Overview and Summary of the Third AIAA High Lift Prediction Workshop

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Overview

• General summary of HiLiftPW-3 results.
  • CFD comparisons against itself (consistency, verification).
  • CFD comparisons against experiment (validation).

• Have things improved since HiLiftPW-2?

• What have we learned?

• What should be done differently for HiLiftPW-4?
Outline

• Introduction
• High lift geometries and experimental data
• Grid systems
• Summary of entries
• Results
  • Turbulence modeling verification
  • HL-CRM
  • JSM
• Statistical analysis
• Conclusions
Where we’ve been (some highlights)

• HiLiftPW-1 (2010).
  • NASA Trapezoidal Wing-Body; including effect of flap deflection.
  • CFD tended to underpredict lift; big spread near stall.
  • No support brackets were included in the CFD (when they were, predicted lift was even lower).
  • Transition modeling seemed to help improve comparisons with experiment.
  • Flow near wing tip was very difficult to predict.
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Where we’ve been (some highlights)

• HiLiftPW-2 (2013).
  • DLR-F11 Wing-Body; including effect of Reynolds number.
  • CFD sometimes underpredicted, sometimes overpredicted lift; again showed bigger spread near stall.
  • Separation behind slat tracks was probably influential in initiating stall; even when including brackets, CFD usually got it wrong (e.g., separation behind wrong brackets).
  • No clear trends with transition modeling stood out.
  • Attaining steady-state convergence sometimes difficult.
  • Experimental oil flows were extremely useful for determining whether CFD was capturing the physics correctly or not.
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• Experimental oil flows were extremely useful for determining whether CFD was capturing the physics correctly or not.
Quick comparison

HiLiftPW-1

HiLiftPW-2

HiLiftPW-3

37 submissions

48 submissions

79 submissions
HiLiftPW-3 geometries and experimental data

- HL-CRM
  - Not yet built

- JSM
  - Tested in JAXA-LWT1 in early 2000s
  - No tripping

Forces
Moment
Cp
Oil flow
Some transition info
HiLiftPW-3 geometries and experimental data

HiLiftPW-3 also partnered with the first Geometry and Mesh Generation Workshop (GMGW-1), using HL-CRM.

Not yet built

Tested in JAXA-LWT1 in early 2000s
- No tripping

Forces
Moment
Cp
Oil flow
Some transition info
Committee-provided grid systems

For HL-CRM and JSM

Average medium grid: approx 71 M points and 120 M cells
Median medium grid: approx 52 M points and 107 M cells
Summary of entries

• 35 individuals/groups with 79 entries.
  • 14 different countries (40% U.S.).
  • Broad representation from industry, academia, CFD vendors, and government research labs.

• Turbulence models:
  • Most used SA or variant (RC, R, neg, QCR, noft2).
  • Lag-EB-ke.
  • SSG/LRR-RSM-w2012.

• Transition models:
  • SST-gamma, AFT2017b, gamma-Ret-SST.

• Non-RANS:
  • Finite element with implicit SGS model.
  • LB with VLES wall model.
  • LB with WALE SGS model.
  • DDES.

• Not everyone submitted all requested cases.
• Details in paper.
Results

• Turbulence modeling verification
• HL-CRM
• JSM
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• Turbulence modeling verification
  • HL-CRM
  • JSM

DSMA661(Model A) airfoil,
M=0.088, alpha=0 deg,
Re_c=1.2 million
(JFM 160:155-179, 1985)
Turbulence modeling verification

Only completed for SA model (SA, SA-neg, SA-noft2)
The important role of verification

2-D verification case
8 different codes produce nearly identical results for SA model
(CFL3D, FUN3D, Kestrel/COFFE, CFD++, OVERFLOW, BCFD, TAU, and LAVA)

Approximately 30% of the codes that ran the verification case were fully verified for the SA model

Additional verification exercises still needed for other models, including SA variants

VERIF/2DANW case from TMR website: https://turbmodels.larc.nasa.gov

Verification removes one possible source of CFD uncertainty, for a given model.
Other sources: grid (size, extent, adherence to geometry), BCs, iterative convergence.
Results

• Turbulence modeling verification
• HL-CRM
• JSM

Focusing on only a few main points here; further details (such as effect of flap gap treatment) are given in the paper.
HL-CRM grid convergence (all results)

Note: blue curves represent grid-adaption results

Drag and moment shown in paper

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The important role of verification

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Blue lines passed the verification test for SA

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HL-CRM
SA models only
The important role of verification

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Blue lines passed the verification test for SA
HL-CRM velocity profiles

FLAP: x=1615, y=638

MAIN: x=1495, y=638
Results

• Turbulence modeling verification
• HL-CRM
• JSM

Focusing on only a few main points here; further details are given in the paper
JSM, no nacelle/pylon

