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Gas Prechamber Combustion Modeling – A Hierarchical Approach for Model Development

Natural gas (NG) is a low-carbon fuel which can be used in the mobility sector to reduce combustion-produced CO2 emissions. This project aims to enhance the understanding of NG prechamber (PC) combustion through experimental and numerical investigations. On the numerical side, Direct Numerical Simulations (DNS) are used to develop understanding of the underlying processes which control PC combustion. Equivalently, on the experimental side, optical investigations in generic and near-production prechamber geometries aim to create advances in understanding and provide validation data under near-engine conditions. A single-cylinder research engine is also used for investigations of emission production and engine efficiency. These results will be used for the development of 3D CFD and 0D-1D phenomenological combustion models, which can be used for the design and optimization of lean-burn gas engine combustion systems

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Introduction

Natural gas (NG) can be used in existing internal combustion engines, but due to its favorable characteristics – namely high resistance to self-ignition (knock) – it can be utilized best in high-compression-ratio, high-efficiency, lean-burn engines. Lean-burn gas engines possess the advantage of lower fuel consumption, and as a result also emit lower CO2 emissions compared to stoichiometric engines. Nevertheless, they suffer from increased cycle-to-cycle variations and unburned hydro-carbon emissions. Prechambers are used to increase the ignition energy and stabilize combustion under increasingly lean conditions by creating optimal conditions near the spark plug for the early flame development and distributed ignition points in the main combustion chamber. This increases combustion speed and reduces unburned hydrocarbon emissions.

Reactive DNS Simulations – SFOE

Reactive Direct Numerical Simulations are used for the in-depth understanding of the early flame propagation within the prechamber, the flame stability at the prechamber exit, the resulting combustion in the main chamber and the influence of the walls on the turbulent flame.

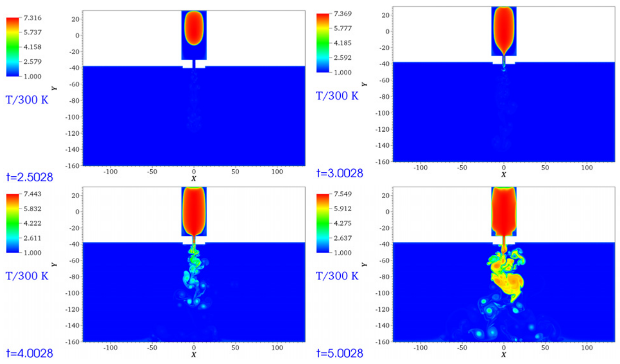

Fig.1: Temperature distribution as the hot gases exit a single-hole prechamber. Conditions: CH_4, laminar, P_{init}=1bar, T_{init}=300K, PC λ=1, main chamber λ=2 [1]

Optical Investigations - CTI ,LMB & EU,GasOn

Optical data is obtained from prechamber combustion systems under near-engine conditions, in order to provide validation data for the simulations and increase the understanding of in-prechamber and main chamber combustion processes. Optical data from within the prechamber will be obtained using an optically accessible generic, single-hole prechamber designed and manufactured within LAV.

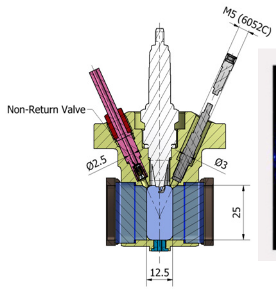

Fig.2: Optically accessible generic PC design

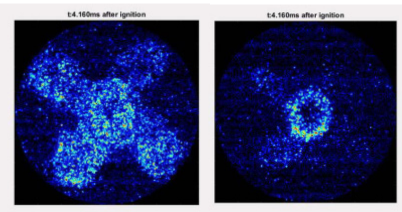

Fig.3: OH* chemiluminescence images obtained from a multi-hole PC geometry with λ=1.6 (left) and λ=1.75 (right)

1-cyl Engine Experiments – CTI,LMB

Single-cylinder research engine experiments will be performed to evaluate different prechamber designs in terms of combustion characteristics, performance, as well as emissions (mainly NOx and CH4 slip). The main aim of the investigations is to extend the operating range of the engine to higher loads and leaner mixtures, in order to reach very low engine-out NOx values.

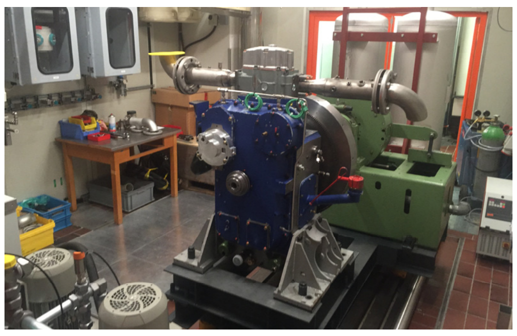

Fig.4: View of the 1-cylinder research engine test-rig

3D CFD & 0/1D Phenomenological Models

The experimental and DNS simulation results will be used to provide an in-depth understanding of the combustion processes within the prechamber, as well as after the jet exist into the main chamber. This data will be used to develop detailed 3D CFD combustion models, to be used in the future for prechamber design and overall engine design optimization. In addition, the data will be used for the development of phenomenological models for prechamber engine design and optimization in wide operating ranges.

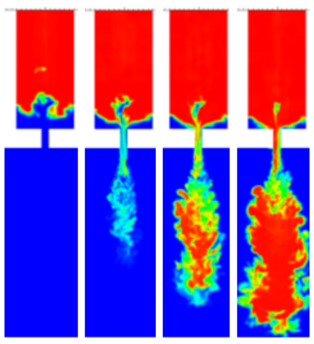

Fig.5: Combustion progress variable in a single-hole prechamber calculated using CMC/LES. Conditions: CH_4, P_{init}=5bar, T_{init}=800K, λ=1 throughout

Expected Impact

The knowledge generated within these projects is expected to contribute significantly to the future design and development of internal combustion engines using prechamber combustion systems. Such engines will allow the widespread use of natural gas as a fuel, which in itself will lead to a 20% reduction of greenhouse gas (GHG) emissions compared to other traditional fossil fuels. In addition, the increase in efficiency due to expansion of the lean limit operating window, the increase in power density as well as the increases in compression ratio will result in a further reduction of fuel consumption and GHG emissions. The optimal design of prechambers should allow the minimization of the CH4 slip, a potent GHG, further decreasing the environmental foot print of such engines. Finally, future use of alternative fuels from power-to-gas processes in prechamber gas engines will allow the complete removal of GHG emissions from power generation using gas engines.

References

[1] Benekos et al., 2016, Direct Numerical Simulation and experimental validation of ignition/early flame propagation and flame-wall interactions in future gas engines, Intermediate report, June 2016

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