LOW EMISSIONS COMBUSTOR TECHNOLOGY DEVELOPMENTS IN THE EUROPEAN PROGRAMMES LOPOCOTEP AND TLC

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Abstract

The local air-quality and global climate change environmental issues linked to aviation require important research and technology developments in all the relevant fields. The engine design and more specifically the combustor optimisation, will determine the environmental performance in term of NOx, CO, UHC and particulates emissions. To answer this need, European collaboration programmes are supported in order to develop the appropriate technology to meet ambitious mid-term and long-term environmental objectives. This is the case of the two programmes, LOPOCOTEP and TLC, where the focus is put mainly on lean combustion in order to reduce significantly NOx emissions. The objective is to demonstrate an 80% reduction from the CAEP2 ICAO regulatory level. An overview of the two programmes, main solutions investigated and principal results achieved or expected, is given. Demonstrated reduction levels together with technological maturity are assessed.

1 Introduction - European collaboration research programmes to answer environmental constraints

As air traffic is rapidly increasing (should double by 2020), the air quality and the risk of climate change linked to the effects of greenhouse gases are two major concerns [1]. In Europe, greater stringency in air quality is expected and various local charges systems at airports such as Erlig are being implemented. The Kyoto protocol ratified in 2004 by Europe entered in force beginning of 2005 and encourages any effort to reduce CO2 emissions and other green house gases. For these reasons, aviation emissions have to be significantly reduced, as any other anthropic emissions. In this prospect, the Strategic Research Agenda of the Advisory Council for Aeronautics Research in Europe, ACARE [2] has set aviation reduction targets of 50% in CO_2 and of 80% in NOx for 2020.

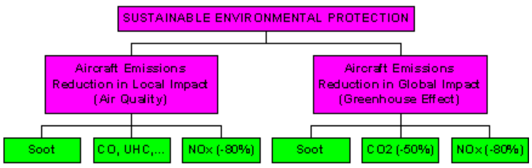

Fig. 1. ACARE Environmental Challenges

A significant answer to these challenges is supported by research and development collaborations within the framework of European programmes. Major benefit is expected from the engine technology innovation as well as from the aircraft technology improvements; air traffic management is also concerned to a lesser extent.

Whereas the reduction in CO_2 will mainly be achieved by improvements in engine efficiency and aircraft performance characteristics, NOx and others species can be significantly reduced by improving combustor technology, in particular by introducing new concepts of injection systems.

The two projects, LOPOCOTEP (Low Pollutant Combustor Technology Project), and TLC (Towards Lean Combustion), are two major European programmes supporting activities in this field. They belong to a cluster of other programmes on combustors, which is covered by the ELECT-AE coordination action [3]. Both programmes, coordinated by SNECMA, involve the main European actors in the field of aero-engine technology: aero-engine manufacturers, national research centres (such as Onera and DLR), and university laboratories.
After having clarified what may be expected from the combustor optimisation (§2), this paper describes the main achievements of the LOPOCOTEP programme, which will be completed at the beginning of 2006 (§3), and the main perspectives of the TLC programme which was initiated in 2005 (§4).

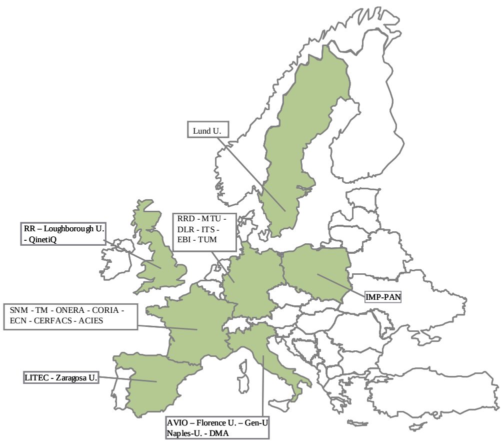

Fig. 2. LOPOCOTEP & TLC consortiums

2 Focus on Aero-engines combustor technology and lean combustion

As the combustion efficiency is always close to one, the optimisation of the combustor will be oriented to minimize NOx, CO, UHC and particulates emissions whereas the engine cycle and engine components efficiencies will impact the CO2 emissions. However, trade-offs occur through the engine cycle definition. For instance, high compression rate, because of elevated temperatures at the combustor entrance may affect NOx and possibly particulates emissions whereas it will ease CO and UHC reduction.

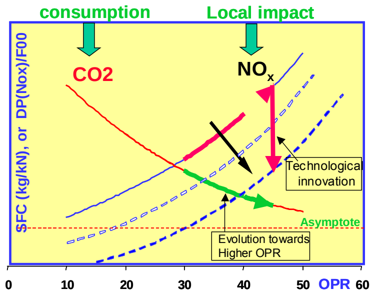

Fig.3. Trade-offs scheme

For this reason, it is essential to be able to optimise the combustor technology for all types of engines, covering then a large range of size, thrust and compression rate. This is the case both in LOPOCOTEP and TLC programmes where the studies cover small turbo-shaft engines explored by Turbomeca, MTU and AVIO to medium and big size engines of SNECMA and Rolls-Royce with maximum overall pressure ratio (OPR) varying on the range [20bar, 40bar].