Lift coefficient

Drag coefficient

Moment coefficient
Lift coefficient

Drag coefficient

Moment coefficient
JSM, deltas between nacelle/pylon on and off

Except for one outlier, participants predicted deltas well (albeit large scatter near max lift)
CFD results that agreed “best” with JSM $C_L$ data

Minimize $\frac{1}{N} \sum (C_L^{CFD} - C_L^{exp})^2$

(ignoring results with no/late $C_{L,max}$)

No nacelle/pylon

With nacelle/pylon
General observation from the workshop

• Most of the RANS codes produced surface flows that had too much separation near the wing tip compared to the experiment and not enough separation near the wing root at and beyond max lift.
  • Notable exceptions: scale-resolving methods (like LB).
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  • Notable exceptions: scale-resolving methods (like LB).
JSM: surface pressure coefficients

Main element, alpha=21.57 deg., no nacelle/pylon
JSM: issues near $C_{L,\text{max}}$

Grid and temporal treatment both have big influence

**No nacelle/pylon**

- Same code & model, different grid

**With nacelle/pylon**

- Same code, model & grid, time-accurate vs. steady-state

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**Graphs:**

- **No nacelle/pylon**
  - $C_L$ vs. $\alpha$, deg
  - experiment
  - 017.1
  - 017.2
  - 019.2
  - 019.3
  - 022.2
  - 022.3

- **With nacelle/pylon**
  - $C_L$ vs. $\alpha$, deg
  - experiment
  - 017.1
  - 017.2
  - 019.2
  - 019.3
  - 022.2
  - 022.3
JSM: further evidence of insufficient grid density

All “SA-verified” codes do not agree well using SA on (different) medium grids

And blue curves point to minor issues with insufficient iterative convergence and/or code setting/version differences
JSM: effect of transition models

- Transition definitely present at this Re
- For 030.1 vs. 030.3 (committee grid E), little influence of transition noted
- For 030.2 vs. 030.4 (participant grid b), transition caused higher CL in the linear range and an earlier stall, in better agreement with experiment
Statistical analysis: HL-CRM

• Main conclusion: general scatter did not always decrease between the medium and fine grids, as would be expected if numerical error due to grid resolution was the primary source of variation.
Statistical analysis: JSM

Focusing on only a few main points here; further details are given in the paper.

$\alpha = 4.36$ deg.

$\alpha = 14.54$ deg.

$\alpha = 20.59$ deg.

$C_v = \sigma / \mu = \text{standard deviation} / \text{median}$

$\text{Scatter limits} = \mu \pm K \sigma \ (K = \sqrt{3})$
Has CFD gotten any tighter since HiLiftPW-2?

Low Re, with brackets, medium grids

<table>
<thead>
<tr>
<th>Cases</th>
<th>Cv, low alpha</th>
<th>Cv, mid alpha</th>
<th>Cv, high alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>HiLiftPW-2, alpha=7, 16, 20 deg.</td>
<td>0.038</td>
<td>0.057</td>
<td>0.060</td>
</tr>
<tr>
<td>HiLiftPW-3, alpha=4.36, 14.54, 20.59 deg.</td>
<td>0.025</td>
<td>0.017</td>
<td>0.073</td>
</tr>
</tbody>
</table>
Conclusions

• In the verification case, only 30% of the CFD codes that participated with the SA turbulence model were fully verified.

• HL-CRM case explored grid convergence.
  • Spread between CFD results did not diminish on fine grids (similar to HiLiftPW-2).
  • Lack of verification in some codes may explain part of the spread.

• JSM explored effect of nacelle/pylon installation.
  • Use of “medium” grid only; deltas were generally well predicted.
  • Large spread in CFD results near $C_{L,\text{max}}$ (similar to HiLiftPW-1 and 2).
  • Significant influence of grid near $C_{L,\text{max}}$, so ”medium” grid probably not fine enough.
  • Transition should be important for this case, but transition models were not always better (grid influence?).
  • Many individual results compared very well with experimental lift curve; but we do not know why.
  • It was possible to get integrated quantities right for the wrong reasons.
  • Scale-resolving methods appeared to predict separation patterns better than RANS.
  • Participants were more consistent (compared to HiLiftPW-2) predicting complex high-lift configuration at low Re with all mounting bracket hardware at low alphas – BUT NOT NEAR $C_{L,\text{max}}$. 

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HiLiftPW-4 status and other questions/thoughts

• What should be done differently in HiLiftPW-4, so that we learn more?
  • Proposal: require the use of one or more specific (verified) models.
    • Identify the “best” (publicly-available) RANS model(s) from this workshop, and request that all RANS participants verify it in their code and use it.
    • Allow additional results using any model or model variant.
  • Near $C_{L,max}$: encourage larger grids, more grid adaption, higher order, time-accurate, more use of scale-resolving methods.
  • No more free-air CFD runs; try to match the wind tunnel semispan testing geometry and BCs.
End
Backup
Introduction

- Specific workshop series focused on the prediction of swept, medium/high-aspect ratio wings in landing/takeoff (high lift) configurations.

