NEWAC

Publishable Final Activity Report

DATE	September 8, 2011
PROJECT	NEWAC - FP6-030876
START DATE AND DURATION	01/05/2006 - 60 months
ABSTRACT	The Publishable Final Activity Report resembles an expanded version of the Publishable Executive Summary which was provided with each Periodic activity report, but in its final form it cumulates and summarises the project activities and publishable results over the full duration.
AUTHOR, COMPANY	ARTTIC with contribution of all partners
WORKPACKAGE / TASK	WP0.1 / T0.1.1
FILING CODE	NEWAC-ART-DEL-FAR-R1.0
KEYWORDS	
RELATED ITEMS	
DOCUMENT HISTORY	

Release	Date	Reason of change	Status	Distribution
0.1	3/08/2011	First draft	Draft	NSC
1.2	7/09/2011	Final version	Final	EC

Table of Contents

Glossary

Acronym	Description
AC	Active Core
ACARE	Advisory Council for Aeronautical Research in Europe
ACC	Active tip Clearance Control
ADVACT	Advanced Actuators (FP6 EU project)
AECMA	European Association of Aerospace Industries
AIDA	Advanced Intermediate Duct Aerodynamics (FP6 EU project)
ANTLE	Affordable Near-Term Low Emissions, Part of EEFAE (FP5 EU project)
ARTE21	Aeronautic Research and Technology for Europe in the 21st Century
ASC	Active Surge Control
BPR	By-Pass Ratio
CAEP	Committee for Aviation Environment Protection
CDR	Critical Design Review
CFD	Computational Fluid Dynamics
CLEAN	Component vaLidator for Environmentally-friendly Aero-eNgine, Part of EEFAE (FP5 EU project)
CO	Carbon monoxide
CO_2	Carbon dioxide
CRTF	Contra-Rotating Turbo Fan
CVC	Constant Volume Combustion
DDTF	Direct Drive Turbo Fan
EB	Electron Beam
EEFAE	Efficient, Environmentally Friendly Aero-Engine (FP5 EU Project)
EIMG	Engine Industry Management Group
EIS	Entry Into Service
ELECT-AE	European Low Emission Combustion Technology in Aero Engine (FP6 EU Project)
ERA	European Research Agenda
EU	European Union
FANN	Full ANNular
FCC	Flow Controlled Core
GTF	Geared Turbo Fan
HEX	Heat Exchanger
HP	High Pressure
HPC	High Pressure Compressor
HPT	High Pressure Turbine
IC	Intercooled Core
ICAO	International Civil Aviation Organisation
IMG4	Industrial Management Group of the industrial aeronautical sectors for airframe, engines, equipment and air traffic management
IP	Intermediate Pressure
IPC	Intermediate Pressure Compressor
IPR	Intellectual Property Right
IRA	Intercooled Recuperative Aero engine
LBO	Lean Blow Out

LDI	Lean Direct Injection
LOPOCOTEP	Low POllution Combustion TEchnology Project (FP5 EU Project)
LOWNOX-III	Low Emission Technology Programme (FP4 EU Project)
LP(P)	Lean Premixed Prevaporised
LPT	Low Pressure Turbine
LTO	Landing and Take-Off
NO_X	Nitrous Oxide
OGV	Outlet Guide Vane = compressor exit stator
OPR	Overall Pressure Ratio
PDR	Preliminary Design Review
PERM	Partially Evaporating Rapid Mixing
PPE	Pre-Programme Evaluation
PR	Pressure Ratio
SAC	Single Annular Combustor
SFC	Specific Fuel Consumption
SILENCE(R)	SIgnificantly LowEr Community Exposure to aircraft noise (FP5 EU Project)
SME	Small and Medium Enterprise
SP	Subproject
SRA	Strategic Research Agenda
STAR21	Strategic Aerospace Review for the 21st Century
TDR	Technical Design Review
TERA	Technoeconomic and Environmental Risk Analysis
TRL	product Technology Readiness Level
TRL 1	Basic principles observed and reported (report)
TRL 2	Technology concept or application formulated (report)
TRL 3	Analytical & experimental critical function proof-of-concept (e.g. process sample test)
TRL 4	Component validation in laboratory environment (e.g. 2D cold test)
TRL 5	Component validation in relevant environment (e.g. component rig, 3D hot test)
TRL 6	System/subsystem prototype demonstration in relevant environment (e.g compressor rig or complex mechanical strength or fatigue test for structures)
TRL 7	System prototype demonstration in “real” environment (e.g. engine test)
TRL 8	System completed and “flight/production qualified” through test and demonstration
TRL 9	“Flight/application” proven through successful mission operations
TRR	Test Readiness Review
ULN	Ultra Low NOx
VITAL	enVIronmenTALly Friendly Aero Engine
VSV	Variable Stator Vane

List of figures

List of tables

1. Project Execution

1.1 Summary Description of Project Objectives

Project title: NEW Aero Engine Core concepts (NEWAC)

Introduction

Commercial aviation has an impressive history of success, having become a means of mass transportation that carries in excess of 2 billion passengers a year. Breathtaking technological improvements have occurred in the past on economical and ecological fronts alike. Air traffic nonetheless faces novel challenges in the wake of diminishing energy supplies and worsening climate changes.

In the past, air traffic grew some 5% a year, and the outlook for the future is much the same. Technological improvements have indeed appreciably reduced specific fuel consumption (per passenger kilometer), yet fast-paced traffic growth keeps increasing fuel consumption and hence CO_2 emissions of the world's aircraft fleets by about 3% annually.

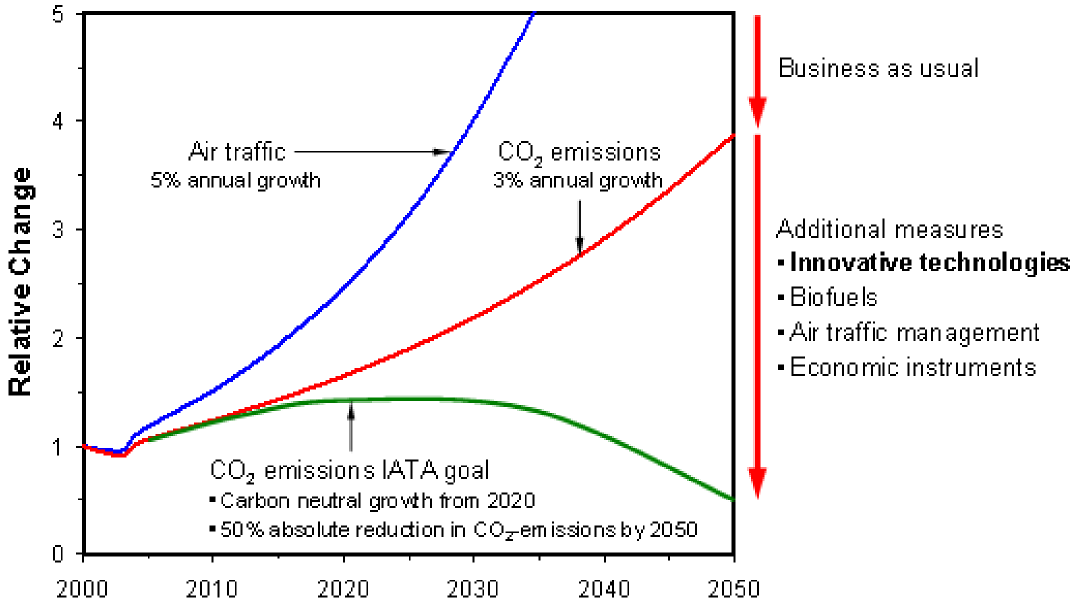


Figure 1: Air traffic and CO_2 emissions

Society expects the aviation industry to satisfy its continuously rising mobility needs while sparing the environment and resources. The International Air Transport Association (IATA), for instance, has aimed to reduce CO_2 emissions by 50% by 2050, compared with 2005 levels. As it became apparent, however, the rate of past technological improvement will no longer be adequate to reach this goal.

A reduction of the air traffic CO_2 emissions can be attained only if all stakeholders collaborate in the improvement of air traffic management, in the introduction of bio-fuels and the development of innovative airframe and engine technologies.

A large part of the necessary improvements will have to come from the engine industry, to a degree such that continuous improvement of engine components in itself will no longer be sufficient. That is why under the NEWAC technology project, novel engine cycles permitting quantum leap improvements were explored.

NEWAC focus was on thermal efficiency to further reduce CO_2 emissions and fuel consumption. For a conventional gas turbine cycle the thermal efficiency is mainly a function of the overall pressure ratio and the turbine entry temperature. A further increase of overall pressure ratio and turbine entry temperature is limited by maximum material temperatures and increasing NO_x emissions.

The first step towards higher thermal efficiency without increasing temperatures is to improve the efficiency of the components. Thus in the NEWAC project new innovative technologies such as active systems (Active Core) and flow control technologies (Flow Controlled Core) to increase efficiency were investigated. Another possibility is to integrate an intercooler to a core (Intercooled Core). It is an enabler for very high overall pressure ratios, which leads to fuel burn improvements. A big step forward is to use an exhaust gas heat exchanger in order to exploit the heat of the engine exhaust gas. Therewith the thermal efficiency increases at a low overall pressure ratio, which is good for low NO_x emissions.

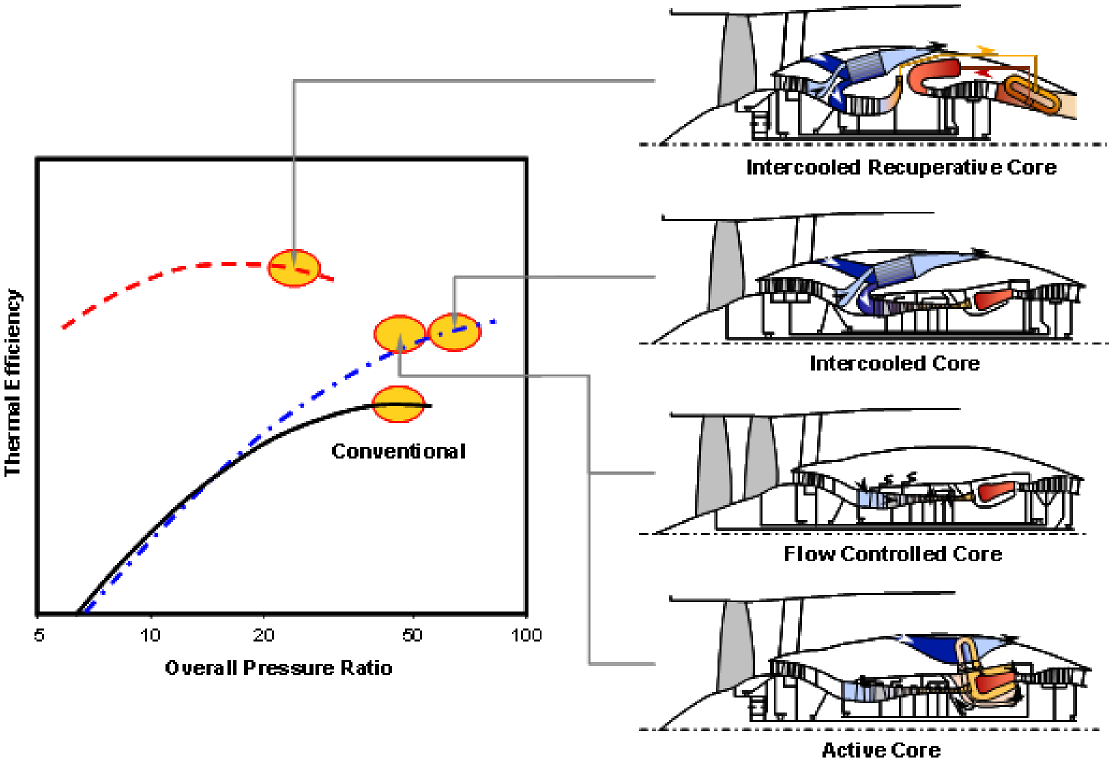


Figure 2: NEWAC core concepts and thermal efficiency

These four configurations were complemented by the development of innovative combustor technologies for ultra low NO_X-emission. Most NEWAC activities were focused on the compressor, for which fundamentally novel approaches were pursued as well, such as improving the surge limit through tip injection, reducing clearance losses through active clearance control and increasing aerodynamic loading through aspiration on blades. As most of these technologies can also find use on conventional engines not only long-term steps towards eco-efficient flight but also immediate improvements are made possible.

Objectives

Global air traffic is forecast to increase at an average annual rate of around 5% in the next 20 years generating the need to counter the related environmental penalties in terms of CO2 and NOX emissions. In order to achieve the ACARE 2020 objectives (minus 20% in CO2 emissions and minus 80% in NOX emissions), it is indispensable to develop new aero engine configurations and to perform complementary research in core engine technologies.

NEWAC is complementary to past and existing EU projects in the field, notably EEFAE (CLEAN and ANTLE) developed in FP5 and VITAL in FP6. The main objectives of NEWAC were fully validated, novel technologies **enabling a 6% reduction in CO_2** emission and **a 16% reduction in NO_X** according to ICAO-LTO cycle. Most importantly, the project addressed the particular challenge in delivering these benefits **simultaneously**.

