DIPARTIMENTO DI INGEGNERIA
CORSO DI DOTTORATO IN INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE - PHD COURSE IN INDUSTRIAL AND INFORMATION ENGINEERING - 36TH CYCLE

Title of the research activity:	Development of experimental methodologies for the fluid-dynamic analysis of pre-chamber systems for spark ignition internal combustion engines.
State of the Art:	In the last years, in the global effort of improving internal combustion engines efficiency, the evolution of the spark ignition engine is moving towards the massive adoption of fuel direct injection technology. This technological evolution is dictated by the stringent CO_2 emission targets (95 g/km to 2021 in EU and similar goals in the main automotive markets). The tightening of the emission standards will continue in the future: EU has set the goal of 15% reduction by 2025 and 37.5% by 2030 with respect to the reference levels in 2021 [1]. An increasing degree of hybridization will play an important role in reducing fuel consumption and emissions [2]. GDI technology offers a higher thermal efficiency potential with respect to PFI systems, mainly due to the capability to overcome the efficiency drop at low loads, that represents the greatest weakness of port fuel injected engines. Direct fuel injection enables the adoption of stratified charge strategy and globally lean combustion[4], reducing fuel consumption at low loads by to 20% over stoichiometric, uniform charge combustion systems. A further significant step for internal combustion engine efficiency increase can derive from the adoption ultra-lean homogeneous charge mixture, but conventional spark ignition systems cannot offer and adequate control of this kind of combustion. In order to obtain a stable, efficient and clean combustion with ultra-lean mixture, the use of pre-chamber combustion systems has been proposed [7-10], in which a small portion of the charge (locally in rich mixture) is burnt in a separate small chamber, which connected to the main combustion chamber by a number of small orifices. The hot gases escaping the pre-chamber ignite the lean charge in the main chamber, increasing significantly the flame speed and extending the dilution limits. As a results, the spark ignited engine can operate with λ=2, obtaining a fuel conversion efficiency levels close to 50% and extremely low NO_x and particulate emission levels.
Short description and objectives of the research activity:	In order to fully exploit the pre-chamber combustion potential in terms of fuel conversion efficiency, reduced pollutant formation and combustion cycle-to-cycle stability, a deep knowledge of pre-chamber fluid-dynamics is required. In order to operate a pre-chamber system, two different strategies can be adopted: passive technology and active technology. With a passive pre-chamber system, one of the fuel jets emerging from the GDI injector spraying in the main combustion chamber is directed into the pre-chamber; the fuel here is mixed with air and ignited by a spark plug. In active systems, a dedicated, single hole GDI injector introduces a very small mass (around 1 mg/shot) of fuel directly in the pre-chamber where it is ignited by the spark-plug; this last technology is normally coupled with a port fuel injector feeding the rest of the fuel to the main combustion chamber.

