Engineering, Operations & Technology
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Contribution to HiLiftPW-3 using BCFD solver

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Summary of cases completed using BCFD

Case	2D Verification study	Turbulence Model(s)
3, airfoil wake	yes	SA, SA-RC, SA-RC-QCR2000, SST

Case	Alpha=8, Fully turbulent, grid study	Alpha=16, Fully turbulent, grid study	Grid	Turbulence Model(s)
1a (full gap)	yes	yes	e2-HLCRM_UnstrPrismTet_AGPS_AFLR, 41.8M, 106.7M, 258.7M cells	SA-RC-QCR2000

Case	Polar, Fully turbulent	Grid	Turbulence Model(s)
2a (no nacelle)	yes	E-JSM_UnstrMixed_ANSA, 108.5M cells	SA-RC-QCR2000
2c (with nacelle)	yes	E-JSM_UnstrMixed_ANSA, 120.2M cells	SA-RC-QCR2000
2d (with nacelle w adaption)	yes	EPIC Adaptation (preliminary)	SA-RC-QCR2000

BCFD Summary

General purpose unstructured grid cell-centered finite volume solver developed by Boeing with many options

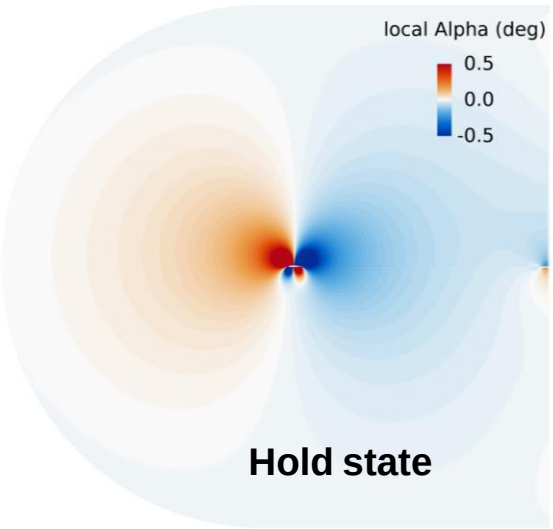
- **For this study, BCFD v8.197 with:**
  - HLLE++ flux function with second order MUSCL slope limiting (Barth-Jespersen)
  - Fully turbulent simulations using Spalart-Allmaras turbulence model with rotation/curvature correction (SA-RC) and quadratic constitutive relation (QCR2000)
  - Full Navier-Stokes viscous discretization (face tangent)
  - Solve using exact first order linearization with Gauss-Seidel and solution-adaptive CFL number

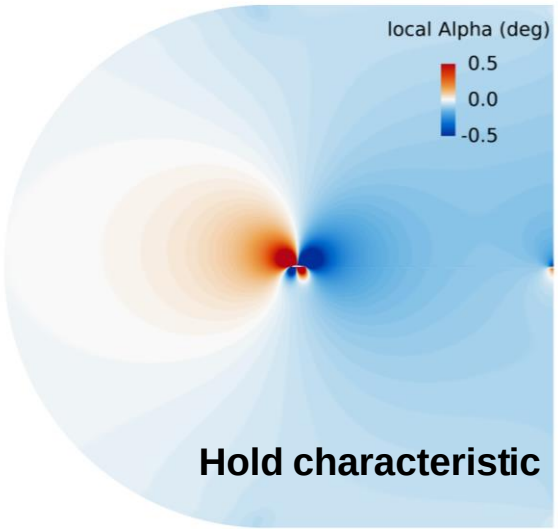
- **References:**

  - Cary, A., Dorgan, A., Mani, M., “Unstructured Grid Solution Accuracy and Mesh Dependency” AIAA 2010-0028.
  - Cary, A., Dorgan, A., Mani, M., “Towards accurate flow predictions using unstructured meshes” AIAA 2009-3650.
  - Mani, M., Cary, A., Ramakrishnan, S. V., “A Structured and Hybrid-Unstructured Grid Euler and Navier-Stokes Solver for General Geometry," AIAA 2004-0524.

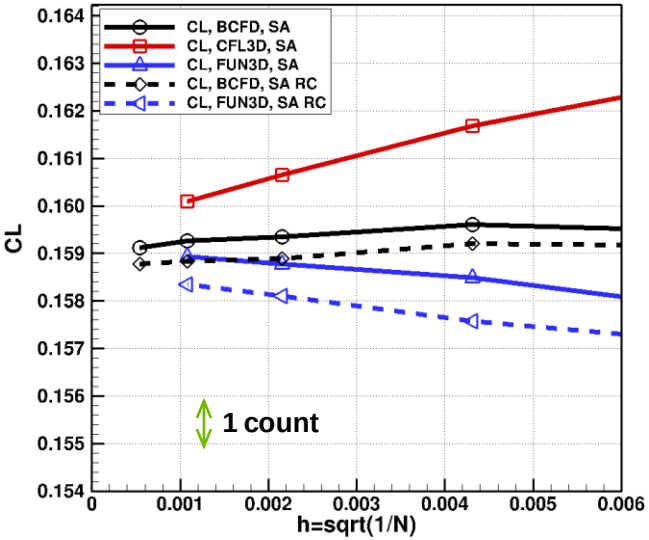
Case 3, TM Verification study (DSMA661 airfoil): Lift & min-vel convergence

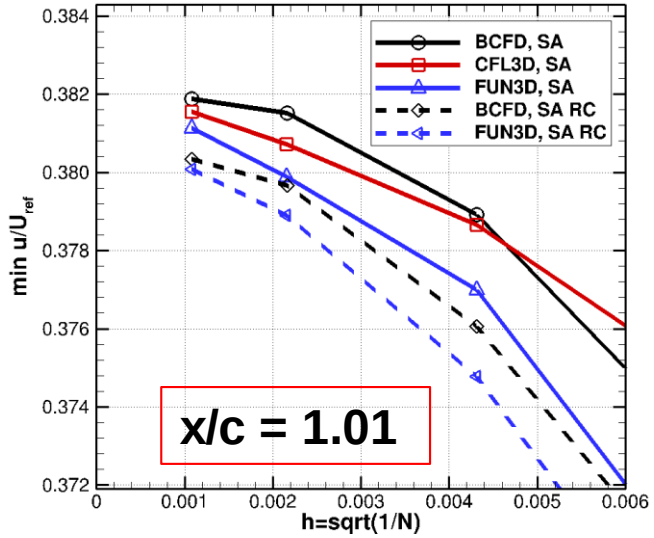
- Analysis performed for multiple models (SA & SST) and variations (SA RC & SA RC QCR2000)
- Sensitivity observed to far field BC on finest meshes. Agreement in loads were obtained with "hold state" BC.
- Differences (<1 drag count) in viscous drag may be associated with integration method
- Excellent agreement of wake velocity profile, wake Reynolds shear stress & surface pressure distribution among BCFD, FUN3D and CFL3D.





