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ASSESSMENT OF NEW AEROENGINE CORE CONCEPTS AND TECHNOLOGIES IN THE EU FRAMEWORK 6 NEWAC PROGRAMME

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Abstract

NEWAC researches new engine core concepts and lean-burn combustion. This paper describes whole engine and technology assessments undertaken, including preliminary design studies to set specifications and technology targets, and use of 'TERA2020' models for sensitivity and optimization studies including economic and environmental assessment of intercooling, recuperation, aspiration and active control technologies.

1 Introduction

'NEW Aeroengine Core concepts' (NEWAC) is a European Union (EU) Framework Six (FP6) Integrated Programme running from May 2006 to April 2011. It aims to reduce fuel burn and emissions by improving thermal efficiency and developing lean combustion technology.

NEWAC researches enabling technologies for the four new engine core concepts shown schematically in figure 1, and for three different types of lean-burn combustor, with the objective of improving core thermal efficiency and reducing emissions of oxides of nitrogen (NOx).

The new technologies include: intercooling, intercooling with recuperation, improved high pressure (HP) compressor aero design and blade tip rub management, 'aspirated' compression systems, active control of surge and tip clearance in compressors, and active control of a cooled cooling air system. These technologies can be combined in different ways

NEWAC is complementary to 'VITAL', another EU FP6 integrated programme targeting noise and propulsive efficiency by addressing low pressure (LP) component design. NEWAC also builds on some earlier EU Framework sub-programmes, such as 'ANTLE' and 'CLEAN'.

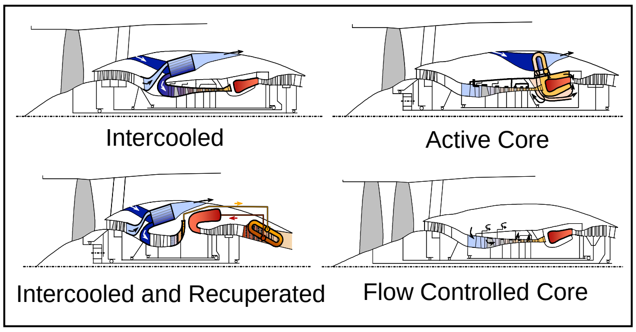


Fig. 1. Four NEWAC engine concepts

The study engines are defined and assessed in sub-programme 1 (SP1), which evaluates the costs and benefits of the NEWAC engine concepts and technologies at the whole-engine and whole-aircraft level in three work packages (WP) 1.1, 1.2 and 1.3, the last being 'Techno-economic and Environmental Assessment for year 2020' (TERA2020). NEWAC partners active in each of these work packages are shown in figure 2.

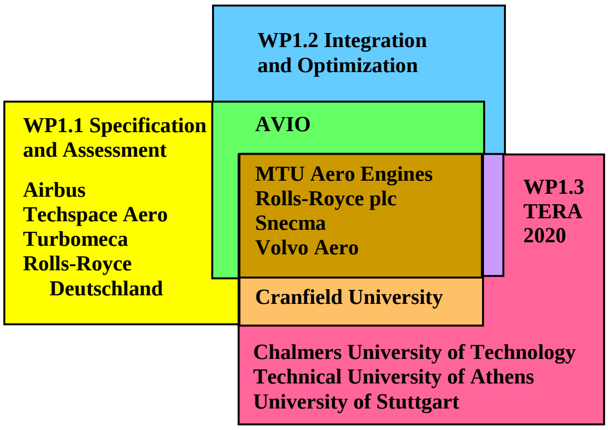


Fig. 2. NEWAC partners' participation in NEWAC SP1

Enabling technologies for each new engine concept are researched in more detail in the NEWAC sub-projects: SP2, SP3, SP4, and SP5, while SP6 researches three different lean-burn combustion systems applicable to a wide range of engine configurations. Seven engines were initially designed for either short-range (SR) or long-range (LR) aircraft, as originally specified in the VITAL programme, then three further designs with different combinations of NEWAC and VITAL engine technologies were composed in WP1.2 to see if they could approach targets set by the Advisory Council for Aviation Research in Europe (ACARE) for engines in 2020.

Further information on NEWAC can be found at www.newac.org including editorials, a list of publications and links to papers including an overview of the whole programme [1].