Lean combustion is the major focus of the two projects. This is the solution expected to reduce significantly the NOx emissions by lowering the flame temperature, and there is confidence that it will be also beneficial to mitigate particulates production. This strategy is also that of the GE TAPS concept [4], already developed at a good maturity level. However, the challenge of lean combustion is not only to be able to perform a sufficient level of fuel premixing and pre-vaporisation but to cope with low regimes requirements: combustion efficiency, trade-off with CO & UHC, lean blow-out limits and relight requirements.

The potential of lean combustion is illustrated hereafter. When the engine combustor entry temperature (T3), entry pressure (P3) and fuel air ratio (FAR), are fixed (with the engine cycle), the NOx emissions measured at the combustor exit will depend on the way the combustion is realised ; The appropriate parameter to consider at the combustor level, is the (average) emission index of NOx

(EINOx=gNOx/kg fuel). The figure 4 shows the EINOx curve against the engine regime (set of P3, T3, FAR values) for a conventional engine combustor (certification measurements) and for a combustor achieving ideal perfect lean combustion (derived from calculation).

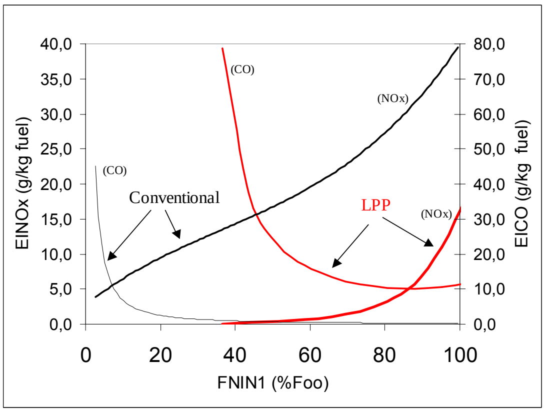

Fig. 4. Lean combustion expectation

This lean combustion benefit is understandable with figure 5 which gives the EINOx value derived from calculation, as a function of residence time and equivalence ratio (ϕ=FAR/FAR$_{stoech}$) and (P3=30bar, T3=800K). Avoiding stoechiometric combustion (ϕ=1) and preferring lean combustion, permits to decrease significantly the EINOx for current residence times (around 5ms). In all the cases, air distribution between injection system and liner wall cooling has to be optimised, knowing the combustor exit equivalence ratio is classically around 0.5.

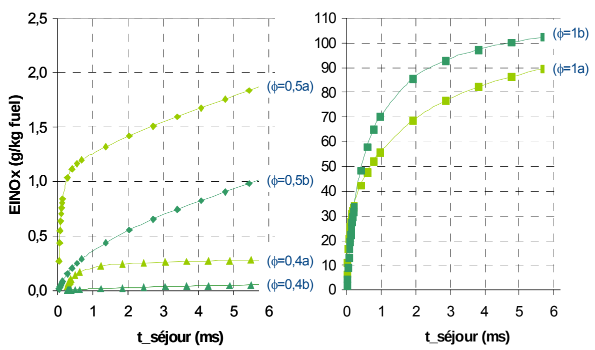

Fig. 5. Average EINOx value depending on residence time FAR a) total b)thermal

Many concepts are investigated by the various industrial partners and their description is proposed in §3. Main target is LTO (landing and take-off) NOx reduction and the objective is an ambitious reduction of 80% from the ICAO CAEP2 standard [5] (see Fig. 6). The reduction is expressed in term of "DP/F00" parameter (DP = estimation of total mass of NOx on the LTO cycle ; F00=take-off thrust of the engine). As they are not concerned by the ICAO regulation on pollution, the target for turbo-shaft engines aimed at in the programme was to reduce NOx emissions by 50%, compared to current technology (in term of NOx emission index for main phases of the flight). Figure 6 provides a status of modern certified engines performance in term of DP(NOx)/F00, and the ACARE objectives targeted by LOPOCOTEP and TLC.

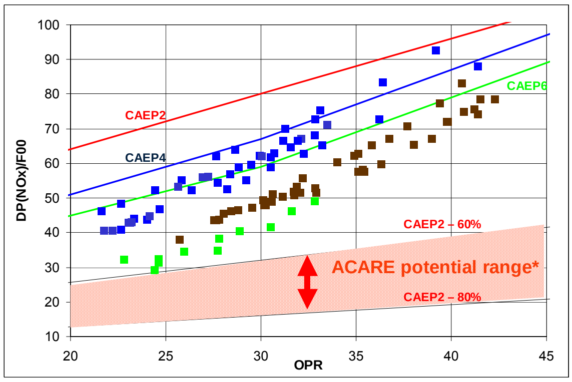

Fig. 6. Status of current certified engines and research target (CAEP6 applied in 2008)

3) Overview of LOPOCOTEP achievements

The FP5 LOPOCOTEP project was initiated in 2001. Technical activities covered injection system and combustor design oriented towards lean combustion except for MTU who worked on a rich combustion approach (RQL). Many experimental campaigns carried out by Onera, DLR, Lund and Technical Univ. of Munich aimed at evaluating on a single sector combustor (case of Onera M1 rig on figure 8), the stability/extinction, auto-ignition and flash-back behaviour of the injection systems as well as providing preliminary results in term of pollutants. Bigger campaigns were performed for some industrials on multi-sector combustors (for medium and large engines) or full annular combustors (return bend combustor for small engines). Complementary studies were performed too, on mixing optimisation (DLR, [15]&[16]), on cooling (Florence Univ. [14], Cnrs-Ensma [13], Loughborough Univ.), on flame speed (QinetiQ), and on instability prediction (Cambridge Univ.).