SA, SA RC

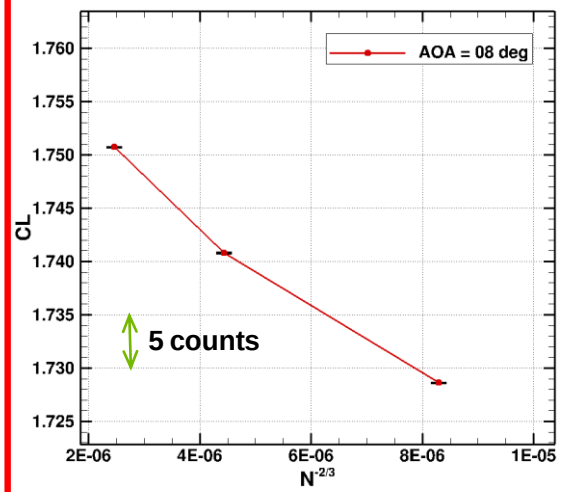


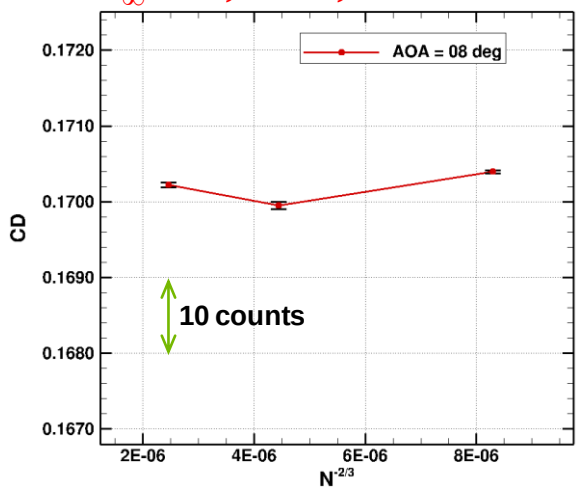


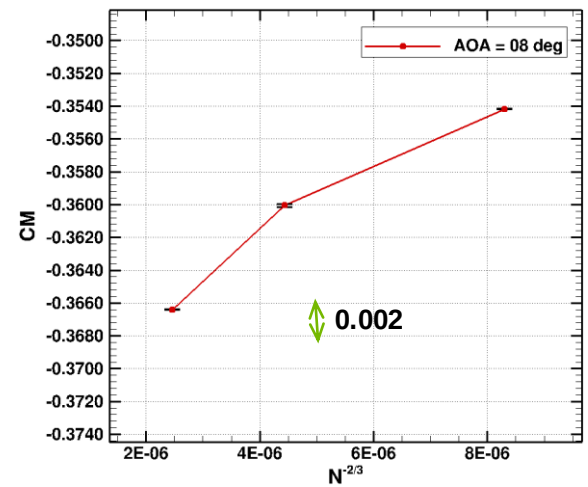
Case 1a, HL-CRM: grid convergence study

Grid	coarse	medium	fine
e2-HLCRM_UnstrPrismTet_AGPS_AFLR	41,826,550	106,739,032	258,730,385

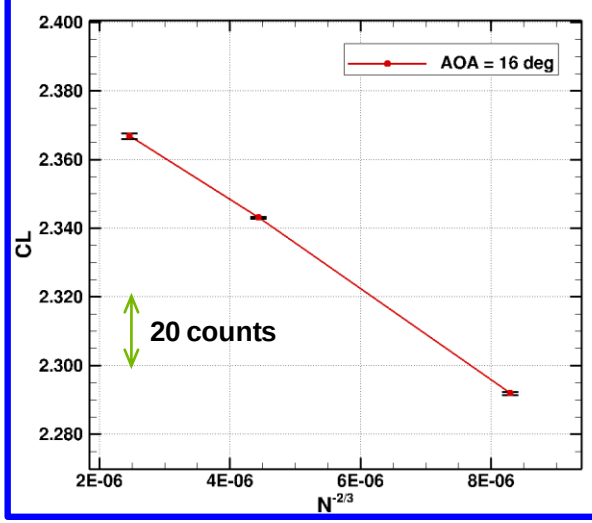
$M_\infty = 0.2$; $\alpha = 8^o$; Re = 3.26 M

