COUPLING INTERNAL NOZZLE FLOW TURBULENCE FEATURES TO DNS OF SPRAYS PRIMARY ATOMIZATION

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Abstract

The understanding of the combustion process in energy generation, both for stationary purpose or for propulsion, is becoming more and more demanding as the technology progress toward a cleaner combustion able to reduce the environmental impact. For this reason, an accurate prediction of the spray formation is mandatory in order to study the combustion from a numerical and experimental standpoint.

As already proved in previous works [1], the boundary inlet conditions for the spray are of fundamental relevance in order to accurately model the atomization regime and therefore the droplet formation. In fact, it has been proved [2] that the atomization process is a result of surface instabilities, that may develop due to liquid core velocity variation.

This goal can be reached throughout the analysis of the internal flow in the nozzle, by means of spectral and statistical analysis of the flow. For this reason, the present work aim to study the behavior of internal flow and effectively relate it to external flow. For the internal flow simulation, a Large Eddy Simulation approach. It has been used to model the turbulence structures inside a turbulent pipe (Re=5050), has allowed to save computational resources and maintain a high level of details in the study of turbulent flows. The opensource code OpenFOAM has been chosen as a simulation environment, while an incompressible Wall Adaptive Local Eddy viscosity model has been selected to model the subgrid turbulence behavior. The simulation domain consists of a cylindrical pipe of L/D= 8, with a diameter of 90μm.

For the external flow modelling, Direct Numerical Simulation (DNS) has been used due to its capability of providing a high amount of data on both space and time, while modelling all scales of motion in the flow. In this work the *one-fluid* method described in [3] and implemented in the PARIS-Simulator is used.

The main aim of this work is to effectively and accurately correlate the turbulence properties extracted from the analysis of the internal flow to the spray simulation though an algorithm for boundary condition generation. The algorithm used in this work is a *Digital Filter Based Method* from [4], which allows to control the size of the turbulent structures, their location and their temporal distribution, while maintaining the random behavior typical of the turbulent flows. This method calculates punctually the velocity turbulent component as

$$u' = \sum_{n=-N}^{N} b_n r_{m+n} \quad (4)$$

Where b_n are the filter coefficients, r_{m+n} are the zero-mean random data series components, N represents the filter support length and m indicates the grid point.

In order to determine the filter coefficients, the assumption of a fully developed homogeneous turbulent field is made in [4], consequently the autocorrelation from [5] for the u' is used as

$$R_{u'u'}(d,0,0) = exp\left(\frac{\pi d^2}{4L^2}\right) \quad (5)$$

Where L is the prescribed integral scale and d is the distance vector. Through the correction of these coefficients the temporal and spatial distribution of the turbulence can be adjusted, acting on the integral length scale, adequately interpreted for the time.

Finally, the velocity profile, as well as the radial turbulence distribution, needs to be implemented in the code. The velocity profile can be implemented once the linear wall correlation and the log-law wall respectively have been verified for the inner nozzle flow upstream of the spray simulation:

$$y^+ = y^+ \ ; \ u^+ = \frac{1}{\kappa}\ln y^+ + B \quad (6)$$

Where κ is the von Karman constant and B is a fitting constant.

In order to determine the turbulence radial distribution, the coefficients of the diagonal form of the Reynolds stress tensor $a_{ii}(r)$ must be determined as function of the radius, so that the determination of the velocity can be achieved through the equation below:

$$u(r,t) = U \cdot f(r) + u'(t) \cdot a(r) \cdot I \quad (7)$$

Where $f(r)$ is a correlation derived from the solution of equation (6), by determining B and y^+ through the LES analysis and I is the turbulence intensity.

The velocity profiles, as well as the turbulence distribution and maximum intensity can be obtained from the statistical analysis of the internal flow and validated against experimental results [6] and DNS results [7].

KEYWORDS: atomization; PARIS-simulator; external flow; diesel injector; nozzle; CFD; *Digital Filter Based Method,* DNS, LES, turbulence.

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