charLES Buffet Working Group Simulations for DPW-8/AePW-4

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AIAA AVIATION 2026, San Diego, 6/7/26

Outline

- Background
- Simulation Results
  - ONERA OAT15A
  - Transonic CRM (JAXA Variant)

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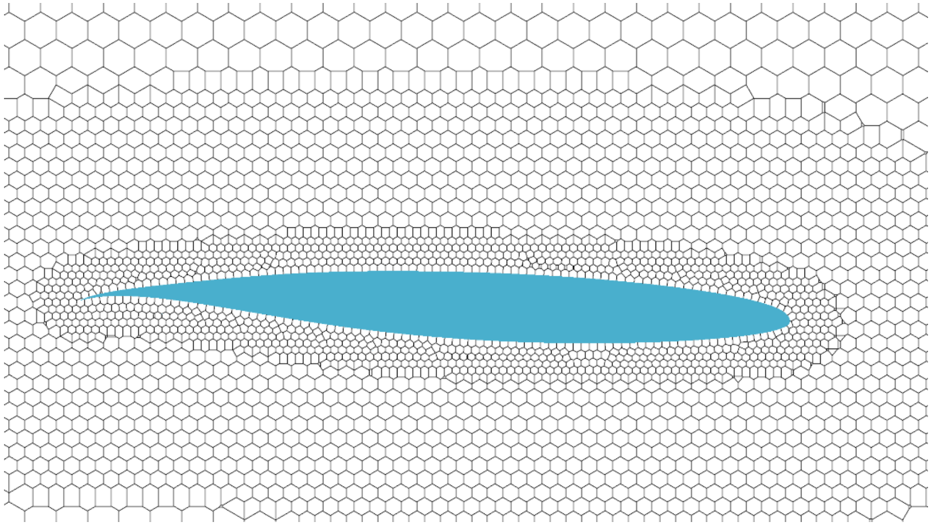
Solver & Grid Generation

- Compressible Flow Solver: charLES
  - Low-dissipation numerical methods*
  - 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 (charLES custom grid generator)
  - Voronoi grids*
  - Level refers to number of points per chord; i.e., higher levels lead to denser meshes
    - $\boldsymbol{\Delta} = \frac{chord}{2^{level}}$



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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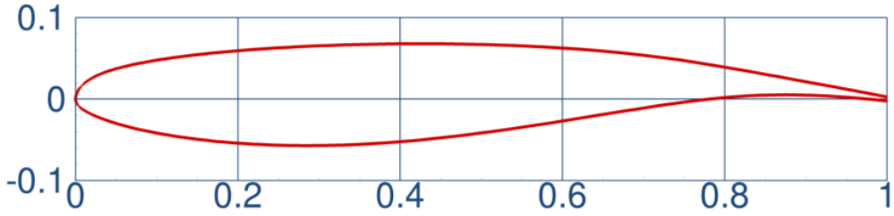
- Summary

ONERA OAT15A

- Focus of DPW-8 Test Case 1b, Unsteady Analysis
- Conditions
  - Mach 0.73, Re_c=3M (based on chord length), T_{static}= 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.

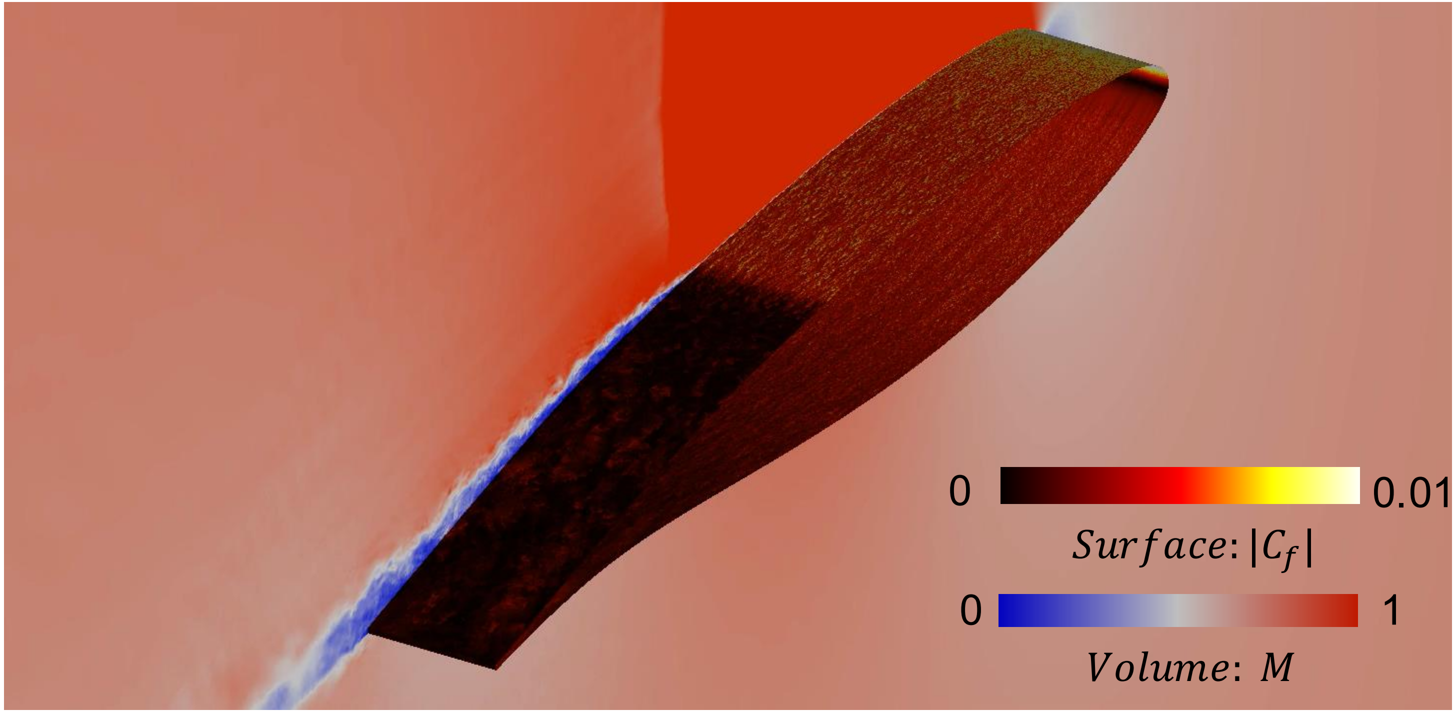


ONERA OAT15A Transonic Airfoil

Progress Since Aviation 2025

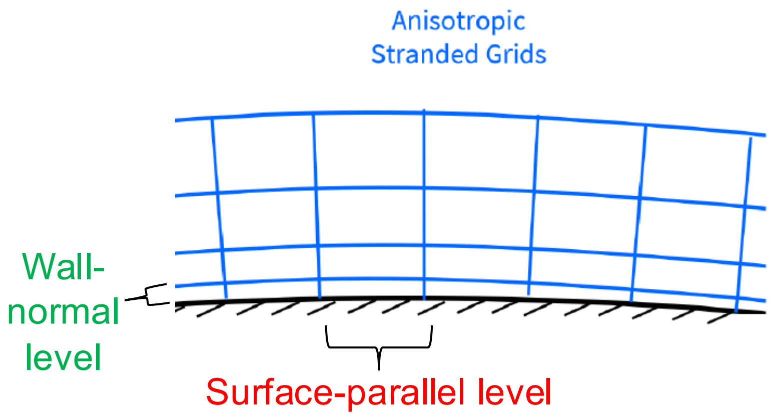
- Computed OAT15A on $2 \times$ finer mesh (max $y^+ \approx 3$)
  - Improved convergence of Cp & Cprms, especially at high aoa
  - Predicted a laminar leading-edge run
- Revisited PSD analysis
  - Collection of a much larger statistical sample (400 flow passes)
  - Improved agreement with experimental frequency data

