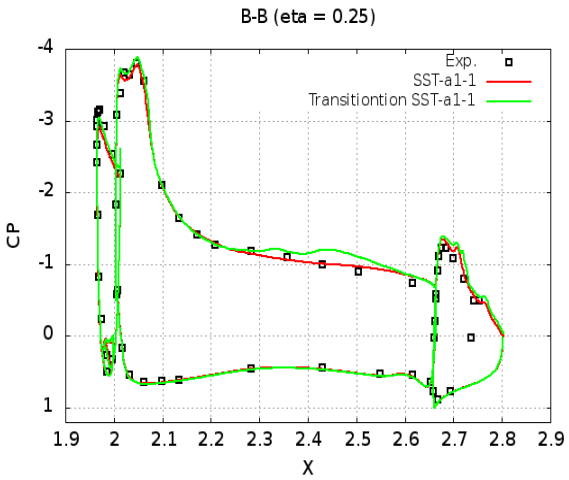
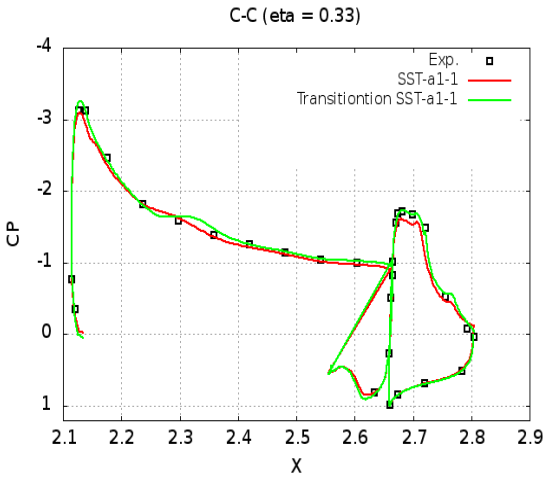
Appendix

