A Hybrid RANS-LES Perspective for the High Lift Common Research Model Using LAVA

Oliver M. F. Browne, Jeffrey A. Housman, Gaetan K. Kenway, Aditya S. Ghate and Cetin C. Kiris

Computational Aerosciences Branch

NASA Ames Research Center

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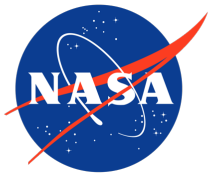
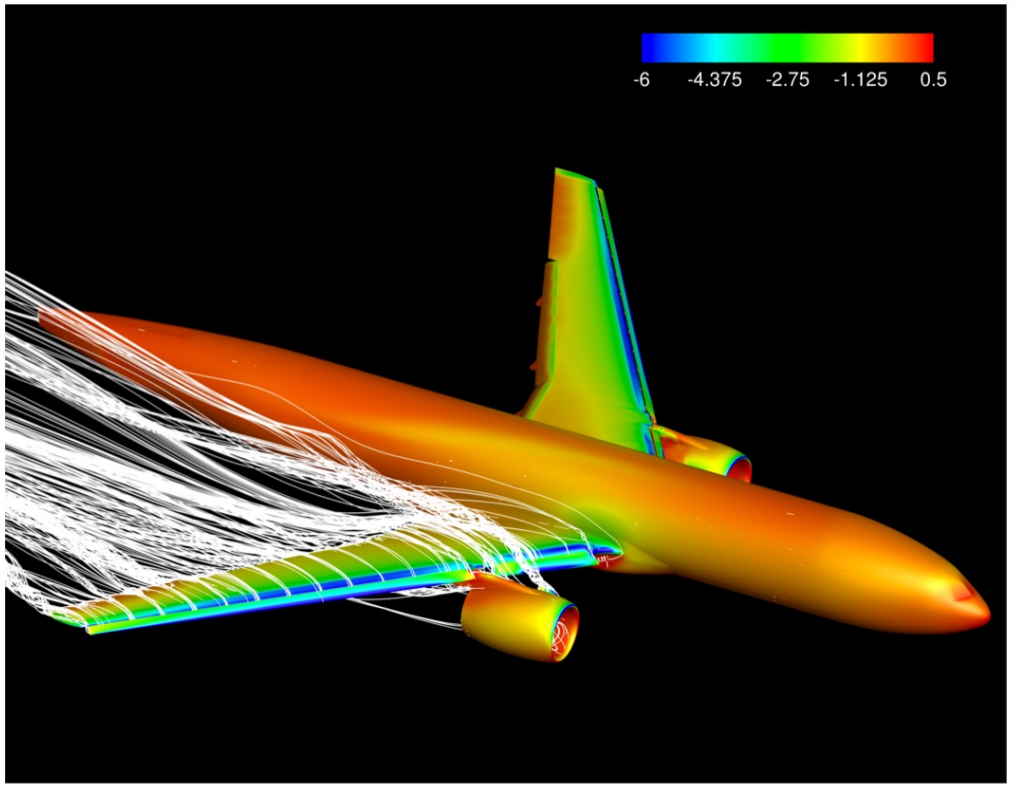
Outline



- Scope of this Work
- Numerical Framework and Meshing Approach
- NASA CRM-HL Results
  - Free air configuration
  - Wind tunnel configuration
- Summary

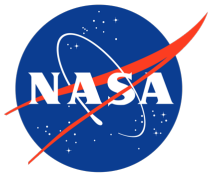
Scope of this Work

- Is HRLES a computationally feasible solution to overcome and address the failures seen in RANS?
- What are the best practices for HRLES scale resolving simulations for CLmax prediction?
- What are the sensitivities of HRLES solution to aspects such as underlying RANS closure and initial condition etc?



(a)

LAVA DDES Discretization



- Compressible Reynolds Averaged Navier-Stokes (RANS) equations.
- Curvilinear Structured Overset Mesh Topology.
- Convective Scheme – blended third upwind/fourth-order centered accurate scheme (best practice); third-order WCNS (was deemed too dissipative); modified Roe (Riemann solver).
- Time Integration – implicit BDF2 time-stepping, 3 orders of residual convergence at each time-step.
- Underlying Turbulence Model – SA-neg (defined as SA for rest of presentation) and where noted with corrections (LRe - low Reynolds number, RC - Rotation Curvature, QCR2000 - Quadratic Constitutive Relation) – **see paper**.
- Shielding Function – ZDES2020 Mode 2 Enhanced Protection (Deck & Renard 2020), maximum cell edge length use as local length scale in LES SGS closure.

Curvilinear Overset Grid Systems

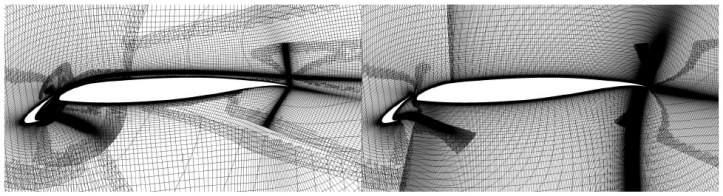
Typical community practice: RANS grids are utilized for HRLES scale-resolving simulations is a common mistake, no universal best practices exist?

best practice grid is Grid H-D and non-dimensional Δt = 1.95e-3

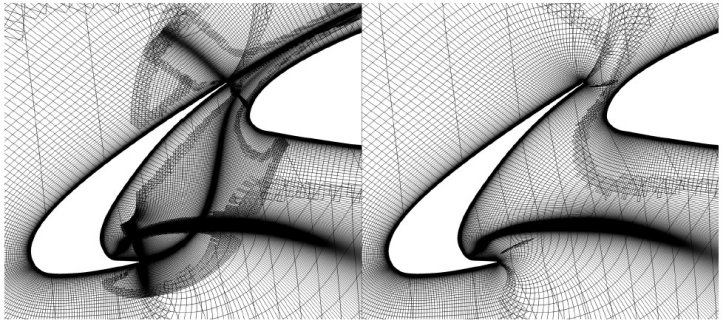
Name	Solve Points	Target y^+	Max Stretching Ratio	Comments
Grid R-C	224M	1.0	1.10	[12, 44]
Grid H-A	365M	1.0	1.10	inboard + outboard refinement
Grid H-B	325M	1.0	1.10	modified slat wake grid + outboard refinement
Grid H-C	421M	1.0	1.10	outboard refinement
Grid H-D	571M	1.0	1.10	inboard + midboard + nacelle refinement

RANS Grid R-C

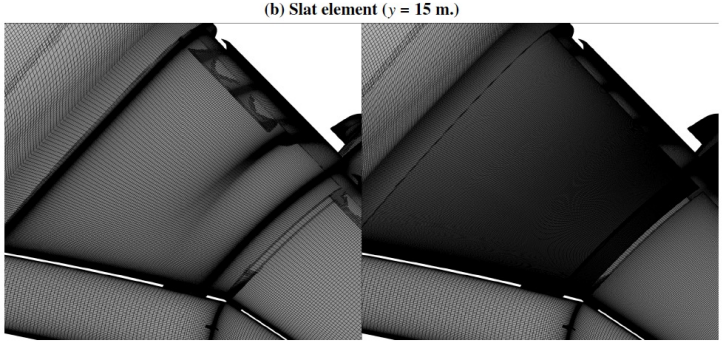
HRLES Grid H-D



(a) Outboard wing (y = 24 m.)



