CHAMPS Contributions to the Fourth High Lift Prediction Workshop
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Summary

• Solver presentation
• Case 3 : Verification
• Case 1b : Grid refinement
• Case 2a : Polar, cold start versus warm start
• Conclusion
CHApel Multi-Physics Simulation

CHAMPS (CHApel Multi-Physics Simulation) is a software developed at Polytechnique Montréal:

- Unsteady Reynolds Averaged Navier-Stokes;
- SA, $k - \omega$ SST, QCR2000 and $\gamma - \text{Re}_{\theta_t}$ turbulence models;
- Aero-icing;
  - Water droplet solver;
  - Thermodynamique model;
  - Stochastic icing;
- Aero-elastic;
- Global linear stability analysis;

Written in Chapel language
Why Chapel?

- Chapel is a new language which is an alternative to the classic C/C++ or Fortran with MPI paradigm;
- Use a global namespace for direct access to local or remote variables;
- Feature rich language, aiming to be as programmable as Python;
- Object-oriented, allowing us to reuse structures for several models;
- Chapel is a productive language:
  - Reduce the barrier of entry to HPC;
  - Developed by a team of 7 (students and researchers);
  - CHAMPS started in the summer of 2019 and was used for the HLPW4, IPW1 and DPW7.
Numerical Method

Flow solver

- Cell-centered finite volume scheme;
- Second order Roe scheme with piecewise linear reconstruction;
- Green-Gauss gradient;
- Venkatakrishnan limiter (removed when possible);
- Standard Spalart-Allmaras turbulence model;
- Relaxation on the update of the gradients;
- Implicit Euler iterative scheme;
- Block Symmetric Gauss-Seidel linear solver.

Initialization strategy

- From free-stream (Cold start);
- From previous $\alpha$ (Warm start);
- Extrapolation from 2 previous $\alpha$ ($W = W_0 + \frac{W_o - W_{oo}}{\alpha_o - \alpha_{oo}} (\alpha - \alpha_o)$).
## CASE 3 - 2D HL-CRM grids

Meshes from the NASA Turbulence Model Resource website.

<table>
<thead>
<tr>
<th>Grid</th>
<th>Family 1</th>
<th>Family 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nb. Nodes (K)</td>
<td>Nb. Cells (K)</td>
</tr>
<tr>
<td>L1</td>
<td>174</td>
<td>174</td>
</tr>
<tr>
<td>L2</td>
<td>294</td>
<td>295</td>
</tr>
<tr>
<td>L3</td>
<td>508</td>
<td>508</td>
</tr>
<tr>
<td>L4</td>
<td>931</td>
<td>931</td>
</tr>
<tr>
<td>L5</td>
<td>1700</td>
<td>1700</td>
</tr>
<tr>
<td>L6</td>
<td>3200</td>
<td>3000</td>
</tr>
<tr>
<td>L7</td>
<td>6000</td>
<td>6000</td>
</tr>
</tbody>
</table>
CASE 3 - Iterative Convergence

2D HL-CRM: Reynolds number 5 million, Mach number 0.2 and $\alpha = 16^\circ$

- Spikes in convergence when the strength of the limiter is reduced;
- No limiter at the end of the simulation;
- Convergence of at least 8 orders of magnitude for the density residuals.
CASE 3 - Forces Convergence

2D HL-CRM: Reynolds number 5 million, Mach number 0.2 and $\alpha = 16^\circ$

- Lift increases when the limiter is reduced;
- Drag decreases when the limiter is reduced;
- Convergence to a steady value reached.
CASE 3 - Grid Convergence

2D HL-CRM: Reynolds number 5 million, Mach number 0.2 and $\alpha = 16^\circ$

- Family 1 one has an offset compared to FUN3D;
- Family 2 is well aligned with FUN3D;
- FUN3D is vertex-centered and CHAMPS is cell-centered. There could be a combination of discretization and grid quality causing this offset.
CASE 1B - HLCRM Grids

Meshes from AIAA High Lift Prediction Workshop 4 website.

