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Written on 01 March 2018 15 minutes of reading
News

- Fundamental Research

- Sustainable mobility
- IC powertrains

Systems and Vehicles

The **transportation sector** is evolving all the time and profound changes are yet to come. A

major challenge
for **future mobility, vehicle's electrification** will be accompanied by **radical technological and software advances**, with the increasing **development of connected and driverless vehicles**, incorporating, in particular, the **principles of responsible eco-driving.**

For all that, **Internal Combustion (IC) engines** will continue to dominate for a few more years to come. The focus must be on reducing their consumption (i.e. decreasing CO_2) and their pollutant emissions, paving the way for the **transition to low-carbon mobility**.

In addition to the development of new software solutions and services for **vehicle electrification and connected mobility**, researchers from the **Powertrain and Vehicle Division** are channeling their expertise into addressing these challenges. Their aims today: to prepare for the changes that will take place in the distant future while going on improving the short term, essential for addressing the
needs of industry and society, working in partnership with internationally-recognized laboratories.

I hope you enjoy reading this issue.

Stéphane Henriot, Director of the Powertrain and Vehicle Division

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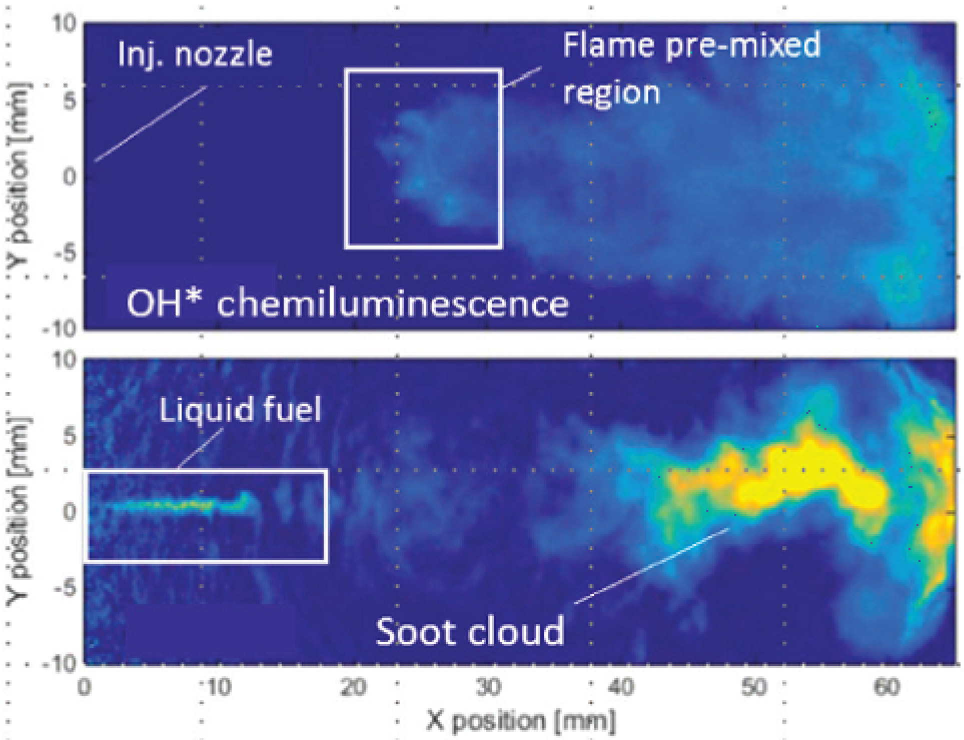
Les brèves

The **reduction in IC engine particle emissions** requires a detailed knowledge of the **physicochemical processes at work during combustion**. While fuels have long since been considered as a constant for each engine type, the gradual introduction of **biofuels** and research conducted in the field of **innovative combustion modes** have made it necessary to take greater account of the impact of
fuel variability on pollutant formation.

The task is painstaking since fuels are made up of thousands of hydrocarbon compounds and accurately reproducing their behavior is beyond the scope of **chemical modeling**. Moreover, **standard characterization tests (for example, cetane number)** are not sufficiently descriptive. In order to understand the relationship **between fuel properties and soot formation in a diesel-type combustion scenario**, an innovative characterization model was set up by IFPEN’s researchers. The model is hinged around a **high-pressure and high-temperature chamber** and employs **advanced optical measurement techniques** with a view to obtaining a simultaneous picture of (figure):

• **reduction zones, by chemiluminescence**[a];
• the **quantitative distribution of soot in the flame**, via 2D extinction[b] measurement.