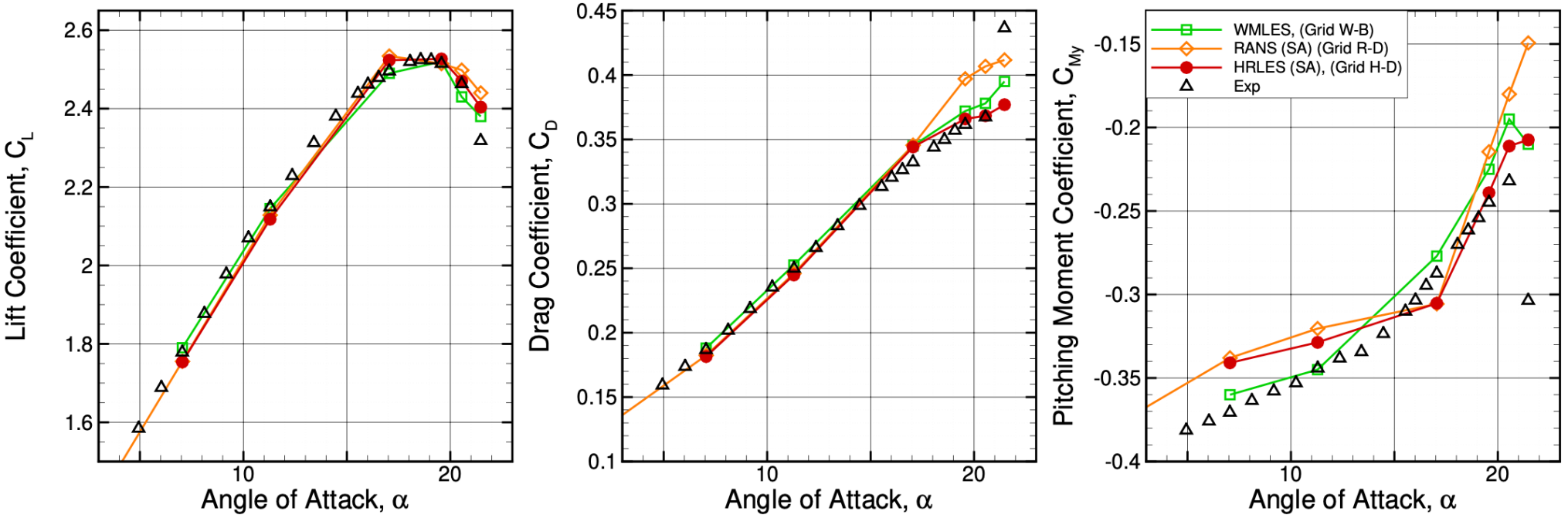
(b) Slat element (y = 15 m.)



(c) Inboard wing upper surface

Free Air – DDES vs Other Methods

Aerodynamic loads comparison between LAVA RANS[1], HRLES and WMLES[2] with corrected experimental results.



[1]*Duensing, J. C., Housman, J. A., Dos Santos Fernandes, L. M., Machado, L. M., and Kiris, C., "A Reynolds-Averaged Navier-Stokes Perspective for the High Lift-Common Research Model Using the LAVA Framework," AIAA Aviation Paper to appear, 2022.*

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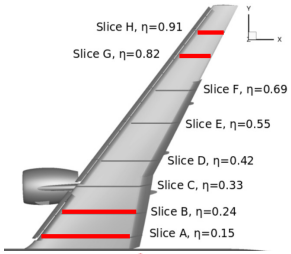
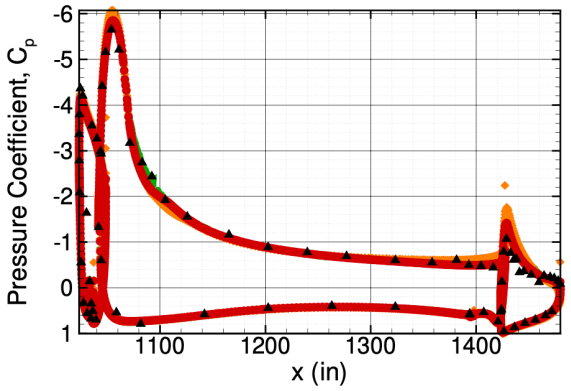
Surface Pressure, Cp – Free Air



