Evaluation of a new Hybrid RANS-LES method in LAVA to Transonic Buffet Prediction for the CRM

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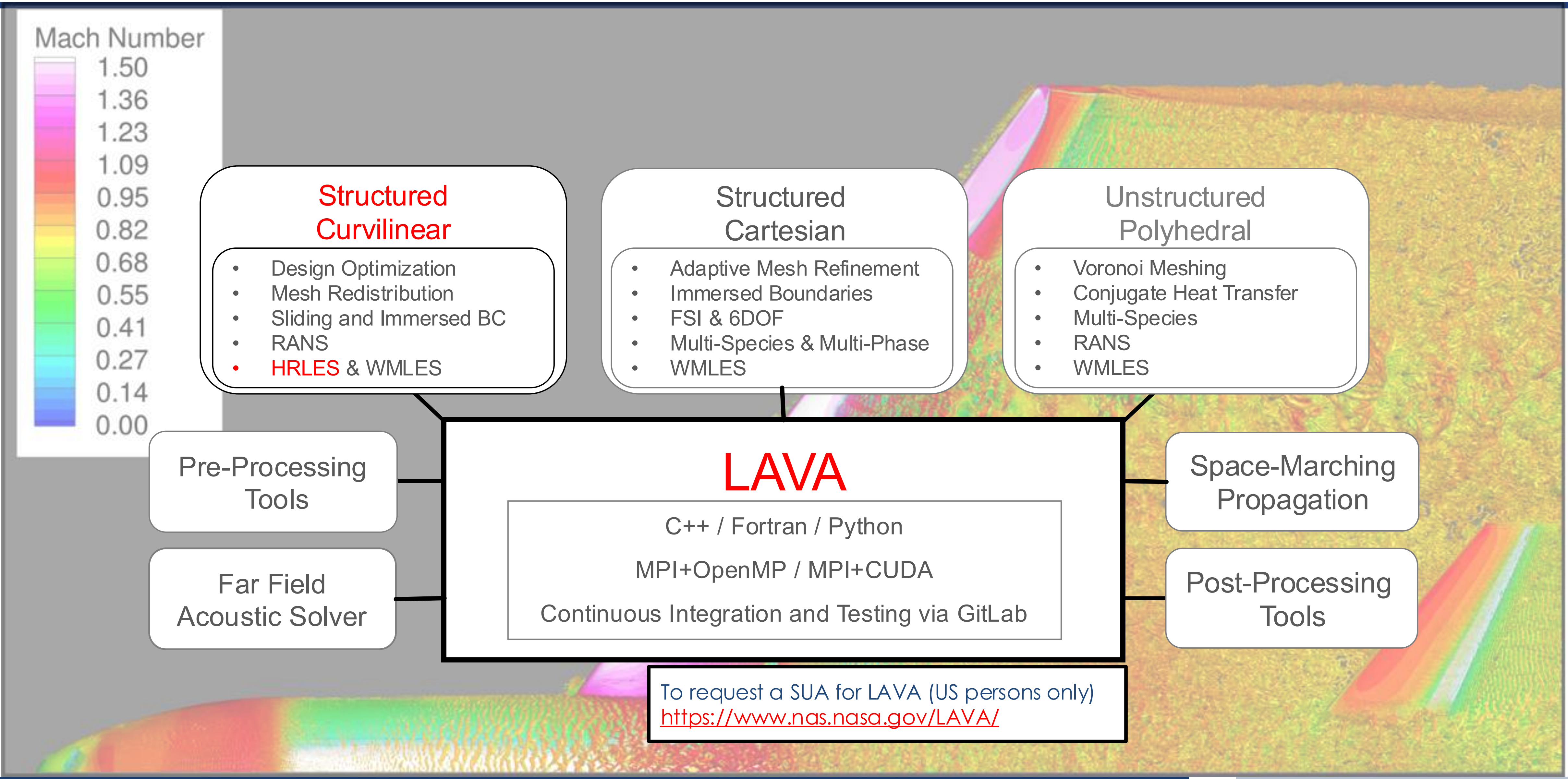
LAVA Framework



Structured Curvilinear

- Design Optimization
- Mesh Redistribution
- Sliding and Immersed BC
- RANS
- HRLES & WMLES

Structured Cartesian

- Adaptive Mesh Refinement
- Immersed Boundaries
- FSI & 6DOF
- Multi-Species & Multi-Phase
- WMLES

Unstructured Polyhedral

- Voronoi Meshing
- Conjugate Heat Transfer
- Multi-Species
- RANS
- WMLES

Pre-Processing Tools

Far Field Acoustic Solver

LAVA

C++ / Fortran / Python

MPI+OpenMP / MPI+CUDA

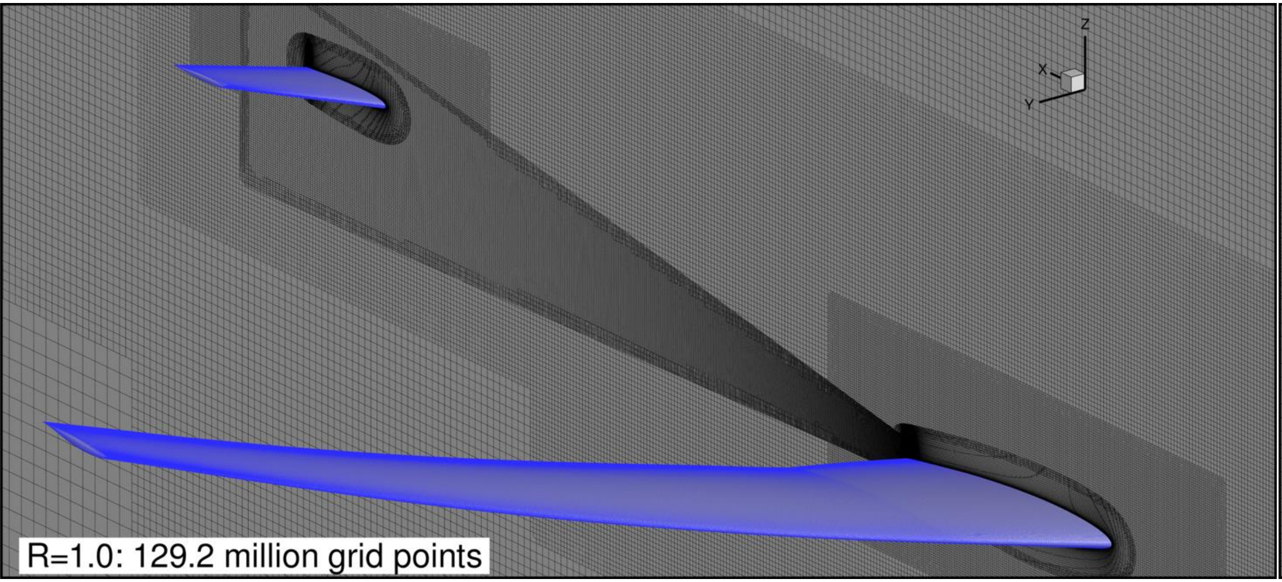
Continuous Integration and Testing via GitLab