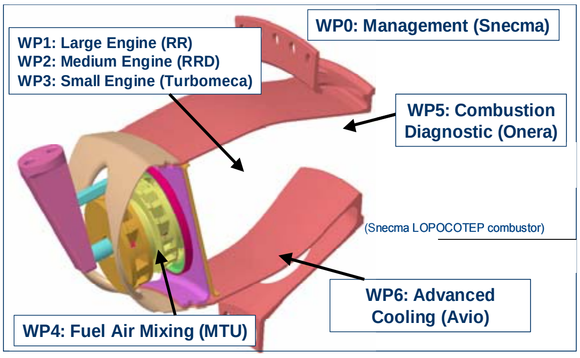

Fig. 7. LOPOCOTEP scope and Work packages activities(with WP leaders)

The various technological approaches are described: “LDI”=Lean Direct Injection (Rolls-Royce UK), “LP(P)”=Lean Premixed partially Prevaporised (Rolls-Royce Deutschland), “Multi-Points” injection (SNECMA), “LPP” = Lean Premixed Prevaporised (Turbomeca and AVIO), “RQL”=Rich Quenched Lean (MTU).

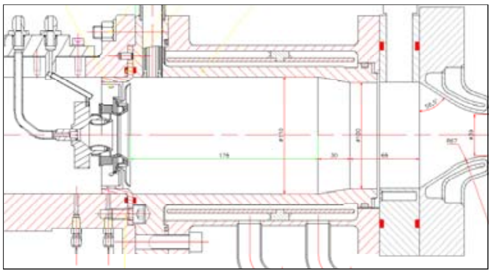

Fig. 8. Onera M1 rig water cooled tubular combustor

The NASA Technology Readiness Level (TRL) scale [6], is used hereafter to assess as much as possible, the maturity of the technology.

3.1) Large and Medium engines

The three industrials concerned, investigated separately their own concepts, exchanging mainly qualitative information. High quality work (not reported here), was performed by Loughborough Univ., to optimise the combustor diffuser design, both for RR & RRD.

Rolls-Royce R&T work and results

The work is a follow-up of that initiated in LowNOx III programme [7 & 8].
Fuel injection was based on Lean Direct Injection technology. Results obtained on a 4 sectors combustor, in term of EINOx for different operating conditions are given on figure 9. Analysis shows that NOx levels consistent with a target of –50% from CAEP2 can be achieved at engine representative conditions (38bar, 900K inlet) in a High Pressure Multi Sector test environment, i.e. demonstrating progress to TRL4.

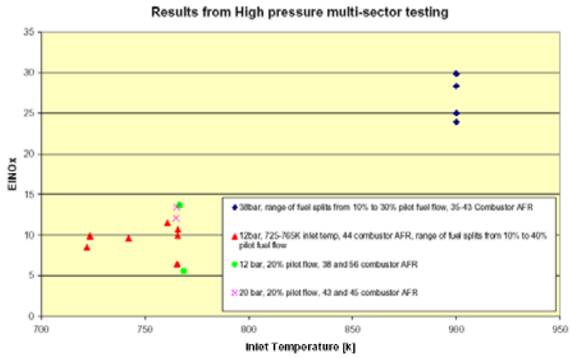

Fig. 9. EINOx results from HPMS rig programme

Varying levels of uncertainty are introduced over assessing other operational parameters due to the nature of sector testing. However, reasonable confidence is established to the viability of this technology with respect to ignition, stability, thermo-acoustic instabilities, wall temperatures and exit temperature profile.

Snecma R&T work and results

A Multi-Points fuel staged injection system has been retained as the promising solution to achieve the desired NOx reduction target, on a single annular combustor with the same engine cycle assumption as in CLEAN project (see table 1). This choice, should demonstrate also satisfactory behaviour for operability requirement, lean blow out (LBO) being an aspect evaluated in the study.

Point	IDLE	7% OACI	30% OACI	85% OACI	100% OACI	Max T/O
P (bar)	3.21	5.12	12.78	27.56	31.84	32.41
T (K)	445	503	643	799	839	880
Φ_ch annu	0.16	0.15	0.23	0.38	0.43	0.44
Φ_inj	0.25	0.23	0.35	0.58	0.65	0.67
Φ_ch tubu	0.21	0.20	0.29	0.49	0.55	0.57

Table 1. Snecma LOPOCOTEP engine cycle

The final design relies partly on CFD calculations (illustrated in figure 10). The Multi-Point approach, realised with a ring of fuel injection holes in the venturi (see figure 11), aims at enhancing the mixing and the homogeneity. The injector was experimentally characterised first under non-reactive conditions and then a campaign at Onera M1 rig on a water cooled tubular combustor (fig. 8) evaluated the LBO behaviour, the instability propensity and finally the pollution performance. Confrontations with experimental results indicated a good agreement of 3D simulations for air split determination and lean blow out limit prediction. Estimations of NOx emissions are well correlated in tendency but accuracy of absolute values needs to be improved. Experiments have highlighted instabilities at low regime pressure.