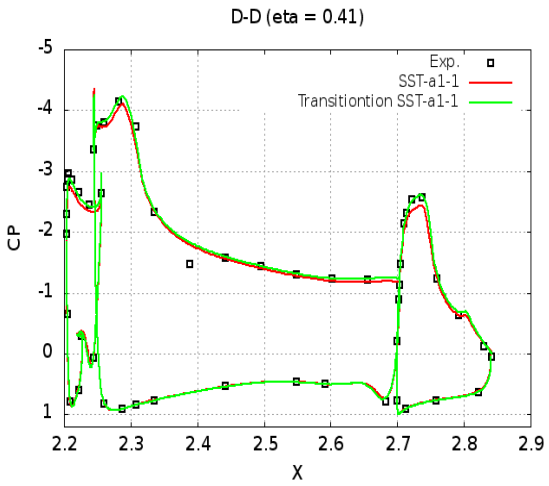
Case 2: JSM-WBNP $\alpha = 14.57^0$

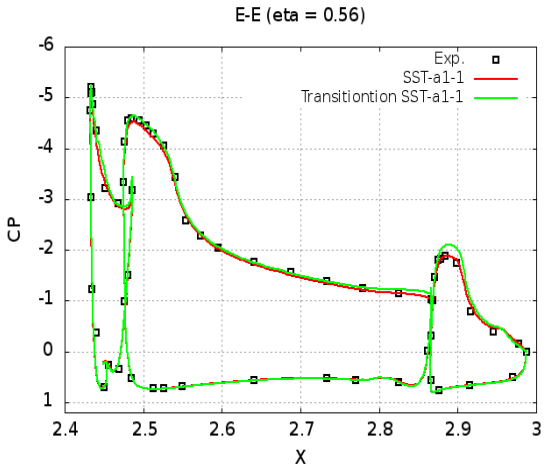
Pressure coefficient plots, fine mesh

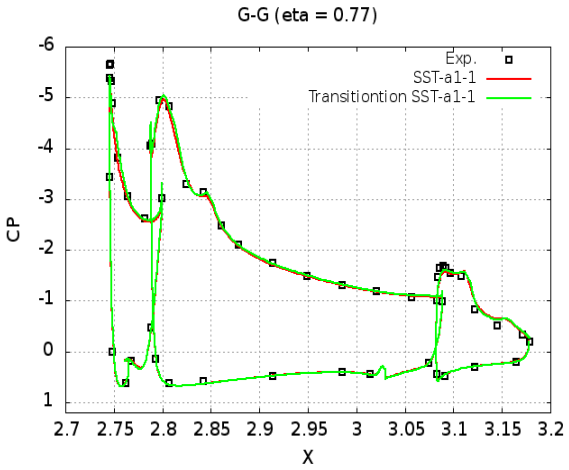


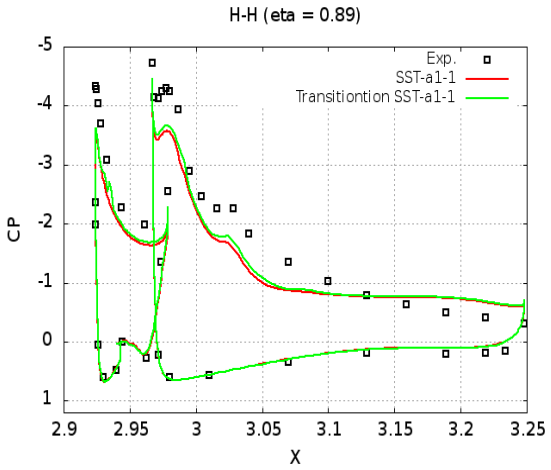