2 NEWAC Engines and Technologies

2.1 WP1.1 Study Engines

The original NEWAC core concepts and study engines for WP1.1 and WP1.3 were the:

- **Intercooled Recuperative Core** for the geared-fan intercooled recuperative aero engine (IRA) which has modest overall pressure ratio (OPR) and builds on the earlier CLEAN IRA with NEWAC SP2 technologies and a Lean Premixed, Prevaporized (LPP) combustor. (LR only.)
- **Intercooled Core** (IC) for a high OPR engine concept based on a 3-shaft direct drive turbofan (DDTF) using a Lean Direct Injection (LDI) combustor and NEWAC SP3 technologies. (SR and LR.)
- **Active Core** (AC) with active systems applied to the geared turbofan (GTF) concept from the VITAL programme and using a Partial Evaporation and Rapid Mixing (PERM) or LDI combustor and NEWAC SP4 technologies. (SR and LR.)
- **Flow Controlled Core** (FCC) with flow control technologies applied to the counter rotating turbofan (CRTF) from the VITAL programme and using a LDI or a PERM combustor and technologies from NEWAC SP5. (SR and LR.)

2.2 WP1.2 Study Engines

Three further engine configurations were selected for the WP1.2 study at the mid point of the programme and worked up in parallel with WP1.1 study engines (though generally not in so much detail). These configurations were:

- **Geared Fan Intercooled Engine**, which combined the GTF and intercooled core with some systems from the Active Core engine. LDI combustor. (LR only.)
- **Flow Controlled Core** CRTF with an optimized NEWAC HPC and selected technologies from SP3 and SP4.
- **Active Core** GTF with an optimized higher pressure ratio NEWAC HP compressor (HPC) incorporating FCC technologies from SP5. LDI combustor. (SR only.)

2.3 Combustor Technologies

Three different lean combustion systems are being researched in SP6, [1] and [2]. The combustor technologies, engine applications and the scientific approach to experimental validation are shown in figure 3.

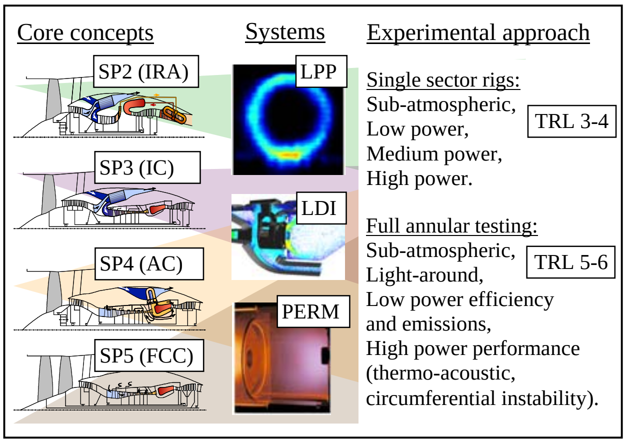


Fig. 3. NEWAC combustor technologies

Full Annular (FANN) combustor rig testing is not yet completed, but sufficient results have been obtained on single-sector HP combustion tests at TRL 3-4 to provide initial estimates of NOx emissions for the NEWAC engines with lean combustors and to compare these figures with reference engines with state of the art combustor designs.

LDI Combustor Design

The lean combustion technology most suited to the higher OPR engines is the single-annular LDI combustor. LDI combustors have been sized for the intercooled study engines and preliminary estimates for their emissions have been made for all the high OPR engines in the study. The final NOx assessments will be made when all combustor testing is completed.

PERM Combustor Design

The PERM injection system concept has now been implemented in FANN validation testing. It is a lean combustion technology appropriate for engines with intermediate pressure ratios.

LPP Combustor Design

LPP technology is limited to low OPR engines because of the increased risk of autoignition and flashback at higher pressures. Implementation of this technology in a reverse flow combustor makes it a good fit with the IRA architecture.

3 Preliminary Design Methods

To assess the NEWAC technologies, two complementary approaches have been adopted. Established preliminary design methods were used by MTU, Rolls-Royce and Snecma to set specifications and technology targets for the seven turbofan engine models in WP1.1. Then the TERA2020 tool (first created in the VITAL programme) was further developed in WP1.3 and used to model similar engines and assess the broader economic and environmental impact of the new designs and technologies. TERA2020 was also used to make sensitivity and optimization studies around the new engine configurations. TERA2020 is now also being used in the FP7 programme 'DREAM' to model open rotor powerplants.

3.1 WP1.1 Specification and Assessment

The specification of a new engine starts with a set of thrust requirements, a basic design concept and initial estimates of the potential performance available from each major component and system. The next step is to construct design and off-design performance models. Major components are then sized and the gas path annulus is defined. Iterative design studies and assessments are then undertaken to refine the performance model and to complete a preliminary mechanical design for the engine. Finally the nacelle lines are constructed and the overall powerplant weight, drag and unit cost can be assessed.

This process relies on the experience of the preliminary design team to produce realistic physical and functional models. All new engine designs build on ones that have gone before. When new or improved technologies are added they are initially modelled on the basis of target levels of performance and target space envelopes and weights. As the research activities raise the technology readiness level (TRL) of each technology, so more reliable component efficiency estimates and design envelopes become available and can be used to refine the whole-engine models. In estimating effects at the whole-aircraft level, exchange rates were initially used to assess the effects of changes in specific fuel consumption (SFC), engine weight and nacelle drag on the aircraft's takeoff weight and fuel burn. Since NEWAC is an 'Integrated Programme', it generally aims to develop the technologies up to TRL 4 or 5 (component rig testing) in SP2 to SP6.

