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Low emissions combustors development for new aero-engines core applications

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OBJECTIVES

- Design, development and validation of low emissions Injection Systems based on innovative concepts for advanced lean burn aero-engine combustors.
- Design of innovative lean burn low emission aero-engine combustion systems based on Single Annular Combustor (SAC) architecture and innovative concepts on Injection Systems, cooling and fuel staging.
- Validation of Lean burn low emissions combustors by full annular (FANN) rig High Pressure tests, covering the entire range of aero-engine Landing/Take-Off LTO cycle conditions.
- Assess the FANN combustors performance and deliver correlations for the New Aero-Engine Core Concepts (NEWAC) evaluation on Pollutant Emissions (NOx, CO, UHC) and CO2.

APPLICATIONS

Aero engines are the main source of CO2 and NOx pollution in commercial and freight aircraft. Large investments have already been made in Europe and the US through R&T programmes and collaborations to reduce the negative environmental effects of aircraft use. The recently started EU integrated programme for **NEW A**ero engine **C**ore concepts NEWAC (reference 1) is focusing on combustor technologies and introduction of new engine core configurations to reduce NOx emissions and further reduce CO2 to achieve the ACARE SRA 2020 objectives. The main result of this programme will be validated new technologies enabling a 6% reduction in CO2 emissions and a further 16% reduction in NOX relative to ICAO-LTO cycle (see figure 1).

In NEWAC the Sub-Project SP6 will design and manufacture three innovative combustors based on different injection system concepts (LPP, PERM and LDI) and perform rig tests to validate the critical technologies. The results will be assessed for 4 engine core concepts :

- Inter-cooled Recuperative Core operating at low OPR and using LPP Combustor concept;
- Active Core applicable for a geared turbo-fan (GTF) and Flow Controlled Core for a counter rotating turbo-fan (CRTF) using PERM or LDI Combustor Concept, depending of S/R or L/R application;
- Inter-cooled core for a high OPR engine concept, based on 3 shaft direct drive turbofan /DDTF) with a LDI combustor concept.

The paper will describe the content of the NEWAC Sub-Project SP6 "Innovative Combustor" and will present first results of concept work already preformed.

RESULTS

The objectives of Sub-Project SP6 are to develop and validate lean fuel injection technology up to TRL 5-6 demonstrating 60% to 70% reduction of NO_X emissions in the LTO cycle versus the CAEP/2 limit. The target is set according to the current and demonstrated state and maturity level of each lean fuel injection technology being investigated, additionally depending on the particular field of envisaged engine applications. Taking into account that the year 2000 technology, i.e. certification on a new engine at this time, shows around 20% - 30% margin versus the CAEP/2 legislation limits, the targets set correspond to approximately 60% reduction of NO_X compared to year 2000 technology, which is only attributed to improvements of the combustion systems.

The technical objective of SP6 is to further develop and validate lean combustion technology in the fields of:

- Lean Fuel Injection Systems: LP(P), PERM and LDI
- Fuel Systems (staging, thermal management)
- Fuel control system
- Advanced cooling systems

The engine significance result will be a Lean Combustion Technology with a NO_X reduction from -60 to -70 % versus CAEP/2, with a further NO_X reduction of 10% of CAEP/2 level. This corresponds approximately to another 30% reduction of the achieved NO_X levels of the EEFAE programme. The NO_X reduction targets are set assuming that emissions of CO, UHC, and soot/smoke remain at least unchanged on the level of year 2000 technology.

Lean burn technologies in SAC Architecture

Lean combustion technology operates with an excess of air to significantly lower flame temperatures and consequently significantly reduce NO_X formation. Up to 70% of the total combustor air flow has to be premixed with the fuel before entering the reaction zone within the combustor module. Therefore, cooling flow has to be reduced accordingly to provide sufficient air for mixing.

Lean combustion comprises the lean direct injection of fuel, premixing with air and at least a partial pre-vaporisation of the fuel before initiating the combustion process. The optimisation of homogeneous fuel-air mixtures is the key to achieve lower flame temperatures and hence lower thermal NO_X formation. However, this homogenisation has a strongly adverse effect on combustion lean stability, drastically narrowing the operating and stability range. To overcome these stability drawbacks while maintaining good NO_X performance, fuel staging is required.

This can be made in a staged combustor architecture by multiple rows of injectors or by internally staged injectors in a SAC architecture. A staged combustor is geometrically separated into at least two zones, so that each zone can be optimised for a particular requirement (regarding different parts of the flight envelope) and could thus offer good stability at low power. Alternatively, fuel staging can be achieved using internally staged injectors in SACs, thus creating a pilot and a main combustion zone downstream of a common fuel injector as Figure 2 illustrates. The combustor geometries are much simpler and thus more advantageous with respect to unit cost, weight and cooling; cheaper to make, lighter and easier to cool. But even for the SAC, cost and weight reasons will demand that the total number of low emission injectors per annulus has to be minimised. As they are more complex compared to conventional air-blast fuel spray nozzles a significant proportion of the combustor cost will now be related to these advanced internally staged injectors.