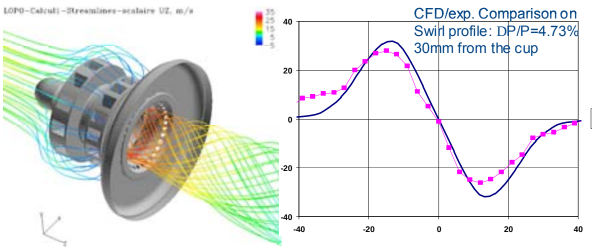

Fig. 10. Injection system design and CFD support

As the estimation of pollution from tubular combustor experiments is generally delicate, a clear methodology was followed: the tubular combustor EINOx corresponding to actual 100% take-off power of P3, T3, and injector FAR values, had to be first extrapolated (see figure 12). Then, 3D reactive calculations (with N3S-NATUR code) on the Onera tubular combustor, were calibrated with experimental results. Lastly, the 3D calculation was performed on the full annular combustor design. On this basis, a 40% NOx reduction from CAEP2 standard is estimated, for the corresponding engine equipped with this technology. This is equivalent to what was achieved on the double annular CLEAN combustor. Further optimisation in TLC, both numerically and experimentally should improve this performance, and avoid also instability problems encountered at low regime.

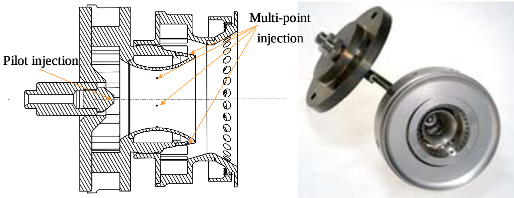

Fig. 11. Snecma multi-point injection system

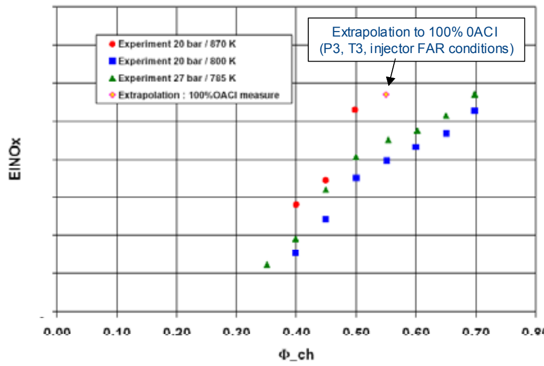

Fig. 12. Pollution results (& extrapolation) on Onera M1 water cooled tubular combustor

Rolls-Royce Deutschland R&T work and results

The target was to develop an advanced low NOx technology concept for medium-thrust engines up to OPR=35 for corporate and regional jet applications. The reference parameters are from the E3E II BRR-MTU future medium size turbo-fan, which was also used in the project CYPRESS.

The objective was to show that a low emissions combustor equipped with an LP(P) lean module can lead to a reduction of 70% in NOx emissions from CAEP2. The work exploits the results obtained in LowNOx III programme [7] where 2 LPP injectors, “LPP1” and “LPP2”, were manufactured and tested. However, it appears that flame stability may become a major constraint regarding the operability of the combustor. In this prospect, 3 new designs, “LPP3”, “LP(P)4” and “LP(P)5” (fig. 13 &14) have been developed in LOPOCOTEP, to improve in particular the lean blow out limit. “LPP3” is an up-scaled “LPP2” ; “LP(P)4” and “LP(P)5” feature an centrally integrated pilot injector (pressure swirl atomiser). These 2 latest concepts were designed to equip a single annular combustor whereas the “LPP1”, “LPP2”, “LPP3”, were dedicated to the main dome of an axially staged combustor.

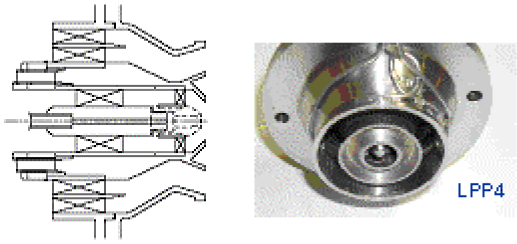

Fig. 13. LP(P)4 injector

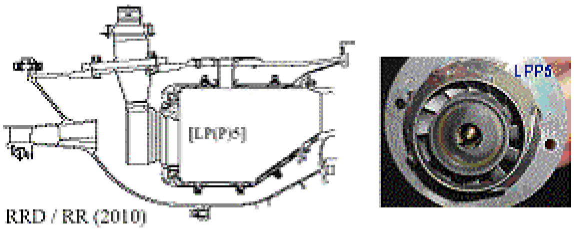

Fig. 14. Single annular combustor target and LP(P)5

The single sector tests performed at Lund (on LP(P)4) and at Onera (on LP(P)4 & LP(P)5) revealed good behaviour in term of weak extinction limit and pressure oscillations. Optical measurements at Lund (fig. 15), exploiting Laser Induced Fluorescence (LIF) technique for vaporized kerosene and Mie scattering technique for droplets, showed qualitatively that the LP(P)4 wide spray cone angle led to fuel impingement on the windows such that only very weak conditions could be optically investigated.

