HiLiftPW-3
Case 1 Results Summary

Tony Sclafani, Jeff Slotnick
The Boeing Company

Mark Chaffin, Jason Feinman
Textron Aviation

Stefan Melber
DLR, German Aerospace Center

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Case 1: Grid Convergence Study

Outline

- Case Description
- Grid Families
- Participant List
- Results
  - Overview
  - Iterative Convergence
  - Lift, Drag and Pitching Moment
  - Pressures and Skin Friction
  - Velocity Profiles
- Conclusions
Case 1: Grid Convergence Study

Geometry and Requested Case

Flow solutions 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 the flow solution for the extra-fine mesh is optional.

Geometry

The NASA High Lift Common Research Model (HL-CRM) is a wing-body high lift system that will be studied in a nominal landing configuration (slat and flaps deployed at 30° and 37°, respectively) without nacelle, pylon, tail, or support brackets.

Case Parameters and Requirements

Case 1a: Full Chord Flap Gap (REQUESTED)

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<th>Parameter</th>
<th>Value</th>
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<td>Reference Static Pressure</td>
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<td>Mean Aerodynamic Chord (MAC)</td>
<td>275.8 inches full scale</td>
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Important Details:

- The intent here is to analyze the full-scale geometry at wind tunnel conditions. Instead of scaling the geometry down to 10% scale, we are analyzing the full-scale grid in a more viscous fluid. In other words, viscosity in this case is not sea level standard, but is scaled up appropriately, to achieve the desired Re of 3.26 million based on 275.8 inches for the full-scale model.
- Run simulations FULLY TURBULENT.
- This configuration is gapped approximately 1” full-scale between the inboard/outboard flaps and between inboard flap and side of body.
- All simulations are “free air”; no wind tunnel walls or model support systems.
Case 1: Grid Convergence Study

Optional Cases

Case 1b: Full Chord Flap Gap with Adaptation (OPTIONAL)
Use grid refinement based on automatic solution adaptation and/or solution-guided grid regeneration to perform the required grid convergence study using the parameters from Case 1a.

Case 1c: Partially-sealed Chord Flap Gap (OPTIONAL)
Using the flow conditions from Case 1a, provide flow solutions for the medium grid only with a partial chord seal between the inboard and outboard flaps, and between the inboard flap and side of body.

Case 1d: Partially-sealed Chord Flap Gap with Adaptation (OPTIONAL)
Use grid refinement based on automatic solution adaptation and/or solution-guided grid regeneration to perform the required grid convergence study using the parameters from Case 1c.
### Case 1 Grid Families

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**Graphs:**
- **Number of Points**
  - Blue = Coarse
  - Green = Medium
  - Black = Fine
  - Red = X-Fine
- **Number of Cells**
# Case 1 Participants

## Detailed List

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<tr>
<th>Item</th>
<th>PID</th>
<th>Author</th>
<th>Model</th>
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- **Y**: Dataset Complete
- **I**: Dataset Incomplete

- 29 Participants
- 46 Datasets
- Case 1a = 46
- Case 1b = 2
- Case 1c = 10
- Case 1d = 2
### Case 1 Participants

#### Detailed List (continued)

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### Dataset Status
- **Y**: Dataset Complete
- **I**: Dataset Incomplete

### Case Breakdown
- Case 1a = 46
- Case 1b = 2
- Case 1c = 10
- Case 1d = 2

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29 Participants
46 Datasets
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Results Overview

Compare Iterative Convergence for Lift and Residual

Forces and Moments:
• Focus on lift prediction for Case 1a
• Plot grid convergence using $N^{-2/3}$
  - grid convergence plots are used to visualize general trends only
• Compare grid convergence trends for various grid and turbulence model types
• Compare grid convergence trends between pre-defined grid family (global uniform refinement) and adapted meshes (targeted refinement)
• Compare increments due to flap gap

Pressures and Skin Friction:
• Focus on Medium Grid, $\alpha = 16^\circ$ data at 3 span stations: $\eta = 0.240, 0.552, 0.908$

Velocity Profiles:
• Focus on Medium Grid, $\alpha = 16^\circ$ data at 2 span stations: $\eta = 0.240, 0.552$
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Lift Convergence

Case 1a, Medium Grid, $\alpha = 8^\circ$

Case 1a, Medium Grid, $\alpha = 16^\circ$

- Due to large variation in iteration, convergence data was normalized for comparison purposes.

$$\text{Normalized Iteration} = \frac{(\text{Current Iteration} - \text{Min Iteration})}{(\text{Max Iteration} - \text{Min Iteration})}$$
• About 90% of Case 1a data shown
• Lift levels appear to be converged to at least the second decimal place
• Dataset G and some of the T datasets stand-out at 16° as varying more in $C_L$ over the second half of the run
Residual Convergence

Based on the limited set of data submitted to date, there's a 1-to-3 order drop in residual for the Medium Grid run at 8° angle-of-attack.