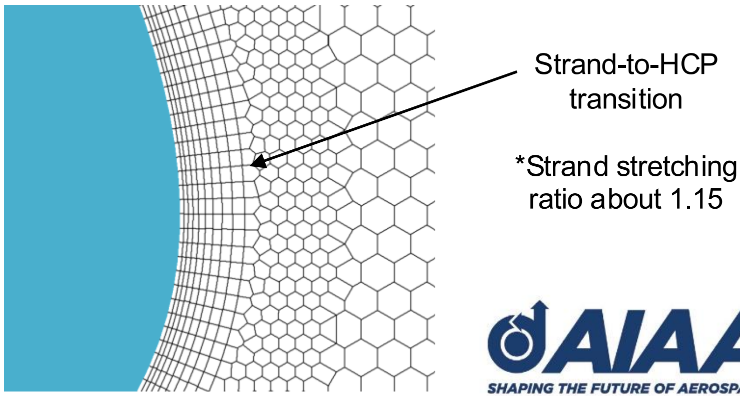
$\alpha = 3.90$ Solution



Grid Nomenclature

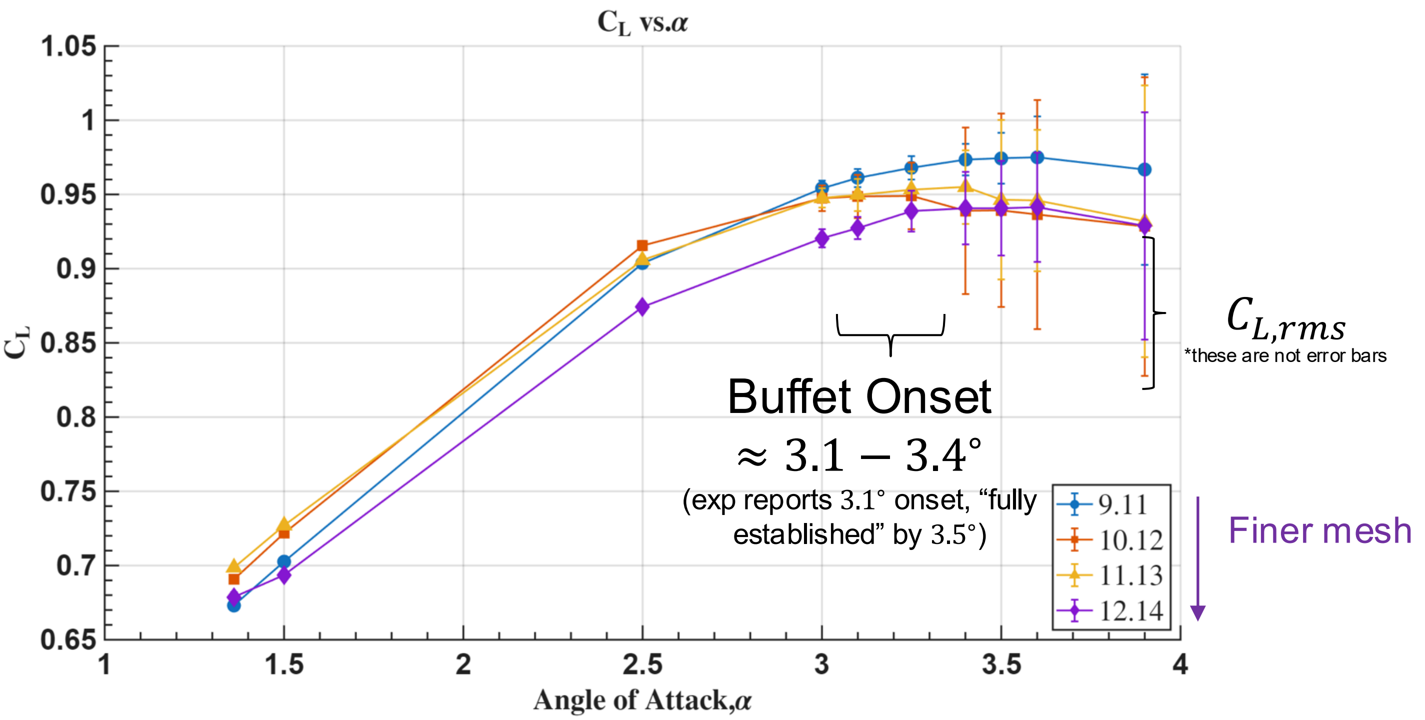
- Voronoi volume grids with near-wall prisms (i.e. “stranded” meshes) were used in these simulations
  - Level refers to number of points per chord – higher level leads to a denser mesh
    - $\Delta = chord * 0.5^{Level}$
  - Meshes used in grid convergence study
    - First number is the surface-parallel 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**
    - 12.14 – 115.0 Mcv, **typical y+ at aoa 2.50 = 3**
  - Domain Size (OAT15A)
    - Spanwise-periodic (extent = c/8)
    - Farfield extent 20*c