3.2 WP1.2 New Engine Assessments

Progress was reviewed at the mid point of the NEWAC programme and a spreadsheet was drawn up to show which VITAL and NEWAC technologies could have further synergies. This led directly to each of the major industry partners selecting the technologies to mix and match in the three new engine configurations. Because these engines were all variants on the original designs, their analysis was relatively straightforward.

3.3 WP1.3 TERA2020 Modelling

TERA2020 is a tool developed by a consortium of university partners that helps to automate part of the aero engine preliminary design process. It is not an expert system, so it still requires the user to have a good understanding of engine performance and design and knowledge of the capabilities of the new technologies available for each engine. The tool is based on a modular design and features a sophisticated explicit conceptual design algorithm, as illustrated in figure 4. Architectural details of TERA2020, as originally developed in VITAL, are given in [3]. Modelling details for each module and various technology assessments can be found in [4] and [5].

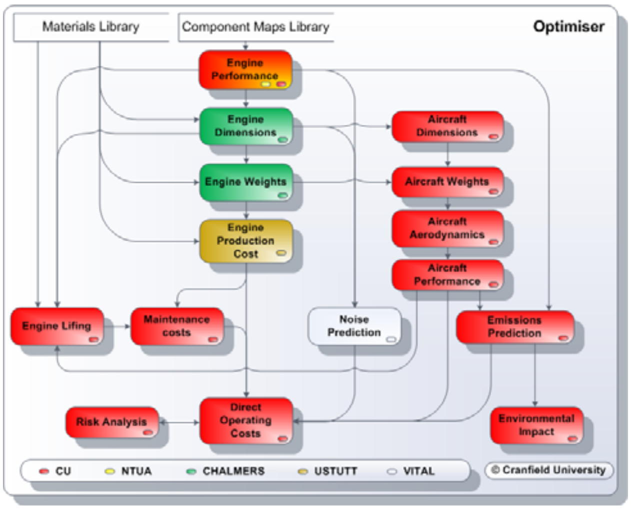


Fig. 4. TERA2020 design algorithm

TERA2020 considers a large number of disciplines typically encountered in conceptual design such as: engine performance, engine aerodynamic and mechanical design, aircraft design and performance, emissions prediction and environmental impact, engine and airframe noise, as well as production, maintenance and direct operating costs. Individually developed modules are integrated together in an optimizer environment. Large amounts of information are available after each design iteration and can be used for many purposes such as technology impact assessment, sensitivity and parametric studies, multi-objective optimisation etc.

Major elements of TERA2020 and the work split between the universities working on it are shown in figure 5. Much of the software integrated into TERA2020 has been developed in earlier EU programmes (‘SOPRANO’ for noise assessment, ‘PROOSIS’ for performance modelling etc). Each university has worked on particular aspects of the software and modeled some of the seven original NEWAC engines. It is anticipated that further engine models will be generated in the final year of the project.

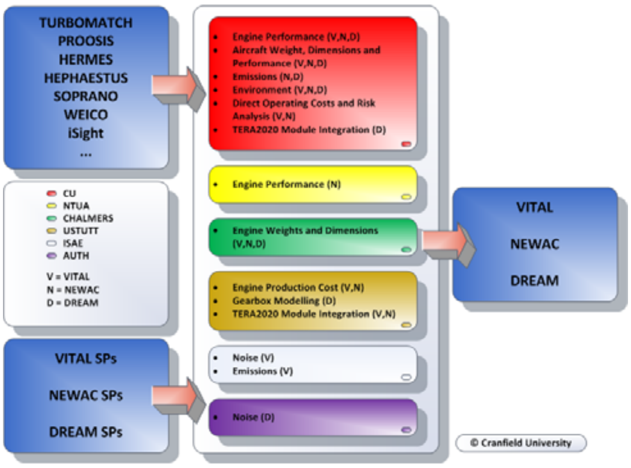


Fig. 5. TERA2020 organization

A simplified example of utilizing TERA-2020 for design space exploration, with active constraints, is illustrated in figure 6. Nacelle drag should also be added as a third dimension when plotting design space exploration results that consider varying levels of specific thrust, but this has been omitted to simplify the plot. Aircraft exchange rates for the baseline design were used for plotting a constant block fuel line (ignoring nacelle drag effects and nonlinearities) and this iso-line therefore defines, in a simple manner, boundaries of trading SFC and weight. During a block fuel optimization with TERA-2020, the optimizer evaluates different engine designs continuously as it searches for optimal solutions. Designs that fail to meet constraints set by the user are discarded as infeasible.