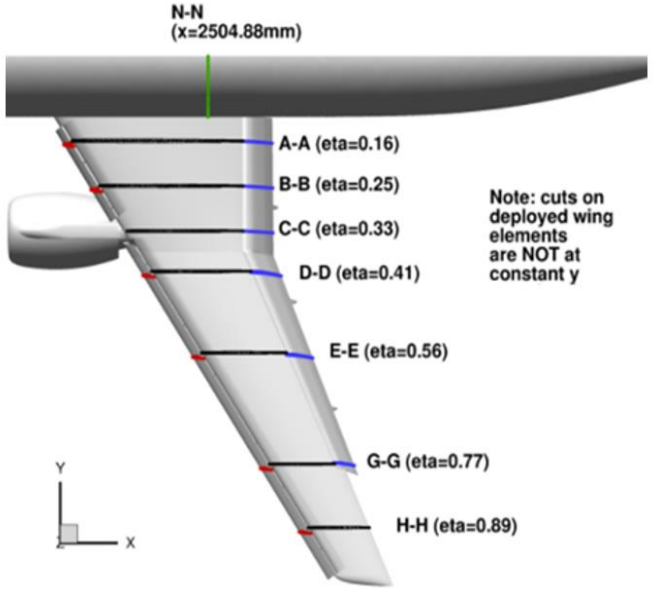












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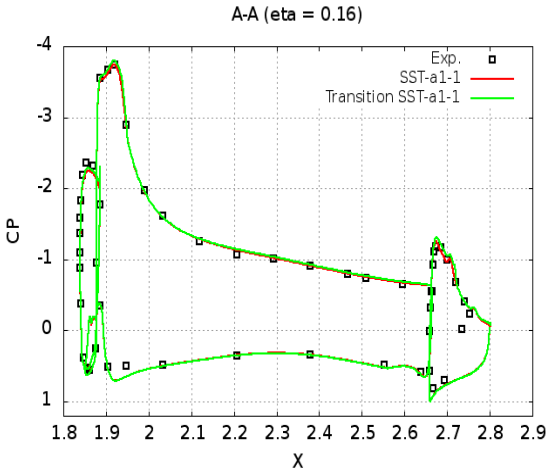
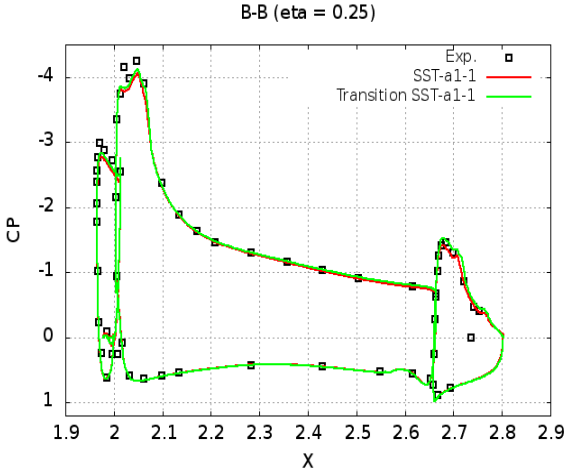
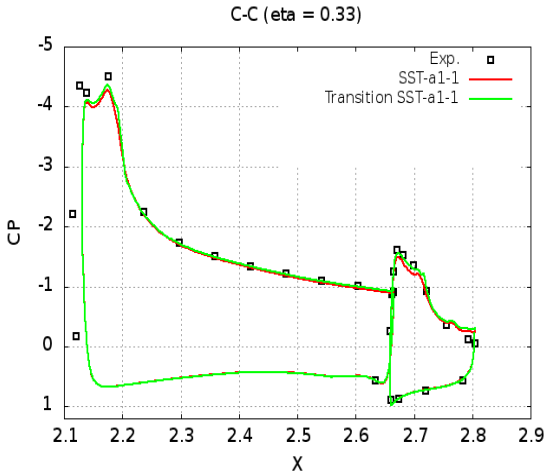
Appendix

