Results from HPCMP CREATE™-AV COFFE for Tasks 1-3 for DPW6

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6th AIAA CFD Drag Prediction Workshop, AIAA Aviation 2016, Washington, D.C., 16-17 June 2016

Outline – COFFE DPW6

- **COFFE Solver Discretization Update**
- **Results**
  - NACA0012
  - Mesh Convergence for Wing Body (WB) and Wing Body Nacelle Pylon (WBNP)
  - Alpha Sweep for Wing Body
- **Conclusions**
- **Acknowledgments**

Solver Discretization Update

- **The SU/PG discretization utilized in COFFE is outlined here:**
  - Ryan S. Glasby, J. Taylor Erwin, Douglas L. Stefanski, Steven R. Allmaras, Marshall C. Galbraith, W. Kyle Anderson, and Robert H. Nichols. "Introduction to COFFE: The Next-Generation HPCMP CREATE™-AV CFD Solver", 54th AIAA Aerospace Sciences Meeting, AIAA SciTech, (AIAA 2016-0567).
- **For these calculations, the SU/PG stabilization term, and the shock indicator are defined as:**

$$\sum_i \oiiint \left[\nabla \phi_i \bullet \frac{\partial F_c\left(u_h\right)}{\partial u_h} \right] \left[\tau \right] \left[PDE_{StrongForm} \right]$$

$$\left[\tau \right]^{-1} = \sum_i \left(\left| \nabla \phi_i \bullet \frac{\partial F_c\left(u_h\right)}{\partial u_h} \right| + \nabla \phi_i \bullet \frac{\partial F_v\left(u_h, \nabla u_h\right)}{\partial \left(\nabla u_h\right)} \bullet \nabla \phi_i \right)$$

$$\varepsilon_{shock} = \frac{\left(u \bullet \nabla p\right) h}{\left(u \bullet \nabla p\right) h + \kappa_{shock} cp}, \; if \; u \bullet \nabla p > 0, \varepsilon_{shock} = 0, if \; u \bullet \nabla p <= 0$$

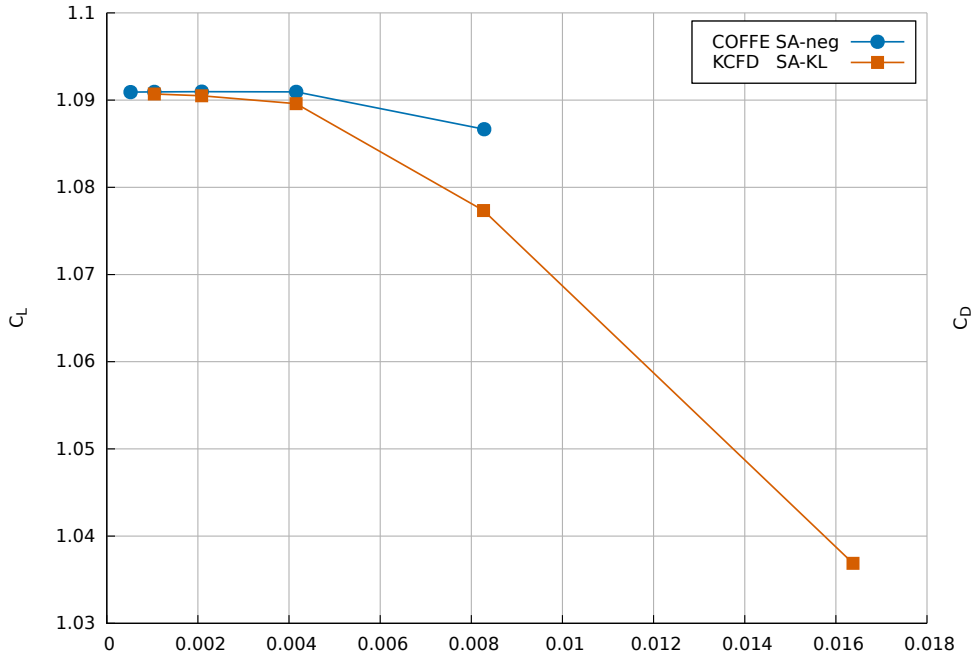
Task 1 – NACA0012 Mesh Convergence

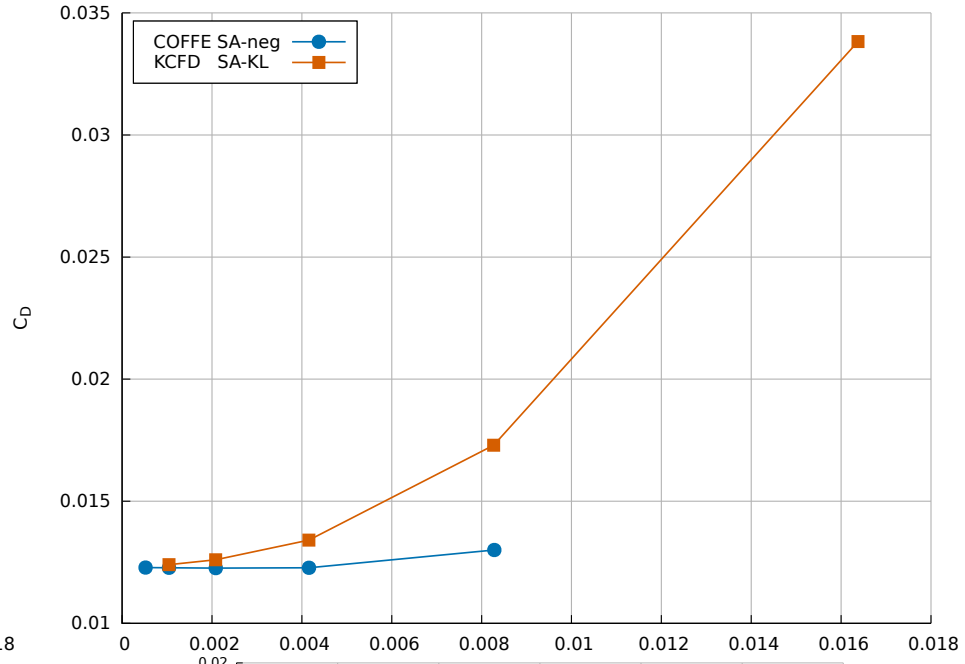
- **2D NACA0012 Airfoil from the Turbulence Modeling Resource (TMR) http://turbmodels.larc.nasa.gov/**
- **Flow conditions: Mach = 0.15, Re_C = 6 million, angle-of-attack = 10 degrees**
- **Far-field boundary condition at 500 chords**
- **Grids: http://turbmodels.larc.nasa.gov/naca0012numerics_grids.html**
- **Expected C_L = 1.0909 - 1.0911, C_D = 0.012270 - 0.012275**
- **COFFE Forces calculated:**

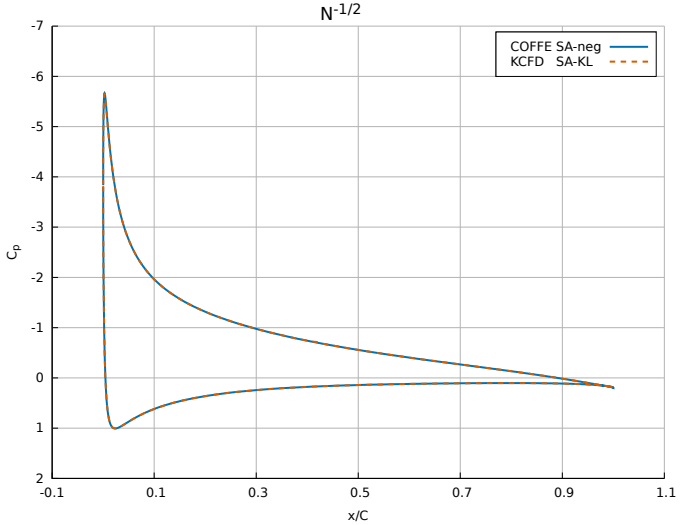
6. Family II 225 x 65	**C_L = 1.0866643, C_D = 0.01300284**
5. Family II 449 x 129	**C_L = 1.0909380, C_D = 0.01227414**
4. Family II 897 x 257	**C_L = 1.0909723, C_D = 0.01225952**
3. Family II 1793 x 513	**C_L = 1.0909464, C_D = 0.01227657**
2. Family II 3585 x 1025	**C_L = 1.0909141, C_D = 0.01228354**

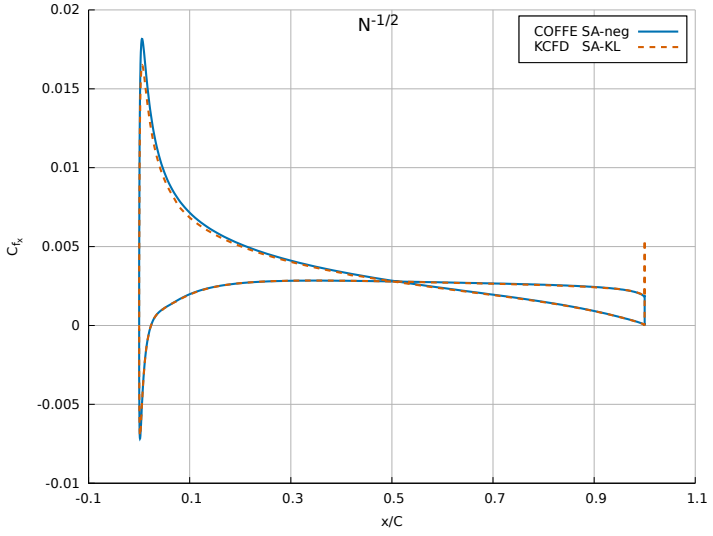
- **Density residual converged to 10^-15, SA-neg turbulence model**

NACA0012 – C_L, C_D, C_p, Cf_x









Task 2 – CRM Mesh Convergence

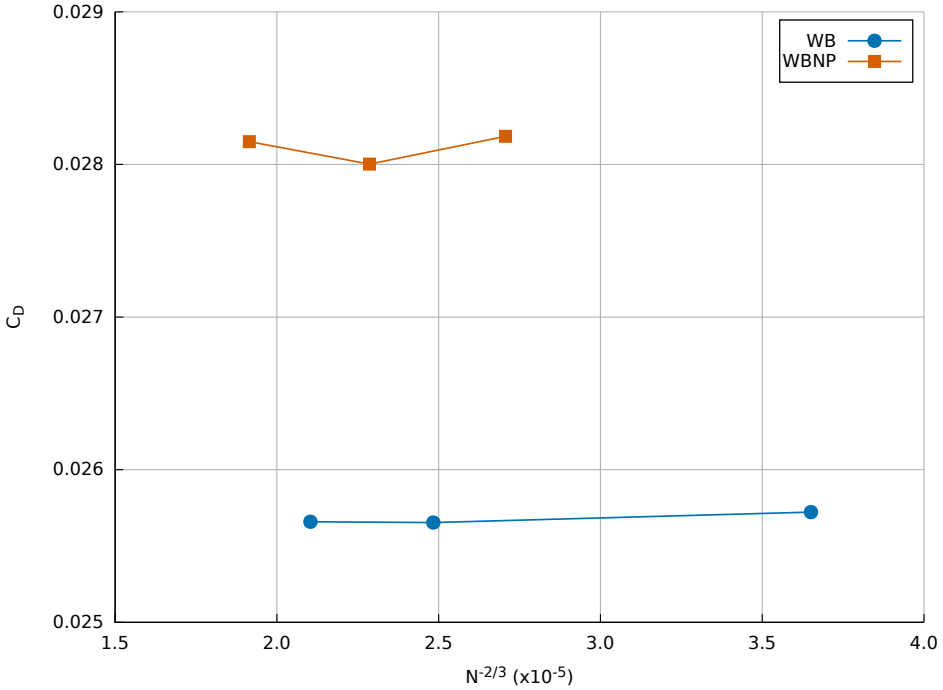
- **Conditions: Mach = 0.85, Re_{MAC} = 5 million, target C_L = 0.5**
- **Series of meshes generated by Steve Karman, Pointwise, Inc.**
- **Surface meshes follow DPW6 meshing guidelines**
- **Meshes made of only tetrahedral elements for COFFE with a maximum angle < 176 degrees**
- **WB meshes, alpha 2.75 geometry**

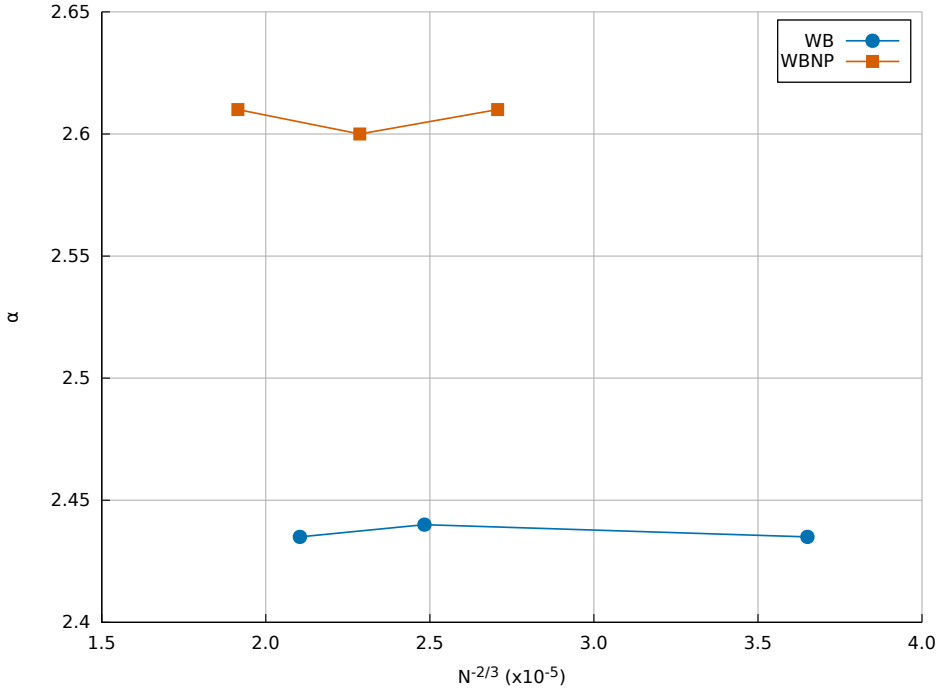
	#Nodes	#Tetrahedra	#Surface Triangles
COARSE	4,533,286	26,780,170	284,502
MEDIUM	6,095,629	36,108,376	329,381
FINE	8,080,127	47,905,028	412,940
EXTRA FINE	10,362,607	61,454,600	520,156

- **WBNP meshes, alpha 2.75 geometry**

	#Nodes	#Tetrahedra	#Surface Triangles
COARSE	7,101,719	42,101,763	362,458
MEDIUM	9,146,625	54,273,284	435,396
FINE	11,935,490	70,854,330	546,524
EXTRA FINE	16,015,360	95,124,160	699,970