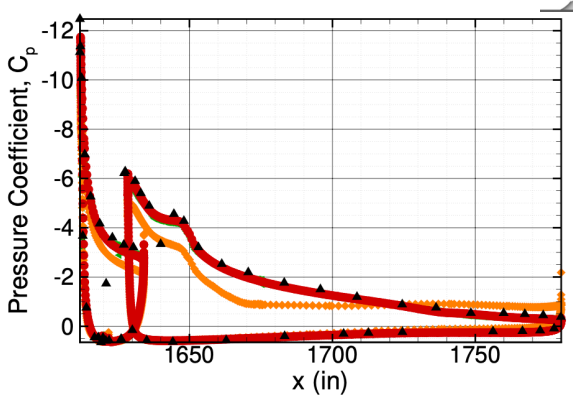
α=19.57

RANS
HRLES
WMLES

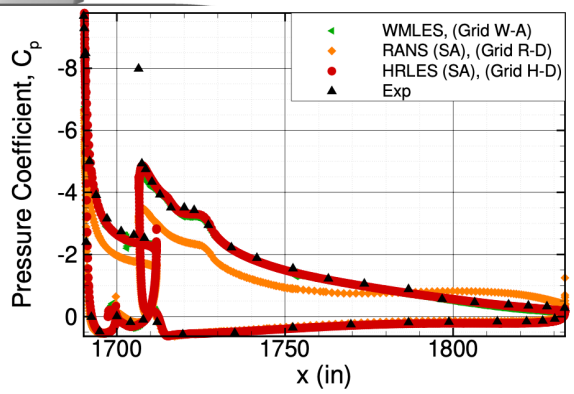
α=21.47



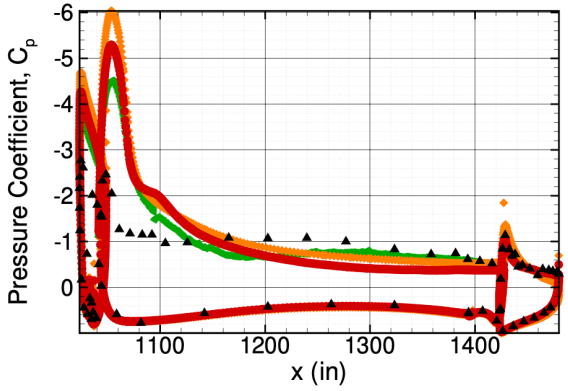
(a) Slice A, $\eta = 0.15$



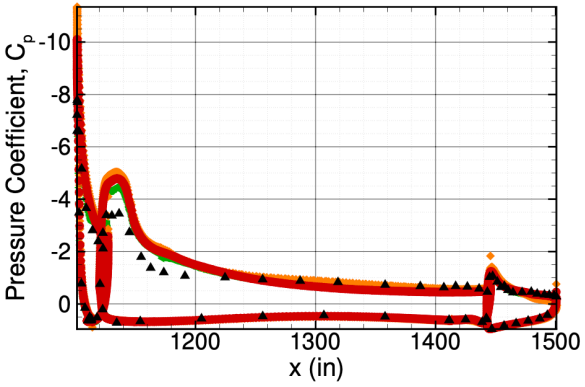
(b) Slice G, $\eta = 0.82$



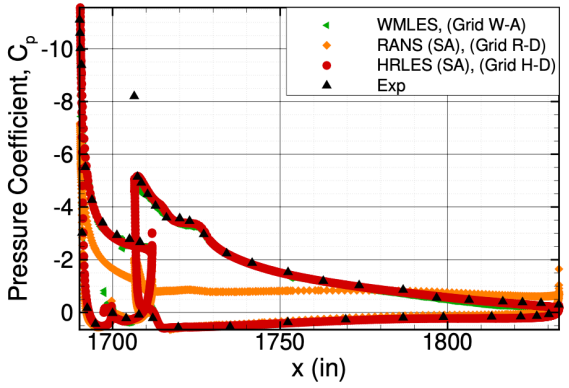
(c) Slice H, $\eta = 0.91$



(a) Slice A, $\eta = 0.15$

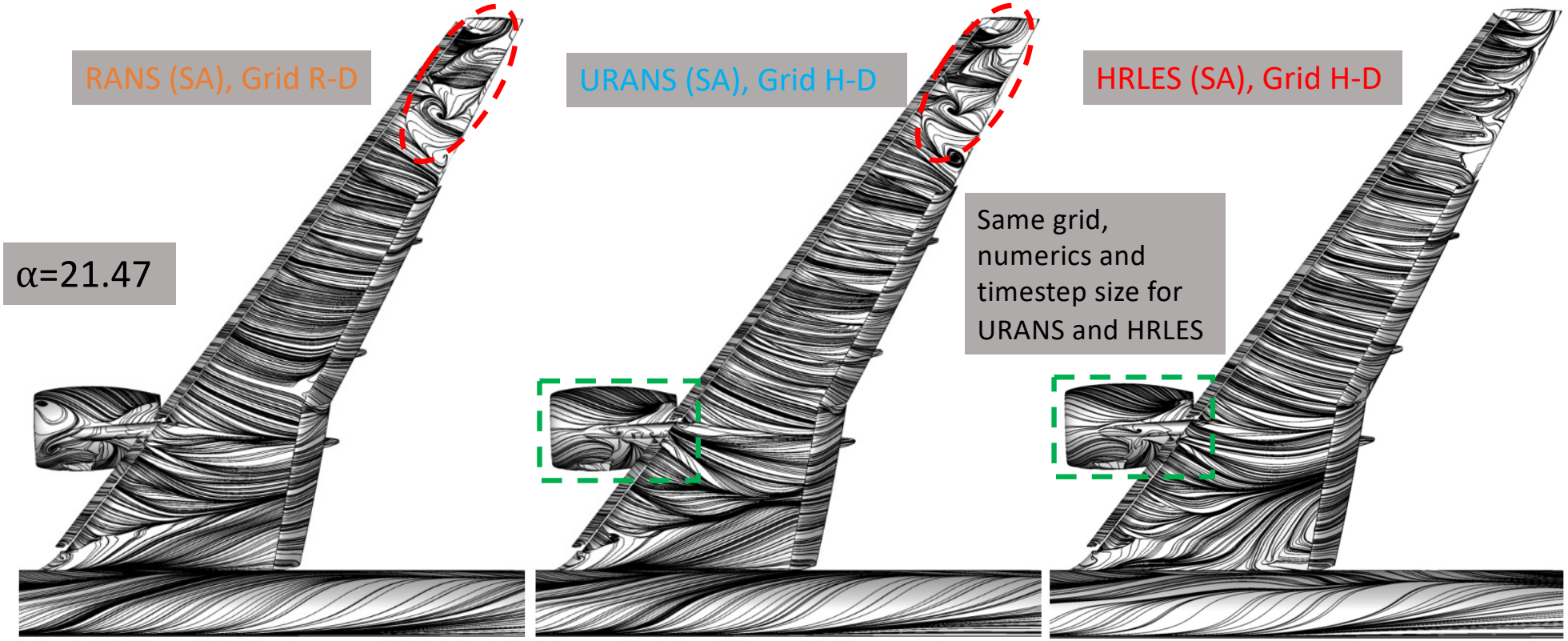


(b) Slice B, $\eta = 0.24$



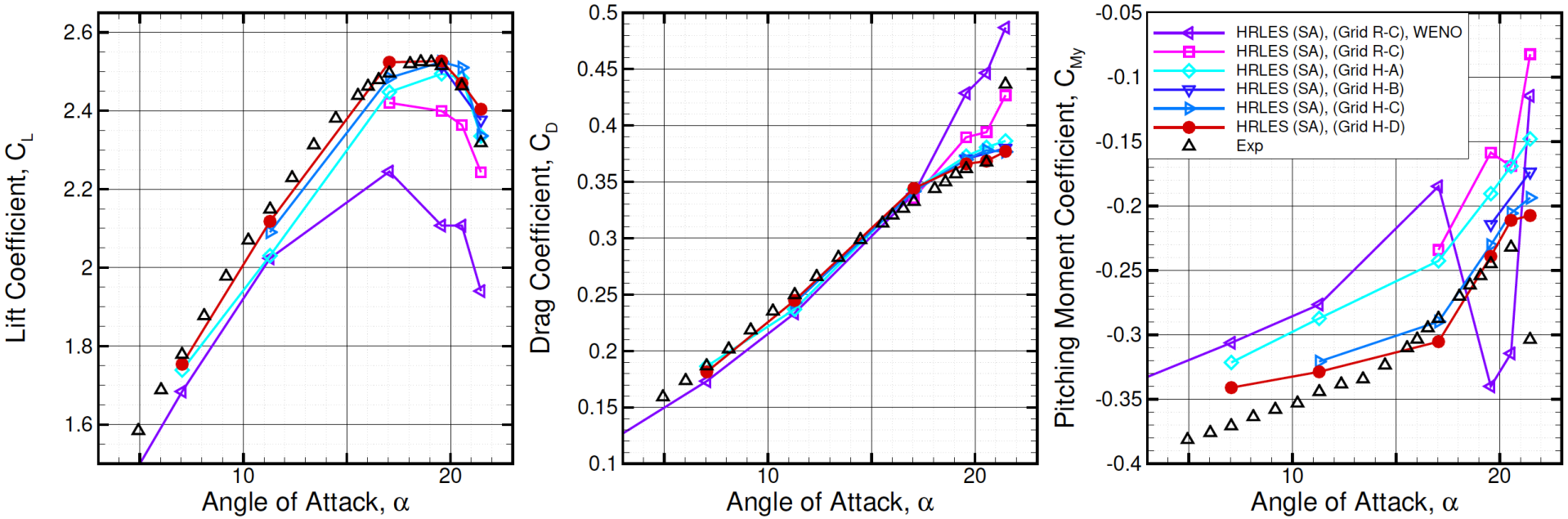
(c) Slice H, $\eta = 0.91$

DDES improvement – closure model or discretization?



Free Air - Effect of Grid Resolution

Aerodynamic loads for various grid levels and numerics computed with HRLES compared with corrected experimental results. Best practice HRLES is shown in red.



