Modeling and simulating the flow generated by new automotive injectors

Executive summary

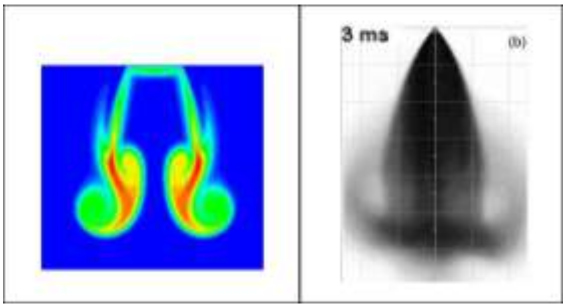
This collaboration contributed to a better fundamental understanding of physical and numerical issues appearing in the study and design of modern injectors that are currently developed to reduce fuel consumption and CO_2 emissions of automobile engines.

Challenge overview

High-pressure direct injection of the fuel in the combustion chamber is nowadays used to respond to the severe European standards for the environmental compatibility of automotive engines. The opportunity to discuss with researchers from the French Institute of Petroleum (IFP) and automotive manufacturers (Siemens Automotive, Peugeot) about these topics was offered by supervising a Master training period at IFP and participating at several industrial congresses. It appeared that new physics was involved and the industrial numerical codes had difficulties in capturing it. In particular, it was pointed out the need of a precise theoretical and numerical description of the large scale vortex structures generated at the tip of the injection flow slug (see figure). After several discussions, the industrial partners were finally convinced to state the problem on a more fundamental basis: use mathematical vortex models to characterize these structures and academic precise numerical codes to simulate the flow. Since it was the first time that an applied mathematics laboratory was involved in this research area, a precise requirement from the industrial partners was to ensure the transfer of the academic knowledge into the industrial framework. The challenge was then to study also the behaviour of main industrial codes and run them on the same test cases as the academic numerical codes. This implied a total immersion into the industrial numerical environment.

Implementation of the initiative

The first collaboration on this topic was established with the IFP, the Division of Energy and Application Techniques, and took the form of an 18 months research contract. Since the industrial aspects of this collaboration were vital to assess, an important part of the work was undertaken in company's offices because of the confidentiality of the industrial numerical tools implied. The second contract on the same topic was concluded with Siemens Automotive (now Continental Automotive France) for a 9 months period. This time, the (small) financial support was entirely devoted to fundamental research and allowed the publication of two papers in first rank journals.



Examples of vortex structures generated during the fuel injection. Numerical simulation of the gas-gas injection using an academic code (left) and experimental visualization of a Diesel injection (courtesy of IFP).

The problem

Vortex rings models are based on an elliptic partial differential equation. The difficulty comes from the fact that the boundary of the definition domain is also an unknown of the problem. Vortex models were obtained numerically and then validated by performing numerical simulations using a full Navier-Stokes academic solver.

Results and achievements

A numerical tool for computing vortex models was developed. The academic Navier-Stokes numerical code was adapted for the simulation of the flow generated by a gas-gas injection. An important effort was devoted to derive, from the obtained theoretical models and numerical data, quantities relevant for the engineer. Diagnosis based on this fundamental study were then used to assess for the performances of industrial codes in simulating the injection systems. The continuation of this theoretical and numerical fundamental study is now part of a three-year national program on the direct gasoline injection systems. We are the only applied mathematics laboratory involved in this huge program coordinated by Continental Automotive and implying several academic and industrial partners.

Lessons learned and replicability

Cooperations with industrial partners require supplementary efforts. Otherwise, it is difficult to maintain the balance between fundamental and industrial research.

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