Space-Marching Propagation

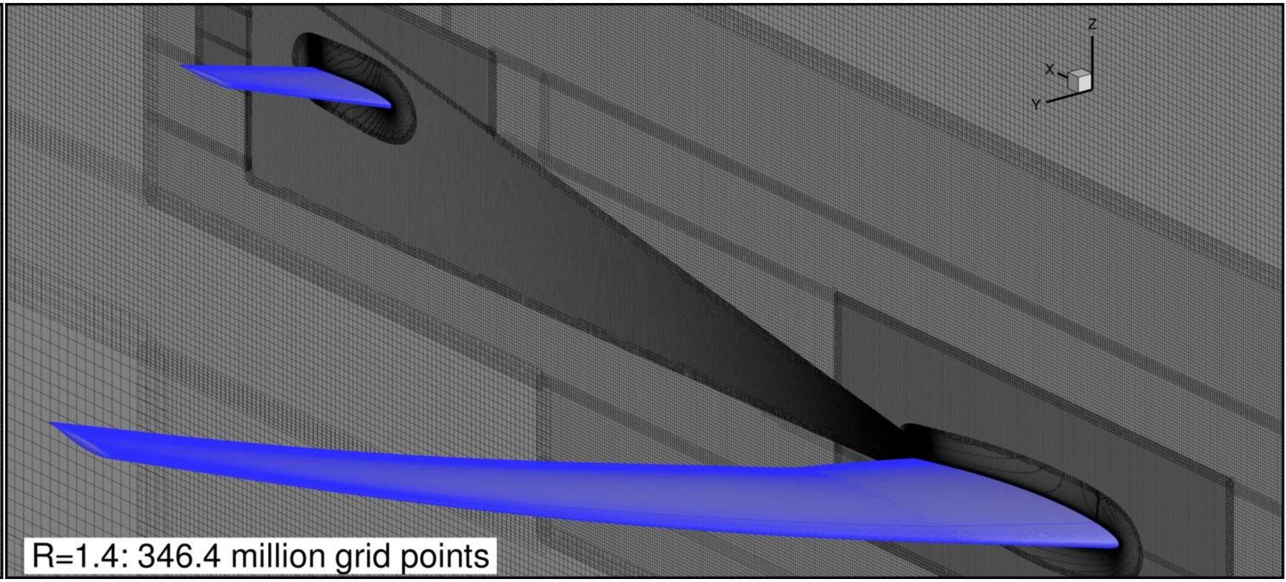
Post-Processing Tools

To request a SUA for LAVA (US persons only)
https://www.nas.nasa.gov/LAVA/

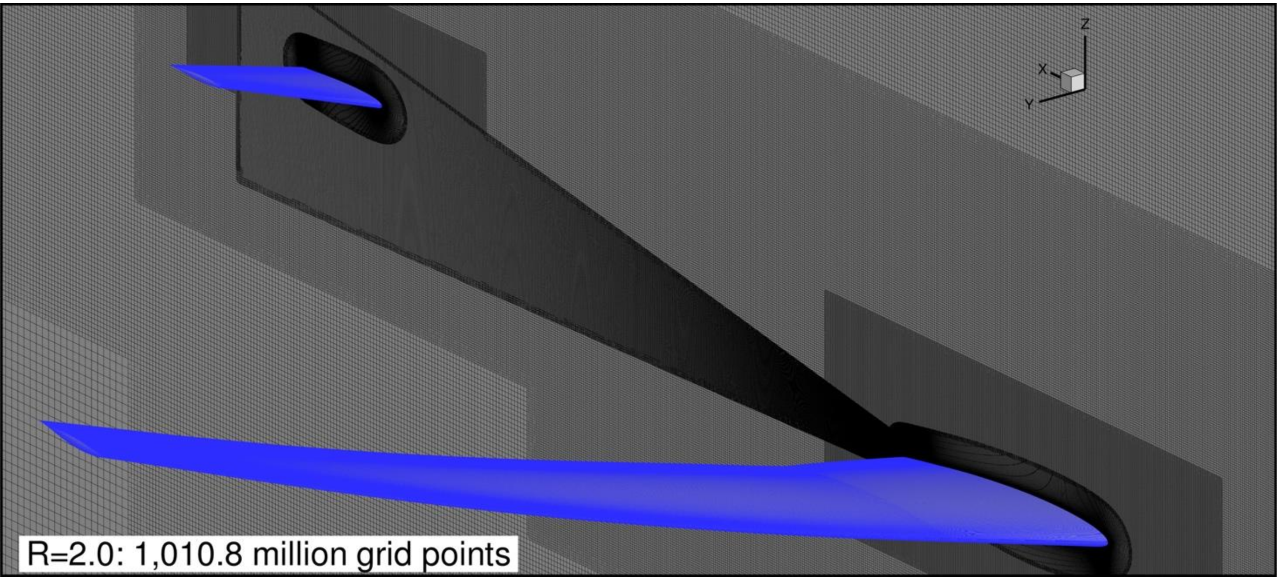
Structured Overset/Multiblock Mesh Family



R=1.0: 129.2 million grid points



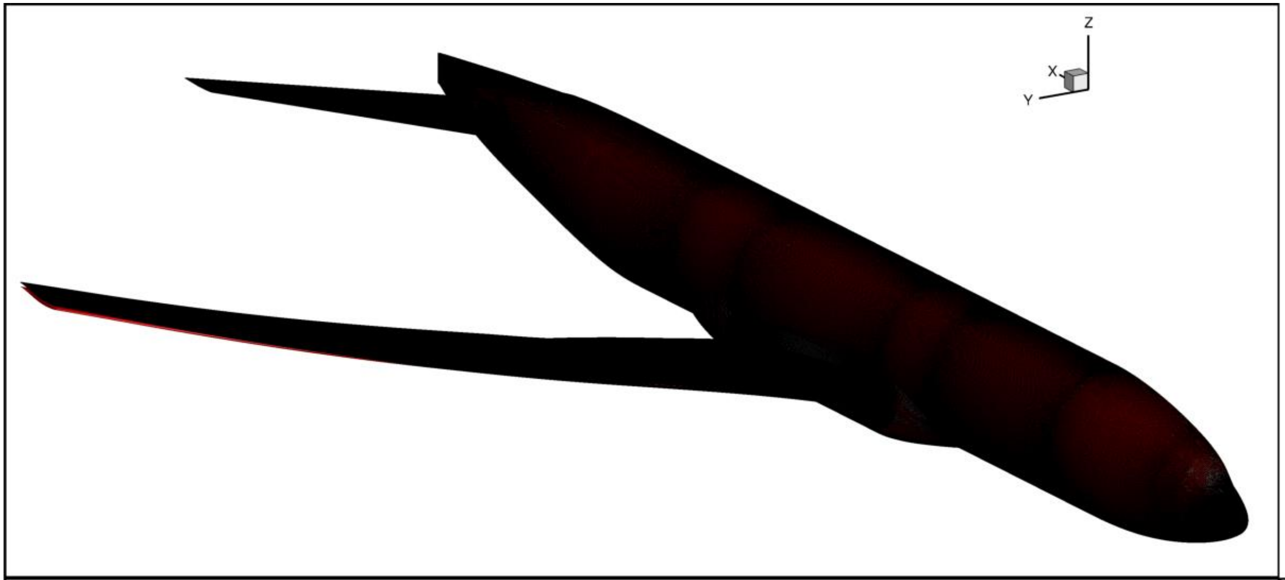
R=1.4: 346.4 million grid points



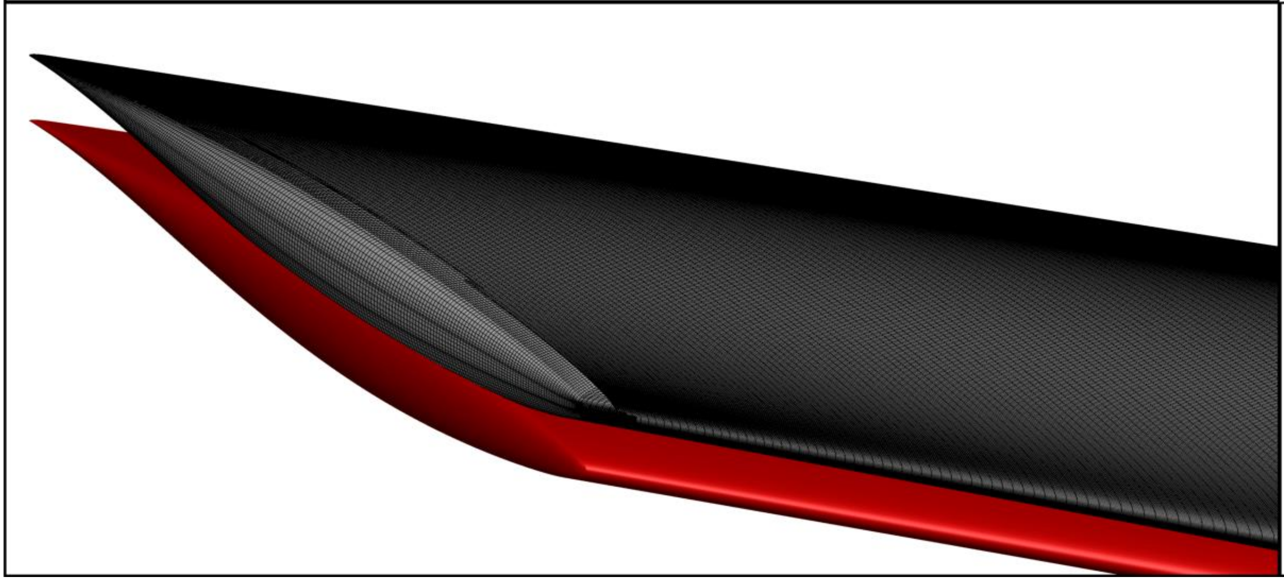
R=2.0: 1,010.8 million grid points

- Manual grid generation for R=1.0 grid, wing deflection alpha 4.84°
  - DPW Guidelines used at LE and TE, fuselage, wall spacing, etc.
  - Tighter constraints for max stream and span spacing
- Medium and fine grid levels constructed using a spline and refine procedure
  - Block-2-block boundaries are inserted at geometric sharp edges