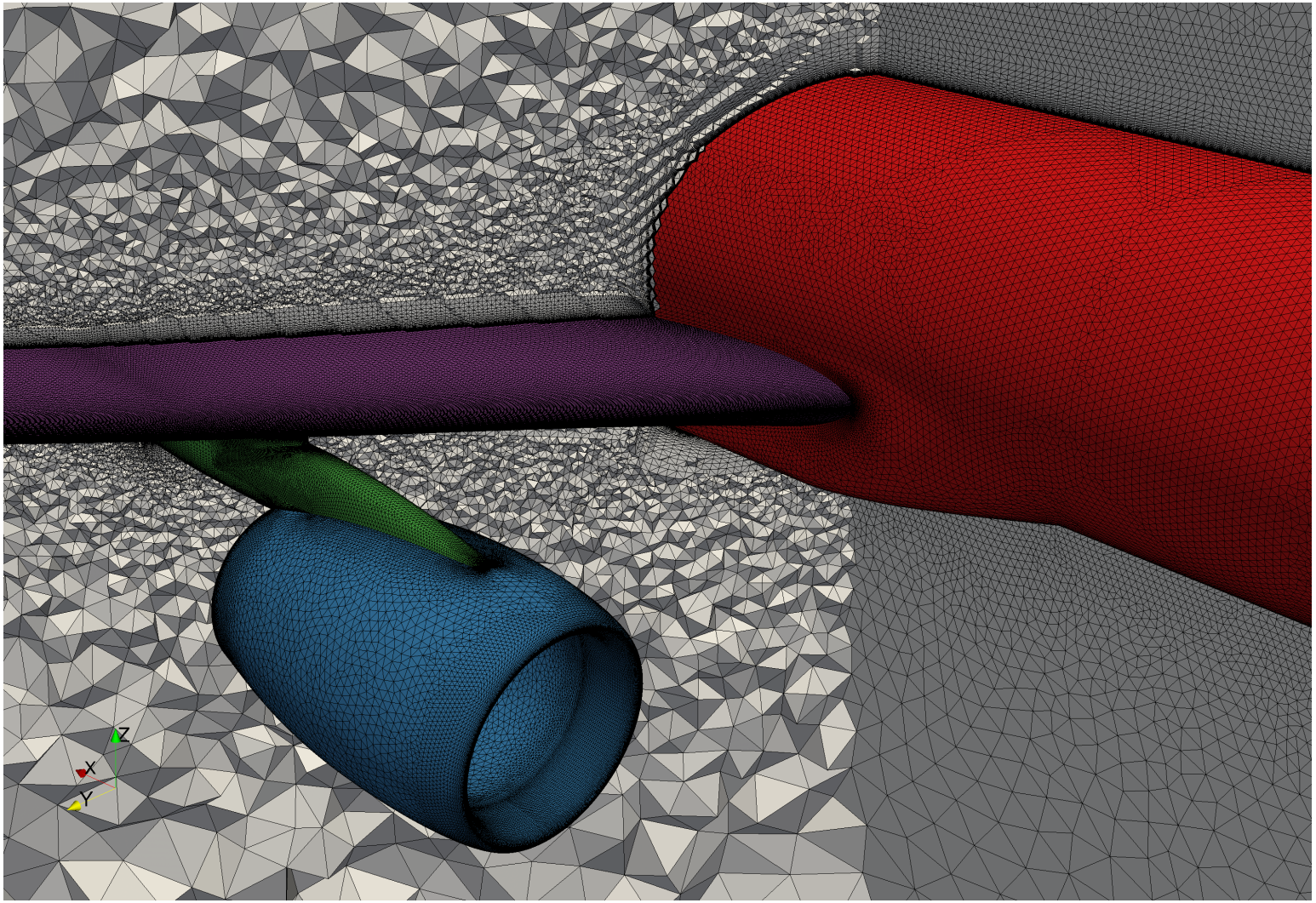
Task 2 – Mesh Convergence WB/WBNP



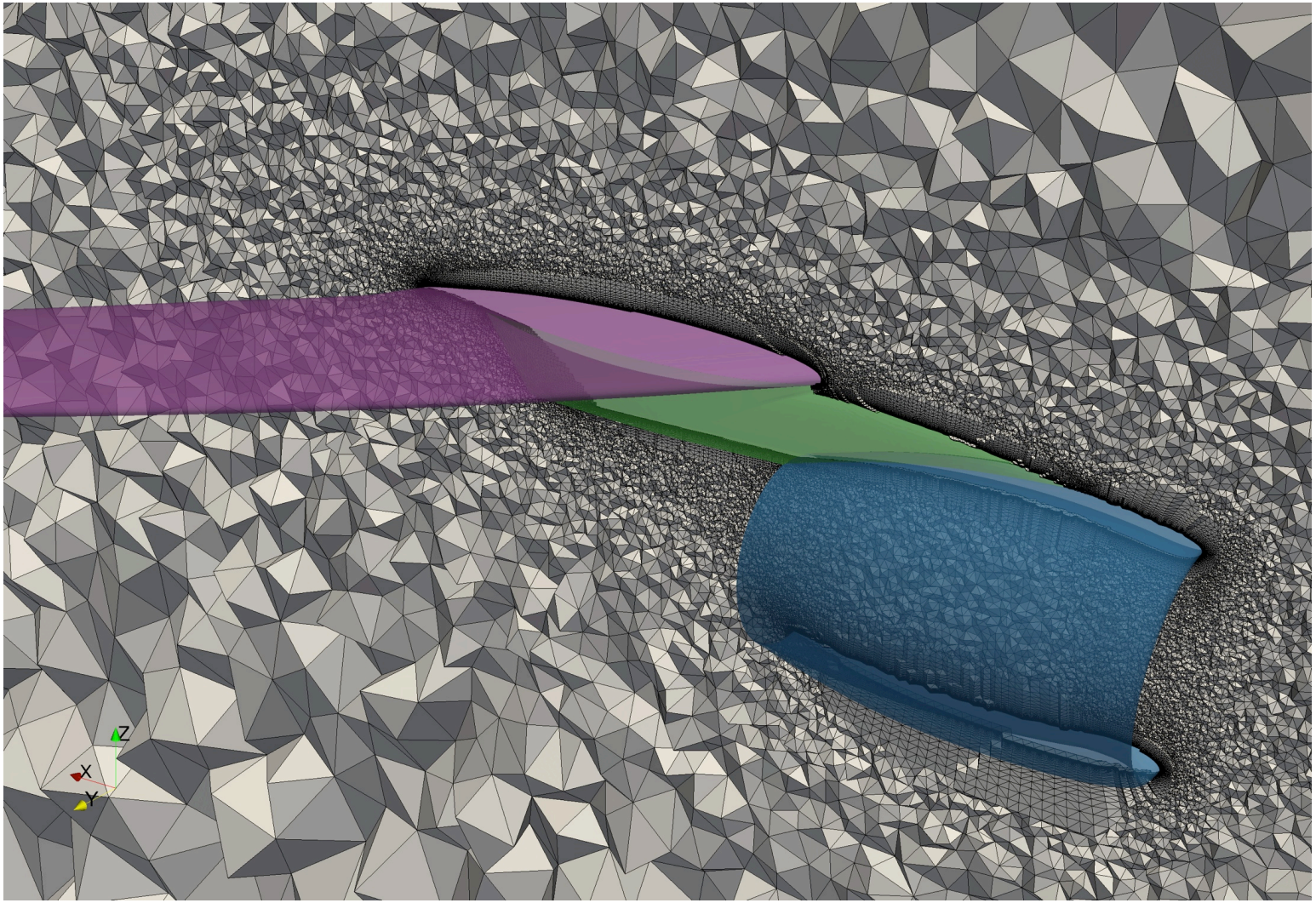


- SA-neg turbulence model
- C_L = 0.5 +/- 0.0001
- **Difference in mesh converged C_D for WB and WBNP = 0.0024911**

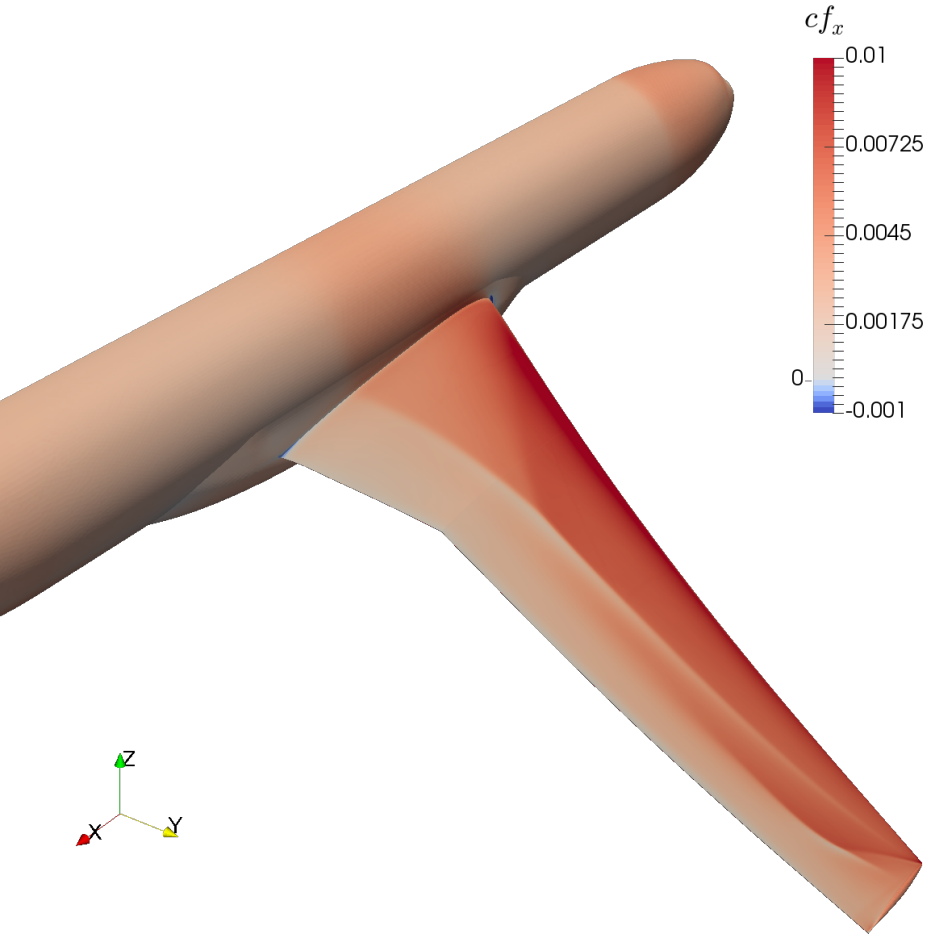
FINE mesh WBNP

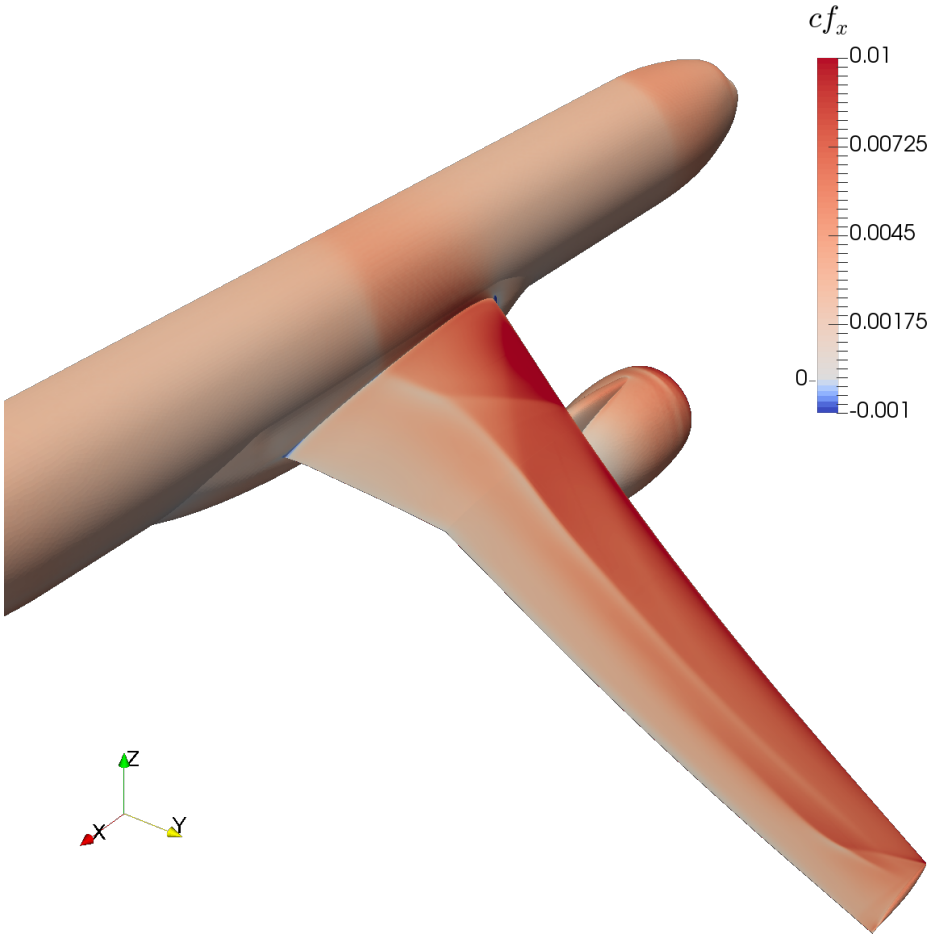


FINE mesh WBNP



WB/WBNP Cf_x Contours FINE Mesh

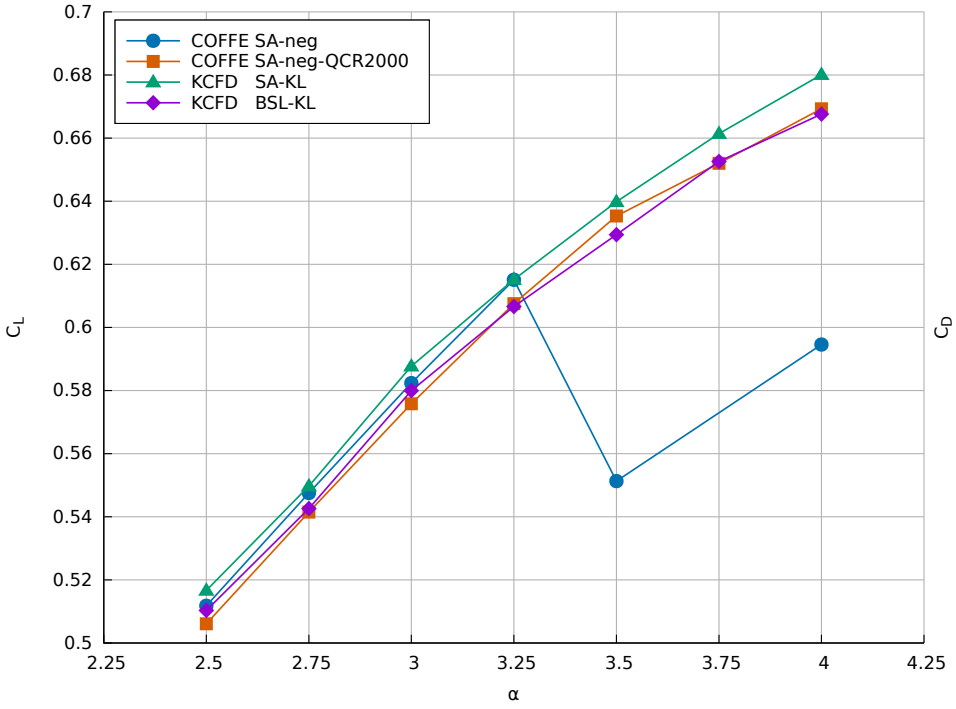


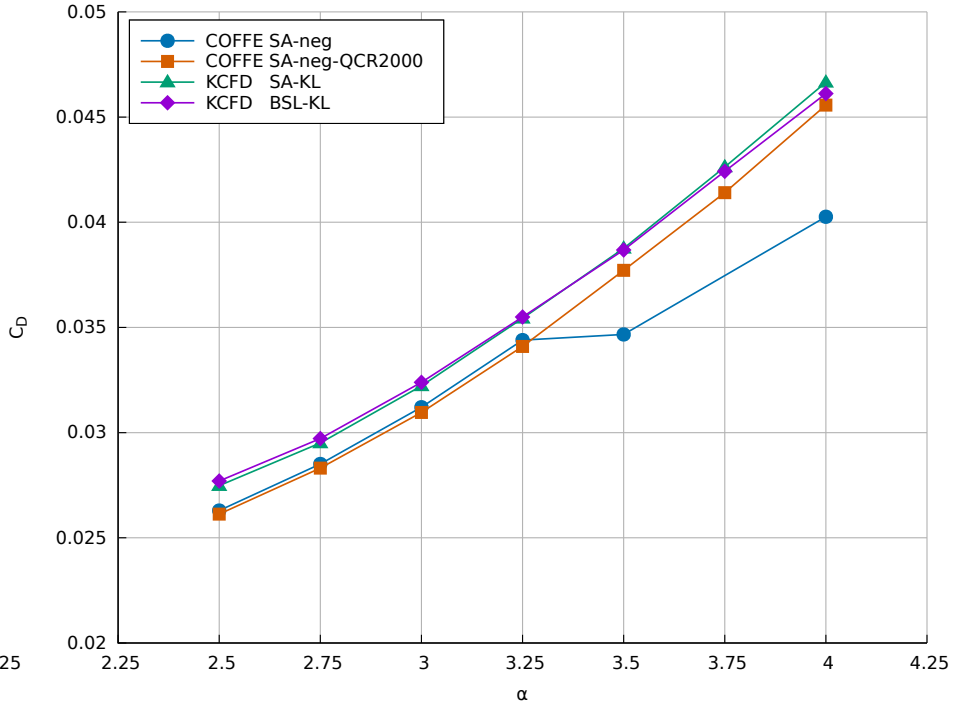


Task 3 – Alpha Sweep

- Conditions: Mach = 0.85, Re_{MAC} = 5 million, angle-of-attack = 2.5, 2.75, 3.0, 3.25, 3.5, 3.75, and 4.0 degrees
- Meshes generated by Steve Karman, Pointwise, Inc.
- Surface meshes follow DPW6 meshing guidelines
- Meshes made of **only tetrahedral elements** for COFFE with a maximum angle < 176 degrees
- For KCFD high aspect ratio BL tetrahedra are merged to prisms
- MEDIUM WB meshes, ~6,000,000 nodes per geometry
- Density residual converged to 10^-15 for COFFE
- SA-neg and SA-neg QCR-2000 results for COFFE, SA-KL results for KCFD
- Line plots of C_p and Cf_x from COFFE at 1%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, and 99% span