	With both the technologies available for pre-chamber combustion systems, it is mandatory achieving a complete control of the fuel spray evolution as it interacts with the air charge and the pre-chamber in order to endure a proper mixture formation in space and time. One of the most promising experimental approaches to investigate the fuel spray/air charge interaction is spray mapping by means of the momentum flux local (MF) distribution. This approach is much more effective than simple visualization as from spray images only the spray shape evolution can be detected with no information about how the 2-phase flow is actually spreading in terms of mass distribution. MF is a perfect complement to more assessed techniques traditionally used for spray characterization such as Phase Doppler Anemometry. Once combustion has started in the pre-chamber, hot gases emerge from the micro-channel connecting it with the main chamber in order to ignite the rest of the mixture. Investigating these gas jets as they protrude from the pre-chamber is another important step in the optimization process of this kind of combustion system, as from the jets evolution the actual development of the overall combustion process is determined. The following steps are planned for the present research project are: - Pre-chamber direct injection systems analysis. GDI injectors are one of the key components of pre-chamber combustion systems, requiring an adequate optimization process in order to ensure adequate characteristics in terms of hydraulic behavior, atomization capability and patter control. - Combustion jets evolution analysis: the analysis and the control capability of the hot gas jets emerging is a crucial step in the development of this technology. In order to investigate this phenomenon, a high temperature, pressurized static combustion chamber will be used, using high speed imaging systems to visualize the gas jets evolution with different pre-chamber configurations and operating conditions.
Bibliography:	[1] European Parliament. Curbing CO2 emissions from cars: agreement with Council (European Parliament: Brussels, 2018). http://www.europarl.europa.eu/news/en/press-room/20181218IPR22101/curbing-co2- emissions-from-cars-agreement-with-council. [2] Rențea, C., Bățăuș, M., Maican, S., Oprean, M., & Frățilă, G. (2020). The Influence of the Hybridization Factor on the Energetic Performance in Test Cycles. In The 30th SIAR International Congress of Automotive and Transport Engineering (pp. 103–110). Springer International Publishing. https://doi.org/10.1007/978-3-030-32564-0_13. [3] Council on Clean Transportation (ICCT). https://theicct.org/sites/default/files/publications/European_vehicle_market_statistics_20192020_20191216.pdf. [4] Park, C. W., Oh, H. C., Kim, S. D., Kim, H. S., Lee, S. Y., & Bae, C. S. (2014). Evaluation and visualization of stratified ultra-lean combustion characteristics in a spray-guided type gasoline direct-injection engine. International Journal of Automotive Technology, 15(4), 525–533. https://doi.org/10.1007/s12239-014-0055-1. [5] Johnson, T., & Joshi, A. (2018). Review of Vehicle Engine Efficiency and Emissions. SAE International Journal of Engines, 11(6), 1307–1330. https://doi.org/10.4271/2018-01-0329. [6] Saliba, G., Saleh, R., Zhao, Y., Presto, A. A., Lambe, A. T., Frodin, B., Sardar, S., Maldonado, H., Maddox, C., May, A. A., Drozd, G. T., Goldstein, A. H., Russell, L. M., Hagen, F., & Robinson, A. L. (2017). Comparison of Gasoline Direct-Injection (GDI) and Port Fuel Injection (PFI) Vehicle Emissions: Emission Certification Standards, Cold-Start, Secondary Organic Aerosol Formation

	Potential, and Potential Climate Impacts. Environmental Science and Technology, 51(11), 6542–6552. https://doi.org/10.1021/acs.est.6b06509. [7] N. Lida: Reasearch and Development of Super-Lean Burn for High Efficiency SI Engine: Chanllenge for Innovative Combustion Technology to Achieve 50% thermal efficiency, Okyama, Japan, 2017. [8] M. Schumacher, M. Wensing: A Gasoline Fuelled Pre-Chamber Ignition System for Homogeneous Lean Combustion Processes: SAE 2016 International Powertrain Fuel & Lubricant Meeting. [9] Nakata K. Nogawa S., Tkahashi D. Yoshihara Y., Kumagai A., Suzuki T.: Engine Technology for Achieving 45 % Thermal Efficiency on S.I. Engine. SAE Technical Paper 2015-01-1896. [10] Abe S., Ishikawa N., Tekeda N., Akimoto S., Matsuura H.: Optimization of Combustion Chamber for Direct Injection Gasoline Engine Employing Center Injection System. SAEe technical Paper 2014-08-0448. [11] Postrioti L, Buitoni G, Pesce FC, Ciaravino C.(2014). Zeuch method-based injection rate analysis of a common-rail system operated with advanced injection strategies. Fuel, 128, 188–98. https://doi.org/10.1016/j.fuel.2014.03.006. [12] Christ, K. (2011) Kalibrierung von Magnet-Injektoren für Benzin-Direkteinspritzsysteme mittels Körperschall, KIT Scientific Publishing, ISSN 2190-6629 [13] Postrioti L, Malaguti, S., Bosi, M, Buitoni G, Piccinini, S., Bagli, G. (2014). Experimental and numerical characterization of a direct solenoid actuation injector for Diesel engine applications. Fuel, 118, 316-328. https://doi.org/10.1016/j.fuel.2013.11.001 [14] Postrioti, L., Cavicchi, A., Brizi, G., Berni, F., & Fontanesi, S. (2018). Experimental and Numerical Analysis of Spray Evolution, Hydraulics and Atomization for a 60 MPa Injection Pressure GDI System. SAE Technical Papers. https://doi.org/10.4271/2018-01-0271.
Scientific coordinator (s)	L. Postrioti
Contact (s)	lucio.postrioti@unipg.it