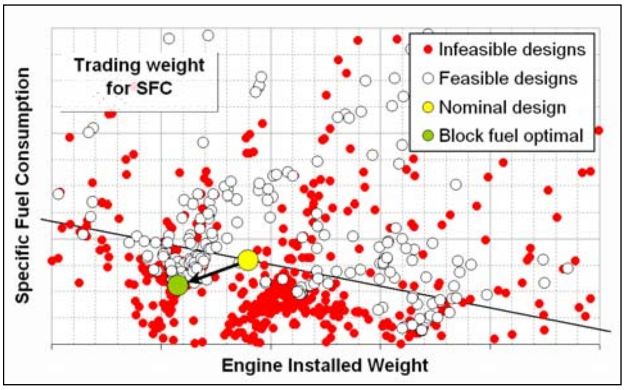


Fig. 6. Visualization example of constrained design space exploration with TERA2020

TERA2020 enables technology assessment within collaborative pre-competitive studies to be broadened to consider additional factors such as economics and global warming potential. It seems most useful for rapid optimization and 'what if' studies about well worked-up designs.

3.4 SP1 Technical Design Reviews

Engine designs have been updated with results from the other sub-programmes and used to assess the new technologies on an ongoing basis, but SP1 results have also been reviewed collectively at annual meetings. The latest SP1 Technical Design Review (TDR) was held in May 2010 and provided results for this paper.

4 NEWAC Technology Assessments

4.1 High OPR Intercooled Core Engines

As the OPR of engines is increased to improve thermal efficiency, intercooling becomes more attractive. This is because optimum intercooled cycles have lower temperatures for high pressure compressor (HPC) delivery air and turbine cooling air at an OPR. They can also have lower combustor flame temperatures that help reduce oxides of nitrogen (NOx) emissions.

In an intercooled aero engine, air diverted from the bypass duct is used to cool the exit flow from an intermediate pressure compressor (IPC) before it enters the HPC. This engine arrangement is shown schematically in figure 7, which also identifies the areas where new component technology is required to realize an efficient and cost effective intercooled engine.

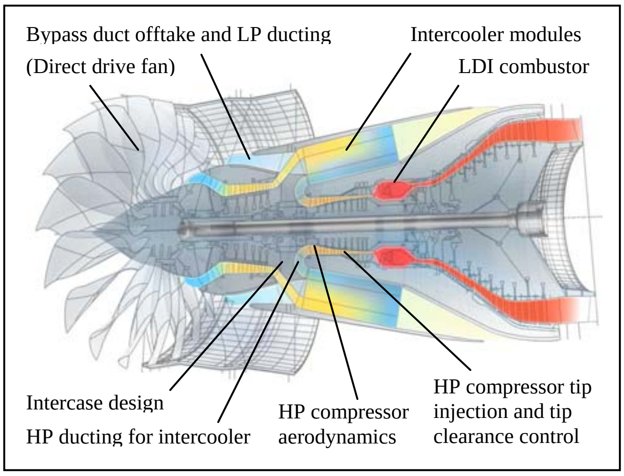


Fig. 7. Intercooled engine and SP3 technologies

Intercooling has the potential to improve thermal efficiency and reduce specific fuel consumption (SFC) and fuel burn by increasing OPR relative to conventional engine cycles. However, these benefits are offset by pressure losses in the intercooler and its associated ducting, by reduced component efficiencies associated with smaller size core components, by increased nacelle drag if intercooled engines need larger nacelles and by any overall weight increase.

Research in NEWAC SP3 aims to show that these potential penalties for intercooled engines can be controlled, so that the project objectives of 4% improved SFC and fuel burn for intercooled engines set in NEWAC WP1.1 can be met. To do this SP3 researches the key technologies needed for an intercooled turbofan. Component technologies include an effective, compact and lightweight low-loss intercooler, low-loss inlet and outlet ducting systems for the intercooler, stiff engine and intercase structures to support the intercooler modules and maintain rotor tip clearances, and new systems and blading designs to maintain the compressor efficiency and operability. However, some of the SP3 technologies are also applicable to the IRA concept and to conventional engines.

A discussion of the factors that led to the intercooled engine SP1 design concept and more detailed descriptions of the technologies researched in SP3 are given in [6].

Successes over the last four years include designing and testing of the intercooler's HP and LP inlet and outlet duct designs, which met their performance targets; and good results from the high-speed HPC rig test, which achieved its surge margin and 90% of its performance improvement targets. Technologies to improve operability were also successfully demonstrated. SP3 has also shown the way forward to minimizing the intercooler matrix entry and exit losses and providing more uniform flow distribution. Cross-corrugated matrices were shown to be superior to conventional plate and fin designs, but the ambitious targets set for intercooler weight and volume (at an effectiveness and pressure loss) have not so far been met. SP1 had to re-specify larger intercoolers for the study engines and then nacelles to accommodate them, resulting in nacelle drag increases.

