Aerodynamic and aeroacoustic simulation around a NACA0018 at various angles of attack

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Motivation of this work

- We would like to catch aerodynamic coefficient and pressure distribution over a NACA0018 at multiple angles of attack
- we would like to reproduce separation and reattachment
- In a second time we want to simulate the noise generated by the flow.
Set up

- $0^\circ$ NACA0018 set up:
  - chord = 0.08[m]
  - $\rho_0 = 1.225[kg/m^3]$, $P_0 = 101300[Pa]$
  - $U_0 = 30[m/s]$
  - $Tu = 1\%$
  - $\frac{\mu}{\mu_t} = 0.1$
  - $tref = \frac{chord}{U_0}$
  - Structured mesh non dimensional $y_w^+ = 1$ 1.4M Nodes.

Figure – Trailing edge meshes.
Aerodynamic and aeroacoustic simulation around a NACA0018 at various angles of attack

<table>
<thead>
<tr>
<th>Name</th>
<th>Mesh size</th>
<th>$y_w^+$</th>
<th>$C_D$</th>
<th>$C_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine mesh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDES $k - \varepsilon$</td>
<td>1.8M</td>
<td>1</td>
<td>0.018</td>
<td>0.02</td>
</tr>
<tr>
<td>DDES $k - R$</td>
<td>1.8M</td>
<td>1</td>
<td>0.015</td>
<td>0.02</td>
</tr>
<tr>
<td>DDES $k - \varepsilon$/DVMS</td>
<td>1.8M</td>
<td>1</td>
<td>0.018</td>
<td>0.03</td>
</tr>
<tr>
<td>DDES $k - R$/DVMS</td>
<td>1.8M</td>
<td>1</td>
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<tr>
<td>Measurements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Du $^1$</td>
<td></td>
<td></td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Boutilier $^2$</td>
<td></td>
<td></td>
<td>-</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table – Coefficients aérodynamique à 0° d’incidence pour un nombre de Reynolds $1.6 \times 10^5$.

Figure – Recirculation bubble using DDES $k - \varepsilon$/DVMS.

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**Figure** – Meanflow pressure coefficient distribution over NACA0018 airfoil at $0^\circ$. 

![Meanflow pressure coefficient distribution](image)
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Aeroacoustic 0 AOA

Sound Pressure Level $SPL = 10 \log_{10} \left( \frac{p^2 - p_{ref}^2}{p_{ref}^2} \right) \ [dB]$, where $p_{ref} = 2 \times 10^{-5} [Pa]$

Figure – Sound pressure level in [dB], DDES/DVMS on left, DDES k-R /DVMS on right.

Figure – Directivity graph of SPL, along r=5.
Spectrum analysis: Experimental data given by Nakano 2000 [Hz] for 0° – 6° AOA.

Figure – Spectrum Analysis of the lift coefficient fluctuation, DDES $k - \varepsilon$/DVMS on left, DDES $k - R$/DVMS on right.
Aerodynamic and aeroacoustic simulation around a NACA0018 at various angles of attack

Set up

- NACA0018 6° set up:
  - chord = 0.08[m]
  - AOA = 6°
  - $\rho_0 = 1.225[kg/m^3]$, $P_0 = 101300[Pa]$
  - $U_0 = 30[m/s]$
  - $Tu = 1\%$
  - $\frac{\mu}{\mu_t} = 0.01$
  - $tref = \frac{chord}{U_0}$
  - Unstructured mesh non dimensional $y_w^+ = 1$ 1.4M Nodes.

![Trailing edge meshes.](image)

*Figure – Trailing edge meshes.*
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<tr>
<td><strong>Fine mesh</strong></td>
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<td></td>
</tr>
<tr>
<td>DDES $k - \varepsilon$</td>
<td>1.4M</td>
<td>1</td>
<td>0.02</td>
<td>0.47</td>
</tr>
<tr>
<td>DDES $k - R$</td>
<td>1.4M</td>
<td>1</td>
<td>0.02</td>
<td>0.52</td>
</tr>
<tr>
<td>DDES $k - \varepsilon$/DVMS</td>
<td>1.4M</td>
<td>1</td>
<td>0.03</td>
<td>0.57</td>
</tr>
<tr>
<td>DDES $k - R$/DVMS</td>
<td>1.4M</td>
<td>1</td>
<td>0.02</td>
<td>0.53</td>
</tr>
</tbody>
</table>

| **Measurements**      |           |         |                  |                  |
| Du$^3$                |           | 0.03    | 0.65             |                  |
| Boutilier$^4$         |           | -       | 0.71             |                  |

Table – Bulk coefficient of the flow around a circular cylinder at Reynolds number 1M, $\overline{C_D}$ holds for the mean drag coefficient, $\overline{C_L}$ is the root mean square of lift time fluctuation.