In contrast to previous projects with several approaches of lean combustor architectures, all partners within SP6 are now concentrating on a SAC architecture with lean injectors. The SAC architecture offers the highest potential to keep penalties on weight and cost associated with the introduction of lean low emission combustion technology at acceptable levels.

Ultra Low NOx Lean burn Injection System Technologies

The Ultra Low NO_X (ULN) combustor core technology is highly depending on the performance of the learn burn injection system. Air quantity needed to the emission abatement is expected to be 60 to 70% of the combustion air, and with this level of injector air-to fuel ratio, operability including ignition, altitude re-light, pull-away, weak extinction stability and thermo-acoustics will be a serious problem, which needs to be carefully taken into consideration during ULN combustor development. On this basis, the ULN lean premixed technology will require fuel-staging system to control the performance of the combustor through the entire engine cycle.

For the fuel injection system the currents status of these techniques does not allow a down-select of injector technology. It would be too risky to make a selection before major performance parameters have been assessed and validated especially the characterisation of operability and thermo-acoustic behaviour. Thus, three different lean fuel injection systems will be investigated in SP6, based on previous EC and national funded projects:

- Lean Pre-Mixed Pre-vaporized (LPP)
- Partial Evaporation & rapid Mixing (PERM)
- Lean Direct Injection (LDI)

They will be developed for applications in a wide range of engine OPR as shown by Figure 3.

LP(P) injection - this concept is much more fitted to low OPR engine cycles, due to the fact that auto-ignition and flash-back constraints are much more lower for this range of engines. It is based on the action of several air flows, one devoted to the fuel atomisation and the second dedicated to the mixing and fuel evaporation. The combination of the two acts also as a promoter for the flame stabilisation in the combustion chamber (figure 4).

PERM - the concept is based on swirler technology development and is addressed to achieve partial evaporation inside the inner duct and a rapid mixing within the combustor, optimising the location of the flame and the stability of the Lean System (figure 5).

LDI – This concept has a controlled premixing: concentric internally staged fuel injection with optimised pilot and main stage flame structure to control their interaction for low NOx and weak extinction stability (figure 6).

OUTLOOK

The NEWAC programme is near the end of the second year. Work is well in progress on the design and development of the Injection systems: first configurations of LDI, PERM and LPP have been defined and test articles are object of investigations on High Pressure Single Sector (HPSS) Tubular combustor test rigs.

The 1st HPSS test has been successfully completed at DLR Cologne. Six LDI configurations, designed by RRD, have been tested in a single-sector up to 12bar, 800K and 2 up to 34bar, 850K. The results show a significant improvement of the estimated LTO NOx on the corresponding NEWAC engine cycles, as shown in figure 7.

Two configurations of the PERM Injection systems have been tested at medium pressure (8 bar) by Karlsruhe University. Promising results have been obtained. The best configuration has been selected for the first test campaign up to High Pressure operating conditions, planned at ONERA Palaiseau.

LPP Injection system configuration is also under extensive validation test campaign at Turbomeca as well as ONERA and Graz University.

Further experimental results will be come soon, in order to have a first overview of the improvement of emissions performance and will be presented at the Conference.

