Particle Reduced, Efficient Gasoline Engines

EUROPEAN COMMISSION
Horizon 2020 | GV-2-2016 | Technologies for low emission light duty powertrains
GA # 723954

Deliverable No.	PaREGEn D1.7	
Deliverable Title	LES 3D CRFD development and knowledge transfer.	
Deliverable Date	30th September, 2019	
Deliverable Type	REPORT	
Dissemination level	Confidential – member only (CO)	
Written By	Nicolò Frapolli (ETH Zurich) Y.M. Wright (ETH Zurich)	
Checked by	Andreas Manz (Bosch)	2019-09-25
Approved by	Y.M. Wright (ETH Zurich) Andreas Manz (Bosch) Simon Edwards (Ricardo)	2019-09-22 2019-09-25 2019-09-28
Status	FINAL	2019-09-30

Publishable Summary

Within next years, medium to premium size passenger cars will most probably be equipped with the next generation of gasoline direct injection (GDI) engines. The PaREGEn project aims to further develop those engines to achieve an improvement in terms of efficiency by at least 15% with respect to previous generation, while complying with the Euro 6c regulations limiting the emitted particle number (PN) per kilometre to 6 x 10^{11} yet measured down to ten nanometres in size. The latter can be considered a rather strict limitation to comply with, due to the inhomogeneities in the air-fuel mixtures inherent in gasoline direct injection engines. One of the most important sources of inhomogeneities is related to the fuel wall-film on the piston or liner of the engine, arising after injection and subsequent droplet-wall interaction, and the associated fuel evaporation from such liquid films. In these regions of the combustion chamber, the formation of polycyclic aromatic hydrocarbons (PAH) and soot during combustion is likely. The PaREGEn project aims to deepen the understanding of the Cause and Effect Relationship (CER) of particle formation of GDI combustion by combining advanced optical diagnostics and numerical simulations. With particular focus on the 3D CFD numerical simulations, in Task 1.4 of the PaREGEn project models for spray development, spray/wall interaction, combustion and soot formation are assessed within a Large-Eddy Simulation (LES) context in three different set-ups. Each set-up is specifically designed to separate different physical aspects by increasing complexity and allowing for additional physical insights: from the simple spray morphology, fuel-wall interaction all the way to combustion and soot formation in a fully developed flow in a real engine.

The first assessment is carried out by means of a constant-volume chamber, where spray development and dynamics are simulated and compared to the corresponding measurement performed at BOSCH. Next, spray development, spray/wall interaction and liquid film formation, combustion development and soot formation, are simulated in an optical accessible flow channel, for which the corresponding experiments are conducted at the University of Duisburg-Essen (UDE) and exposed in deliverable D1.6. For this case, spray morphology as well as wall-film formation is assessed by measurements of the spray penetration and two-dimensionally resolved wall-film deposition on the cylinder-wall on the opposite side to the injector. Flame propagation is visualized by means of chemiluminescence from the side and front view with respect to the injector, while soot is characterized by natural luminosity. Finally, spray formation and impingement, subsequent liquid film evolution, combustion initiation and development and soot formation are simulated and compared to the experiments in a single cylinder optical engine. Experiments are performed by and at BOSCH in an optically accessible engine, where side and through-piston views are available. Combustion evolution is also assessed within the same engine but with a metal piston.

In deliverable D1.3, the capabilities of the numerical models to reproduce a correct spray development and subsequent liquid film formation were assessed with the experiments performed by BOSCH, reported in deliverable D1.2. The project injector was first tested in a constant volume bomb for different injection pressures, ambient pressures and fuel injection temperatures. Combinations thereof led to different physical aspects, which span from a typical spray evolution at ambient conditions (1 bar) to flash-boiling conditions and/or spray collapse in the case of throttled conditions (lower pressure than ambient conditions). In the same deliverable, preliminary results for the spray evolution and wall-film formation in the optical engine at fixed piston positions were also reported. The spray evolution was observed to be very similar to the one in the spray chamber at constant volume. This set-up was therefore considered well suited for the evaluation of wall-film models without the added complexity due to interactions with the bulk flow induced by piston and valve motion at high speeds. Wall-film results from numerical simulations are compared to the LIF results acquired at BOSCH.

In the present deliverable, D1.7 the work conducted on the assessment of liquid film formation is extended to engine operation with a moving piston. It is shown, that the model presented later can be used to simulate liquid film evolution in an LES context, in a real engine configuration for a large variety of operating conditions. The same geometry is then employed to extend the model assessment to combustion and soot formation. In particular, a selected operating condition is studied in detail and compared with the images of liquid film, flame and soot evolution available from the experiments. In parallel, the same models are assessed in the flow channel, comparing the numerical results with the experiment performed by and at the University of Duisburg-Essen (UDE). For this case as well, liquid film evolution is simulated for both non-reacting and reacting cases, and the models are also assessed in terms of liquid film evolution and, in the reacting case, in terms of flame propagation and soot formation.

The results reported confirm the predictive capabilities of the developed numerical platform with respect to I) qualitatively and quantitatively capturing liquid film evolutions for all studied set-ups under different operating conditions, and II) good reproduction of the flame development in the flow channel and heat release rates in the case of the engine. Soot prediction shows good qualitative agreement with the observations. The model and sub-models together with the related parameters and tuning parameters are discussed for each set-up.

Supporting the experimental observations, the numerical findings also suggest that fuel-rich regions in the vicinity of fuel-wall films are prone to formation of soot in GDI engines, which motivates further research and development of injection systems and strategies towards reducing fuel deposition on chamber surfaces.

All information and measurements reported here about experimental results are collected from Sub-task 1.3.

Appendix A – Acknowledgement

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

Project partners:

#	Partner	Partner Full Name
1	RIC	RICARDO UK LIMITED
2	DAI	DAIMLER AG
3	JLR	JAGUAR LAND ROVER LIMITED
4	BOSCH	ROBERT BOSCH GMBH
5	FEV	FEV EUROPE GMBH
6	JM	JOHNSON MATTHEY PLC
7	HON	HONEYWELL, SPOL. S.R.O
8	JRC	JOINT RESEARCH CENTRE – EUROPEAN COMMISSION
9	UNR	UNIRESEARCH BV
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16	UFI	UFI FILTERS SPA
17	UOB	UNIVERSITY OF BRIGHTON
18	Garret	GARRET MOTION CZECH REPUBLIC SRO

This project has received funding from the European Union’s Horizon2020 research and innovation programme under Grant Agreement no. 723954.