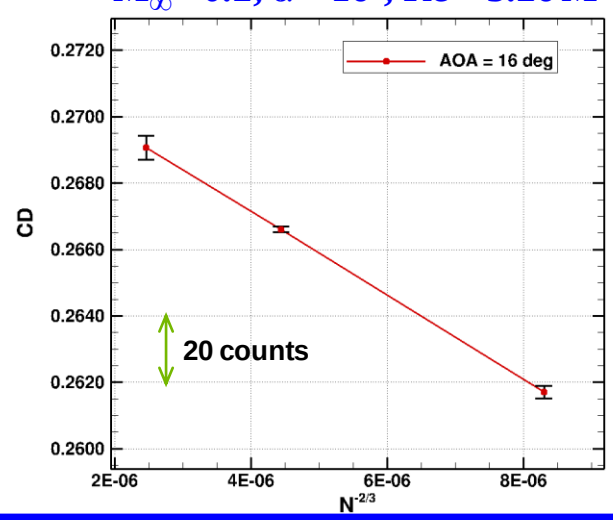


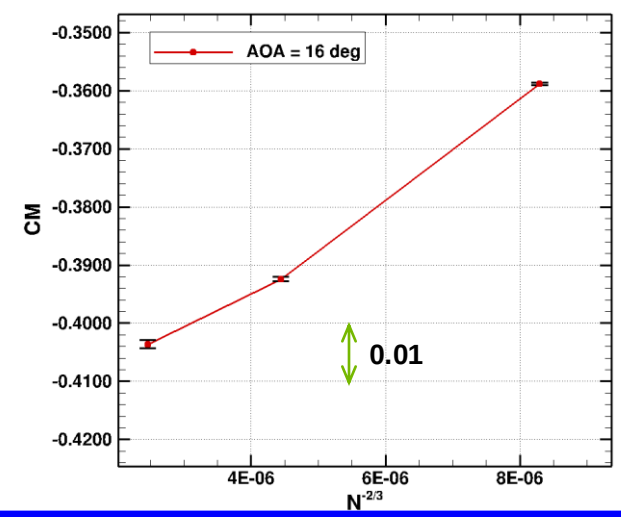




$M_\infty = 0.2$; $\alpha = 16^o$; Re = 3.26 M

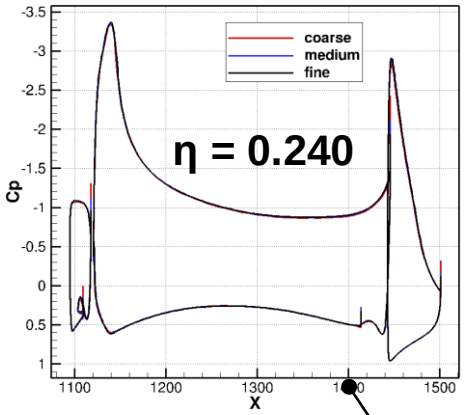


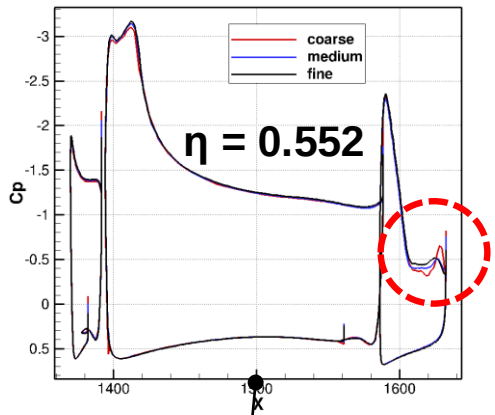


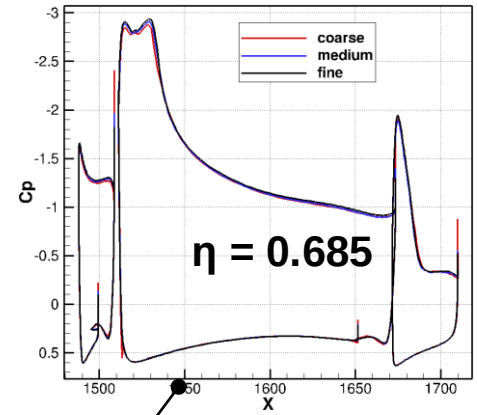


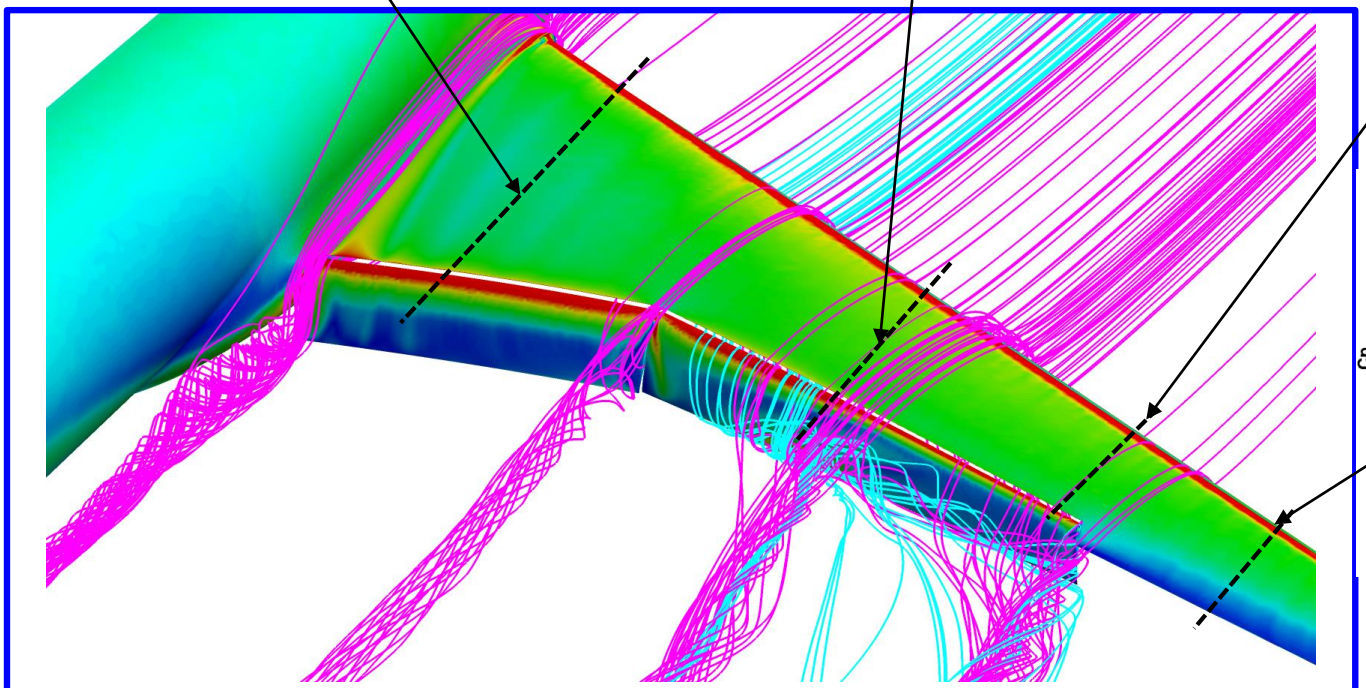
Good grid convergence observed, especially at 16°