Note: pitch break not guaranteed in free air case

Free Air – Grid Resolution Near CLmax

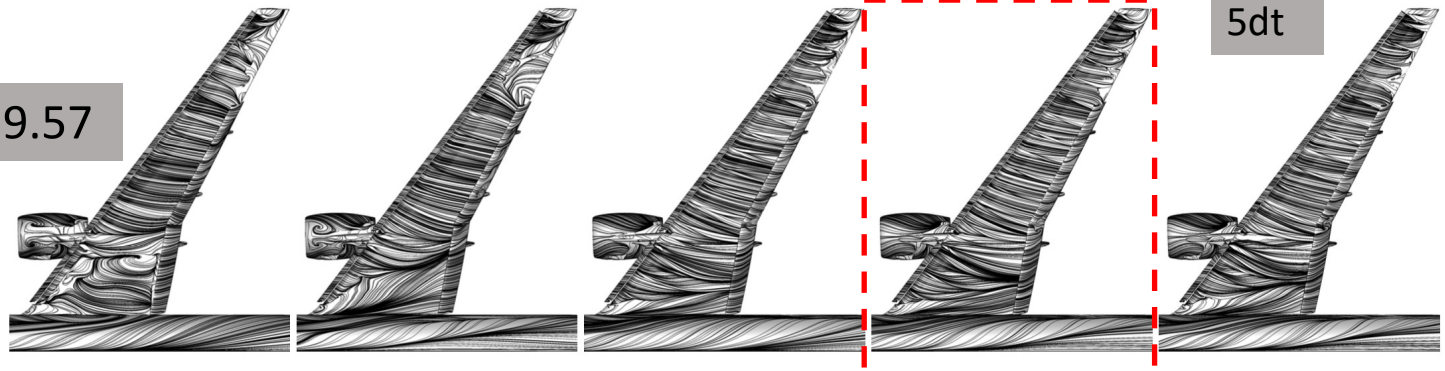
Reducing numerical dissipation

Increasing spatial resolution

Reducing timestep size

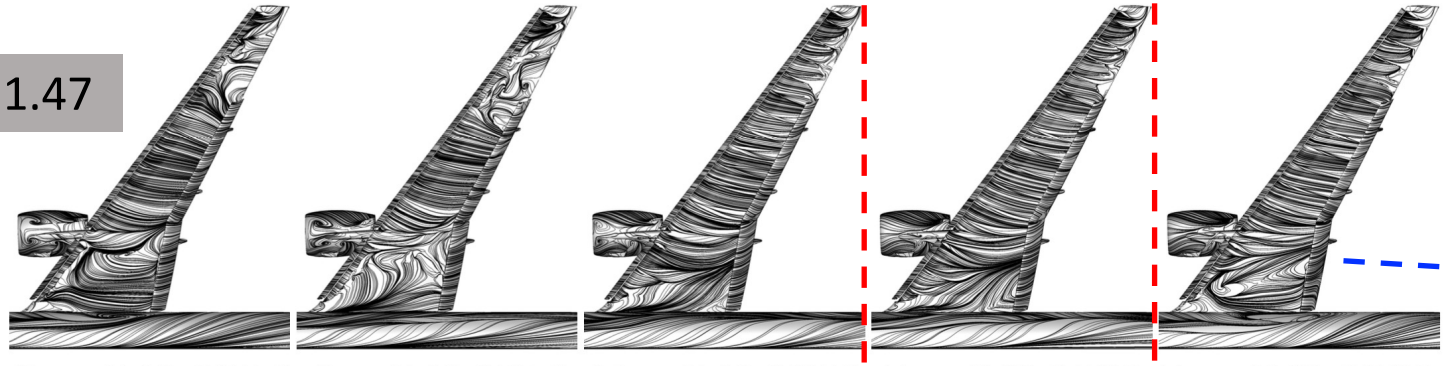
5dt

α=19.57



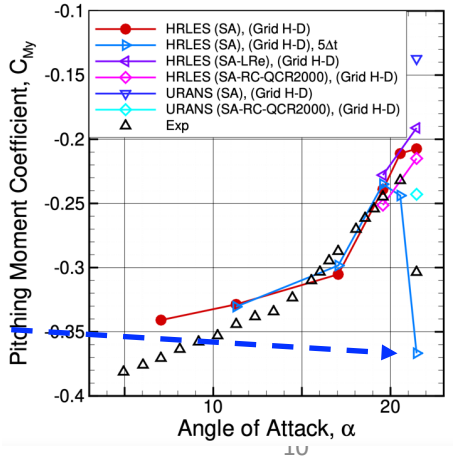
(f) α = 19.57°, Grid R-C, WENO (g) α = 19.57°, Grid R-C (h) α = 19.57°, Grid H-C (i) α = 19.57°, Grid H-D (j) α = 19.57°, Grid H-D, $5\Delta t$

α=21.47

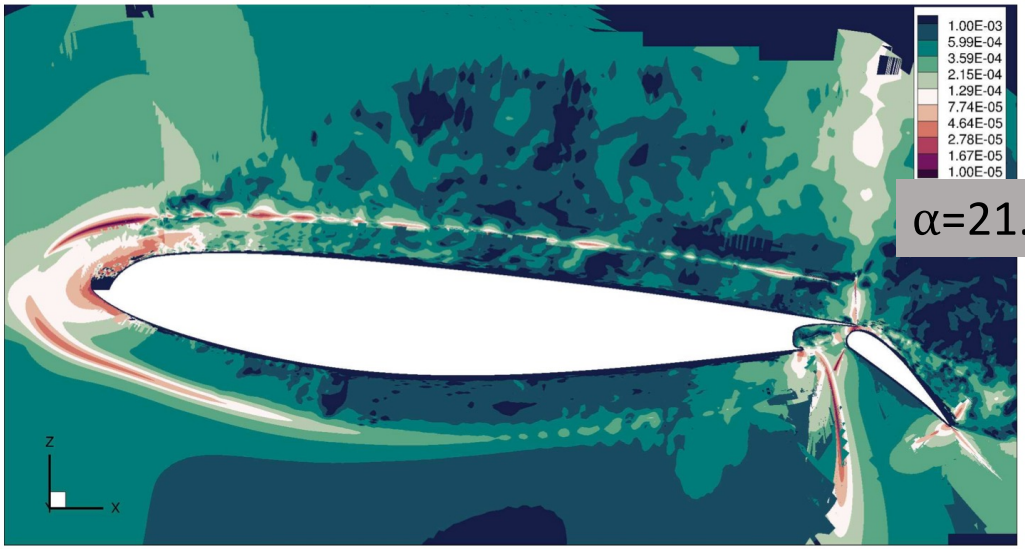


(k) α = 21.47°, Grid R-C, WENO (l) α = 21.47°, Grid R-C (m) α = 21.47°, Grid H-C (n) α = 21.47°, Grid H-D (o) α = 21.47°, Grid H-D, $5\Delta t$

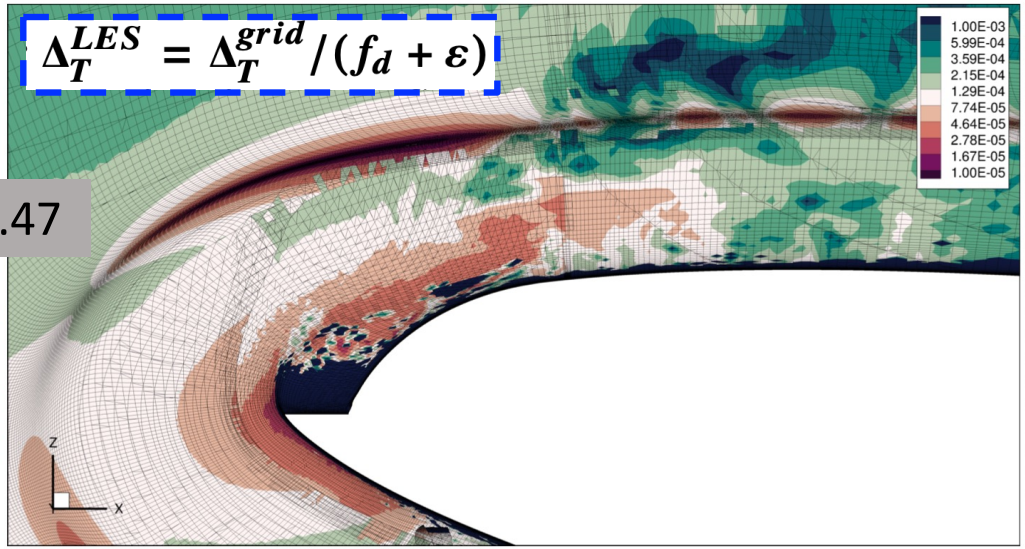
Surface skin friction Cf coefficient for CLmax and post-stall for various grid level, numerics and time-step size. Best practice shown in red.



Free Air – Choice of timestep size?