The LR whole engine mechanical model (WEMM) confirmed that the small diameter intercooled core and the more complex intercase structures were relatively flexible and that thrust loads would affect HPC tip clearances. New designs were proposed in mitigation and work is underway on an alternative intercase design that should have better stiffness/weight.

Early studies down-selected a passive tip clearance control system for the relatively small HPC blades of the intercooled engines. Testing is imminent and then more detailed systems and integration studies should follow.

A summary of the status of SP3 research activities is given in table 1.

SP3 Technologies:	Status:
Improved IPC exit and HPC entry ducts for intercooler, designed and tested	Performance targets met
LP bypass offtake duct experiments completed, including bled diffuser testing	Performance targets met
Improved intercooler matrix entry and exit geometry, flow distribution to reduce losses	Enabling technologies
Prototype intercooler modules designed, analysed and manufactured (limited testing)	Predicted losses exceed targets *
Whole Engine Mechanical Model (WEMM) studies to ensure core has adequate stiffness	Case distortion greatly reduced *
Intercooled engine intercase: alternative aero designs thermo-mechanically analysed	Stress OK, stiffness/weight issue *
HPC rig test to improve efficiency also to demonstrate adequate surge margin	Performance targets 90% met *
HPC tip blowing system demonstration	Successful test
HPC passive clearance control experiments	Tests ongoing
* Potential 4% CO_2 reduction is not yet demonstrated because these four technologies have not met their performance or weight targets	

Table 1. Intercooled engine (SP3) technology assessment

On current assessments DDTF intercooled engines will not meet NEWAC weight targets without further improvements to the intercooler design and engine structures. Weight penalties reduce the fuel burn benefits for intercooling, especially for the shorter-range aircraft.

The GTF LR intercooled study engine in WP1.2 offers a modest improvement relative to the direct drive turbofan engine. It reduces the number of LP turbine stages (more so than for conventional engines since intercooled engines have higher bypass ratio for a given thrust and fan diameter.) Because the geared fan engine has reduced LP shaft diameter the smaller HP system can be speeded-up, making it more efficient. The SP4 active tip clearance control system is also credited with improving the efficiency of this WP1.2 study engine.

4.2 Intercooling and Recuperation

The IRA cycle benefits from increased propulsive and thermal efficiency and offers the potential of up to 20% reduced fuel consumption and CO_2 emissions relative to year 2000 engines in service. The optimized IRA cycle has an OPR well below 30, around half that of a highly efficient conventional high OPR engine cycle. The low OPR supports low NOx combustion since it permits the use of ultra-low NOx combustor technologies such as LPP, which are not suitable for higher OPR engines.

The NEWAC IRA design is scaled up from the IRA study engine in the EEFAE CLEAN programme [7]. It is a three-spool design with the IPC exit air cooled before it enters the HPC, but in the IRA a recuperator also extracts heat from LP turbine exhaust to pre-heat the air entering the combustor. The IRA engine is shown schematically in figure 8, together with technologies researched in NEWAC SP2 and SP6 to improve its performance.

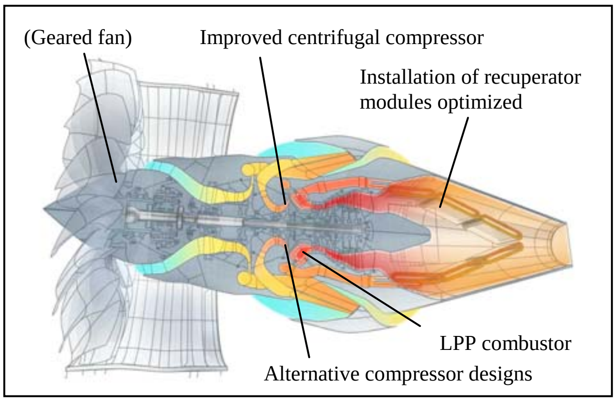


Fig. 8. IRA engine and NEWAC technologies

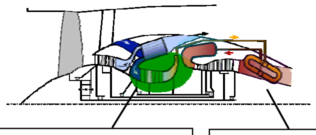
In NEWAC the aim is to demonstrate a further 2% SFC improvement for this concept, beyond the 16% improvements already claimed in the EEFAE-CLEAN project. SP2 focuses on selected technologies for IRA component and installation improvements, including:

- An installation concept study to address attachment and mounting of the heavy recuperators in the hot nozzle section.
- A comparative study of different HPC configurations with consideration given to IRA interface and ducting constraints.
- Development of an advanced radial HPC with significantly increased performance

and efficiency, with a surge margin to satisfy IRA requirements, including design, manufacture and rig testing, and studies of stability enhancement using internal recirculation technologies.

