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Analysis of spatial and spatio-temporal coherence of engine flows. Statistical tools, short note on Lagrangian approaches.

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One key challenge with present engine development is the modeling, understanding and control of cycle to cycle variations (CCV). This cyclic variability is understood here as a large scale cycle to cycle variation that ultimately controls the gas motion and composition in the vicinity of the spark plug and at the time of ignition. This industrial and environmental challenge has triggered a large amount of research work. Recent developments in measurement technology now enable the study of both spatial and temporal coherence of in-cylinder flows using high speed PIV. On the modeling side, large eddy simulation (LES) or hybrid RANS/LES methodologies are becoming attractive. For such complex geometries, it is already a challenge to obtain reliable experimental or numerical results and to gather data bases relevant for statistical analysis. However, one should not forget that analyzing the large amount of data generated is also very challenging. For engine flows, but also for a very large class of internal and external aerodynamic flows, such analysis techniques should provide: (i) key flow patterns responsible for CCV including flow structure, kinetic energy and mixing ; (ii) objective guidelines to compare unsteady computations to experiments – a posteriori validation ; (iii) pertinent indications to turbulence modeling and rigorous tests of associated closures – a priori validation ; (iv) information to new modelling routes like reduced-order models or cluster-based reduced order models.

The main part of this talk will be devoted to a presentation of the use of proper orthogonal decomposition (POD) and extended POD in this context, including some practical concerns. We will particularly insist on spatio-temporal strategies: phase invariant POD will be used to propose a conditional statistical study of the breakdown of a tumbling motion. Moreover, we will define and illustrate a cluster-based analysis of cycle-to-cycle variations for the same flow. A part of the talk will consider another route, namely Lagrangian Coherent Structure eduction techniques. These methods are seen here as a natural extension of topology based analysis for unsteady flows. One difficulty is to apply them to high Reynolds turbulent flows but they are believed to be promising ways to explore the spatial and temporal coherence of in-cycle flows.

These methodologies are applied here to engine flow but can of course clearly be valuable for any periodically driven fluid flows at large Reynolds numbers. Such approaches can be used for the very large set of data generated by PIV or LES, using any kind of informations (velocity, concentration, …) in any region of space.

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