Wing Deformation: An Inverse Design Approach

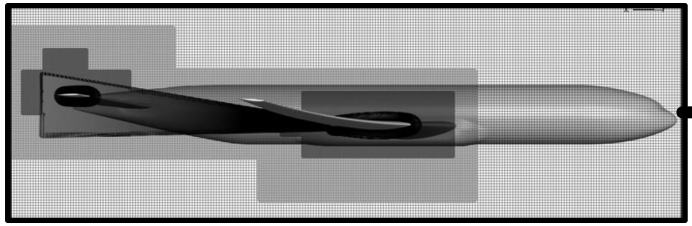


- An inverse design approach applied for deflection
  - Surface triangulation constructed from CAD
  - Inverse design tool applied to twist and bend wing surface grid to "match" the surface triangulation
  - The volume grid "warped" to be consistent with the "designed" wing surface
- Grids are available at: https://dpw.larc.nasa.gov/DPW8/Buffet/Test_Case_2/LAVA_Grids.REV00



Stress-Corrected LES

- Based on Chen S, Xia Z, Pei S, et al. "Reynolds-stress-constrained large-eddy simulation of wall-bounded turbulent flows." Journal of Fluid Mechanics. 2012;703:1-28. doi:10.1017/jfm.2012.150
- Basic Concepts:



Favre Filtered LES equations solved in entire CFD domain

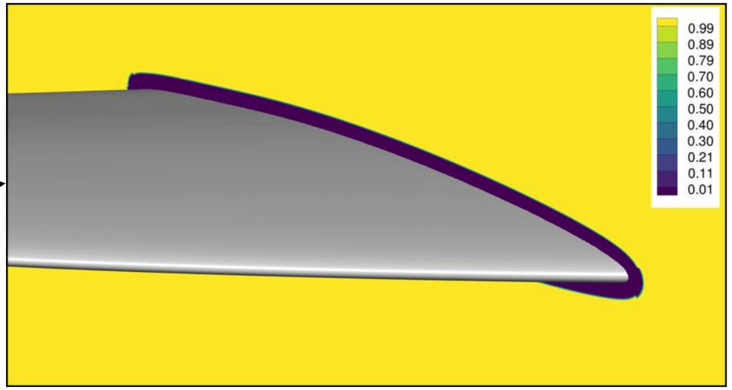
Time-filtered inputs <Q>

RANS turbulence model equation(s)

$$\tau_{ij}^{SGS_{correction}} = \langle \tau_{ij}^{RANS} \rangle - b_1 \langle \tau_{ij}^{Resolved} \rangle - b_2 \langle \tau_{ij}^{SGS} \rangle$$

Construct sub-grid scale stress-correction

b_1 and b_2 are constants which control which components are included in the stress correction



Apply stress-correction within the constraint region

Complete description of the model will be provided in AIAA SciTech conference paper, "*Application of a Hybrid RANS-LES method to the Boeing Transonic Truss-Braced Wing High-Lift Configuration*"

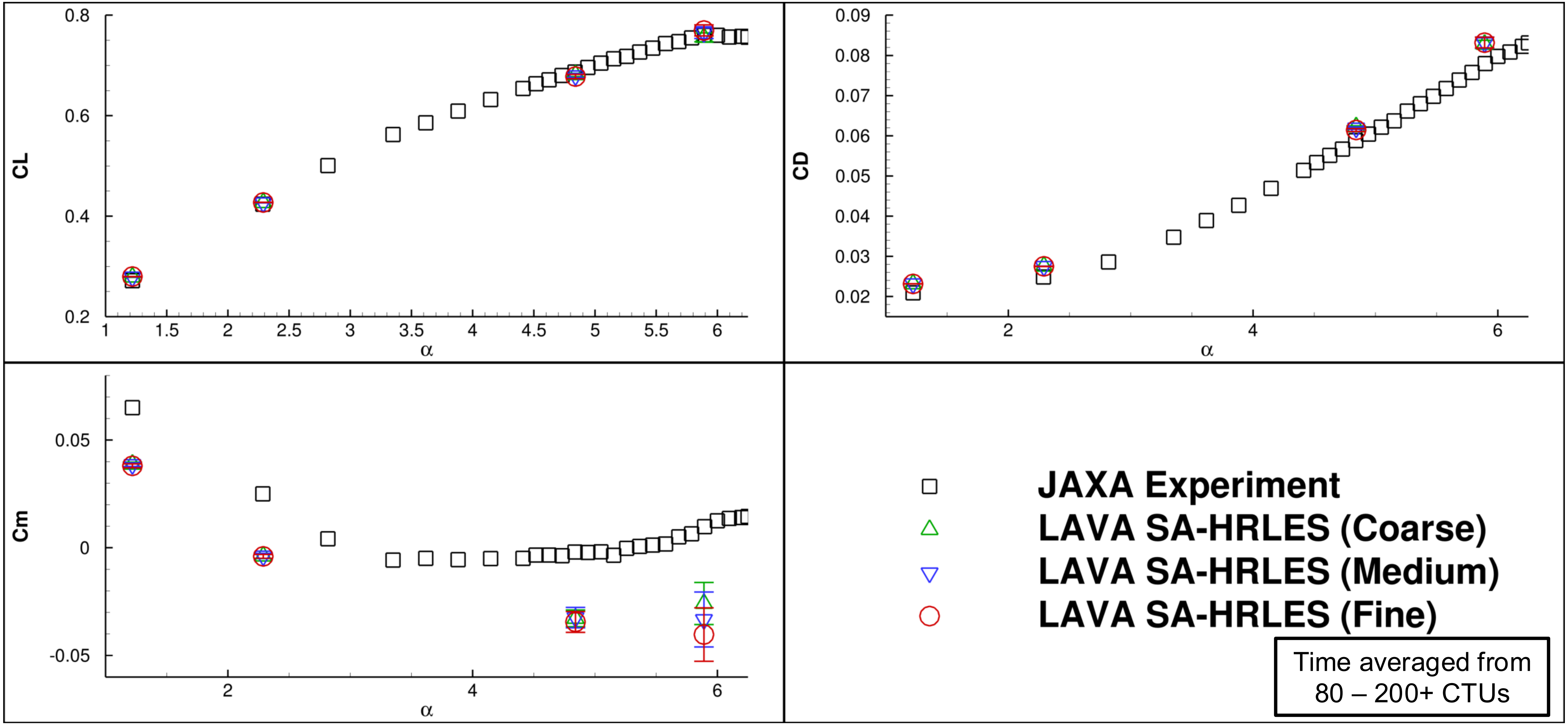
Stress-Corrected LES

- Model selections
  - RANS turbulence model: SA-neg (no corrections)
  - LES SGS model: Sigma (c_{SGS} = 1.35)
  - Fixed constraint distance based on estimated turbulent flat plate boundary layer height
  - Exponential time-filtering coefficient chosen based on estimated time-scale for turbulent wall-normal diffusion

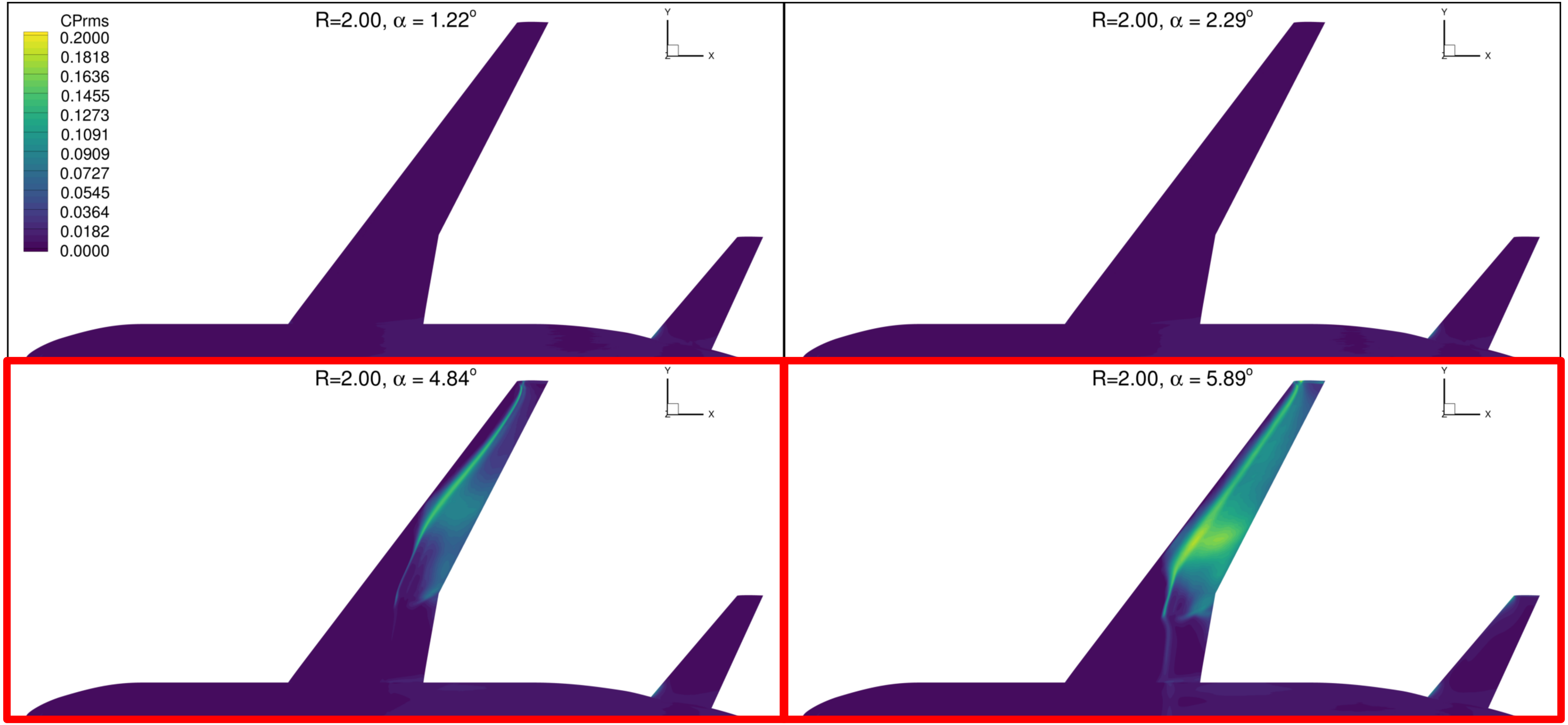
- Important discretization options
  - Convective flux discretization: low-dissipation modified Roe flux with blended upwind/centered 3rd-order/4th-order left/right state reconstruction and Koren slope limiter
  - Blending parameter based on AIAA-2012-1174, "*Sensitivity of Landing-Gear Noise Predictions by Large-Eddy Simulation to Numerics and Resolution*", Spalart *et al*.

