**DLR F11 Flow Predictions**

- **Solver:**
  - CFD++, Unified Grid Finite Volume solver
  - Unstructured Mixed-Element Cell-Based
  - 2nd order HLLC Riemann solver
  - Preconditioned
  - Multigrid acceleration
  - Run fully turbulent
## DLR F11 Flow Predictions

<table>
<thead>
<tr>
<th>Turbulence Model</th>
<th>Freestream Turbulence Level (%)</th>
<th>Eddy Viscosity Ratio ($\mu_t/\mu$)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>k-ε-Rt</td>
<td>0.05</td>
<td>20</td>
<td>no freestream $\mu_t$ decay</td>
</tr>
<tr>
<td>S-A</td>
<td>0.05</td>
<td>1</td>
<td>no freestream $\mu_t$ decay</td>
</tr>
<tr>
<td>SST</td>
<td>0.05</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>
**Solution information (Case 1 medium grid, 32M cells, unstructured hexa)**

- **Computer Platform:**
  - Up to 14 nodes used
  - Each node: 2 AMD Opteron 6172 (12 cores), 128 GB ram
  - Up to 336 cores used
  - Operating System: Centos/Redhat OS 5.5
  - Compiler: gcc 3.2.3
  - Run Time: 700 steps, incl. files outputs, 7.5 hours (288 cores)
  - Memory used: ~560 MB/process, 107 GB total (288 cores)
  - Lift and drag converged in 500 iterations or about 5 hours
**Hexa mesh (coarse, medium, fine grids)**

- **ICEM (A_uns_1to1_Case1Config2_v2)**

<table>
<thead>
<tr>
<th>MESH</th>
<th>No. of cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>9,556,725</td>
</tr>
<tr>
<td>Medium</td>
<td>31,998,440</td>
</tr>
<tr>
<td>Fine</td>
<td>100,561,536</td>
</tr>
</tbody>
</table>
Typical convergence history with k-ε-Rt model
DLR F11 Case 1 (grid sensitivity)
Case 1 Cp contours ($\alpha=7^\circ$) $k-\varepsilon-R_t$

Coarse | Medium | Fine

root
mid
tip
Case 1 Cp plots ($\alpha=7^\circ$)

$k$-\(\varepsilon\)-\(R_t\)
Case 1 Cp contours ($\alpha=16^\circ$)

$k-\varepsilon-R_t$
Case 1 Cp plots (α=16°) 

\( k-\varepsilon-R_t \)
Mach contours ($\alpha=7^\circ$) 

$k-\varepsilon-R_t$
Mach contours ($\alpha=16^\circ$)

$k-\varepsilon-R_t$
**Fine grid contours (α=16°)**

$k$-$\varepsilon$-$R_t$, SST, S-A

<table>
<thead>
<tr>
<th>Root Mach</th>
<th>Upper Cp</th>
<th>Lower $\tau_x$</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Root Mach" /></td>
<td><img src="image2" alt="Upper Cp" /></td>
<td><img src="image3" alt="Lower $\tau_x$" /></td>
</tr>
<tr>
<td><img src="image4" alt="Root Mach" /></td>
<td><img src="image5" alt="Upper Cp" /></td>
<td><img src="image6" alt="Lower $\tau_x$" /></td>
</tr>
<tr>
<td><img src="image7" alt="Root Mach" /></td>
<td><img src="image8" alt="Upper Cp" /></td>
<td><img src="image9" alt="Lower $\tau_x$" /></td>
</tr>
</tbody>
</table>

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Case 1 Forces/Moments Summary (k-ε-Rt)
Case 1 Forces/Moments Summary (SST)
Case 1 Forces/Moments Summary (SA)
As a unique exercise for this Workshop we ran both pre-conditioned and non-preconditioned modes to answer the often asked questions:

1. What is the effect of pre-conditioning?
2. Which approach is better?

- Both modes were used on coarse, medium and fine grids
- As expected, preconditioned results show better and much faster grid convergence
- On the finest meshes, non-preconditioned results edge toward the preconditioned ones as seen in the following slides
Precon. vs. non-precon. $\alpha=16^\circ$

S-A MODEL, FINE MESH

- Non-preconditioned
- Preconditioned

Upper $\text{Cp}$

Lower $\tau_x$

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Precon. vs. Non-precon. (S-A)
## DLR F11 Cases 2 (forces & moments)

- Prisms/Tets mesh (medium grid)
- Pointwise (C_uns_mix_Case2Config4_v1)

<table>
<thead>
<tr>
<th>MESH</th>
<th>No. of cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>149,963,804</td>
</tr>
</tbody>
</table>
DLR F11 Case 2(a+b) (forces & moments)

S-A Model
DLR F11 Case 2a ($\tau_x$)
DLR F11 Case 2b ($\tau_x$)
Summary and Conclusions

- CFD++ flow solver used for DLR F11 high-lift flow computations
- $k-\varepsilon-R_t$, SST and S-A turbulence models invoked on various unstructured and structured meshes provided by NASA
- Predictions on medium and fine grids very close for $C_\ell$, $C_d$
- Preconditioning enables faster and better grid convergence than non-preconditioned computations
- S-A closure predictions shown for Cases 2 (a) and (b)
- High Reynolds predictions closer to data than the low-Re ones (may be a transitional effect not taken into account)