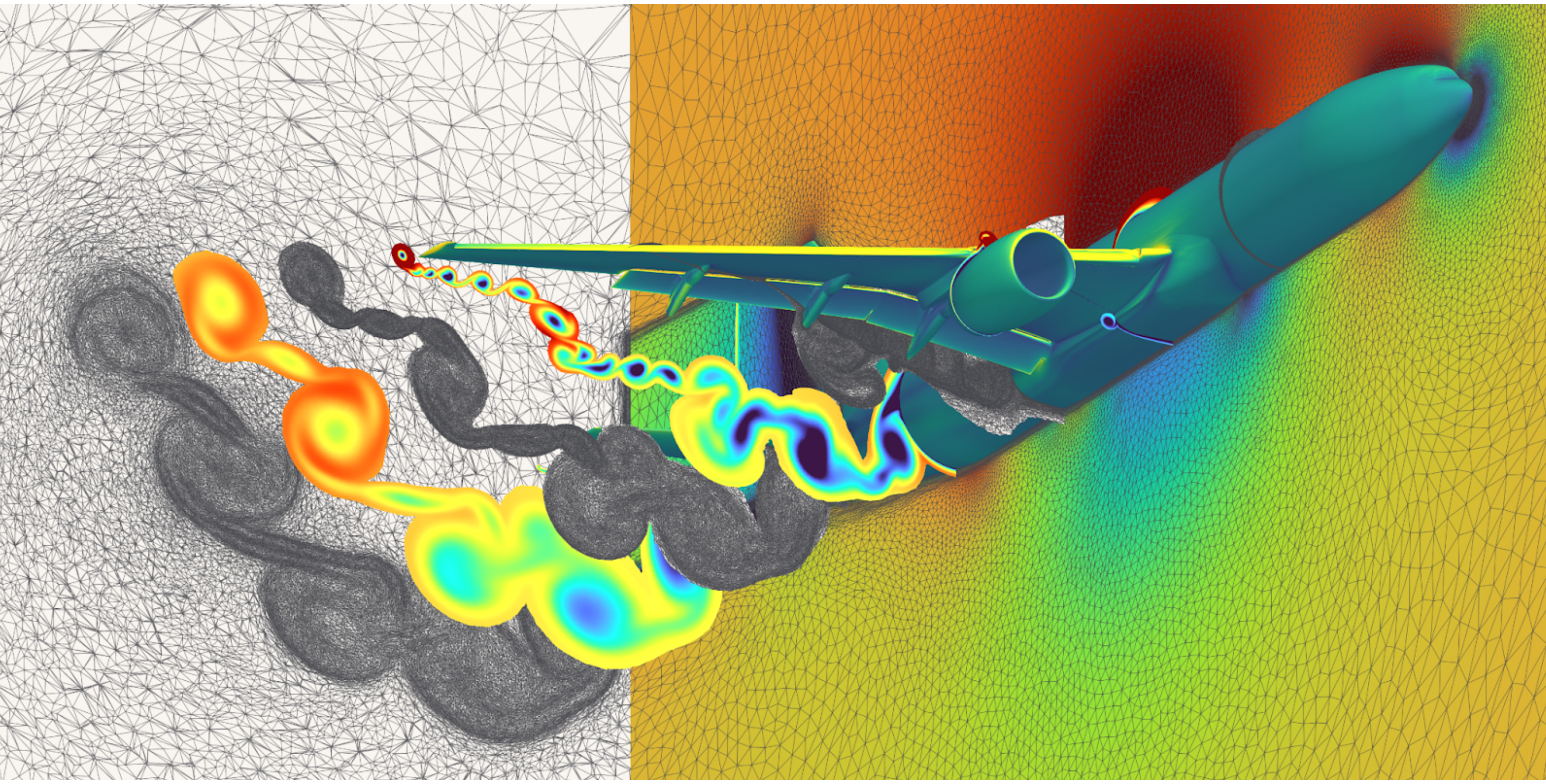
luminary

Accelerating Innovation in **Aerospace**

HLPW-5 Cases 1 and 2.2:
High Lift Prediction Workshop 5 (2024)



BACKGROUND

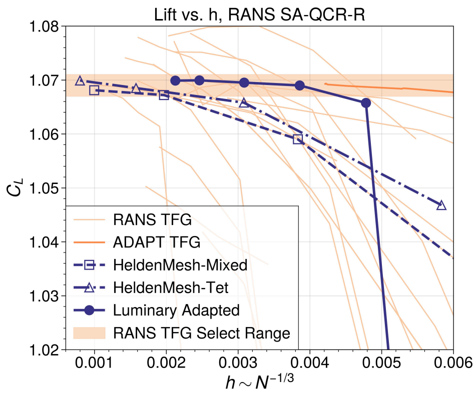
The series of High Lift Prediction Workshops (HLPW) exist to assess the numerical prediction capability of current-generation CFD technology for realistic high-lift aircraft configurations towards practical CFD aerodynamic design and optimization. Government, academia, industry, and commercial vendors convene to establish the state-of-the-art of the international CFD community in an open, impartial forum. HLPW-5 supplied a range of verification and validation test cases. The workshop organized participants into Technical Focus Groups (TFGs) based on their simulation approach. Results are compared across two key TFGs: the RANS TFG focused on Reynolds-averaged Navier Stokes simulations on fixed (non-adaptive) meshes, and the ADAPT TFG, which incorporated mesh adaptation to achieve higher accuracy through better resolution of geometry and flow features.