Test Case Results

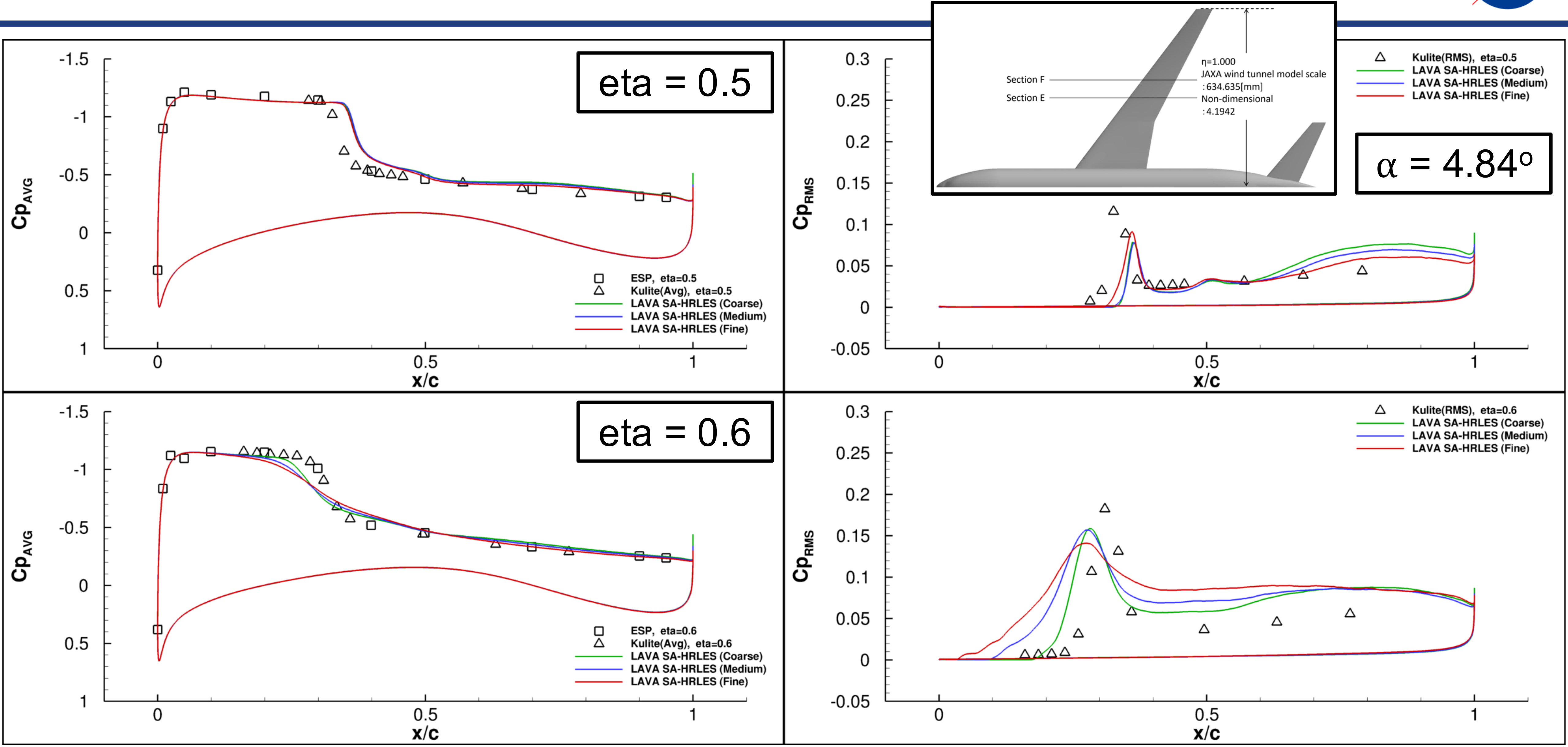
Time-Averaged Aerodynamic Loads



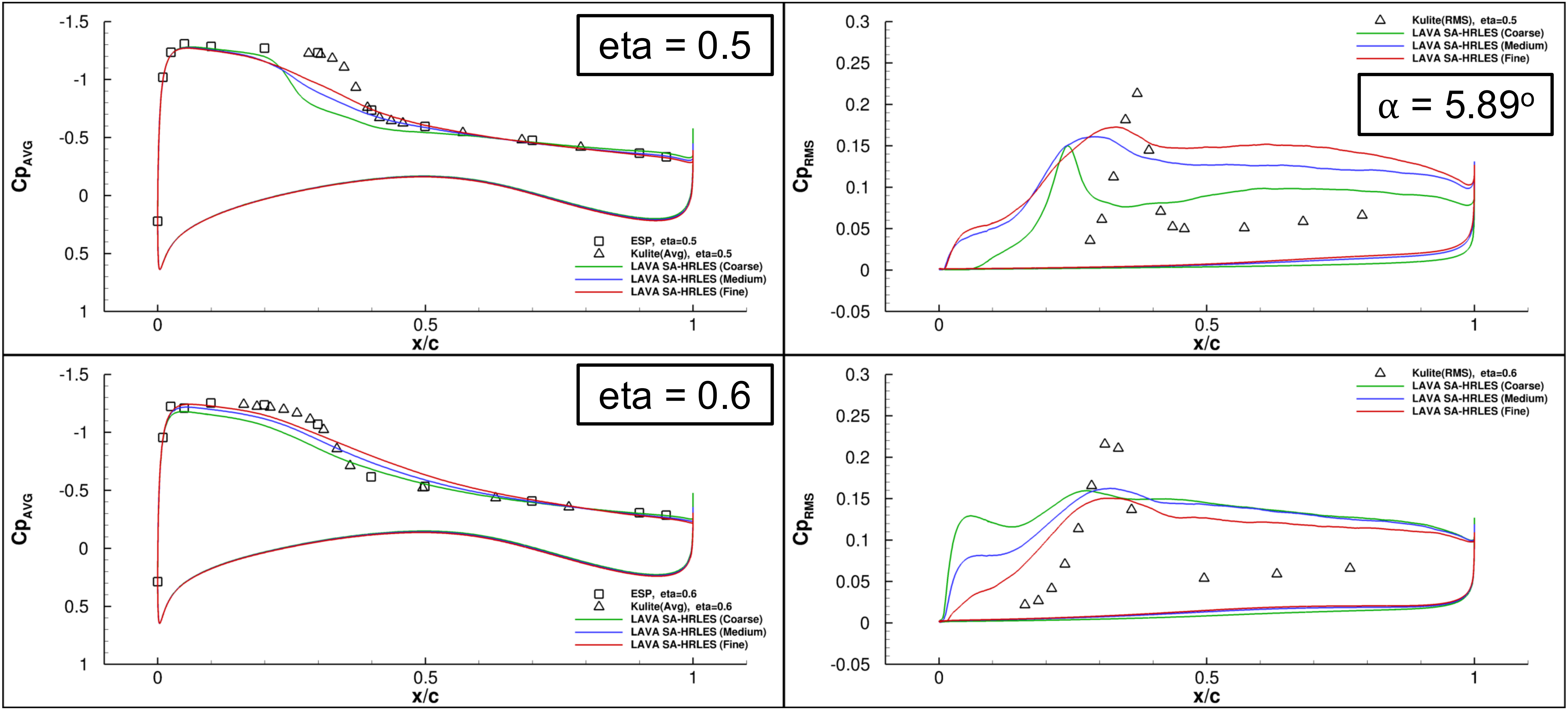
Surface Cp_{RMS}



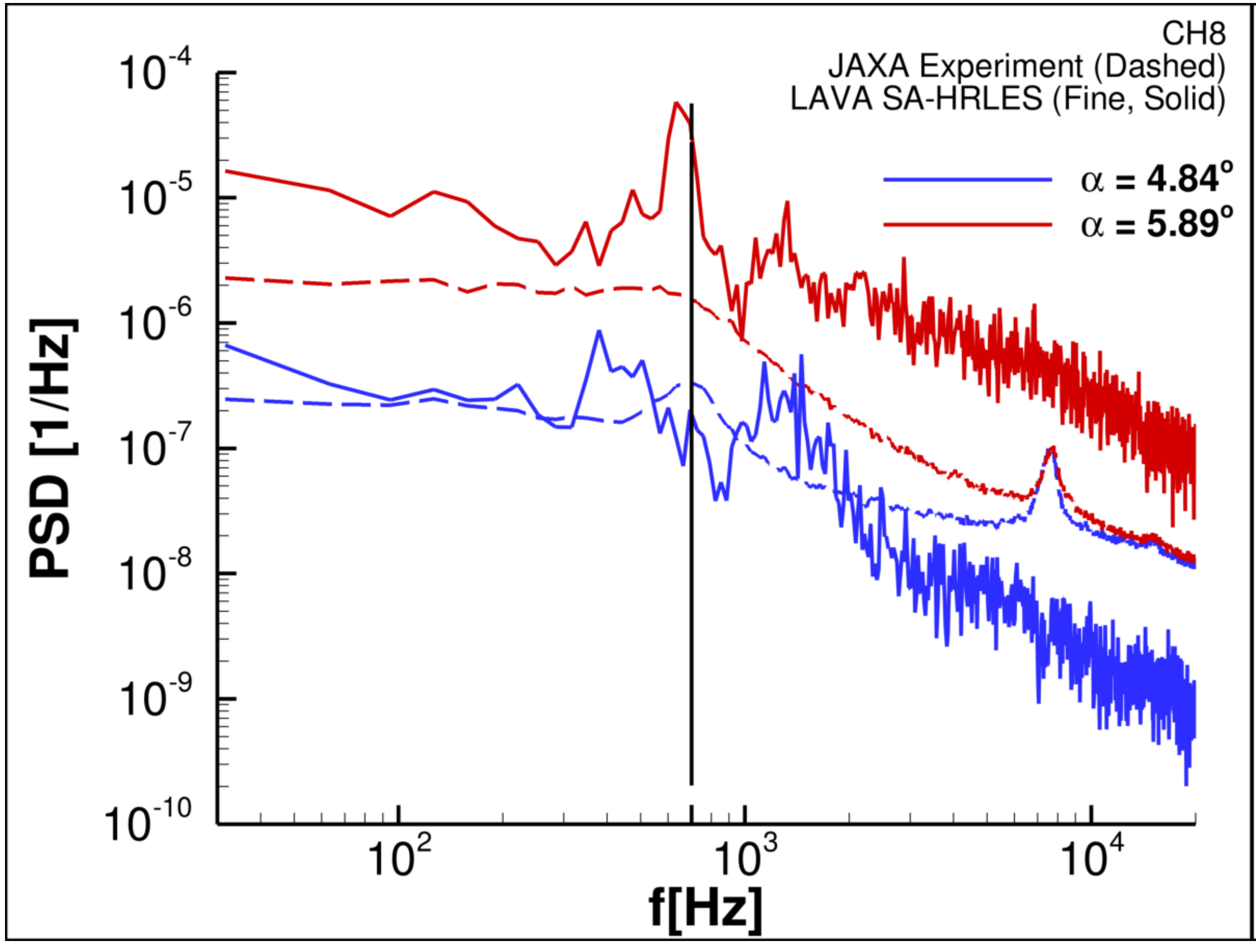