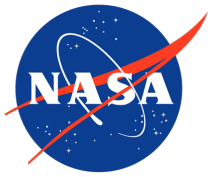


(a) $y = 4.0$m slice



(b) $y = 4.0$m slice (zoomed in view)

Summary – Free Air



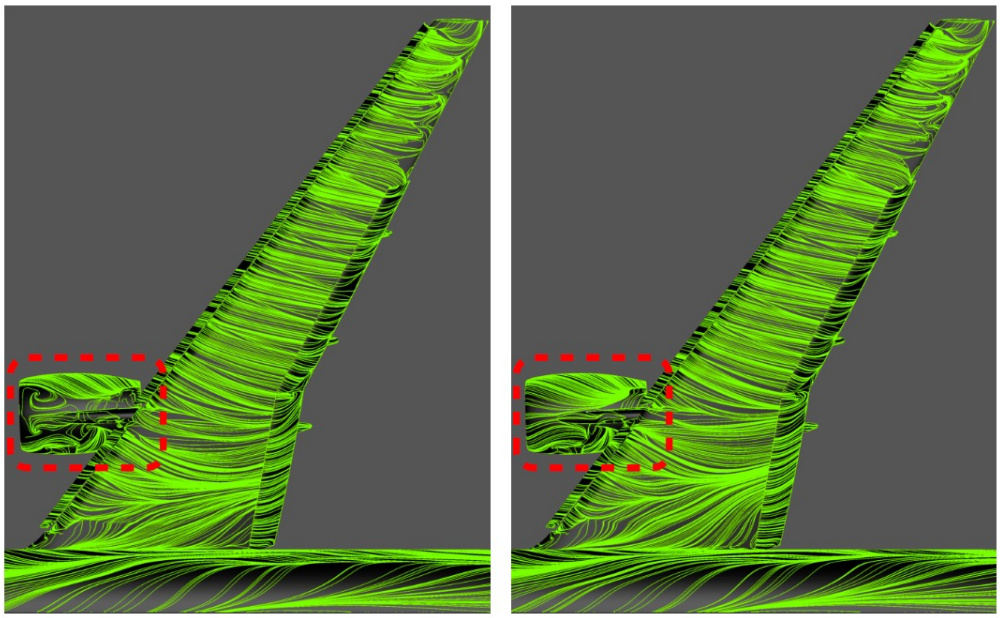
DDES can produce reasonable results if…

1. LES-appropriate grids when shielding function is in LES mode
2. LES-appropriate discretization (low dissipation)
3. LES-appropriate timestep size

Lessons learned applied to in tunnel simulations…

Wind Tunnel (WT) – Sensitivity to Initialization?

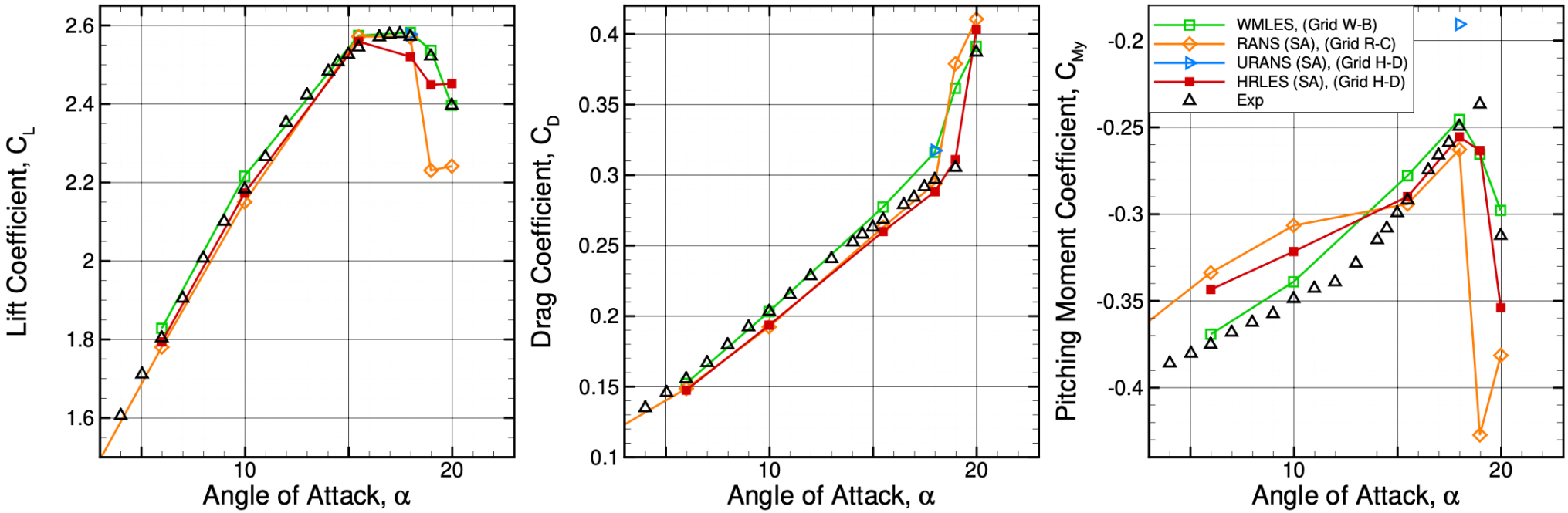
Comparison of tunnel initialization procedure with a “pseudo-cold-start” (from freestream conditions) and from a steady state RANS solution.



(a) Initial condition - RANS (b) Initial condition - freestream

Integrated Loads – WT

Aerodynamic loads comparison between LAVA RANS[1]/URANS, HRLES and WMLES[2] with uncorrected experimental results.



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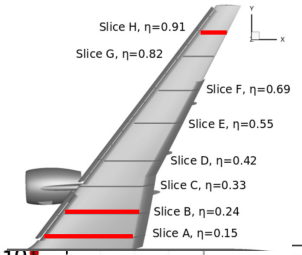
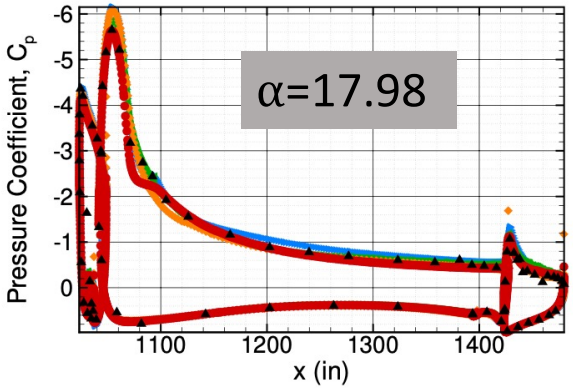
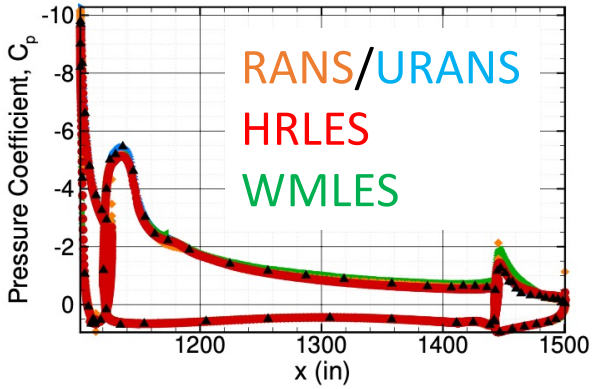
Surface Pressure, Cp – WT

