LES of the flow in a DISI engine: analysis of turbulent scalar – velocity correlations

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Abstract

The underlying correlations between cyclic variability in the velocity field, spray boundary conditions and the spatial distribution of equivalence ratio in a realistic direct injection spark ignition engine have been investigated by means of Proper Orthogonal Decomposition (POD). The method of snapshots has been employed to perform both phase-dependent and phase-independent decomposition of the scalar-velocity correlations. LES based simulation of 30 engine cycles has been used for POD analysis.

INTRODUCTION

Direct injection spark ignition (DISI) engines have a large potential to reduce emissions and specific fuel consumption. Large Eddy Simulation (LES) based analysis is used to characterize the cyclic variations of the flow field and their impact on the mixture preparation and combustion processes in a realistic IC-engine. The analysis of the effect of the cycle-to-cycle velocity fluctuations on the spray injection and mixing preparation processes has been reported in [1].

Proper Orthogonal decomposition has been applied to investigate cyclic variability in motored optically accessible engines [3-5], more rarely to the analysis of numerical data. Large Eddy Simulations can provide very detailed information on the flow field, with almost unlimited ability to capture the finest details of complex geometries, and be therefore effectively paired to advanced analysis techniques as POD.

In the present work, the method of snapshot proposed by Sirovich [6] has been adopted to investigate the existence of correlations between large-scale motions and the distribution of fuel under variable injection conditions.

1 NUMERICAL METHODS AND INVESTIGATED CONFIGURATION

The investigated configuration represents a four stroke DISI engine with variable charge motion system. This is a realistic IC engine with four canted valves, an asymmetric cylinder head and an asymmetric piston bowl [1]. Data in the tumble plane at 315° CA (i.e. where the highest cyclic variability has been observed) have been selected over 30 cycles to perform at this initial stage of the investigation only a *phase-dependent* POD decomposition of the scalar and velocity modes. In both cases 30 modes were extracted. The POD methodology is further described in [2].

2 RESULTS AND DISCUSSION

Figures 1-3 present the comparison of intensity of cycle-to-cycle fluctuations of velocity (left) and mass fraction (right) in the cross section of combustion chamber for the cases described below. The investigation has been split into 3 stages in order to highlight the following processes: a) the effect of cyclic velocity variations on the mixture preparation processes, see Figure 1. b) The effect of variable spray boundary conditions on the flow field pattern, see Figure 2. This analysis helps to separate the effects of velocity and spray cyclic fluctuations on the mixing process. c) The joint effect of both velocity cyclic fluctuations and variable spray boundary conditions is shown in Figure 3.

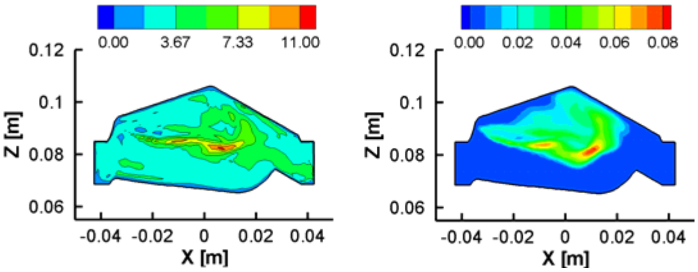

Figure 1: Root mean square of velocity (left) and mass fraction (right) at

CA = 315°. Two-phase flow with constant spray boundary conditions.

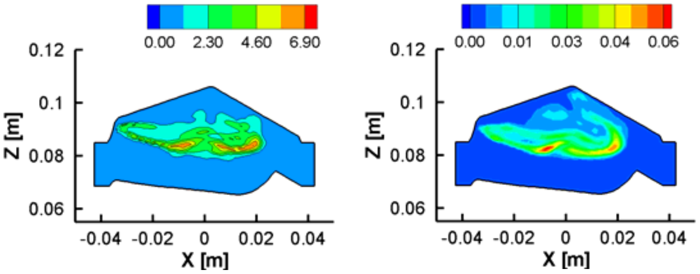

Figure 2: Root mean square of velocity (left) and mass fraction (right) at CA = 315°. Two-phase flow with variable spray boundary conditions.