Time-Averaged Cp and RMS



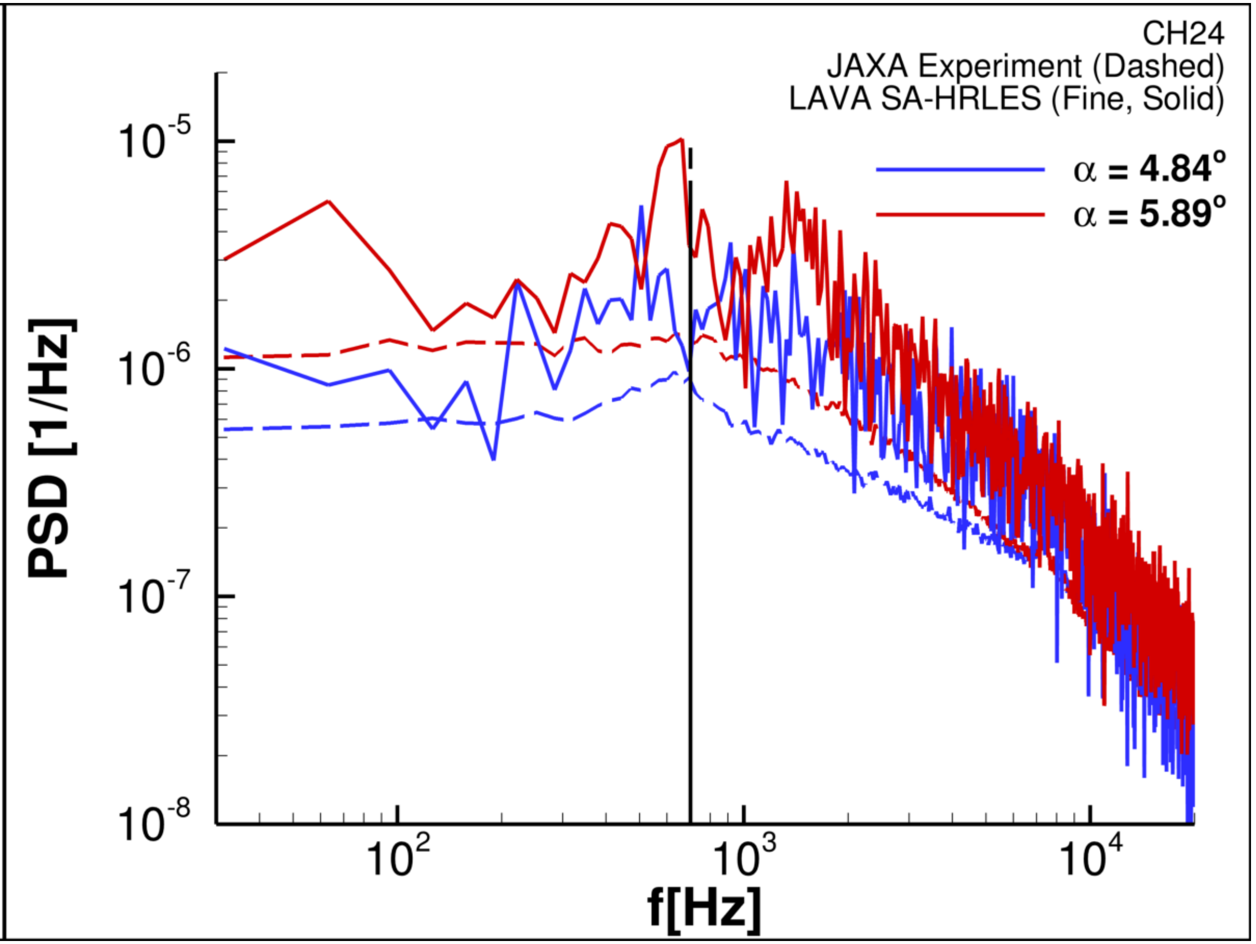
Time-Averaged Cp and RMS



PSD Comparisons



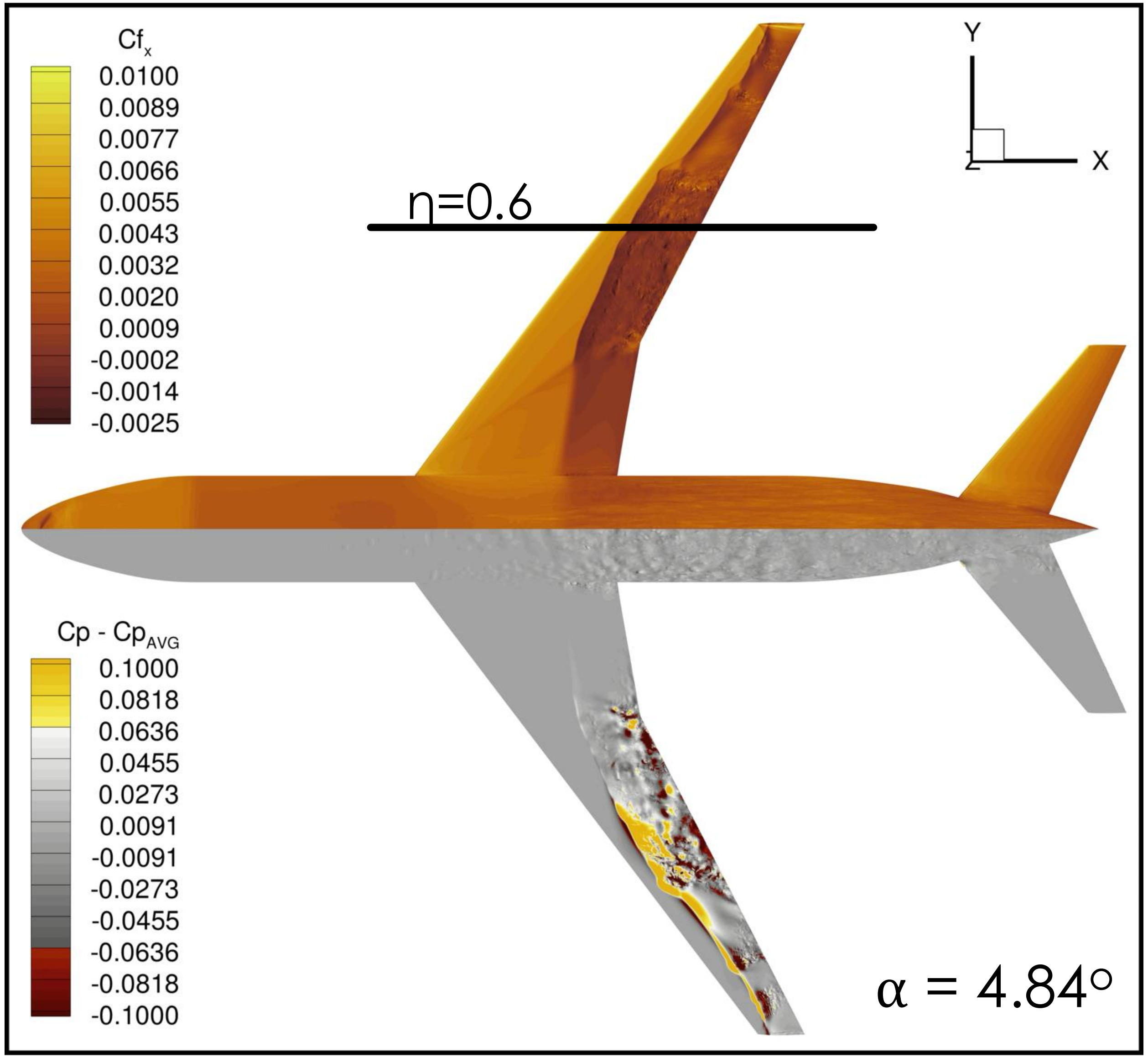
x/c = 0.4360, eta = 0.5