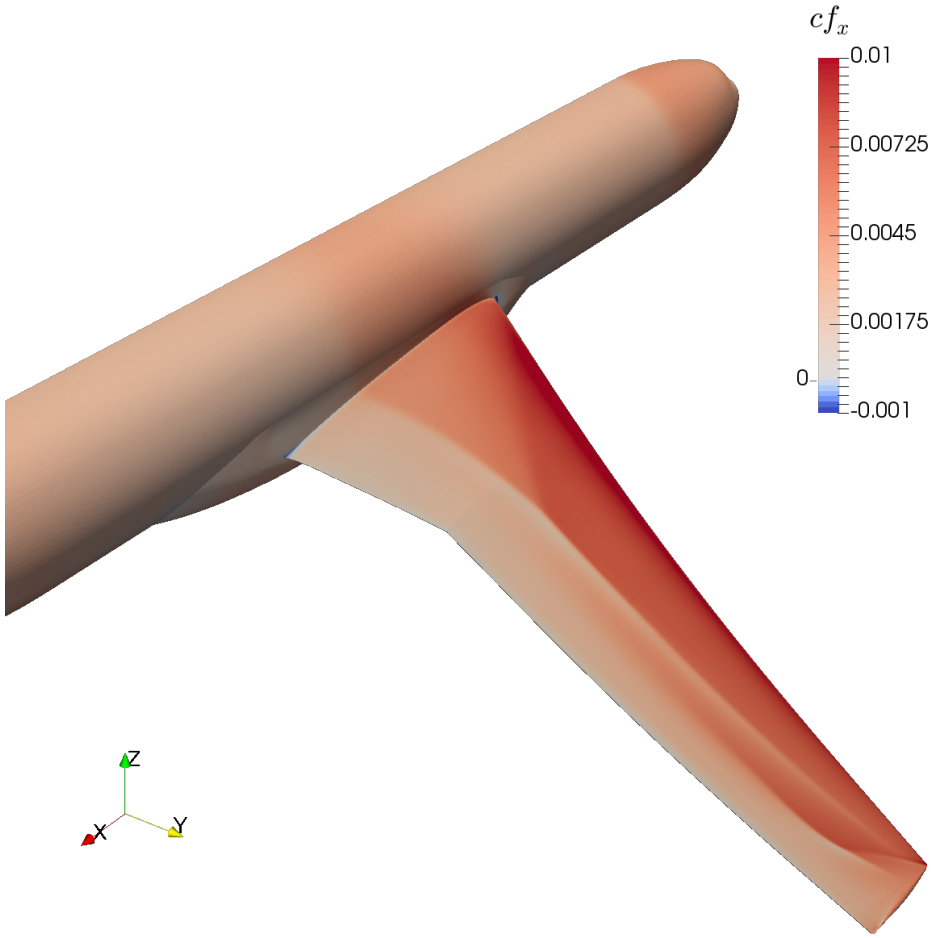
Task 3 – Alpha Sweep – Forces



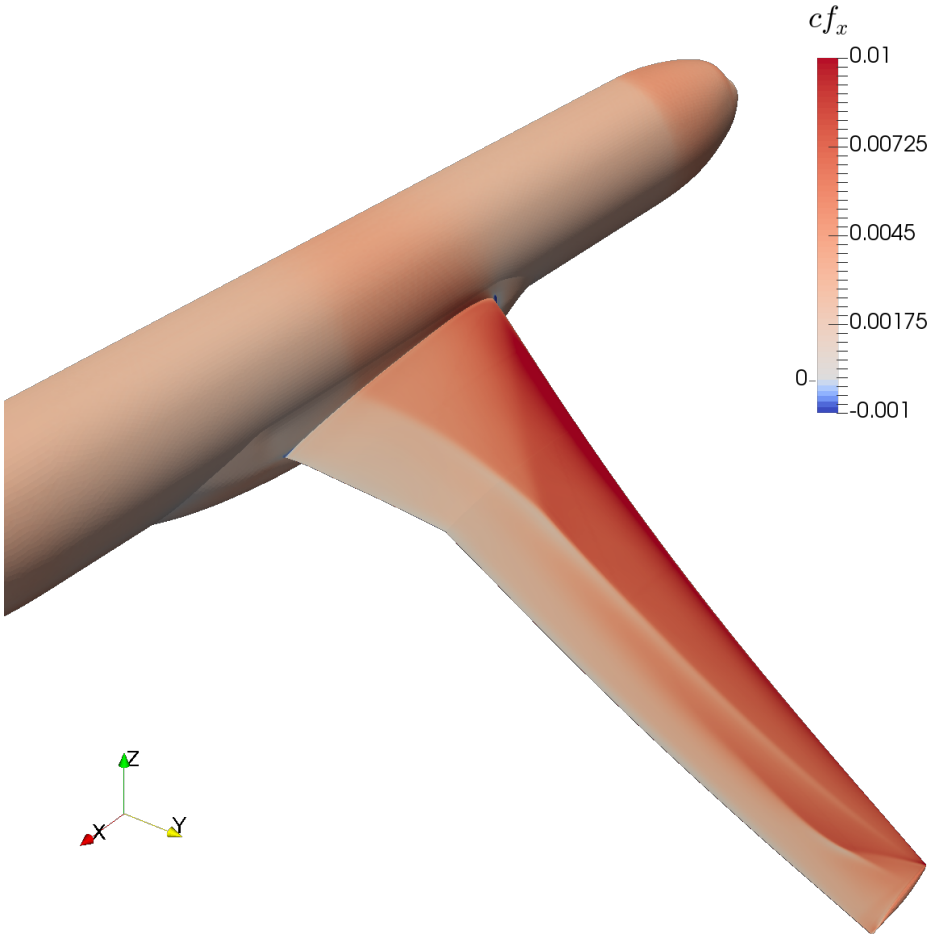


- **COFFE solutions validated by code-to-code comparison with KCFD**

COFFE Results – Alpha 2.5, Cf_x

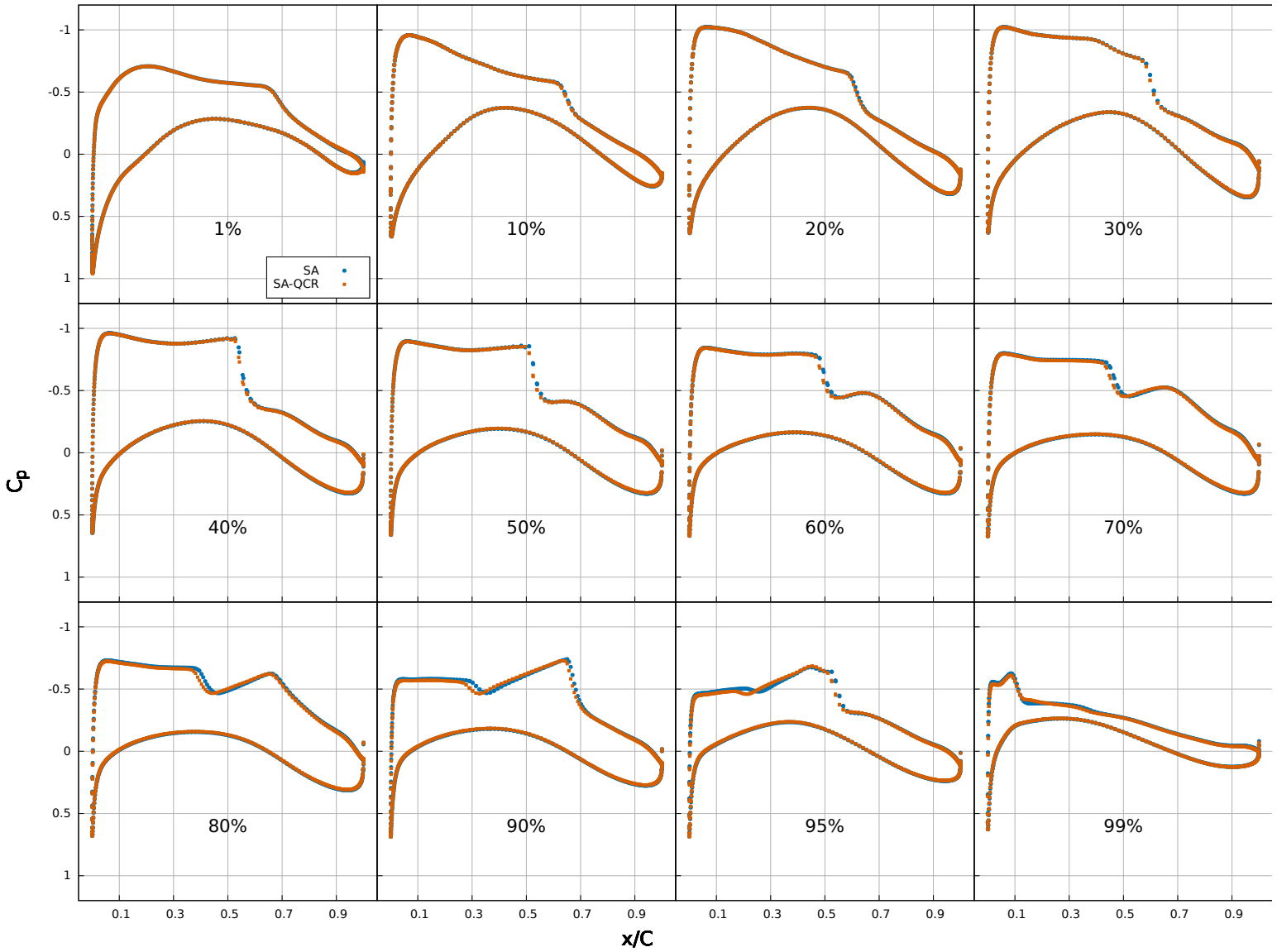


SA

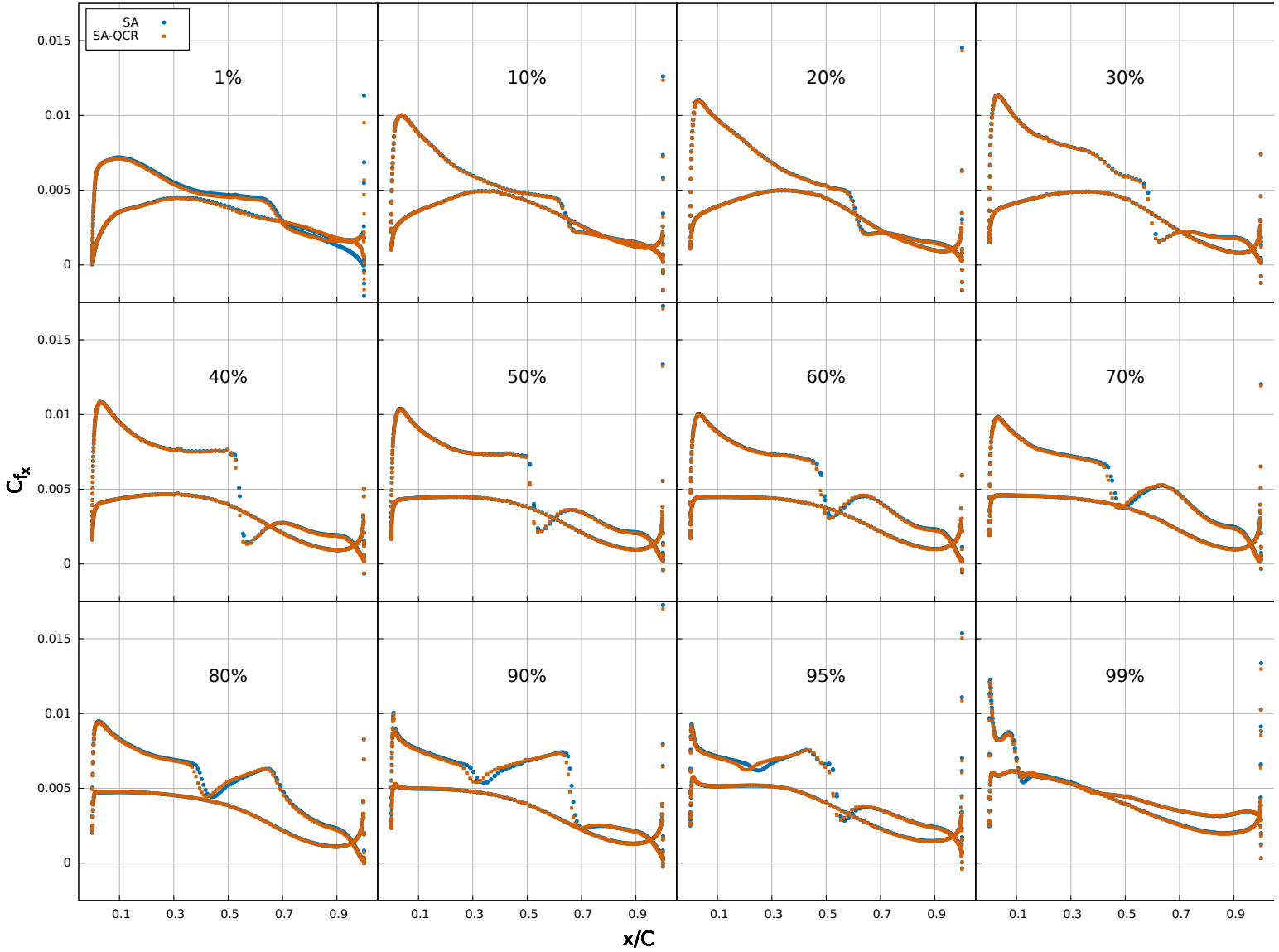


SA - QCR

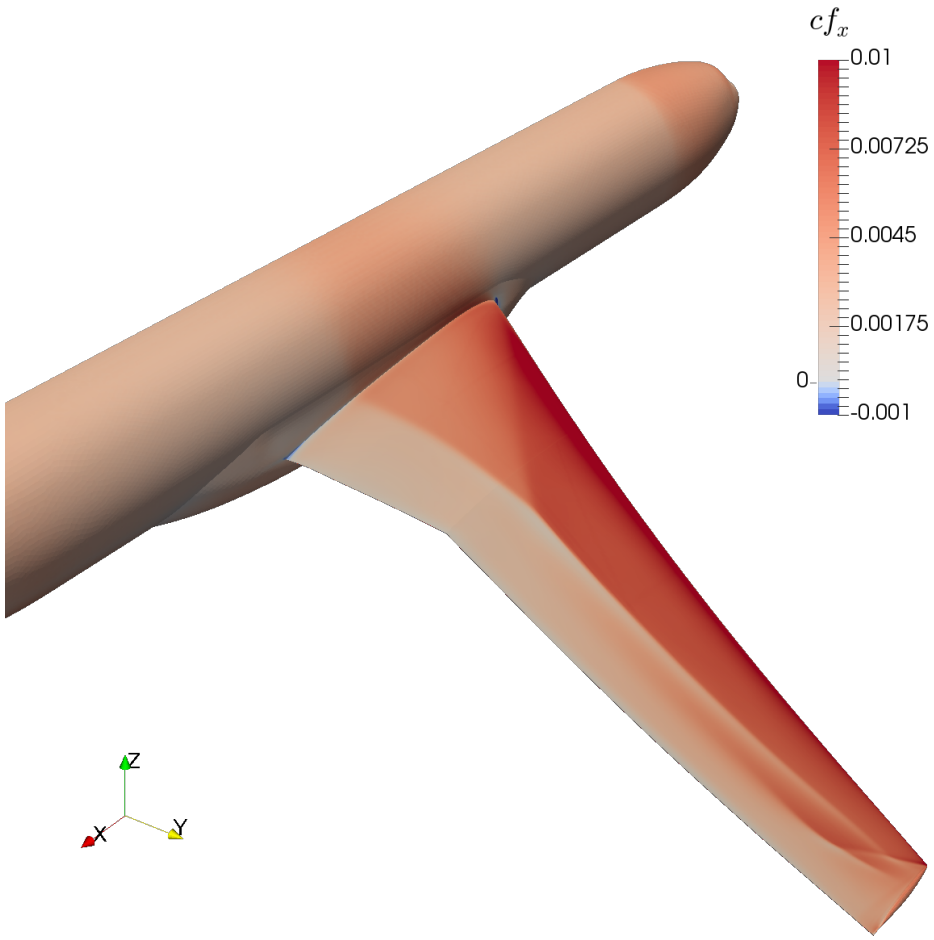
