charLES Buffet Simulations of the ONERA OAT15A Airfoil for DPW-8/AePW-4

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Outline

- Background
- ONERA OAT15 Results
- Summary

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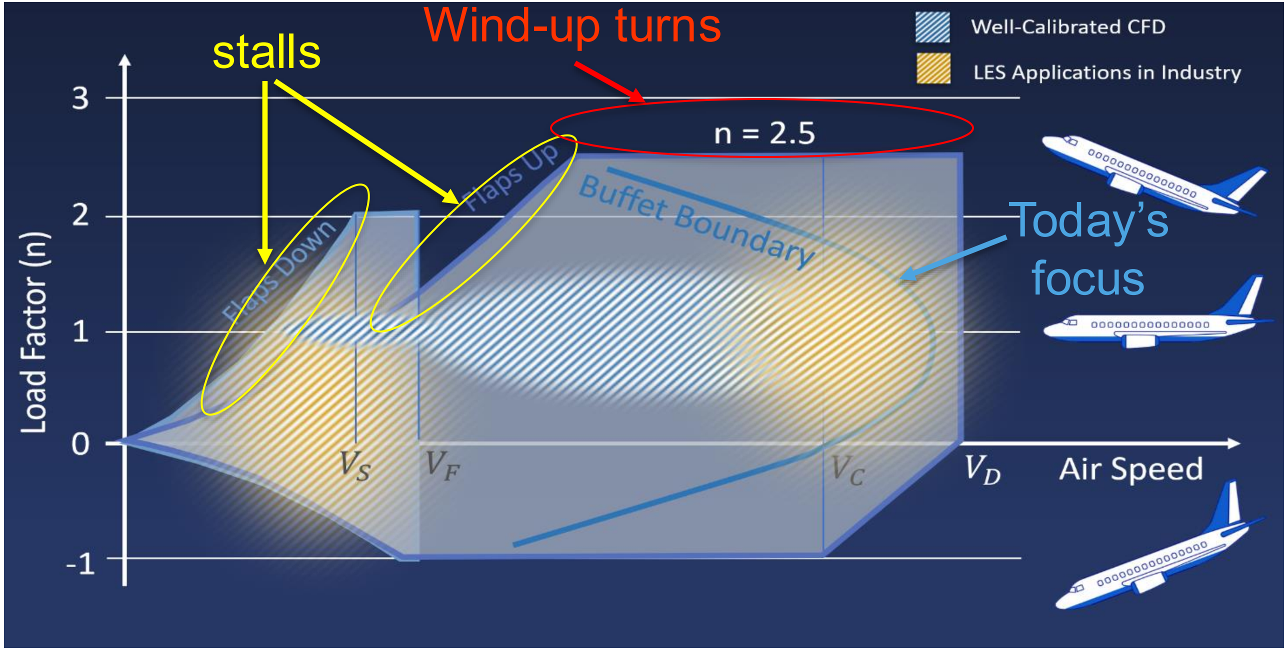
Expanding CFD Across the Flight Envelope

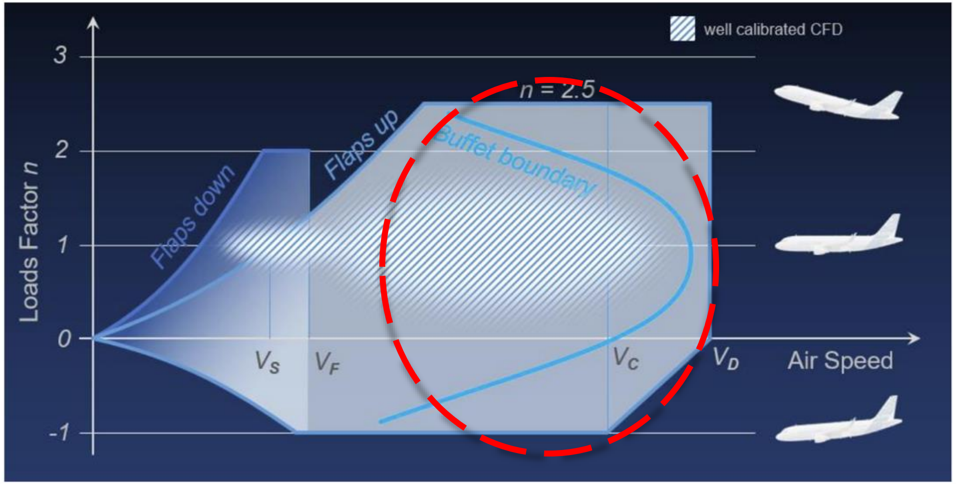


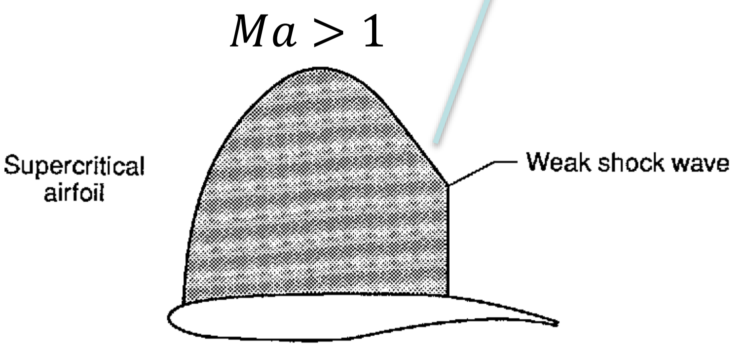
CFD used in the aerospace industry (mainly steady RANS) has been calibrated only in relatively small regions of the operating envelope (cruise, low speed with stowed flaps)

➢ Significant opportunity for high-fidelity methods (e.g., LES) to **expand the applicability of simulations for certification and design**

Transonic Buffet

- *Buffet* is a form of vibration caused by aerodynamic excitation. In cruise configuration, it is typically associated with **unsteady undulations in the shock location caused by an increase in angle of attack, Mach number, or both.**
  - There is a need for studies on canonical problems (e.g., ONERA OAT15A) to assess predictive capabilities of LES in this flow regime





Previous Work

BEST PAPER

Studies of transonic aircraft flows and prediction of initial buffet onset using large-eddy simulations

Konrad Goc, Rahul Agrawal, Parviz Moin and Sanjeeb Bose

12-16 June 2023 | AIAA AVIATION 2023 Forum

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Abstract

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Studies of Transonic Aircraft Flows and Prediction of Initial Buffet Onset Using Large-Eddy Simulation