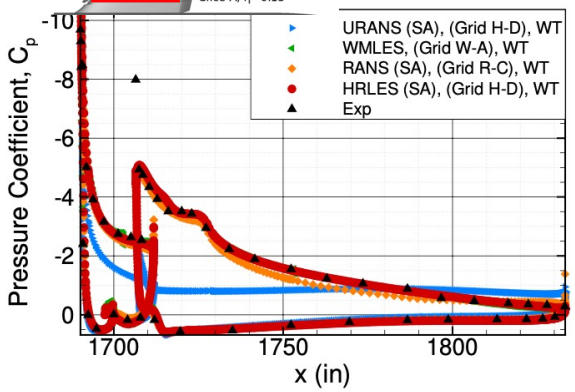




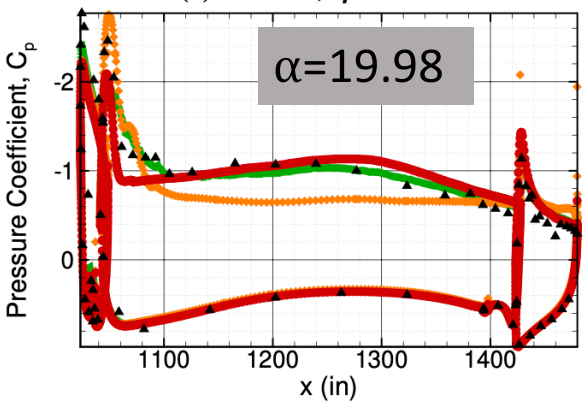
(a) Slice A, $\eta = 0.15$



(b) Slice B, $\eta = 0.24$



(c) Slice H, $\eta = 0.91$



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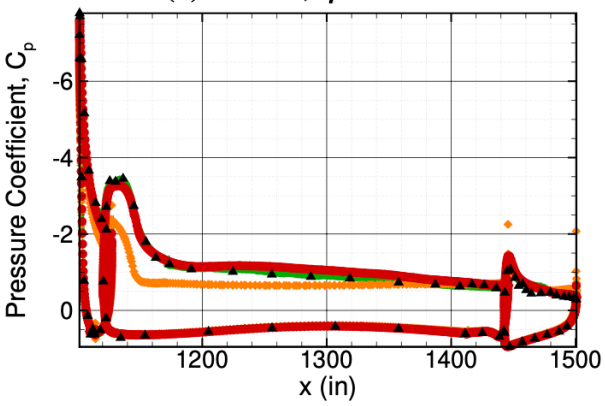

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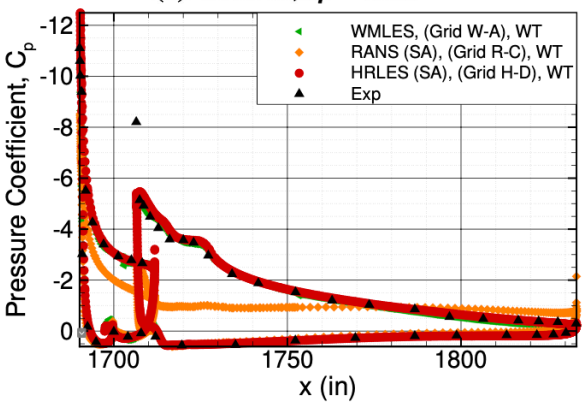
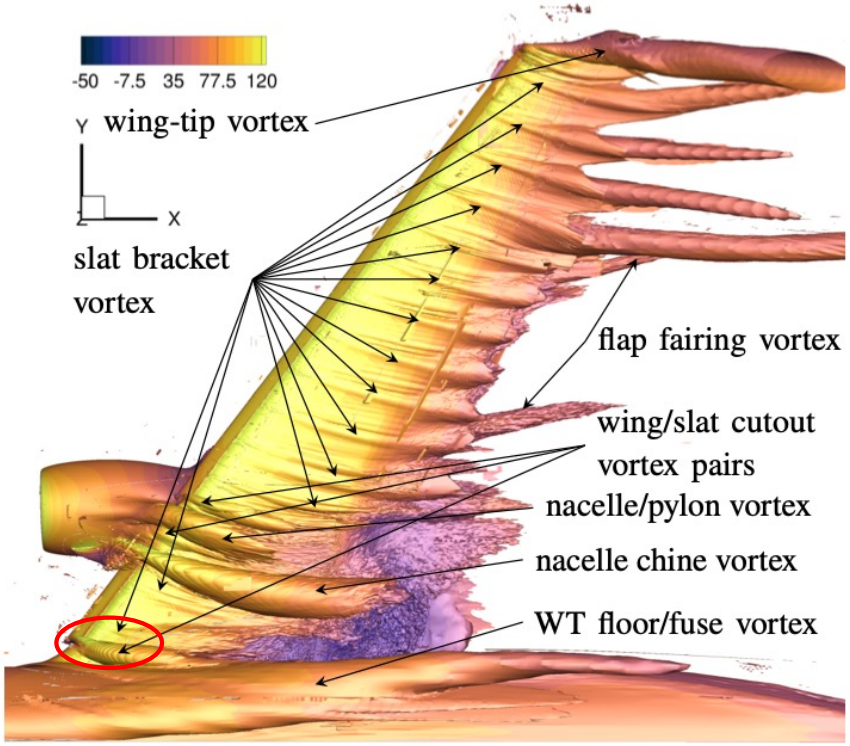


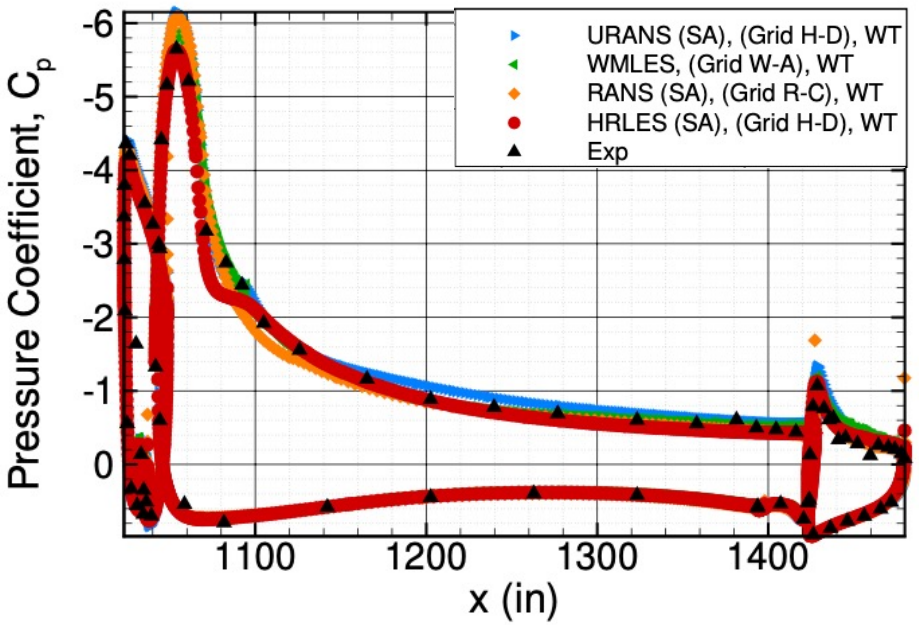
(c) Slice H, $\eta = 0.91$

Inboard Surface Pressure at CLmax

HRLES (SA), α=17.98



α=17.98

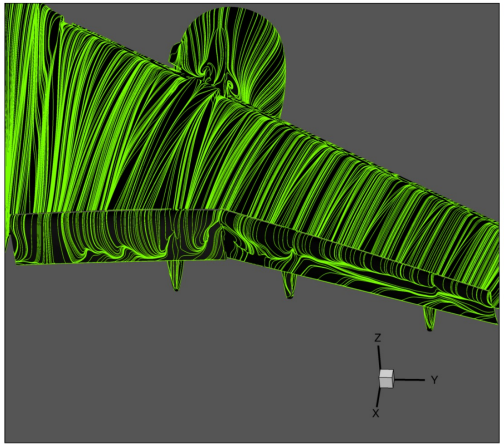


(a) Slice A, $\eta = 0.15$

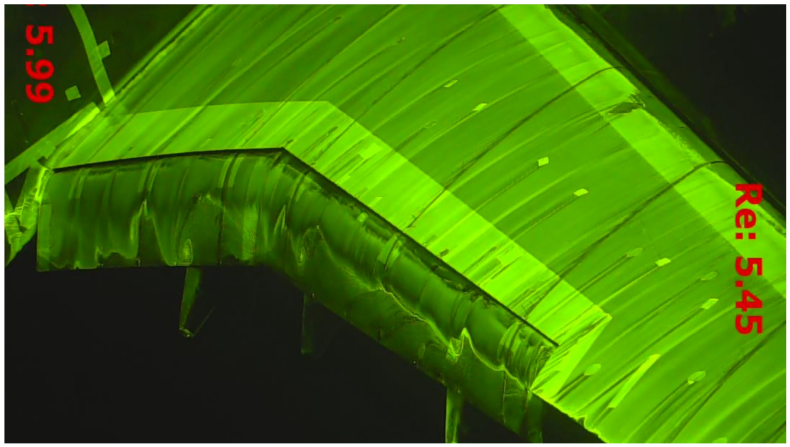
Vorticity magnitude computed from time averaged velocity field