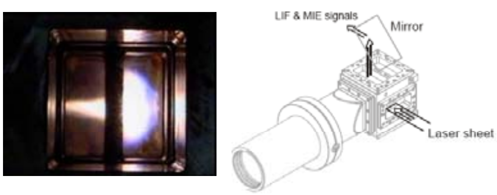

Fig. 15. Lund LTH rig. Normal photograph of the flowfield (left) ; LIF/MIE measurement (right)

Figure 16 presents a set of pollution results, for various operating conditions and fuel splits between pilot zone and main zone of the injector, up to 20 bar. Analysis of these results and extrapolation on a real single annular combustor for actual engine cycle parameters, permitted to estimate an NOx reduction between -46% to –60% CAEP2.

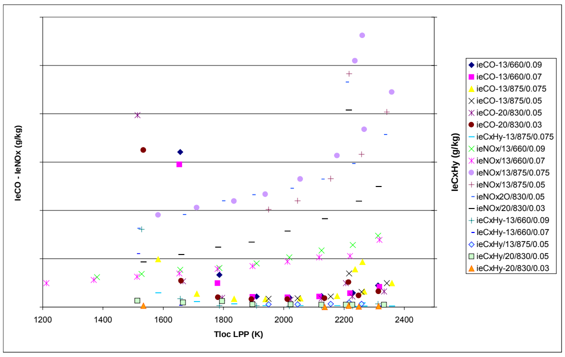

Fig. 16. Pollution results on Onera M1 water cooled tubular combustor

The LP(P)5 injector was finally tested in an axially staged combustor with 4 main sectors, as in LowNOx III, but equipped with a split pre-diffuser for improved air feed. The pre-diffuser envelope was developed by Loughborough Univ. (figure 17). Low and high pressure tests up to 20 bar, were performed at RRD rig at DLR Cologne.

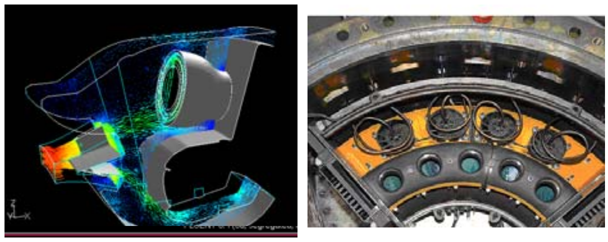

Fig. 17. Split diffuser optimisation and axially staged multi-sector combustor tested at DLR

The analysis of HPMS results reveals that lean weak extinction limit is acceptable and only very low amplitudes of thermo-acoustic pressure oscillation are observed at all conditions.
Emission performance has potential for improvement; main fuel injection has to be refined to achieve homogeneous premixing and quicker pre-vaporization (will be beneficial for NOx, UHC, CO). Best combustion behaviour

was obtained and lowest NOx emissions were measured when the entire pilot zone of the axially staged combustor was switched off.

The actual NOx level achieved represents 36,1% of the CAEP2 limit (as measured). Although this is a very positive result, especially combined with the low pressure oscillation capability, the LP(P)5 is a concept only. There are many open issues, which have not yet been approached. The development of this type of LP(P)5 burner is being continued in INTELLECT D.M. More information may be found in [9], [10], and [11].

3.2) Small engines

The three partners, Turbomeca, Avio and MTU have worked in collaboration on a small engine return bend combustor adapted to a turboshaft engine. Same engine cycle assumption has been retained, and is given in table 2. Avio and Turbomeca have worked with the same combustor design, adapting their own solution in term of LPP injector whereas MTU has been working on rich combustion (RQL approach), which required quite specific work on the combustor. The work was in continuation of what had been explored in LowNOx III.

		Take-Off	Altitude Cruise	Ground Cruise	Idle
pressure	bar	20	13	7.7	6
temperature	K	760	650	580	500
FAR	%	2.6	2	2	1.3
AFR	[-]	38.5	50	50	77

Table 2. Engine cycle hypothesis for small engine

The two combustors layouts deriving from the study, are given on figures 18 & 19.

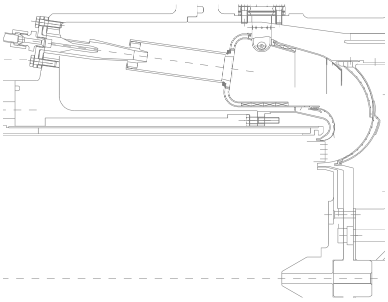

Fig. 18. TM & Avio LPP return bend combustor

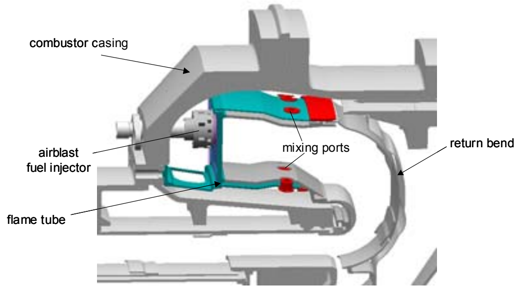

Fig. 19. MTU RQL return bend combustor

Turbomeca R&T work and results

Turbomeca has pursued in LOPOCOTEP the optimisation of LPP injection systems, with a special effort to reduce the size obtained in LowNOx III project. Four LPP different configurations and one LP(P) configuration have been designed, manufactured and tested on a single sector combustor either at Munich University of Technology (TUM), or at Onera M1 rig.