Case 1a, HL-CRM: skin friction distribution, streamlines & sectional Cp

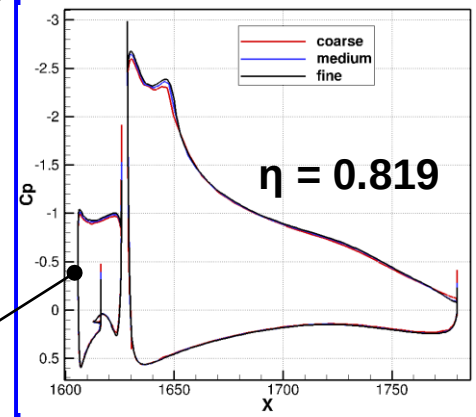






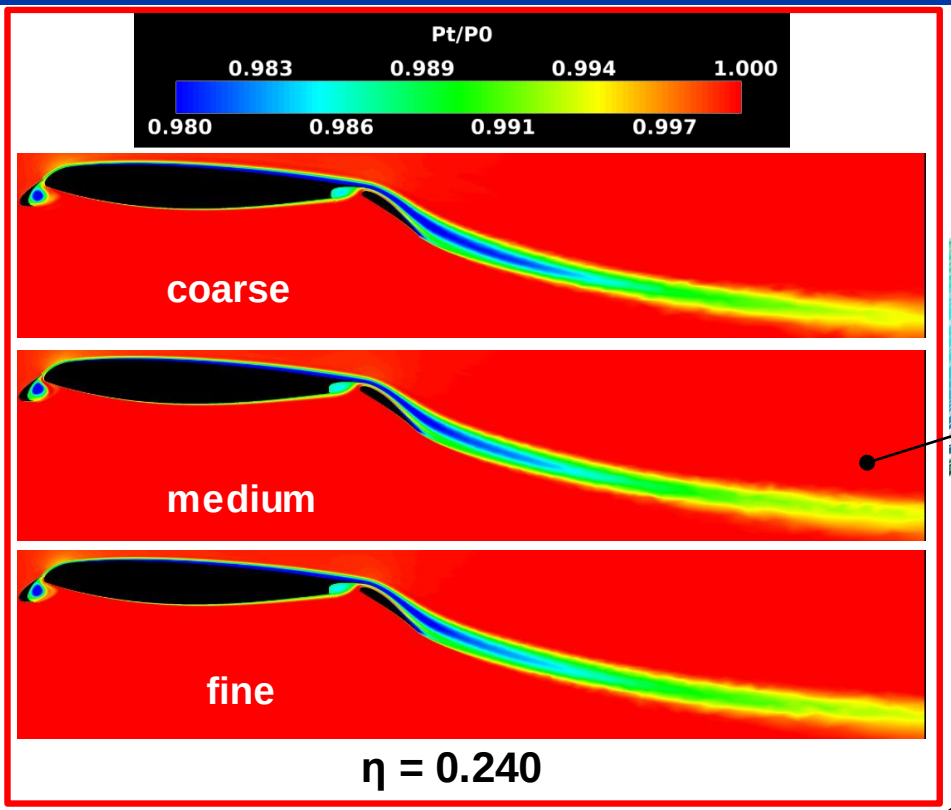


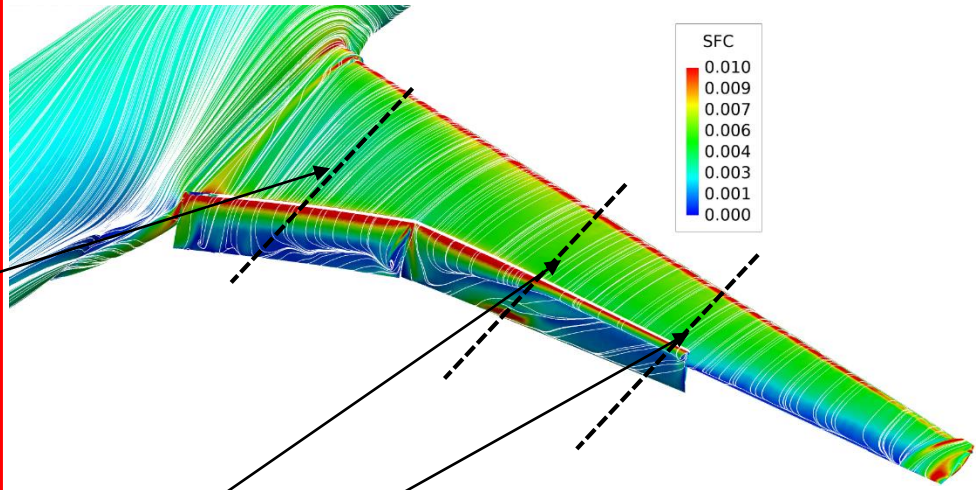
Medium grid (106.7 million cells); α = 8°