Streamline vs Oil-Flow Comparison – WT

α=5.98



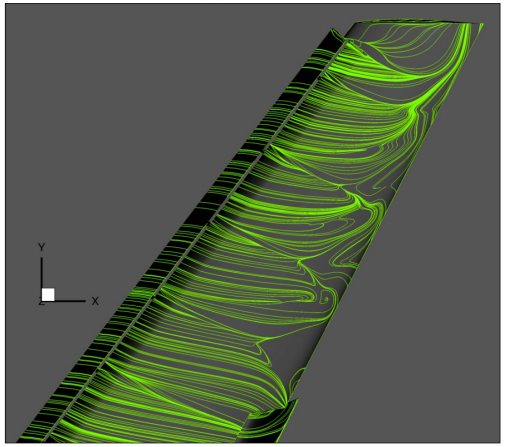
(a) HRLES



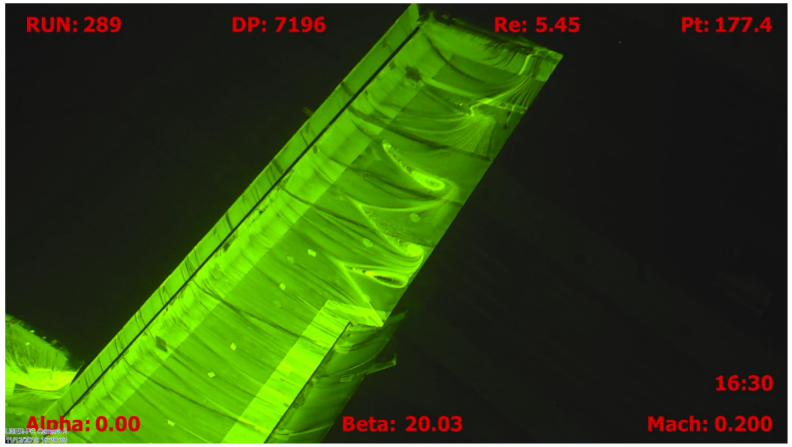
(b) Oil Flow

Comparison of inboard and outboard flaps

α=19.98



(a) HRLES



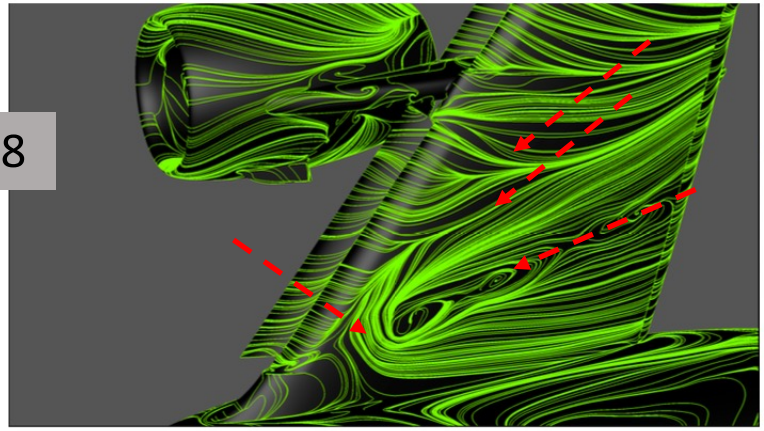
(b) Oil Flow

Comparison of outboard region of the wing

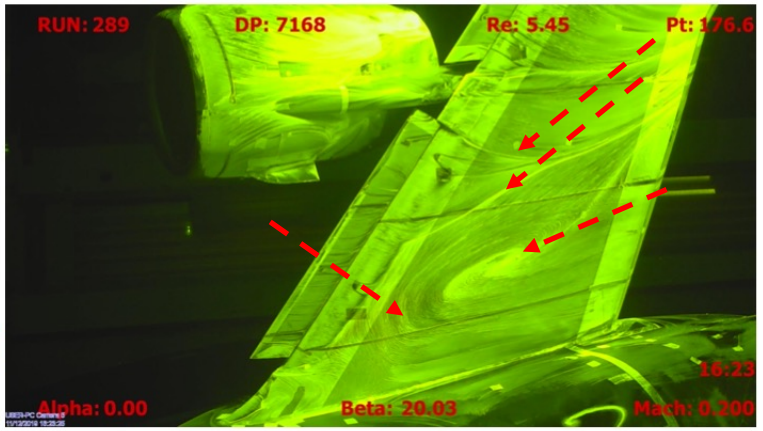
QinetiQ tunnel experiments
https://hiliftpw.larc.nasa.gov