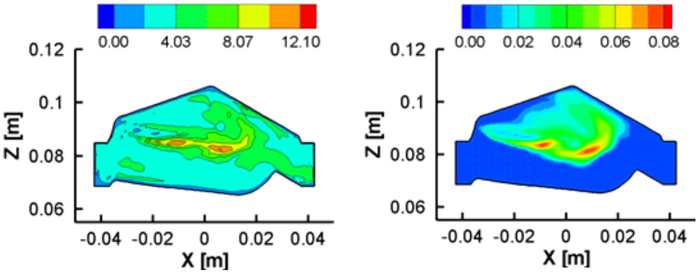

Figure 3: Root mean square of velocity (left) and mass fraction (right) at CA = 315°. Two-phase flow with the joint effect of both velocity cyclic fluctuations and variable spray boundary conditions.

It is obviously possible to perform a joint decomposition of the scalar-velocity correlations. Although the physical significance of such quantities is clear (turbulent scalar fluxes), the interpretation of the POD mode and relative reconstruction coefficients is not intuitive. For this reason a different procedure has been adopted, where the velocity and scalar field have been independently decomposed and the corresponding reconstruction coefficient subsequently analysed.

In Figure 4 the eigenvalues and energy convergence for the scalar and velocity fields are shown, while in Figure 5 the temporal (i.e. cyclic) variations of the reconstruction coefficients are presented.

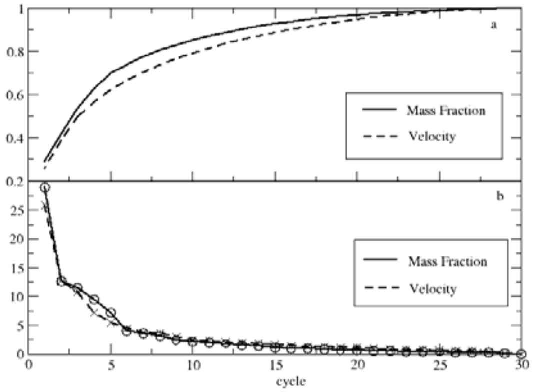

Figure 4: a) Energy convergence: $\lambda_k / \sum \lambda_k$ *; b) Eigenvalues* λ_k *.*

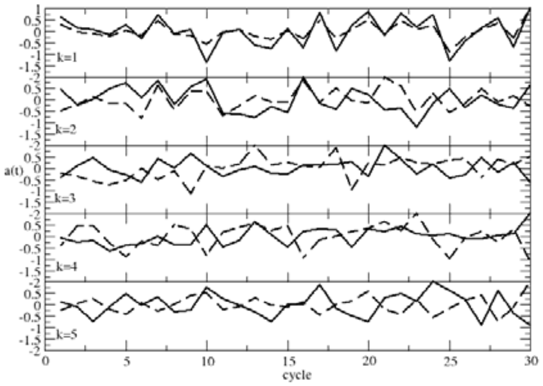

Figure 5: Time (cycle) dependence of the reconstruction coefficients for velocity (solid line) and scalar (dashed line) field.

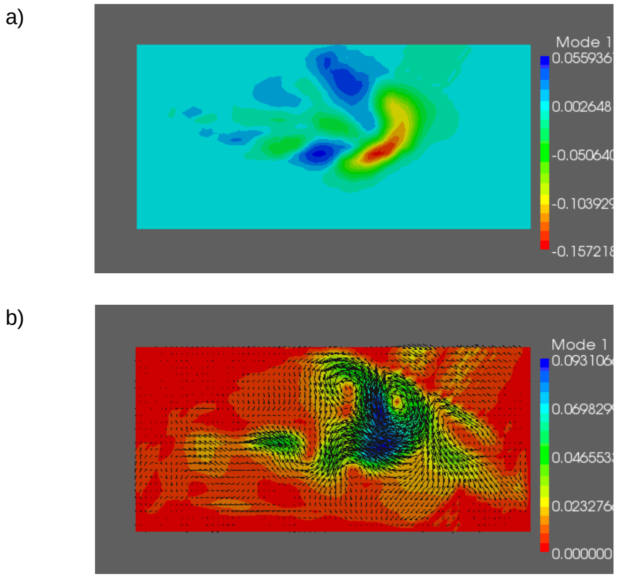

Figure 6: First scalar (a) and velocity (b) mode.

