**HLPW4 - Adaptation Technology Focus Group**

**Key Questions**

1. By canceling discretization error, can mesh adaptation help answer the question, “Is there any realistic path for RANS simulations to predict CLmax with the correct flow physics”?
2. Can adaptive mesh convergence be achieved on the full HLCRM model across the AoA range?
3. Do adaptive meshes improve prediction of CLmax and/or improve modeling of important high-lift physical flow characteristics?
4. What are the best practices for adaptive mesh modeling of high-lift applications (error estimate choice, flow solver settings, complexity schedule, solution continuation, geometry handling, …)?
5. What are the best practices for computing increments with adaptive meshes?
6. What are the outstanding technical issues in using mesh adaptation for CLmax prediction?

**Updated on 12/21/2020 to be consistent with HiLiftPW4 Official Test Cases Version 14**

**Adaptation TFG Test Cases**

Definitions:

* CL = lift coefficient
* CD = drag coefficient = CD,p + CD,v
* CD,p = drag coefficient due to pressure
* CD,v = drag coefficient due to viscous effects
* Cm = total pitching moment coefficient
* CP = pressure coefficient
* Cf,x = x-component of skin friction coefficient
* DOF = degrees of freedom (typically the number of nodes or cells in a mesh)
* 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
* t = eddy (turbulent) viscosity
*  = dynamic (laminar) viscosity
* ̂ = SA model’s turbulence variable
* = kinematic viscosity
* ref = indicates reference (freestream) conditions
* Mesh level is where the degrees of freedom changes by ~ 2

**Case 1 - Method Verification (Required)**

**Case Description**: Demonstrate mesh convergence and verify solver turbulence model implementation on HLPW4 Case 3a (2d HLCRM airfoil).

**Objective:** Verify that adaptive process (including flow solver, error estimate, and mesh mechanics) meets basic mesh convergence criteria. Verify solver and turbulent model implementation by comparing to “truth” solution.

**Run Conditions**:

|  |  |
| --- | --- |
| 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 () | 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]](#footnote-1) (̂freestream/̂∞=3). * All simulations are “free air”. * There is no experimental data for this case. * Outer boundary should be located at 1000 chord lengths. |
| Data Delivery | RANS results should be fully iteratively converged (machine zero if possible).  For all mesh levels, please provide:   * CL, CD, CD,p, CD,v, and Cm   For the finest grid level provide:   * Surface CP and Cf,x on all 3 elements * Flowfield information (u/Uref, v/Uref, w/Uref, t/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”.) |
|  |  |

**Approach**:

*Participant Actions*

1. Run adaptive mesh simulation on the HLCRM airfoil model at the run condition specified in the table above.
2. Adaptive mesh simulation should consist of a sequence of adaptive meshes with increasing DOF (a minimum of 4 mesh levels is desired with a 150% or greater increase in DOF between each mesh level). Continue adaptive process until reaching a targeted level of mesh converge where CL and CD change less than 0.01 and 0.0001 between successive mesh levels. If you are not able to achieve the target level of mesh convergence, continue adaptive process to the finest mesh level that you can reach.
3. Provide requested data for your simulation.

**Case 2 - Adaptive Mesh Simulation in Linear Lift Slope (Required)**

**Case Description**: Generate adaptive mesh solution of nominal HLCRM model (inboard/outboard flap deflections of 40°/37°), in free air at attached flow condition (see HLPW4 Case 1b description available on the HLPW4 web site for full run condition details).

Supports key questions 2,3,4,6

**Objective**: Compare mesh convergence of fixed/adaptive methods.

**Run Conditions**:

|  |  |
| --- | --- |
| Mach Number | 0.2 |
| Angle of Attack | 7.05° (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 |
| Semi-span model reference area | 297,360.0 in2 |
| Flap Deflection | 40°/37° inboard/outboard (nominal) |
| Important Details: | * Geometry is given in full-scale inches. * Geometry is for the half model, y-symmetry can be used. * For RANS, run simulations fully turbulent. Run at least one simulation fully turbulent with **SA** and/or **SA-neg** only. Additional turbulence models can be run as additional cases if desired. * All simulations are “free air”; no wind tunnel walls or model support systems. (The 7.05° angle in free air corresponds with 5.98° incidence when tunnel walls are included.) * Participants are requested to use the standard outer boundary definition available on the HLPW4 geometry download site. If an alternate boundary is used it should be located at a minimum of 1000 chord lengths. |
| Data Delivery | Forces/moments, surface pressures, skin friction, surface streamlines, velocity profiles, mesh images on finest mesh. Forces/moments on all mesh levels. |