Many of the solutions stop converging very early in the run.
Case 1: Grid Convergence Study

Outline

• Case Description
• Grid Families
• Participant List
• Results
  ➢ Overview
  ➢ Iterative Convergence
  ➢ Lift, Drag and Pitching Moment
  ➢ Pressures and Skin Friction
  ➢ Velocity Profiles
• Conclusions
• Data show a general increase in lift with grid refinement
• There is a greater lift variation at higher alpha
• 16° plot shows larger slopes indicating greater sensitivity to grid refinement
• Datasets P, T, Z, d, g have slopes and levels significantly different than most other datasets

Note: The Z data are for a Reynolds number of 32.6 million instead of 3.26 million
- The variation in $C_L$ for the medium grid is significant at both angles-of-attack.
- Spread at 8° is roughly 8% of $C_{L_{max}}$

- Based on continuum values at 8° and 16°
- Estimate level at 0° and $C_{L_{max}}$ using CFD from design
- Error bars defined by participant data spread for medium grid
With data plotted separately, there are no obvious differences in refinement trends due to grid type.
Case 1a Sorted by Grid Type: 16°

- With data plotted separately, there are no obvious differences in refinement trends due to grid type.
The Spalart-Allmaras (SA) turbulence model was broken-out because it was used in 63% of the Case 1 datasets.

Excluding datasets Z and g, the multi-colored SA results appear to be tightly bunched together and trending in a consistent manner.
Not clear what effect QCR and the Rotation (R) and Correction (C) terms have.

“All Others” is made up of various TM types (including LBM), so it’s not surprising to see more $C_L$ variation compared to just the SA results.
• Not clear what effect QCR and the Rotation (R) and Correction (C) terms have.
• “All Others” is made up of various TM types (including LBM), so it’s not surprising to see more $C_L$ variation compared to just the SA results.
Uniform Refinement vs. Adaption

G data represent expected result at 8° where coarser adapted mesh produces similar lift level as finer uniformly refined mesh.

The 16° adapted mesh data does not converge as quickly as 8°.
Considerable increase in drag variation at higher AOA.

The g dataset is an extreme outlier at 8°.

The b dataset is an extreme outlier for pitching moment.
Removed datasets P, T, Z, b, d, g based on general observations of $C_L/C_D/C_M$ data trends and levels.

Note: The Z data are for a Reynolds number of 32.6 million instead of 3.26 million.
• Based on continuum values at 8° and 16°
• Estimate level at 0° and $C_{L_{\text{max}}}$ using CFD from design
• Error bars defined by participant data spread for medium grid

Removed datasets P, T, Z, b, d, g based on general observations of $C_L/C_D/C_M$ data trends and levels.

• With outliers removed, the variation in $C_L$ for the medium grid level looks more promising
Effect of Flap Gap

\[ \alpha = 8^\circ \]

\[ \alpha = 16^\circ \]

<table>
<thead>
<tr>
<th>( \Delta = \text{(PARTIAL CHORD GAP - FULL CHORD GAP)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>med</td>
</tr>
<tr>
<td>001.1</td>
</tr>
</tbody>
</table>

Full Chord Gap

Partial Chord Gap
Case 1: Grid Convergence Study

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• Conclusions
eta = 0.240

- Significant variation in wing minimum Cp levels
- Flap minimum Cp levels vary more than wing
eta = 0.552

- Significant variation in wing minimum Cp levels
- Flap minimum Cp levels vary more than wing
- Dataset P predicts significantly higher flap suction pressure
Pressure – Case 1a, Med, 16°

eta = 0.908

- Significant variation in wing minimum Cp levels
- Datasets d and P bracket all upper surface wing pressures

Datasets d and P bracket all upper surface wing pressures
Variation in skin friction is considerably larger than pressure variation.

Datasets Z, P and S represent the extremes for the wing.