Inspection of the contours of the modes extracted from the scalar and velocity correlations (Figures 6 and 7) indicate the presence of a strong coupling, as expected, between the large structures in the velocity field and the distribution of the scalar variance, however provides little insight in the relationship, if any, between the modal components of the scalar and velocity. If the reconstruction coefficients are represented as scatter plot (see Figure 8), it is evident that a strong correlation exists between component 1 of both scalar and velocity but also between component 3 of the velocity field and 2 of the scalar field. On the contrary, several modes have been found to be in opposition of phase as expected. Although the analysis presented in this work focussed only on one particular crank angle, the results obtained are encouraging and show that the technique adopted could be used to investigate how the correlation identified in this particular case could evolve along the entire cycle and over a number of cycles.

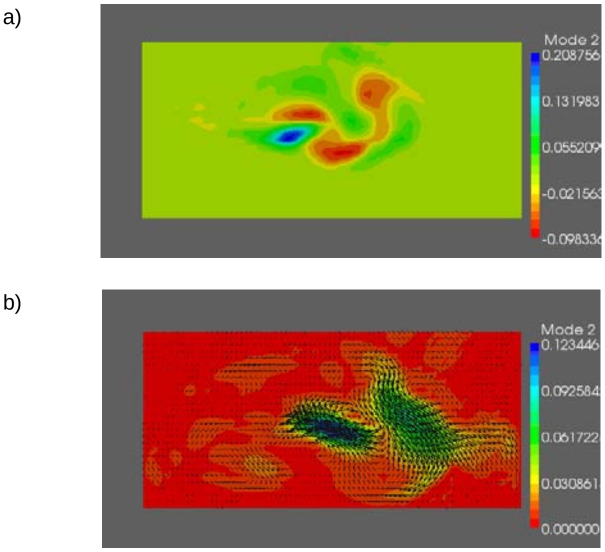

Figure 7: Second scalar (a) and velocity (b) mode.

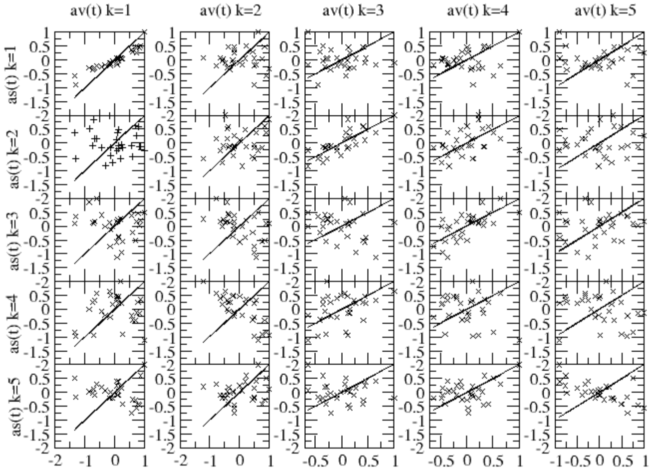

Figure 8: Correlation between reconstruction coefficients of the first 5 modes of the velocity and scalar fields. Solid line: self correlation of the velocity coefficients for visual aid.

CONCLUSIONS AND FUTURE WORK

The results of a highly resolved Large Eddy Simulation of IC engine with variable injection parameters have been analysed by means of phase-dependent POD. Inspection of the scalar and velocity reconstruction coefficient reveal interesting correlation patterns which could be used to determine the relative sensitivity of the corresponding modes to variation in the configuration parameters. A phase-independent investigation is needed to assess further the correlations between the scalar and velocity fields and also the possibility of reconstructing entire dataset from existing information.

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