COFFE Results – Alpha 2.5, Cp



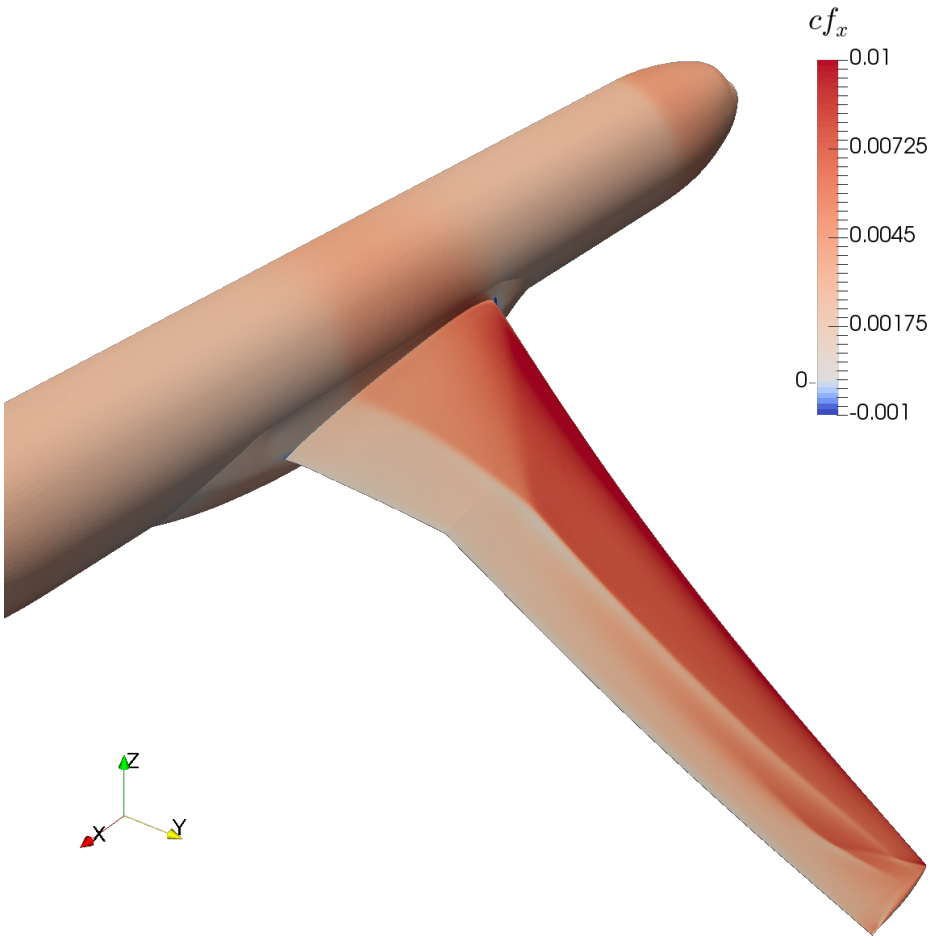
COFFE Results – Alpha 2.5, Cf_x



COFFE Results – Alpha 2.75, Cf_x

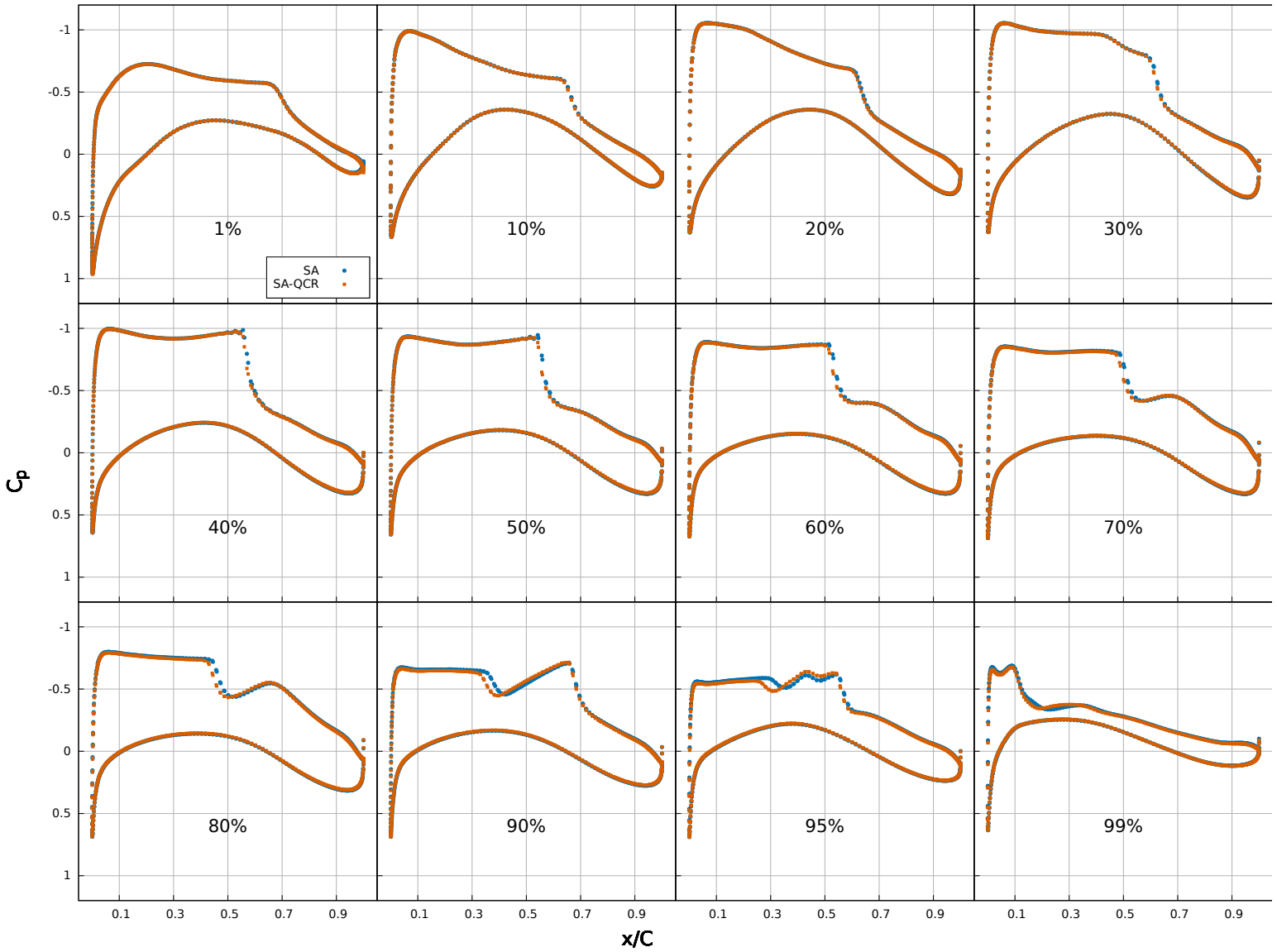


SA

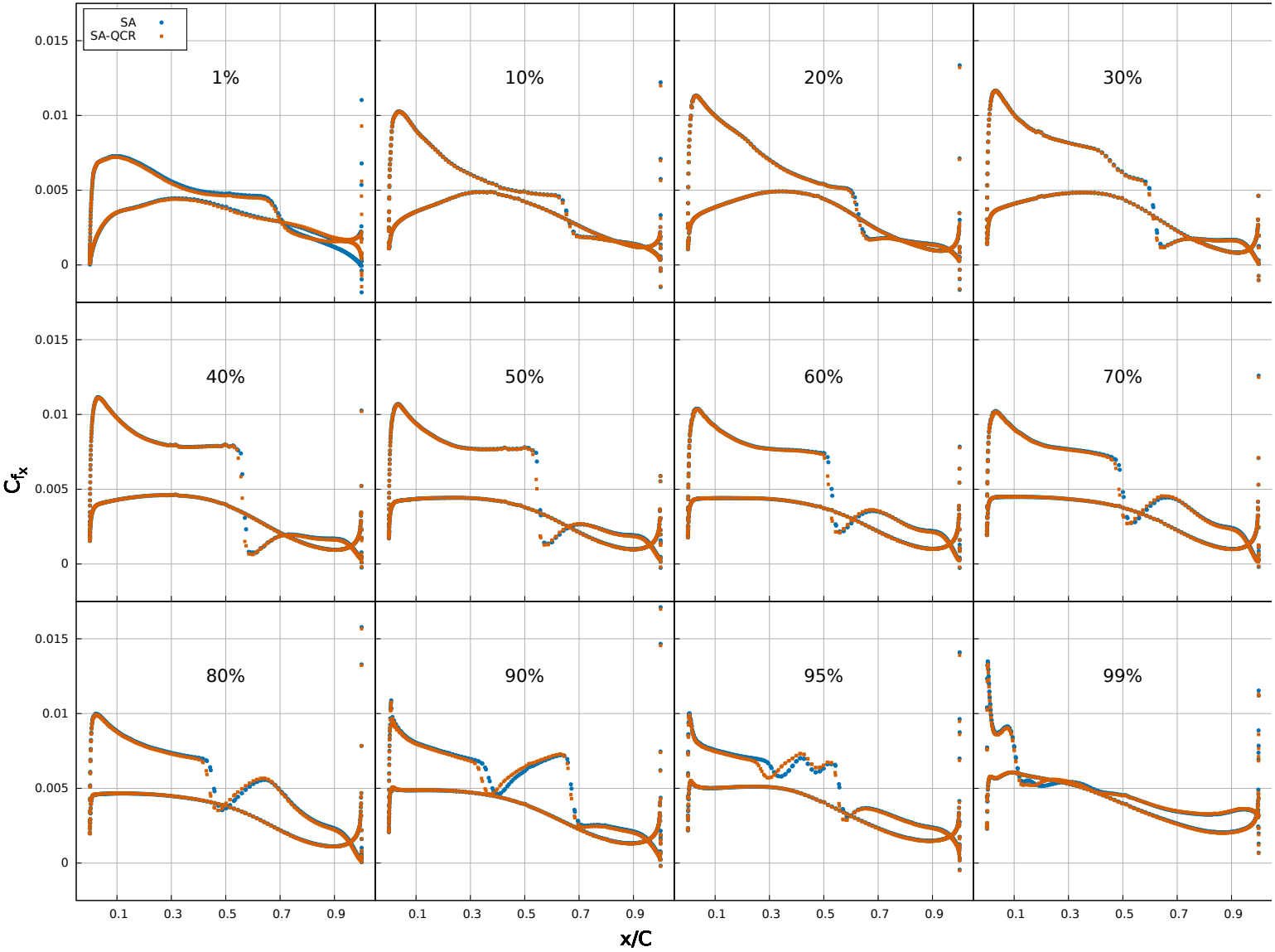


SA - QCR

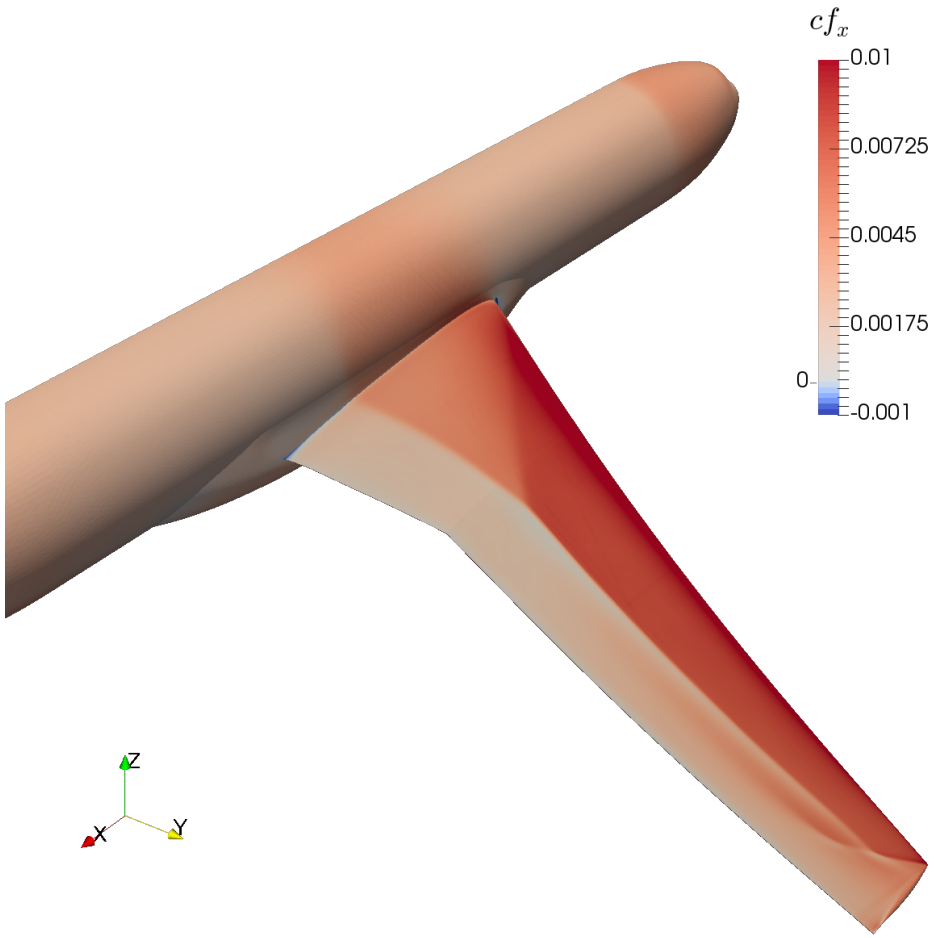
COFFE Results – Alpha 2.75, Cp