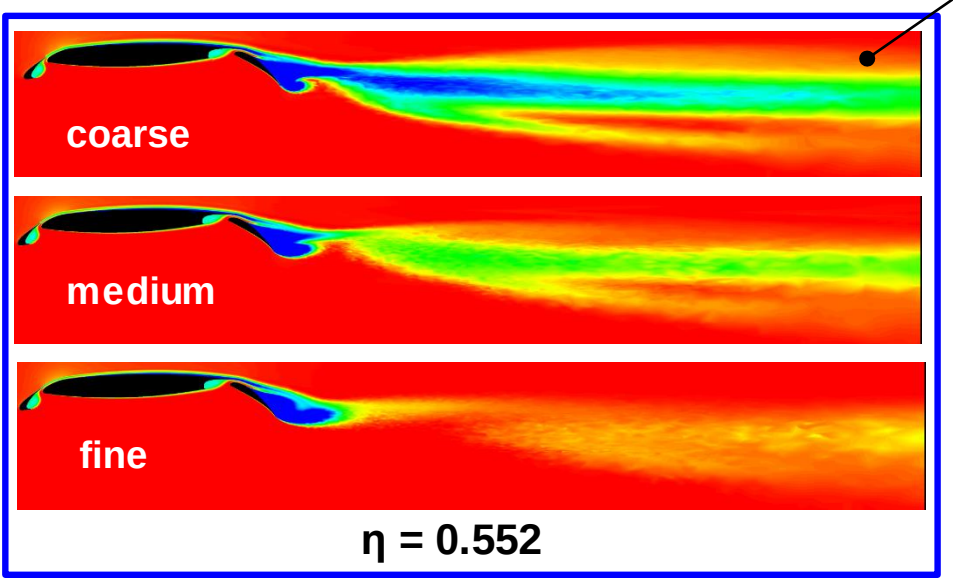


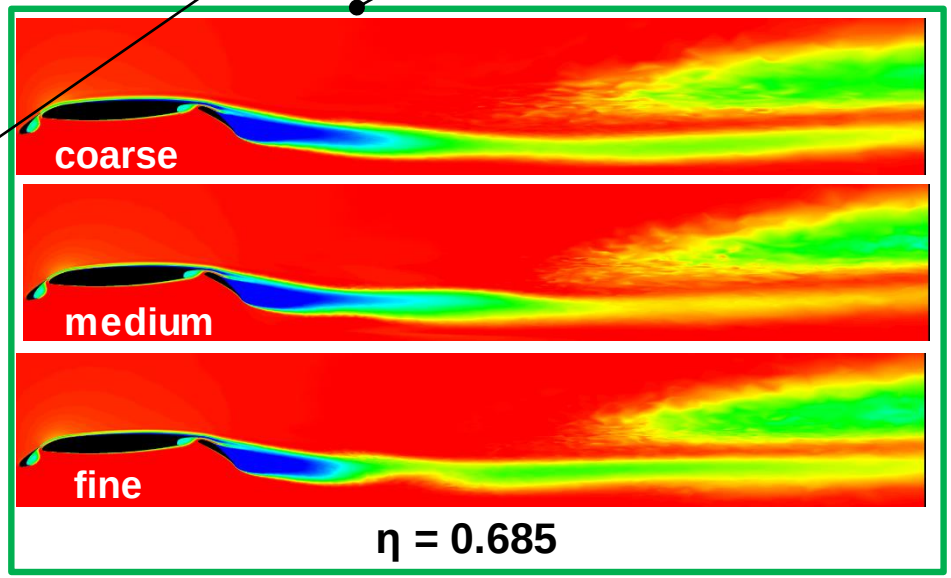
Grid sensitivity associated with resolution of spanwise flow over flap