Note: The Z data are for a Reynolds number of 32.6 million instead of 3.26 million.
Variation in skin friction is considerably larger than pressure variation.

Datasets Z, P, b and S represent the extremes for the wing.

Note: The Z data are for a Reynolds number of 32.6 million instead of 3.26 million.
Skin Friction – Case 1a, Med, 16°

- Structured-Overset
- Unstructured, Tet
- Unstructured-Mixed, Prism/Tet
- Unstructured-Mixed, Hex dom.
- Participant Grid

\[ \eta = 0.908 \]

- Variation in skin friction is considerably larger than pressure variation
- Datasets Z, P and S represent the extremes for the wing

Note: The Z data are for a Reynolds number of 32.6 million instead of 3.26 million
Case 1a, Fine, 8°

Wing LE, Upper

- Irregular Cp distributions on wing and flap suggest surface curvature issues
Case 1: Grid Convergence Study

Outline

• Case Description
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  ➢ Velocity Profiles

• Conclusions
Vel Profile 1 – Case 1a, Med, 16°

eta = 0.240
Wing Rake

- Comparison covers 100” off surface (36% of Cref)
- Dataset T profiles show flow deceleration (slat wake?) near the surface where others do not
Vel Profile 2 – Case 1a, Med, 16°

\[ \eta = 0.240 \]

IB Flap Rake

- Comparison covers 100” off surface (36% of Cref)
- Dataset r appears to be offset
- Datasets P and T represent wing BL and wake profile extremes
eta = 0.552
Wing Rake

- Comparison covers 100” off surface (36% of Cref)
- Datasets P and T represent wing BL profile extremes
eta = 0.552
OB Flap Rake

• Comparison covers 100” off surface (36% of Cref)
• Dataset K shows extreme flap BL profile near surface
• Datasets P and T represent profile extremes away from flap surface
Vel Profile 6 – Case 1a/b, 16°

Data submittal issue: profile is for initial coarse grid

eta = 0.552
OB Flap Rake

007.1 Committee Grid → B1, Tetrahedral
- Nodes: 26M for Medium Grid
  70M for Fine Grid
- Cells: 157M for Medium Grid
  416M for Fine Grid

008.1 Committee Grid → B3, Mixed (hex)
- Nodes: 27M for Medium Grid
  71M for Fine Grid
- Cells: 48M for Medium Grid
  119M for Fine Grid
Conclusions

Lift convergence looks reasonable for most datasets

Grid Convergence Plots:
• Relatively large variation in lift level in the Medium Grid range
• Data scatter increases with angle-of-attack
• After removing outliers, lift variation improved substantially

\( C_L/C_D/C_M \) increments due to partial chord flap seal are consistent

No clear data trends due to grid type or turbulence model

Pressure, skin friction and velocity data helpful in identifying potential outliers

Irregular pressure distribution on wing and flap suggest surface curvature issues
Back-Up
Lift convergence at 8° looks similar for the Medium and Fine Grids

Need to plot Normalized Iteration and include labels to comment further
Lift Convergence: Grid Effect

- Lift convergence at $16^\circ$ looks similar for the Medium and Fine Grids
- Need to plot Normalized Iteration and include labels to comment further
Limited set of data for Case 1c
Even more limited set for Case 1b/d (not shown)

• Case 1a = 46
• Case 1b = 2
• Case 1c = 10
• Case 1d = 2
Case 1a Sorted by Grid Type

- Does not appear to be unique groupings or trends due to grid type
Flap Pressures – Case 1a, Med, 8°

eta = 0.329

- Structured-Overset
- Unstructured, Tet
- Unstructured Mixed, Prism/Tet
- Unstructured Mixed, Hex dom.
- Participant Grid

eta = 0.418

- Structured-Overset
- Unstructured, Tet
- Unstructured Mixed, Prism/Tet
- Unstructured Mixed, Hex dom.
- Participant Grid

Cp and Cf extraction locations for HiLiftPW-3 (clean HL-CRM config)

y = 1050 (eta = 0.908)
y = 947 (eta = 0.819)
y = 792.5 (eta = 0.685)
y = 638 (eta = 0.552)
y = 483.5 (eta = 0.418)
y = 380.5 (eta = 0.329)
y = 277.5 (eta = 0.240)
y = 174.5 (eta = 0.151)

(x values in full-scale inches)

(y values in full-scale inches)