DETECTION OF STRUCTURES WITH VARIOUS GROUP VELOCITIES IN FULLY DEVELOPED TURBULENT PIPE FLOW

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Coherent structures are known as organized motions which posses coherence in space and time being defined as entities which stay observable while evolving in space and changing moderately within a certain time span. Given the transport-dominated nature of structures in wall bounded turbulent flows, standard decomposition methods like Dynamic Mode Decomposition (DMD) will fail to reconstruct a reduced-order model of the flow with a minimal number of modes. Using a Lagrangian DMD instead (Sesterhenn & Shahirpour), the structures will be followed in a properly chosen frame of reference along the characteristics which represent the convective velocity of the structure to be captured. In the present study this method is applied to existing DNS of fully developed turbulent pipe flow at bulk Reynolds number range of $3 \times 10^3 \leqslant Re_b \leqslant 25 \times 10^3$, aiming at capturing energetic motions traveling at different velocities.

The latter will take place using a coordinate transformation from physical space into spatio-temporal space. The transformation will be in form of a rotation in space and time with the rotation angle corresponding to the most dominant group velocity u_g in the flow, determined by the maximum drop of the singular values. The transformed snapshots will be decomposed using the standard DMD algorithm (Schmid and Sesterhenn 2008). In the final step, the dynamic modes being reconstructed in the spatio-temporal space will be transformed back to physical space. The latter will represent a reduced order model of the system using only a few modes accommodating the structure with the dominant group velocity. As an example the first Lagrangian DMD ($\mathcal{L}$DMD) mode and the space time diagram corresponding to DNS data for turbulent pipe flow at $Re_b = 25 \times 10^3$ are shown in figure 1. The first few captured modes with the least decay rates, prove to have the maximum contribution to the total energy content of the flow at wave lengths corresponding to that of the outer spectral peak of the full-field. This is observable by comparing the premultiplied velocity spectrum of the full-field with the spectra of single and summed up $\mathcal{L}$DMD modes.

The most energetic modes will then be summed up to constitute a structure with a certain group velocity. In order to extract structures with the next largest group velocities, the mentioned modes will be projected out, the flow field will be reconstructed using all remaining modes, and similar steps will be carried out on the reconstructed field. Having access to reduced order model of structures separated by their group velocities, allows to analyze each of them in terms of their length scales, decay or growth rates, energy content and their contribution to turbulent properties like Reynolds stress tensor. As validations prove, structures resulted from the $\mathcal{L}$DMD modes, represents a higher energy level with fewer modes in comparison with the standard DMD results, hence providing a better means of understanding the dynamics of such structures. Furthermore, a comparative study of the flow at different Reynolds numbers, will also reveal Reynolds number dependence of structures and their characteristic features.

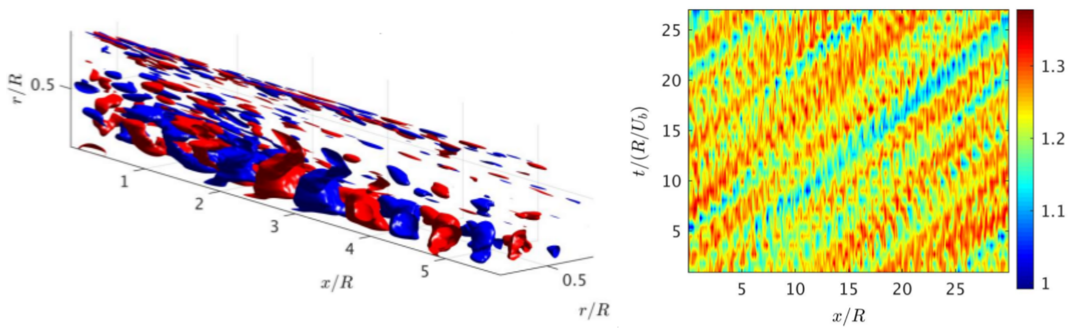

Figure 1. The first $\mathcal{L}$DMD mode (with the least decay rate) with group velocity of $U_g = 0.89u_b$ (left) and space time diagram at $r/R = 0.2$ (right). Red and blue iso-surfaces in the left figure correspond respectively to $\overline{U} \pm u_b$.

References

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