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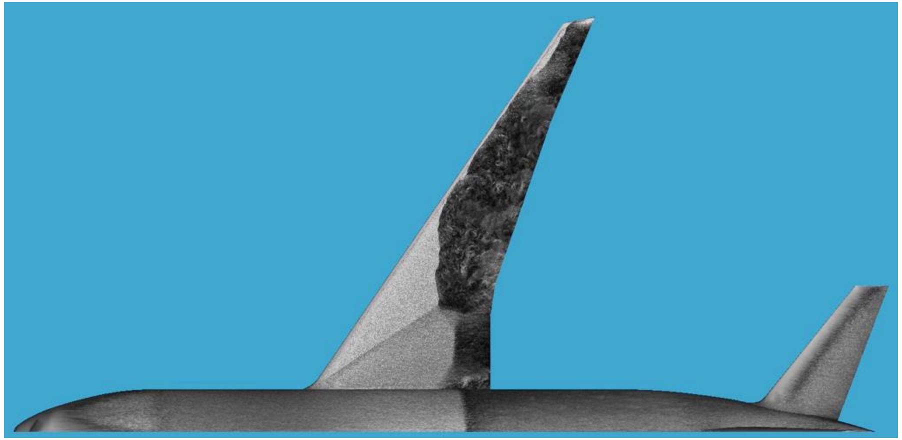
This paper utilizes the large-eddy simulation (LES) paradigm with a physics-based turbulence modeling approach, including a dynamic subgrid-scale model and an equilibrium wall model, to examine the flow over the NASA transonic Common Research Model (CRM), a flow configuration that has been the focus of several AIAA Drag Prediction Workshops (DPWs). The current work explores sensitivities to laminar-to-turbulent transition, wind tunnel mounting system, grid resolution, and grid topology and makes suggestions for current best practices in the context of LESs of transonic aircraft flows. It is found that promoting the flow transition to turbulence via an array of cylindrical trip dots, including the sting mounting system, and leveraging stranded boundary-layer grids all tend to improve the quality of the LES solutions. Non-monotonic grid convergence in the LES calculations is observed to be strongly sensitive to grid topology, with stranded meshes rectifying this issue relative to their hexagonal close-packed counterparts. The details of the boundary-layer profiles, both at the leading edge of the wing and within the shock-induced separation bubble, are studied, with thicknesses and integral measures reported, providing details about the boundary-layer characteristics to turbulence modelers not typically available from complex aircraft flows. Finally, an assessment of the initial buffet prediction capabilities of LES is made in the context of a simpler NACA 0012 flow, with computational predictions showing reasonable agreement with available experimental data for the angle of attack at initial buffet onset and shock oscillation frequency associated with sustained buffet.

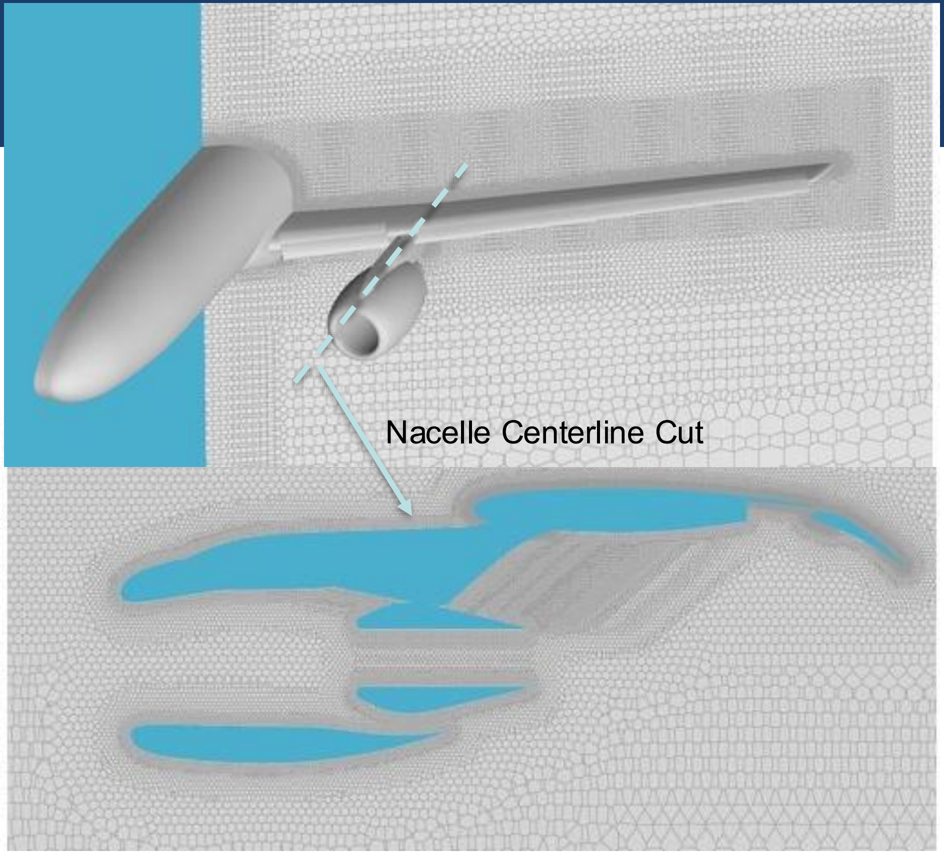


Transonic CRM Unsteady Buffet

Solver & Grid Generation

- Compressible Flow Solver: charLES
  - Low-dissipation numerics*
  - Second order finite volume*
  - RK3 time integration*
- Wall Model (variable exchange location*):
  - Equilibrium wall model*
  - Separation sensor wall model [1]
  - Transition sensor wall model [2]
- Subgrid-Scale Models:
  - Dynamic Smagorinsky*
  - Static Vreman
  - Non-Boussinesq Tensor Coefficient Model [3]
- Grid Generation: stitch
  - Custom grid generator for charLES
  - Voronoi grids*

BLUE* = used in this work



[1] Agrawal, et al., *Physical Review Fluids*, 2024.
[2] Bodart & Larsson, CTR *Annual Briefs*, 2012.
[3] Agrawal, et al., *Physical Review Fluids*, 2022.