- Optimization of the hot nozzle section and recuperator geometry to provide more uniform flow through recuperator matrices and lowest possible pressure losses. For the analytical part of the study a porosity model was used and this has been validated experimentally.

A summary of the status of SP2 research is given in figure 9. Final results are not yet available, but indications are that the new technologies will meet the NEWAC programme objectives for CO_2 and NOx.



Optimized radial HP compressor design for improved efficiency.
at lower weight:

- No loss of stability
- New inlet hub/tip ratio
- Radial/axial diffuser to match ducting

Recuperator and hot nozzle geometry arrangement to reduce hot flow losses:

Minimize loss for fixed matrix

- Modified exchanger/nozzle geometry
- Adapted flow guidance
- Resized heat exchanger

Design and integration

Fig. 9. IRA engine SP2 technology status

4.3 Active Core Engines

These study engines have assessed the costs and benefits of active systems in the core engine that can alter and improve the thermodynamic cycle, offering a breakthrough regarding fuel burn and operability because an actively controlled core can be adapted to the very different operating conditions throughout a flight mission. Active systems also open up design freedoms other than designing on a worst-case basis, as by adjusting to actual conditions, deterioration in the core can, to an extent, be compensated for.

Systems investigated and rig tested in SP4 include actively modulated cooled cooling air for HP turbine cooling, and systems using active elements in the HPC: active tip clearance and active surge control.

These systems and related research activities are described in more detail in [8]. The technologies have been assessed in both SR and LR engines based on VITAL GTF designs with high-speed boosters.

The high-level objective was to develop and validate a system of interrelated core engine technologies to reduce SFC by 4% by increased core component efficiency, core cycle improvements and overall engine effects. They will also increase core specific power and reduce core mass flow, reducing propulsion system weight by 1% without any increase in NO_X production.

Two promising areas of application for active systems were identified and investigated, as indicated in figure 10. They were an active cooling air system (ACAC) that can lower the temperature of the cooling air for the HP turbine and other cooled parts, and the so-called ‘Smart’ HPC with active clearance control (ACC) and active surge control (ASC) systems.

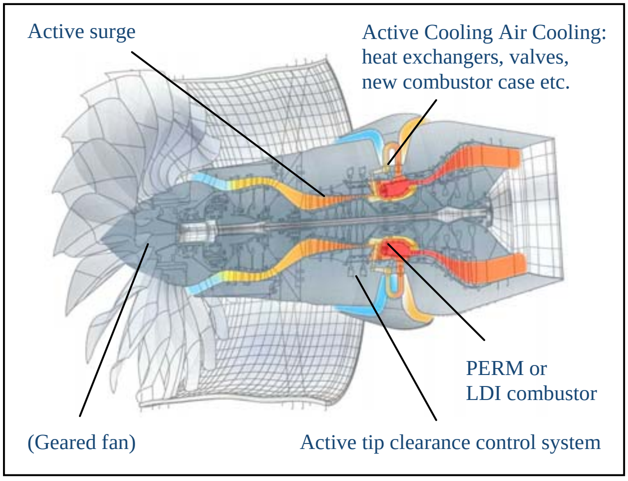


Fig. 10. Active Core engine and SP4 technologies

The design of the cooling air flow path for ACAC has to meet stringent requirements for low total pressure losses and heat pick-up. The combustor case is a key component, because it needs more complex geometry and experiences stronger temperature gradients.

The availability of cooled cooling air at HPC exit pressure enables it to be used to cool the HPC rear cone, which has high thermal gradients, temperatures and stress levels. It also enables advanced manufacturing technologies to be addressed for this component as cooled cooling air allows new approaches with regard to thickness, material and manufacture.

For the ‘Smart’ HPC, the never-ending goals of higher pressure ratio and efficiency at a stage count proposed two themes: clearance control for the rear stages, improving efficiency and full-speed surge margin, and surge control for the front stages, giving higher part-speed surge margin. For the first task, mechanical actuators were integrated into the casing, and rotor to casing clearances were controlled by tip clearance sensor signals and intelligent control algorithms. The chosen option for surge control in the front stages was injection of air taken from inter-stage bleed, or compressor exit, via slots in the casing in front of the first rotor.

For technology validation a series of rig tests was conducted to raise TRL. The mechanical ACC system was tested in a ‘proof-of-concept’ rig together with all necessary hardware and controls, proving the feasibility and mechanical function of the system and its control software, including appropriate reactions to failure scenarios. The system of ASC by air injection was tested in a full-size 8-stage HPC rig, varying key parameters like air temperature, slot number, geometry, injection flow rate, etc.

A summary of the conclusions from SP4 research is given in table 2.