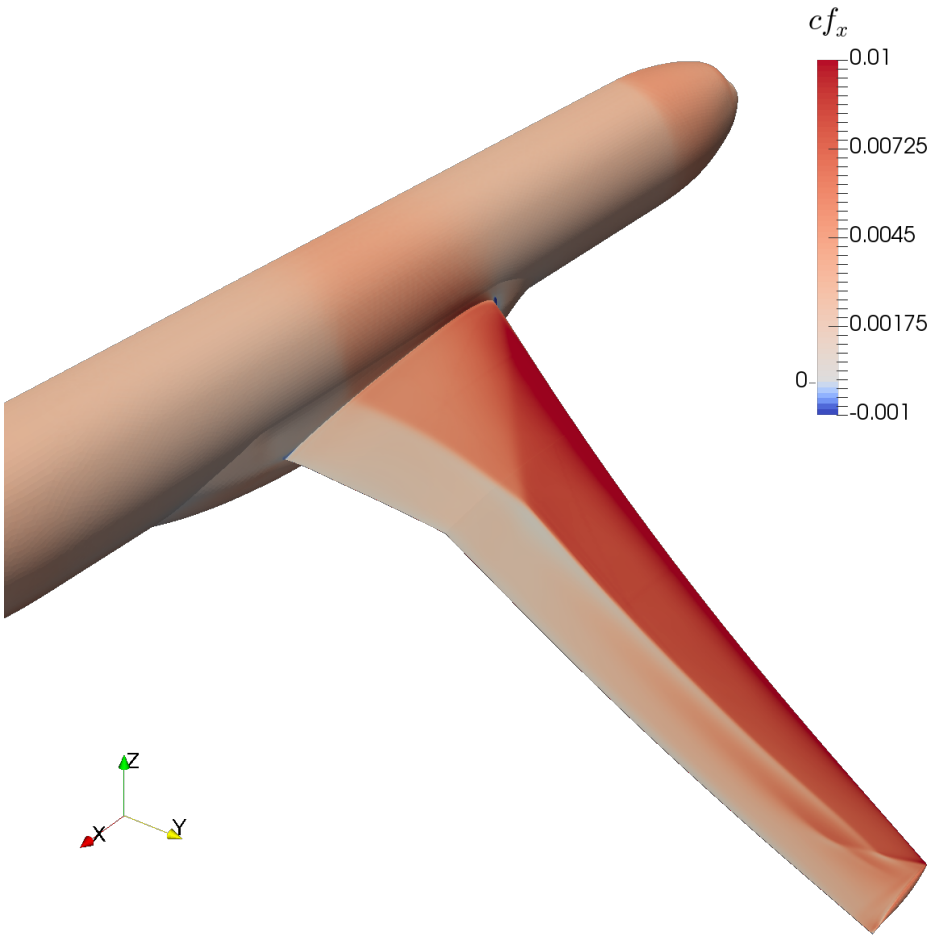
COFFE Results – Alpha 2.75, Cf_x



COFFE Results – Alpha 3.0, Cf_x

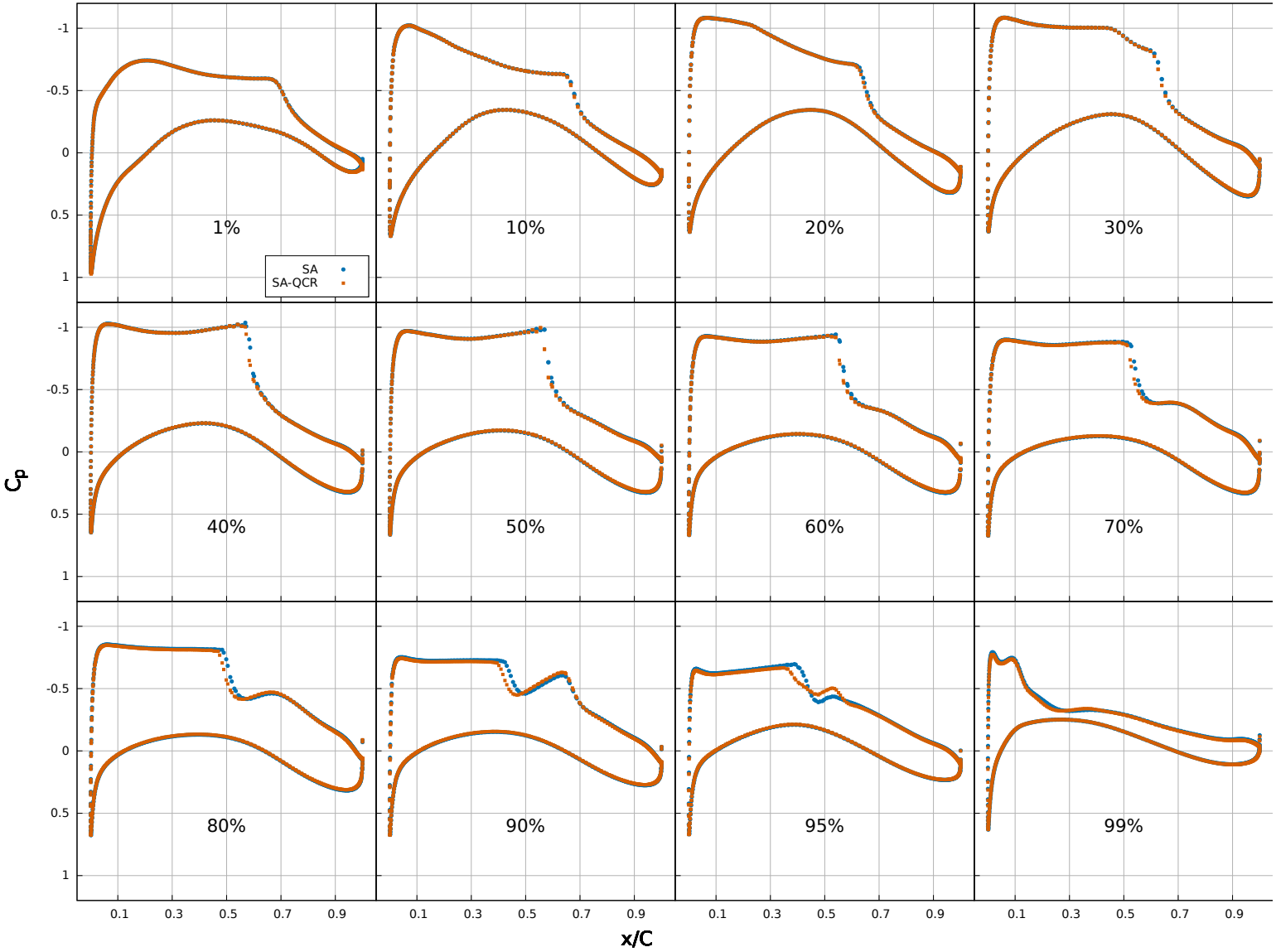


SA

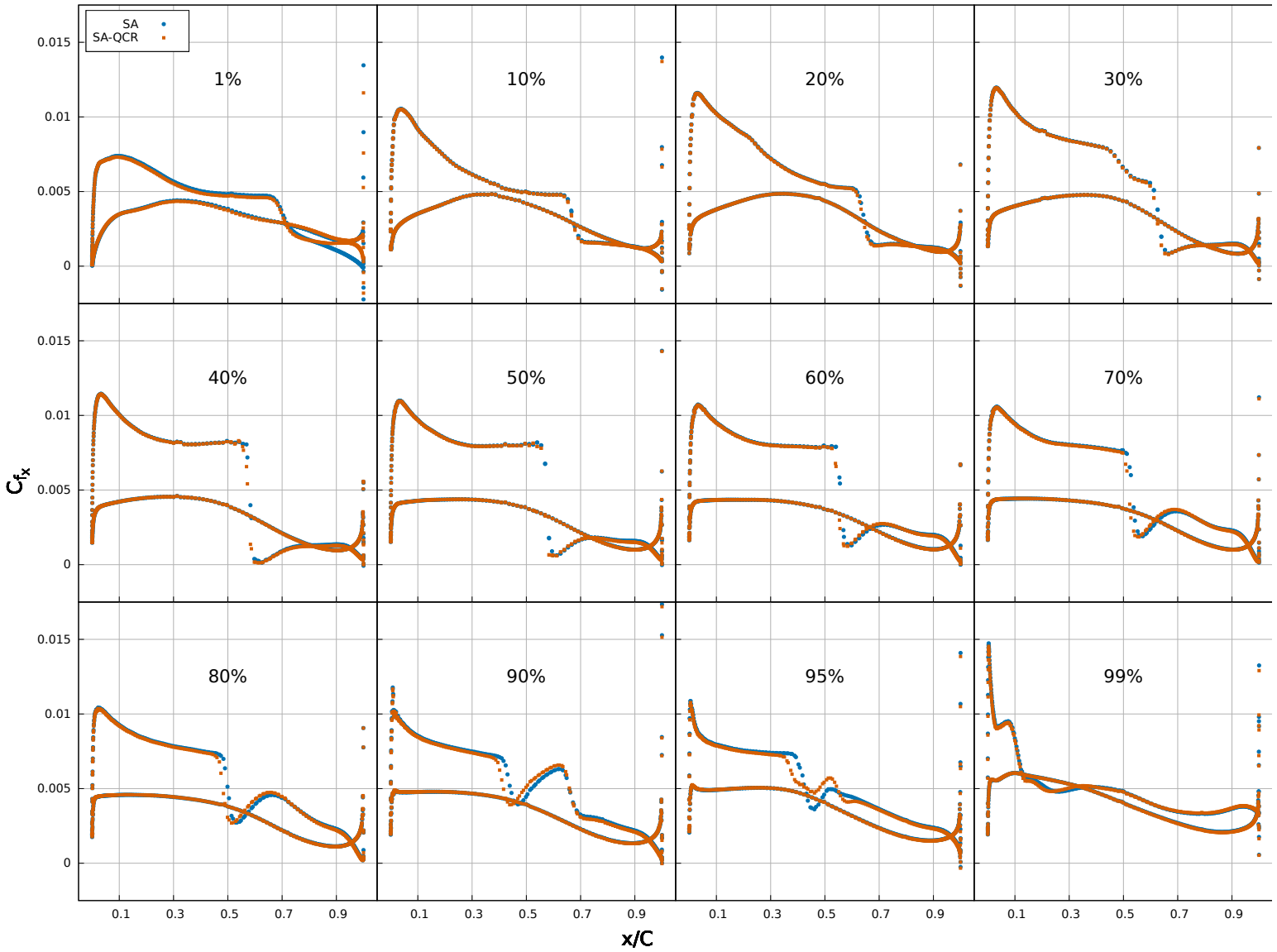


SA - QCR

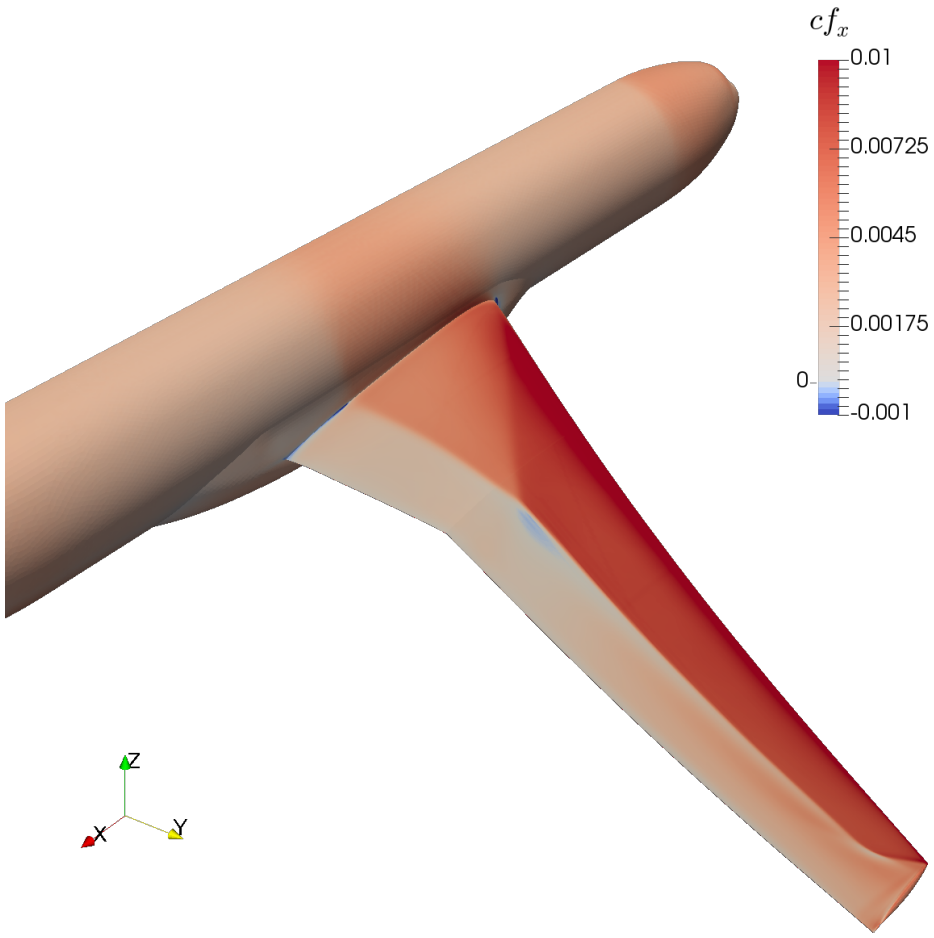
COFFE Results – Alpha 3.0, Cp



COFFE Results – Alpha 3.0, Cf_x



COFFE Results – Alpha 3.25, Cf_x