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- **ONERA OAT15 Results**
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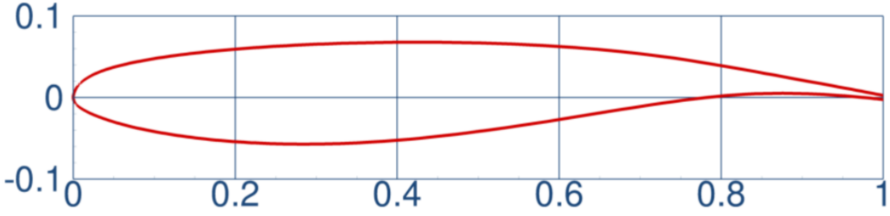
ONERA OAT15A

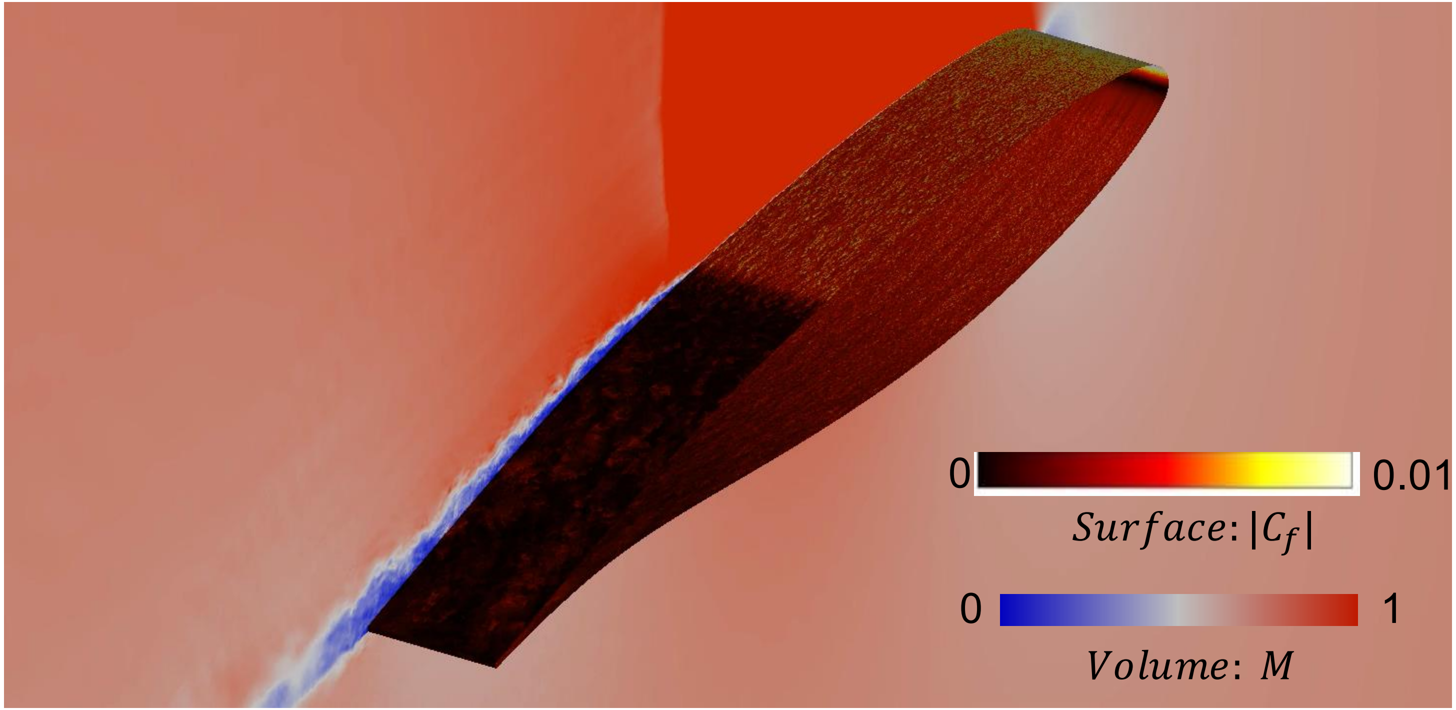
- Focus of DPW-8 Test Case 1b, Unsteady Analysis
- Conditions
  - Mach 0.73, Rec=3M (based on chord length), Tstatic= 271 K (487.8 R)
  - Alpha: 1.36, 1.50, 2.50, 3.00, 3.10, 3.25, 3.40, 3.50, 3.60, and 3.90

Jaquin, et al. "Experimental Study of Shock Oscillation over a Transonic Supercritical Profiles." AIAA Journal, Vol. 47, No. 9, 2009. Pages 1985-1994.