Simultaneous images of the reaction zone (top) and soot distribution (bottom).

The use of these techniques demonstrated that fuel composition acted independently on several aspects of combustion, including the two principal factors influencing soot formation in the flame: **equivalence ratio in the pre-mix zone and local chemistry**. The impact of different families of hydrocarbons[c] was characterized in representative engine operating conditions(1) and this new method could also be used either to evaluate new fuels or to validate surrogate fuels used in computational simulation tools.

a - Measurement of light emitted by a chemical reaction.
b - Light absorption measurement.
c - Such as long-chain aliphatic alkanes (n-dodecane) or aromatics (n-propylbenzene).

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(1) M. Bardi, G. Bruneaux, O. Colin, SAE Technical Paper 2017-01-0721, 2017
DOI : 10.4271/2017-01-0721

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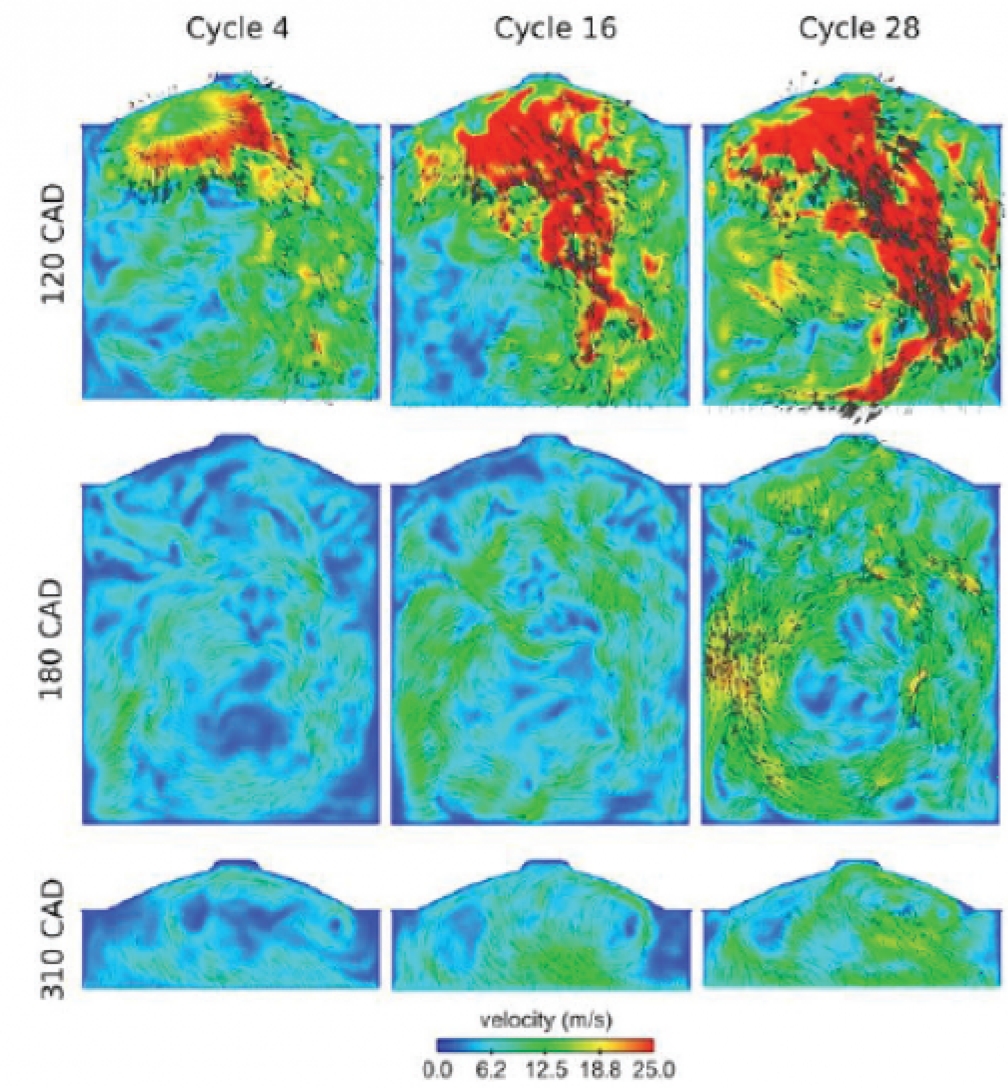
Observation of soot in a diesel flame

Gasoline direct injection engines emit soot particles during rapid transients. This still poorly understood phenomenon is taken into account during **new WLTCs**[a], aimed at more accurately reproducing real vehicle use.