NEWAC aimed and provided through its research and intensive validation activities the following technological achievements:

- For the **Intercooled Recuperative Aero Engine** configuration, an optimised recuperator arrangement, ducts with reduced pressure losses and a radial compressor optimised for the actual IRA core engine specification has been validated with rig tests.
- For an **Intercooled Core** configuration, a compact and efficient intercooler with an aggressive ducting has been validated in rig tests and an advanced compressor with improved transient behaviour that can be integrated into an intercooled engine has been validated in rig test.
- For an **Active Core** configuration, a new type of casing treatment for the compressor rear stages has been developed. Here, the goal was not only to improve the full speed surge margin, but also the design point efficiency by lowering the tip clearance sensitivity of the rear stages by the casing treatment. Such a type of casing-treatment – together with a semi-active clearance control system – competed with the above mentioned ACC system for rear stages and was tested in a compressor rig.
- For a **Flow Controlled Core,** outer flow-path control technologies from casing, an air aspiration concept applied on blades or vanes, a new advanced 3D compressor aerodynamic design and a robust and tight rotor/stator clearance management has been validated in model and a compressor rig test.
- For the different core configurations **innovative combustors** as LP(P) technology applied for low OPR engines (IRA), PERM (Partially Evaporated Rapid Mixing) technology for medium OPR engines (active or flow controlled core) and LDI (Lean Direct Injection) technology for medium to high OPR engines (intercooled core) has been validated in model tests, atmospheric rig test and full annular high pressure tests.

All new configurations investigated in NEWAC were **compared** and **assessed** regarding their benefits and contributions to the global project targets. Detailed specifications were provided based on the global project target for all innovative core configurations. Analytical studies compared the different environmental and economic impact. As a result, NEWAC **identified** the technology routes to environmentally friendly and economic propulsion solutions. The developed components further resulted in **optimised engine designs** based on the NEWAC technologies but also in combination with the results of the EEFAE, SILENCER and VITAL programmes. To be able to exceed the ACARE 2020 objectives also even more innovative core configurations were investigated and benchmarked with the engine specification mentioned above.

1.2 Work Breakdown Structure (WBS)

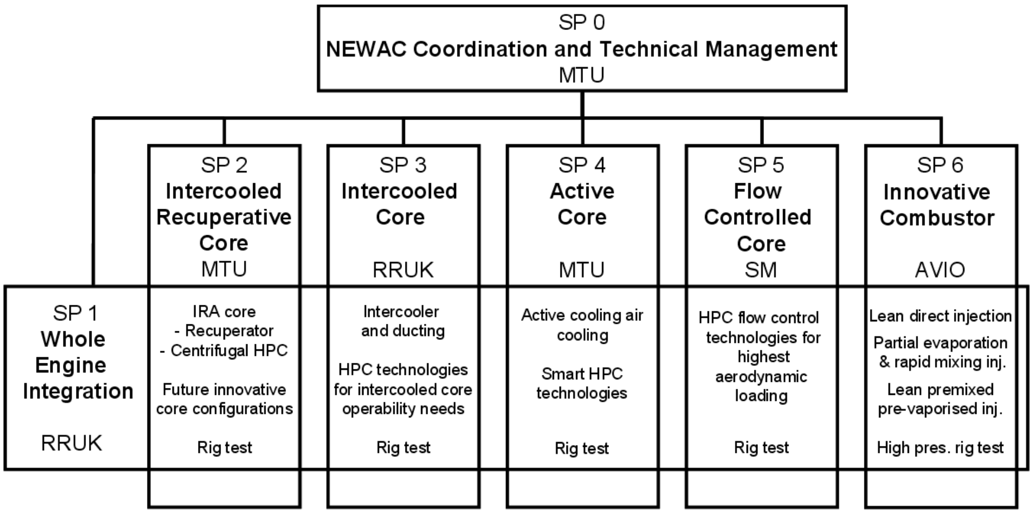


Figure 3: NEWAC work breakdown structure at subproject level

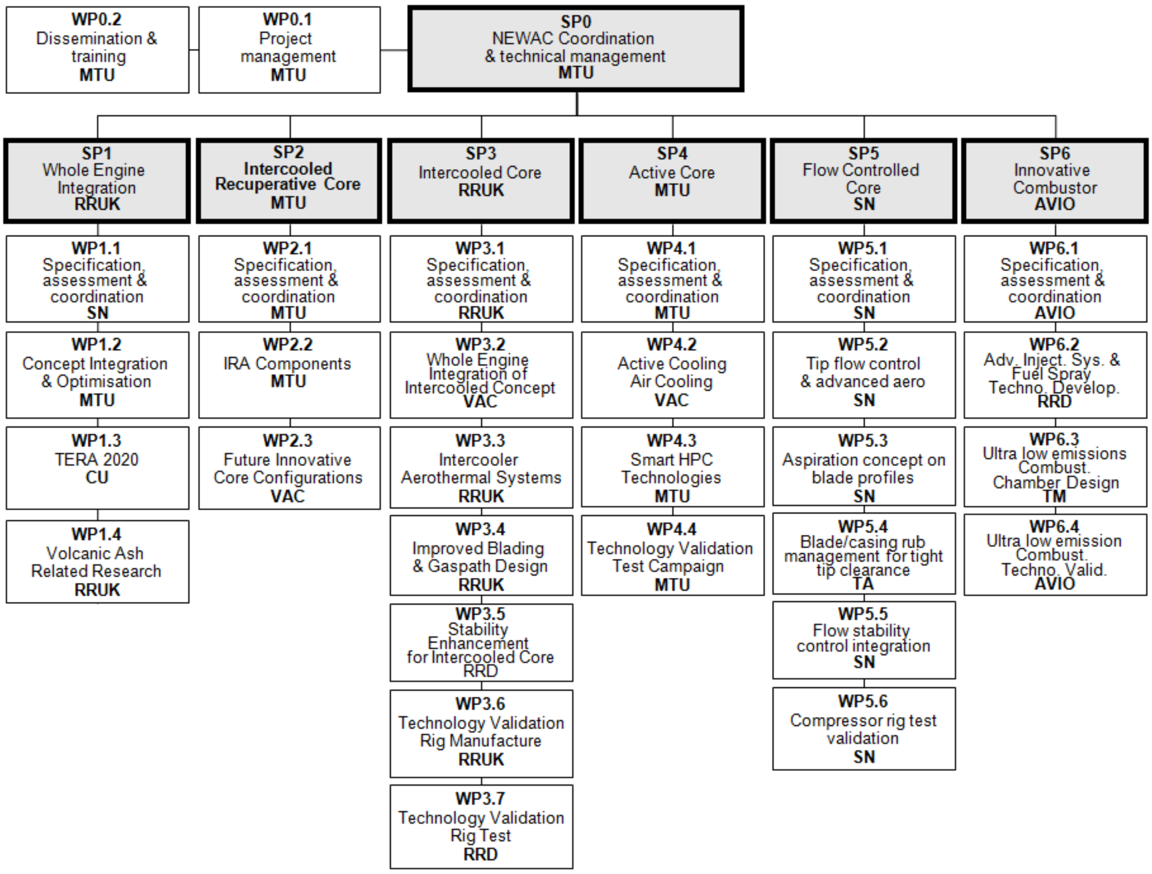


Figure 4: NEWAC work breakdown structure at workpackage level

1.3 Methodologies and Approaches Employed

To achieve the outmost ambitious goals – the reduction of the engines emissions by 6% in CO_2 and simultaneously by 16% in NO_X – breakthrough core engine technologies were developed and validated in NEWAC.

Due to the fact that the engines are operated in very different applications like short/long range or low/high thrust, different approaches are needed to optimise the emission reduction. Four approaches were undertaken to reduce the CO_2 emissions:

- The increase of the thermal efficiency by heat management.
- The introduction of active systems.
- The high power density core engine to enable very high bypass ratio engines.
- More efficient core components.

To reduce the NO_X emissions, the following three options were utilised in NEWAC:

- The reduction of fuel burn related to the above mentioned CO_2 reductions result in an equivalent decrease of the produced NO_X, provided that the combustion temperature is unchanged.
- The reduction of the combustion temperature leads to lower NO_X emissions.
- The combustor technology itself exhibits potential for NO_X reductions.

In the following paragraphs, these basic ideas are explained in more details and how these approaches are transferred into different core configurations:

Core cycle improvements by heat management: The thermal efficiency of gas turbine cycles can be effectively increased, if heat transfers between flows are taken into account, which is already widely done in ground based applications. NEWAC picked up this idea for aero engines in three different approaches:

- Firstly, the intercooled recuperated core was further investigated. This concept exploits the heat of the engines exhaust gas and maximises the heat pick up capacity of the combustor inlet air by intercooling in front of the HP compressor.
- Secondly, the introduction of an intercooler to a core configuration is an enabler for very high OPR cycles. It leads to fuel burn improvements and – by reducing the combustor inlet temperature – to lower NO_X emissions.
- Finally, the introduction of a high pressure turbine cooling air cooling with a smart management system leads to significant fuel burn reductions due to a reduced cooling air mass flow.

Active core engine systems: Aero engines are operated in very different operating conditions during their flight mission. As an actively controlled core can be adapted to each operating condition, a breakthrough is expected regarding fuel burn and operability. Furthermore, active systems open up additional degrees of freedom in the design, as the core needs not to be designed any more on a worst case basis. Finally, efficiency and safety penalties due to deterioration can be compensated to a certain degree by adjusting the core to the actual conditions.

Core engine technologies enabling very high bypass ratio engine designs: High bypass ratios, required for good propulsion efficiencies and low noise, have challenging implications for the core engine, which has to exhibit a high power density. Especially engine concepts with a low speed, low pressure ratio booster, as for example the direct driven turbofan engine (DDTF) and the contra rotating turbofan engine (CRTF) addressed in VITAL, require a compact HP compressor with very high pressure ratio, which has to compensate the low booster pressure ratio. Therefore, flow control technologies were investigated in NEWAC, which helped in the specific field of very high aerodynamic loaded HPC to increase efficiency and stall margin. Increased robustness towards deterioration in service, more critical for such architectures, was also addressed.

Innovative combustion technologies: Strong efforts were undertaken in NEWAC on innovative combustor technologies for all thrust ranges. The lean combustion technology derived within the EEFAE project were significantly improved and validated for the envisaged engine ranges. All concepts were based on single annular combustor architectures, whereas the different operating conditions of the various engine sizes required the improvement of individual lean burn fuel injection concepts: The LP(P) for low OPRs, the PERM for medium OPRs and LDI for medium to high OPRs.

Based on these ideas four NEWAC core configurations – shown in the following figures – were derived aiming at different applications concerning thrust and mission. For each configuration the most critical key elements were investigated in NEWAC.

As the related technologies could not be tested in one validator, different test vehicles were envisaged. In all cases, the test vehicles and experimental data for the baseline geometry already existed so that this approach was cost-effective. Furthermore, this approach allowed for a more precise evaluation of the investigated concepts and technologies, in comparison to an integrated validator.

It is a matter of fact that the high pressure compressor is the most critical engine component concerning complexity, development risk and engine operability. For that reason, changes in the engine layout always require an adaptation of the HPC, to ensure that this sensitive component still guarantees an appropriate performance and operability. The four approaches even had extremely strong implications and demands on the HPC, for example the additional volumes of heat exchangers and ducting in the compression system, the variable need of cooling air mass flow, or the demand of very high aerodynamic loading. Consequently, besides the combustor technology and the heat exchanger and ducting technology, a further focus of NEWAC was the HP compressor.

Besides the above mentioned near and medium term approaches, in NEWAC also studies on highly innovative core configurations were undertaken, which originally had a TRL of 1. The goal of the studies was to pick up ideas available in the research field and identify those, which show high improvement potential using real engine specifications and therefore may be developed in the farer future. By this, NEWAC also generated basic concepts to close upcoming technology gaps and opened up a long-term perspective of further improvements.

1.4 Sub-project 0 - NEWAC coordination and technical management

Within this subproject, the **Coordinator** (MTU) was responsible for all aspects of the interface between the project and the EC. MTU has appointed a **NEWAC Coordinator** who was the focal point for the overall coordination of the project as wells as for administrative and financial content. The NEWAC coordinator’s responsibilities were to: manage the EC contract, handle and distribute the funds according to the rules agreed within the consortium, maintain the interface with the Project Officer assigned by the EC, maintain regular contact with the partner organisations, organise the Steering Committee and chair the Management Committee meetings and ensure global project coordination with the aim to meet the project schedule and objectives.

The Project **Support Team** was in charge of daily management work and logistics. The Support Team was made of a Project Office provided by ARTTIC with experienced Project Manager and Project Administrator. ARTTIC worked in close cooperation with the Coordinator. Whilst the Coordinator took care of the scientific, technical and strategic management of the project, ARTTIC took care of the operational management, the various day-to-day management and coordination tasks. The Project Office was in particular responsible for group management and facilitation, project administration and reporting (including financial and payment aspects), management of subcontracts, helpdesk and enquiry centre for participants, communication facilities and coordination (web based collaborative tool), event management and support for external communication. The information flow was ensured through monthly reports, and continuously updated and improved follow-up indicators (deliverable and milestone status tables, risk register, person-months and cost status tables).

This sub-project has also been dedicated to coordination of dissemination activities. The dissemination of NEWAC results targeted several user groups: scientists in industry and academia, policymakers and the general public via various media. Within the project duration, results have been disseminated through scientific publications (see dedicated section “List of publications), NEWAC presentations outside the Consortium, and press articles. The NEWAC film proved to be a great success and is available for the public for download from the public website. NEWAC communication material has been generated through the public website including regularly published editorials by the sub-project leaders. Moreover, flyers and brochures have been distributed.