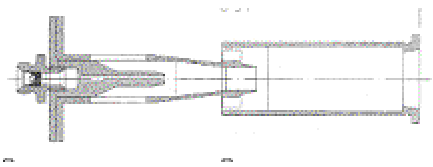

Fig. 20. Turbomeca LNIII configuration optimised in LOPOCOTEP (5 configurations)

At TUM, laser induced Fluorescence (LIF) measurements were used to get information on the qualitative distribution of vaporized fuel and by means of Mie scattering fuel droplets were made visible. All investigated configurations could be operated stable at pressure levels from 1 to 5 bar and a constant inlet air temperature of about 500 K. Complete analysis was delivered to turbomeca, and more detailed information is available in [12].

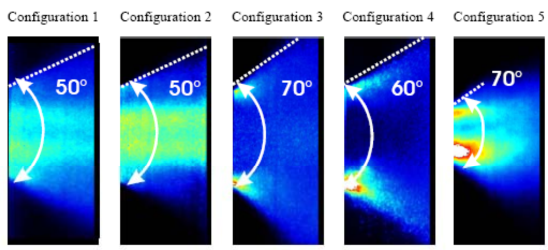

Fig. 21. Spay cone characterisation of vaporised fuel at centre plane (pressure at 1 bar) ; TUM optical rig

The axial fuel injector and film fuel injector (configurations 1 & 2) were identified as to be the best ones. They were tested on the Onera auto-ignition rig in a water-cooled tubular combustor. The axial fuel injector configuration had the best blow out limits and did not present any risk with regard to auto-ignition and flashback phenomena whereas low frequency (20hz) instabilities appeared at a pressure higher than 13bar, for the film fuel injector, which can trigger flashback phenomena. Pollutant emissions were therefore realised on the axial fuel injector, up to 20bar, 760K. They are displayed on figure 22.

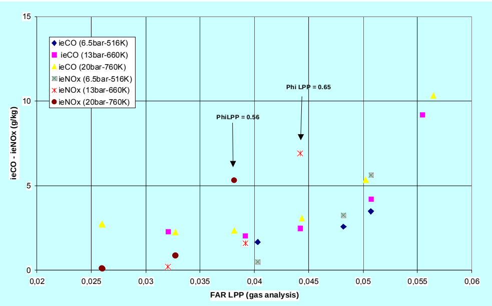

Fig. 22. Pollutant emissions versus LPP fuel air ratio (configuration 1 ; Onera M1 rig).

The LPP full annular combustor was designed jointly by Turbomeca and Avio, and manufactured by Turbomeca. It was tested with the axial fuel injectors at atmospheric (figure 23) and medium pressure (up to 10bar, 650K). More detailed analysis of the full annular combustor results are however still expected, in order to appreciate the performance of the proposed technology.

Fig. 23. LPP return bend combustor and TM P0 tests

MTU R&T work and results

The RQL concept was previously investigated by MTU during the LowNOxIII project, as a pilot module for the Snecma Large-Engine staged LPP/RQL double annular combustor and has demonstrated a great potential for NOx emissions reduction. The focus of the activity of MTU in LOPOCOTEP was to adapt the LowNOxIII RQL concept to the small engine architecture.

Starting from the concept previously developed in the LowNOxIII, the air distribution for the combustor was adjusted to cope with the need for a return bend, typically for small engine applications. Different concepts for the cooling configurations have been regarded in particular for the primary zone. The mixing module was optimized by a number of 3-D CFD calculations (see figure 24). The development and the characterisation of the fuel nozzle (swirl cup type) was carried out in collaboration with EBI (Karlsruhe Univ.). Based on the detailed design, the MTU RQL full annular combustor was manufactured (figure 25). Combustion tests were carried out in atmospheric combustion rig and at medium pressure, up to 10 bar.

Based on the results for the three different operating conditions (6 bar / 650 K, 10 bar / 650 K, 10 bar / 760 K), a pressure and a temperature dependence was derived for the LOPOCOTEP RQL combustor by which the data of the current measurements have been interpolated to another operating point.

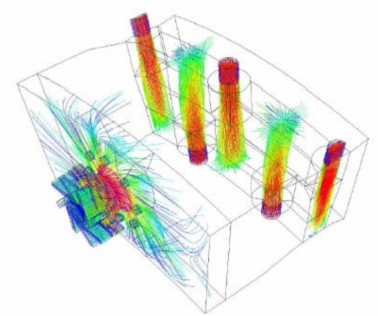

Fig. 24. Quenching numerical optimisation (MTU RQL combustor)

Compared to current engine technology a reduction of 30 % for the measured EINOx could be achieved for the take-off point and 50% for ground and altitude cruise points.