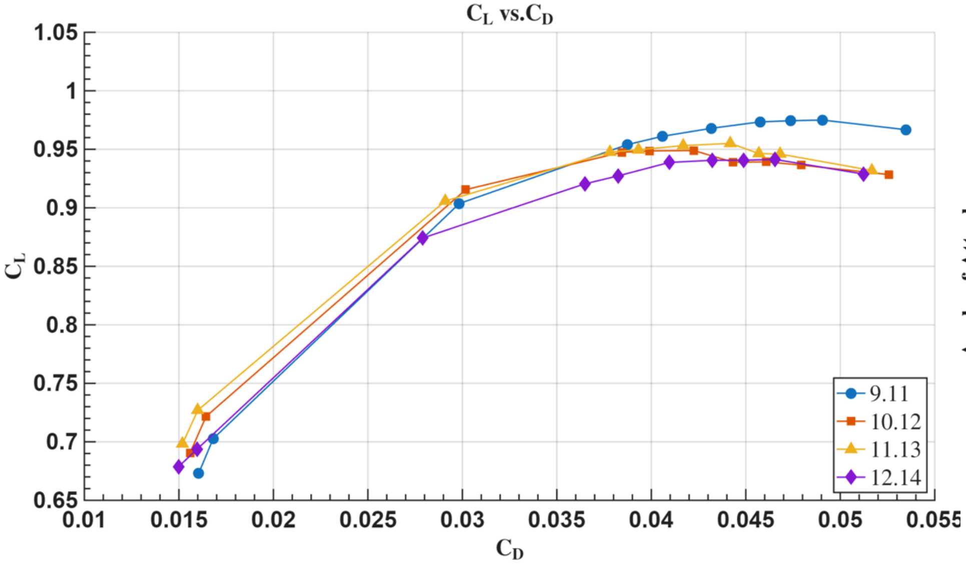
*Strand stretching ratio about 1.15

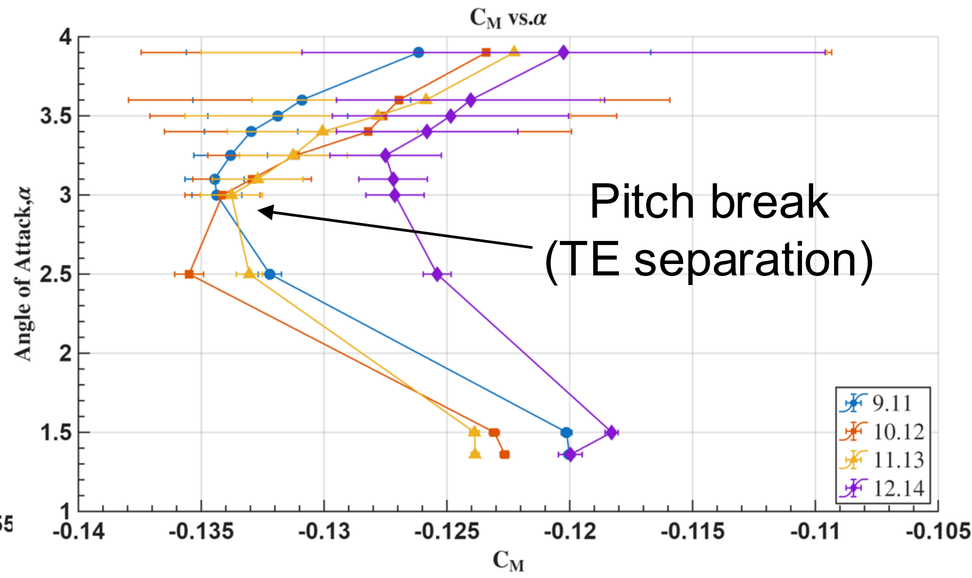
Lift Force


C_L vs.α
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
C_L
1
1.5
2
2.5
3
3.5
4
Angle of Attack,α
9.11
10.12
11.13
12.14
$C_{L,rms}$
*these are not error bars
Buffet Onset
$\approx 3.1 - 3.4°$
(exp reports 3.1° onset, "fully established" by 3.5°)
Finer mesh

Drag & Pitching Moment

Oscillation bars omitted for readability

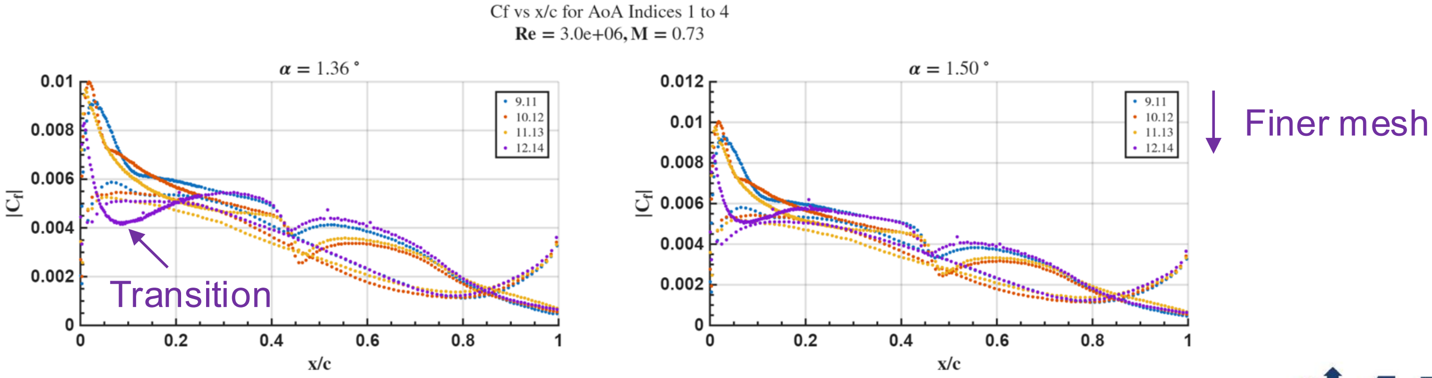




SHAPING THE FUTURE OF AEROSPACE

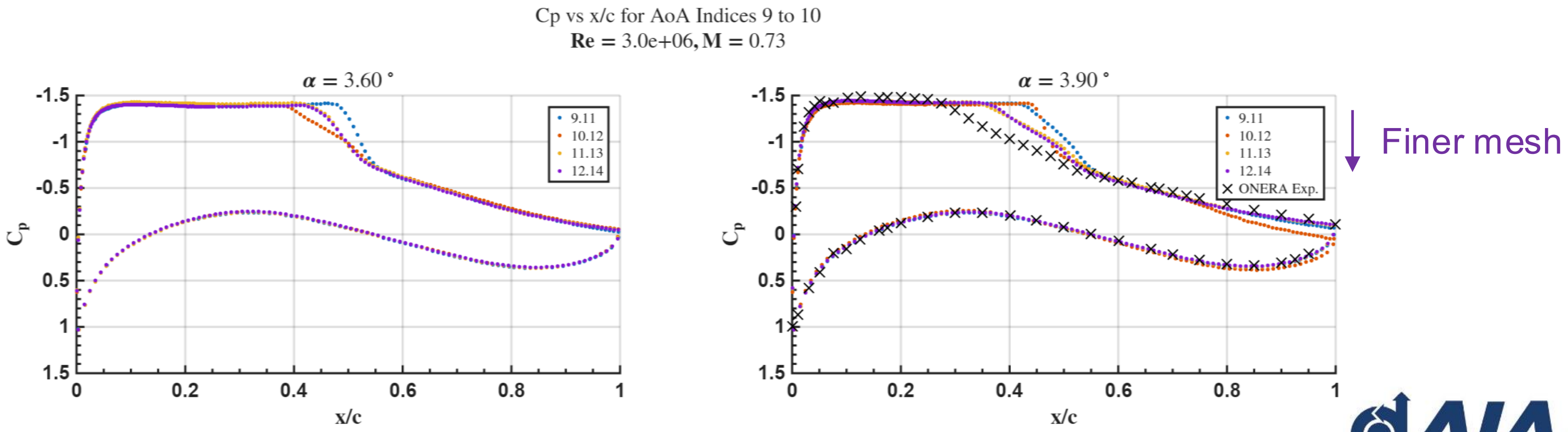
Skin Friction Coeff.

- Free transition simulations were fully turbulent on the $y^+ \approx 6$ grids, while a leading-edge laminar run up to $\frac{x}{c} \approx 0.2$ was predicted on the $y^+ \approx 3$ grid
- Caused a significant change in low angle of attack C_l, C_m
- Would be interesting to run a fixed transition case on the same grids, but lacked bandwidth to do so as part of the current study



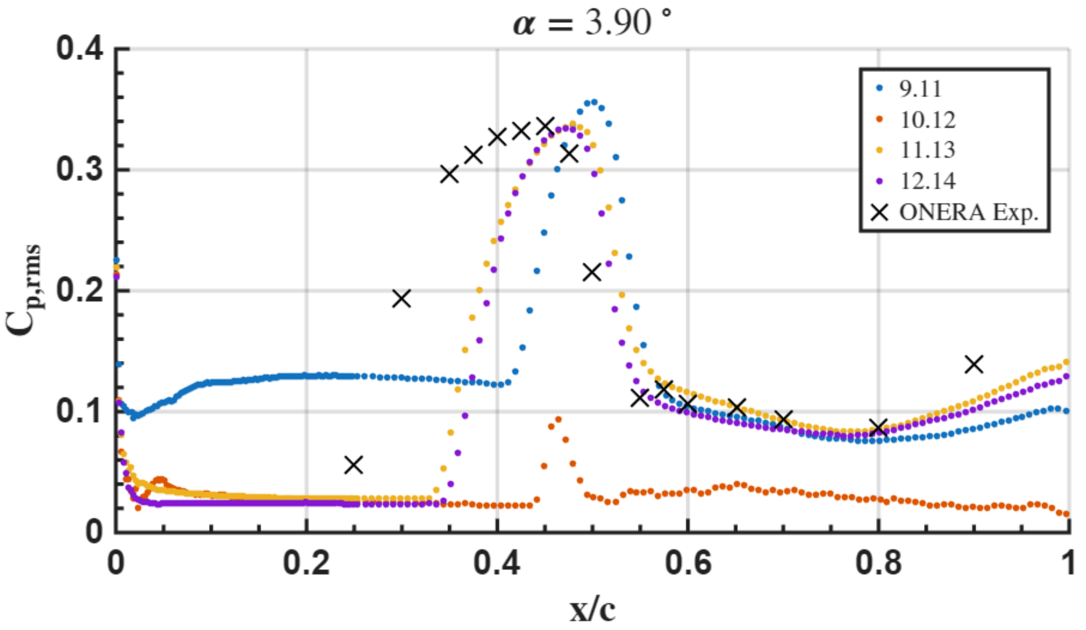
Pressure Coeff.