For scientific exchange two successful workshops have been held:

- **European Engine Technology Workshop** held in June 2009 at Warsaw University of Technology
    - 99 participants gathered from 11 countries to get the latest information and present on future European aero engine research programmes and to make contacts with industry, SMEs, research institutes and academia for possible future collaborations.
    - The programme encompassd the presentation of research and technology development performed in NEWAC.
    - Besides NEWAC a comprehensive overview of current major European aero engine research projects (VITAL, DREAM, CLEANSKY) have been presented.
- **European Workshop on New Aero Engine Concepts** held in June 2010 in Munich.
    - The workshop offered insight to 109 experts into innovative core engine technologies, and presented solutions developed by NEWAC programme.
    - The workshop summarized the 4 years of international collaborative research between 40 partners through over 40 technical presentations and a comprehensive exhibition.

- The importance of European Research projects was highlighted in the presentation of European Commission by Daniel Chiron, Deputy Head of Unit Aeronautics and responsible Scientific Officer for NEWAC.
- Besides NEWAC a comprehensive overview of current major European aero engine research projects and future research opportunities has been presented: VITAL, DREAM and Clean Sky.
- The workshop provided also an outlook on further research efforts needed to fully realize or surpass ACARE 2020 objectives. In the concluding high-level panel discussion the benefits gained were summarized and an outlook for the exploitation of the technologies in future applications was provided.

Figure 5: Impressions from the European Workshop on New Aero Engine Concepts

1.5 Sub-project 1 - Whole Engine Integration

1.5.1 Achievements vs. the State-of-the-Art

Other NEWAC sub-programmes have taken technologies for the four new aero engine core concepts and three types of lean combustor and developed them up to TRL4-5, but it is sub-programme SP1 that has brought the technologies together and integrated them into whole engine concept designs. The engines were then assessed to quantify the benefits of the new technologies and to help determine priorities for taking each technology forward. While some of the NEWAC technologies can be incorporated almost straight away, most of the more radical new technologies will need validation to TRL6 before they can be considered for incorporation in actual production engine designs.

The four engine concepts have already been described in section 1.1. These are the Intercooled and Recuperated Aero-engine, the high OPR intercooled engine, the Active Core engine and the Flow Controlled Core engine.

NEWAC followed precedents set in the VITAL programme for whole engine modelling and assessments and used the same two reference aircraft to provide representative missions and engine thrust requirements. Two of the NEWAC engine concepts applied new core technologies directly to propulsion system designs already worked up in VITAL, while the remaining two needed completely new designs.

It was recognised that the intercooled and recuperated engine was best suited to a long-range aircraft, so just one engine was designed and assessed for this application. The other three engine concepts were assessed for both long-range and short-range aircraft applications. This gave a total of seven engine designs addressed in WP1.1.

WP1.2, active later in the programme, selected and assessed three further engine designs. These designs combined the NEWAC technologies in different ways, and they brought to ten the total number of engines assessed.

WP1.1 started out with requirements capture for the new technologies. By defining performance cycles for the seven original engines it generated detailed performance targets for specific technologies required by each engine. SP1 also set targets for sub-system weights and space envelopes, which were based on preliminary mechanical layouts that were worked up into general arrangement drawings during the first year of the project. Thus physical and functional targets were defined for the new technologies.

A series of SP1-specific review meetings was held annually from the end of the second year of the programme onwards. These reviewed progress in the other sub-programmes and updated the whole engine assessments. A dedicated SP1/SP6 meeting was held to review modelling and interpretation of combustor technologies and emissions assessments at the whole engine level.

Assessment of the Active Core engines and of the Intercooled and Recuperated engine was led by MTU, while the High OPR Intercooled engines were assessed by Rolls-Royce and the Flow Controlled Core engines were assessed by Snecma. However, in parallel with these WP1.1 and WP1.2 activities, further modelling of the engine designs was conducted by the group of universities participating in WP1.3. The primary tool for these studies was TERA2020. TERA2020 was initiated in the VITAL programme, building on tools developed in earlier EU programmes, and it provides integrated comparative assessments of engine performance, weight, manufacturing cost, maintenance cost, noise, emissions and their environmental impact.

The studies undertaken in NEWAC SP1 and preliminary conclusions were provided at the second NEWAC public workshop in Munich in June 2010 and at the ICAS Conference in Nice in September 2010 (paper ICAS-2010-408). Further details are available on the NEWAC website.

Table 1 and Table 2 summarise the conclusions from the SP1 studies.

Table 1: Summary of NEWAC WP1.1 and WP1.2 fuel-burn 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% target 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

Because most of the test programmes for the NEWAC technologies had delivered their results a year earlier there were only minor changes to the fuel burn assessments at the final SP1 review in March 2011. However, further testing and analysis in SP6 did result in some better validated and reduced emissions estimates being presented for the NEWAC lean burn combustors.

Results from the WP1.3 studies are summarised in Table 2. This shows that significant improvements could be made by optimising the engine cycles for the particular long-range (LR) and short-range (SR) aircraft applications. These results should not be interpreted as ranking the different concepts because much of the benefit comes from re-sizing the engines. TERA2020 complements the WP1.1 methods and assessments, and provides insight into the influence of the design parameters on overall performance.

Table 2: Comparison of optimised TERA2020 models with the original non-optimised models

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

Details of the WP1.3 studies were given in the 2010 Munich workshop presentations and in the ASME Journal, and more details will be published in two papers for the AiAA Journal of Propulsion and Power. TERA2020 studies on the IRA engine will be described at the ISABE conference in Gothenburg in September 2011 (ISABE-2011-1318).

Following the eruption of Eyjafjallajökull in Iceland in 2010, WP1.4 was added to SP1 to address an urgent requirement to increase the capability to predict the effects of volcanic ash on the operation of gas turbine aero engine components. Initial observations on the volcanic ash cloud were reported at the ICAS conference in Nice in 2010 (ICAS 2010-5.8.1).

The NEWAC partners organised research proposals for volcanic ash into three themes, to address its effects on core compressor, combustor and turbine components, and in the last year of the NEWAC programme new experiments were designed, new rigs were built, and the accretion and erosion effects of the Icelandic ash were measured and compared. The behaviour and distribution of ash particles within the engine was also modelled and improvements in the methods used for the prediction of ash damage have enhanced our understanding of the service implications of engine operation in low concentrations of ash. Volcanic ash was shown to erode compressor blade materials at rates comparable with fine silica sand.

A paper describing all of the NEWAC WP1.4 studies will be presented in September 2011 at the ISABE conference (ISABE-2011-1418) and later in the same month a paper comparing the erosive effects of volcanic ash and sand on compressor materials will be presented at the DLRK conference in Bremen.

1.5.2 Impact on Industry or Research

NEWAC sub-programme SP1 has brought the results of the whole programme together, and by quantifying the costs and benefits of the new technologies in representative applications, it has helped to determine priorities for their ongoing development prior to their incorporation in actual engine designs.

Despite the very encouraging progress made in the NEWAC programme, there are still significant challenges with respect to implementing aspirated compression systems and to integrating large air-to-air heat exchangers for heat exchange cycles, or for cooled cooling air. These technologies all offer benefits in certain applications, but more work is required to validate them to TRL6. Some of these NEWAC technologies will be taken further in EU Framework 7 programmes such as LEMCOTEC and Clean Sky.

The development of the TERA2020 tool has provided new insights into whole engine design and optimisation, and the working relationships established between the universities and industry have been a real bonus to all parties. We now have a much better understanding of the benefits and limitations of the new technologies and we demonstrated that no one set of technologies is best for all applications. Each new technology needs to “buy its way on” to future engine projects according to specific requirements.

Following on from the NEWAC WP1.4 volcanic ash research, recommendations are being made by the NEWAC research team for more detailed research, particularly into the effects of ash on the hotter components of current and future engines.

1.6 Sub-project 2 - Intercooled Recuperative Core

1.6.1 Achievements vs. the State-of-the-Art

The NEWAC SP2 has investigated the IRA-Intercooled Recuperated core. The IRA cycle uses significant benefits from further increased propulsive and thermal efficiencies with a potential of up to 20% fuel consumption- and CO_2-emission reduction versus the year 2000 state of art. The references for NEWAC SP2 are investigations and results from previous EC-projects EEFAE-CLEAN and AEROHEX. The significant low OPR of an appropriate intercooled- recuperated cycle supports by itself ultra low NOx combustor conditions and, hence, technologies, which are not applicable to high OPR engine cycle conditions as for instance the lean prevaporized premixed (LPP) combustor concept with related technology.

For targets beyond 2020, the SP2 has initiated studies on even more innovative core concepts relative to IRA on system study level.

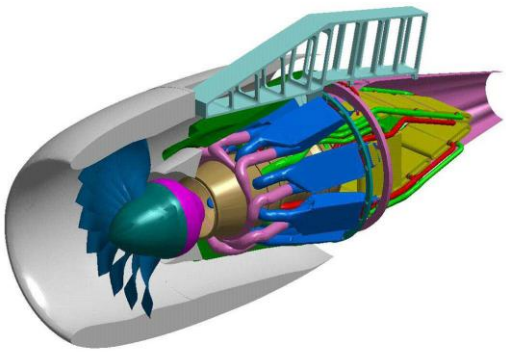


Figure 6: 3-D view of installed IRA Aero-engine

The IRA engine concept consists of the main features 3-shaft architecture, gearbox, high speed variable geometry LPT, ultra low-NO_x combustor (LPP-concept) and MTU profile tube heat exchanger.

The technical approach of SP2 was aiming at improving and optimising the IRA core modules:

- Radial HP compressor with respect to efficiency, weight & surge margin and with respect to a satisfying fit to the interface for the radial arrangement
- Hot nozzle installation with recuperator arrangement with respect to minimising pressure drop while keeping the recuperator matrix constant by the means of geometry arrangement modifications, adapted flow guidance and modified, improved loss modelling
- Integration of advanced LPP-concept based low NO_x emission combustor as contribution from the NEWAC SP6

The objectives for NEWAC SP2 were set at 2% fuel burn saving in addition to 16% fuel burn reduction already achieved as result from the EEFAE-CLEAN reference by the module-targets given below:

- +0.8% HPC efficiency gain and, at the same time, 10% module weight saving at increased operational range

- 15% recuperator pressure loss reduction in the hot nozzle arrangement at constant weight
- Identification of 5% SFC improvements versus the IRA baseline by studies on future innovative core concepts

Results from IRA integration and attachment concept study (T2.2.1)

An additional interface structure [IFS (orange)] was introduced between pylon (green), engine (blue) and recuperator-modules (green) in order to maintain standard engine mounting capabilities and procedures with the HEX-Modules combined to a one-frame assembly feature. The picture shows the upper section of HEX & HEX-frame feature at the attachment. Adapted solutions were investigated for bottom and sides.

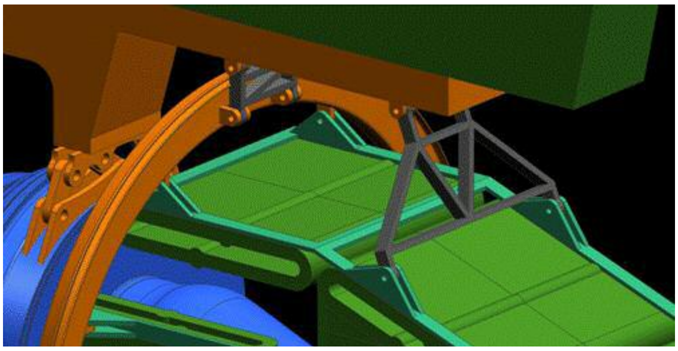


Figure 7: Minimised assembly & disassembly effort by introduction of an additional interface structure (orange)

Results from hot nozzle geometry and arrangement optimisation studies (T2.2.2 & T2.2.3)

The geometrical complexity of the used profile tube recuperator being characterized by a large number of lancets with elliptic cross-section requires a different model approach.

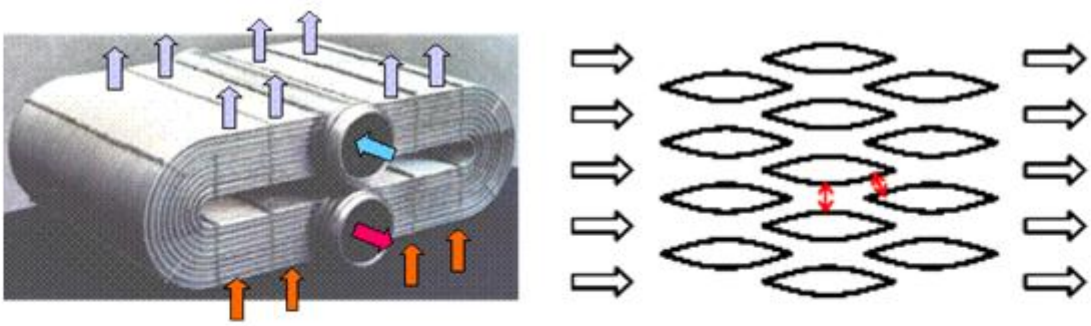


Figure 8: MTU profile tube HEX package for IRA (left) and cross-section of elliptical lancets (right)

The proposed solution for the purpose of SP2 hot nozzle geometry optimisation was a porosity model methodology: The modelling of the HEX-induced pressure loss is introduced by the use of source terms applied within a domain defined as 'porous'. The Darcy-Forchheimer formulations for the pressure loss through a porous media were chosen in order to describe the pressure loss across the HEX-matrix. Permeability and loss coefficients have been defined and validated by experiments. The porosity model was integrated in 3D CFD quarter nozzle setup. The results obtained for the optimised hot nozzle arrangement are leading to an ideal mass-flow distribution within a range of -1.0% … +1.3% from 25% base (initial range: -3.3% … +4.1% from 25% base in CLEAN) and, hence, are providing a pressure loss reduction of the order of ~12%.