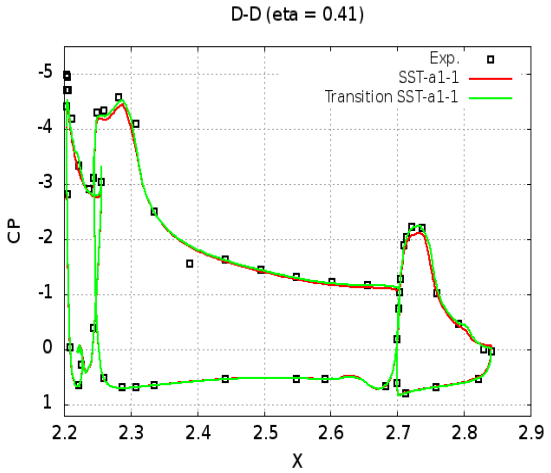
Case 2: JSM-WB $\alpha = 14.57^0$

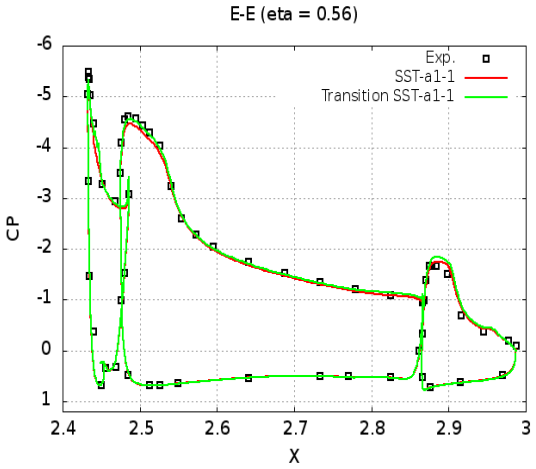
Pressure coefficient plots, fine mesh

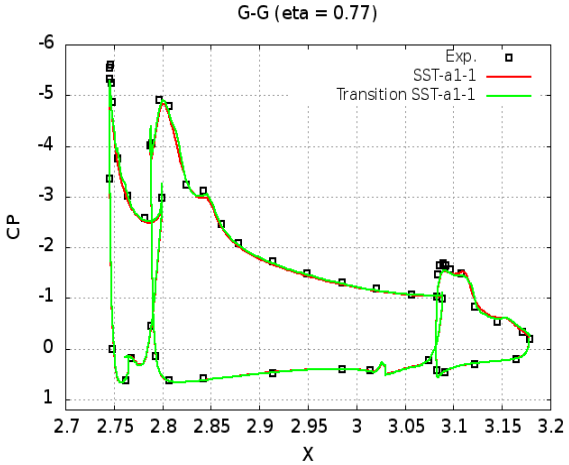


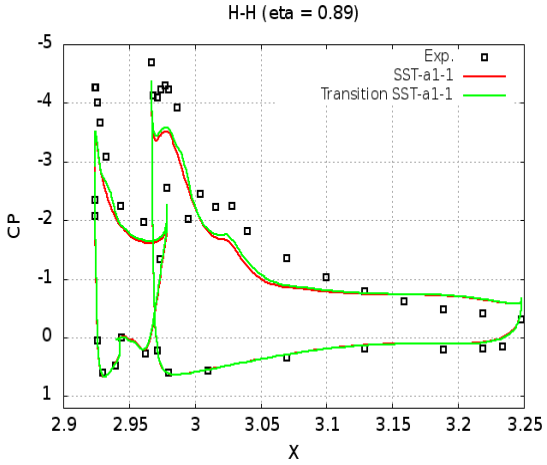