High-resolution, digital flow simulations in the combustion chamber, capable, in particular, of resolving **cycle-to-cycle variations**, can be used to gain a better understanding of the mechanisms behind this soot formation. However, these simulations, based on **LES**[b], are mastered on **stabilized operating points**(1), where they give relevant results, but they have never been carried out for transients.
Research conducted by IFPEN(2-3) in the ANR **Astridec** project demonstrated the relevance of LES for tackling this problem, via the first ever **calculations involving 1D-3D code coupling**.

In particular, these simulations reproduced the **impact of engine transients**, i.e. engine speed variations (for example, acceleration between 1,000 rpm and 1,800 rpm in the figure), on the acoustics in the intake line, and thus on filling and aerodynamics in the combustion chamber.



LES resolution of instantaneous velocity ranges
for three crankshaft angles, and for three transient
cycles: cycle 4 (1,000 rpm), cycle 16 (1,400 rpm)

and cycle 28 (1,800 rpm).

Further work is now required to fine-tune the results, separating the average and fluctuating components of velocity ranges. To do this, research is focusing on two areas: obtaining a usable average based on several transients, and the implementation of specific after-treatment analyses, such as **EMD**[d] [(4)].

a - Worldwide harmonized Light vehicles Test Cycles.
b - Large-Eddy Simulation.
c - Aerodynamics and Sprays during Transients of Gasoline Direct Injection Engines.
d - Empirical Mode Decomposition.

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(1) A. Robert, S. Richard, O. Colin, L. Martinez, L. de Francqueville et al, Proc. Combust. Inst. 35(3), 2015.

(2) B. Roux, IFPEN, Ph.D. thesis 2015.

(3) A. Poubeau, S. Jay, A. Robert, E. Nicoud et al., SAE Technical Paper 2017
DOI : 10.4271/2017-24-0028

(4) M. Sadeghi, K. Abed-Meraim, F. Foucher, C. Mounaïm-Rousselle, iTi Conference on Turbulence, Bertinoro, Italie, sept. 2014.

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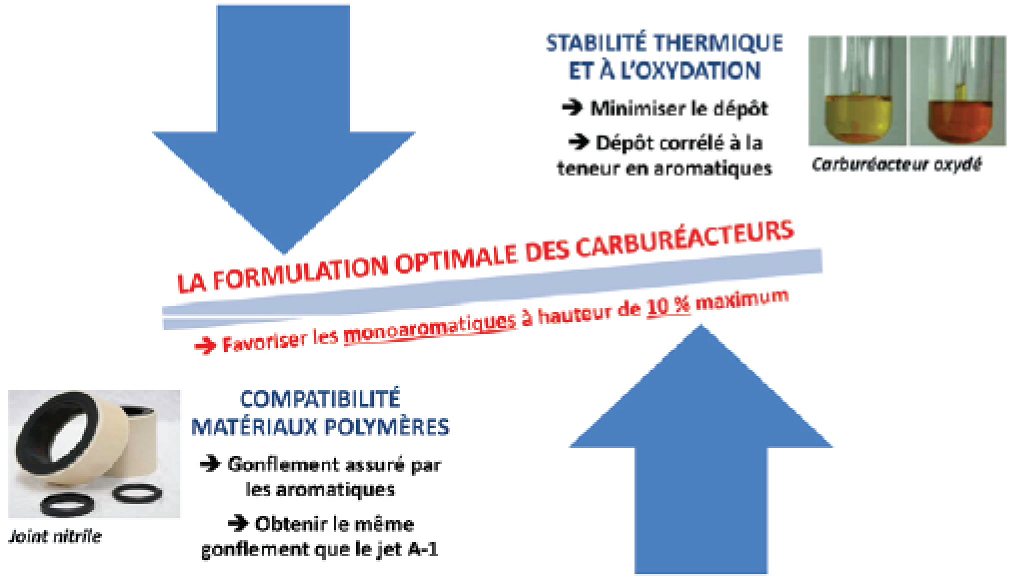
LES moves to rapid transients for cleaner powertrains

In the aviation sector, fuels derived from hydrotreated vegetable oils (HEFA[a]) are seen as an alternative to **petroleum based Jet A-1**[b] to **reduce the environmental footprint of air transport**. However, the use of these primarily **paraffinic alternative fuels** may generate problems related to circuit impermeability. To avoid this issue, a minimum aromatic content is needed, since aromatics are absorbed by polymer seals, ensuring their expansion. However, the quantity of these compounds needs to remain limited since they cause deposits and pollutant formation.