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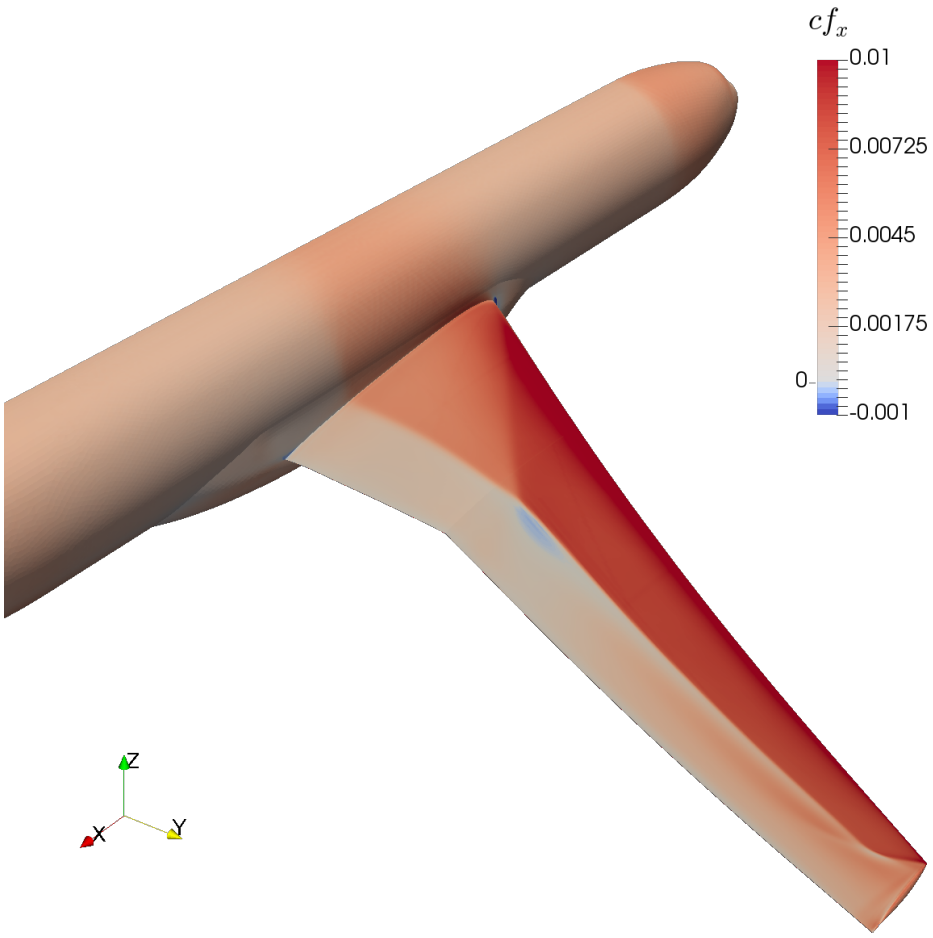
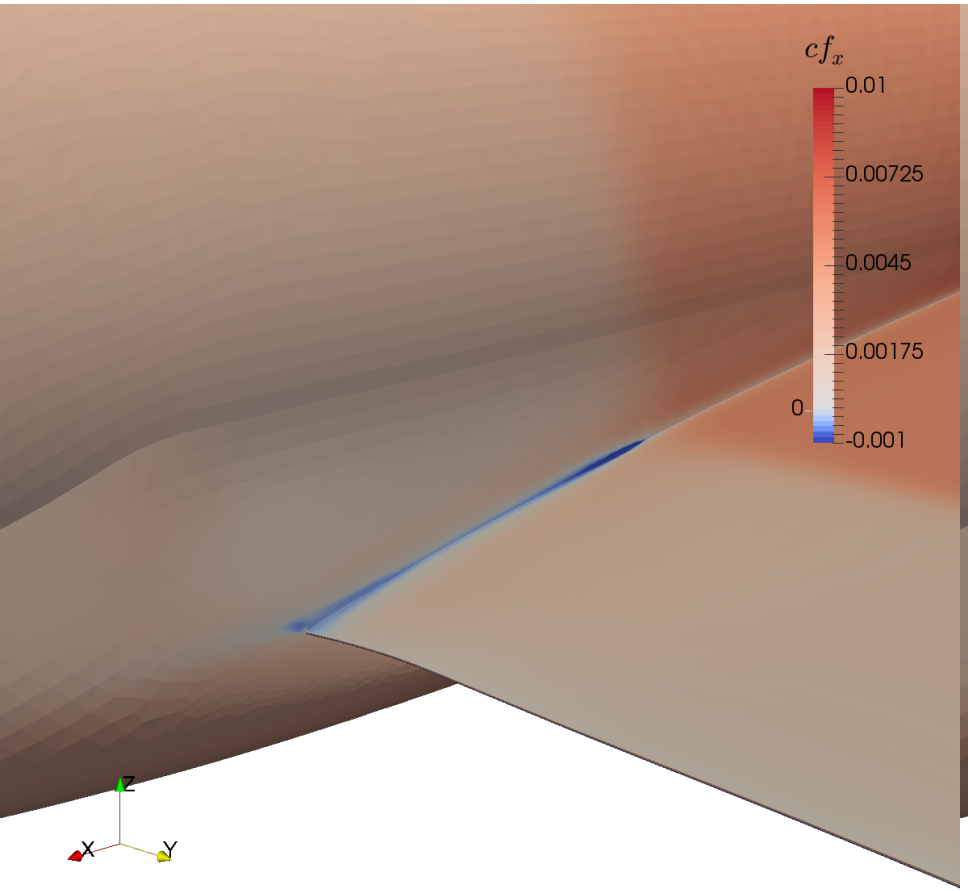


SA - QCR

COFFE Results – Alpha 3.25, Cf_x



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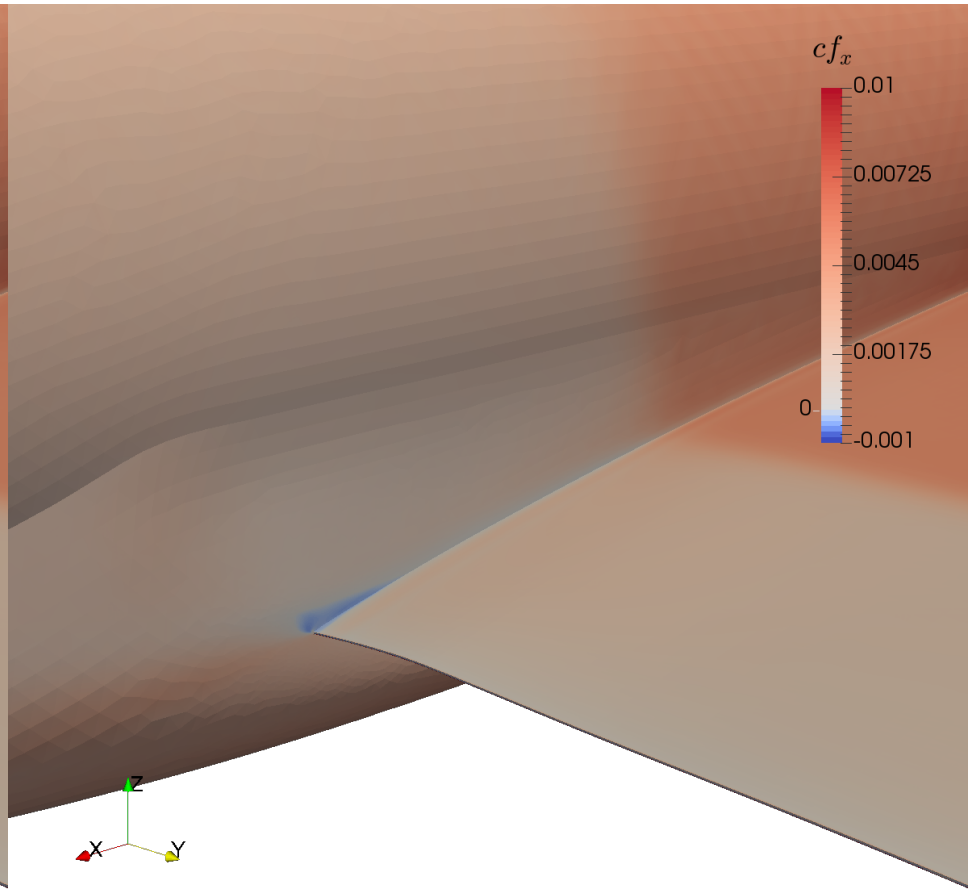
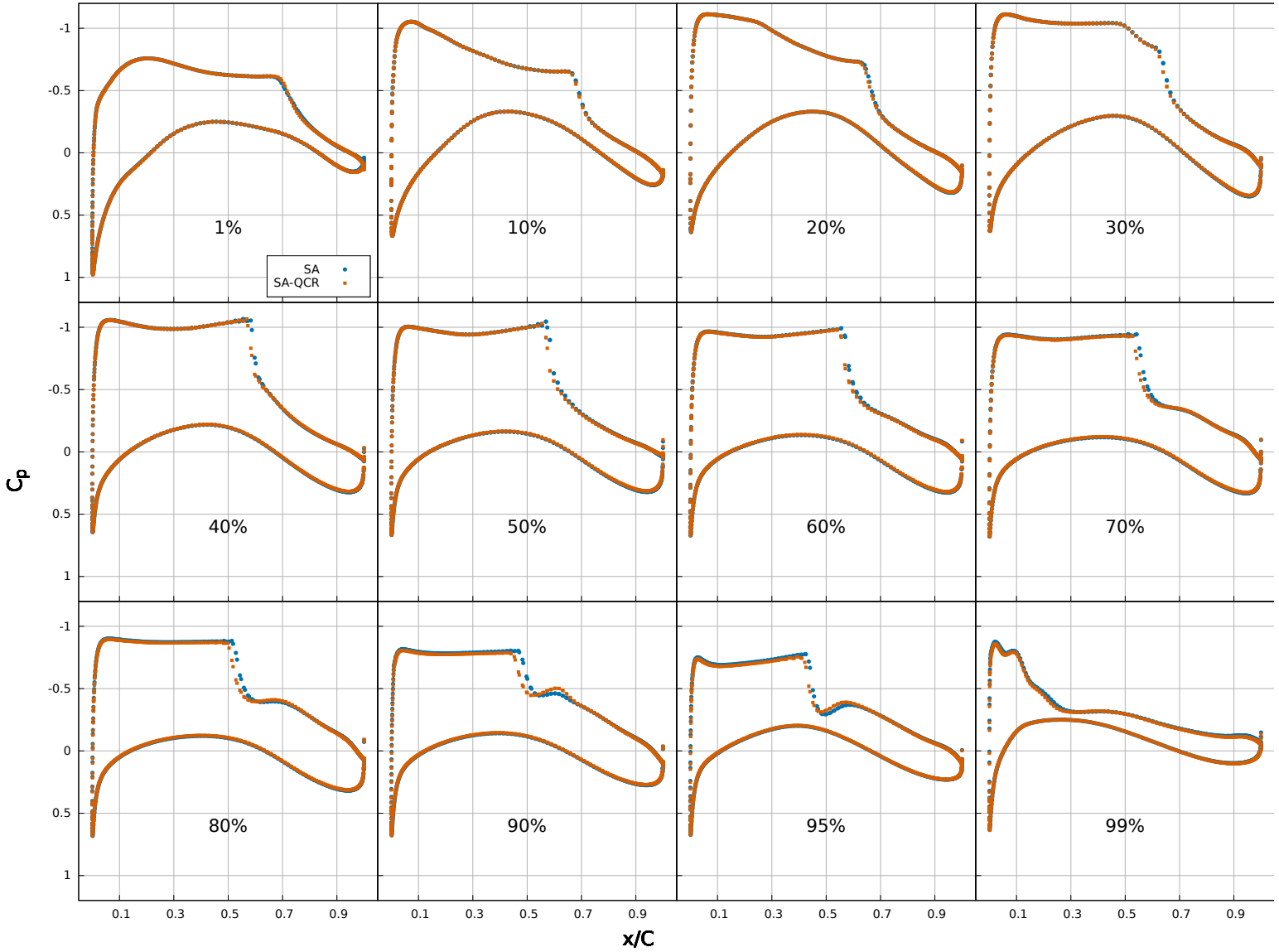
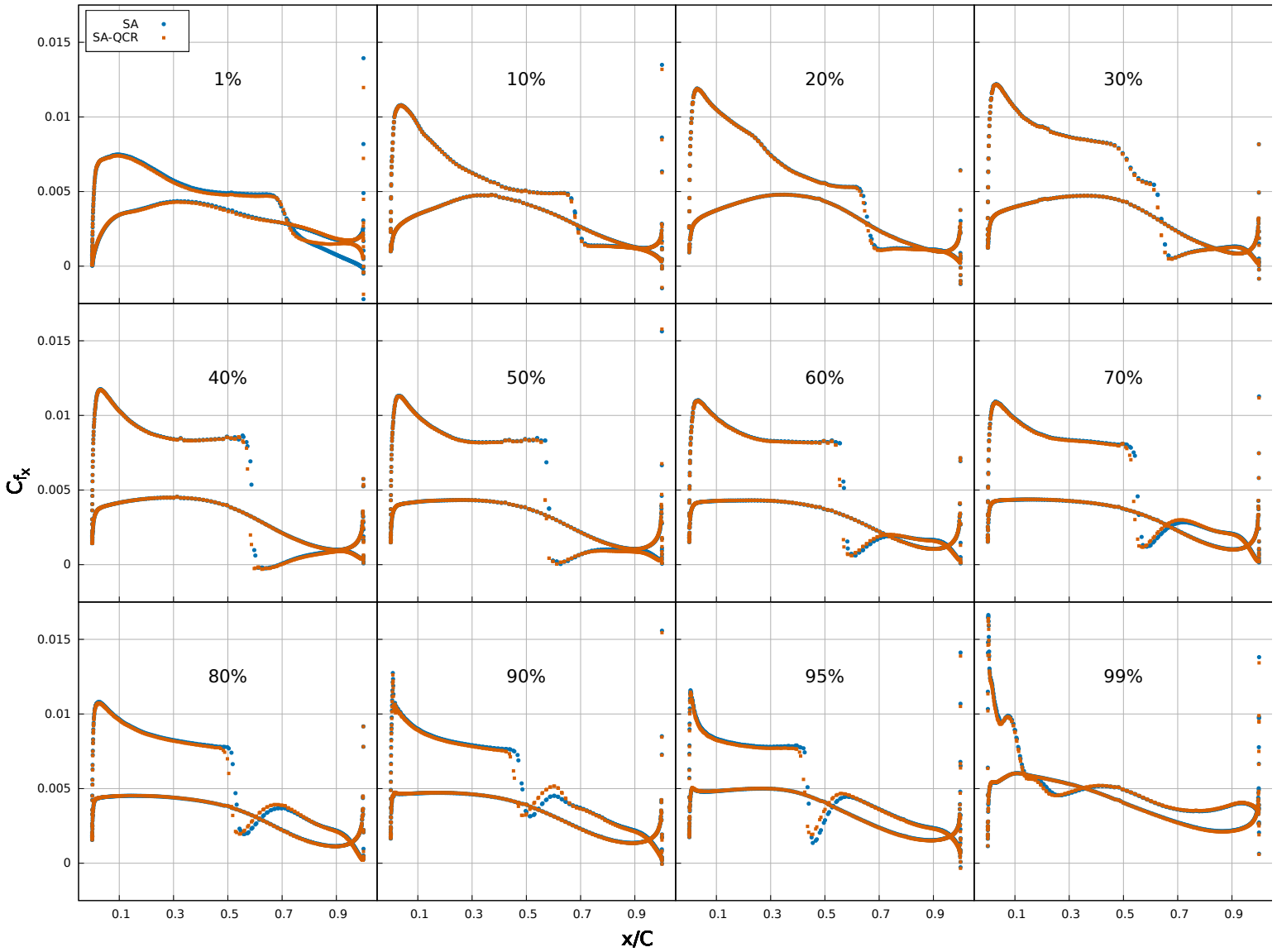