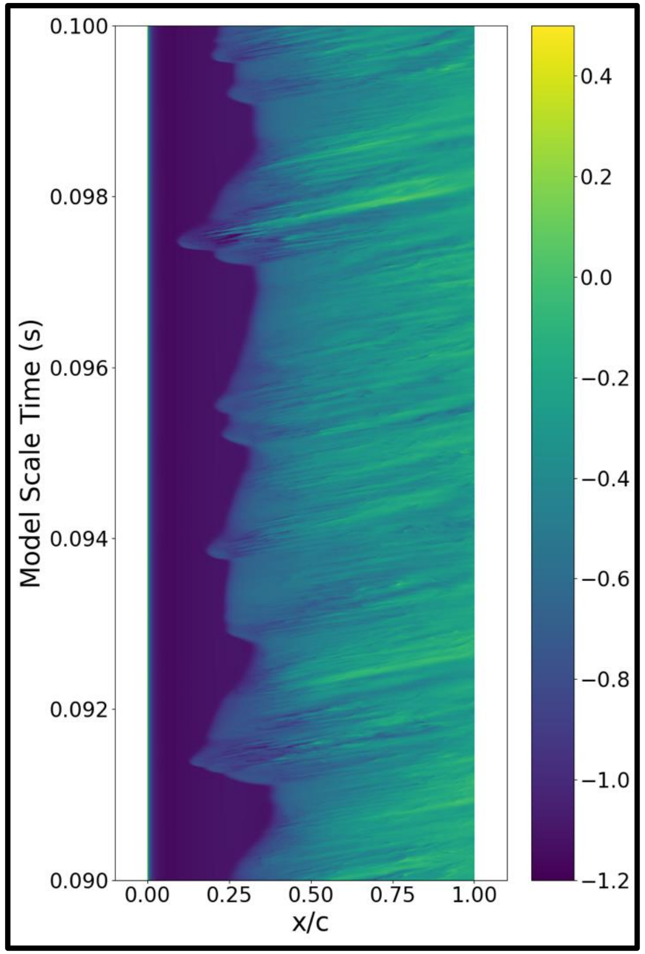


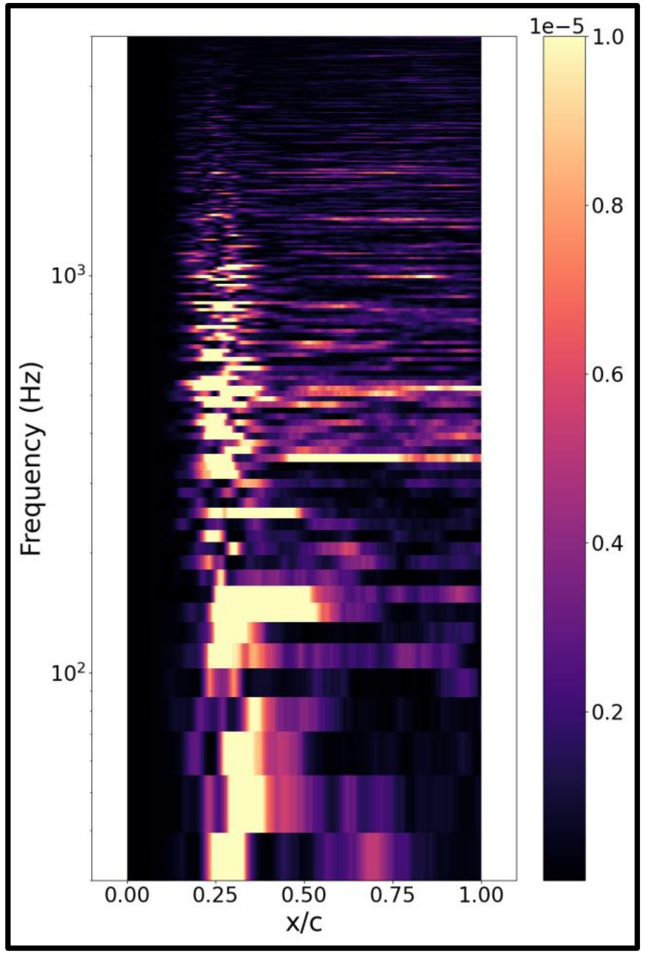
x/c = 0.7677, eta = 0.6

Vertical line represents experimentally measured peak (700 Hz)