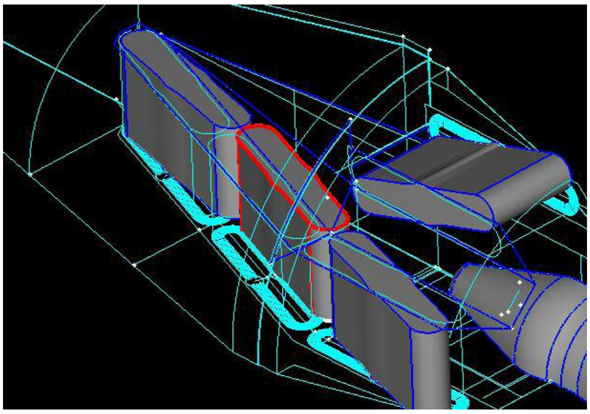


Figure 9: Optimised IRA hot nozzle geometries and arrangement

Results from the optimisation of advanced radial HP compressor design (T2.2.4 & T2.2.5)

The objective of the development of an advanced radial HP compressor was increase in efficiency (eta pol = +0.8%) and a decrease in module weight by ~8% at unchanged respective enhanced compressor stability level by the means of extensive use of 3D CFD analysis. The following steps forward have been performed:

- test of conventional 'state of art' HP compressor
- design for test bench and compressor
- 1st rig test campaign of advanced compressor design
- 2nd rig test campaign with casing treatment features

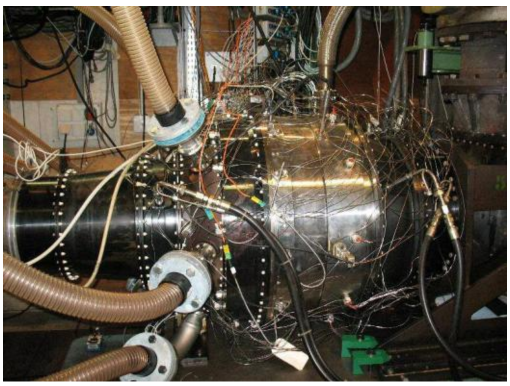


Figure 10: Rig setup of advanced radial HP compressor on test bench

Results of the compressor development show that the NEWAC SP2 objectives were nearly met. An analytical design investigation on selected HP compressor candidate architectures of different combinations of axial and radial compressor stages:

- pure radial
- 5 stage pure axial
- 1 stage axial + 1 stage radial
- 3 stage axial + 1 stage radial

was aiming at optimising the IRA HP compressor in terms of efficiency, weight, inertia and operability providing additional benefit options to the HPC. The SP2 activities on radial compressor improvement were supplemented by a comparative study on stability enhancement by the means of internal recirculation devices. The CFD analytics have been validated by corresponding experiments.

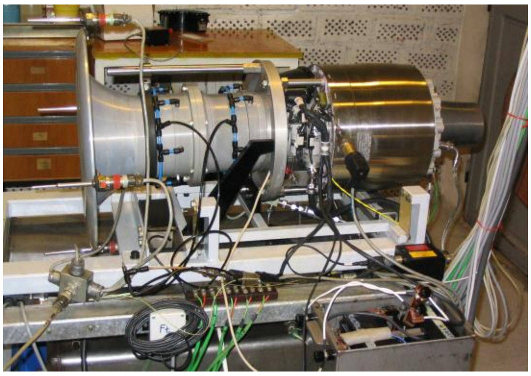


Figure 11: Engine bench with small scale radial HP compressor for internal recirculation testing

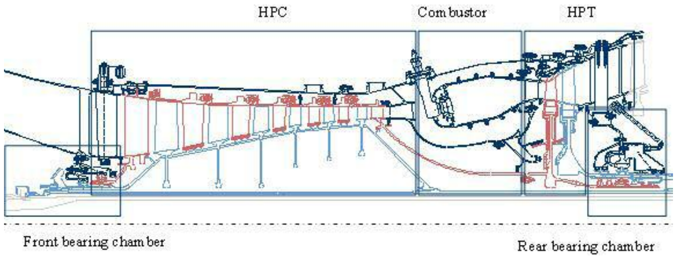
Results from study on innovative core concepts (T2.3.2, T2.3.3, T2.3.4 & T2.3.5)

4 selected studies on system level with time horizon beyond 2020 have been performed. The tasks with the selected configurations are:

Figure 12: Sketch of variable core cycle study (left) and of innovative combustion with pulse detonation features (right)

1st study on a variable geometry core concept (Fig. 12, left) including a statorless HP turbine, a partially overlapping contra rotating core and, last but not least, an adaptive variable geometry burner for supporting the variable core flow capabilities.

2nd study on innovative combustion features pulse detonation devices (Fig. 12, right). Besides the thermodynamic improvements, integration aspects and measures to avoid phase effects caused by the pulse detonation principles have been investigated.



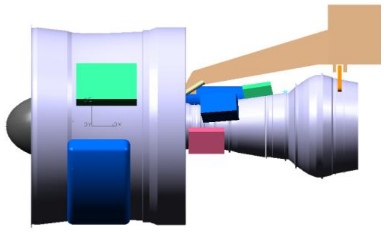


Figure 13: Sketch of contra-rotating core study (left) and of innovative heat management system (right)

3rd study on a design solution for a contra rotating core including contra rotating HP compressor and contra rotating HP turbine aiming at a performance gain mainly due to length and weight reduction (Fig. 13, left). A side study has concentrated on a partial overlapping contra rotating HP compressor architecture with improved fit to work split constraint of a contra-rotating device and better variable geometry capabilities.

4th study covered an investigation on the potential of an innovative heat management system including an advanced direct fuel metering concept with fuel de-oxigenisation device in order to enhance the cooling capacity potential of the entire system (Fig. 13, right).

1.6.2 Impact on Industry or Research

The four system studies have identified additional fuel saving potentials cumulative in the order of 5%; however at low technology readiness level compared to the main NEWAC objectives. The results are promising and require more detailed investigations in the future.

1.7 Sub-project 3 - Intercooled Core

1.7.1 Achievements vs. the State-of-the-Art

NEWAC SP3 investigated technologies for the high overall pressure ratio intercooled concept and for the particular long-range and short-range study engines assessed in SP1.

Activity in SP3 included aerodynamic, aero-thermal and mechanical design studies, and rig tests and experiments that related to the design of efficient, compact and lightweight intercooled compression systems with the enhanced operability needed for a very high OPR engine.

Intercooling becomes increasingly attractive as OPR is increased to improve thermal efficiency, because it enables lower HP compressor delivery and turbine cooling air temperatures, and tends to reduce NOx emissions. Some industrial and marine gas turbines already use intercooling, but with water cooling.

In a three-shaft intercooled aero engine the flow exiting the IP compressor will be cooled before it enters the HP compressor, using cool air taken from the bypass duct as shown in ***Figure 14***.

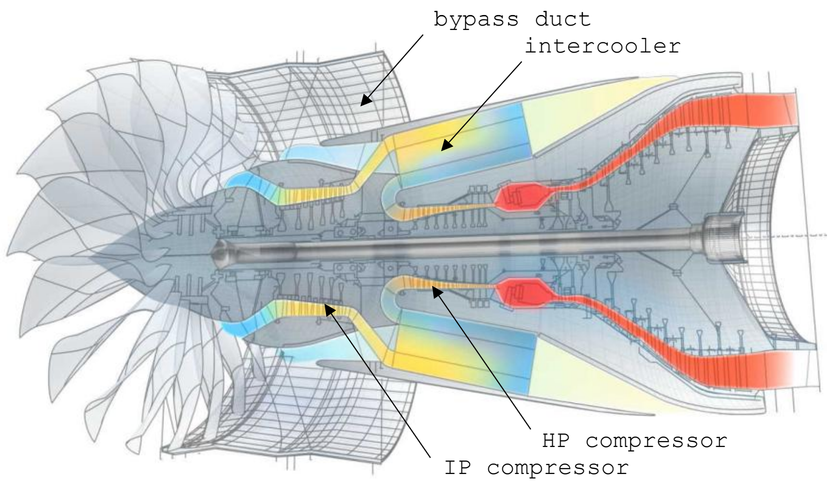


Figure 14: High OPR Intercooled Engine Concept

Component technologies in SP3 included 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 to maintain rotor tip clearances, and new systems and blading designs to maintain compressor efficiency and operability in these higher OPR intercooled engine cycles. Some SP3 technologies are also applicable to conventional engines and to intercooled and recuperated engine.

The general arrangement of a typical three-shaft intercooled turbofan is shown in ***Figure 14*** and ***Figure 15*** shows the layout of the intercooled compression system, which has an array of intercooler modules around the core of the engine and inboard of the bypass duct. The ducting connects the modules to the IP and HP compressors and to the bypass duct.

The bypass duct offtake and a separate diffusing duct diffuse the cooling air before it gets to the intercooler to avoid high pressure losses. Because the cooling air mass flow is comparable with the core mass flow, a fully annular offtake is used. The IP compressor exit air also needs to be diffused upstream of the intercooler to reduce pressure loss at entry to the heat exchanger matrix.

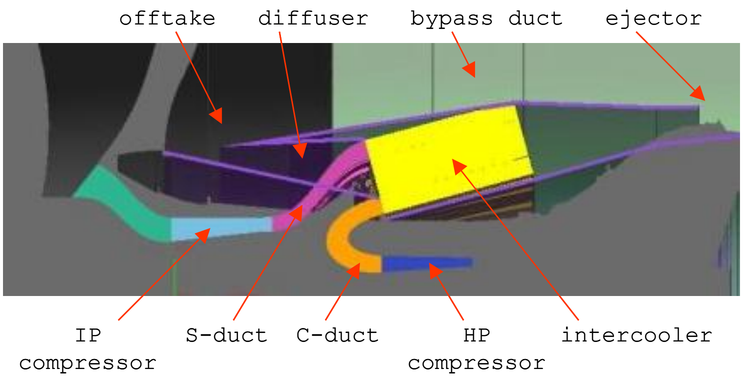


Figure 15: Intercooled Compression System Layout

The intercooler inlet ducts need a certain length to diffuse the flow efficiently and to recover static pressure. Also, since it is hard to diffuse and turn a flow at the same time, the diffusing ducts need to be fairly straight, though they can be slightly "S" shaped. These considerations effectively fix the intercooler location. The design of the inlet duct to the HP compressor has accelerating flow that can more easily be turned through the nearly 180º to bring it around to the HP compressor inlet. We call this the "C-duct".

Maintainability is eased by having several small intercooler modules, rather than one big intercooler, and this also helps to minimize overall weight and volume. In the proposed configuration each module has two cross-flow matrix units, like car radiators, but angled to the cooling flow to minimize frontal area. The matrix units are arranged in a V-shape as shown schematically in ***Figure 16***.

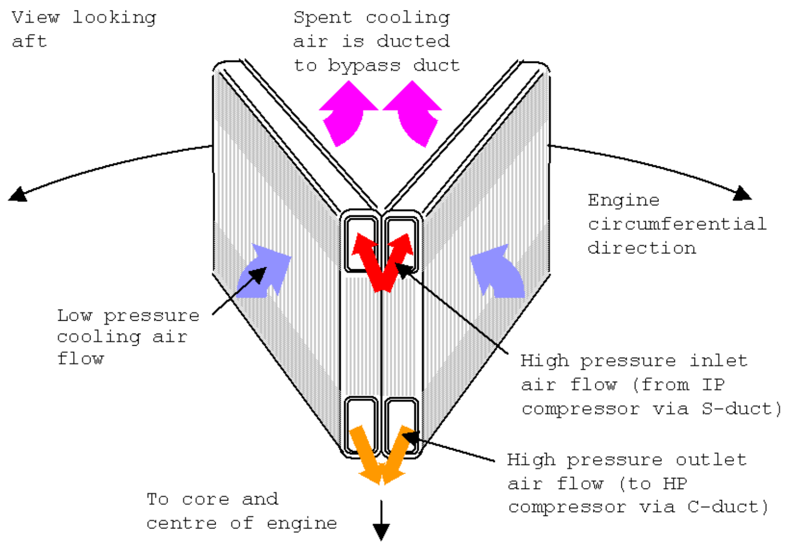


Figure 16: The V-shaped Intercooler Module Concept

In the NEWAC intercooled engine designs the modules are arranged in four groups leaving gaps at the top and bottom and at the sides of the engine core to improve core access as shown in ***Figure 17***.

Preliminary compressor designs were generated for the long-range and short-range intercooled engines and the compressor efficiencies were assessed. Compared with existing 3-shaft Trent engine designs the IP compressors have lower pressure ratios and fewer stages and the HP compressors have higher pressure ratios and more stages. This is to optimize the IP/HP work split for the intercooled cycle. The compressors all have axial flow, but the outlet guide vanes for the IP compressors are angled to help turn the exit flow away from the engine axis and they do not need to remove all the exit swirl.