SA - QCR

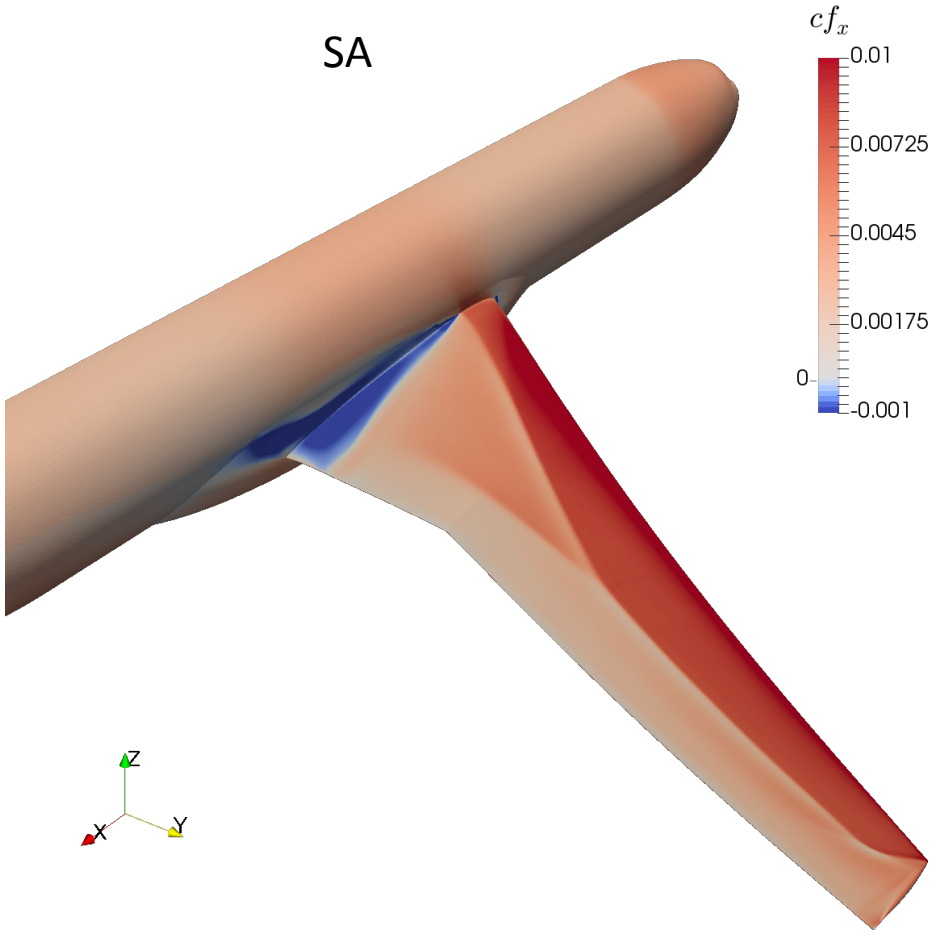
COFFE Results – Alpha 3.25, Cp

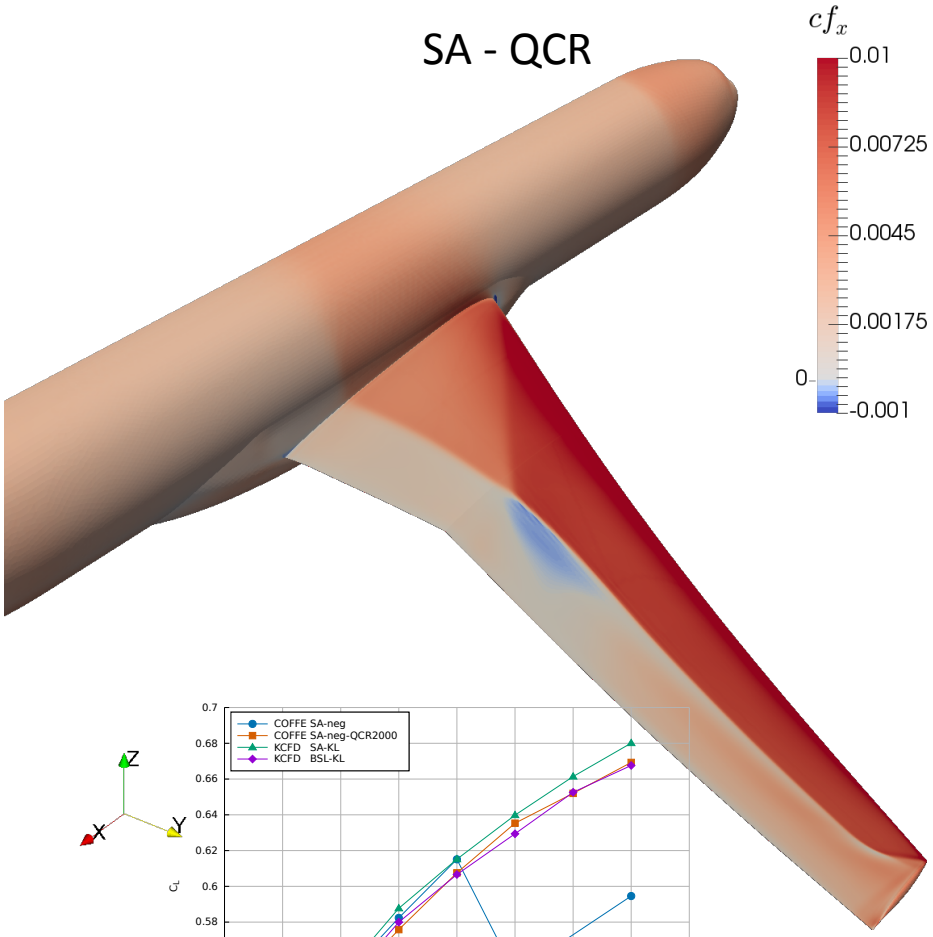


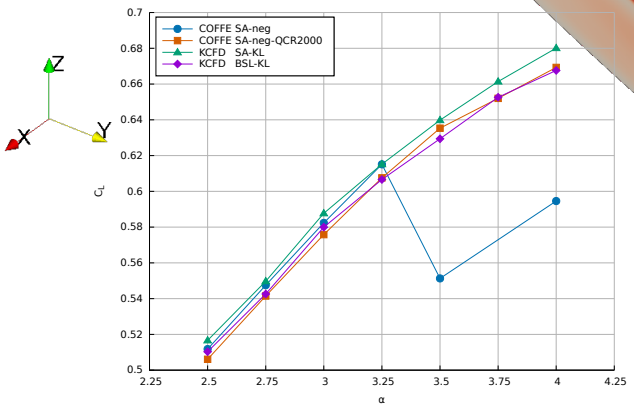
COFFE Results – Alpha 3.25, Cf_x



COFFE Results – Alpha 3.5, Cf_x

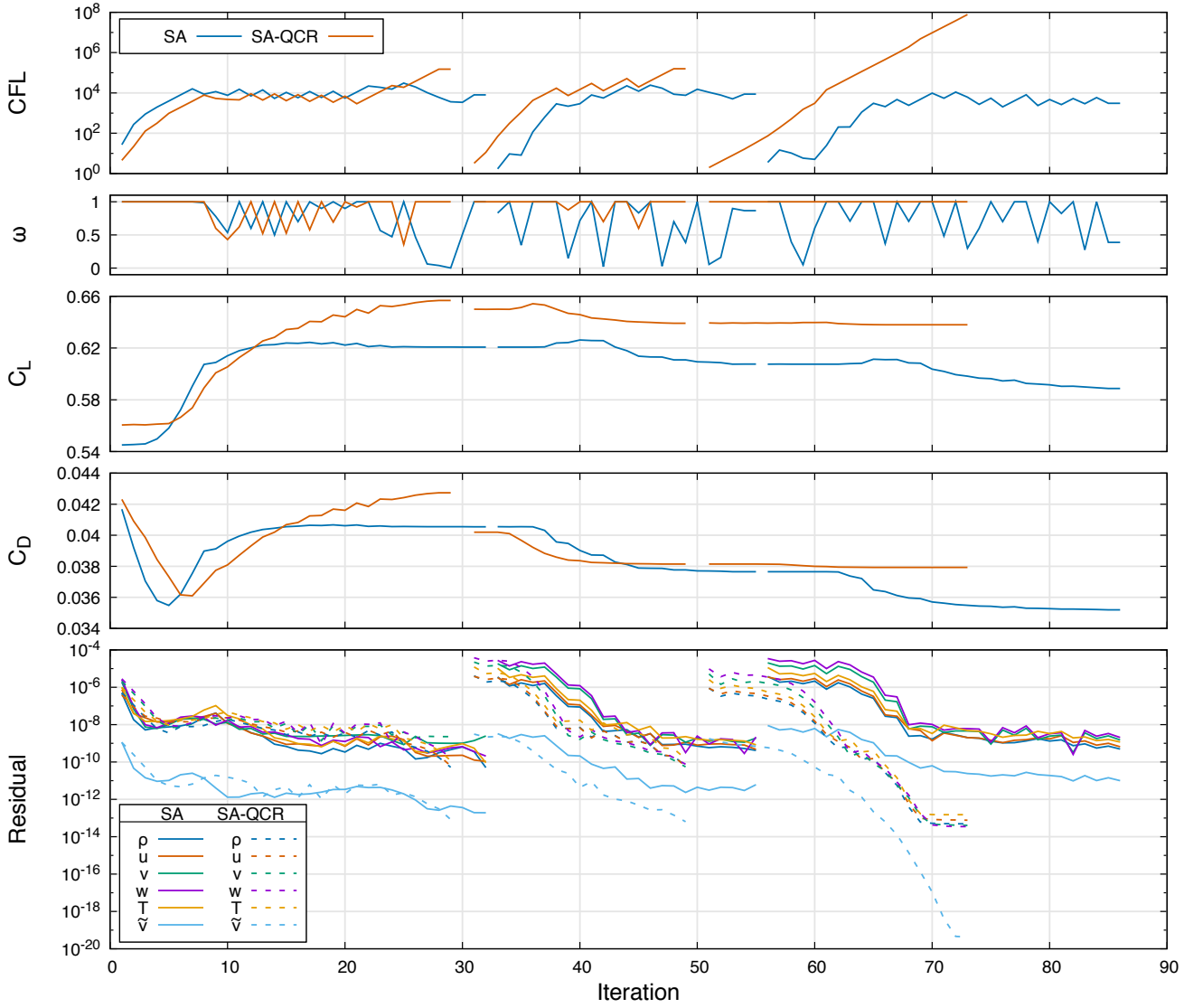




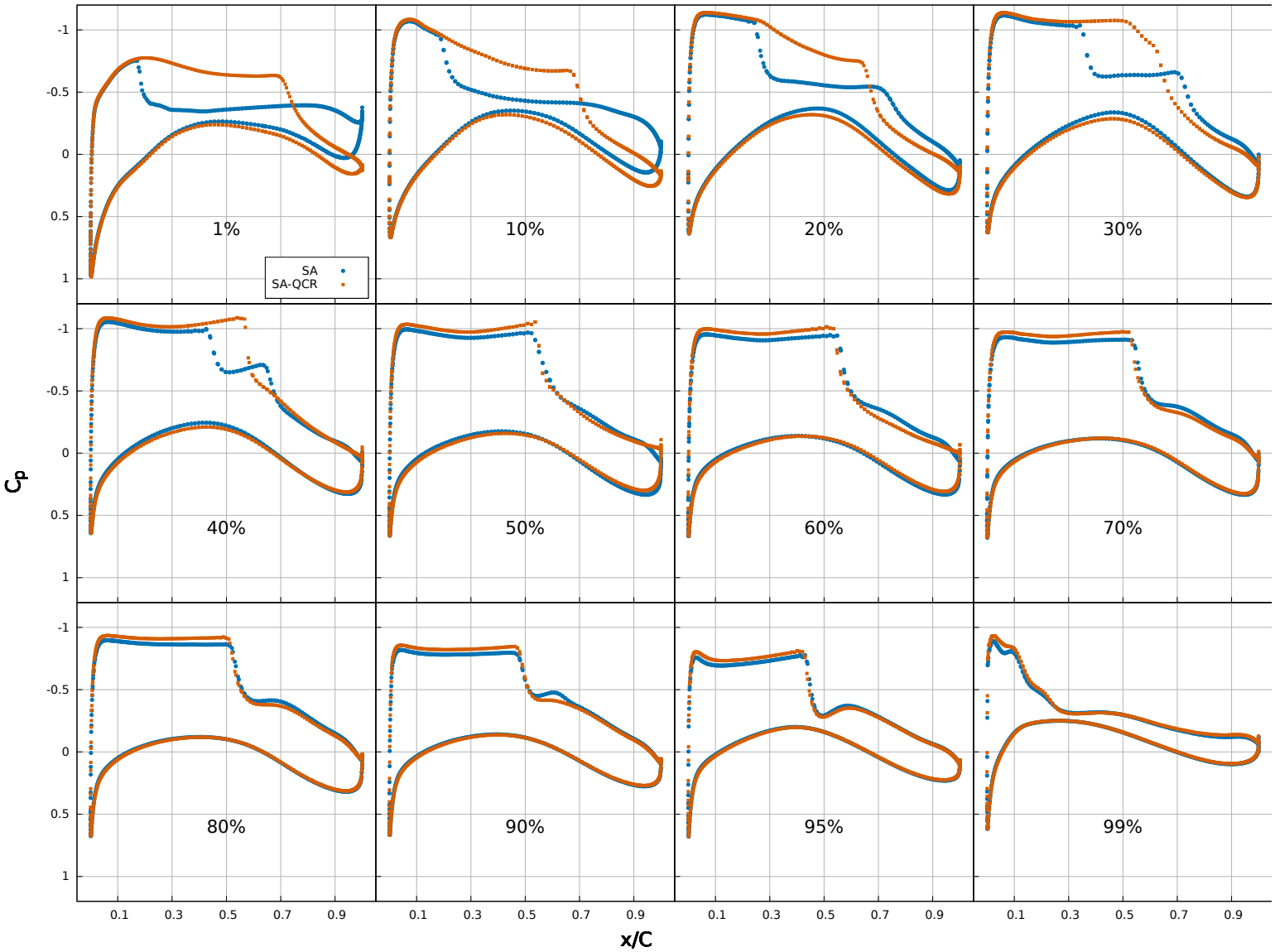


- Shock/Separation Bubble interaction
- Viscous term: TLNS Vs. FNS
- Accuracy/Mesh Convergence
- Nonlinear Convergence