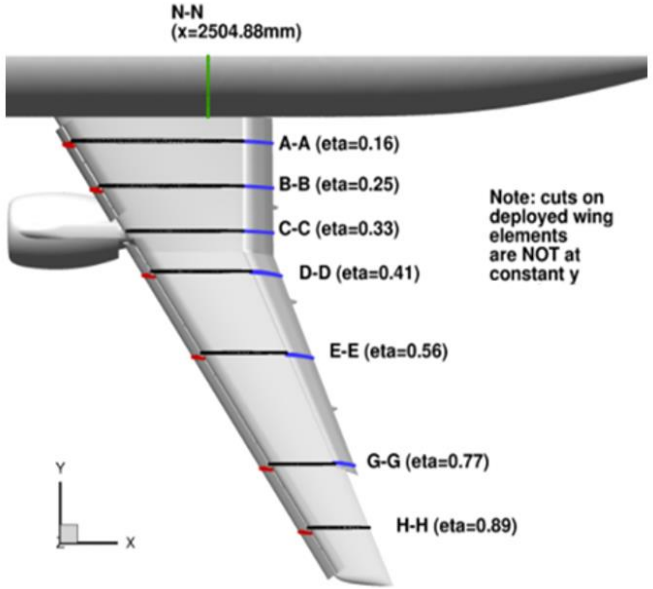












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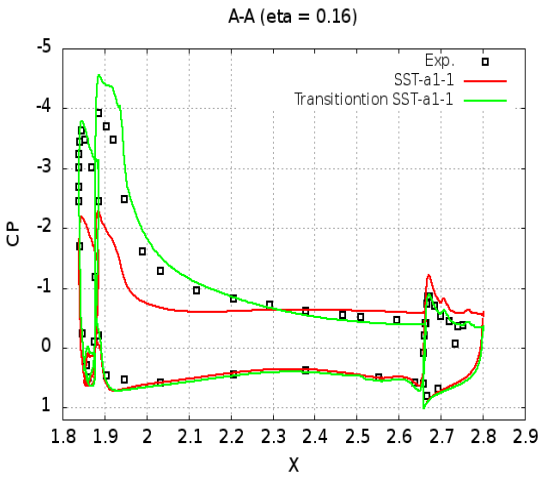
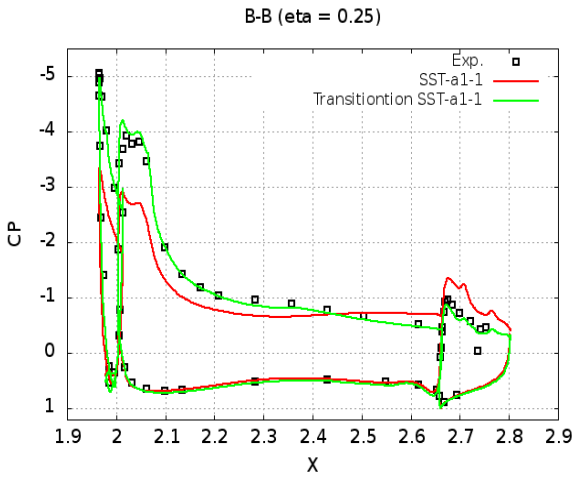
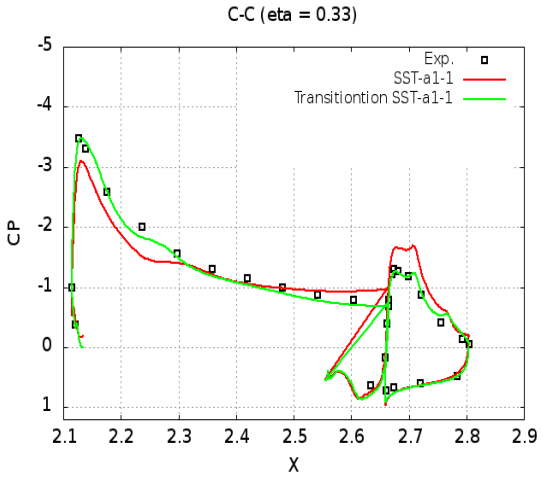
Appendix