- Near grid-independence of Cp achieved across all aoa's with $y^+ \approx 3$ mesh
- 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*



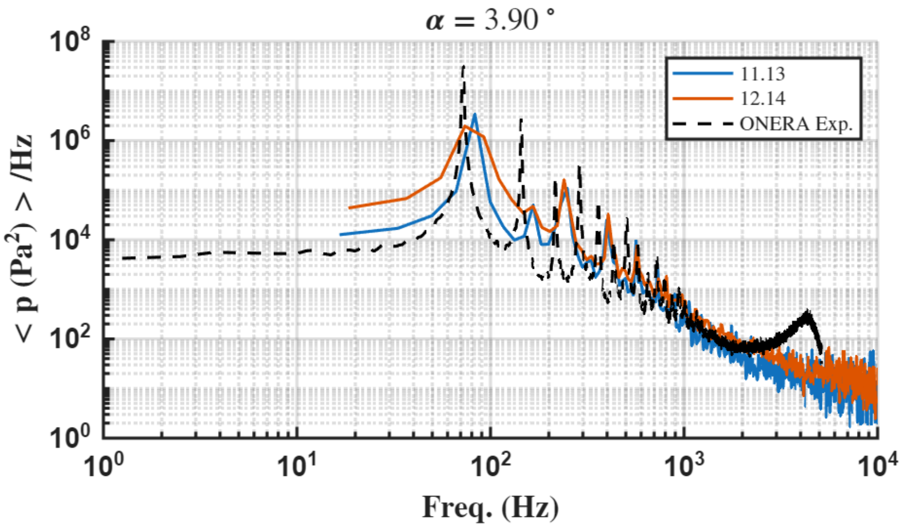
$C_{p,rms}$

- Finer mesh solution **nearly converged Cprms prediction**
  - Generated new 12.14 solution after Aviation 2025
- Coarse mesh features grid-induced noise upstream of the shock, contaminating the solution
- 10.12-12.14 solutions do not have upstream noise, but do not have sufficient upstream shock motion extent



PSD Spectra

- Improved agreement since mini-workshop at Aviation 2025
  - Applied proper normalization of Strouhal number, dimensional scaling of simulation vs. experiment
  - Larger statistical sample size
- Cases run for 200+ flow passes to collect large statistical sample of low-frequency oscillations (11.13 solution run for 400 CTU's)
- Good agreement in dominant frequency, some phase shift in higher frequency overtones at $\alpha = 3.9°$
  - Buffet is slightly delayed in α, low frequency tone not captured until $3.5°$, exp sees it at $3.25°$



SHAPING THE FUTURE OF AEROSPACE

ONERA OAT15A Conclusions

- **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.
- Completed grid refinement study
  - Promising grid-independence trends, especially in Cp and Cprms
  - Experimental trip was not represented in the LES, resulting in LE laminar differences which notably affected force/moment convergence at low aoa
- PSD spectra
  - Long simulation run time to collect low frequency buffet phenomena
  - Encouraging **agreement between sim & exp in dominant buffet freq. prediction**

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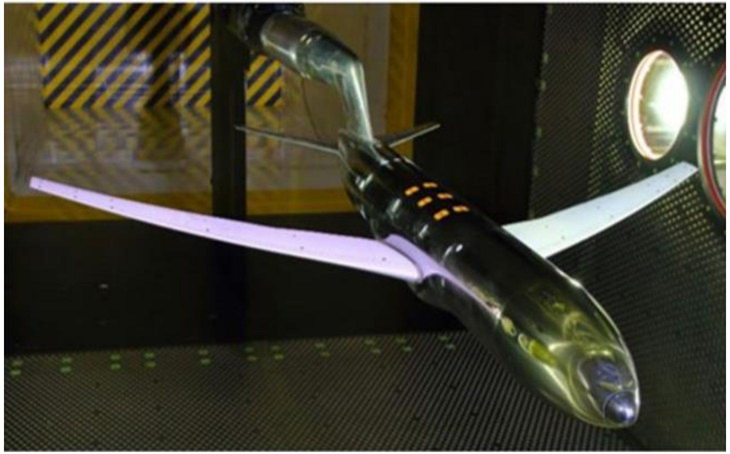
Transonic CRM (JAXA Variant)

- JAXA CRM Wing/Body/Tail
  - 80% of the classic NTF model scale
- M = 0.85, Re = 1.515e6
- α = [1.22°, 2.29°, 4.84°, 5.89°]
- LES simulations used 10.12 (medium mesh) resolution from OAT15A
  - 300 Mcv, typical $y^+ \sim 5 - 15$



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

https://doi.org/10.2514/6.2023-4338

Abstract ⌄ First Page Read Now

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

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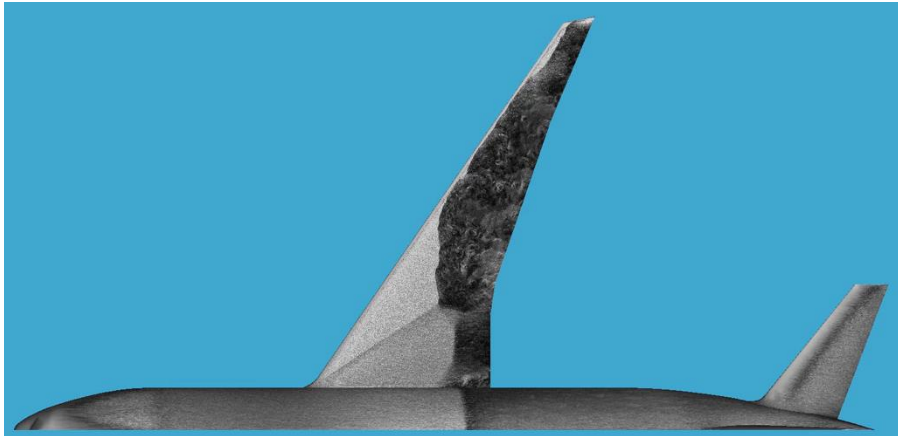
https://doi.org/10.2514/1.C038129

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.