- Goals of HiLift workshop series:
  - Assess the numerical prediction capability of current-generation CFD technology.
  - Develop practical modeling guidelines for CFD prediction of high lift flow fields.
  - Advance the understanding of high lift flow physics to enable development of more accurate prediction methods and tools.
  - Enhance CFD prediction capability for high lift aerodynamic design and optimization.
  - Provide an impartial forum.
  - Identify areas needing additional research and development.
Test cases

• Case 1 - Grid Convergence Study on the NASA HL-CRM (free air, fully turb).
  • 1a: Full chord flap gap, M=0.2, $Re_{MAC}=3.26$ M, alpha=8, 16 deg.
  • 1b: Same as 1a, with grid adaption.
  • 1c: Same as 1a except partially-sealed flap gap.
  • 1d: Same as 1c, with grid adaption.

• Case 2 - Nacelle Installation Study on the JSM (free air, fully turb or with transition).
  • 2a: Nacelle/pylon off, M=0.173, $Re_{MAC}=1.93$ M, six alphas.
  • 2b: Same as 2a, with grid adaption.
  • 2c: Same as 2a except Nacelle/pylon on.
  • 2d: Same as 2c, with grid adaption.

• Case 3 - Turbulence Model Verification Study (fully turb).
  • VERIF/2DANW from http://turbmodels.larc.nasa.gov
## Grid systems

### HL-CRM “committee grids”

<table>
<thead>
<tr>
<th>Label</th>
<th>Grid tool</th>
<th>Org</th>
<th>Type</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
<th>Extra-fine</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-HLCRM</td>
<td>ANSA+ Chimera</td>
<td>NASA</td>
<td>str</td>
<td>24/23</td>
<td>65/64</td>
<td>189/185</td>
<td>564/554</td>
<td>Overset</td>
</tr>
<tr>
<td>B1-HLCRM</td>
<td>Pointwise</td>
<td>Pointwise</td>
<td>unstr</td>
<td>8/48</td>
<td>26/157</td>
<td>70/416</td>
<td>206/1228</td>
<td>Tet</td>
</tr>
<tr>
<td>B2-HLCRM</td>
<td>Pointwise</td>
<td>Pointwise</td>
<td>unstr</td>
<td>8/22</td>
<td>26/65</td>
<td>70/170</td>
<td>206/541</td>
<td>Mixed/prism/tet</td>
</tr>
<tr>
<td>B3-HLCRM</td>
<td>Pointwise</td>
<td>Pointwise</td>
<td>unstr</td>
<td>8/18</td>
<td>27/48</td>
<td>71/119</td>
<td>208/397</td>
<td>Mixed</td>
</tr>
<tr>
<td>C-HLCRM</td>
<td>GridPro</td>
<td>GridPro</td>
<td>str</td>
<td>10/8</td>
<td>77/68</td>
<td>338/311</td>
<td>n/a</td>
<td>One-to-one</td>
</tr>
</tbody>
</table>

**Notes:**
- HL-CRM: “committee grids”
- Points/cells
# Grid systems

## JSM “committee grids”

<table>
<thead>
<tr>
<th>Label</th>
<th>Grid tool</th>
<th>Org</th>
<th>Type</th>
<th>Medium, no N/P</th>
<th>Medium, with N/P</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-JSM</td>
<td>Chimera</td>
<td>NASA</td>
<td>str</td>
<td>221/216</td>
<td>235/230</td>
<td>Overset</td>
</tr>
<tr>
<td>B-JSM</td>
<td>DLR-SOLAR</td>
<td>DLR</td>
<td>unstr</td>
<td>102/162</td>
<td>126/207</td>
<td>Mixed</td>
</tr>
<tr>
<td>C1-JSM</td>
<td>VGRID</td>
<td>Spaceship &amp; Gulfstream</td>
<td>unstr</td>
<td>16/97</td>
<td>21/124</td>
<td>Tet</td>
</tr>
<tr>
<td>C1-JSM</td>
<td>VGRID</td>
<td>Spaceship &amp; Gulfstream</td>
<td>unstr</td>
<td>16/52</td>
<td>21/65</td>
<td>Mixed</td>
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<tr>
<td>D-JSM</td>
<td>JAXA tools</td>
<td>JAXA</td>
<td>unstr</td>
<td>50/120</td>
<td>59/139</td>
<td>Mixed</td>
</tr>
<tr>
<td>E-JSM</td>
<td>ANSA</td>
<td>U Oxford &amp; BETA-CAE</td>
<td>unstr</td>
<td>52/107</td>
<td>58/120</td>
<td>Mixed</td>
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