Figure – Recirculation bubble using DDES $k - \varepsilon$/DVMS.
Figure – Meanflow pressure coefficient distribution around body airfoil at 6° incidence.
Aerodynamic and aeroacoustic simulation around a NACA0018 at various angles of attack

Aeroacoustic 6 AOA

- Sound Pressure Level $SPL = 10 \log_{10} \left( \frac{p^2 - p_{ref}^2}{p_{ref}^2} \right)$ [dB], where $p_{ref} = 2 \times 10^{-5} [Pa]$

Figure – Sound pressure level in [dB], DDES/DVMS on left, DDES k-R /DVMS on right.

Figure – Directivity graph of SPL, along $r=5$. 

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Figure – Sound pressure level in [dB], DDES/DVMS on left, DDES k-R /DVMS on right.

Figure – Directivity graph of SPL, along $r=5$. 

Spectrum analysis: Experimental data given by Nakano 2000[Hz] for $0 - 6^\circ$ AOA.

Figure – Spectrum Analysis of the lift coefficient fluctuation, DDES $k - \varepsilon$/DVMS on left, DDES $k - R$/DVMS on right.
Set up

- NACA0018 15° set up:
  - chord = 0.08[m]
  - AOA = 15°
  - $\rho_0 = 1.225[kg/m^3]$, $P_0 = 101300[Pa]$
  - $U_0 = 30[m/s]$
  - $Tu = 1\%$
  - $\frac{\mu}{\mu_t} = 0.01$
  - $tref = \frac{chord}{U_0}$
  - Unstructured mesh non dimensional $y_w^+ = 1$, 1.4M Nodes.

Figure – Trailing edge meshes.
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</tr>
<tr>
<td>DDES $k - \varepsilon$</td>
<td>1.4M</td>
<td>1</td>
<td>0.22</td>
<td>1.02</td>
</tr>
<tr>
<td>DDES $k - R$</td>
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<td>0.25</td>
<td>0.77</td>
</tr>
<tr>
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<td>1</td>
<td>0.21</td>
<td>0.99</td>
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<tr>
<td>DDES $k - R/DVMS$</td>
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<td>0.26</td>
<td>0.73</td>
</tr>
<tr>
<td><strong>Measurements</strong></td>
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<tr>
<td>Du et al$^5$</td>
<td></td>
<td></td>
<td>0.20</td>
<td>0.50</td>
</tr>
<tr>
<td>Boutilier$^6$</td>
<td></td>
<td></td>
<td>-</td>
<td>0.51</td>
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</tbody>
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Table – Bulk coefficient of the flow around a circular cylinder at Reynolds number 1M, $\bar{C}_D$ holds for the mean drag coefficient, $\bar{C}_L$ is the root mean square of lift time fluctuation.

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**Meanflow pressure coefficient**  \(Re = 0.16M\)

**Figure** – Meanflow pressure coefficient around body airfoil.
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Aeroacoustic 15 AOA

- Sound Pressure Level $SPL = 10 \log_{10} \left( \frac{p^2 - p_{ref}^2}{p_{ref}^2} \right)$ [dB], where $p_{ref} = 2 \times 10^{-5} [Pa]$

Figure – Directivity graph of SPL, along r=5.

Figure – Sound pressure level in [dB], DDES/DVMS on left, DDES k-R /DVMS on right.
Spectrum analysis: Experimental data given by Nakano there is no high frequency tonal peak at 15° AOA.

Figure – Spectrum Analysis of the lift coefficient fluctuation, DDES $k - \varepsilon/DVMS$ on left, DDES $k - R/DVMS$ on right.