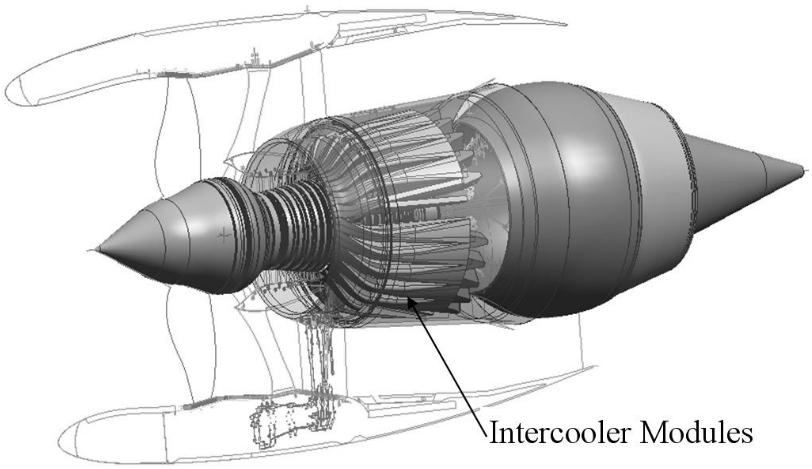
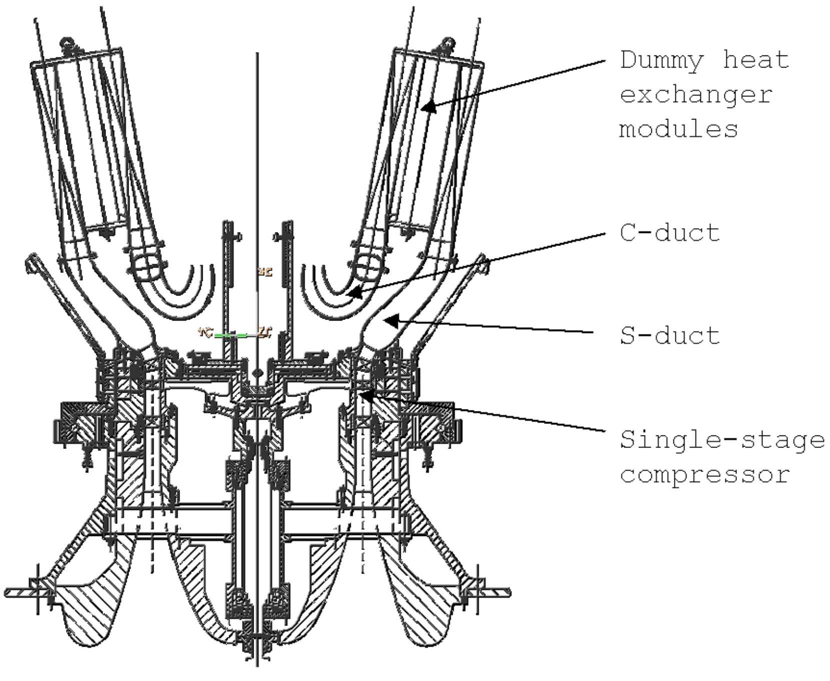


Figure 17: Intercooler Arrangement for the long-range Intercooled Engine

The aerodynamic design of the HP ducting was designed for the long-range intercooled engine and near full scale models were tested and a single stage compressor was used to generate inlet conditions to represent the flow out of the IP compressor. The diffusing S-ducts take advantage of the inlet swirl to help distribute the air between the unevenly spaced intercooler modules. More details are given in the paper "Duct Aerodynamics for Intercooled Aero Gas Turbines: Constraints, Concepts and Design Methodology" presented at ASME Turbo Expo 2009 (GT2009-59612).

The HP ducting rig is shown in cross-section in ***Figure 18*** and fully built up for testing in ***Figure 19***.



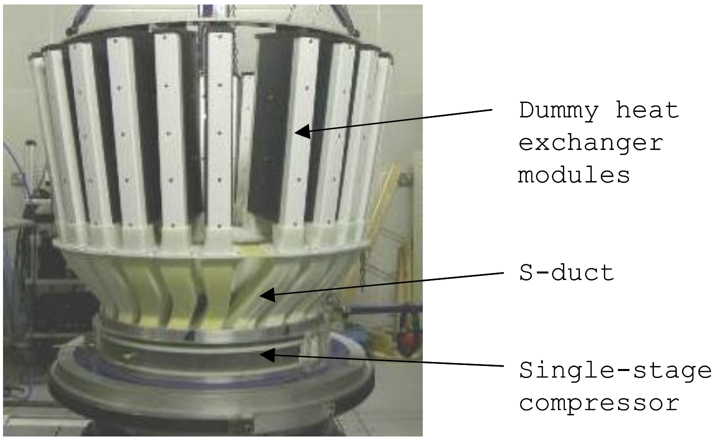


Figure 18: The Cross-section of the HP Ducting Rig at Loughborough University

Figure 19: The Fully Assembled HP Ducting Rig at Loughborough University

The conclusions from the HP ducting tests were that the target performance could be met provided that the S-duct splitters were not made too fat and the velocity profile at inlet to the C-duct was controlled.

For the low pressure ducting, the studies have concentrated on the annular offtake from the bypass duct and the downstream diffuser. A second fully annular test rig was commissioned to conduct a flexible series of experiments in different builds to explore different offtake and diffuser geometries and various area and mass flow ratios. Diffusion occurs both upstream and downstream of the bypass duct offtake.

This rig also had a single-stage compressor, and in this case it was custom designed to simulate a fan and its outlet guide vane. To avoid testing at a very small scale, a cropped fan and a bypass duct of reduced bypass ratio were modelled. This made best use of the available airflow for the rig.

Figure 20 shows a half-section through the rig configuration for build 4, which had a diffusing duct down-stream of the splitter. In the final phase of testing, bleed air was drawn off from the inner annulus just aft of the splitter to represent a core ventilation flow. It was demonstrated that this improved performance at higher overall diffusion (i.e. with some pre-diffusion upstream of the splitter and controlled diffusion downstream of the splitter).

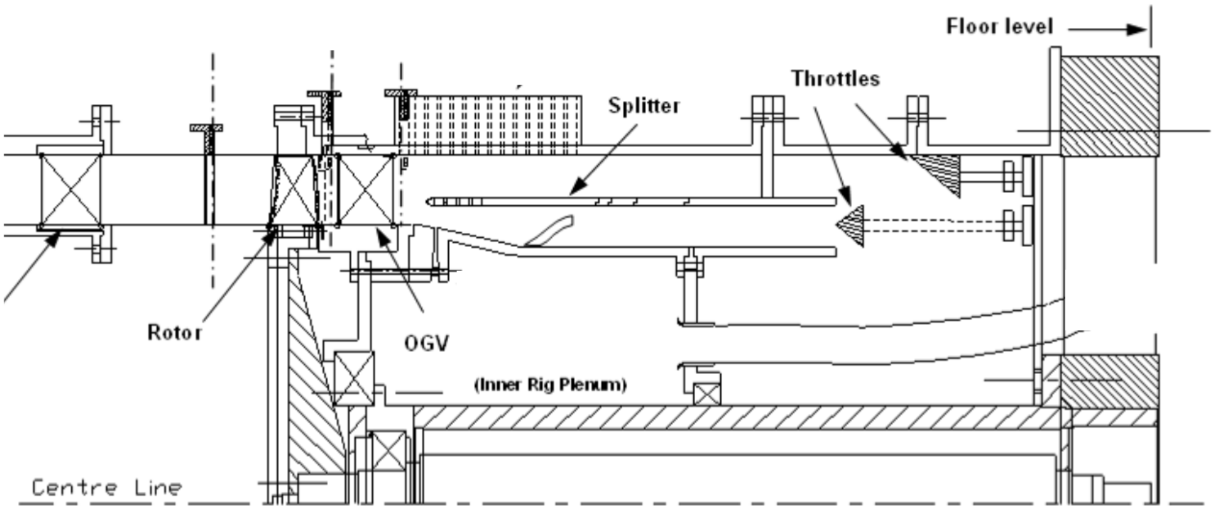
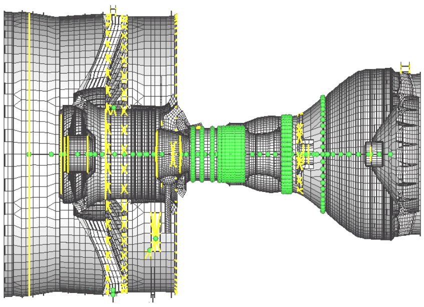


Figure 20: Rig for Experiments on Alternative LP Duct Arrangements

The intercase or frame between the IP and HP compressors is a main structural component of the engine and critical to maintaining carcass stiffness. The mechanical design is more complex in the intercooled engines because it must accommodate the S-duct and C-duct. Two alternative intercase designs were generated for the long-range engine and ***Figure 21*** shows quarter segment models for the two different designs. In the later design the S-ducts and C-ducts are crossed over.

Figure 21: Models of Alternative Intercase Designs for an Intercooled Engine

A potential problem for the intercooled engines is that their smaller diameter cores may be more flexible than those of conventional engines, and under thrust loads and manoeuvre loads the HP casings may be subject to more distortion, giving a disproportionate increase in tip clearance to the now smaller HP compressor and turbine blades. Initial whole engine mechanical modelling of the long-range engine with the baseline intercase confirmed that this was a real hazard that could affect the HP compressor efficiency. Further modelling with the alternative intercase design demonstrated that a significantly stiffer structure was possible, giving much improved tip clearances for a small weight increase. ***Figure 22*** shows the original whole engine model without nacelle components.



Note small diameter core in relation to fan case

Figure 22: Initial Whole Engine Mechanical Model

Because of the need to minimize the frontal area of the intercooler assembly, both hot and cold airflows need to turn through nearly 90° at matrix entry and exit, giving high approach velocities that have the potential to produce flow mal-distributions reducing intercooler effectiveness and increasing loss. These design issues were addressed by respective research studies. ***Figure 23*** shows an experimental configuration for rig testing. The flow distribution on the LP side of the intercooler was improved by modifying matrix entry and exit geometry and effects of detail design changes on heat transfer performance and pressure loss at entry to the matrix were quantified. More details are given in the NEWAC Munich Workshop presentations.

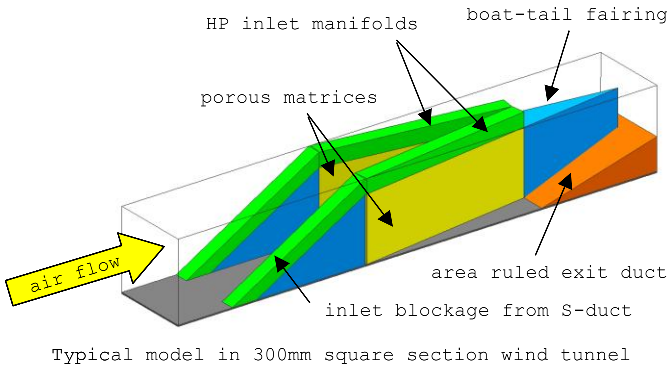


Figure 23: Intercooler LP Air Flow Rig Arrangement

The intercooler operates up to around 300ºC and 8 bar. A wide range of materials and constructions could have been selected, but the chosen intercooler matrix was a titanium cross-flow cross-corrugated primary surface design and prototype intercoolers were manufactured using powder bed deposition by selective laser melting. This may not be the preferred manufacturing route for production intercooler modules, but it was thought that this technology would enable new designs with complex and novel features to be made and tested relatively quickly. In practice the technology was not sufficiently well developed to make such complex components with high integrity and low porosity, so only limited testing was carried out. A prototype cross-corrugated intercooler is shown in the NEWAC Technologies brochure.

Intercooling a 3-shaft engine creates additional challenges for the core compressors. The high OPR proposed to maximize the cycle efficiency gains must be achieved without compromising component efficiencies or compressor operability. The IP/HP work split and the compressor working lines are significantly different to conventional designs, increasing demands for off-design handling capability. Also the small core size puts extra pressure on maintaining competitive tip clearances, which become limited by some mechanical and manufacturing constraints that do not scale.

With these challenges in mind a substantial element of the work in SP3 was aimed at the design of highly efficient and operable core compressors. The three main areas of research were: (1) advanced blading design, (2) stability enhancement, and (3) tip clearance improvement. As these technologies are to a large degree also relevant to conventional engine cycles with increased OPR (that are foreseen in the medium term) this research contributes to improved efficiency and reduced SFC for both engine types. These technologies are demonstrated on low-speed rigs and by high-speed HP compressor rig testing.

The latest parallel 2D/3D blade CFD design methods were applied throughout the compressor including optimized leading edge shapes and camber distributions to minimize secondary losses. A particular design aim was to desensitize compressor performance to tip clearances such that any potential deficit due to the reduced core size would have less effect on compressor efficiency and operability. The new blading is shown in ***Figure 24***.

Figure 24: HP Compressor Blading

The final HP compressor design was tested on a high-speed rig at the AneCom Aerotest facility. The test campaign involved overall performance characterization as well as detailed flow measurements that have been used to validate CFD tools. The test was very successful and so the originally planned second build was deleted from the programme and the funding was redistributed for additional research activities by all partners in the final year of the NEWAC programme. A final assessment trading compressor surge margin and efficiency showed that the original objectives had been fully met.

Methods of enhancing the stability of the compressors were investigated focussing on re-energizing the tip flow via recirculation of a small portion of the core mass flow. A tip recirculation system was developed utilizing rear stage compressor air that is injected through casing slots over the front rotor stages as shown in ***Figure 25***. The effectiveness of the system in extending the operating range of the compressor was demonstrated in low-speed tests (carried out prior to NEWAC) and refined through steady and unsteady CFD calculation. It was fully validated as part of the NEWAC SP3 high-speed rig testing.