HL-CRM: aoa = 8 deg
sectional non-dim. total pressure plot



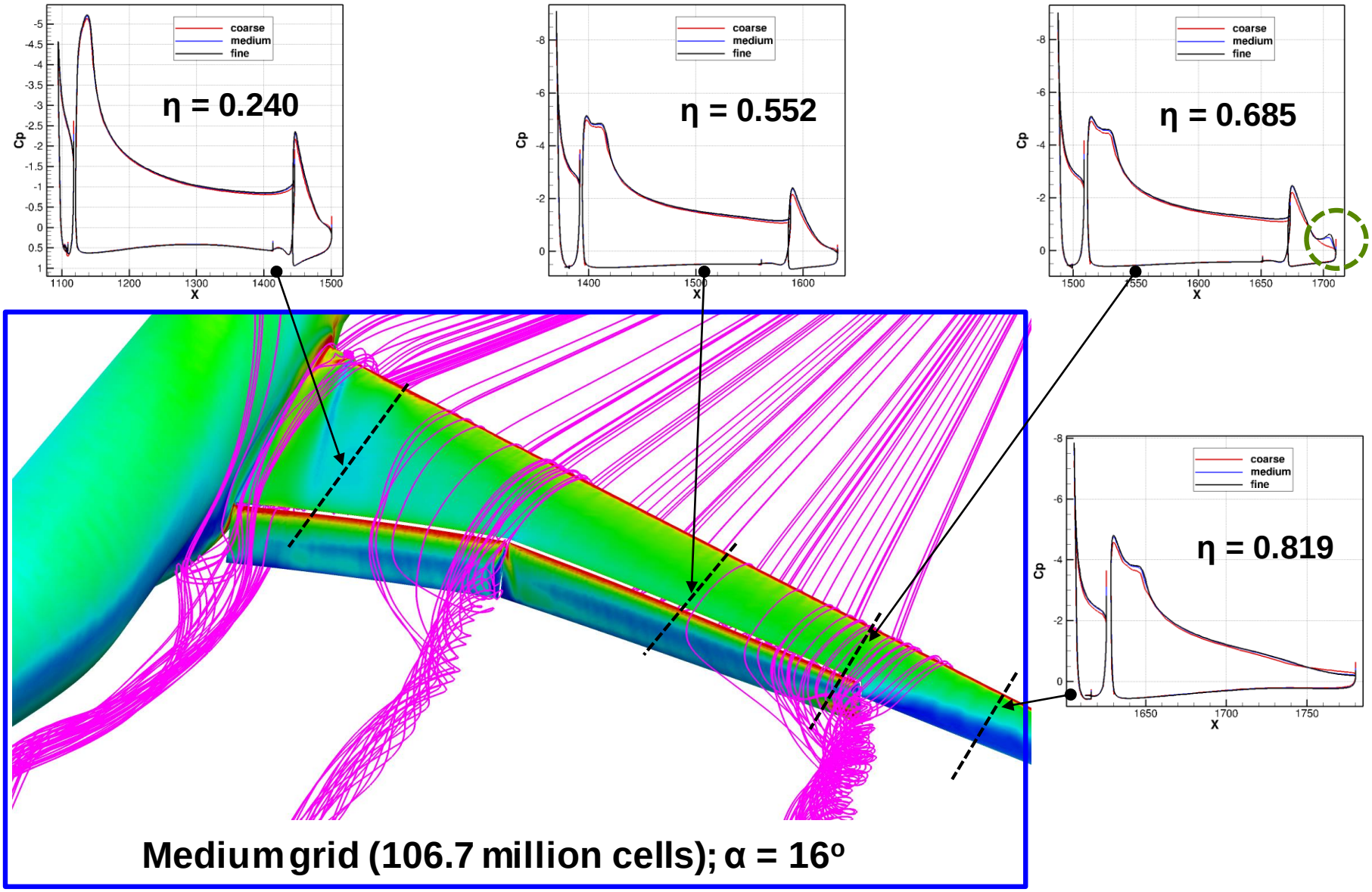






Grid resolution study

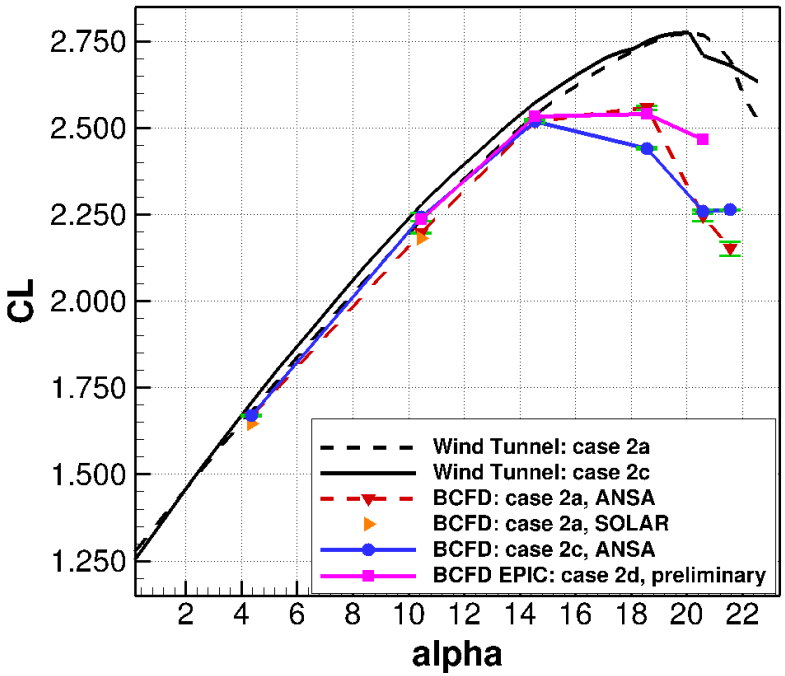
Case 1a, HL-CRM: skin friction distribution, streamlines & sectional Cp

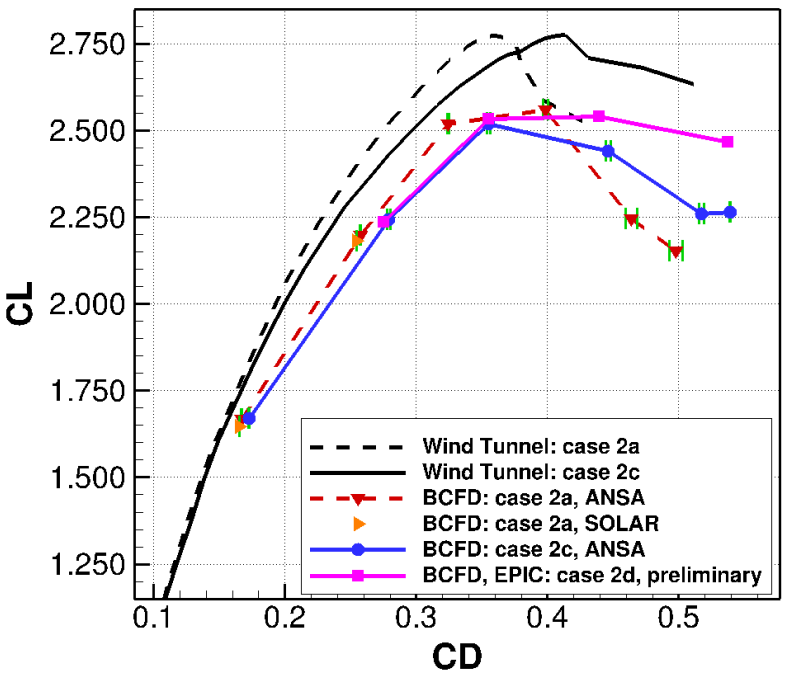


Spanwise flow over flap not as dominant at 16°; Slight sensitivity at flap outboard edge

Case 2a & 2c, JSM with nacelle/pylon OFF/ON: loads comparison

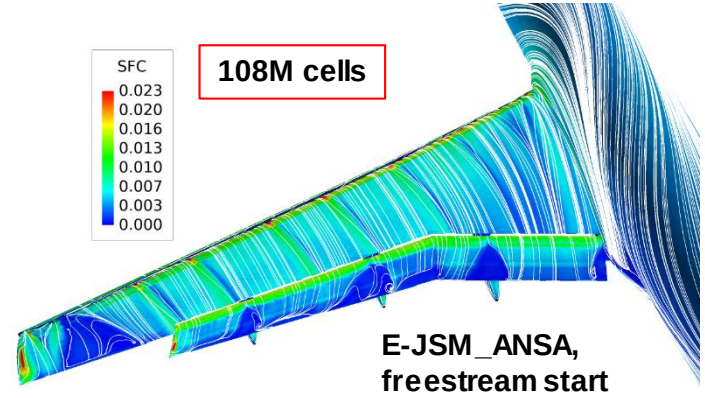
Grid	case 2a	case 2c
E-JSM_UnstrMixed_ANSA	108,519,653	120,213,635