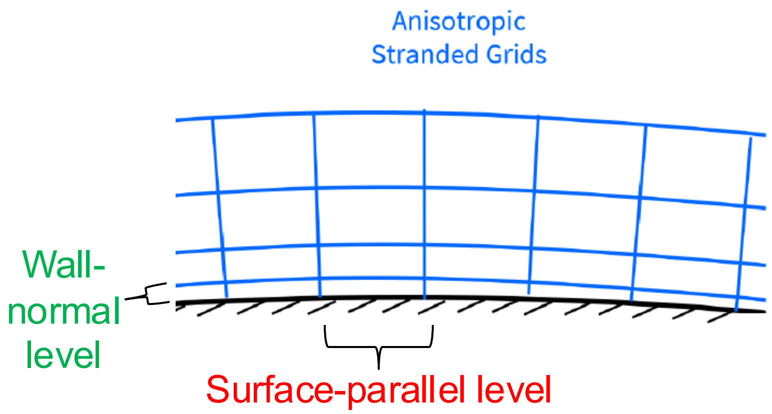
ONERA OAT15A Transonic Airfoil

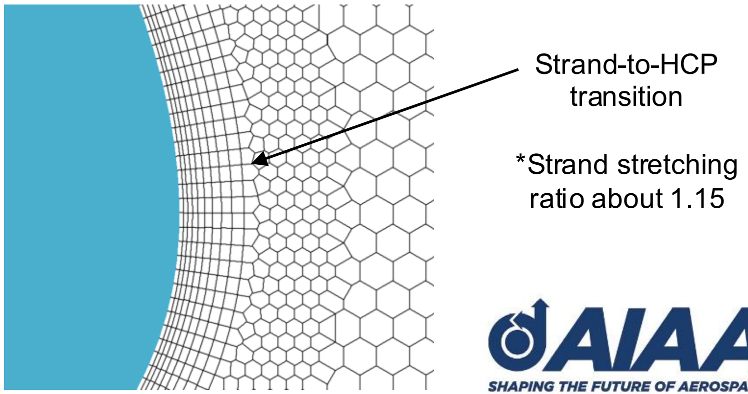
$\alpha = 3.90$ Solution



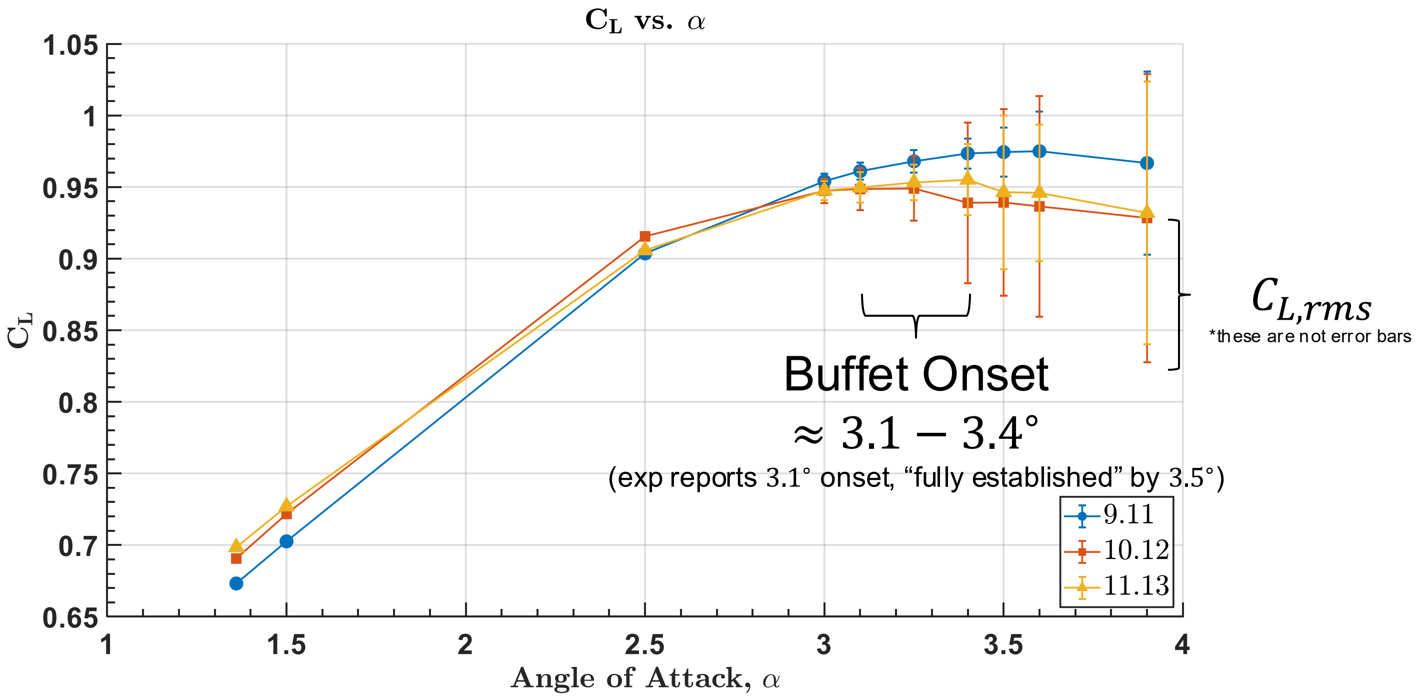
Grid Nomenclature

- Voronoi volume grids with near-wall prisms (i.e. “stranded” meshes) were used in these simulations
  - Level refers to number of points per chord – higher level leads to a denser mesh
    - $\Delta = chord * 0.5^{Level}$
  - Meshes used in grid convergence study
    - First number is the surface-parallel grid level
    - Second number is the wall-normal grid level
    - 4:1 aspect ratio (4x finer in wall-normal direction than wall-parallel)
    - 9.11 – 9.2 Mcv, **typical y+ at aoa 2.50 = 25**
    - 10.12 – 14.3 Mcv, **typical y+ at aoa 2.50 = 12.5**
    - 11.13 – 34.6 Mcv, **typical y+ at aoa 2.50 = 6**
  - Domain Size
    - Spanwise-periodic (extent = c/8)
    - Farfield extent 20*c