The **optimization of the formulation of synthetic aviation fuels** was the focus of the **CAER**[c] project. A dedicated experimental
research program was conducted on materials compatibility, thermal stability and oxidation resistance tests[(1)].



Jet fuel formulation optimization.

Using cutting-edge techniques, IFPEN's teams thus investigated the various mechanisms involved in thermal and oxidation stability, also combining measurements on real fuels and model fluids. The latter were produced from Jet fuel formulation optimization.

Gasoline direct injection engines emit soot particles during rapid transients. This still poorly understood phenomenon is taken into account during **new WLTCs**[a], aimed at more accurately reproducing real vehicle use.

High-resolution, digital flow simulations in the combustion chamber, capable, in particular, of resolving cycle-to-cycle variations, can be used to gain a better understanding of the mechanisms behind this soot formation. However, these simulations, based on **LES**[b], are mastered on stabilized operating points[(1)], where they give relevant results, but they have never been carried out for transients.

Research conducted by IFPEN[(2-3)] in the ANR **Astridec** project demonstrated the relevance of LES for tackling this problem, via the first ever **calculations involving 1D-3D code coupling**. In particular, these simulations reproduced the impact of engine transients, i.e. engine speed variations (for example, acceleration between 1,000 rpm and 1,800 rpm in the figure), on the acoustics in the intake line, and thus on filling and aerodynamics in the combustion chamber.

Further work is now required to fine-tune the results, separating the average and fluctuating components of velocity ranges. To do this, research is focusing on two areas: **obtaining a usable average based on several transients**, and the **implementation of specific after-treatment analyses**, such as **EMD**[d] [(4)]. LES resolution of instantaneous velocity ranges for three crankshaft angles, and for three transient cycles: cycle 4 (1,000 rpm), cycle 16 (1,400 rpm) and cycle 28 (1,800 rpm).

a - Hydroprocessed Esters and Fatty Acids.
b - Carburant utilisé dans l'aviation.
c - .Carburants alternatifs pour l'aéronautique, coordonné par IFPEN.

(1) A. Ben Amara, M.-H. Klopffer, B. Veyrat, L. Starck, International Congress and Expo on Biofuels & Bioenergy, August 29-31, 2016 Sao Paulo, Brésil.

(2) A. Ben Amara, M.-H. Klopffer, M. Alves Fortunato, L. Starck, Optimal jet fuel composition with stability and improved oxidation. Patent WO 2017/050687 A1.

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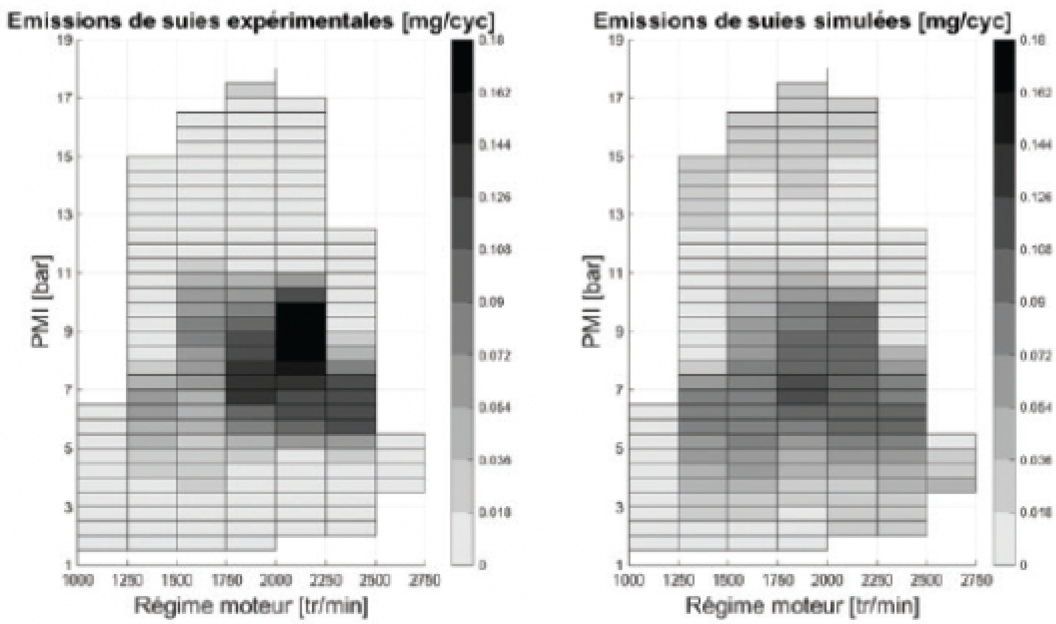
Where aviation fuels are concerned... compromise is the name of the game