<table>
<thead>
<tr>
<th>Grid</th>
<th>Nb. Nodes (M)</th>
<th>Nb. Cells (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pointwise 2.3.A</td>
<td>12.3</td>
<td>21.8</td>
</tr>
<tr>
<td>Pointwise 2.3.B</td>
<td>32.3</td>
<td>52.8</td>
</tr>
<tr>
<td>Pointwise 2.3.C</td>
<td>92.0</td>
<td>141.5</td>
</tr>
<tr>
<td>Pointwise 2.3.D</td>
<td>203.0</td>
<td>301.0</td>
</tr>
<tr>
<td>ANSA 101.C</td>
<td></td>
<td>216.7</td>
</tr>
</tbody>
</table>
CASE 1B - Iterative Convergence

CRM-HL: Reynolds number 5.49 million, Mach number 0.2 and $\alpha = 7.05^\circ$

- Density convergence stagnates for grid 2.3A and 101.C;
- Spalart-Allmaras residual does not converge (this seems to be caused by a small number of cells near the slat).
CASE 1B - Forces Convergence

CRM-HL: Reynolds number 5.49 million, Mach number 0.2 and $\alpha = 7.05^\circ$

- Steady force value or small limit cycle achieved;
- Non-monotonic convergence;
- Grid convergence is not achieved with the pointwise grid family.
CASE 1B - Skin Friction

(a) Level A

(b) Level C

(c) Level D
CASE 2A - Polar

CRM-HL : Reynolds number 5.49 million and Mach number 0.2

- Different solutions obtained when changing the initialization;
- Level B and Level C lift coefficient are very similar.
CASE 2a - Level C Cold Start

(a) $\alpha = 11.29^\circ$

(b) $\alpha = 17.05^\circ$

(c) $\alpha = 19.57^\circ$

(d) $\alpha = 17.98^\circ$

(e) $\alpha = 18.97^\circ$

(f) $\alpha = 19.98^\circ$
CASE 2a - Level C Warm Start

(a) $\alpha = 11.29^\circ$

(b) $\alpha = 17.05^\circ$

(c) $\alpha = 19.57^\circ$

(d) $\alpha = 17.98^\circ$

(e) $\alpha = 18.97^\circ$

(f) $\alpha = 19.98^\circ$
CASE 2A - Solution Extrapolation

CRM-HL : Reynolds number 5.49 million and Mach number 0.2

First-order warm start : $W = W_o + \frac{W_o - W_\infty}{\alpha_o - \alpha_\infty} (\alpha - \alpha_o)$

- Lift coefficient directly jumps with the first-order warm start;
- The warm start method changes the path of the convergence.
CASE 2A - Level A Convergence

CRM-HL : Reynolds number 5.49 million and Mach number 0.2

First-order warm start: \[ \mathbf{W} = \mathbf{W}_o + \frac{\mathbf{W}_o - \mathbf{W}_oo}{\alpha_o - \alpha_{oo}}(\alpha - \alpha_o) \]
CASE 2A - Level A Skin Friction

(a) $\alpha = 11.29^\circ$, cold start

(b) zero order warm start

(c) first order warm start

(d) $\alpha = 17.05^\circ$, cold start

(e) zero order warm start

(f) first order warm start

Surface friction coefficients Increasing $\alpha$. 
CASE 2A - Level A Skin Friction

(a) $\alpha = 11.29^\circ$, cold start
(b) zero order warm start
(c) first order warm start
(d) $\alpha = 17.05^\circ$, cold start
(e) zero order warm start
(f) first order warm start

Surface friction coefficients Decreasing $\alpha$. 
CASE 2A - Level A Convergence

CRM-HL: Reynolds number 5.49 million and Mach number 0.2

First-order warm start: \( W = W_o + \frac{W_o - W_{oo}}{\alpha_o - \alpha_{oo}} (\alpha - \alpha_o) \)
CASE 2A - Level A Skin Friction

(a) $\alpha = 19.57^\circ$, cold start

(b) zero order warm start

(c) first order warm start

(d) $\alpha = 20.55^\circ$, cold start

(e) zero order warm start

(f) first order warm start

Surface friction coefficients increasing $\alpha$. 
CASE 2A - Level A Skin Friction

(a) $\alpha = 19.57^\circ$, cold start
(b) zero order warm start
(c) first order warm start
(d) $\alpha = 20.55^\circ$, cold start
(e) zero order warm start
(f) first order warm start

Surface friction coefficients Decreasing $\alpha$. 
Conclusion

Case 3:

- Standard Spalart-Allmaras turbulence model is verified;
- Solution in line with the reference (FUN3D) are obtained for the family 2, but a significant difference is obtained with family 1;
- Grid quality and refinement make a difference, even on this simple 2D case.

Case 1b:

- A 300 million cells fixed grid is still too coarse to obtain a monotonic convergence;
- Very similar solutions are obtained between the grid level B and C for the full polar (Case 2a).

Case 2a:

- Solution initialization has a large impact on the solutions;
- Using a first-order extrapolation warm-start might be a robust way of doing these simulations;
- Better convergence are required to assess the possible multiple solutions.
Acknowledgements

Computations were performed on Compute Canada/Calcul Québec Beluga and Narval clusters.