[Version 1.9, March 18 2024]

# 5th AIAA CFD High Lift Prediction Workshop
# Official Test Cases

The test cases outlined in this document have been constructed to help achieve the goals of the High Lift Prediction Workshop (HLPW). Participants are asked to provide flow solution data for these cases using grids appropriate for their particular methodology. A limited set of grids will be provided by the HLPW committee, but participants are also encouraged to create their own grids and share them with the committee. All grids will be made available from the High Lift Prediction Workshop website: https://hiliftpw.larc.nasa.gov. For more information on the parameters required to generate your own grids, see the Gridding Guidelines posted to the HLPW website. Participants generating results with their own grids are expected to share the resulting mesh.

For this workshop, consolidated CFD results are requested from Technology Focus Groups (TFGs) established ahead of the workshop. These groups include, but are not limited to: (1) fixed-grid RANS, (2) mesh adaptation RANS, (3) high-order discretization RANS, (4) hybrid RANS/LES (HRLES), and (5) wall-modeled LES (WMLES). Lattice Boltzmann simulation efforts may align to either HRLES or WMLES, as desired. Results summaries addressing specific technical questions will be presented by each TFG at the workshop. Individuals who choose not to participate on a TFG are free to compute and submit the cases on their own, but their results will not be included in any summary presentations at the workshop. Three sets of required test cases are specified, including Case 1 for verification, Case 2 for configuration build-up, and Case 3 for study of Reynolds number effects.

Material necessary to run the cases will be released in a staggered manner, with Case 1 starting roughly in March 2023, Case 2 in July 2023, and Case 3 in November 2023. It is expected the focus of the TFGs will shift as the cases are released.

## A General Note on Geometry

This workshop will utilize different configurations of the High Lift Common Research Model (CRM-HL) [1]. The CRM-HL is an open-source, publicly-available commercial transport aircraft geometry in a high lift configuration that is being utilized for CFD validation within a broad international CRM-HL Ecosystem. Specific test case geometry will either reflect the CRM-HL reference configuration, or explicitly match the “as-designed” geometric CAD definition of one particular wind tunnel models that were designed, built, and tested by an Ecosystem partner. Physical model geometry will often differ from the true reference geometry because of particular model requirements, however the differences are expected to be small and well documented.

## Geometry Reference Quantities

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| Mean Aerodynamic Chord (MAC) | 275.8 inches |
| Moment Reference Center (MRC) | x = 1325.9 inches, y = 0.0 inches, z = 177.95 inches |
| Semi-span model reference area (Sref) | 297,360.0 in$^2$ |

# Case 1: CRM-HL Wing-Body Verification *[required]*

Previous High Lift Prediction Workshops have highlighted the importance of solver verification to obtain consistent solutions for complex flows. The verification problem for this workshop is based on the reference CRM-HL Wing Body (CRM-HL-WB) configuration. The verification problem for this test case will be the same as the one initially introduced and utilized for the High Fidelity CFD Verification Workshop (HFCFDVW) [2], planned for SciTech 2024. The target characteristics of this study are grid convergence of lift, drag, and moment coefficients (HFCFDVW does not require moment coefficient, but we require it here).

## Key Questions

- Are RANS solvers able to demonstrate verification on this problem and series of grids?
- For Non-RANS solvers, what is the most consistent approach to grid families that can demonstrate a trend towards grid independence on this problem?
- Is there enough consistency amongst non-RANS approaches that there is reasonable agreement on a grid independent solution?
- Does the ensemble of answers amongst modelling approaches compared to the experimental free air corrected data tell us anything useful about uncertainty?

## Geometry

This test case uses the reference CRM-HL Wing Body (CRM-HL-WB) geometry. This geometry is similar to that of the simplest version of Test Case 2 (2.1, outlined below), but without empennage or flap fairings. The geometry for this case includes a rectangular cuboid computational domain with dimensions $-65{,}000 \le x \le 65{,}000$, $0 \le y \le 65{,}000$, $-65{,}000 \le z \le 65{,}000$. Symmetry is specified at the y=0 plane, and farfield boundary conditions based on Riemann invariants are assigned at all other farfield boundaries of the computational domain.

## Case Parameters and Requirements

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| Geometry | CRM-HL-WB |
| Mach Number | 0.20 |
| Chord Reynolds Number | $5.6 \times 10^6$ |
| Angle of Attack | 11° |
| Reference Static Temperature | 521 °R |
| Important Details | • Geometry is provided in full-scale inches<br>• When using a dimensional code, it is recommended to adjust viscosity to a non-physical value to match requested Reynolds number<br>• All simulations are “free air” only<br>• When using RANS:<br>○ $\hat{\nu}_{farfield}/\nu_{ref} = 3$ for SA-based models<br>○ Adiabatic wall BC (not isothermal)<br>○ SA-neg-QCR2000-R is recommended; coefficient for rotation correction (-R) should be changed to $C_{rot}$=1 for verification (standard value of $C_{rot}$=2 can be used as an “optional” case) |

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| | ○ Ideal gas, $\gamma = 1.4$, Pr=0.72, $Pr_t$=0.9, dynamic laminar viscosity via Sutherland's Law<br>○ Other details in AIAA paper 2023-1244 [2] |

### RANS Solvers

SA-neg-QCR2000-R is highly recommended, run fully turbulent, as detailed in [2]. If this model variant is not possible, then the SA or SA-neg model should be used instead. If a different turbulence model is employed, then model details should be provided so that others can duplicate your work.