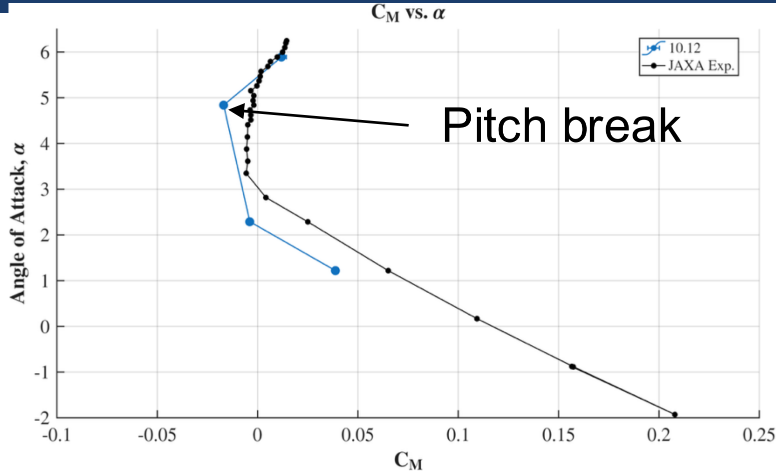


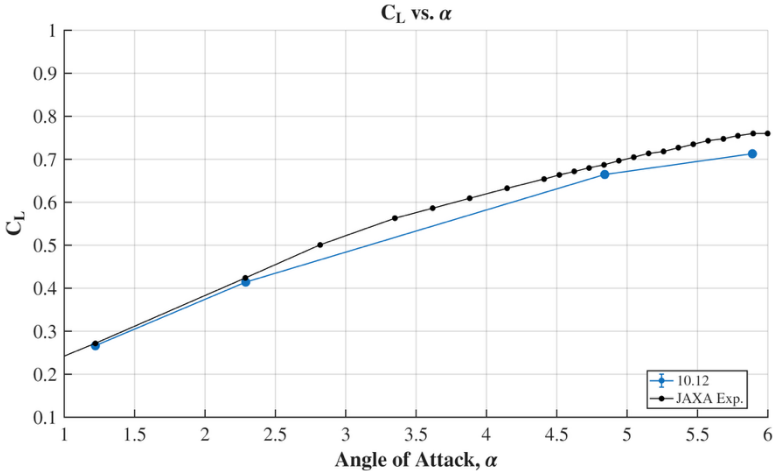
Transonic CRM Unsteady Buffet

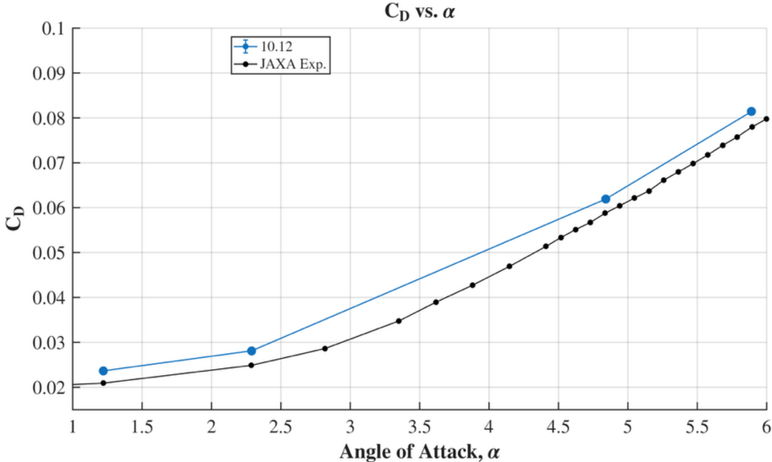
Goc, K. A., Agrawal, R., Bose, S. T., & Moin, P. (2025). Studies of transonic aircraft flows and prediction of initial buffet using large-eddy simulation. *Journal of Aircraft*.

Force/Moment Plots

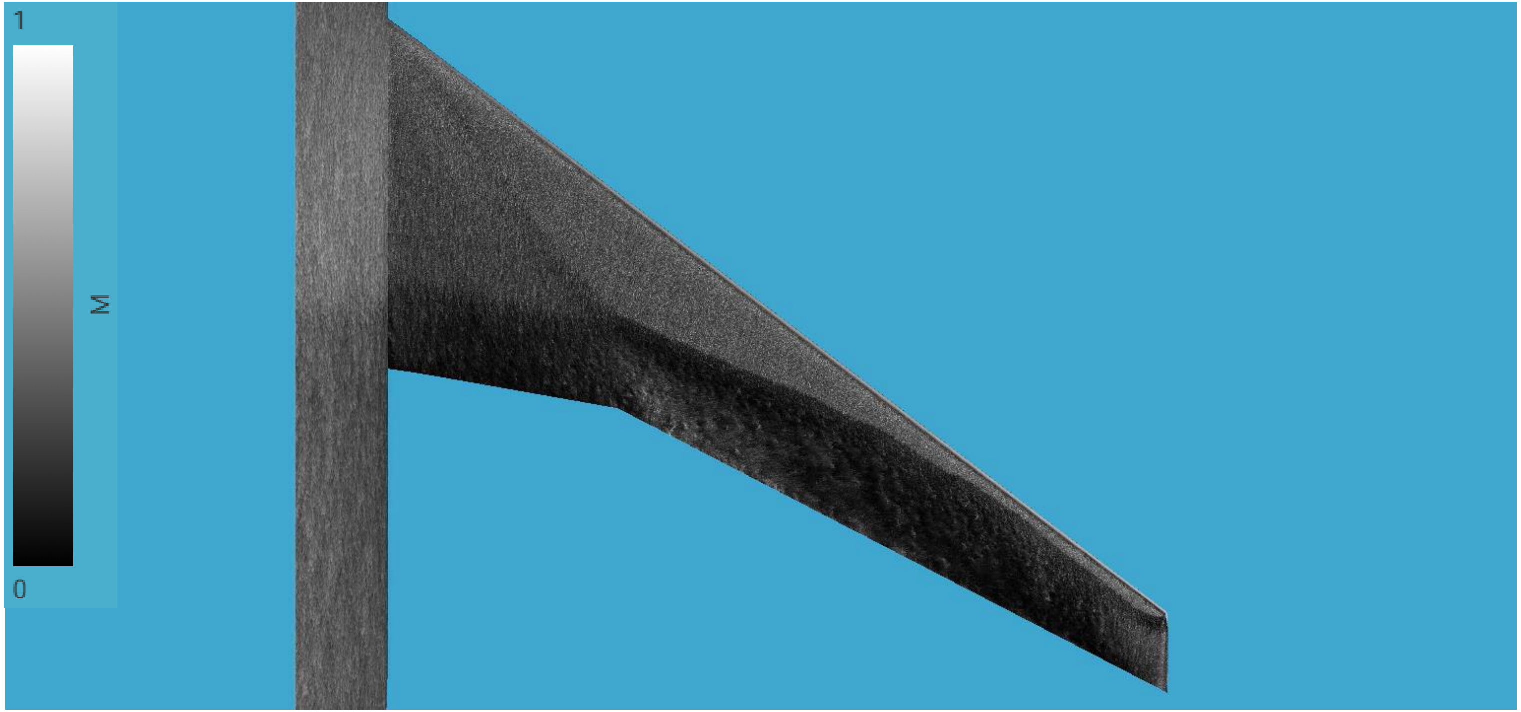
- Nose-up C_M pitch break predicted at $\alpha = 5.89°$
  - Too much nose-down C_M at low AoA's
- C_D is 20-30 counts too high across all AoA's
  - Simulations were fully turbulent, while the exp. had LE trip dots





