Comparison of DES and LES for the separated flow over an axisymmetric hill

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Solvers

FOAM – Finite volume code used by FOI, used for LES results. FOAM is based on the same principles as open source code OpenFOAM.

CFD++ - Commercial finite volume code, used for RANS results
LES validation

Turbulent jet, Fureby 2001  Channel flow, Fureby et al. 2001  Cylinder, Persson et al. 2005
Naval Applications with LES

Yacht keel, Bensow *et al.* 2005

Darpa SubOff Aff-8, Svennberg *et al.* 2003

DTMB 5415, Svennberg *et al.* 2004

Propeller E779A, Wikström *et al.* 2002
Turbulence modelling:

LES combined with subgrid models:

OEEVM
One Equation Eddy Viscosity Model.
Combined with LES wall model.

MIXED
OEEVM + Scale similarity model.
Combined with LES wall model.

DES
Modified Spalart–Allmaras Turbulence model.
Built in wall handling.

Steady RANS:
Cubic k-epsilon model by Craft, Launder & Suga
Built in wall handling.
LES Wall-Modeling
Determine (locally) the $u_\tau$ from $v^+$ and *modify the viscosity*

$$\bar{v}^+ = \text{Law of the Wall} \quad \nu + v_{BC} \equiv \tau_w / (\partial v_y / \partial y)_p = u_\tau y_{y,p} / v_{y,p}^+$$

Hybrid RANS/LES (DES)
Combination of RANS and LES, RANS in the near wall region and LES in the slip-stream

RANS Wall-Modeling
Solve equations cubically all the way to the wall, requires high resolution $y^+ \approx 1$.
Combine with wall model based on the law-of-the-wall (Launder), requires lower resolution.

**Alternative methods for LES**

**Homogenisation based wall modeling**
Solve a subgrid problem within the boundary layer
Computational settings

Short Domain

• Computational domain 12H x 3.205H x 10H (Short)
• Computational domain 40H x 3.205H x 10H (Long)
• Computational grid 70 x 120 x 120 cells (Short)
• Computational grid 140 x 120 x 120 cells (Long)
• Computational grid 140 x 120 x 240 cells (Fine, Short)
• Computational grid 85 x 205 x 120 cells (RANS)
• Steady inlet velocity profile
• Noslip boundary condition on top and bottom wall
• Slip boundary condition on side walls

Long Domain

• Computational domain 12H x 3.205H x 10H (Short)
• Computational domain 40H x 3.205H x 10H (Long)
• Computational grid 70 x 120 x 120 cells (Short)
• Computational grid 140 x 120 x 120 cells (Long)
• Computational grid 140 x 120 x 240 cells (Fine, Short)
• Computational grid 85 x 205 x 120 cells (RANS)
• Steady inlet velocity profile
• Noslip boundary condition on top and bottom wall
• Slip boundary condition on side walls
Inlet profiles

\[ v_{in} = \begin{cases} 
U_\infty \left(\frac{y}{\delta}\right)^{1/n} & y < \delta, \\
U_\infty & y \geq \delta,
\end{cases} \]

\[ \tilde{v}_{in,\text{high}} = \begin{cases} 
0.08U_\infty d* / \delta(y - y^2 / \delta) & y < \delta, \\
0 & y \geq \delta,
\end{cases} \]

\[ \tilde{v}_{in,\text{low}} = \begin{cases} 
0.0027U_\infty d* / \delta(y - y^2 / \delta) & y < \delta, \\
0 & y \geq \delta,
\end{cases} \]

Filter definition

\[ \Delta_{LES} = 6 * V_{cell} / A_{cell} \]

\[ \Delta_{DES} = \max(\Delta x, \Delta y, \Delta z) \]
## Computational Matrix

<table>
<thead>
<tr>
<th>Case</th>
<th>Domain</th>
<th>Grid size</th>
<th>Subgrid Model</th>
<th>( \Delta x^<em>, \Delta y^</em>, \Delta z^* _\text{Freestream}[\text{mm}] )</th>
<th>( \Delta \text{Body}[\text{mm}] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>A</td>
<td>70x120x120</td>
<td>OEEVM</td>
<td>600,10,280</td>
<td>5 0.3</td>
</tr>
<tr>
<td>II</td>
<td>A</td>
<td>70x120x120</td>
<td>MM</td>
<td>600,10,280</td>
<td>5 0.3</td>
</tr>
<tr>
<td>III</td>
<td>A</td>
<td>70x120x120</td>
<td>DES</td>
<td>600,10,280</td>
<td>5 0.3</td>
</tr>
<tr>
<td>IV</td>
<td>A</td>
<td>70x120x120</td>
<td>DES</td>
<td>600,10,280</td>
<td>5 0.3</td>
</tr>
<tr>
<td>V</td>
<td>A</td>
<td>85x205x120</td>
<td>RANS</td>
<td>480,1,280</td>
<td>- -</td>
</tr>
<tr>
<td>VI</td>
<td>A</td>
<td>140x120x240</td>
<td>MM</td>
<td>300,10,140</td>
<td>3 0.3</td>
</tr>
<tr>
<td>VII</td>
<td>B</td>
<td>140x120x120</td>
<td>MM</td>
<td>620,10,280</td>
<td>5 0.3</td>
</tr>
<tr>
<td>VIII</td>
<td>B</td>
<td>140x120x120</td>
<td>DES</td>
<td>620,10,280</td>
<td>5 0.3</td>
</tr>
</tbody>
</table>

\[
\lambda_T = \sqrt{15} \beta^{-1/2} \text{Re}_l^{-1/2} \ l = 0.84 \text{mm}
\]

\[
\lambda_K = \beta^{-1/4} \text{Re}_l^{-3/4} \ l = 12 \mu m
\]

\[
\Delta = 6 * V_{cell} / A_{cell}
\]
Structures in the turbulent wake

- Mixed, short (Instantaneous)
- DES Low, short (Instantaneous)
- DES High, short (Instantaneous)
- RANS, short (Averaged)
Pressure distribution

\[ C_p = \frac{p_{\text{local,static}} - p_{\text{ref,static}}}{(p_{\text{ref,total}} - p_{\text{ref,static}})} \]
Separation along centerline

- **Experiment**
- **OEEVM, short**
- **Mixed, short**
- **DES High, short**
- **DES Low, short**
- **RANS, short**
- **Mixed Fine, short**
- **Mixed, Long**
- **DES, Long**
Velocity field at $x/H = 3.69$

- Experiment
- OEEVM, short
- Mixed, short
- DES High, short
- DES Low, short
- RANS, short
- Mixed Fine, short
- Mixed, Long
- DES, Long
2D plots
Conclusions

- DES, LES and RANS calculations are performed on the separated flow over axisymmetric hill.
- Both LES and DES are capable of predicting the flow with a high accuracy.
- RANS totally fails to predict the correct flow pattern.
- DES are sensitive to $\tilde{\nu}$ on inlet.
- The length on the inlet before the hill is important to predict a correct pressure distribution.
- All calculations predicts a too early separation along the centerline.
- The counter rotating vortex in the wake are predicted by both LES and DES.