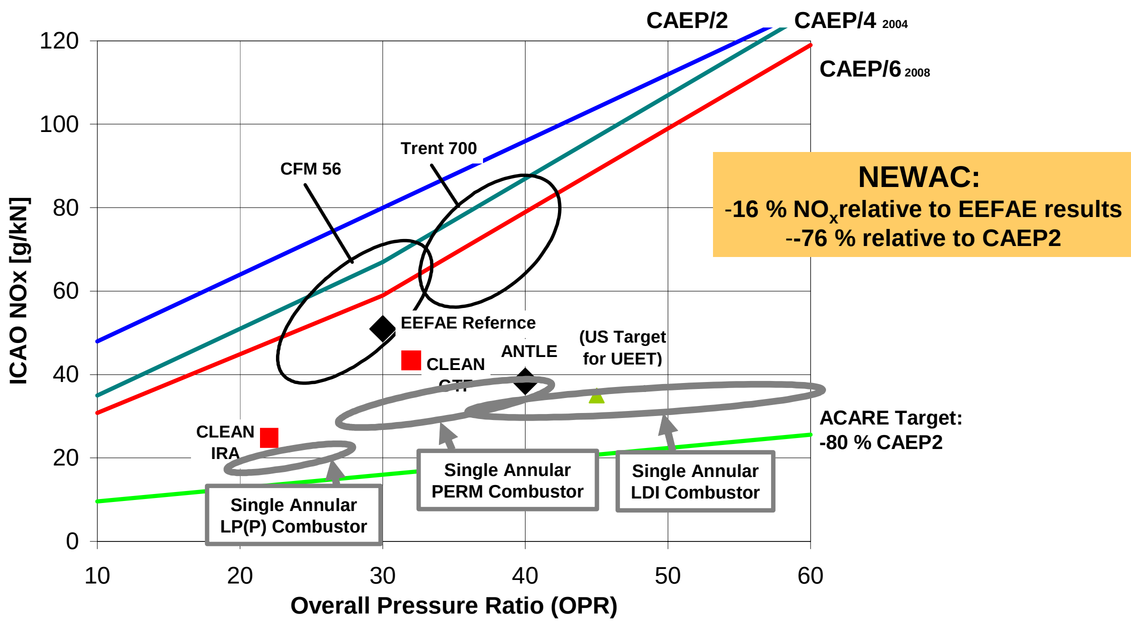

Fig. 1 : Goals of the technology programme NEWAC

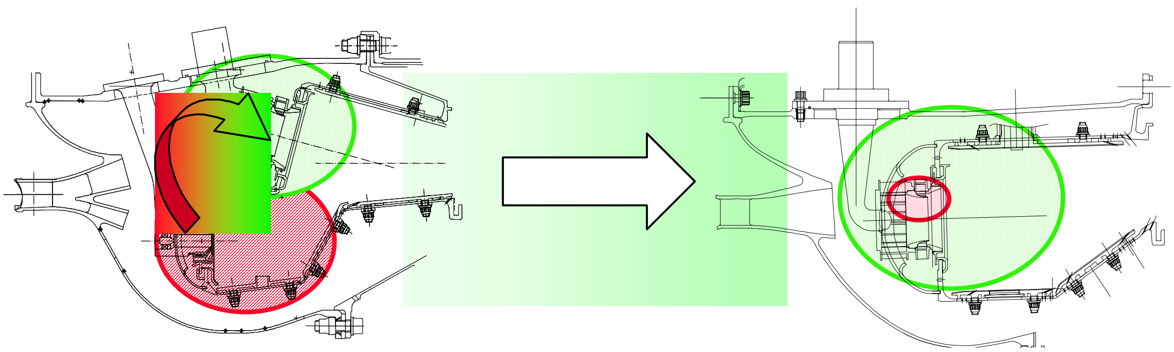

Fig. 2 : Development towards a lean burn technology Single Annular Combustor

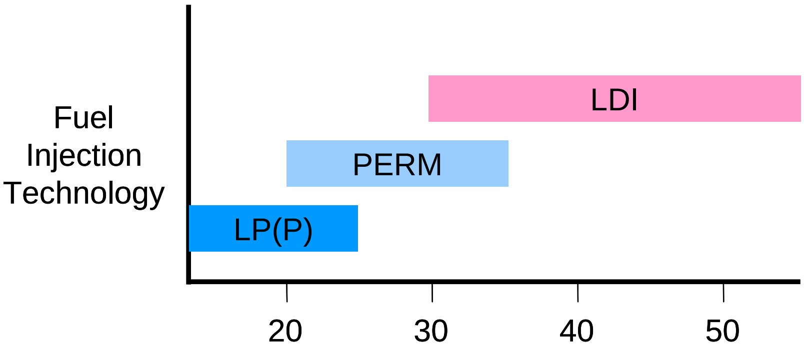

Fig. 3 : Application of different Fuel Injection technologies depending of engine OPR