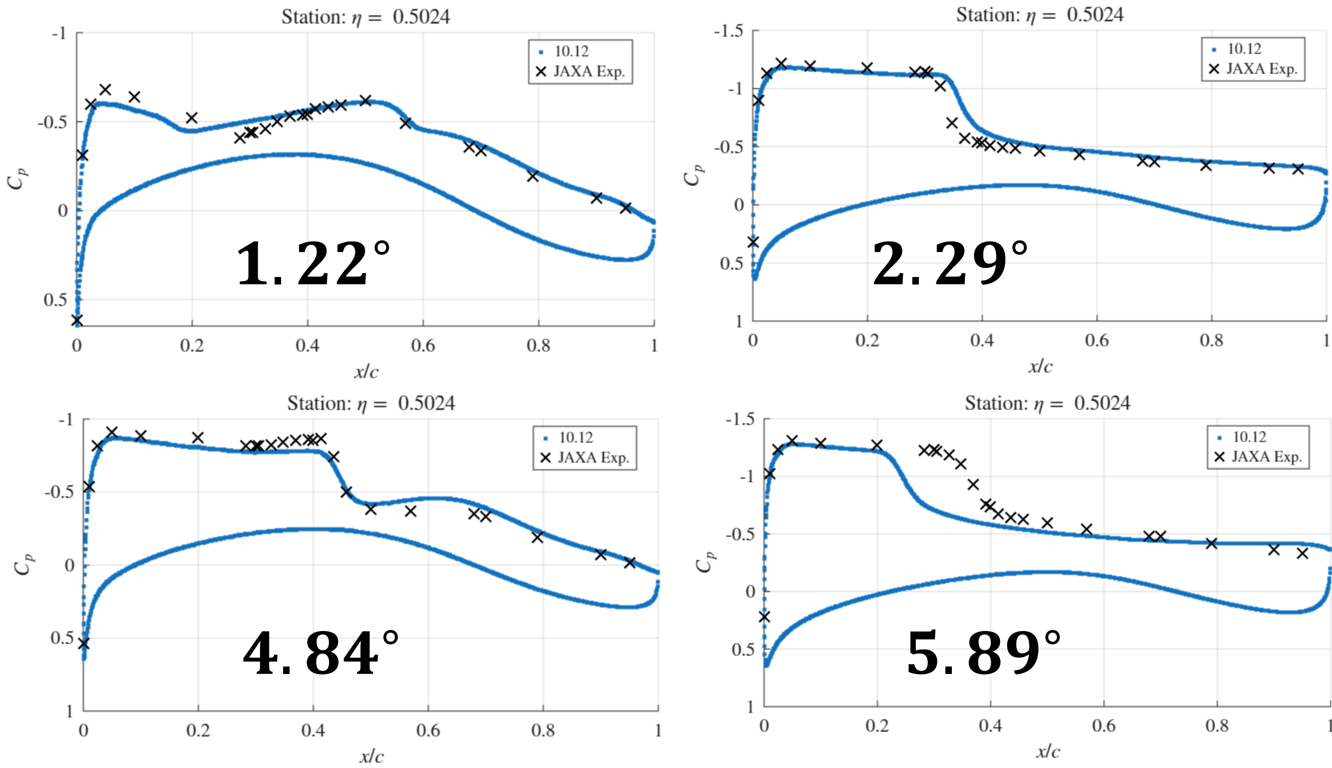


Inst. Mach Contours: AoA 5.89°



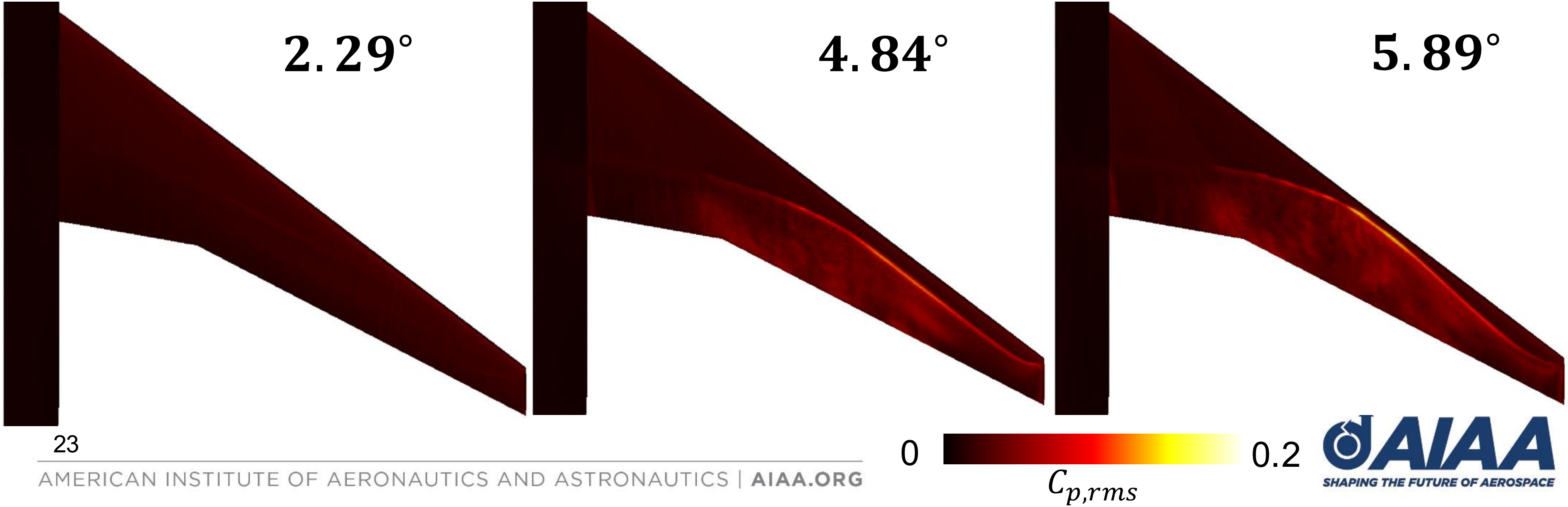
Sectional Cp's

- Cp reasonably predicted at the low AoA's
- Premature shock at highest AoA



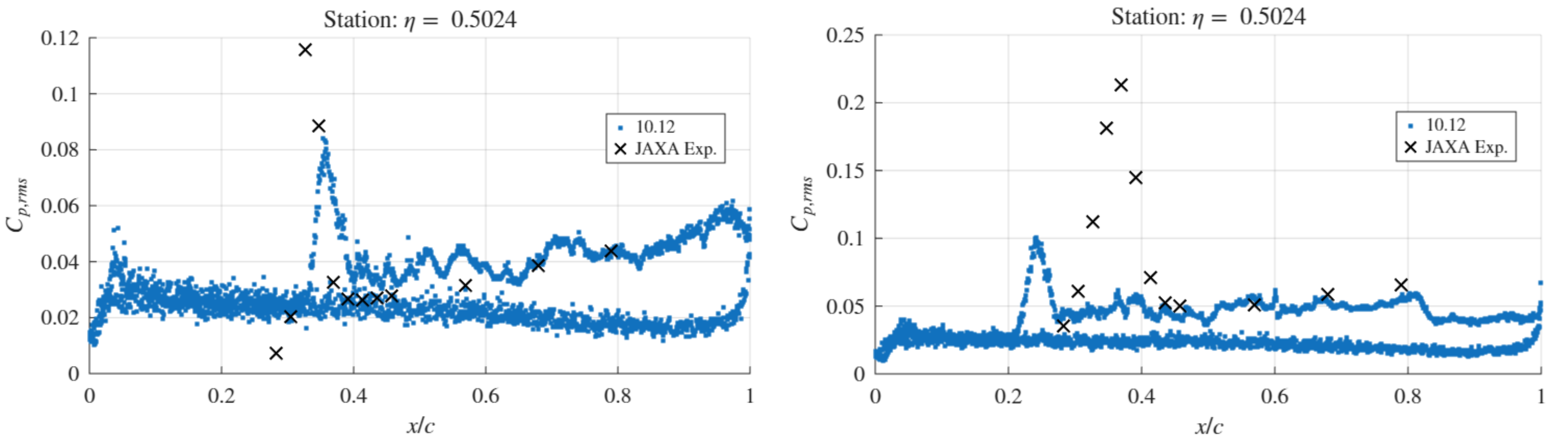
Cprms Contours

- Elevated $C_{p,rms}$ levels, especially around the shock at $\alpha = 4.84°$ and $5.89°$ - indicative of buffet onset
  - $\alpha = 2.29°$ shows little to no unsteady content



