4th 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). As with past workshops, participants are asked to provide flow solution data for these cases using a common set of baseline grids. Workshop-provided meshes for standard Reynolds-averaged Navier-Stokes (RANS) toolsets will be available from the High Lift Prediction Workshop website: https://hiliftpw.larc.nasa.gov.

Independently generated grids can be used, but participants are encouraged ***to run the requested cases on workshop-provided grids, when indicated***. For more information on the parameters required to generate your own grids, see the Gridding Guidelines posted to the HLPW-4 website. Participants generating results with their own grids are expected to share their grids upon request.

For this workshop, consolidated CFD results are requested from Technology Focus Groups (TFGs) established ahead of the workshop. These groups include (1) fixed-grid RANS, (2) mesh adaptation RANS, (3) high-order discretization RANS, (4) hybrid RANS/LES, and (5) wall-modeled LES (WMLES) and Lattice-Boltzmann (LB). Results summaries addressing specific technical questions will be presented by each technology focus group at the workshop. Individuals who are not part of a technology focus group 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.

Case 1: Flap Deflection Study

Flow solutions are requested to assess the ability of CFD methods to accurately predict trailing edge (TE) flap deflection increments. Flow solutions are requested for a high lift configuration at three flap deflections at a single angle-of-attack and Reynolds number. CFD results will be compared to Wind Tunnel (WT) test data.

Geometry

The **High Lift Common Research Model (CRM-HL)** is an open-source, publicly-available wing-body high lift configuration being utilized for CFD validation within a broad international CRM-HL ecosystem. Geometry associated with the **NASA 10% scale, semi-span model configuration [1]** tested in the QinetiQ 5-metre wind tunnel is used for this study. This configuration was tested at three inboard/outboard TE flap deflections (37°/34°, 40°/37°, and 43°/40°) with a nominal 30°/30° inboard/outboard leading-edge (LE) slat setting, nacelle, pylon, nacelle chine, LE brackets, TE support fairings, but no landing gear, horizontal or vertical tail. The model had boundary layer trips installed on selected surfaces to ensure turbulent flow [2].

Case Parameters and Requirements

Case 1a: Comparison with QinetiQ WT Data (REQUESTED)

Mach Number	0.2
Angle of Attack	7.01° (wall corrected)
Reynolds Number based on MAC	5.49 million
Reference Static Temperature	521 °R
Reference Static Pressure	24.67 psi
Mean Aerodynamic Chord (MAC)	275.8 inches
Moment Reference Center (MRC)	x = 1325.9 inches, y = 0.0 inches, z = 177.95 inches
Flap Deflection	3 different geometries: • 40°/37° inboard/outboard (nominal) • 37°/34° inboard/outboard • 43°/40° inboard/outboard

Important Details:	• Geometry is given in full-scale inches. • For RANS, run simulations fully turbulent. • All simulations are "free air"; no wind tunnel walls or model support systems. (The 7.01° angle in free air corresponds with 6° incidence when tunnel walls are included.)
Data Delivery	Forces/moments, surface pressures, surface streamlines

Case 1b: Grid Convergence for Nominal Landing Configuration (OPTIONAL)

Flow solutions for the CRM-HL landing configuration (nominal 40°/37° inboard/outboard TE flap setting only) on a series of consistently refined fixed grids are requested to assess grid convergence. At a minimum, flow solutions should be provided for at least one family of coarse, medium, and fine workshop-provided meshes. Providing flow solutions at other mesh resolutions is optional. Data delivery is the same as in Case 1a.

Case 2: $C_{L,max}$ Study

Flow solutions are requested to assess the ability of CFD methods to accurately predict maximum lift ($C_{L,max}$). Simulations may be run at a user-defined set of points along the lift curve, but must include the data at selected angles-of-attack from the wind tunnel test. Simulations performed in free-air will be used to assess CRM-HL flow physics and the effects of numerics, grids, modeling strategies, etc. on the results. They will also help guide future wind tunnel testing requirements and desired flow measurements. Simulations with wind tunnel walls modeled will be compared to applicable test data from the QinetiQ 5-metre wind tunnel.

Geometry

Case 2 uses the landing configuration with nominal 40°/37° inboard/outboard TE flap setting only.

Case Parameters and Requirements

Case 2a: Flow Physics Exploration for Future WT Testing (REQUESTED)

Mach Number	0.2
Angles of attack	2.78, 7.01, 11.29, 17.53, 19.57, 21.46° (wall corrected)
Reynolds Number based on MAC	5.49 million
Reference Static Temperature	521 °R
Reference Static Pressure	24.67 psi
Mean Aerodynamic Chord (MAC)	275.8 inches
Moment Reference Center (MRC)	x = 1325.9 inches, y = 0.0 inches, z = 177.95 inches
Flap Deflection	40°/37° inboard/outboard (nominal)
Important Details:	• Geometry is provided in full-scale inches. • For RANS, run simulations fully turbulent. • All simulations are "free air"; no wind tunnel walls or model support systems.
Data Delivery	Forces/moments, surface pressures, surface streamlines, skin friction contours, off-body velocity profiles, etc.

Case 2b: Comparison with QinetiQ WT Data (OPTIONAL)

Mach Number	0.2
Angles of incidence in tunnel	2, 6, 10, 16, 18, and 20° (uncorrected)
Reynolds Number based on MAC	5.49 million

Reference Static Temperature	521 °R
Reference Static Pressure	24.67 psi
Mean Aerodynamic Chord (MAC)	275.8 inches
Moment Reference Center (MRC)	x = 1325.9 inches, y = 0.0 inches, z = 177.95 inches
Flap Deflection	40°/37° inboard/outboard (nominal)
Important Details:	• Geometry is provided in full scale inches. When including tunnel walls, the model geometry needs to be scaled 10% (the MAC and MRC are also scaled). • For RANS, run simulations fully turbulent. • All simulations include wind tunnel walls and model installation at floor.
Data Delivery	Forces/moments, surface pressures, surface streamlines, skin friction contours, off-body velocity profiles, etc.