SP4 Technology Targets:	Status:
Active Cooling Air Cooling	Basic test of heat pick-up
Cycle benefit from 35% reduced cooling air mass flow	Partly achieved *
+1% improved turbine efficiency	Partly achieved *
Smart HPC technologies: +1.5% improved compressor efficiency +15% surge margin	Demonstration on two different rigs
Active surge control with air injection	Validated by rig test
Active clearance control - thermal	System studies only
Active clearance control - mechanical adequate surge margin	Demonstrated on static rig test
Combined benefits -4% SFC -1% weight	Largely achieved, but over-weight
* Potential for 4% CO2 reduction has not been fully demonstrated (the technologies do not consistently benefit all phases of flight)	

Table 2. Active Core engine technology assessment

4.4 Flow Controlled Core Engines

The Flow Controlled Core engine applies flow control technologies to developed versions of the CRTF study engines from the VITAL programme.

The Flow Controlled Core engine is shown schematically in figure 11, which also illustrates where technologies that are being researched in NEWAC SP5 would be applied.

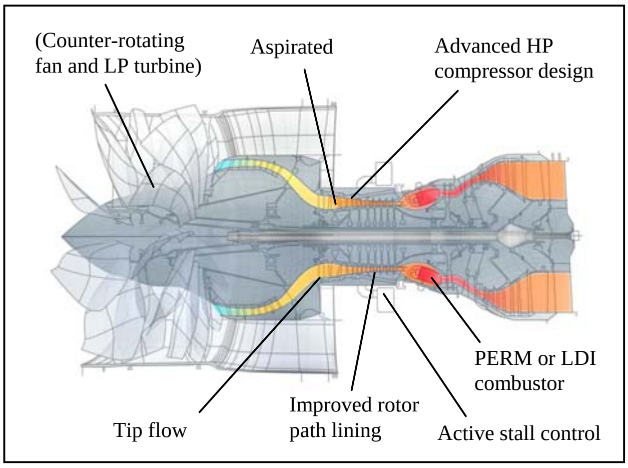


Fig. 11. Flow Controlled Core SP5 engine technologies

New technologies in the FCC engine are centered on improvement of the HPC:

- An HPC 3D optimized design with innovative technologies at the casing.
- The aspirated compressor concept is applied to the front stage rotor and stator, which raises some new challenges linked to the integration of the concept (in terms of aerodynamics, aerothermal integration and the aeromechanical design). The boundary layer air drawn off from the compressor is reused in the engine’s secondary air system.
- A new design methodology for low rubs between blade tips and abradable coatings, resulting in tighter clearances and lower in-service deterioration.
- Stall control systems that are activated upon stall detection (either the EEFAE CLEAN fast-opening valves concept, or by air-recycling at the casing).

The flow control technologies are investigated by analysis and elementary tests, and also validated in a high-speed compressor rig test. A summary of the status of SP5 research is given in table 3.

SP5 Technology Targets	Status
HPC high-speed rig test with tip flow control	Significant efficiency gain demonstrated
Aspiration on blade profiles to enable blade count reduction	Assessment shows a modest efficiency benefit
Active stall control by fast acting valves	Significant improvement in surge margin but with some weight penalty
Stall control by tip flow recirculation (advanced casing treatment concepts)	Second round assessment shows a useful improvement in surge margin, with less weight penalty than the fast acting valve system
Rub management	The model of the abradable and wear is being correlated
Development of an improved abradable material	Rub test comparisons with a baseline material are completed

Table 3. Flow Controlled Core technology assessment

5 Results

SP1 assesses the value of the new technologies in the original NEWAC engines and also in the three new engine designs in WP1.2 that combine technologies from the NEWAC and VITAL programmes in different ways. The results from SP6 and WP1.3 will be reviewed first before presenting the overall conclusions.

5.1 Emissions Assessments from SP6

Interim 'Landing & Takeoff' cycle (LTO) NOx predictions for various NEWAC engines with LDI, PERM and LPP combustors are shown in figure 12. These SP6 predictions are based on TRL 4 and 5 test results that are extrapolated to the NEWAC engine OPR levels.

The NEWAC targets are for 10% NOx reduction for the IRA engine relative to the CLEAN IRA engine, and 16% NOx reduction relative to reference engines using ANTLE combustors. The predicted reductions in NOx emissions for the high OPR engines, relative to engines with conventional rich-burn combustors are very substantial and are in the range of the NEWAC targets. Note that lean combustion particularly benefits the higher OPR NEWAC cycles, but that NOx production still tends to increase with increasing OPR. In assessing the overall impact of LTO NOx, consideration must also be given to the thrust scale of the engines. More efficient engines will burn less fuel and enable lighter aircraft with smaller, lower thrust engines. These additional NOx reductions are not reflected in figure 12, but are accounted in SP1 and in TERA2020 optimization studies.