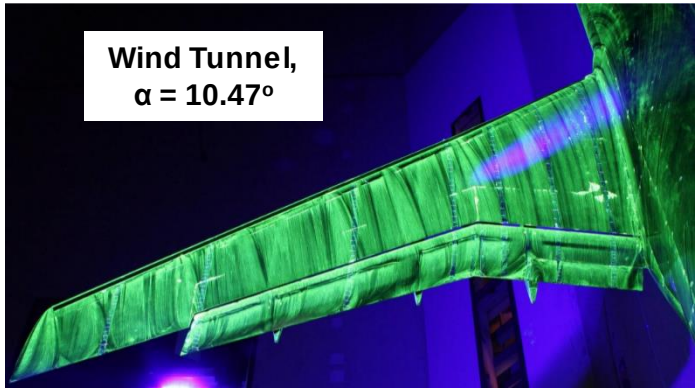


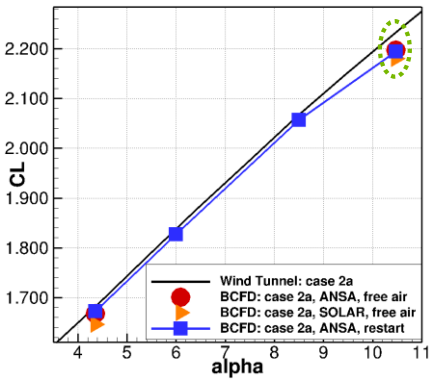


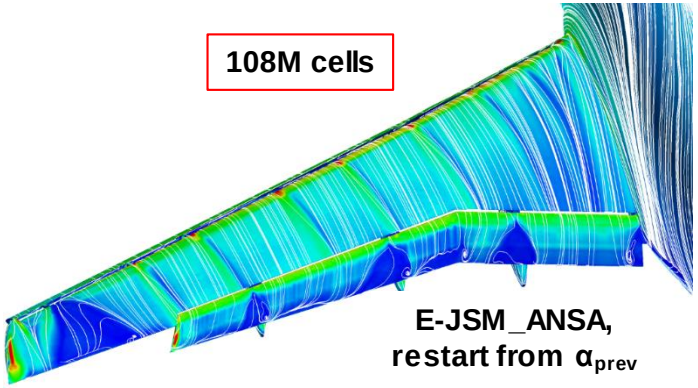
- BCFD computations carried out on a finer grid (SOLAR grid, 160M cells) predict loads comparable with computations carried out on ANSA grid.
- Drag prediction on JSM with nacelle/pylon ON is marginally higher for all angles of attack in comparison with no nacelle/pylon case.
- The lift breaks down at lower angle of attack in the case of JSM with nacelle/pylon ON.
- Preliminary EPIC adapted results suggests large grid sensitivity in the solution especially at higher angles of attack.
- Convergence difficulties are encountered for the nacelle/pylon case, specifically at $\alpha = 18.58^{o}$.

JSM, case 2a: skin friction distribution and surface flow visualization (α = 10.47°)

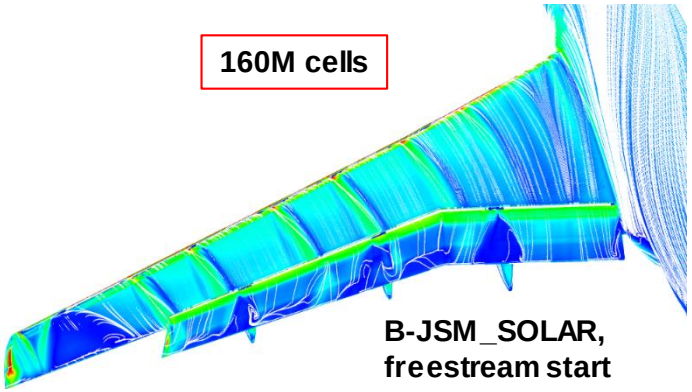








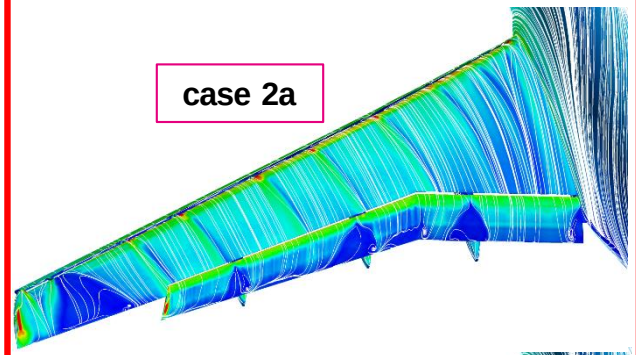
JSM, case 2a, α = 10.47°	Simulation	CL	CD	CM
E-JSM_UnstrMixed_ANSA	freestream start	2.197	0.2573	-0.424
E-JSM_UnstrMixed_ANSA	restart from α_{prev}	2.197	0.2580	-0.426
B-JSM_UnstrMixed_SOLAR	freestream start	2.180	0.2547	-0.418
Wind Tunnel	-	2.233	0.2259	-0.463

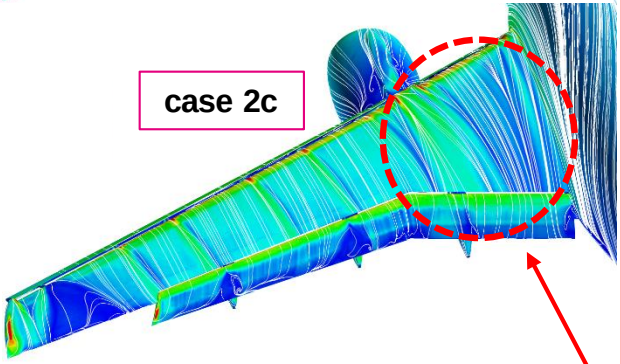


- Outboard separation, observed in BCFD computations at α=10.47°, is not present in the experiment.
- Outboard separation was not indicated by BCFD for α ≤ 8.5°. Integrated loads were in good agreement with experiment.
- For α = 10.47°, the freestream start and AOA continuation (4.36° => 6° => 8.5° =>10.47°) led to essentially the same solution.
- Outboard separation is observed consistently even on a finer grid (B-SOLAR, 160M cells).