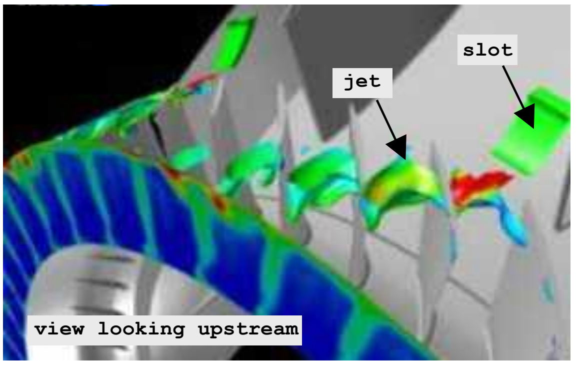


Figure 25: Tip Blowing Jets for Enhanced Compressor Stability

An alternative approach was followed with recirculation carried out at a more local level. In this arrangement air is bled from within a given rotor stage and re-injected into the tip flow. Careful placement and design of the offtakes enabled the system to be most active at the off-design points where the re-injected flow is most effective in extending the operating range of the stage. In a follow-on study to this low speed testing the effects of variability in compressor blading was studied on the same compressor rig.

In an attempt to minimize the impact of the small core size and the risk of additional carcass distortions in an intercooled cycle engine, studies were undertaken to identify casing and rotor concepts that could reduce the level of tip clearance required throughout the flight cycle. These studies were mostly focused on passive and adaptive technologies that minimize the mismatch between rotor and casing thermal responses or isolate the rotor path from the thermo-mechanical loads.

One of the more promising technologies involved speeding up the rotor drum transient thermal response by careful use of core flow bleeds into the drum cavities combined with features that enhance the heat transfer. CFD studies and validation rig testing were carried out utilizing a rotating disc heat transfer rig.

Further details of the research in SP3 are given in the NEWAC Munich Public Workshop presentations and in several papers including ISABE-2009-1278 “Intercooled Turbofan Engine Design and Technology Research in the EU Framework 6 NEWAC Programme”.

1.7.2 Impact on Industry or Research

Many technologies were developed to higher TRL in SP3. The work has given the research partners enhanced capabilities and has provided a much better appreciation of the potential of high OPR intercooled engines. Many of the problems associated with intercooled engine designs have now been solved, but others will still need further research. To make intercooled engines truly competitive further improvements are needed in the design and installation of compact lightweight intercoolers and in improved engine structures to minimise performance losses due to casing distortions. Alternative intercooler designs and engine architectures will be investigated in the EU FP7 LEMCOTEC programme.

The compressor research in SP3 was particularly successful and the lessons learned are already finding their way into new Rolls-Royce Trent engine designs.

1.8 Sub-project 4 - Active Core

1.8.1 Achievements vs. the State-of-the-Art

One of the new engine configurations investigated within NEWAC is based on a Geared Turbofan engine incorporating an active core and a lean burn low emission combustor as depicted below.

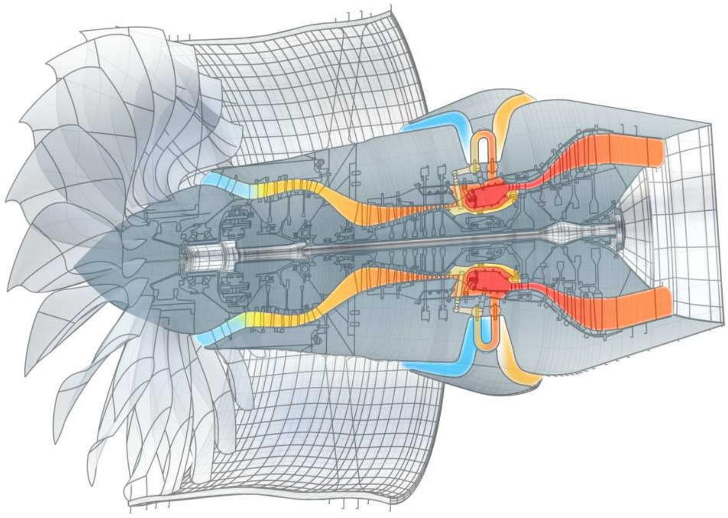


Figure 26: Schematic of Geared Turbofan engine with active core and lean burn low emission combustor

Since an active core can be adapted to the very different operating conditions of a flight mission (e.g. climb, cruise, idle), a breakthrough is expected regarding fuel burn and operability. Furthermore, active systems open up additional degrees of freedom in the design. Finally, efficiency penalties due to deterioration can be compensated to a certain degree by adjusting the core to the actual conditions.

The high-level objective of NEWAC subproject 4 'Active Core' relative to EEFAE was to develop and validate a system of interrelated core engine technologies which reduce the SFC of an aero engine by 4% due to increased core component efficiencies, core cycle improvements and related overall engine effects. Together with a lean burn low emission combustor developed by NEWAC subproject 6 'Innovative Combustor', the engine configuration described above aimed at reducing the NO_X emissions by 16%.

During the work within NEWAC two most promising areas of application for active systems were identified and investigated. The first one was an active cooling air cooling (ACAC) system, which lowers the temperature of the cooling air for the high pressure turbine and for other cooled parts. The second one was the so-called smart HPC that exhibits a big improvement potential by the adoption of both an active clearance control (ACC) and an active surge control (ASC) system.

Regarding ACAC, the combustor case with its cooling air flow path is one of the key issues of a cooling air cooling system, because this component will have a more complex geometry and has to bear strong temperature gradients. In addition to that, the design of the flow path for the cooled cooling air has to meet strong requirements for low total pressure losses and low heat pick-up in the hot environment. Furthermore, the availability of cooled cooling air at HPC exit pressure level offers the opportunity to use this air also for cooling the HPC rear cone, which has to bear high temperature levels and gradients at high stress levels.

A general concept study indicated a significant reduction of the cooling air mass flow, a remarkable increase of HPT efficiency (due to the significant reduction of coolant mixing losses) and a slight weight reduction. Since cooled cooling air will allow for new design approaches concerning thickness, material and manufacturing methods, the work on ACAC finally focussed on advanced manufacturing technologies.

As far as smart HPC technologies are concerned, the persistent goal of a higher pressure ratio at unchanged stage count and higher efficiency was directly leading to two key issues of HPC development: Active clearance control for the compressor rear stages, resulting in higher efficiency and higher full speed surge margin, and active surge control for the compressor front stages, resulting in higher part speed surge margin. To meet the first target, actuators working on a mechanical basis were integrated into the casing. The clearance between rotor and casing was controlled by signals from tip clearance sensors and adequate intelligent control algorithms. The chosen option for surge control in the front stages was the injection of air taken from inter-stage bleed or compressor exit through slots in the casing in front of the first rotor.

For the validation of the mentioned technologies a series of rig tests were conducted in order to reach high technology readiness levels (TRL). The mechanical ACC system was tested in a so-called proof-of-concept rig with all hardware and controls needed. It proved the feasibility and mechanical function of the system as well as all related control software including appropriate reaction to failure scenarios. ASC by air injection was tested in a high-speed 8-stage HPC rig varying key parameters like slot number and geometry, injection flow rate and air temperature.

The ACC test campaign showed the potential to remarkably increase the HPC efficiency. As a result of the ASC test campaign, the part speed surge margin could be significantly increased which offers the potential of a reduced blade count translating into a further efficiency benefit. Therefore, the best benefit in terms of HPC efficiency can be achieved in combination of ACC and ASC. However, both technologies proved to require some additional weight vs. the reference design.

Although ASC and ACC are considered to have a significant potential to increase the HPC stability both at part load and in the upper speed range, multi-stage Casing Treatment (CT) could be an attractive alternative in terms of system complexity and reliability. This was checked in a related test campaign with the 2.5-stage axial compressor rig of RWTH.

For the NEWAC Geared Turbofan engine with an active core, these results translated into a significant reduction of CO_2 emissions close to the 4% objective. In terms of reduction of NO_X emissions, the active core engine was capable to fully meet the objectives by using the lean burn combustor developments from NEWAC subproject 6 ‘Innovative Combustor’.

1.8.2 Impact on Industry or Research

As a conclusion, the work within NEWAC subproject 4 ‘Active Core’ provided a multitude of concepts, studies, designs and tests to verify predicted improvements towards overall goals. The rig tests on smart HPC technologies showed encouraging results. The manufacturing and sensor technology development contributed vital input for the use of active elements in future engine programs. Finally, the cooperation of partners from engine industry, suppliers and university has proven to be an effective way forward.

1.9 Sub-project 5 - Flow controlled core

1.9.1 Achievements vs. the State-of-the-Art

High BPR and/or new architectures require highly loaded, efficient and operable HPC (+20/25% Surge Margin vs. in-service compressor). Enhancement of highly loaded HPC is achievable through innovative concepts linked to Flow Control and an integrated optimised design.

NEWAC SP5 strategy was to validate the Flow Controlled Core concept by developing flow control approach into HPC, linking advanced aerodynamic design with innovative concepts and maturing the integration in real-engine environment.

The high level objective for SP5 was a significant increase of efficiency and stall margin for the HPC and a significant reduction of Fuel Burn and emissions for the engine.

The technical approach of SP5 is described in the following chart:

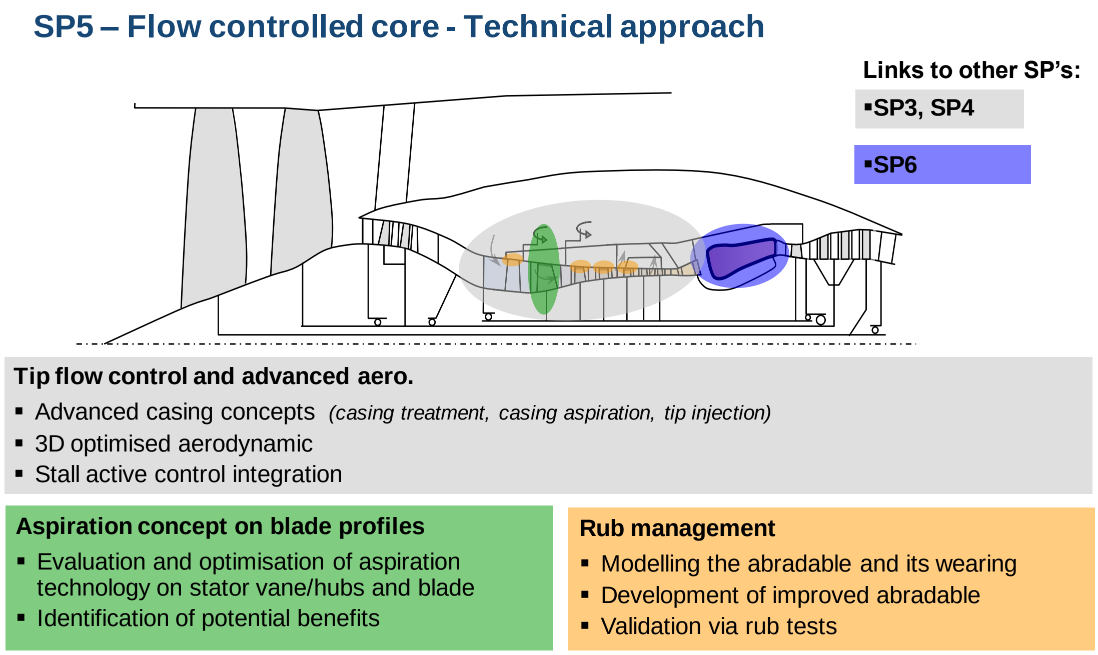


Figure 27: Flow controlled core – Technical approach

SP5 activity has been divided into three parts:

- Tip flow control and advanced aero: an in-house 6 stage highly loaded compressor has been redesigned: 3D aero optimised profiles have been designed in line with technological concepts used to control the tip and hub behaviour of the flow: non axisymetric endwall at the hub of rotor 1, advanced casing treatment above rotor 2, axisymetric casing treatment above rotor 3 and casing aspiration above rotor 4. The aim was to increase the efficiency while keeping the stall margin, and also to reduce the sensitivity to tip clearance opening. The hereafter chart summarizes the modifications that have been implemented and rig tested.