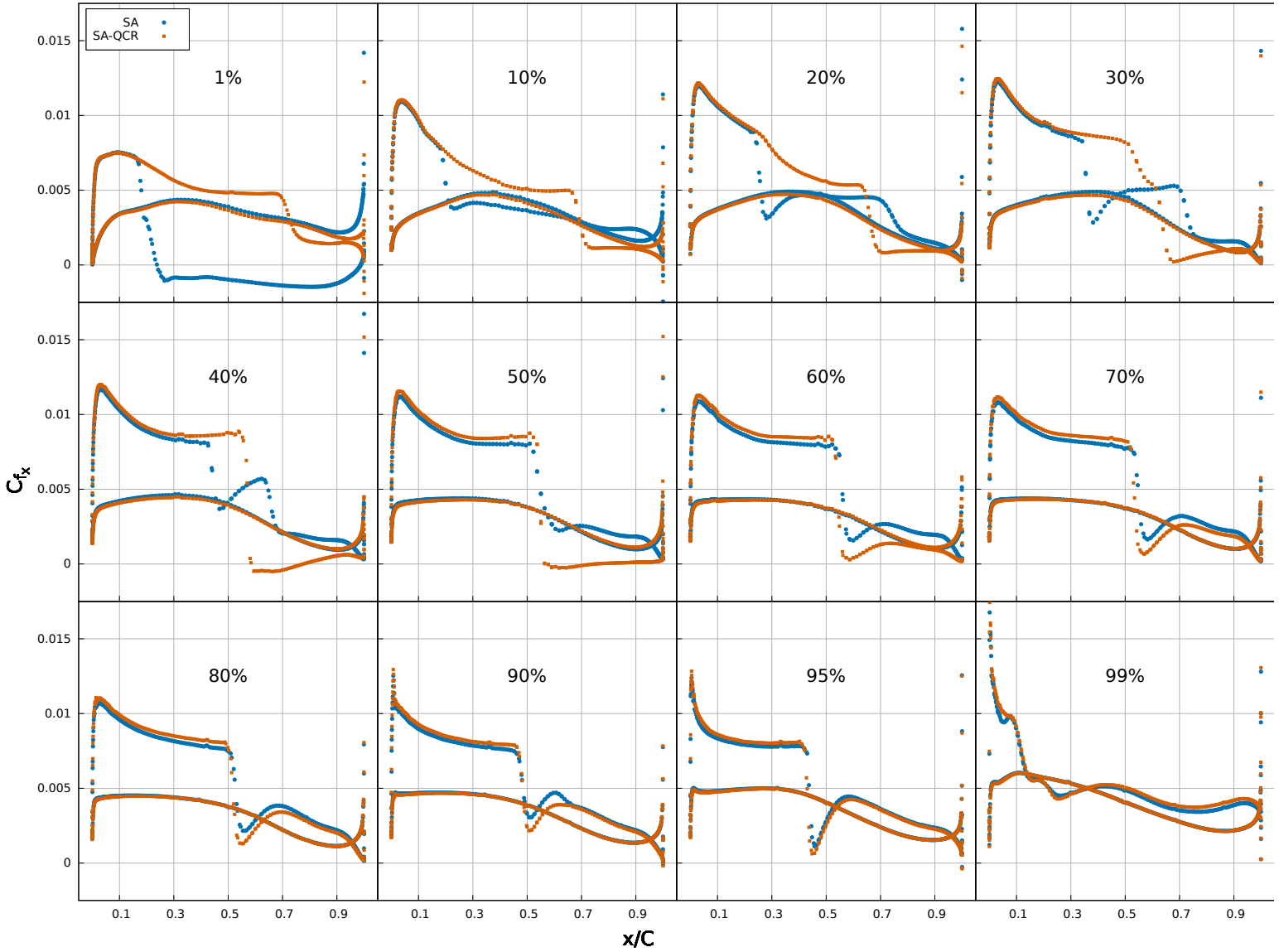
COFFE Results – Alpha 3.5



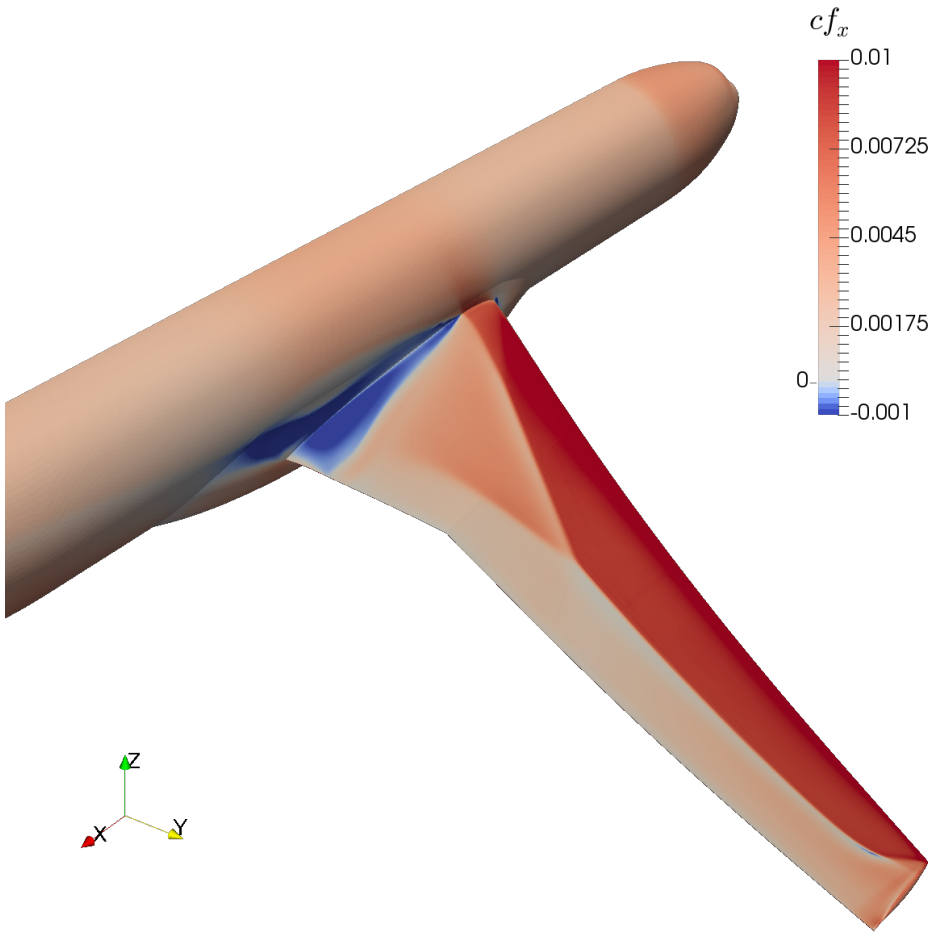
COFFE Results – Alpha 3.5, Cp



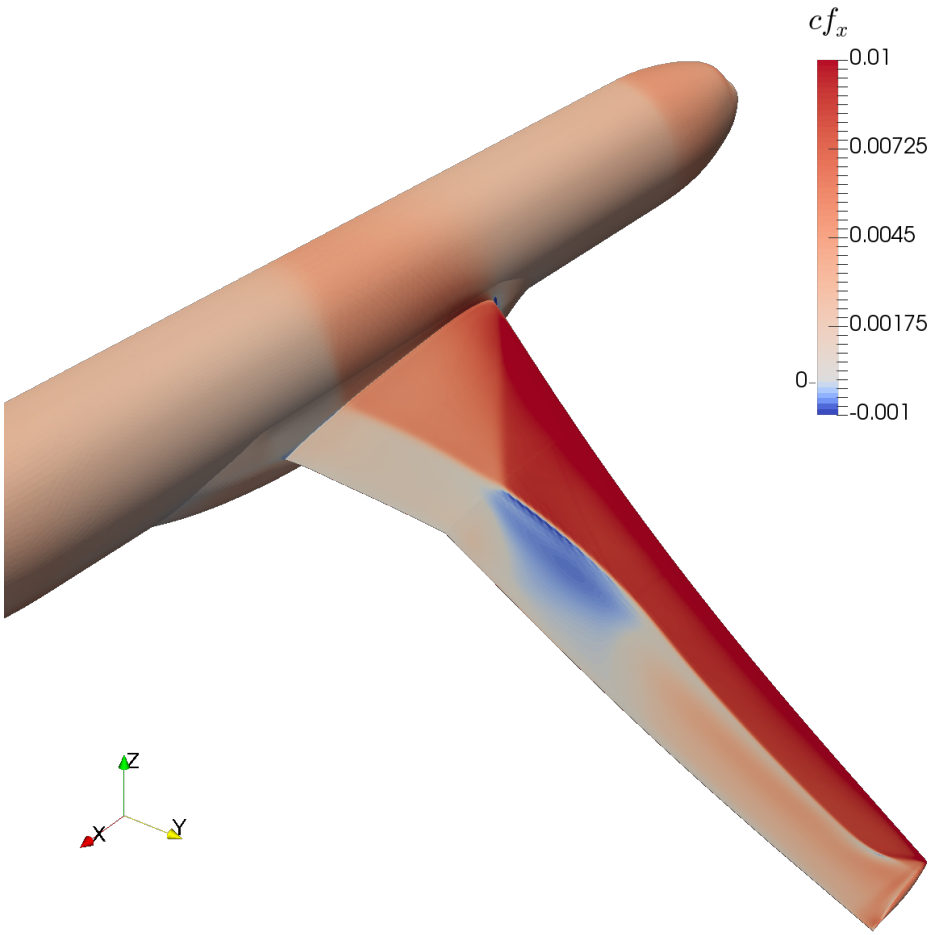
COFFE Results – Alpha 3.5, Cf_x



COFFE Results – Alpha 4.0, Cf_x

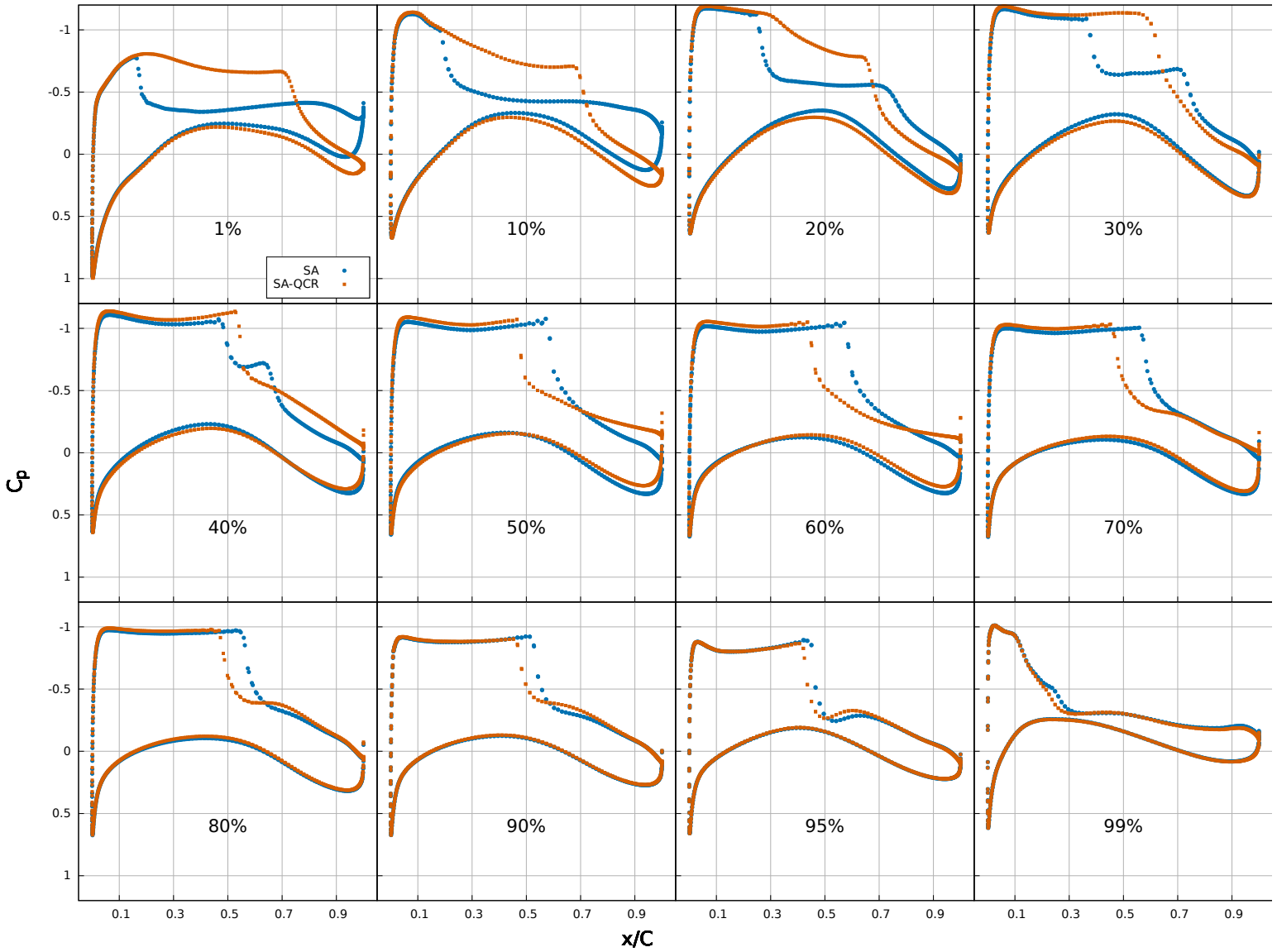


SA

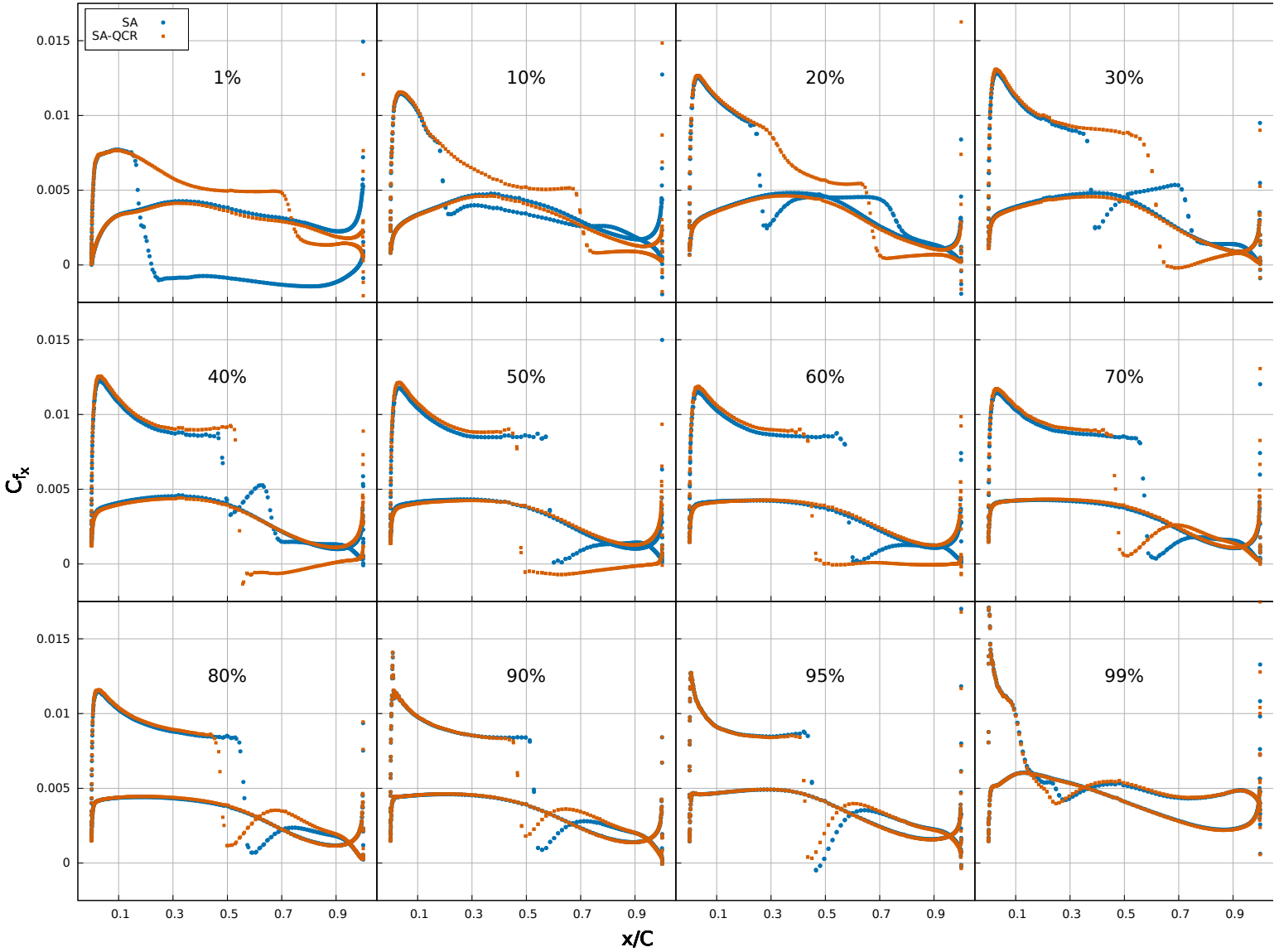


SA - QCR

COFFE Results – Alpha 4.0, Cp

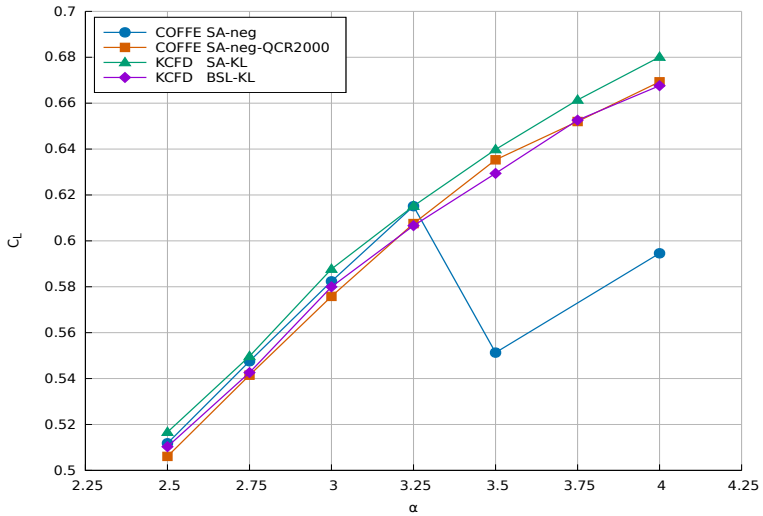


COFFE Results – Alpha 4.0, Cf_x



Conclusions

- High quality tetrahedral meshes without large angles generated by Steve Karman with Pointwise software
- Task 2/3 Cases generally took ~6-8 hours
- Subdomain decomposition with ~11,000 nodes per process
- Difference in mesh converged for task 2 C_D for WB and WBNP = 0.0024911
- SA-QCR improved the CL/CD vs. alpha polar for task 3



Acknowledgements

- **Material presented in this paper is a product of the Air Vehicles element of the HPCMP CREATE™ program. The authors would like to thank the HPCMP for the many hours of computing time that are so critical for the successful development and validation of COFFE.**
- **The authors would also like to thank their colleagues on the CREATE™-AV senior management and Kestrel teams for their support and hard work in producing the exceptional HPCMP CREATE™-AV Kestrel product. Specifically, a special thanks goes to Dr. Robert Meakin and Dr. Nathan Hariharan as well as Dr. Scott Morton and Dr. David McDaniel.**
- **Significant mentorship from:**
- **Dr. Steven R. Allmaras and Dr. Marshall C. Galbraith**
  - Department of Aeronautics and Astronautics, Massachusetts Institute of Technology
- **Dr. Robert H. Nichols**
  - University of Alabama Birmingham