Unsteady Flow Physics and Periodogram

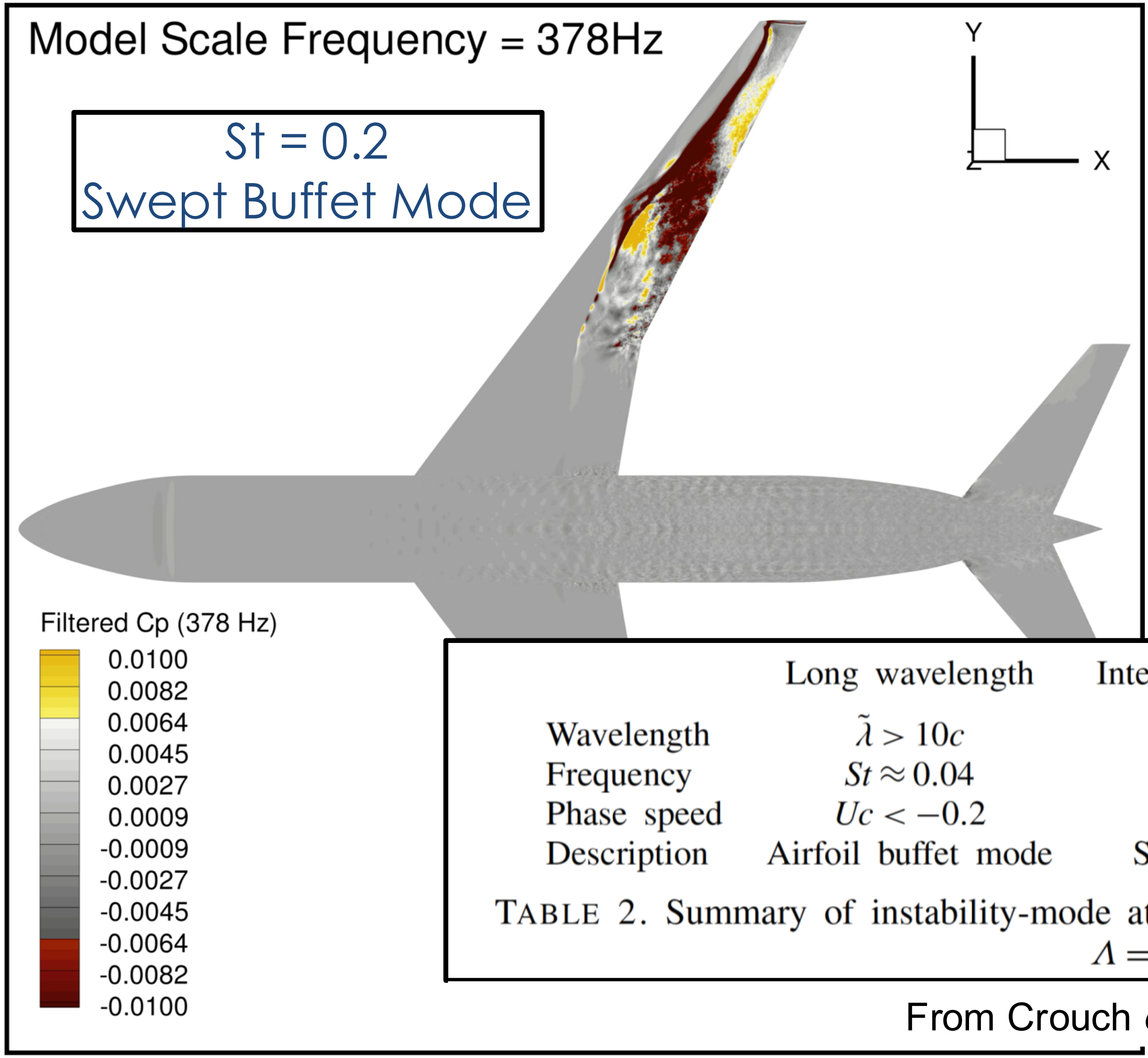


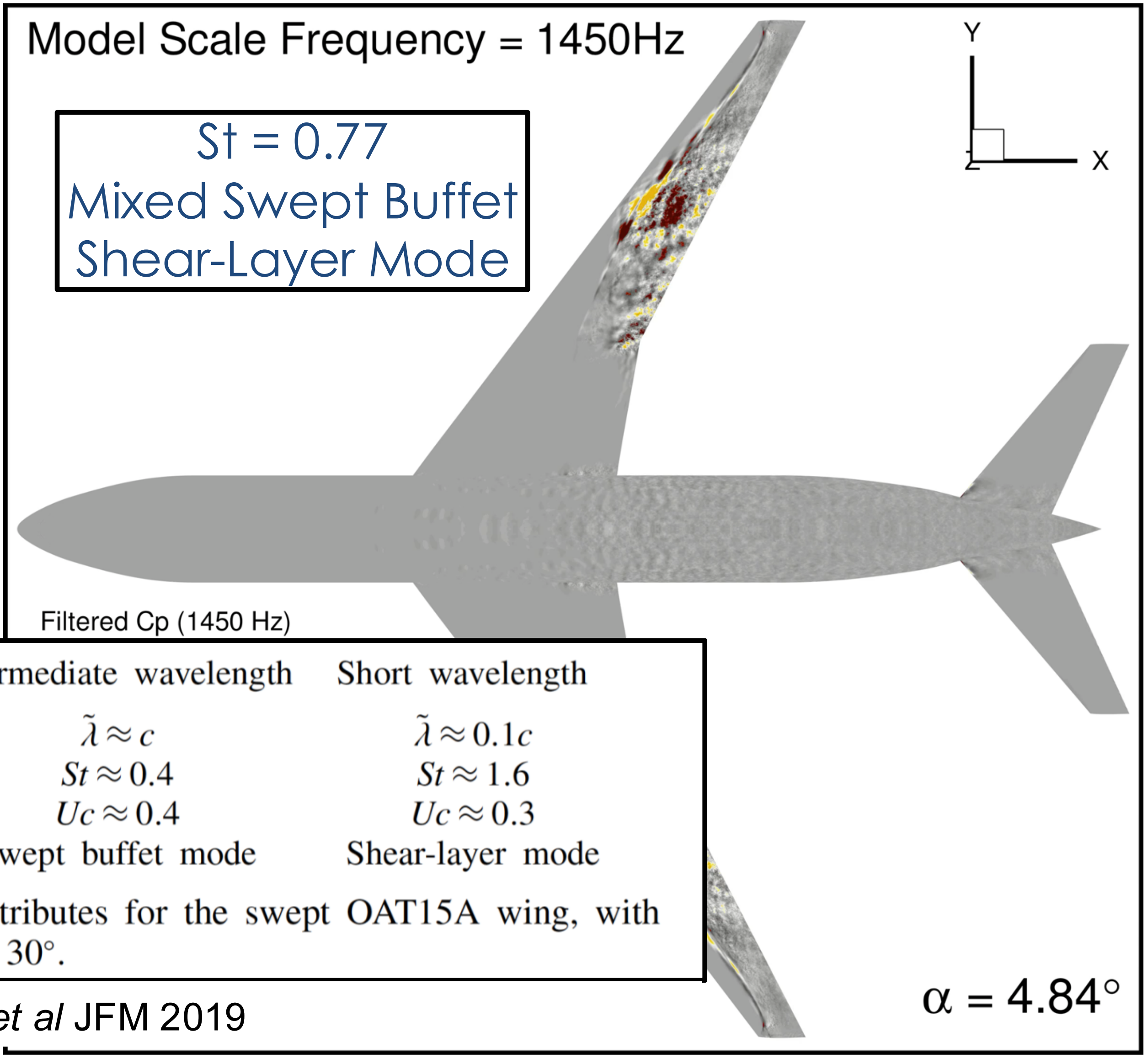




- Disturbance pressure field illustrating complex shock motion pattern
- Periodogram at eta = 0.6 demonstrating buffet spectral modes as a function of x/c

FFT Analysis





	Long wavelength	Intermediate wavelength	Short wavelength
Wavelength	$\tilde{\lambda} > 10c$	$\tilde{\lambda} \approx c$	$\tilde{\lambda} \approx 0.1c$
Frequency	$St \approx 0.04$	$St \approx 0.4$	$St \approx 1.6$
Phase speed	$Uc < -0.2$	$Uc \approx 0.4$	$Uc \approx 0.3$
Description	Airfoil buffet mode	Swept buffet mode	Shear-layer mode

TABLE 2. Summary of instability-mode attributes for the swept OAT15A wing, with $\Lambda = 30°$.

From Crouch *et al* JFM 2019

Summary

- Stress-Corrected LES model applied to a family of structured overset grids for transonic buffet prediction of the CRM wing-body-tail0
- Successful qualitative prediction of the correct buffet behavior
  - Pre-buffet AOAs (1.22° and 2.29°) show no buffet behavior
  - Post-buffet AOAs (4.84° and 5.89°) show strong buffet behavior
- Good agreement in lift coefficient, but a constant shift is observed in drag
- Offset in pitching moment increases with increasing AOA
- Over-prediction of shock motion, typically traveling too far upstream
- Improvements in Cp_{RMS} and PSD predictions are achieved with mesh refinement. (Not uniformly across the entire wing)
- Buffet related frequencies are predicted at approximately 378 and 1450 Hz at alpha 4.84° and 650 and 1300 Hz at alpha 5.89°, which differs from experimental value of 700 Hz