Vehicle approval standards require increasingly high levels of engine performance (low fuel consumption and low emissions) over a broad working range. It is for this reason that **new engine architectures** incorporate technologies such as **direct injection** and **burned gas recycling systems**, two levers for **combustion optimization**. In this context, engine control strategies are becoming extremely sophisticated, hence increasing recourse to system simulation.

However, the complexity of the **mechanisms involved in the formation of pollutants in the combustion chamber**, particularly soot, makes their detailed incorporation in traditional system simulation approaches difficult. To overcome this difficulty, IFPEN has developed phenomenological models, i.e. based on the physics of phenomena but using more global descriptors.

Significant correlations exist **between soot emissions and the thermochemical conditions of the fuel-air mixture** at known and specific locations within the **diesel fuel jet**[(1)]: particularly at the **lift-off length** (region where soot forms) and within the **diffusion flame** (location of soot oxidation). These factors are themselves directly related to the engine control parameters.



Comparison of measured and calculated soot quantities for a running engine(b).

This knowledge has formed the basis for the development of a model capable of describing such conditions throughout the engine cycle[2] and, from this, deducing a quantitative **prediction of soot formation** (figure). The model obtained, which also makes it possible to predict the impact of adjustment variations with respect to a given operating point (**injection strategy, dilution ratio, turbocharging rate**), was incorporated in the **IFP-Engine library for the Simcenter Amesim™** [a] software marketed by Siemens Digital Industries Software. The challenge now is to cover a broader range of engine operating conditions, and, in order to do so, to establish the applicability of the correlations employed.

a - Multi-physical simulation tool.
b - IMEP: Indicated Mean Effective Pressure.

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(1) L. Pickett, D. Siebers, Combustion and Flame, 138: p. 114–135, 2004

(2) A. Dulbecco, G. Font, SAE Technical Paper 2017-24-0022.
DOI : 10.4271/2017-24-0022, 2017

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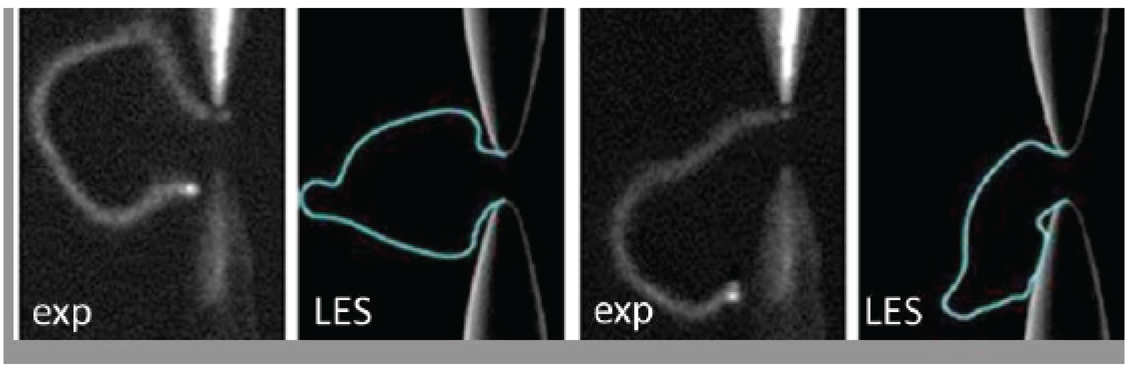
Life and death of soot: a model to control the phenomenon

In order to reduce fuel consumption in gasoline engines, manufacturers are focusing their efforts on **turbocharging and downsizing**. However, this option leads to an increase in the **knock phenomenon (destructive engine self-ignition)**. This can be avoided by significantly increasing the **dilution ratio using re-circulated burned gases**, but such an approach is to the detriment of **flame stability during spark ignition**, and hence to the detriment of **engine stability**.