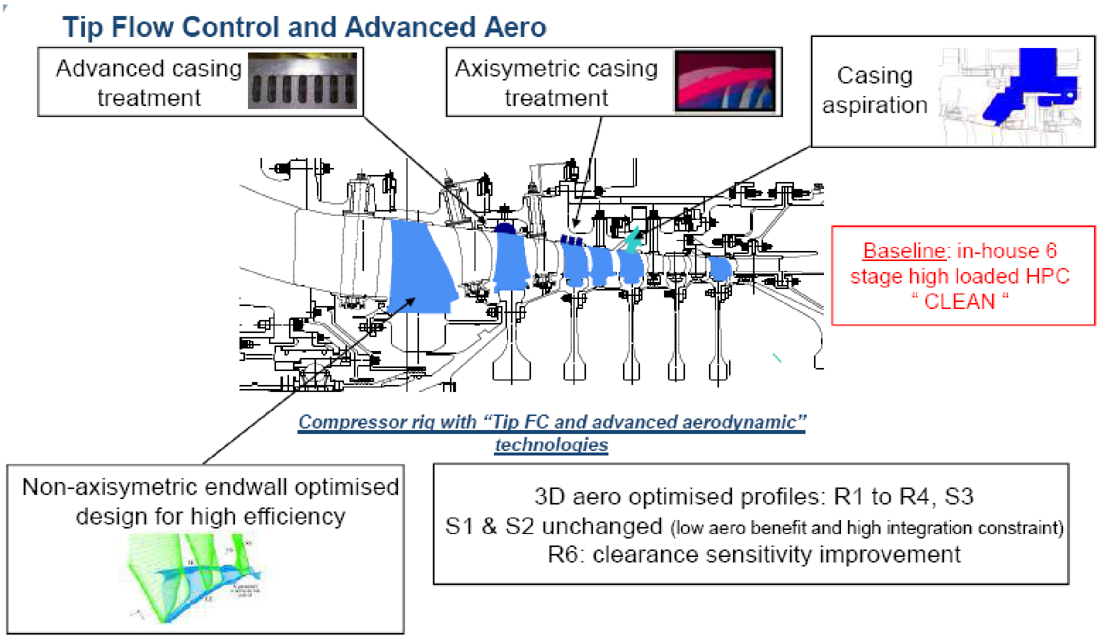


Figure 28: Tip Flow Control and Advanced Aero

- Rub management: the importance of the tip clearance between rotor and casing for the performance of the compressor requires a very good management of the rubbing between tip rotor and casing. The abradable wearing of the casing above the rotor is a key part for that management: a new abradable has been developed and test validated, to improve its abradability and its corrosion. In parallel, a blade / casing numerical simulation tool has been developed and validated thanks to a full-scale blisk test.
- Aspiration concept on blade profiles: to go a step further in the flow control concept, the aspiration concept has been extended to blade aspiration. The aim is here to increase the blade performance, and so to be able to increase the blade loading. Cascade tests of an aspirated stator have been conducted, demonstrating the interest of hub and blade aspiration, as well as the ability of reducing the blade count with such a technology. In parallel, performance studies have been conducted to ensure the interest of aspiration at engine level.
- Flow controlled technologies have been validated by a rig test in a highly loaded six-stage compressor.
- An aspiration concept has been validated by cascade tests and integration studies at engine level.
- Blade/ casing rub management has been improved by numerical simulations validated by tests and new abradable coating development.

- The SP5 results are summarized by an HP Compressor efficiency increase of 1.9 points, a stall margin increase of 7.5 %, and a weight penalty of 17 kg. These results are consistent with a short range application.

1.9.2 Impact on Industry or Research

The Technology Readiness Level achieved in these activities allows the implementation of the flow controlled technologies in the future engines currently in elaboration.

1.10 Sub-project 6 - Innovative Combustor

1.10.1 Achievements vs. the State-of-the-Art

SP6 main objective is to develop and validate lean fuel injection technology up to TRL 5, demonstrating 60% to 70% reduction of NO_X emissions in the LTO cycle versus the CAEP/2 limit. The NO_X reduction targets are set assuming that emissions of CO, un-burnt hydrocarbons, and soot/smoke remain at least unchanged on the level of year 2000 technology.

Depending on the size and thrust range of the particular engine application, three different lean burn fuel injector technologies (LPP, PERM and LDI) have been considered (*Figure 29*):

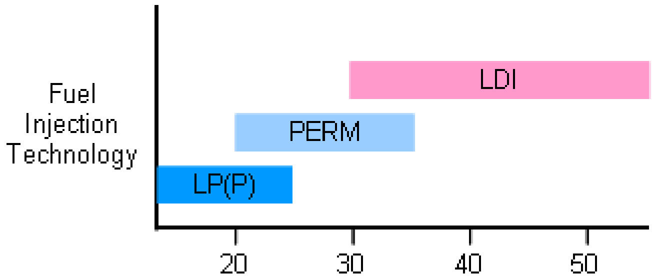
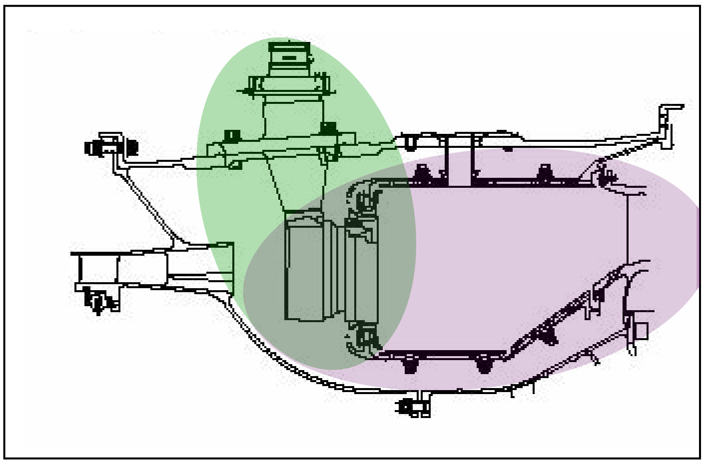


Figure 29: Application of different lean burn fuel injector technologies depending on engine OPR

The technical approach used in SP6 is shown in *Figure 30*.



Injection Systems

- Design three different concepts of advanced Lean-Burn Injection Systems
- Develop the concepts though detailed investigations of the components
- Validate the concepts by combustion tests to assess emissions & operability

Improved SAC Lean Burn Combustor

- Improved cooling technology with significant cooling flow reduction
- Fuel staging system to optimize emission performance through entire engine cycle
- Combustor Validation by FANN HP Rig Tests

Figure 30: SP6 Technical Approach to develop and validate lean burn innovative concepts

Work accomplished in SP6:

- Injection systems improved through several iterations from TRL 2 to TRL 4
- Combustion systems validated at TRL 5 in terms of pollutant emissions and operability
- NOx emissions evaluated for NEWAC engine cycles and assessed versus target

In the following the main achievements are presented for each lean burn combustion concept.

Combustor with staged Lean Direct Injection (LDI) – [Task 6.2.1, 6.3.1, 6.4.1]

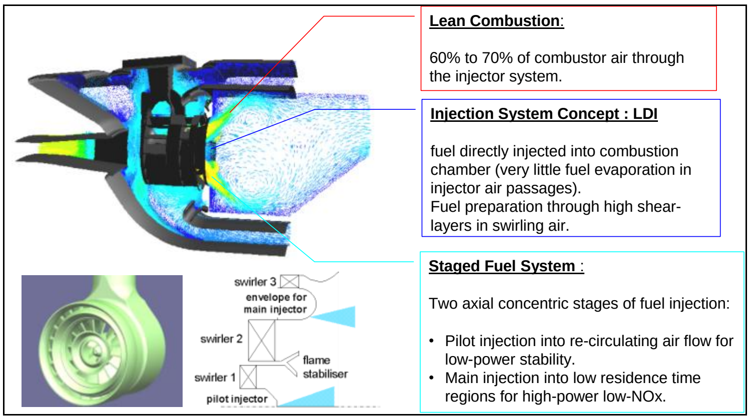


Figure 31: Lean Direct Injection (LDI) Combustor

Description

The Lean Direct Fuel Injection concept (*Figure 31*) is characterized by the fact that most of the air for combustion, with the exception of the ‘cooling’ flow, enters through the fuel injector. The fuel is directly injected into a single annular combustor architecture with the spray preparation through high shear swirling air. To ensure a stable operating range, fuel staging is arranged within the injector. A concentric pilot nozzle is injecting fuel into a recirculating flow to establish low-power flame stability. The main fuel is injected into low residence time regions to enable high-power low nitrogen oxide emissions. The pilot/main fuel split is following an optimized schedule throughout the engine operating range.

The combustion process and the 2-phase-flow have been characterized with Laser-optical methods. New measurement methods have been established in an optical high-pressure test rig. In particular, an extension of the applicability of Laser Doppler and Phase Doppler Anemometry in the operating range could be demonstrated in terms of reacting high pressure two-phase flows in combustion chambers, where quantitative data are available.

Benefits

- Reduction of climate effective nitrogen oxide emissions from aero engines
- 70% NO_x reduction relative to CAEP2 regulations
- Application of laser-based measurement techniques at engine conditions

Partially Evaporating Rapid Mixing (PERM) Combustor – [Task 6.2.2, 6.3.2, 6.4.2]

Figure 32: Partially Evaporating Rapid Mixing (PERM) Combustor Development

Description

For a medium OPR range a combustion system based on the concept of Partially Evaporated and Rapidly Mixing (PERM) Injection technology and liners effusion cooling optimization (*Figure 32*) has been investigated. The lean combustion is generated by the mixing of more than 60% air through the nozzle with the fuel, locally and circumferentially staged, in order to minimize NO_x emission and assure operability in each point of the mission.

Different PERM injection systems have been designed and validated by experimental investigations up to low/medium pressure (8 bar). PERM injection system concept validation has been completed by pollutant emissions on tubular combustor HP tests up to 25 bar. Advanced effusion cooling system technology has been investigated through numerical and experimental activities. Eventually, the complete combustor aerodynamic and reactive flow-fields have been numerically analysed. And a Full Annular Combustor high pressure test campaign has been carried out with the aim to assess pollutant emissions by exhaust measurements at real engine conditions.

Benefits

- 42% NO_x reduction relative to CAEP2 regulations

Lean Premixed Prevaporised (LPP) Combustor - [Task 6.2.3, 6.3.3, 6.4.3]

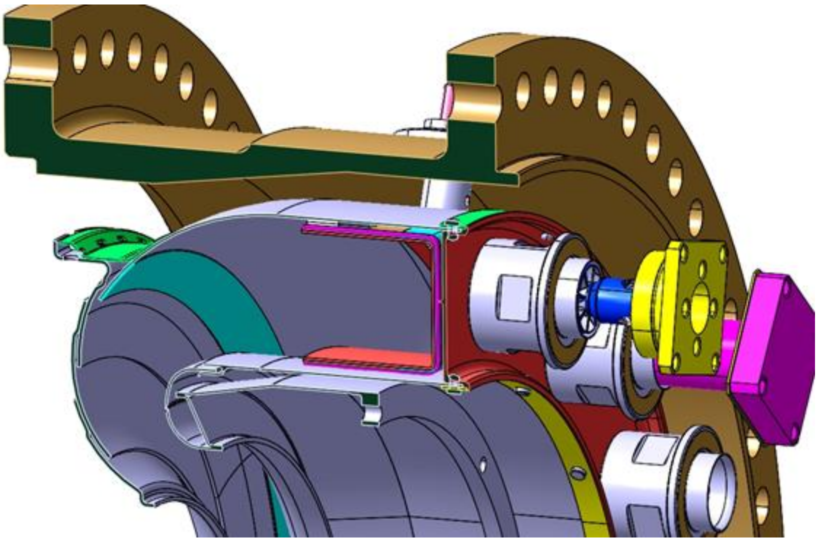


Figure 33: Lean Premixed Prevaporised (LPP) Combustor 3D view

Description

The reduction of the NO_x emissions by 80%, which is a target of the ACARE group, needs the development of the lean combustion technology: Indeed, to maximize the NO_x reduction, the best way is to create a lean uniform mixture between vaporized fuel and fresh air before its introduction into the combustor. This is well adapted to the low OPR cycle engine, like the IRA engine studied in the NEWAC project, because the low air pressure value minimized the risk of auto ignition inside the injection system.

Lean Premixed Prevaporised injector concepts have been developed and validated on a full annular combustor (*Figure 33*) at the LTO cycle points of the IRA engine.

Benefits

57% NO_x reduction relative to CAEP2 regulations

1.10.2 Impact on Industry or Research

SP6 results have demonstrated the capabilities to reach significant results in the design/development and validation of lean burn technologies up to TRL 5, as a specific step-forward contribution reaching the ACARE 2020 target.

1.11 Contractors Involved

Coordinator: MTU AERO ENGINES GMBH
Dachauer Strasse 665
80995 Muenchen / Germany
http://www.mtu.de

Austria

TECHNISCHE UNIVERSITÄT GRAZ	www.tugraz.at

Belgium

CENAERO - CENTRE DE RECHERCHE EN AERONAUTIQUE	www.cenaero.be
TECHSPACE AERO	www.techspace-aero.be
UNIVERSITE DE LIEGE	www.ulg.ac.be

Czech Republic

PBS - PRVNÍ BRNĚNSKÁ STROJÍRNA	www.pbs.cz

France

AIRBUS OPERATIONS SAS	www.airbus.com
ARTTIC	www.arttic.eu
DGA - DIRECTION GENERALE DE L'ARMEMENT	www.defense.gouv.fr/dga/
ECOLE CENTRALE DE LYON	www.ec-lyon.fr
ONERA - OFFICE NATIONAL D'ETUDES ET DE RECHERCHES AEROSPATIALES	www.onera.fr
SNECMA	www.snecma.com
SOCIETE DES NOUVELLES APPLICATIONS DES TECHNIQUES DE SURFACE	www.sonats-et.com
TURBOMECA	www.turbomeca.com
UNIVERSITE DE TECHNOLOGIE DE BELFORT-MONTBELIARD	www.utbm.fr

Germany

AACHEN UNIVERSITY OF TECHNOLOGY	www.rwth-aachen.de
DLR - DEUTSCHES ZENTRUM FÜR LUFT- UND RAUMFAHRT	www.dlr.de
KARLSRUHE INSTITUTE OF TECHNOLOGY	www.kit.edu
MTU AERO ENGINES	www.mtu.de
ROLLS-ROYCE DEUTSCHLAND LTD & CO. KG	www.rolls-royce.com/deutschland
STEIGERWALD STRAHLTECHNIK GMBH	www.steigerwald-eb.de

UNIVERSITÄT STUTTGART www.uni-stuttgart.de

Greece

ARISTOTLE UNIVERSITY OF THESSALONIKI www.auth.gr
NATIONAL TECHNICAL UNIVERSITY OF ATHENS www.ntua.gr

Italy

AVIO S.p.A. www.aviogroup.com/en
ENGINSOFT www.enginsoft.com
UNIVERSITÀ DEGLI STUDI DI FIRENZE www.unifi.it