Streamline vs Oil-Flow Comparison – WT

α=19.98

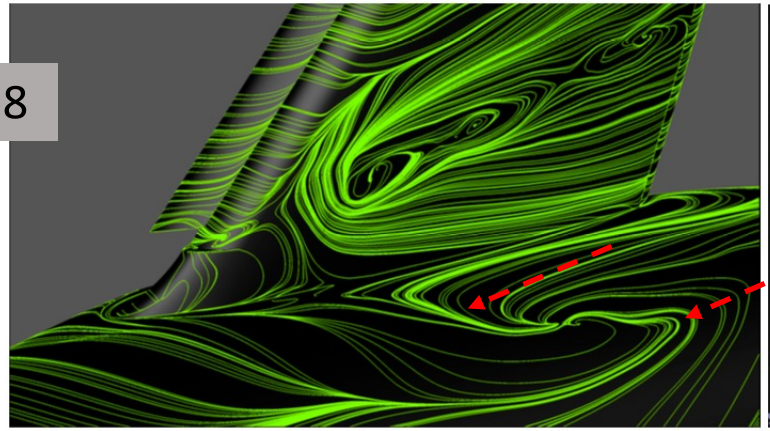


(a) HRLES

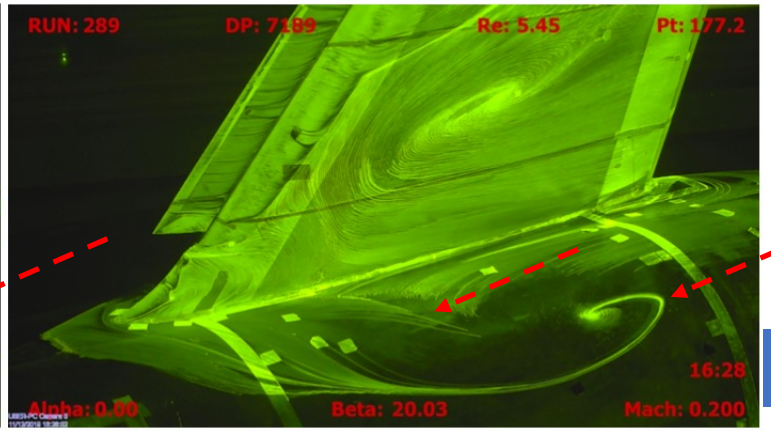


(b) Oil Flow

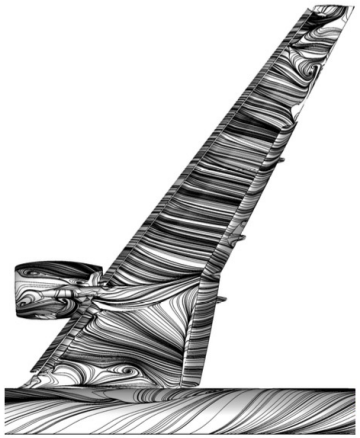
α=19.98



(a) HRLES



(b) Oil Flow



(d) RANS (SA), $\alpha = 19.98°$

QinetiQ tunnel experiments
https://hiliftpw.larc.nasa.gov

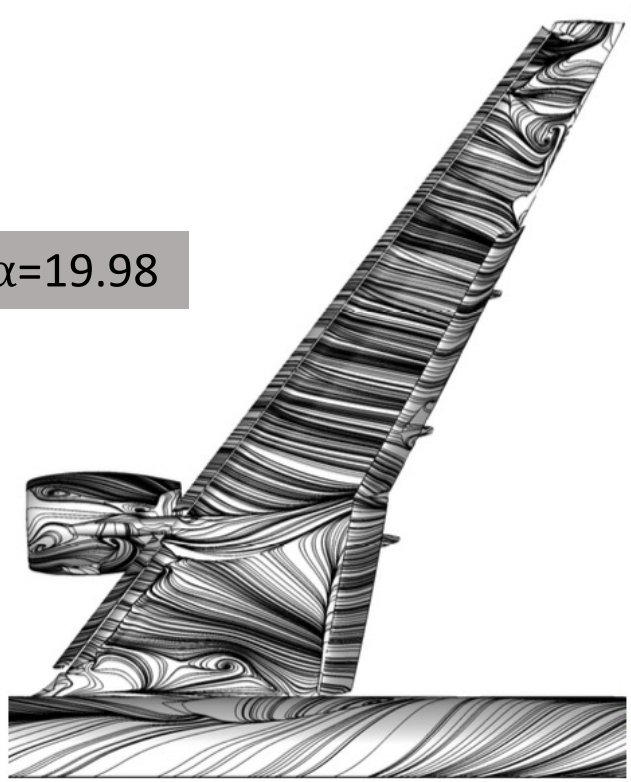
Surface Cf Streamline Comparison – WT

RANS

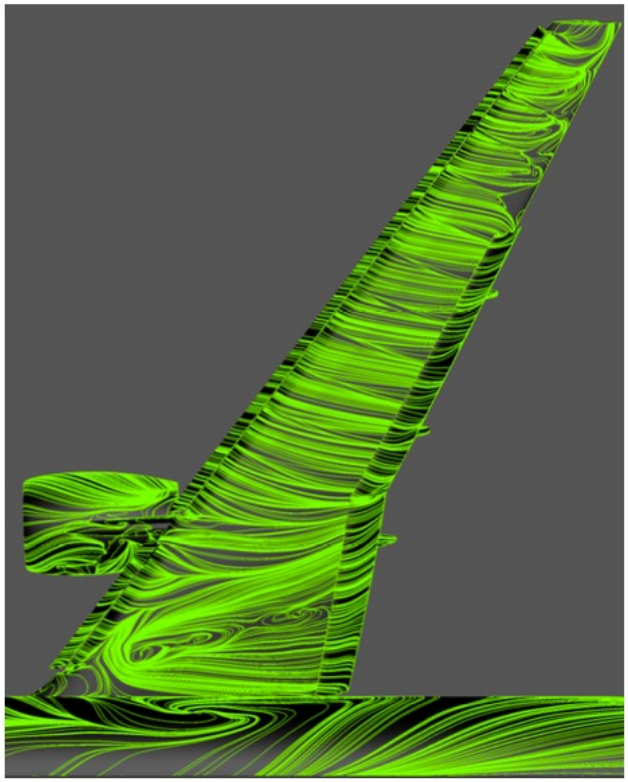
HRLES

WMLES

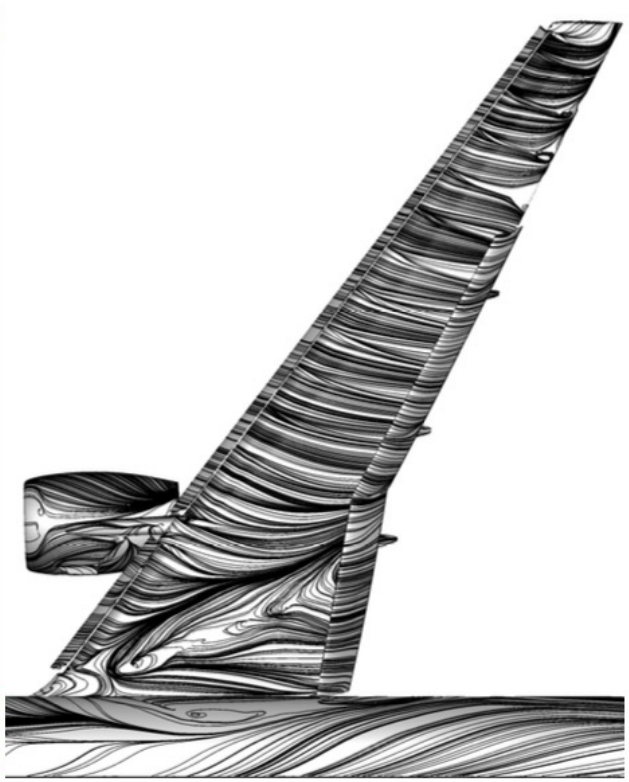
α=19.98



(d) RANS (SA), $\alpha = 19.98°$

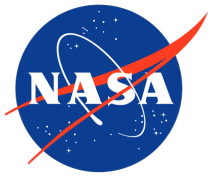


(e) HRLES (SA), $\alpha = 19.98°$



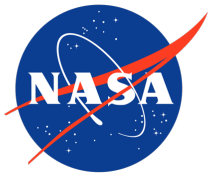
(f) WMLES, $\alpha = 19.98°$

Summary and Outlook



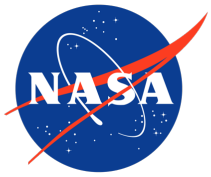
- A comprehensive assessment of the HRLES approach for CLmax and post-stall prediction of the NASA High-Lift Common Research Model (CRM-HL) was performed.
- An objective case has been made for HRLES as a viable approach for CLmax and post-stall prediction of high-lift aircraft geometries.
  - Roughly an order of magnitude more expensive in computational cost when compared with a steady-state RANS run.
- The HRLES method was evaluated for both the free air and wind tunnel configurations and its predictions were compared against experimental results from the QinetiQ tunnel and numerically against RANS and WMLES approaches.
- In addition HRLES addressed some of the shortcomings in RANS approaches and was competitive with WMLES in terms of solution accuracy.

Summary and Outlook (cont.)



- For the free air and the WT configurations, HRLES made modest improvements over RANS at the low angles-of-attack for pitching moment. More significant improvements for HRLES at CLmax and post-stall when compared to RANS.
- HRLES is able to address the sharp loss of lift predicted by RANS (in tunnel) at the two highest angles-of-attack.
- Good agreement is shown across the board for HRLES and WMLES in the free air configuration. This holds largely true for the wind tunnel configuration as well.
- Excellent qualitative agreement was obtained when comparing the streamlines from the HRLES and the oil-flow from the QinetiQ experiment at CLmax and post-stall.
- Simply *"turning-on"* the HRLES model, with the RANS grid and employing numerics more suited to RANS produced predictions that were far inferior to RANS.

Summary and Outlook (cont.)



- Critical points for success with HRLES for CRM-HL:
  - It is important to refine (tangential spacing) the inboard/outboard regions of the wing to address the erroneous behavior of the RANS.
  - Remove anisotropic cells in the volume grid outside the boundary layer.
  - Sufficiently small time-step, and a low dissipation numerical scheme were all instrumental in achieving good agreement with the experimental data and WMLES.

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