In this context, manufacturers have turned to **CFD**[a] and, in particular, **LES**[b] in order to understand the causes of – and thereby address – **cycle to cycle fluctuations** which reduce engine stability. However, existing combustion models capable of describing spark ignition, do not take sufficient account of these fluctuations.

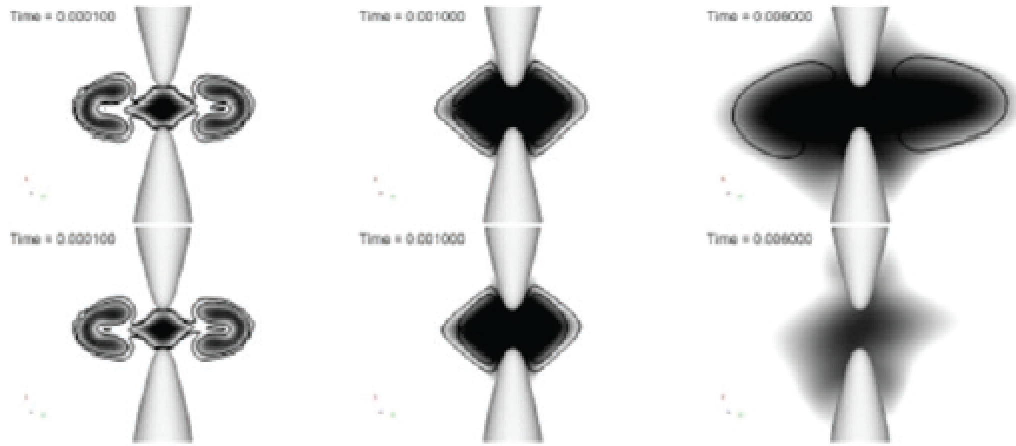
To develop such a model[(1)], IFPEN took part in the **Famac**[c] project, providing an **electric circuit model** for a **standard vehicle coil**, capable of accurately reproducing the energy transferred by the spark plug.

Since energy is deposited along the electric arc, this first model was then supplemented by a **Lagrangian arc model**, which reproduces the shape and evolution of the real arc (figure 1).



Experience vs LES comparison for the two electric arc images.

This approach made it possible to correctly simulate the **critical ignition energy at rest**, without turbulence (figure 2). The first calculations for **"standard engine conditions"** (with turbulence) also demonstrated good consistency with experience. These first models representing **complex ignitions in turbulent conditions** will be evaluated for concrete cases and be used to propose **ignition strategies designed to reduce knocking**. Ultimately, they will also be used to help design the new, more robust ignition systems that will form the basis of more fuel efficient, cleaner engines.



Propane/air ignition at rest. 107 mJ (top) and
78 mJ (bottom) of energy leading to ignition success
and failure respectively.

a - Computational Fluid Dynamics.
b - Large-Eddy Simulation.
c - Ignition fundamentals for the spark ignition engine.

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(1) ***O. Colin*** *et al., DNS and LES of spark ignition with an automative coil, soumis au Symposium on Combustion 2018*

