Simulations of the flows over round cylinder at different Reynolds’ numbers
Re_D=140000

- The basic turbulence model does not influence on the results noticeably
- The usage of less dissipative SGS model (DDES based on Δlsq+S3QR) has led to worse results (more close to no model ones)

- The most challenging case
  - due to laminar separation (in the shear layer) without turbulent reattachment
  - the results depend on too many options (SGS model, numerics, mesh, luck, ...)
  - mesh refinement does not lead to convergence [Breuer, 2000]
  - the most challenging for the DES [Travin et al, 1999]
  - is challenging for “the best” recent DDES formulation too (maybe classic old-school DDES can work better because it “properly” delays RANS-to-LES transition in shear layers)
  - can be solved using (I)DDES+LT transition model [Kim&Kwon, 2021]

<table>
<thead>
<tr>
<th>Experiments</th>
<th>$C_d$</th>
<th>$C_{l,rms}$</th>
<th>$C_{p,b}$</th>
<th>$St$</th>
<th>$\theta_{sep}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantwell&amp;Coles (1983) [2]</td>
<td>1.24</td>
<td>1.21</td>
<td>0.179</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zdravkovich (1997) [3]</td>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KIAM simulations</th>
<th>$C_{p}$</th>
<th>$\theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>fine SA</td>
<td>0.458</td>
<td>107.5</td>
</tr>
<tr>
<td>fine SST</td>
<td>0.439</td>
<td>93.2</td>
</tr>
<tr>
<td>fine no model</td>
<td>0.154</td>
<td>95.65</td>
</tr>
<tr>
<td>fine lsq+S3QR</td>
<td>0.209</td>
<td>96.5</td>
</tr>
<tr>
<td>coarse</td>
<td>0.309</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing $C_p$ vs $\theta$ with various simulations and experiments]
The DDES results are becoming converged while $Re_D$ is increasing
- with the corresponding experimental values
- with each other for different Reynolds numbers

### $Re=10^6$

<table>
<thead>
<tr>
<th>Experiments</th>
<th>$C_d$</th>
<th>$C_{l,\text{rms}}$</th>
<th>$-C_{p,b}$</th>
<th>$St$</th>
<th>$\theta_{\text{sep},^\circ}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Szechenyi (1975) [4]</td>
<td>0.25</td>
<td>0.32</td>
<td>0.35</td>
<td></td>
<td></td>
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<tr>
<td>Zdravkovich (1997) [3]</td>
<td>0.2-0.4</td>
<td>0.1-0.15</td>
<td>0.2-0.34</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

| KIAM simulations      |       |                   |            |      |                  |
| fine                  | 0.255 | 0.065             | 0.618     | 0.3  | 107.5            |
| coarse                | 0.226 | 0.027             | 0.568     | 0.32 | 107.1            |

### $Re=2\cdot10^6$

<table>
<thead>
<tr>
<th>Experiments</th>
<th>$C_d$</th>
<th>$C_{l,\text{rms}}$</th>
<th>$-C_{p,b}$</th>
<th>$St$</th>
<th>$\theta_{\text{sep},^\circ}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shih et al.</td>
<td>0.24</td>
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<tr>
<td>Scheue</td>
<td>0.24</td>
<td>0.02</td>
<td>0.48</td>
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<tr>
<td>Szechenyi</td>
<td>0.25</td>
<td>0.32</td>
<td>0.35</td>
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<tr>
<td>Golling</td>
<td>0.35</td>
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<td></td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>Zdravkovich</td>
<td>0.17-0.4</td>
<td>0.1-0.15</td>
<td>0.2-0.34</td>
<td>0.5-0.18</td>
<td></td>
</tr>
</tbody>
</table>

| KIAM simulations      |       |                   |            |      |                  |
| fine                  | 0.234 | 0.051             | 0.583     | 0.315 | 109.5           |
| coarse                | 0.215 | 0.027             | 0.548     | 0.34  | 109.4           |
Suggestions for the paper

• Focus only on the cylinder cases (with different Re numbers)

• Experimental values vary much: use all of them to emphasize the complexity and sensitivity of the case (and its uncertainty)

• The case is challenging for both simulation and experiment. We should focus on basic trends and peculiarities of different hybrid models
  o **why DDES/DVMS is good** but recent DDES is not

• One more “let’s refine the mesh and hope to obtain similar to experiment results” attempt is to be done (only for the 1M and 2M cases)