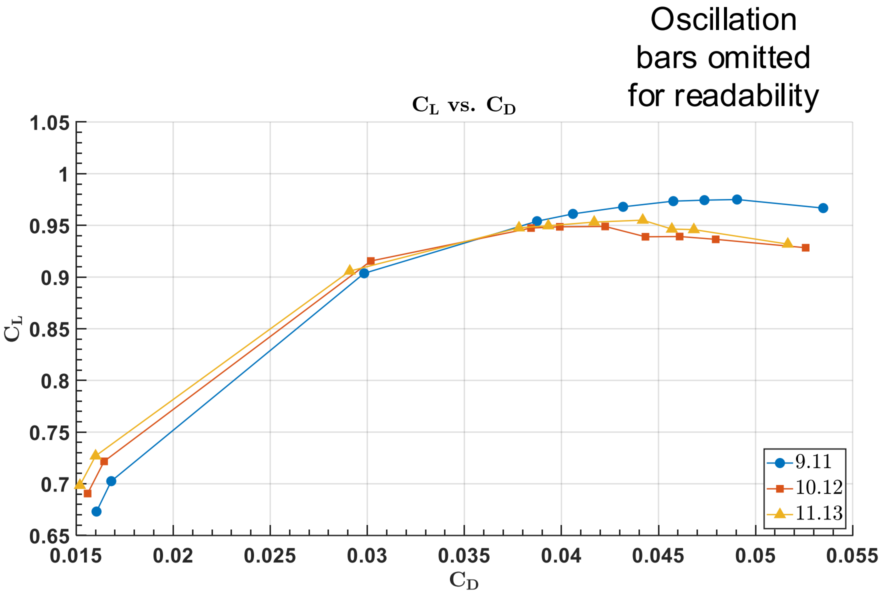


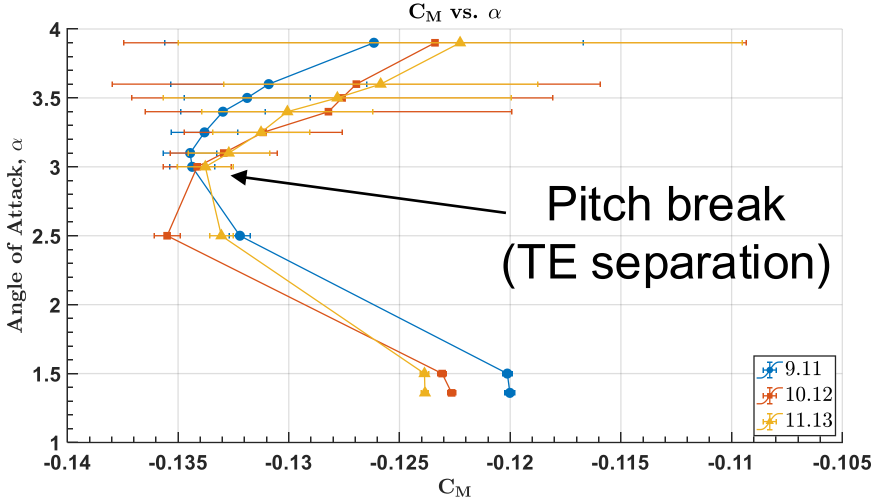


Grid Convergence Study: Lift Force

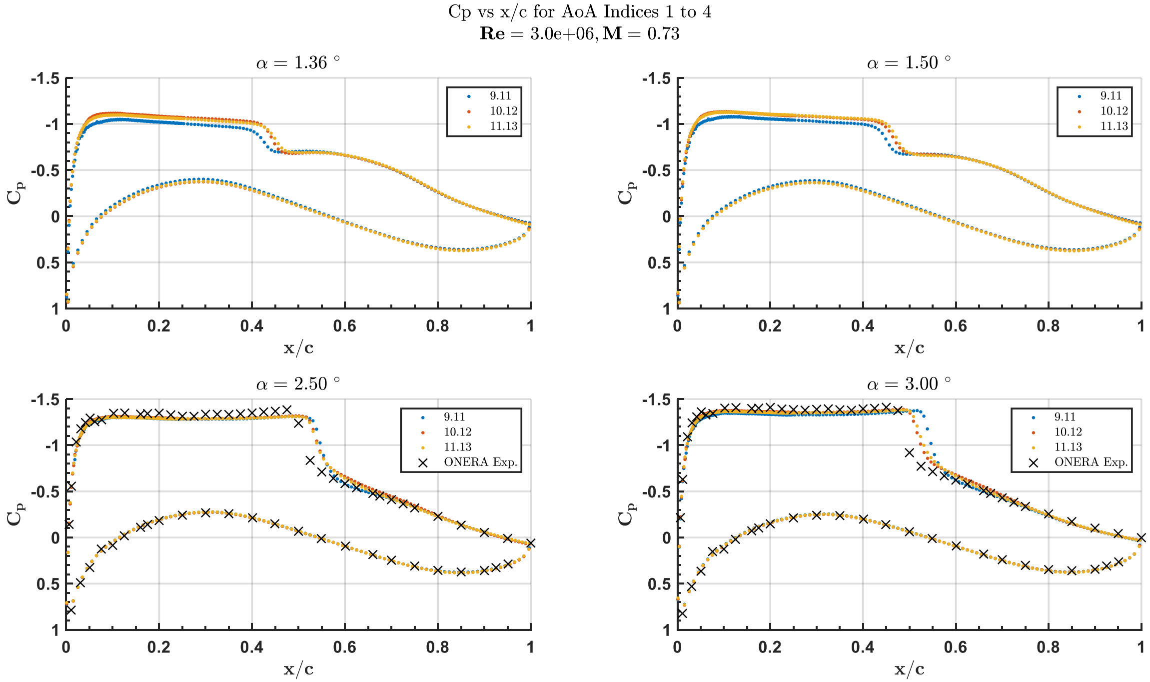


Grid Convergence Study: Drag & Pitching Moment



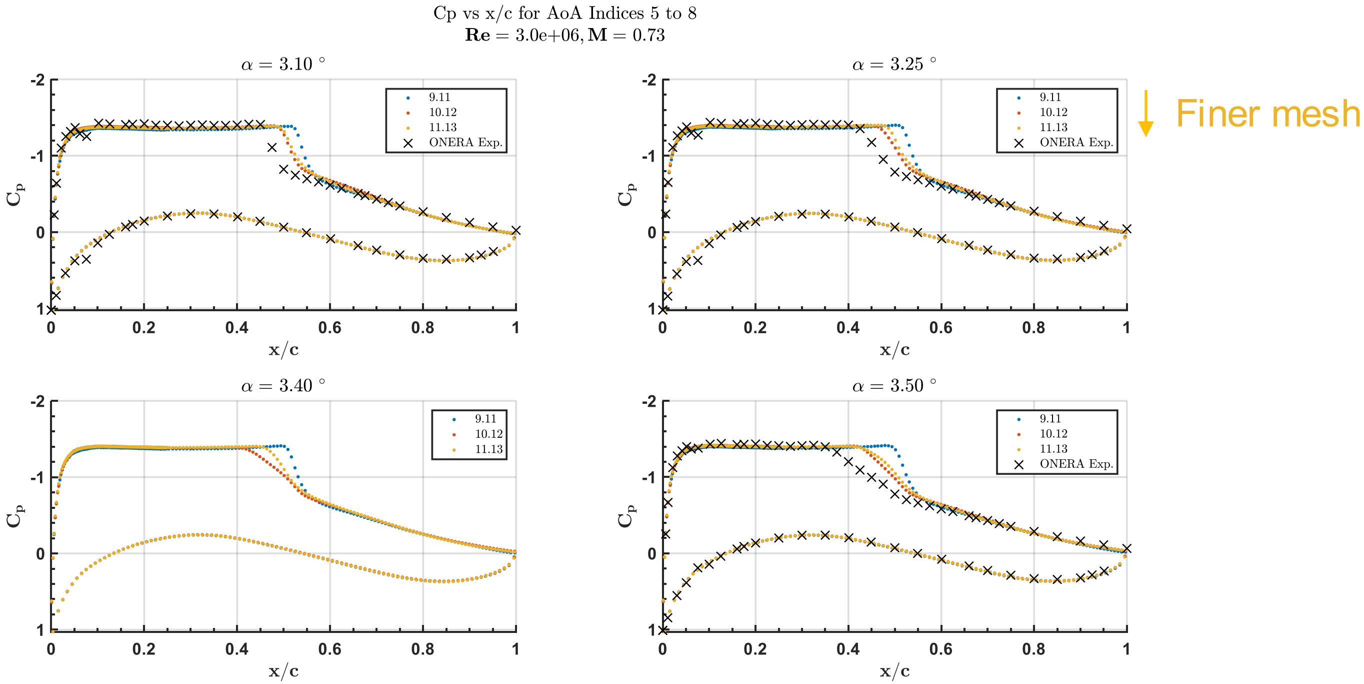


Grid Convergence Study: Pressure Coeff.