HFCFDVW has generated a family of unstructured mixed-element grids (labeled Mesh Series 1.R.01-1 on the HLPW website). It is strongly recommended that RANS participants utilize these grids for the verification study. However, if a particular solver requires an alternate gridding methodology, a similar grid family should be created and utilized in order to generate comparable results.

### Non-RANS Solvers

The many varieties of solution methodologies expected to be used for the workshop (particularly scale-resolving simulations) will make verification using standard practices difficult due to unique grid requirements/topologies, temporal discretization and averaging methods, and even equation sets. As a result, there is not enough overlap in related results to meaningfully declare any one specific solution the standard. Therefore, participants using non-RANS solvers are encouraged to demonstrate grid convergence on this problem using multiple grid levels along with their best practice solver settings, looking at convergence of the lift, drag, and moment coefficients. The gridding requirements in this section are purposefully left vague (also, the farfield domain may deviate from the cuboid specified for RANS). Discussions within TFGs are expected to provide further guidance on how to best family grid sequences for these approaches.

## Case 2: Configuration Build-up *[required]*

Flow solutions are requested to assess the ability of CFD to predict the effect of varying geometric fidelity through component build-up to help isolate specific types of flow physics associated with high-lift aerodynamics. Geometry is provided for four separate geometric configurations of increasing levels of complexity, with simulations to be performed free-air and compared to fully corrected data. Experimental data will be provided from wind tunnel campaigns utilizing both the ONERA [3] and Boeing models, tested at the ONERA F1 and QinetiQ 5m facilities, respectively. For this case, a set of grids should be employed with mesh size determined by current "best practice" guidelines. However, to build confidence in the simulations, it is recommended that participants explore mesh sensitivities thru grid resolution studies, particularly near CLmax and in the linear region of the lift curve and in other areas of interest, as appropriate. Resolution studies conducted at the lowest and second-highest listed angles-of-attack are recommended, at a minimum. Farfield domain is preferred to be a hemisphere with distance 100*MAC, although other similar "best practice" domain extents are allowed.

### Key Questions

- Does the consistency in integrated forces/moments from CFD simulations improve when modeling geometrically simpler HL configurations?

  - Are there unique CFD modeling requirements (e.g. mesh, solver, etc.) for an unprotected Leading Edge (LE)?
  - How does the additional of the LE device (slat) effect CFD modeling, both in terms of accuracy and consistency?
  - How does the additional of the TE device (flap) effect CFD modeling, both in terms of accuracy and consistency?
  - How does the additional of the pylon/nacelle effect CFD modeling, both in terms of accuracy and consistency?
- If accuracy falls off due to the presence of a single component, can better modeling approaches be established to improve the predictions?

## Geometry

Test case 2 utilizes CRM-HL model geometries of varying component complexity. All configurations include a full empennage (horizontal and vertical stabilizers = HV). The buildup configurations are:

2.1) Wing-Body with HV (CRM-HL-WBHV)
2.2) Wing-Body-Slat with HV (ONERA_LRM–WBSHV)
2.3) Wing-Body-Slat-Flaps with HV (ONERA_LRM–WBSFHV)
2.4) Wing-Body-Slat-Flaps-Nacelle with HV (ONERA_LRM–LDG)

Validation data for the subcase 2.1 is expected to be obtained in the QinetiQ 5-metre wind tunnel using the as-designed Boeing 6% full-span WBHV model, which is expected to be identical to the reference WB definition plus HV and flap fairings (CRM-HL-WBHV). For the other three subcases, the geometry definitions from the as-designed ONERA 1/19.5 model tested in the F1 wind tunnel are utilized. Although small geometric differences are expected between the reference CAD definition and the ONERA model definitions, those differences will be well documented, and are expected to be aerodynamically insignificant. Also, the maximum Reynolds number achievable by the Boeing 6% full-span WB model will be slightly lower than that achieved with the ONERA model. This is not expected to have any noticeable impact, but nonetheless the flow conditions for CFD for these cases reflect this difference. These test cases are recommended to be run fully turbulent.