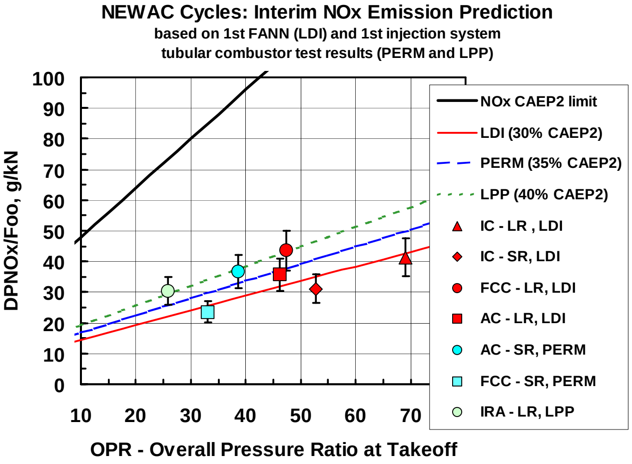


Fig. 12. NEWAC SP6 interim emissions assessments

5.2 TERA2020 Studies

Optimization studies indicate considerable potential for improving the original NEWAC engine designs in terms of block fuel as well as noise margins and Direct Operating Costs (DOC). The block fuel benefits result mainly from improvements in:

- Thermodynamic cycle (considering the engine weights and the aircraft mission).
- Matching the engine to the aircraft (assessing the 'snowball' thrust reduction effects by using a 'rubberized wing' aircraft model).

Table 4 shows the best engines for block fuel improvements achieved by optimization in the TERA2020 study (not necessarily the best all-round designs). The results need explanation and careful interpretation. It should be noted that the original (non-optimized engines) were designed for a set of thrust requirements that have been completely reassessed in this study. It was found that takeoff distance and time to height constraints were more easily met on the SR aircraft and this has resulted in greater reductions in thrust, block fuel and DOC for the SR engines. Different design constraints come in to play as the various engines are scaled. (For example, the IRA benefits greatly when it is able to use a smaller recuperator.)

Engine Configuration	Block Fuel	DOC	Noise Margin [EPNdB]
DDTF-IC-LR	-2.8%	-1%	+1.3
CRTF-FCC-LR	-3.2%	-3.6%	+1.7
GTF-AC-LR	-3.2%	-0.5%	+3.5
IRA-GTF-LR	-5.7%	-2.0%	+0.8
DDTF-IC-SR	-7.4%	-6.7%	+3.5
CRTF-FCC-SR	-6.4%	-4.5%	+3.5
GTF-AC-SR	-5.7%	-4.4%	+6.0

Table 4. Comparison of TERA2020 optimisation results with corresponding initial (nominal) TERA2020 models

It should be noted that the benefits in table 4 assume that all the component and systems technology targets set in NEWAC will be met, but sensitivity study results from TERA2020 can be used to assess the impact of missing some of the technology targets.

Table 4 should not be interpreted as ranking the engine concepts. TERA2020 complements the WP1.1 methods and assessments, and provides insight into the influence of different design parameters on overall performance.

6 Conclusions

The NEWAC project relies on the assessments in SP1 and SP6 to show which technologies will buy their way onto future engines and merit the investment to bring them up to TRL 6 (engine demonstration) in future programmes.

To be competitive with conventional cycle engines the NEWAC engines must show a fuel burn benefit, have good operability, low emissions, acceptable first cost, long life on wing and lower overall life cycle costs. This requires an holistic assessment from SP1.

Large engines on LR aircraft have most to benefit from intercooling, or from intercooling and recuperation, but improvements in compact, lightweight intercooler design and lower-loss installations are required to give these engines a competitive advantage. Such engines must be considered medium to long-term prospects that are unlikely to be realized in the ACARE 2020 timeframe. However, some of the technologies in SP2 and SP3 and many lessons learned with respect to heat exchanger installation can already be read across to other types of engines.

The technologies assessed on the active core engines can more realistically be applied in the ACARE 2020 timeframe, but SP1 studies show that they may not always buy their way on to every engine. The merits of each technology must be assessed for each new engine design. FCC technologies have considerable potential to improve efficiency and could be applicable to a wide range of engine designs.

Table 5 summarizes the CO_2 assessments.

Engine Concept	Status re. Fuel Burn at Fixed Thrusts
High OPR Intercooled engine	NEWAC -4% target is not met yet because of weight and drag penalties. A lighter and more compact intercooler installation is needed. Some SP3 technology can apply to other engines types
Intercooled and Recuperated engine	NEWAC target for -2% fuel burn relative to the CLEAN engine is achieved
Active Core engine	NEWAC -4% targets nearly achieved, with the ACAC technology giving the biggest benefit
Flow controlled Core engine	NEWAC -3% fuel burn targets forecast to be met for LR engine and nearly met for SR engine
NEWAC WP1.2 Study engines	The best combinations of technologies will come close to meeting the NEWAC -6% CO2 target

Table 5. Summary of NEWAC fuel burn assessments

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