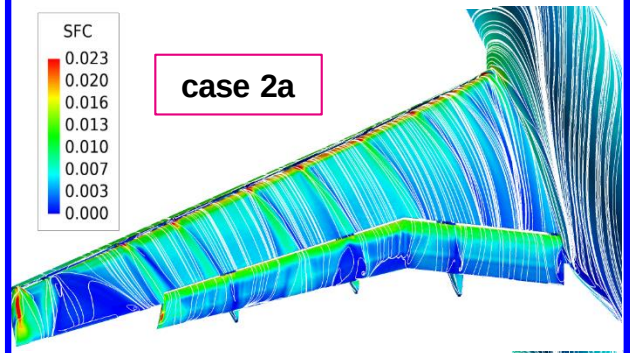
JSM nacelle installation study: Results for α = 10.47°, 14.54° & 18.58°

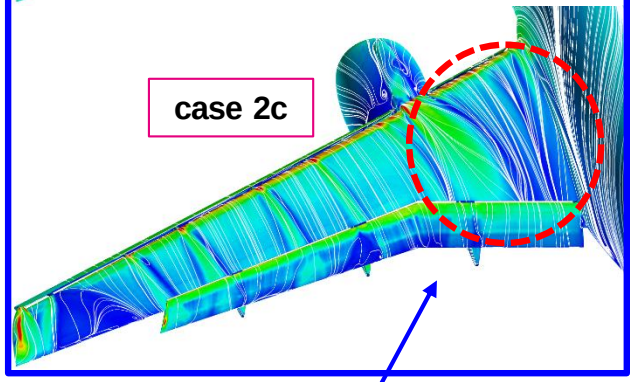
α = 10.47°

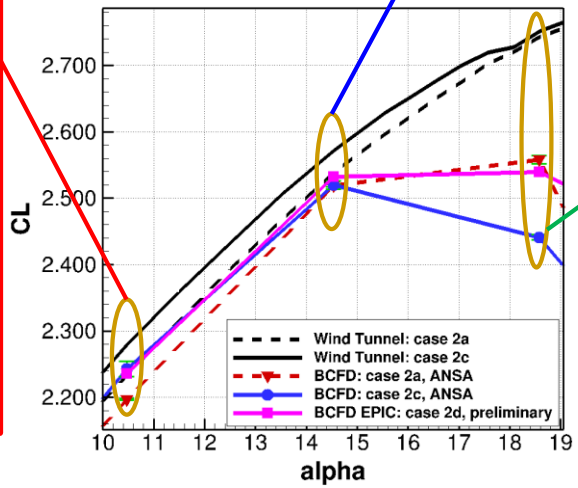




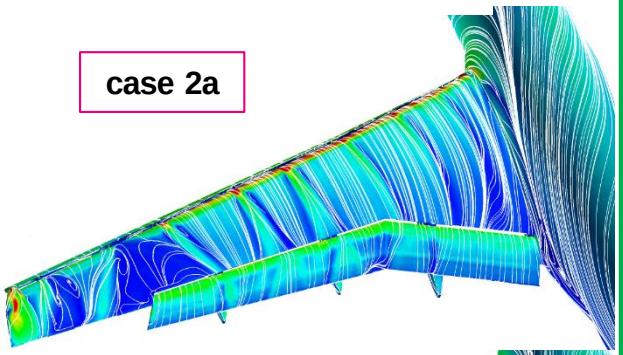
α = 14.54°

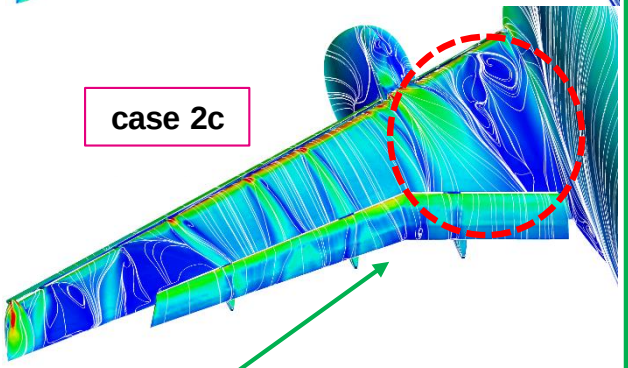


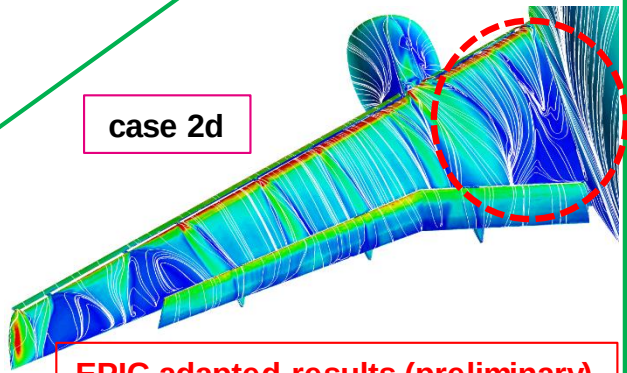




α = 18.58°







EPIC adapted results (preliminary)

Summary & Conclusions:

- Case 3: Turbulence Models Implementation Verification Study
  - Analysis carried out with SA & SST models and variants of SA, SA RC & SA RC QCR2000.
  - Sensitivity of results to far field BC is observed as referenced in TMR webpage, primarily on finest meshes.

- Case 1a: Grid Convergence Study
  - Good grid convergence behavior observed across the family of grids.
  - Strong spanwise vortex and flow activity is observed on the outboard flap, probably the reason for the slight loss in monotone behavior of drag convergence at 8°.

- Case 2a & 2c: JSM Nacelle Installation Study
  - Integrated loads agree well for the lower angles of attack ($\alpha \leq 8.5^o$). The outboard separation possibly triggered by the slat bracket is observed at $\alpha = 10.47^o$.
  - Separation initiated at various regions on the wing could be geometry/grid resolution effects, based on preliminary EPIC adapted results.
  - Nacelle/pylon interaction is observed downstream on the wing with increased suction associated with additional flow deflected over wing.
  - Grid sensitivity issues requires further investigation.

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