## Case Parameters and Requirements

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| Geometries | 2.1: CRM-HL-WBHV<br>2.2: ONERA_LRM-WBSHV<br>2.3: ONERA_LRM-WBSFHV<br>2.4: ONERA_LRM-LDG-HV |
| Mach Number | 0.20 |
| Chord Reynolds Number | 5.4 x $10^6$ (subcase 2.1), 5.9 x $10^6$ (subcases 2.2 - 2.4) |
| Angles of Attack | 2.1: 6°, 10°, 12°, 13°, 14°<br>2.2: 6°, 10°, 17.7°, 20°, 21.5°, 23°, 23.8°<br>2.3: 6°, 10°, 14°, 16°, 17.7°, 20.7°, 23.5°<br>2.4: 7.6°, 10°, 14°, 16°, 17.7°, 19.7°, 23.6° |
| Reference Static Temperature | 518.67 °R |
| Reference Static Pressure | 14.696 psi |
| Important Details | • Geometry is provided in full-scale inches |

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| | • When using a dimensional code, it is recommended to adjust viscosity to a non-physical value to match requested Reynolds number<br>• All simulations are run Free-Air with no tunnel or support systems included |

## Optional: Case 2a – Increased Fidelity

Several elements of the computational modeling can be investigated to explore sensitivity of solutions. These include, but are not limited to:

- Use of specific wind tunnel model geometry associated with a particular test campaign
- Use of static tunnel aeroelastic deformations
- Performing in-tunnel simulations (either with the test section only, or including expansion/contraction sections)
- Physical tripping or transition modelling
- Systematic mesh refinement

Note that experimental data to help characterize some of the above modeling effects may not be available from every facility. Additional data will be provided as required, and when available, on a case by case basis. It is expected that decisions to explore one or more of these areas in more depth will be left to individual TFGs, with requests for additional data provided to the organizing committee.

## Case 3: Reynolds Number Study *[required]*

Flow solutions are requested to assess the capability of CFD to predict the effects of increasing Reynolds number on the aerodynamic performance of the CRM-HL in the reference landing configuration. This case serves to provide blind CFD predictions of wind tunnel data to be obtained in the CRM-HL ecosystem in the future. Solutions are requested across specified angles of attack, at four different Reynolds numbers (Cases 3.1 through 3.4). It is recommended that participants explore mesh sensitivities thru grid resolution studies, particularly near CLmax and in the linear region of the lift curve and in other areas of interest, as appropriate. Resolution studies conducted at the lowest and second-highest listed angles-of-attack are recommended, at a minimum. Farfield domain is preferred to be a hemisphere with distance 100*MAC, although other similar “best practice” domain extents are allowed.

### Key Questions

- How do gridding requirements change with Reynolds number?
- How does grid convergence behavior change with Reynolds number?
- How consistent are CFD predictions with each other across a range of Reynolds numbers?

### Geometry

Test case 3 utilizes the NASA 5.2% model geometry in the standard LDG configuration. This configuration includes nominal inboard/outboard TE flap deflections of 40°/37°, nominal 30°/30° inboard/outboard leading-edge (LE) slat setting, nacelle, pylon, nacelle chine, LE brackets, TE support fairings, but no landing gear, vertical tail, or horizontal tail. These test cases are recommended to be run fully turbulent. However, at the lowest (optional) Re near 1 million, transition studies may be of interest.

## Case Parameters and Requirements

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| Geometry | NASA_5.2%-LDG |
| Mach Number | 0.20 |
| Chord Reynolds Number | 3.1: 1.05 x $10^6$ (optional)<br>3.2: 5.49 x $10^6$<br>3.3: 16 x $10^6$<br>3.4: 30 x $10^6$ |
| Angles of Attack | 6, 10, 14, 16, 18, 19, 20, 22 for each Re |
| Reference Static Temperature | 518.67 °R |
| Reference Static Pressure | 14.696 psi |
| Important Details | • Geometry is provided in full-scale inches<br>• When using a dimensional code, it is recommended to adjust viscosity to a non-physical value to match requested Reynolds number<br>• All simulations are run Free-Air with no tunnel or support systems included |

# References

1. Lacy and Clark, "Definition of Initial Landing and Takeoff Reference Configurations for the High Lift Common Research Model (CRM-HL)", AIAA-2020-2771, AIAA Aviation 2020 Forum, Virtual Event, June 2020.
2. Diskin, Liu, and Galbraith, "High Fidelity CFD Verification Workshop 2024: Spalart-Allmaras QCR2000-R Turbulence Model", AIAA-2023-1244, AIAA SciTech 2023 Forum, National Harbor, MD, January 2023.
3. Mouton, S., Charpentier, G., and Lorenski, A., "Test Summary of the Full-Span High-Lift Common Research Model at the ONERA F1 Pressurized Low-Speed Wind Tunnel," AIAA-2023-0823, AIAA SciTech Forum, January 2023.

# Additional Information

Please check the website (http://hiliftpw.larc.nasa.gov) periodically for updates, and register with hiliftpw@gmail.com to receive email notifications. Also, if you plan to participate in the workshop, you must join a Technology Focus Group (TFG).

Changes from previous versions:

- V1.9 – changes Case 3 to be blind (CFD only)
- V1.8 – defines AoAs for Case 3; also made Case 3.1 optional and the others mandatory.
- V1.7 – specifically defines cases 3.1 through 3.4 (one for each Reynolds number), although many are still TBV.
- V1.6 – now mentions resolution studies at the lowest and second-highest listed angles-of-attack for Test Cases 2 and 3 (V1.5 listed unused AoAs).