Acknowledgements

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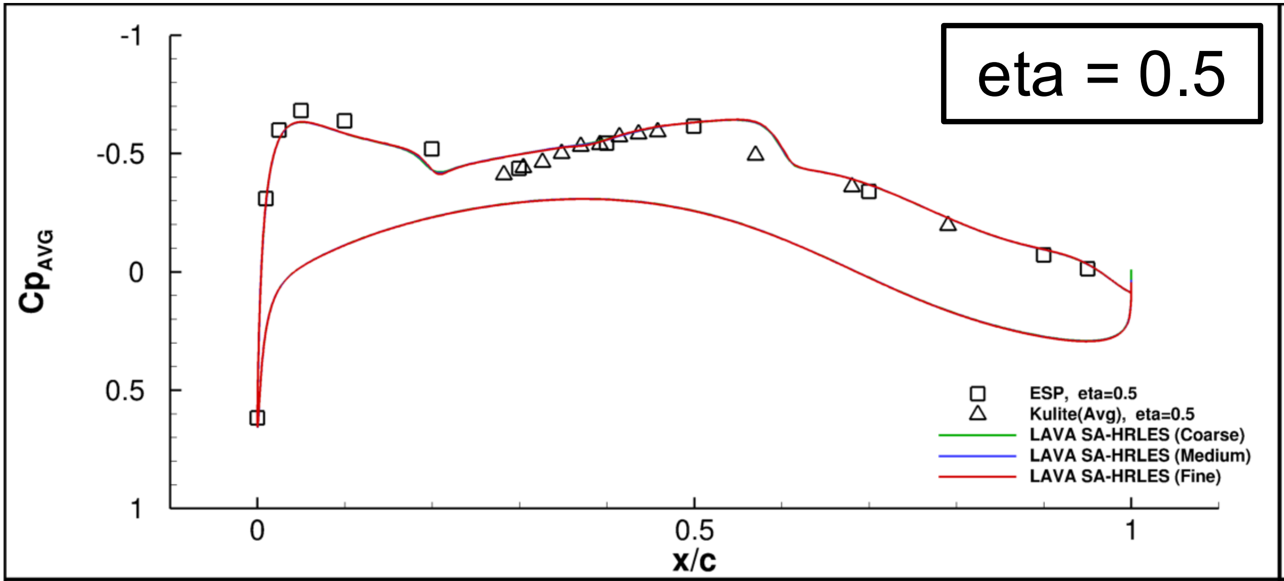
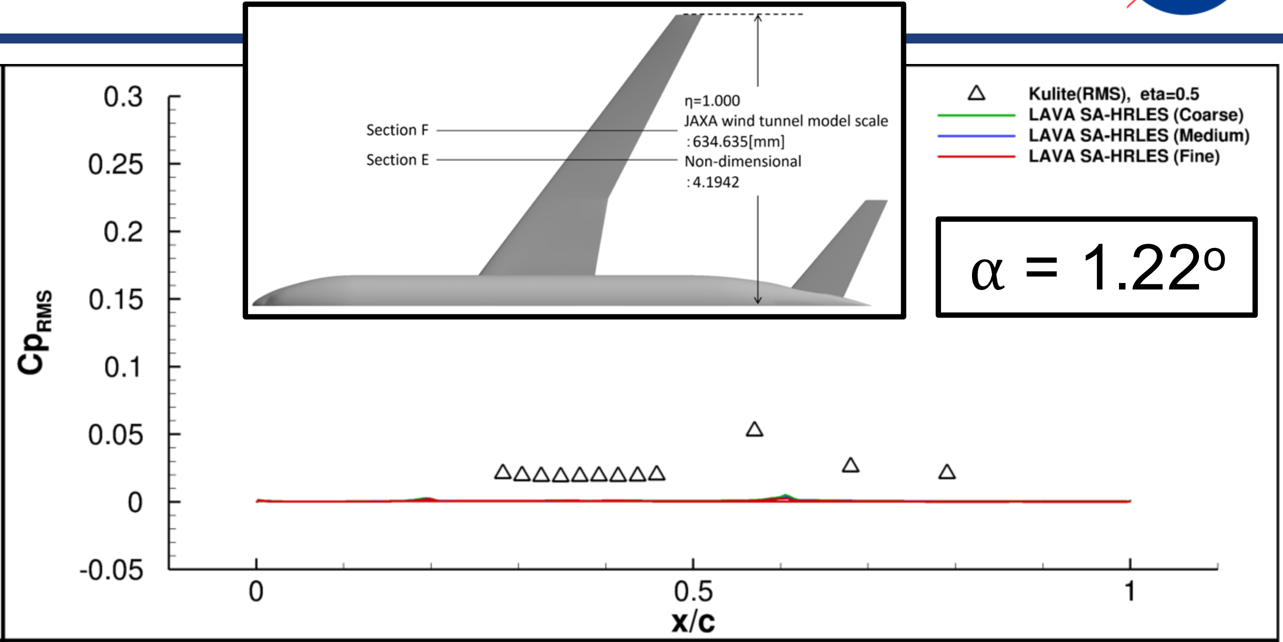
- LAVA teams members especially Ercan Dumlupinar, David Craig-Penner, Chase Ashby, and Francois Cadieux for valuable discussions

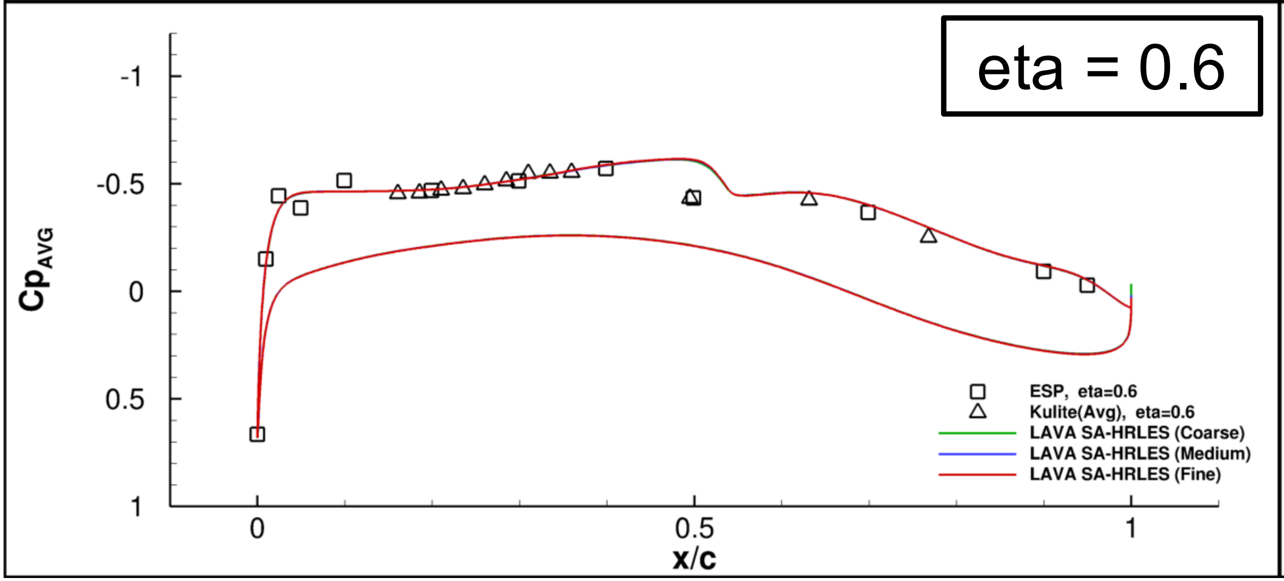
Thank You

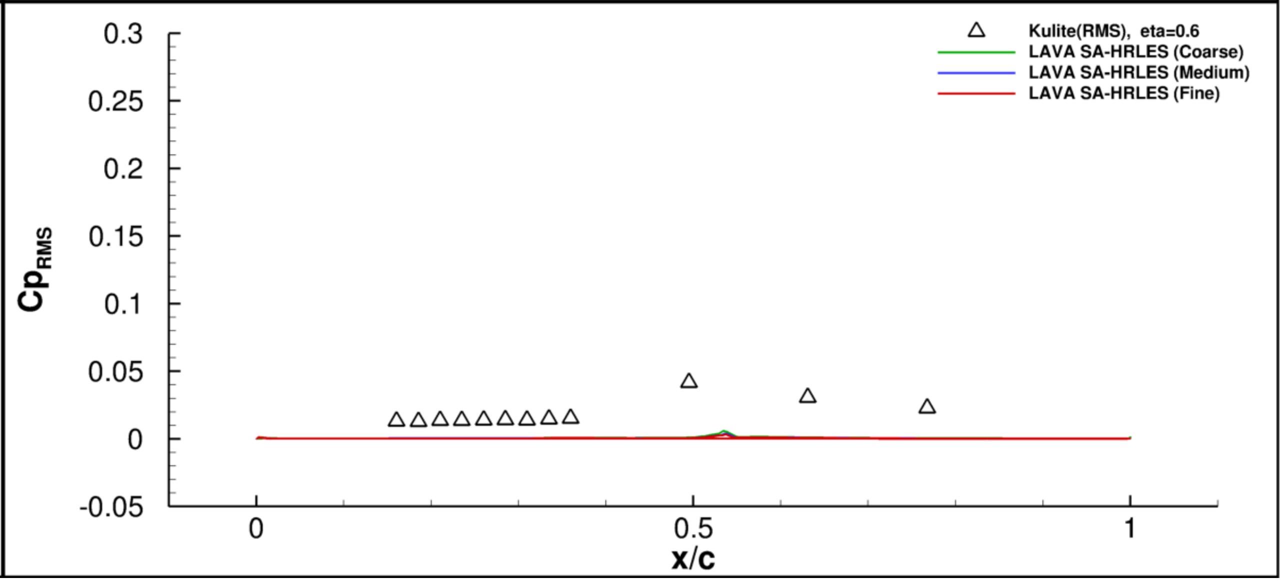
Backup Slides

Time-Averaged Cp and RMS









Time-Averaged Cp and RMS