Case 3: Turbulence Model Verification and SRS Capability Study

The configuration used in this test case is a simplified two-dimensional (2-D) multi-element airfoil configuration [3]. This same configuration was used for the 2020 AIAA Aviation GMGW Special Session [4].

The main purpose of this exercise is to demonstrate accurate and consistent implementation of the standard Spalart-Allmaras (SA) turbulence model used in conjunction with RANS, as documented on the NASA TMR [5] website. This is an important activity, because often codes with ostensibly the same turbulence model are compared at workshops, but they sometimes contain hidden implementation differences. These hidden differences cause confusion when attempting to assess the influence of grid and numerics, and they make it difficult to validate a turbulence model's collective results against experiment.

A secondary purpose of this case is the exploration of scale-resolving simulation (SRS) methods. For this specific application, the 2-D geometry should be extruded spanwise, with sufficient grid resolution and appropriately-specified lateral boundary conditions, and results using 3-D SRS methods explored/compared/documented. With SRS, this case is no longer strictly a verification study, although it could lead to insights regarding SRS capabilities for attached and separated multi-element airfoil flow, including tripping effectiveness and solution consistency when making use of different methodologies and grid strategies. Note: at 16° angle-of-attack, RANS simulations indicate that there is likely no flow separation, except in the coves. Therefore, for SRS studies, other angles-of-attack beside 16° may be instructive. For instance, a small amount separation may occur on the flap at 6° and 8° (more separation for the former), and on- or off-body separation may occur above 20°. Different fundamental smooth-body separated case(s) other than this configuration may be considered for SRS studies, at the discretion of the TFGs.

Geometry

This exercise is conducted on a previously-defined 2-D section of the CRM-HL configuration with slat, main, and flap elements. A family of unstructured grids are provided for this test case. Note that with these grids, the x direction is stream-wise, the z direction is "up", and the y (spanwise) direction is unused. You must run on at least each of the 4 finest grids. If you make your own grids, they must have a farfield extent of at least 1000 chords, and should follow best practice guidelines for grid family creation, with sufficiently fine grid distribution, spacing, and stretching so that at least the 3 finest grids levels lie within the "asymptotic range" of grid convergence for RANS.

Case Parameters and Requirements

For RANS, the compressible equations should be used, with air as the working medium. The dynamic viscosity is to be modeled using Sutherland's law. For force calculations, the reference area is 1 m (the chord with unit span). The farfield boundary should be imposed with a Riemann invariant or characteristic boundary condition. The wing surfaces are to be imposed as no-slip adiabatic walls or equivalent.

Case 3a: Turbulence Model Verification (REQUESTED)

Mach Number	0.2
Alpha	16° (for RANS SA turbulence verification)
Reynolds Number	5 million (per stowed chord length = unit 1 in provided meshes)
Reference Static Temperature	272.1 °K (489.8 °R)
Ratio of Specific Heats (γ)	1.4
Prandtl number	0.72
Turbulent Prandtl number	0.9
Reference Static Pressure	14.7 psi
Chord	1.0
Important Details:	• For RANS, run simulations fully turbulent with **SA** and/or **SA-neg** only[1] ($\hat{\nu}_{freestream}/\hat{\nu}_{\infty}$=3). • All simulations are "free air". • There is no experimental data for this case.
Data Delivery	RANS results should be fully iteratively converged (machine zero if possible). For each grid level, please provide: • C_L, C_D, $C_{D,p}$, and $C_{D,v}$ • Surface C_P and $C_{f,x}$ on all 3 elements • Flowfield information (u/U_{ref}, v/U_{ref}, w/U_{ref}, μ_t/μ_{ref}), along a vertical line (in the z-direction) at x=-0.03 (over the slat), x=0.4 (over the main), and x=0.95 (over the flap). (Note: v should be identically zero for a 2-D RANS run with z "up".)

Definitions:

- C_L = lift coefficient
- C_D = drag coefficient = $C_{D,p}$ + $C_{D,v}$
- $C_{D,p}$ = drag coefficient due to pressure
- $C_{D,v}$ = drag coefficient due to viscous effects
- C_P = pressure coefficient
- $C_{f,x}$ = x-component of skin friction coefficient
- u = component of velocity in the x-direction
- v = component of velocity in the y-direction
- w = component of velocity in the z-direction
- U = reference (freestream) velocity
- μ_t = eddy (turbulent) viscosity
- μ = dynamic (laminar) viscosity
- $\hat{\nu}$ = SA model's turbulence variable
- ν = kinematic viscosity
- ref = indicates reference (freestream) conditions

References

1. Lin. J, et al., "High Lift Common Research Model for Wind Tunnel Testing: An Active Flow Control Perspective", AIAA-2017-0319, AIAA SciTech Forum, 55th Aerospace Sciences Meeting, Grapevine, TX, January 2017.
2. Model Boundary Layer Trip Guide – NASA 10% semi-span model tested in QinetiQ 5 Metre WT
3. https://turbmodels.larc.nasa.gov/multielementverif.html

[1] Because the Reynolds number is fairly high, the use of SA-noft2 is expected to yield essentially the same results as SA for this case, but please be sure to identify if you are using this particular model version.

4. http://www.gmgworkshop.com/gmgw25.shtml
5. https://turbmodels.larc.nasa.gov/spalart.html#sa

Additional Information

Please check the website (http://hiliftpw.larc.nasa.gov) periodically for updates, and/or register with hiliftpw@gmail.com to be notified directly.