Fig. 25. MTU RQL full annular combustor

The major challenge in the current small engine application is the large nozzle distance compared to the primary zone height, which is highly demanding with respect to the fuel air mixing process which is to be realized by the fuel nozzle design. For further optimization and NOx reduction of the current LOPOCOTEP small engine RQL an improvement to the fuel nozzle design has to be applied in order to increase again the homogeneity of the primary zone.

<u>Avio work and results</u>

Avio pursued in LOPOCOTEP the development of an LPP injection system for small engine to replace the one originally mounted on the annular combustor of the LowNOx III project. The target was to reduce the duct length of 50%, with the same swirl number and vaporisation rate.
Two different configurations of the premixing duct were designed and manufactured (configuration retained on figure 26). Both of them were tested at atmospheric conditions at Onera. The best one was tested at high pressure in 2005 on the Onera water cooled combustor. After that it was mounted on the annular combustor designed by Turbomeca/Avio for the high-pressure tests, carried out in April 2006. This last recent campaign requires still analysis, and comparison with Turbomeca results, before any conclusion.

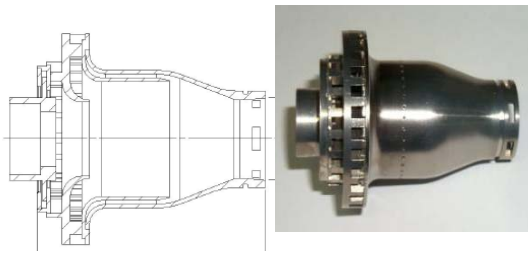

Fig. 26. Avio LPP injector

After the tubular combustor tests, an extensive analysis was carried out by means of Avio in-house code BODY3D in order to better understand the behaviour of the LPP duct and for the validation of the combustion and Nox models (figure 27).

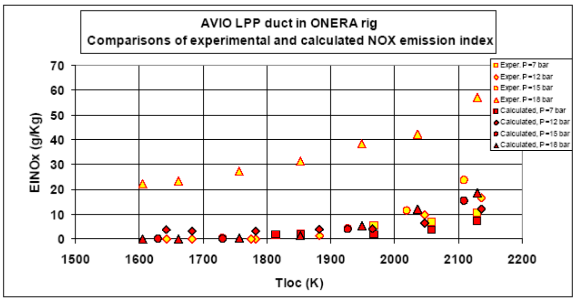

Fig. 27. Onera water cooled tubular combustor NOx results and comparison with numerical predictions

The NOx emission index is fairly well predicted by the CFD calculations and it seems not to be much influenced by pressure except for a pressure of 18 bar, where there is a sudden increase of the values of the experimental data not predicted by the calculations. It could be explained by the presence of recirculation of the flame inside the LPP duct with the rise of conditions that can’t be simulated by the NOx model.

3.3 LOPOCOTEP summary status

The previous description provides an insight of selected results among the large amount of those supported by the LOPOCOTEP project. Focus is done on the visible part of the technological developments and on the final performance, which is assessed with a certain effort and a certain extrapolation exercise uncertainty. More detailed analysis such as found in the publications issued by some of the partner, give essential complementary information, covering pollutant performance assessment but also main operability aspects. The specific work performed on diffuser design and cooling devices optimisation, by Loughborough Univ., Florence Univ., LCD-CNRS, and Avio, are not described here but should be considered also as fundamental issues of future low emissions combustor technology.

With these remarks in mind, the table 3 proposes a technological status, mainly focused on the NOx mitigation target. It illustrates the large panel of solutions, which were explored in the project, and reveals the progress realised as well as the effort still required.

At last, the technical programme of the project was realised entirely as initially planned, offering either promising results in term of pollutant emission performance and operability , or useful knowledge on the difficulties to be still overcome. Further projects, like INTELLECT or TLC, will contribute to it.

	MTU	AVIO	TM	RRD	SN	RR
Engine class	Small engine			Medium	Large-Medium	Large
OPR target (bar)	20			35	32	40
NOx target	-50% (from current technology)			-70% CAEP2	-80% CAEP2	-60% B7CAEP2
Concept investigated	RQL reverse bend combustor	LPP reverse bend combustor		LP(P)	Lean Multi-Points	LDI
Investigation summary	¤ injection systems Characterisation: up to (20bar, 760K) for TM & Avio ¤ full annular combustor (P0 & HP) tests up to (10bar, 760K) for MTU & Avio up to (10bar, 650K) for TM			¤ 3 Injection Systems Characterisation up to (20bar, 830K) ¤ HPMS combustor test up to (20bar, 830K)	¤ Injection System Characterisation up to (27bar, 785K)	¤ HPMS combustor tests up to (38bar, 900K)
Results analysed	Auto-ignition/Flash-back/LBO & cooling efficiency gaseous pollutants comparison of the 3 concepts			Auto-ignition/Flash-back/LBO & air-distribution control & gaseous pollutants	Auto-ignition/Flash-back/LBO & gaseous pollutants	Stability / Instabilities / Exit temperature profiles / gaseous pollutants
Qualitative judgement	¤ homogeneity of primary zone can be improved	not yet available	not yet available	¤ LBO behavior acceptable, no instabilities, ¤ potential improvements for pollution (CO at low regime, NOx) ¤ coking risk to be evaluated… => further work in INTELLECT	¤ Instabilities encountered at low regime ¤ optimisation still required for pollution => further work in TLC	Satisfactory
NOx reduction demonstrated	-30% to -50% from current technology (EINOx)	currently evaluated	currently evaluated	-60% CAEP2	-40% CAEP2	-50% CAEP2
Maturity achieved	TRL4-5			TRL3 (no clear conclusion at TRL4)	TRL3	TRL4