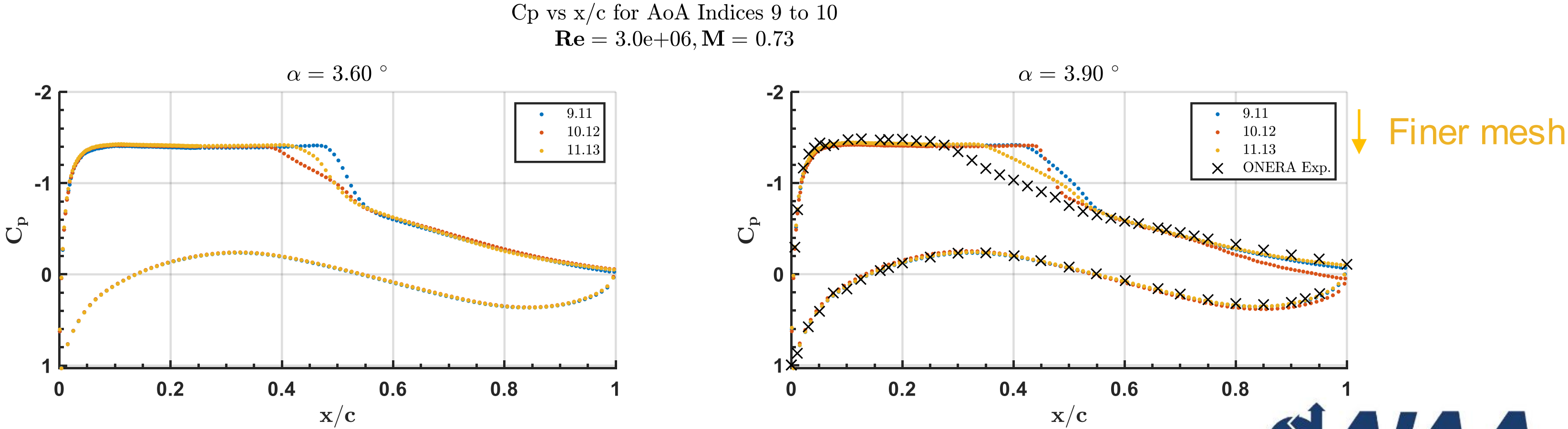
Finer mesh

Grid Convergence Study: Pressure Coeff.



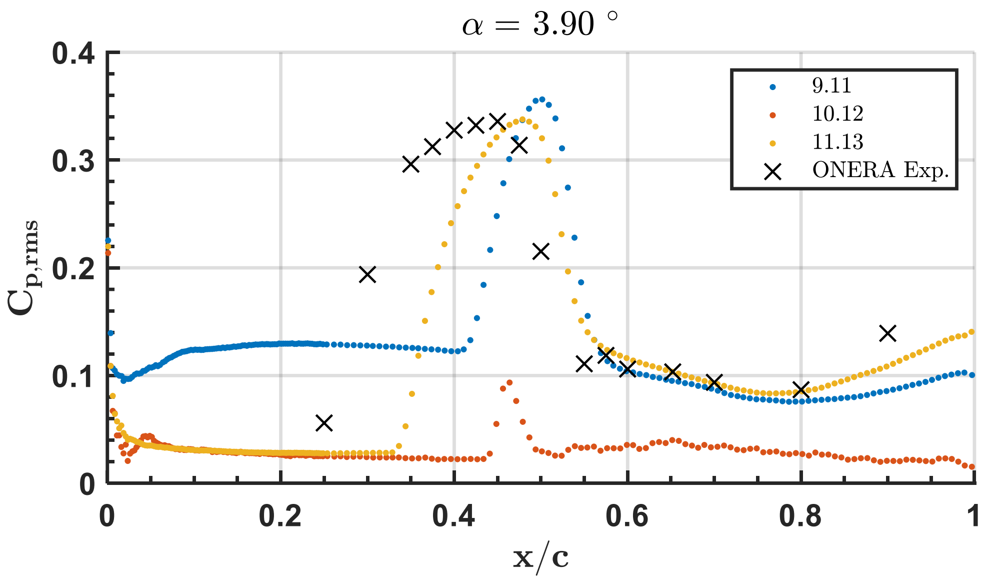
Grid Convergence Study: Pressure Coeff.

- Better grid independence of Cp observed at the low angles of attack
- Some delay ($\approx 5\%\ x/c$) in the mean shock location for the buffeting cases, even on the finest mesh, perhaps due to *tripping differences*
  - 12.14 mesh is likely needed, esp. for the buffeting cases, but was compute resource-limited in the current study



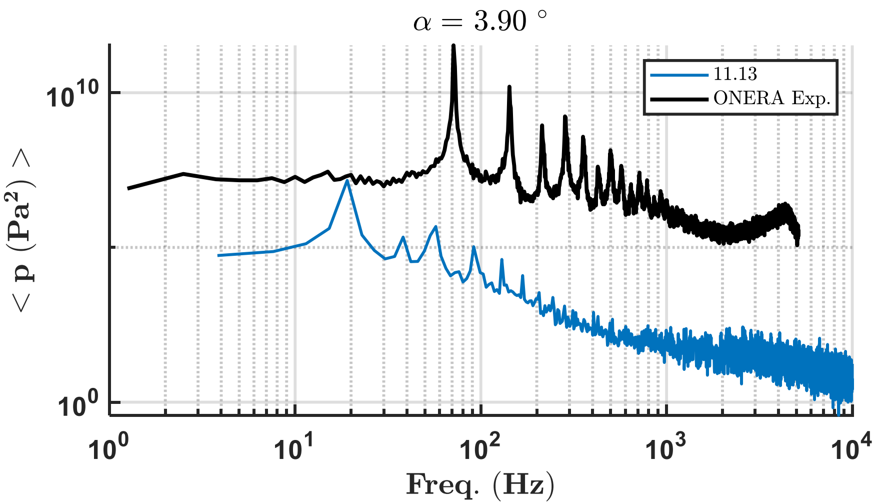
Grid Convergence Study: Cp,rms

- Cp,rms is more difficult to converge than Cp
  - Coarse mesh features grid-induced noise upstream of the shock, contaminating the solution
  - 10.12 and 11.13 solutions do not have upstream noise, but have too weak shock strength/not sufficient upstream shock motion extent respectively
  - Finer mesh solution needed



HELP NEEDED: PSD Spectra

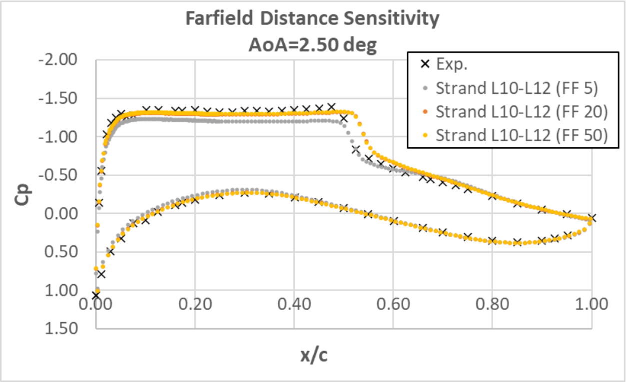
- Significant differences in spectral (PSD) data between simulations and experiment
- Are other participants seeing this?
  - Would help to cross-plot results from submissions that included PSD
- Using DPW-provided analysis script, but not an expert in signal processing
- Cases run for 200+ flow passes to collect large statistical sample of low-frequency oscillations