Sectional $C_{p,rms}$

- Peak $C_{p,rms}$ levels are low relative to experimental values
- At $\alpha = 5.89°$, $C_{p,rms}$ peak is too far forward, consistent with premature shock prediction
- Pre-shock $C_{p,rms}$ levels are too high in the LES – simulations are fully turbulent



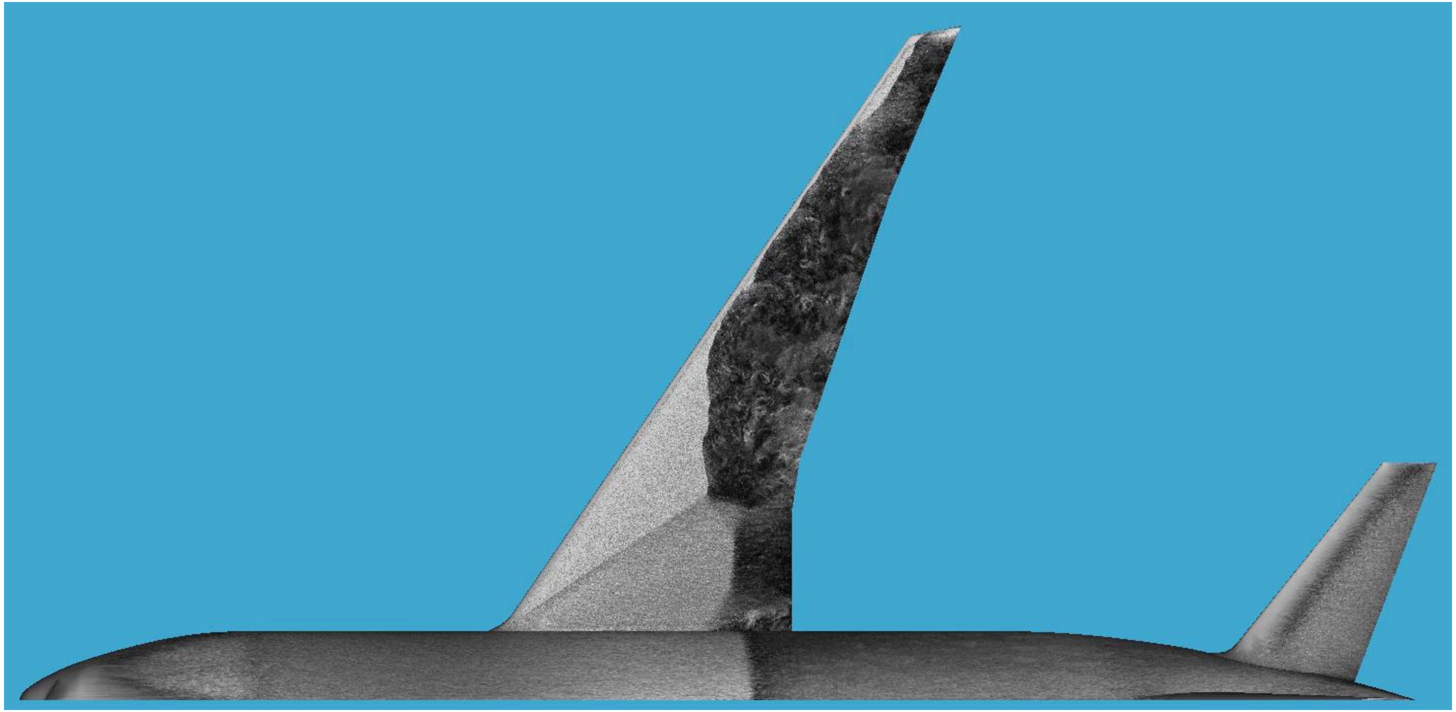
4.84° **5.89°**

JAXA CRM Conclusions

- Low Re of the exp. posed challenges for LE transition treatment in LES
  - LE transition treatment was not applied in this study due to limited bandwidth, but this has been demonstrated in the past to improve shock location prediction[1]
  - Would be **helpful to have CAD of the trip dots**/experimental trip characterization
- Accurate prediction of Cp at α = [1.22°, 2.29°, 4.84°], premature shock at α = [5.89°]
- α = [4.84°, 5.89°] showed a level of Cprms oscillations that were indicative of **buffet onset**
  - Significantly more challenging to predict unsteady Cprms on a full aircraft config compared to canonical OAT15A
- Is there a role for scale-resolving methods in the high-speed community for prediction of corner of the flight envelope conditions (e.g. buffet), even if cruise drag prediction is worse than RANS?

1. Goc et al. (2025), *J. of Aircraft*

QUESTIONS?



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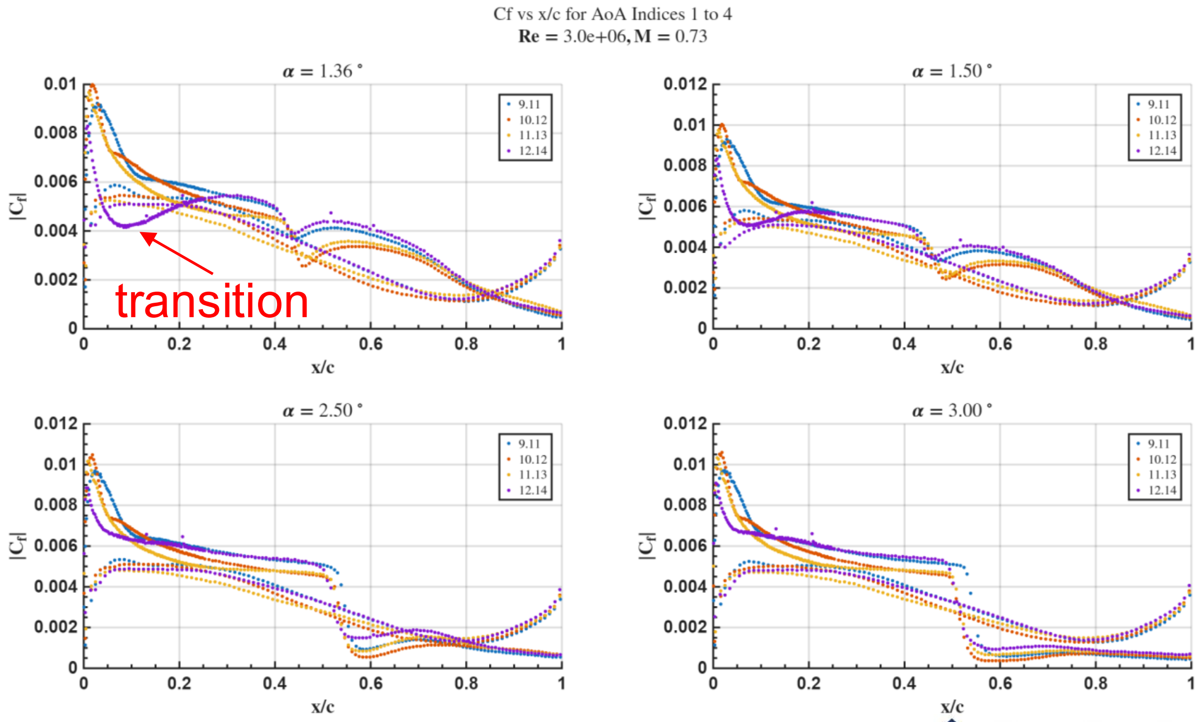
Backup

