DETACHED-EDDY SIMULATION OF FLOW AROUND A 1:5 RECTANGULAR CYLINDER

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1 INTRODUCTION

The simulation of unsteady separated flows around bluff bodies is still a challenging issue due to complex physical phenomena such as massive separation and reattachment, laminar-to-turbulent transition and alternating detachment of large eddies. In addition, the flow field is usually three-dimensional, even for simple two-dimensional geometries. The strategy of turbulence modelling is particularly important for the simulation of such flows. The employment of unsteady Reynolds-Averaged Navier-Stokes (URANS) equations represent a reasonable choice, given that two-dimensional geometries can be modelled with 2-D meshes and that the required grid resolution is still affordable. Nevertheless, this approach, even when the most advanced turbulence models are used, shows limited accuracy when massive separation and strong curvature of streamlines occur (e.g. Ref. [1]). The alternative is to use Large-Eddy Simulation (LES) approach, which is expected to perform better for this type of flows. However, LES requires full three-dimensional grids and it becomes unaffordable when high-Reynolds-number turbulent boundary layers have to be resolved due to the necessary grid refinement (e.g. Ref. [2]). In order to overcome this limit, Detached-Eddy Simulation (DES) was introduced in 1997 (Ref. [2]). It is a hybrid technique based on a definition of the turbulent length scale which allows to switch between RANS approach near solid walls and LES at a certain distance from them, where large vortices can be properly resolved. However, 3-D meshes are needed and consequently the computational cost becomes very high, limiting so far the use of this technique to research more than industrial applications.
In this paper a rectangular prism with chord-to-thickness ratio \( B/H = 5.0 \) at low Mach number \( (Ma = 0.1) \) and relatively high Reynolds number \( (Re = 132,000) \) is taken into account, since the flow past this simple geometry is known to be characterized by complex features and is often considered to be a benchmark case for studies dealing with bridge aerodynamics and aeroelasticity. Therefore, an experimental campaign studying this profile, conducted by one of the authors (Ref. [3]), is underway in the high-pressure wind tunnel of DLR-Göttingen.

The flow is simulated using the finite-volume unstructured solver DLR-Tau code (e.g. Ref. [4]). As compared to preliminary computations presented in Ref. [1], meshes herein are particularly designed for DES applications, on the basis of recommendations of Ref. [5] and previous experience.

2 PRESENTATION AND DISCUSSION OF RESULTS

In this work hybrid meshes are employed, characterized by a structured-like arrangement around the profile (body-aligned quadrilateral cells) and unstructured triangular cells in the remaining part of the domain. Non-reflecting farfield boundary condition is assumed at one-hundred chord distance from the body, while viscous wall and periodic boundary conditions are imposed respectively at the body contour and at the lateral planes of the computational domain. Fig. 1 shows the 3-D grid (1,703,585 nodes and 2,957,440 cells) obtained by extruding a 2-D grid for one chord length in the spanwise dimension. Perfectly isotropic cells in the “focus region” represent the optimal conformation for the LES mode of DES.

Fig. 2 reports the lift and drag time histories computed with 3-D URANS and DES methods. In the URANS case the governing equations are closed with the two-equation Linearized Explicit Algebraic (LEA) \( k - \omega \) turbulence model (Ref. [6]). In the SA-DES approach the one-equation turbulence model of Spalart and Allmaras (SA) is used for the URANS mode and as a sub-grid-scale model for the LES mode (Ref. [2]). The DES constant has a value of \( C_{DES} = 0.45 \), as recommended in Ref. [4], and the nondimensional time-step size for time-advancing is \( \Delta s = \Delta t U_\infty / B = 0.0034 \), which is already smaller than what is suggested in Ref. [5] on the basis of the cell size in the focus region. In Tab. 1 the computed Strouhal frequency of wake oscillation \( (St) \), mean drag \( (C_D) \) and rms values of lift and drag \( (C'_L \text{ and } C'_D) \) are compared with experiments and with the results of the URANS-SA (Ref. [7]) and URANS-LEA computations performed on the corresponding 2-D mesh. It is worth noting that the simulation

![Figure 1: Views of the near-body portion of the three-dimensional mesh used in the computations.](image-url)
based on the unsteady RANS equations closed with the SA turbulence model predicts unrealistically steady flow solution. The 3-D URANS-LEA computation gives approximately the same Strouhal number and mean drag coefficient as the corresponding 2-D calculation. Nevertheless, the three-dimensional mesh implies a significant increase of the mean fluctuating value of the drag coefficient. In addition, the flow is no longer perfectly periodic. The chaotic component is significantly enhanced in the SA-DES case, where the integral results seem to further approach the experimental ones.

Fig. 3 depicts two snapshots of skin friction and streamlines for the 3-D computations. The flow field simulated with the URANS-LEA approach is nearly two-dimensional, whereas complex three-dimensional structures are evident in the case of the SA-DES computation.

Figure 2: Computed lift and drag coefficient time histories.

<table>
<thead>
<tr>
<th></th>
<th>$St$</th>
<th>$C_D$</th>
<th>$C_L'$</th>
<th>$C_D'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-D URANS-SA</td>
<td>-</td>
<td>0.968</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2-D URANS-LEA</td>
<td>0.094</td>
<td>1.060</td>
<td>0.198</td>
<td>0.019</td>
</tr>
<tr>
<td>3-D URANS-LEA</td>
<td>0.098</td>
<td>1.070</td>
<td>0.206</td>
<td>0.033</td>
</tr>
<tr>
<td>3-D SA-DES</td>
<td>0.097-0.113</td>
<td>1.011</td>
<td>0.128</td>
<td>0.068</td>
</tr>
<tr>
<td>Exp.</td>
<td>0.111</td>
<td>1.074</td>
<td>&lt;0.16</td>
<td>&lt;0.18</td>
</tr>
</tbody>
</table>

Table 1: Integral results of numerical simulations and comparison with experiments (Ref. [3]).

3 CONCLUSIONS

The following preliminary conclusions can be drawn at this stage. The efficient 2-D URANS computations, associated with the two-equation LEA turbulence model, give reasonable results when compared to the wind-tunnel data. Still, an improvement can be obtained switching to more expensive 3-D test cases. The Detached-Eddy Simulation strategy, which is comparable to the 3-D URANS with respect to the CPU requirements, seems to be able to enhance considerably the accuracy of the results, given a high-quality computational grid. This approach is also able to capture dominant three-dimensional features of the flow.
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