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Ignition simulation

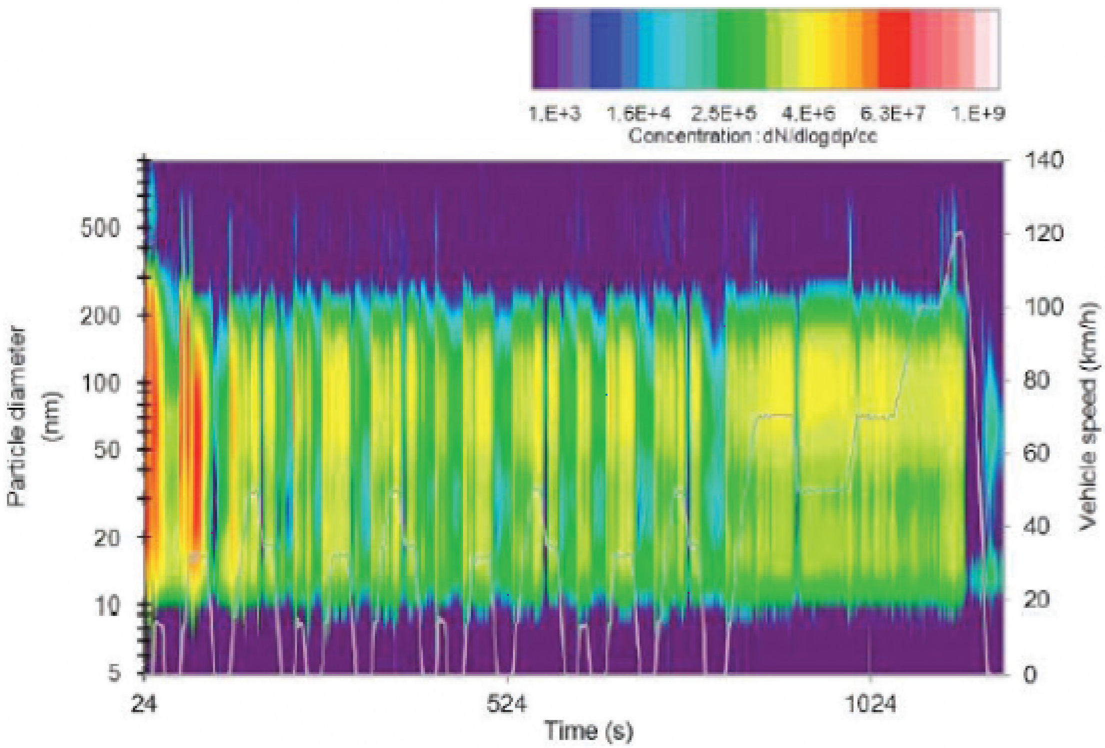
Vehicle approval certifies that the **emissions of said vehicle** meet the specifications imposed by existing standards. Although current regulations only concern a **limited number of chemical species**, the impact of the latter on human health and the environment is
leading to a tightening up of legislation, with a reduction in emission thresholds and the inclusion of new pollutants.

Consequently, there is a need for a more in-depth understanding of the various types of chemical species emitted and their concentrations, **depending on vehicle operating modes**. To address this need, IFPEN coordinated two projects that shed light on emissions – regulated or not – from vehicles representative of the French market.

The **Cappnor** project highlighted:

• **high levels of ultra-fine particle emissions from a gasoline direct injection powertrain** (figure),
• the **very high efficiency of Diesel particle filters**, thanks to which the **exhaust emission concentrations are indistinguishable from urban atmospheric levels**[1].

The **Cappnor 2** project demonstrated that the efficiency of the two major technologies aimed at **reducing nitrogen oxide emissions (NOx)**[a] **of Diesel engines** was heavily dependent on the way they were implemented by manufacturers within the various engine operating ranges[2].



Particle concentrations (color) emitted by a gasoline direct injection vehicle: evolution over time depending on their diameter when speed varies (gray curve) (b).

Vehicle approval procedures evolved in 2017 to ensure **low emission levels** over a broader range of use of an **internal combustion engine**. The results of these two projects provide legislators with a basis for defining improved emission reduction measures. They also indicate the development priorities that IFPEN should be focusing on in terms of designing **new pollution control systems**.

In parallel, the continuous improvement process is being pursued with the **Rhapsodie** project, focusing on the various forms of polycyclic aromatic hydrocarbons present in particles and in the gas phase.

*a - Catalytic reduction using urea (**SCR Selective Catalytic Reduction**) and **NOx trap** (LNT: Lean NOx Trap).*
b - When the speed (gray curve) and the temperature entering the catalytic converter (red curve) are varied.

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(1) S. Zinola, S. Raux, M. Leblanc, SAE Technical Paper 2016-01-2283, 2016.
>> DOI : 10.4271/2016-01-2283

(2) M. Leblanc, L. Noël, B. R'Mili, A. Boréave, B. D'Anna, S. Raux, Journal of Earth Sciences and Geotechnical

Engineering, vol.6, no. 4, 2016, 29-50
>> https://www.scienpress.com/journal_focus.asp?main_id=59&Sub_id=IV&Issue=1921

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