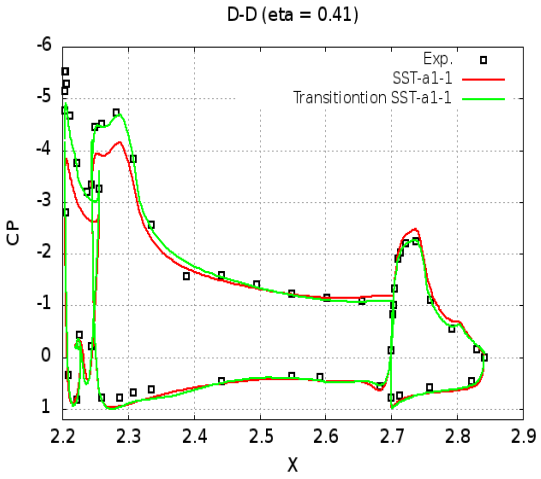
Case 2: JSM-WBNP $\alpha = 20.59^0$

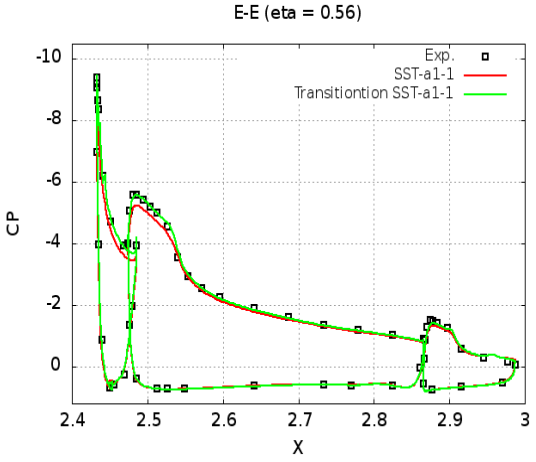
Pressure coefficient plots, fine mesh

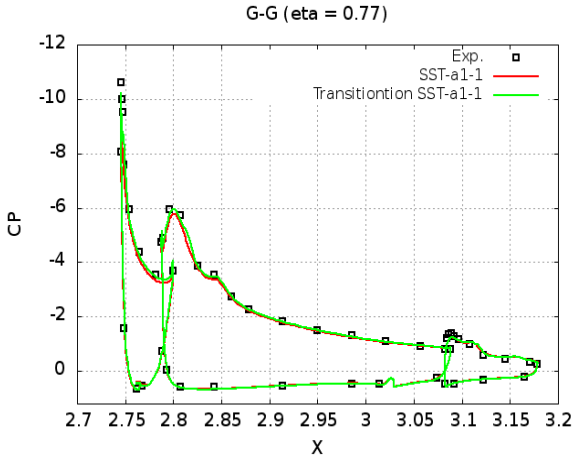


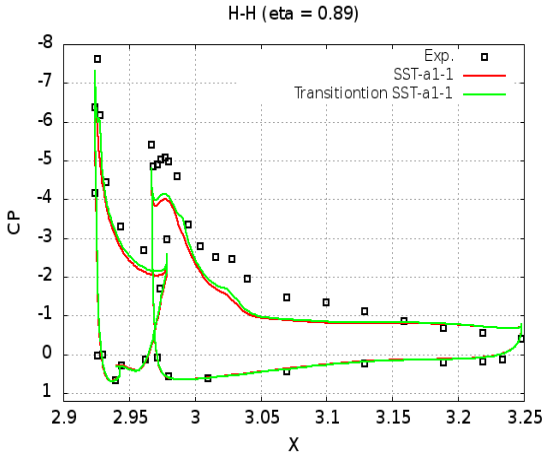


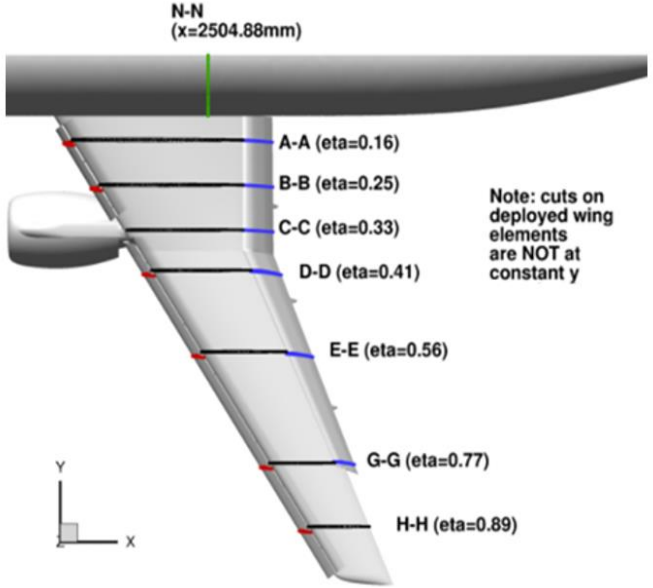












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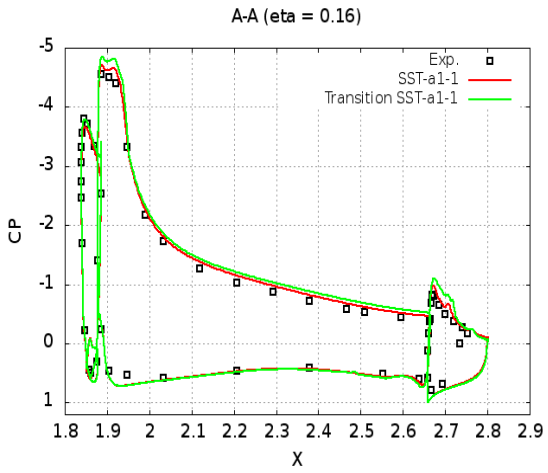
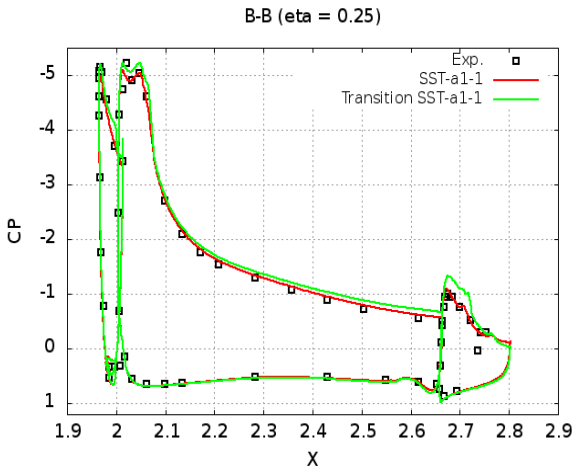
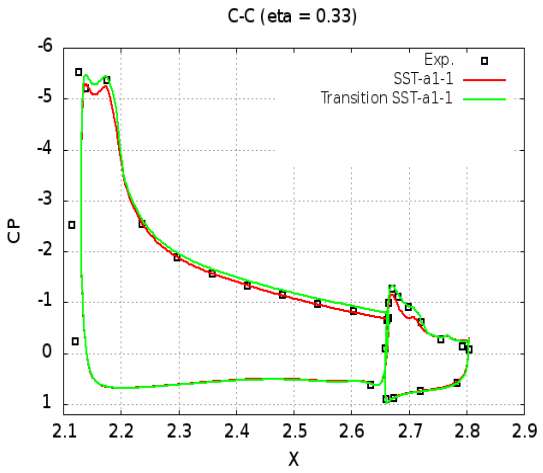
Appendix