**Approach**:

*Participant Actions*

1. Run adaptive mesh simulation on the nominal HLCRM model (inboard/outboard flap deflections of 40°/37°) with your adaptive mesh process at the single flow condition specified in the table above (Mach 0.2, 7.05° angle of attack). All participants should run at least one adaptive mesh simulation using the **SA** or **SA-neg** only turbulence model to provide a consistent basis for comparison between methods. Other turbulence models can be run and submitted as additional data sets if desired. An adaptive mesh process includes choice of one flow solver/algorithm, one turbulence model, mesh mechanics approach, and error estimate. Separate data should be generated for each solver algorithm, turbulence model, mesh mechanics, error estimate combination.
2. Adaptive mesh simulation should consist of a sequence of adaptive meshes with increasing DOF (a minimum of 4 mesh levels is desired with a 50% or greater increase in DOF between each mesh level). Continue adaptive process until reaching a targeted level of mesh converge where CL and CD change less than 0.01 and 0.0001 between successive mesh levels. If you are not able to achieve the target level of mesh convergence, continue adaptive process to the finest mesh level that you can reach.
3. Run same flow solver(s) and turbulence model(s) used for the adaptive mesh simulation in step 1, on one or more meshes from one of the committee provided fixed mesh families or on a participant generated fixed mesh family (possible teaming with fixed mesh RANS TFG member).
4. Compare results (fixed and adaptive mesh with experimental data):
   1. Compare lift, drag, viscous drag and pitching moment mesh convergence for the fixed and adaptive mesh simulations.
   2. Compare surface pressures, skin friction, surface streamlines, and velocity profiles, and mesh images on the fixed and adaptive solutions with the highest mesh resolution.
   3. Compare important flow features and associated mesh characteristics between the adaptive and fixed mesh simulations. Key features to be compared will be identified by the adapt TFG planning team.
   4. Optional: Report labor and computational cost of the fixed and adaptive mesh simulations. Cost comparisons between fixed and adaptive simulations should be made at a mesh resolution of comparable accuracy if possible. Cost comparisons should be broken into geometry preparation, mesh generation, solution generation, if possible. Any post simulation rework (i.e. modification of process or mesh because of solution divergence) in the cost estimates.
5. Complete and return data submittal form.
6. Identify best practice guidelines and share with TFG team

*Adapt TFG Team Actions*

1. Compare data from all participant adaptive mesh processes.
2. Develop best practice guidelines (general)
3. Identify open simulation issues - design additional investigations to explore open issues as appropriate and as time permits
4. Assemble participant teams to perform additional investigations identified above (actual studies will depend on results and participant interest)
   1. Example of an additional investigation: vary initial mesh and mesh complexity schedule to identify best process efficiency

**Case 3 - Adaptive Mesh Simulations Approaching CLmax** **(Optional)**

**Case Description**: Generate adaptive mesh solutions for nominal HLCRM model (inboard/outboard flap deflections of 40°/37°) in free air across the full AoA range (see HLPW4 Case 2a available on the HLPW4 web site for full run condition details)

Supports key questions 1-4 and 6

**Objective**: Investigate behavior and accuracy of adaptive mesh methods for flow fields approaching CLmax.

**Run Conditions**:

|  |  |
| --- | --- |
| Mach Number | 0.2 |
| Angles of attack | 2.78, 7.05, 11.29, 17.05, 19.57, 20.55, 21.47° (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 |
| Semi-span model reference area | 297,360.0 in2 |
| 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. * Participants are requested to use the standard outer boundary definition available on the HLPW4 geometry download site. If an alternate boundary is used it should be located at a minimum of 1000 chord lengths. |
| Data Delivery | Forces/moments, surface pressures, skin friction, surface streamlines, velocity profiles, mesh images on finest mesh. Forces/moments on all mesh levels. |