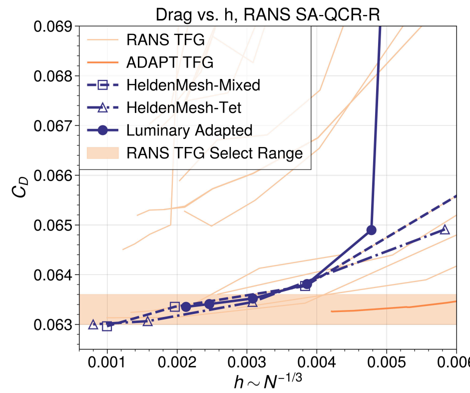
VERIFICATION: HLPW-5 CASE 1

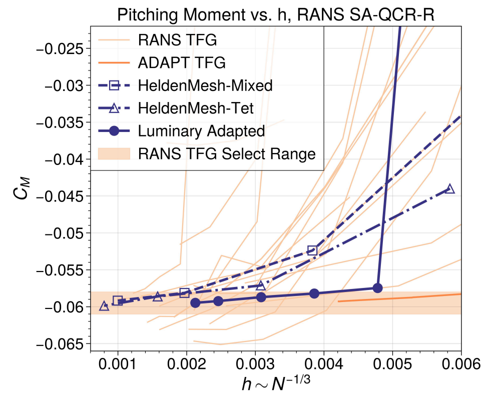
With its simpler geometry relative to Case 2 and lower angle-of-attack, Case 1 from HLPW-5 is ideal for solver verification as there are no significant regions of flow separation. The geometry for Case 1 is the CRM-HL Wing-Body, and the case focuses on the SA and SA-QCR2000-R RANS turbulence models.

Solvers implementing these turbulence model variants should converge to the same force coefficient values with mesh refinement. On the following figures, the lift, drag, and moment coefficients are plotted against effective mesh spacing. Meshes become finer towards the left.

All submitted RANS and ADAPT TFG results are shown on the plot as lines. A small subset of RANS TFG results were identified as "Select" based on strict convergence criteria described in the RANS TFG Summary presentation, establishing a tighter consensus range for force predictions. These submissions fell within the “Select Range” of values that is shown on the plot as a horizontal band.







RESULTS

The Luminary solver with identical flow conditions and solver settings was run on three different families of meshes: HeldenMesh 1.R.05 (mixed element), HeldenMesh 1.R.06 (tetrahedra), and a series automatically generated with Luminary mesh adaptation (LMA) technology.

The figures contain the grid convergence of C_L, C_D, and C_M for the SA-QCR2000-R model with meshes containing up to 2 billion cells. The tables contain the force coefficient results for the final mesh in the LMA series for both turbulence model variants.

In all cases, Luminary results show grid convergence within the Select Range, verifying both the SA and SA-QCR2000-R turbulence models in Luminary. Furthermore, Luminary adapted meshes are able to produce results within the Selected Range with 10x fewer cells than when using the workshop-supplied HeldenMesh meshes.

In terms of performance, the 131M cell mesh from HeldenMesh 1.R.05 run at 10 degrees angle-of-attack met the suggested RANS TFG convergence criteria in 5.5 minutes with a total solver throughput of 3.24 billion face-iterations per second on 16 NVIDIA H100 GPUs.

Case 1 LMA (145M cells): SA

Dataset	C_L	C_D	C_M
Luminary	**1.07832**	**0.06377**	**-0.06637**
Select Range	1.075-1.080	0.635-0.640	-0.068-0.065

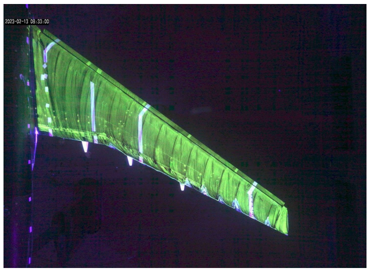
Case 1 LMA (104M cells): SA-QCR2000-R

Dataset	C_L	C_D	C_M
Luminary	**1.06988**	**0.06335**	**-0.05948**
Select Range	1.067-1.071	0.063-0.636	-0.061-0.058

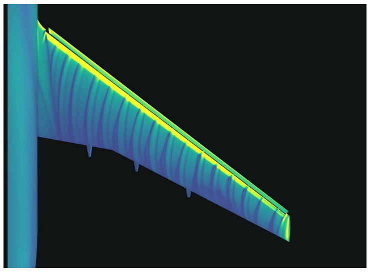
VALIDATION: HLPW-5 CASE 2.2

The CRM-HL Wing-Body-Slat with Horizontal and Vertical Tail validation case is part of a study investigating the impacts of geometric complexity across the angle of attack range on predictions from CFD. Simulation results are compared with wind tunnel data in addition to computed results from other solvers.