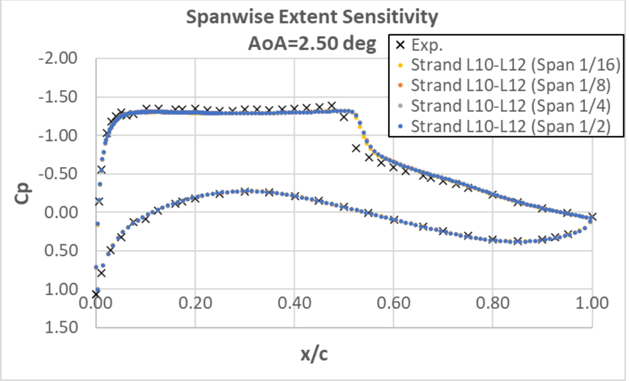


SHAPING THE FUTURE OF AEROSPACE

Domain Extent Study

- Study is really a re-visiting of established best practices for 2.5D simulations of transonic spanwise-periodic airfoils (e.g. N0012)
  - Farfield extent of 20 chords
    - At 5c, solution very much feels the limited domain
  - Spanwise extent of c/8
    - Very low sensitivity at $\alpha = 2.5°$ to spanwise extent, will be more sensitive at higher α





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Summary/Conclusions

- Simulation campaign using established charLES best practices was carried out on the ONERA OAT15A
- **Good prediction of buffet onset** at $\alpha = 3.1°$ (consistent with exp.) suggests promising capability of LES for flows in unsteady transonic regime
- Some delay of mean shock location (up to 5% x/c), potentially tied to fundamentally different transition mechanism between simulation and exp.
- Further grid refinement needed to fully establish grid independence
  - Finer cases are doable, but computing resources were lacking at time of this study
- Additional work required to validate $C_{p,rms}$ and PSD spectra

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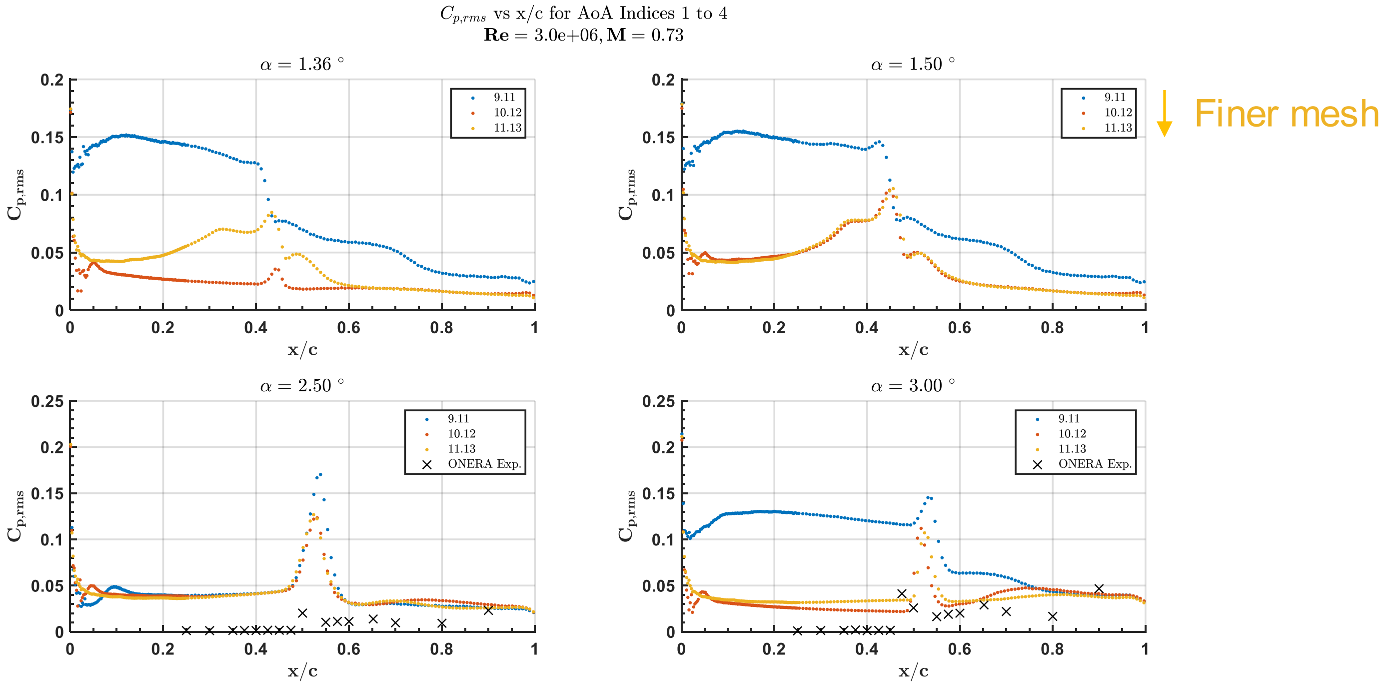
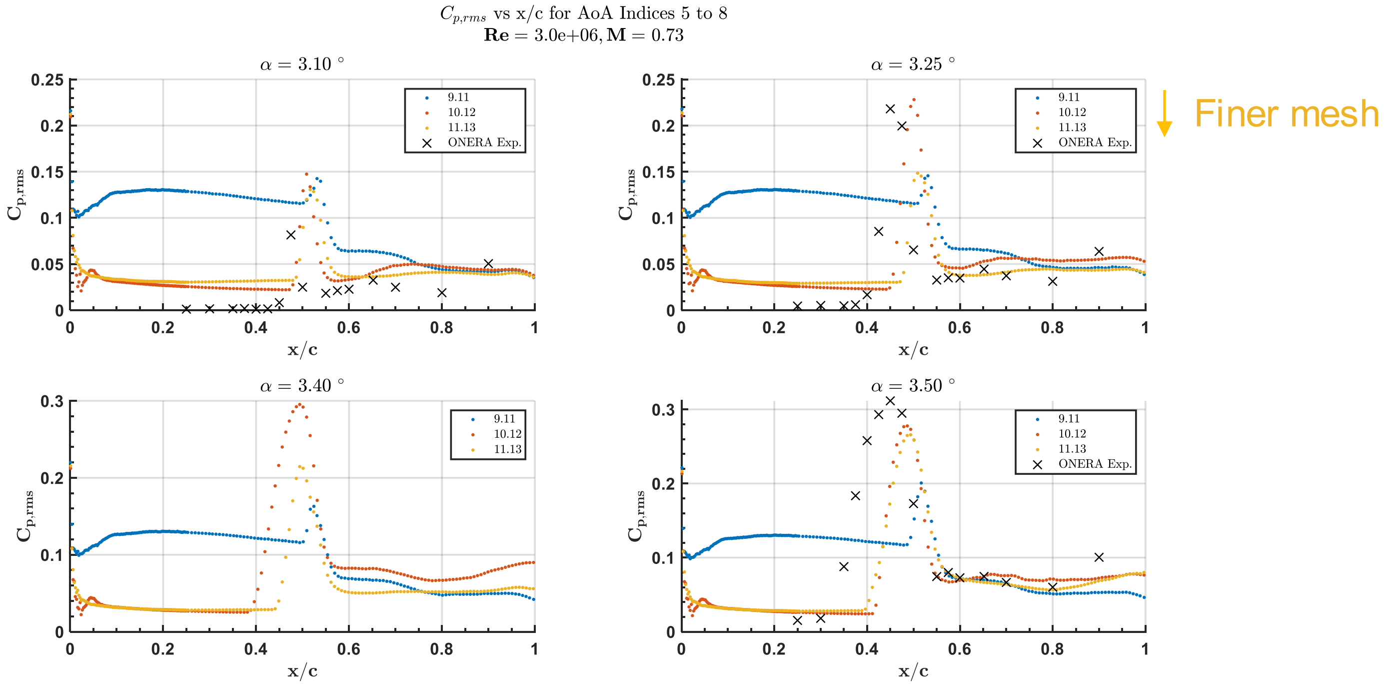
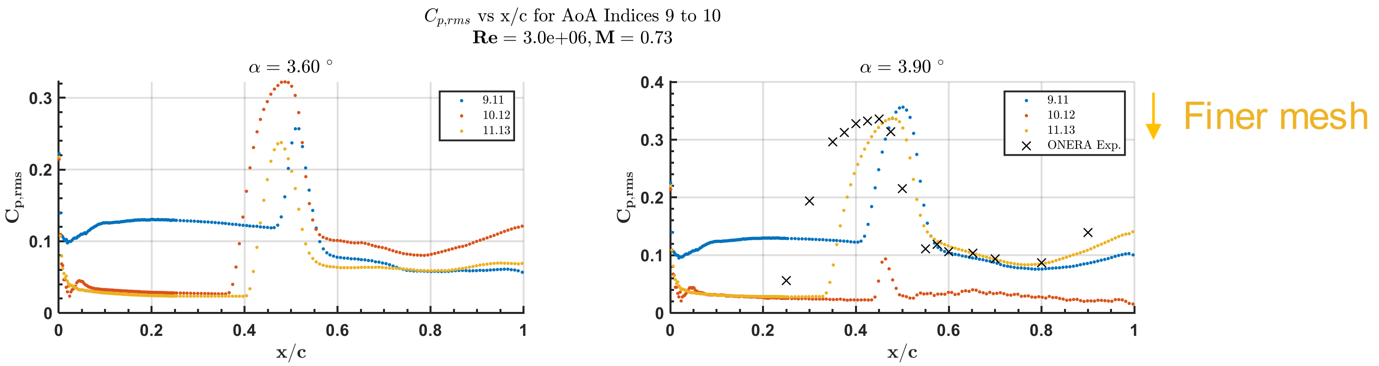
BACKUP - Grid Convergence Study: Cp,rms