**Approach**:

*Participant Actions*

1. Run an adaptive mesh simulation on the nominal HLCRM model (inboard/outboard flap deflections of 40°/37°) with your adaptive mesh process for the angles of attack specified in the table above. If multiple solvers, turbulence models, error estimates or mesh mechanics are used, separate data should be generated for each solver algorithm, turbulence model, mesh mechanics, error estimate combination.
2. Each adaptive mesh solution should consist of a sequence of adaptive meshes with increasing DOF (a minimum of 4 mesh levels is desired with a 50% or greater increase in DOF between each mesh level). Continue adaptive process until reaching a targeted level of mesh converge where CL and CD change less than 0.02 and 0.002 between successive mesh levels. It is expected that this target will be difficult to achieve particularly for angles of attack near CLmax. If you are not able to achieve the target level, report the mesh convergence criteria that you used.
3. Numerical hysteresis is expected where flow separation patterns are sensitive to initial conditions. There is likely to be low (more flow separation) and high (less separation) lift attractors. Participants are encouraged to seek the high lift attractor through angle of attack continuation or other means. Initialization and continuation techniques should be documented as well as the presence of multiple solutions at given freestream flow conditions. Participants may need to compute multiple angles of attack between the requested values to maintain a proximity to the high lift attractor.
4. Compare results (adaptive mesh with experimental data):
   1. Evaluate lift, drag, viscous drag and pitching moment mesh convergence for the adaptive mesh simulations.
   2. Compare surface pressures, skin friction, surface streamlines, and velocity profiles, and mesh images for the highest resolution adaptive mesh solutions.
   3. Compare important flow features and associated mesh characteristics between the adaptive mesh simulations. Key features to be compared will be identified by the adapt TFG planning team.
5. Complete and return data submittal form.
6. Identify best practice guidelines and share with TFG team

*Adapt TFG Team Actions*

1. Compare data from all participant adaptive mesh processes.
2. Develop best practice guidelines (general)
3. Identify open simulation issues - design additional investigations to explore open issues as appropriate and as time permits
4. Assemble participant teams to perform additional investigations identified above (actual studies will depend on results and participant interest)
5. Example additional investigations:
   1. Create simplified model of wing with one bracket to investigate “pizza slice” separation.
   2. Investigate approaches to stay on high-lift solution branch (alpha continuation, separation adverse turbulence model, mixed complexity restarts …)
   3. Investigate alternative turbulence models with adaptive meshes
   4. Use of adaptive meshes with URANS for separated conditions

**Case 4 - Adaptive Mesh Simulation of Flap Increments** **(Optional)**

**Case description**: Generate adaptive mesh solutions for three HLCRM geometry models with inboard/outboard TE flap deflections of (37°/34°, 40°/37°, and 43°/40°) in free air at attached flow condition (HLPW4 Case 1a available on the HLPW4 web site for full run condition details).

**Run Conditions**:

|  |  |
| --- | --- |
| Mach Number | 0.2 |
| Angle of Attack | 7.05° (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 |
| Semi-span model reference area | 297,360.0 in2 |
| 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. * Y-symmetry can be used for all models * For RANS, run simulations fully turbulent. * All simulations are “free air”; no wind tunnel walls or model support systems. * Participants are requested to use the standard outer boundary definition available on the HLPW4 geometry download site. If an alternate boundary is used it should be located at a minimum of 1000 chord lengths. |
| Data Delivery | Forces/moments, surface pressures, surface streamlines, for all finest mesh level. Forces/moments for all mesh levels. |

**Objective**: Investigate approaches for computing flap deflection increments using adaptive meshes.

Supports key questions 4-6.

**Approach:**

*Participant Actions*

1. Run an adaptive mesh simulation on each of the 3 flap deflection geometry models at the flow condition in the above table. If multiple solvers, error estimates or mesh mechanics are used, separate data should be generated for each solver algorithm, mesh mechanics, error estimate combination.
2. Run solution adaptive process on a sequence of adaptive meshes with increasing DOF (a minimum of 4 mesh levels is desired with a 150% or greater increase in degrees of freedom between each mesh level). In order to compute meaningful increments at each mesh level, attempt should be made to converge to static forces and moments at each adaptive mesh resolution by generating multiple adaptive meshes with constant DOF.
3. Continue the adaptive process until reaching a targeted level of mesh converge where CL and CD change less than 0.02 and 0.002 between successive mesh levels. If you are not able to achieve the target level of mesh convergence, report the mesh convergence criteria that you used.
4. Compute lift, drag and pitching moment increments between the 37°/34° and 40°/37° models and between the 43°/40° and 40°/37° models at a minimum of 4 mesh resolution levels.
5. Compare results:
   1. For each of the three flap deflections, evaluate lift drag and pitching moment convergence at each DOF and mesh convergence for increasing mesh levels. Compare force and moment data with experimental and fixed mesh results where available.
   2. Compare surface pressures, skin friction, surface streamlines, and velocity profiles, and mesh images for the highest resolution adaptive mesh solutions.
   3. Compare important flow features and associated mesh characteristics between the three flap deflection simulations. Key features to be compared will be identified by the adapt TFG planning team.
6. Complete and return data submittal form.
7. Identify best practice guidelines and share with TFG team

*Adapt TFG Team Actions*

1. Compare data from all participant adaptive mesh processes.
2. Develop best practice guidelines for increment calculation.
3. Identify open simulation issues - design additional investigations to explore open issues as appropriate and as time permits
4. Assemble participant teams to perform additional investigations identified above.

1. [↑](#footnote-ref-1)