On the right, wind tunnel oil flow measurements are shown alongside simulated wall shear stress magnitude on the upper wing surface at 17.7 degrees angle-of-attack. The figures show lift coefficient predictions for both the fixed-mesh and adaptive-mesh (LMA) predictions. Similar to Case 1, submissions from the RANS TFG that met a strict criteria are included in a “Select Range” highlighted as a band on the plots.



Test case 2.2 upper wing planform view of oil flow measurement at 17.7 deg



Test case 2.2 upper wing planform view with contours of wall shear stress magnitude at 17.7 deg

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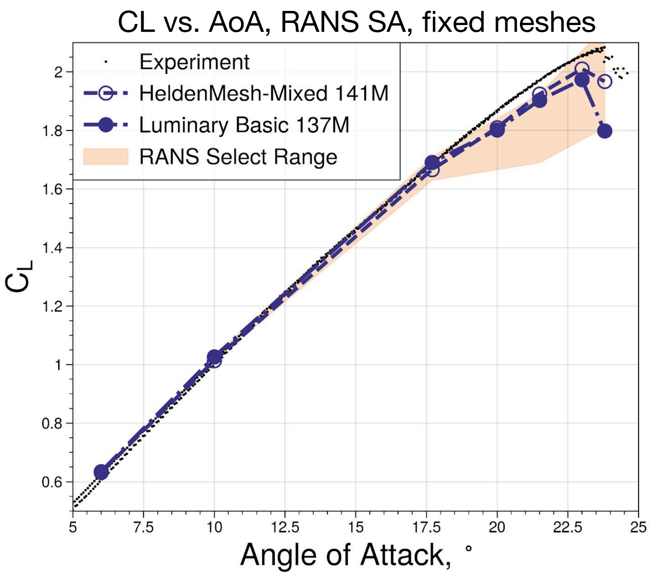

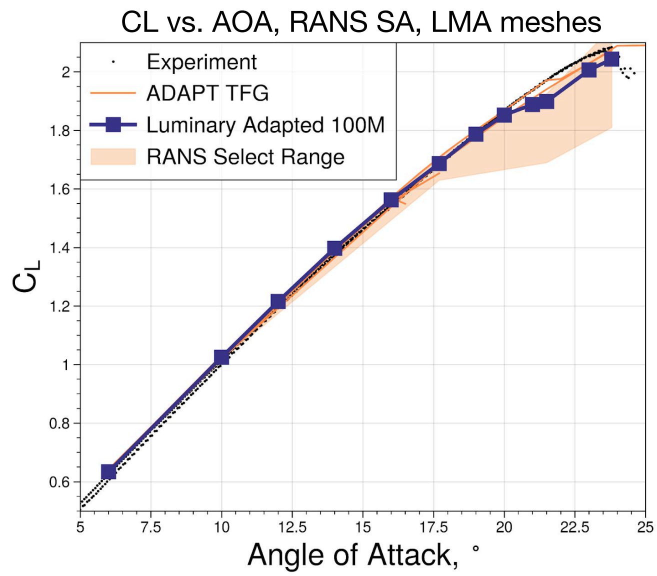

RESULTS

Validation results demonstrate excellent agreement between solutions computed on two different fixed-mesh families with the SA turbulence model: the workshop-provided HeldenMesh series (141M cells) and the automatically-generated Luminary meshes (137M cells). The close alignment of these results, despite their independent mesh generation approaches, provides additional confidence in Luminary's automated meshing capabilities.

LMA automatically handles the increased geometric complexity including slats and slat brackets, flaps and flap track fairings, and horizontal and vertical tails, while capturing important flow features like vortices and wakes with high accuracy, significantly improving upon the fixed mesh results.

Luminary predicts aerodynamic performance within 1% of wind tunnel measurements in the linear aerodynamic range and 4% at C_{Lmax}. Luminary is shown to be correct and useful for prediction of the complex flow patterns created by a realistic high-lift configuration.

RESULTS: LUMINARY IS PROVIDES BEST-IN-CLASS PERFORMANCE AND ACCURACY

HLPW-5 provides a unique opportunity to ensure the correctness of CFD implementation (verification) and the simulation prediction utility (validation) for a complex high-lift system. Luminary's solver accuracy is on par or better than all of the commercial and research CFD solvers used by participants in the workshop. With Luminary's mesh generation and adaptation technology, these accurate results are achieved with significantly fewer cells (10.8x fewer for Case 1) while removing the complexity of manual mesh generation, providing a fully automated end-to-end simulation framework that maintains high accuracy even for complex aerospace configurations.

The performance of the Luminary solver scales very closely with raw GPU memory bandwidth numbers, which are expected to double with the next generation of GPUs. Soon it will be possible to converge the type of large, complex RANS simulations that are the focus of HLPW-5 in seconds, not minutes.

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