LAGRANGIAN COHERENT STRUCTURES IN OPEN CAVITY FLOWS.

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Abstract
In this article is presented new algorithms for fast computations of Finite-Time Lyapunov Exponent fields and identification of Lagrangian Coherent Structures. The algorithms are applied to open cavity flows driven by shear layer. 2D experimental dataset and 3D numerical dataset are explored, in order to identify key features of the underlying dynamics of the flows.

Fluid mechanics experimenters are used to insert particles in a fluid. For instance, Particule Image Velocimetry (PIV) allows, through the displacement of particles, to have accurate velocity field in a dense mesh in experimental fluid flows. In a more legacy fashion way — for instance smoke visualization[1] —, particles were used to reveal some topologies of the flow. Actually, time-lines may be view as "Lagrangian fronts" : as seeding particles are assimilated to fluid particles, one can follow their trajectories. As timelines are advected and wringed up by the flow, they may reveal chaotic mixing local properties.

As a matter of facts, coherent structures can be extracted from the observation of the trajectories of the fluid particles. From the divergency rate between trajectories of initially close particles derive the definition of lagrangian manifolds. Lagrangian structures are closely related to the mixing properties of the flow. Moreover, they are coherent, as shown in [2]. Lagrangian structures are a way to have a better understanding of the underlying physics of the flow since fluid particles will have different behaviours and fates depending on their position, relatively to the lagrangian frontier. In [2, 3], these structures are defined as Lagrangian Coherent Structures (LCS). Practically, LCS are the ridge of a scalar field, the Finite Time Lyapunov Exponent (FTLE) field. The field is defined, at each space point, as the largest eigenvalue of the Cauchy-Green strain tensor. When the horizon time is well-defined, with respect to the physical time scales, then the LCS are true material frontiers in the flow, i.e. there is no mass flux through these frontiers.

Therefore, one can see LCS as a good way to separate the fluid flows into different areas, physically relevant, driven by different dynamics. One of the drawbacks of tracking LCS is the computing time, as the trajectories of all particles have to be computed, at each time. In this contribution, we expose some improvements on the algorithm allowing vectorization, SIMD and GPU Deported computations to the legacy way of computing such structures. The gain is typically about three orders of magnitude.

In this presentation we are interested in the space-time dynamics of LCS in an open cavity flow driven by a shear layer. Our analysis is based on two datasets. One dataset is made of 2D experimental velocity fields acquired by high-speed particle image velocimetry (PIV). The second dataset is made of 3D velocity fields produced by direct numerical simulations (DNS) of the Navier-Stokes equations.

Figure 1 shows a (quasi) hyperbolic point, at the intersection of an attractive and a repulsive LCS, identified in the 2D PIV dataset. The hyperbolic point is first created inside the main recirculation, in the inner-flow, then transported into the shear layer. It is finally advected downstream, toward the cavity trailing edge, as the core of an impinging vortex. This observation suggests that perturbations of the shear layer are not only initiated at the leading edge but also somewhere in between both cavity corners by the inner flow recirculation.

Figure 2 shows LCS identified in the 3D cavity flow dataset. Although the features between 2D and 3D FTLE fields is remarkably close, strong 3D structuration of the LCS is observed in regions where Taylor-Gortler vortices are present[4].

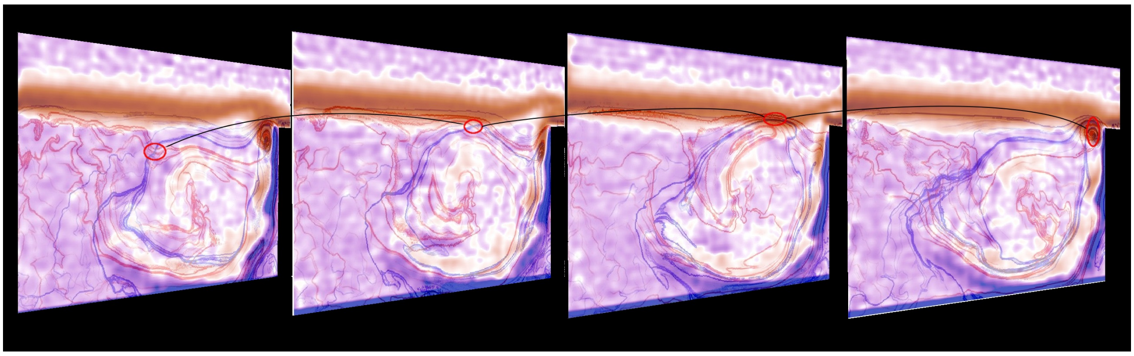

Figure 1. Tracking of an hyperbolic point in the experimental 2D PIV dataset. Red and blue lines represent finite-time attractive and repulsive LCS while the background field is the vorticity field.

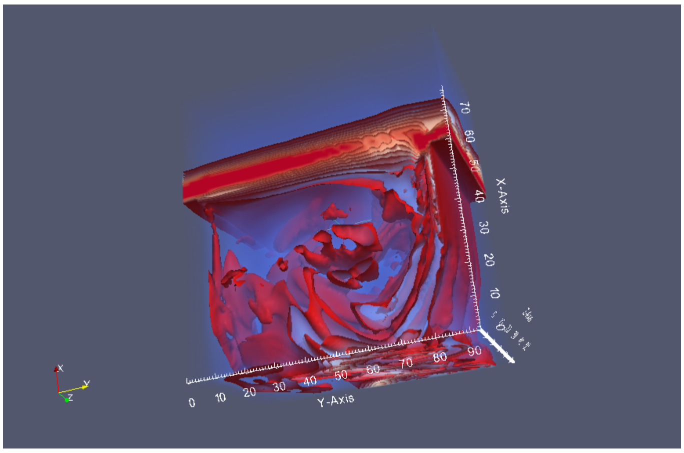

Figure 2. Lagrangian Coherent Structures in the 3D numerical cavity flow. Only the central third of the spanwise direction is represented.

References

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