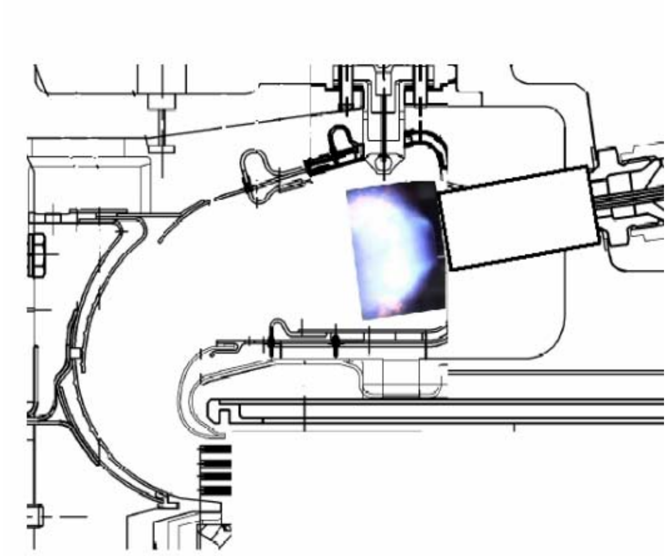

Fig. 4 : LPP Combustor

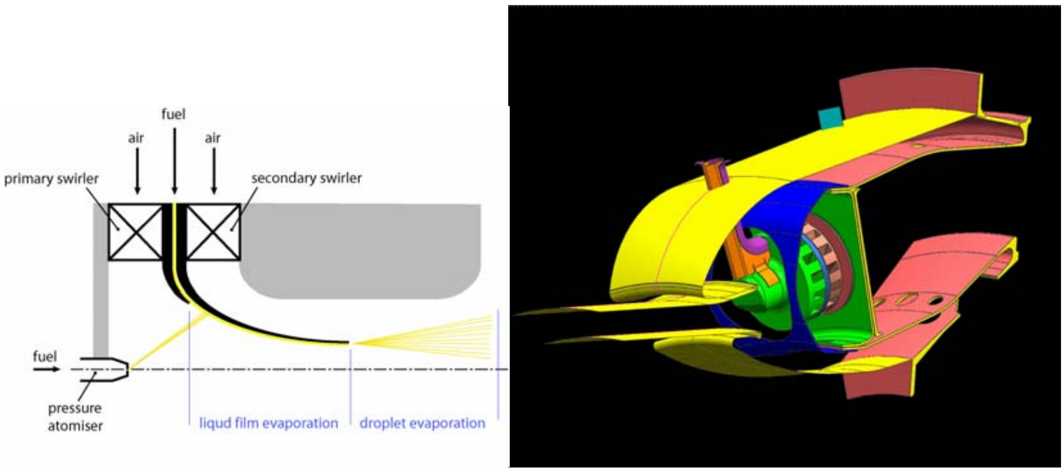

Fig. 5 : PERM Combustor

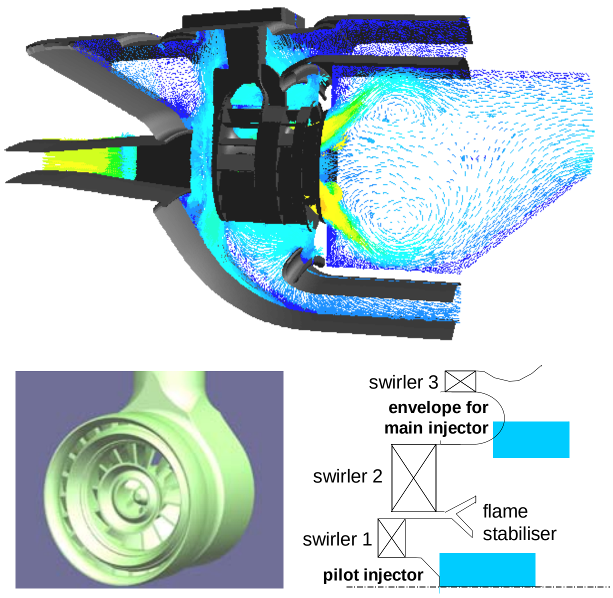

Fig. 6 : LDI Combustor

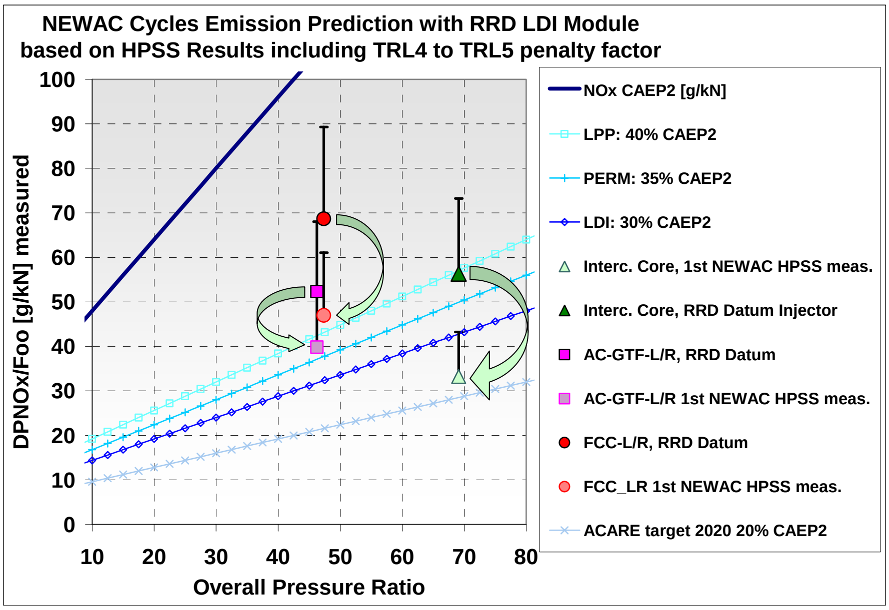

Fig. 7 : NEWAC Emission cycles prediction based on first HP Single Sector Tests

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