Table 3. LOPOCOTEP Technological status

4) Overview of TLC perspectives

The FP6 European Project TLC started in March 2005 and contributes to pursuing many of the LOPOCOTEP RTD activities going further in the maturity and the objectives. It involves 19 partners from 6 EU nations, most of them already in LOPOCOTEP (see fig. 2).
The technological focus is on injection systems in order to achieve lean combustion. The LOPOCOTEP "–80% CAEP2 NOx" goal is still valid but is completed by a cruise EINOx=5 target and specific work on particulates characterisation (DLR, Coria-Cnrs, Onera). The technological part is highly supported by the development of non-intrusive laser diagnosis (LIF, CARS, LII...) by Onera, DLR and Lund partners, by finer optimisation strategy by industrials and by numerical diagnosis (RANS & LES).

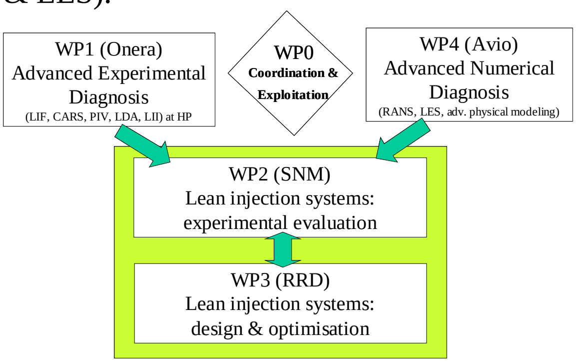

Fig. 28. TLC scope and Work packages activities(with WP leaders)

The following table summarises main expectations of the project.

Technical activities	MAIN RESULTS expected in TLC	STATE OF THE ART
Advanced experimental diagnosis	New non intrusive techniques available for aircraft engine harsh combustors conditions	Most of measurement techniques not mature and not developed at High Pressure
Lean injection systems / experimental evaluation	Demonstration of lean injection systems emissions & operability performances at higher TRL maturity Target for emissions: *Medium & Large engine*: -80% CAEP2 (if no trade-off to overcome) Small engine: -50% with minimized size	*Medium & Large engines*: between -60% to - 70% CAEP2 *Small engines*: -50% with critical size problems TRL Maturity: medium
Lean injection systems / design & optimisation	Optimisation methodology & lean injection systems design criteria Application to various concepts: multi-point, lifted flame, TVC ...	no systematic approach
Advanced numerical diagnosis	Assessment of State of the Art for numerical diagnosis applied to aircraft engine combustors (emissions, combustion)	many developments but more accurate assessment necessary

Table 4. TLC activities & expected results of the project

One year has been recently completed and first results will come soon. As an illustration, the figure 29 gives a scheme of the High Pressure Single Sector combustor rig with optical access to be manufactured by Onera (target 30bar, 800K) dedicated to laser measurements, and the existing HPSS test also will optical access, at Lund university (able to be run up to 16bar, 650K). Fig. 30 illustrates experimental non intrusive laser diagnosis as well as numerical laser diagnosis, which are essential tools of the technological development carried out in WP2 et WP3.

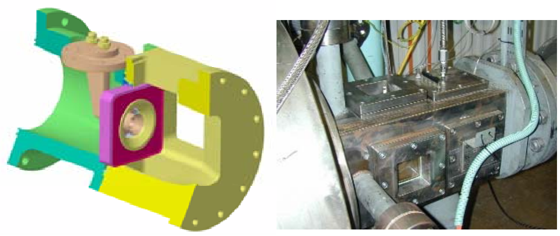

Fig. 29. HPSS with optical access (left: ON ; to be manufactured ; right: Lund. Already exploited in LOPOCOTEP)

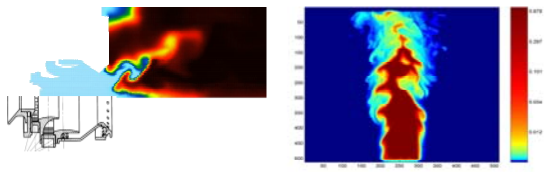

Fig. 30. Cerfacs LES calculation (left) & Onera PLIF of kerosene(right ; Mixture fraction 1bar, 700K)

5) Conclusion

The paper proposes an overview of the two European projects, LOPOCOTEP and TLC, on low emission combustor technology. LOPOCOTEP activities have been successfully completed, in accordance with initial technical plan and TLC will permit to improve the results. More detailed information on the numerous results, which have been obtained, may be found in technical papers issued by the various partners (available with general public information on the project web site www.lopocotep.com). The global strategy, which is pursued, is explained and a technological status achieved in LOPOCOTEP is given.

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