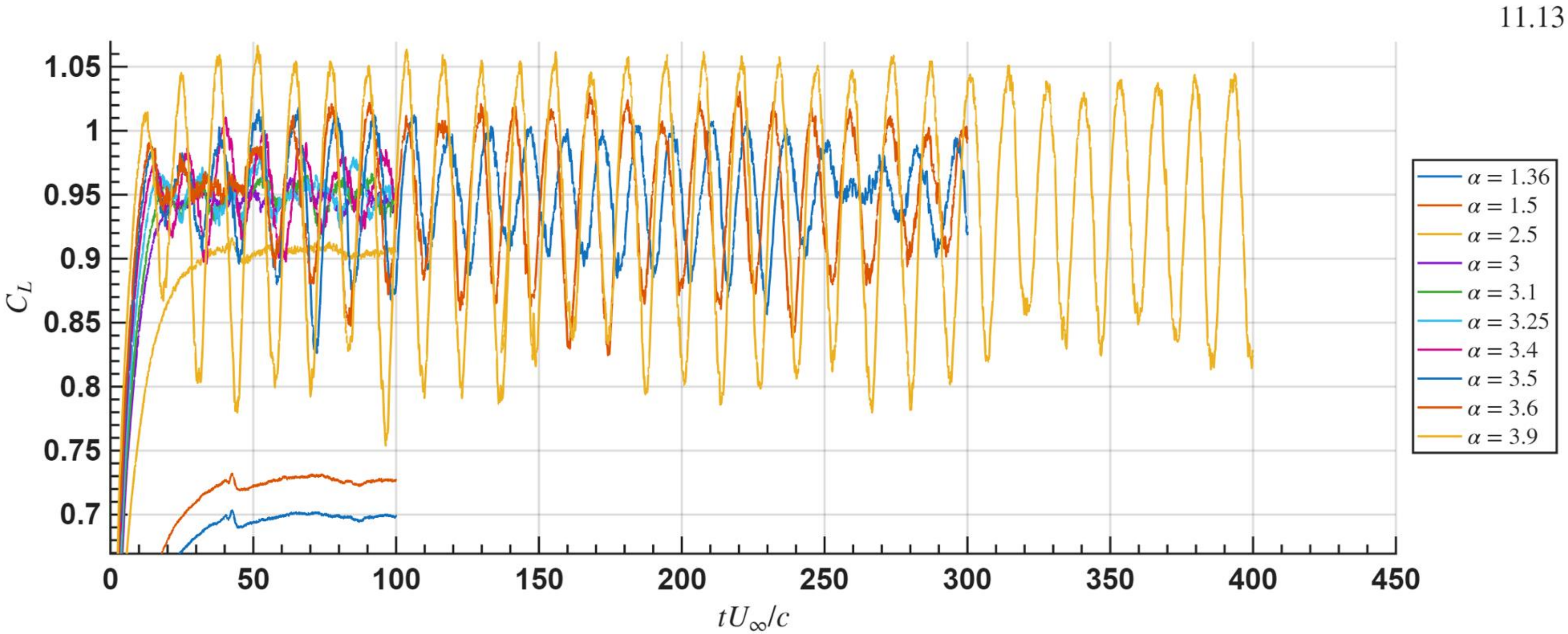
OAT15A

BACKUP – Skin Friction

- 11.13 mesh solution is fully turbulent from the attachment line
- 12.14 solutions have a lengthy transitional zone at the LE
- Exp. was tripped at $\frac{x}{c} \sim 10\%$



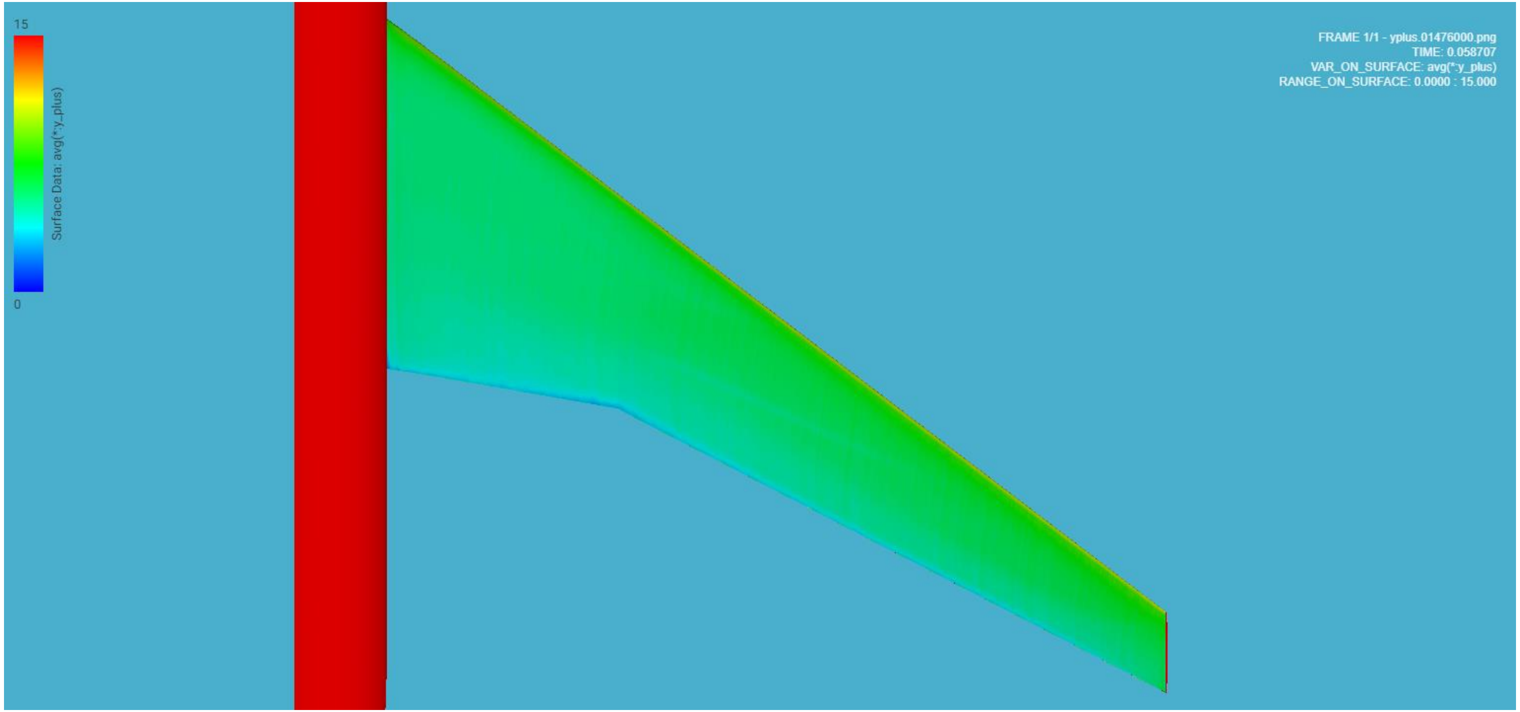
BACKUP – Force Time History



Backup

JAXA CRM

BACKUP – CRM y+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0
FRAME 1/1 - yplus.01476000.png
TIME: 0.058707
VAR_ON_SURFACE: avg(*:y_plus)
RANGE_ON_SURFACE: 0.0000 : 15.000