BACKUP - Grid Convergence Study: Cp,rms

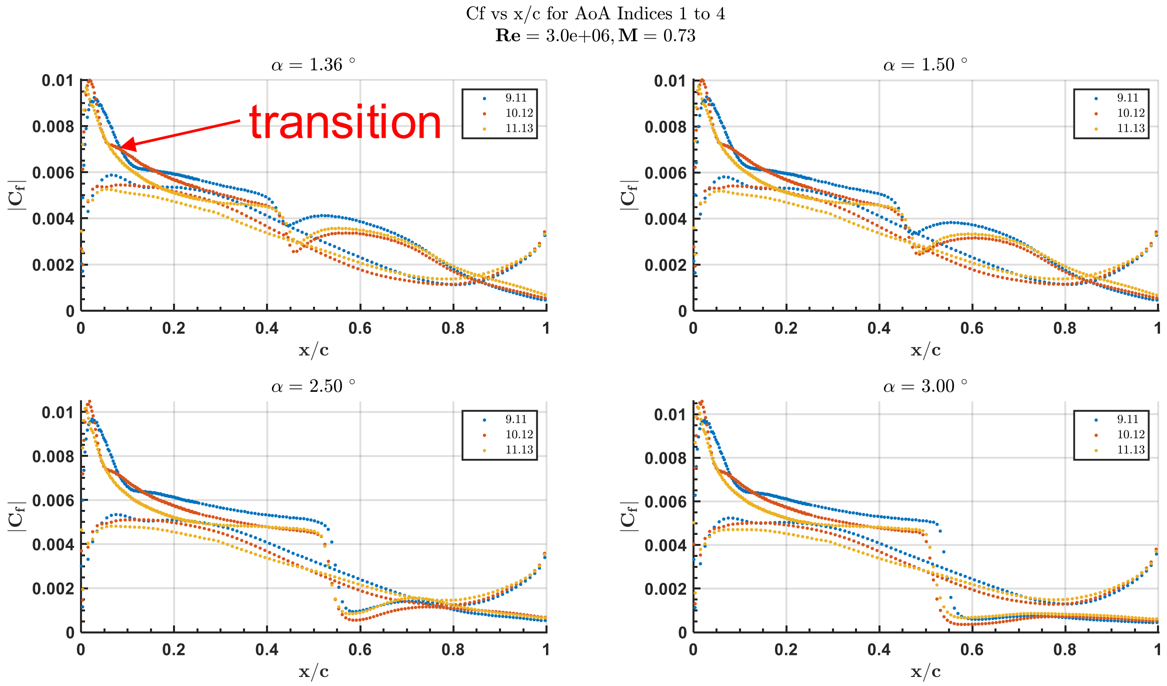


BACKUP - Grid Convergence Study: Cp,rms



BACKUP – Skin Friction

- 11.13 mesh solution is fully turbulent from the attachment line
- 9.11/10.12 solutions have a transitional zone at the LE
- Exp. was tripped, so the fully turbulent case is likely most appropriate behavior



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BACKUP – Force Time History