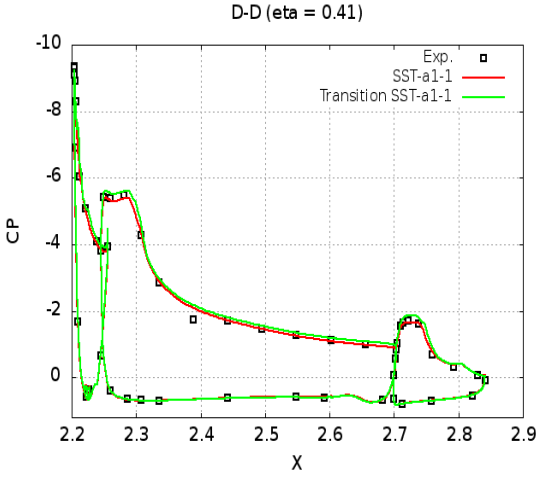
Case 2: JSM-WB $\alpha = 20.59^0$

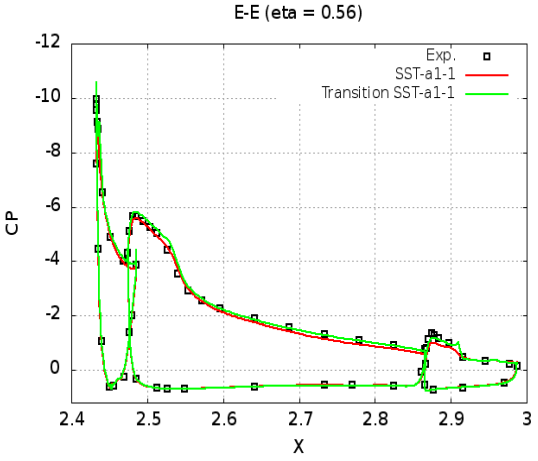
Pressure coefficient plots, fine mesh

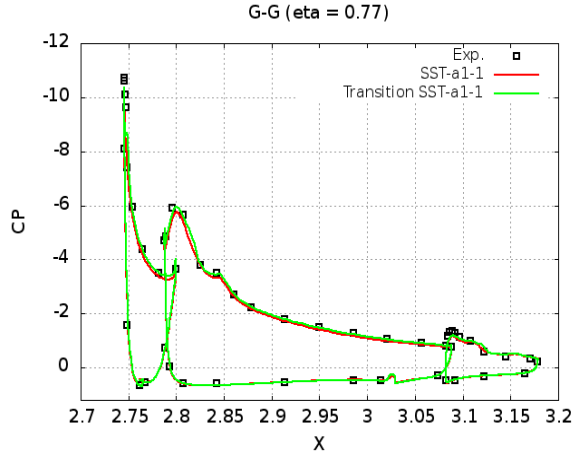


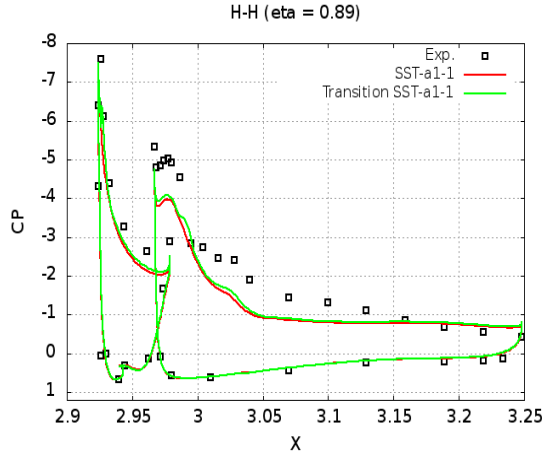


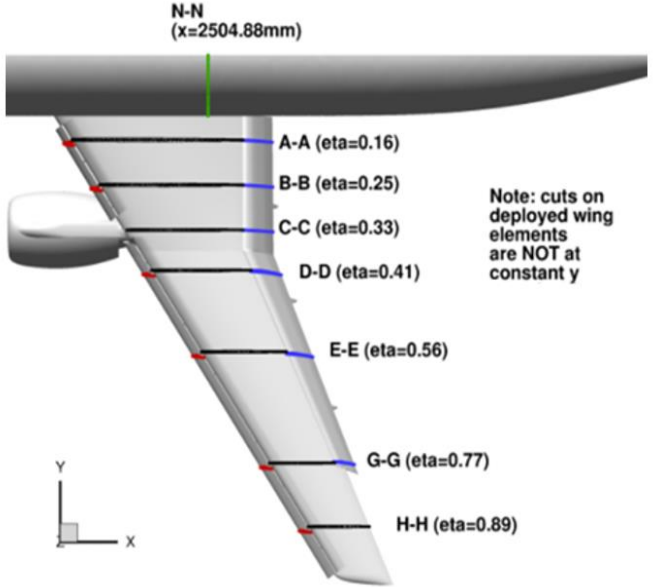












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