Full-field pressure from 3D PIV snapshots in convective turbulent flow

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In this work full-field pressure is determined from volumetric three-dimensional (3D) synthetic particle image velocimetry (PIV) velocity data. In view of the many difficulties involved in experimental direct pressure measurement techniques, indirect methods of acquiring pressure estimations are rapidly advancing. In the present work a technique that combines an Eulerian approach with Taylor’s hypothesis for the computation of the flow acceleration is used (de Kat and Ganapathisubramani 2013). Independent time-frames from Direct Numerical Simulations (DNS) of a turbulent channel flow from the John’s Hopkins University Database (Graham et al. 2013, Li et al. 2008, Perlman et al. 2007) are used to create synthetic 3D PIV velocity volumes. Using the exact pressure field available, the method’s accuracy is evaluated. The technique’s dependence on grid resolution and noise level is also assessed, as well as the performance of different convection velocity approaches employed in the Taylor’s Hypothesis formulation.

In order to simulate the effect of synthetic PIV, the DNS data are interpolated onto an equidistant grid and subsequently filtered (Scarano and Riethmuller 2000). To assess the dependence of the method in grid resolution, three different interrogation volume sizes, l, are tested, simulating an overlap factor (OF) of 75% in all three directions. PIV has also shown to create additional noise on the velocity field, on top of the physical noise originated from the particle motion (Foucaut et al. 2004). To simulate this influence, separate random noise fields are generated, filtered, cropped and subsequently added to the three velocity components. To evaluate the dependence of the proposed technique on the noise level, four different noise magnitudes, ε, are used.

Apart from the grid and noise variations, three different approaches for the convection velocity are tested: using the mean velocity in the dominant direction, using a filtered version of the velocity in the dominant direction and using the mean of each of the three velocity components (resulting in a vector field).

As expected, with increasing noise level, the method becomes less accurate and for the maximum noise level in the best resolution, the correlation coefficient drops to 0.6 from 0.75 for noiseless data (Fig. 1).

![Fig. 1 Correlation coefficient for different noise levels, ε.](image)

<table>
<thead>
<tr>
<th>ε/ε_max</th>
<th>0</th>
<th>0.25</th>
<th>0.5</th>
<th>0.75</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>U_0 = U</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>U_0 = U(f)</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>U_0 = U(h)</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
</tr>
</tbody>
</table>

A similar loss of accuracy is observed with decreasing resolution, where the correlation coefficient shows a decrease of about 20% for the coarsest grid (four times coarser than the finest). The effect of resolution is shown in figure 2, where pressure contours are presented for different resolutions (using the mean streamwise velocity as the convection velocity and a noise level of 1%).

![Fig. 2 Pressure contours for different resolutions.](image)

The results also indicate that in terms of the convection velocity, the most accurate approach tested is to use the mean streamwise velocity which attains, for zero noise and the best resolution, a pressure correlation coefficient of about 0.75. The other two approaches for the convection velocity show a decrease in correlation by almost 6%.

Future analysis of the full time history of the flow will enable the implementation of a purely Eulerian technique for the estimation of acceleration as well as a Lagrangian technique in order to compare their performance with the accuracy provided by the proposed method.

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