THE MINIMAL COMPUTATIONAL DOMAIN FOR CAPTURING TAYLOR–GÖRTLER VORTICES IN STREAMWISE-ROTATING CHANNEL FLOW

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DNS is performed to investigate the minimum computational domain size required for correctly capturing Taylor-Görtler (TG) vortices. To assess the effect of the system rotation on the scales of TG vortices, a wide-range of rotation numbers have been tested, varying from \( R_{\phi} = 0 \) to 150. The highest rotation number tested in the current research far exceeds that reported in literature (\( R_{\phi} = 30 \)). In order to precisely capture TG vortices, DNS has been performed in a very large box domain of \( 512\pi h \times 2h \times 8\pi h \), where \( h \) is one-half the channel height. A two-layer pattern of TG vortices is observed, and the scales of TG vortices are quantified using the pre-multiplied two-dimensional energy spectra \( \phi_{ii} \).

Figure 1 demonstrates the effect of the channelwise computational domain size on the mean spanwise velocity \( \langle u_3 \rangle^+ \), which exhibits a complex “(double) S-shaped triple-zero-crossing pattern”. It is evident that a minimal spanwise domain size of \( L_1 = 64\pi h \) is needed for an accurate prediction of \( \langle u_3 \rangle^+ \). As displayed in figure 2(a), the computational domain size needs to be very long because TG vortices are streamwise-elongated. Figures 2(b) shows that two layers of counter-rotating TG vortex pairs are present in the cross-stream plane. But at a different location as demonstrated in figure 2(c), the TG vortices form a one-layer pattern. In order to precisely determine the scales of TG vortices, we consider the pre-multiplied energy spectra \( \phi_{ii} \) for \( i = 1, 2, \) and 3. Figure 3 depicts that in the \( x_1-x_3 \) plane for \( x_2 = 0.5h \), \( L_1 = 512\pi h \) is needed to capture the complete outer isopleth for \( \phi_{11} = 0.125 \max (\phi_{11}) \), inside which the corresponding eddies are deemed to be energetic. However, if we may increase the threshold value for defining the outer isopleth, then a smaller computational domain size could also be judged as satisfactory for capturing all energetic eddies. To avoid this ambiguity, we may instead directly consider the characteristic streamwise length scale \( \xi^+ \) of TG vortices associated with the peak of \( \phi_{ii} \). Figure 4 shows that \( L_1 = 256\pi h \) is sufficient for achieving a domain-size-independent result of \( \xi^+ \). Figure 5 shows that \( \xi_{1i}^+, \xi_{2i}^+, \) and \( \xi_{3i}^+ \) all increase monotonically as the rotation number increases, indicating that a larger computational domain size is needed for capturing TG vortices at a higher rotation number.

Figure 1. Profiles of mean spanwise velocity \( \langle u_3 \rangle^+ \) based on various computational domain sizes for \( R_{\phi} = 150 \).

Figure 2. Elongated TG vortex structures for case E5. (a) Time-averaged 3D isosurfaces of \( \overline{u_3}^+ \) = ±0.02. (b) and (c) Local TG vortices in two arbitrary cross-stream \( (x_2-x_3) \) planes visualized by the contours of \( \overline{u_3}^+ \) superimposed with time-averaged velocity vectors.

Figure 3. Isopleths of \( \phi_{11} \) in plane \( x_2/h = 0.5 \) for case E5. Cross symbol denotes the location corresponding to \( \max (\phi_{11}) \).

Figure 4. Locations corresponding to the peak value of \( \phi_{11} \) in the \( \lambda_1^+ - \lambda_3^+ \) plane for cases E1–E5.

Figure 5. Streamwise scale of TG vortices \( \xi^+ \) corresponding to the peak of \( \phi_{ii} \) at various rotation numbers.