Poland

WSK - WYTWORNIA SPRZETU KOMUNIKACYJNEGO “PZL-RZESZOW” SA www.wskrz.com

Sweden

CHALMERS UNIVERSITY OF TECHNOLOGY www.chalmers.se
VOLVO AERO CORPORATION www.volvoaero.com

Switzerland

ECOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE www.epfl.ch
MEGGITT SENSING SYSTEMS www.meggittsensingsystems.com
SULZER METCO AG www.sulzermetco.com

United Kingdom

CRANFIELD UNIVERSITY www.cranfield.ac.uk
LOUGHBOROUGH UNIVERSITY www.lboro.ac.uk
PCA ENGINEERS LTD www.pcaeng.co.uk
ROLLS-ROYCE PLC www.rolls-royce.com
SCITEK CONSULTANTS LTD www.scitekconsultants.co.uk
THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF OXFORD www.ox.ac.uk
THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF CAMBRIDGE www.cam.ac.uk
UNIVERSITY OF SUSSEX www.sussex.ac.uk

1.12 Project Logo and Website

www.newac.eu

2. Dissemination and Use

Publishable results

První Brněnská Strojírna

Result description Product(s) envisaged, functional description, main advantages, innovations	Publication "CFD ANALYSIS OF A SURGE SUPPRESSION DEVICE FOR HIGH PRESSURE RATIO CENTRIFUGAL COMPRESSOR" had been presented at ANSYS user meeting held in Czech Republic 2010.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	babak.m@pbsvb.cz

Aristotle University of Thessaloniki

Result description Product(s) envisaged, functional description, main advantages, innovations	Heat and Fluid flow phenomena through heat exchangers specifically designed for aero engine applications. Experimental derivation of pressure drop laws through heat exchangers in order to be integrated in a CFD solver. Experimental assessment of heat exchanger performance. Experimental and computational investigation of noise transmission in heat exchangers for aero engine applications. Results have been or will be published in International Scientific Journals with high IF and in International Conferences.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	The results can be used in further research regarding the weight and the dimensions of the heat exchangers in order to have better performance with lesser weight.
Stage of development Laboratory prototype, demonstrator, industrial product …	Laboratory prototype.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Dr. Kyros YAKINTHOS, assistant professor Laboratory of Fluid Mechanics & Turbomachinery Department of Mechanical Engineering Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece e-mail: kyak@auth.gr tel. +30 2310 996411 fax +30 2310 996002

The Chancellor, Masters and Scholars of the University of Cambridge

Result description Product(s) envisaged, functional description, main advantages, innovations	New casing treatment which selectively re-circulates flow near stall but does not reduce efficiency at compressor design conditions.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Aero-engine compressors. Axial compressors for industrial use.
Stage of development Laboratory prototype, demonstrator, industrial product …	Laboratory prototype.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	Available for use by Rolls-Royce and other aero-engine companies.
Collaborator details Type of partner sought and task to be performed	Further development necessary on high-speed compressor. Aero-engine manufacturers.
Intellectual property rights granted or published	
Contact details	Ivor Day, ijd1000@cam.ac.uk

Cranfield University

Result description Product(s) envisaged, functional description, main advantages, innovations	NEWAC TERA 2020 models, assessments and multi-disciplinary optimisation studies Propulsion System Integration (PSI) model Dissemination via: Theses (MSc and PhD) Publications
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Vishal Sethi, Cranfield University v.sethi@cranfield.ac.uk

Deutsches Zentrum für Lüft- und Raumfahrt e.V.

Result description Product(s) envisaged, functional description, main advantages, innovations	Implementation of a nonlinear Explicit Algebraic Reynolds Stress Turbulence Model (EARSM) in the DLR solver TRACE.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Increased predictive accuracy for CFD application in the turbomachinery design process. After industry-ready stability of the model the improvements can be used for design of new advanced engine components.
Stage of development Laboratory prototype, demonstrator, industrial product …	A prototype code including two quartic EARSMs is available. Pilot applications include typical turbomachinery cases such as a compressor cascade, a compressor stage and a multi-stage turbine.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Edmund.kuegeler@dlr.de

Result description Product(s) envisaged, functional description, main advantages, innovations	NUMERICAL INVESTIGATION OF THE PRESURE DROP FOR A HEAT EXCHANGER FOR AERO ENGINE APPLICATION
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Build up of knowhow in the area of heat exchanger. In future application the implementation and sue of a pressure drop law can be announced.
Stage of development Laboratory prototype, demonstrator, industrial product …	Prototype of a process how to evaluate loss coefficients for a pressure drop law.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Edmund.kuegeler@dlr.de

Result description Product(s) envisaged, functional description, main advantages, innovations	Results of injector tests at engine conditions using optical diagnostic methods. Description of procedures for the optimization of measurement methods like PDA or planar laser-induced florescence in view of meeting specific demands posed by GT combustor environments: reconstruction of 3D distributions from multiple 2D measurements, optical layout and operation of PDA and LDA equipment
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Increased accuracy of optical testing; reduction of test time and –costs Support of development strategies for lean injectors Extendable to other injector concepts
Stage of development Laboratory prototype, demonstrator, industrial product …	Evaluation of methodology and demonstration of procedures performed during LDI injector testing in NEWAC. Test data available for project partner.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Ulrich.meier@dlr.de

Ecole Polytechnique Fédérale de Lausanne

Result description Product(s) envisaged, functional description, main advantages, innovations	The experimental and numerical observation of the test model flow results have been and will further be presented on specialised conference (e.g. the European Turbomachinery Conference) and journal publications.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	Laboratory prototype of the compressor.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	The partners collaborated with other researchers from the Laboratoire de Mecanique de Fluides et d'Acoustique from Ecole Centrale de Lyon doing research in the domain of flow control by aspiration. This cooperation will be set forth for future developments.
Collaborator details Type of partner sought and task to be performed	Academic Partner
Intellectual property rights granted or published	
Contact details	peter.ott@epfl.ch

Loughborough University

Result description Product(s) envisaged, functional description, main advantages, innovations	**Design methodology for low pressure loss HP ducting systems** Design methodology for HP ducting systems for use within intercooled gas turbine aero-engines
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	The research led by Rolls-Royce plc in the NEWAC programme has focussed on the design of high overall pressure ratio intercooled turbofan engines and their intercooled compression systems and related enabling technologies. Such engines, with reduced CO_2 and NOx emissions could be used to power future large civil aircraft. The experimental and theoretical research work undertaken at LOUGH has led to several publications and helped to attract and retain high quality PhD students, research assistants and staff, enhancing the capability of LOUGH to undertake further leading edge research in this field.
Stage of development Laboratory prototype, demonstrator, industrial product …	Prototype methodology.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	j.f.carrotte@lboro.ac.uk

Result description Product(s) envisaged, functional description, main advantages, innovations	**Design methodology for LP ducting systems for use in intercooled aero-engines** Design methodology for LP ducting systems for use within intercooled gas turbine aero-engines
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	The research led by Rolls-Royce plc in the NEWAC programme has focussed on the design of high overall pressure ratio intercooled turbofan engines and their intercooled compression systems and related enabling technologies. Such engines, with reduced CO_2 and NOx emissions could be used to power future large civil aircraft. The experimental and theoretical research work undertaken at LOUGH has led to several publications and helped to attract and retain high quality PhD students, research assistants

	and staff, enhancing the capability of LOUGH to undertake further leading edge research in this field.
Stage of development Laboratory prototype, demonstrator, industrial product …	Prototype methodology
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	j.f.carrotte@lboro.ac.uk

National Technical University of Athens

Result description Product(s) envisaged, functional description, main advantages, innovations	NEWAC TERA 2020 models, sensitivity and multi-disciplinary optimisation studies. Dissemination via Publications.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	a.alexiou@ltt.ntua.gr

ONERA

Result description Product(s) envisaged, functional description, main advantages, innovations	Numerical simulation of casing and blade aspiration on compressors using the Chimera technique (in congress or journal)
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	beaumier@onera.fr

Result description Product(s) envisaged, functional description, main advantages, innovations	On the use of PLIF technique for the characterization of injection systems (in congress or journal)
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	

Intellectual property rights granted or published	
Contact details	beaumier@onera.fr

The Chancellor, Masters and Scholars of the University of Oxford

Result description Product(s) envisaged, functional description, main advantages, innovations	The use of external and integrated flow conditioning systems to increase the flow uniformity both through heat exchanger and at the exit from the heat exchanger installation. (A paper on this work will be presented at ASME IGTI 2011) The detailed heat transfer and pressure loss on the primary surfaces of the heat exchanger will be presented at an international conference, and submitted to a journal. At present the ASME IGTI conference 2012, Copenhagen is the most probable target for this work.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Aerospace, vehicular heat exchangers
Stage of development Laboratory prototype, demonstrator, industrial product …	End of lab prototype stage, needs demonstration at near engine condition.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	Further research projects / consultancy with industrial collaborators.
Collaborator details Type of partner sought and task to be performed	Industrial Partner
Intellectual property rights granted or published	
Contact details	david.gillespie@eng.ox.ac.uk

PCA Engineers Limited

Result description Product(s) envisaged, functional description, main advantages, innovations	Results of preliminary studies into 3 alternative configurations of HP compressor for the NEWAC engine were presented at the 2010 ASME Turbo Expo
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Gas turbine engines for aeronautical or industrial applications
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	www.pcaeng.co.uk

Rolls-Royce Deutschland

Result description Product(s) envisaged, functional description, main advantages, innovations	Tip injection showed to be a measure to significantly increase the low speed surge margin. Detailed descriptions can be found in paper 293 of the European Turbomachinery Conference 2011 in Istanbul.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Future gas turbine aero engines. NEWAC tip injection results will feed into further maturity development programmes towards TRL 6
Stage of development Laboratory prototype, demonstrator, industrial product …	TRL 5 (high speed rig test)
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	Partner in national and European funded research programmes
Collaborator details Type of partner sought and task to be performed	Universities, research organisations
Intellectual property rights granted or published	
Contact details	Henner.Schrapp@rolls-royce.com

Result description Product(s) envisaged, functional description, main advantages, innovations	Evaluation of Lean Direct Injection system for combustor applications (note : publications had been presented in some international congress)
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Future gas turbine aero engines. NEWAC LDI results will feed into further maturity development programmes towards TRL 6
Stage of development Laboratory prototype, demonstrator, industrial product …	TRL 4 (single sector high-pressure and optical combustor rig) TRL 5 (full-annular combustor rig) TRL 6 (core demonstrator within German national funded programme)
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	Partner in national and European funded research programmes
Collaborator details Type of partner sought and task to be performed	Universities, research organisations
Intellectual property rights granted or published	

Contact details	Sebastian.Bake@rolls-royce.com

SONATS

Result description Product(s) envisaged, functional description, main advantages, innovations	Results not disclosed (NDA)
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Strategy under construction
Stage of development Laboratory prototype, demonstrator, industrial product …	Advanced demonstrator and prototype used on lab equipments
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	European Technologies Company as our main support to develop our solution
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	Not disclosed for the moment
Contact details	Dr Olivier BRIERE – o.briere@sonats-et.com +33 (0) 2 40 52 99 35 www.sonats-et.com – www.groupe-et.com

Steigerwald Strahltechnik GmbH

Result description Product(s) envisaged, functional description, main advantages, innovations	Automatic beam alignment. The electron beam can be proved prior welding. The beam can be adjusted to best quality independent on the variety of human machine operators.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Part of electron beam welding machines
Stage of development Laboratory prototype, demonstrator, industrial product …	Hardware is ready. Software and applications are in development
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	Partners out of the aviation industry are welcome to investigate/cooperate with SST in the field of this invention
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	m.muecke@steigerwald-eb.de

Graz University of Technology

Result description Product(s) envisaged, functional description, main advantages, innovations	**Combustor test rig for elevated pressure and temperature conditions** Validation of the air feed lines of the test rig. Published in: * Leitgeb, T.; Giuliani, F.; Niederhammer, A.; Pirker, H.-P.: Computer Aided Dimensioning And Validation of A Versatile Test Facility For Combustion Chambers And Turbines. - in: ASME Turbo Expo ; 2009 * Leitgeb, T.; Giuliani, F.; Heitmeir, F.: Design and adaptation of a versatile test facility for turbines and combustion chambers. In Proceedings of the 8th European Turbomachinery Conference. 2009
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Franz.Heitmeir@tugraz.at

Result description Product(s) envisaged, functional description, main advantages, innovations	**Laser Vibrometry** Several publications on the development / adaptation of Laser Vibrometry to combustion: * Andreas Lang, Thomas Leitgeb, Jakob Woisetschl□ager, Alain Strzelecki, Pierre Gajan, and Fabrice Giuliani. Analysis of a Pulsed Flame at Intermediate Pressure. In Proceedings of the 13th International Symposium on Flow Visualisation and 12th French Congress on Visualization in Fluid Mechanics, 2008. * Fabrice Giuliani, Thomas Leitgeb, Andreas Lang, and Jakob Woisetschl□ager. Mapping the Density Fluctuations in a Pulsed Air-

	Methane Flame Using laser-Vibrometry. In Journal of Engineering for Gas Turbine and Power, 132
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Franz.Heitmeir@tugraz.at

Result description Product(s) envisaged, functional description, main advantages, innovations	**Design of an air flow modulator** Validation of the air flow modulator. Published in: * Fabrice Giuliani, Andreas Lang, Klaus Johannes Gradl, Peter Siebenhofer, Johannes Fritzer. Air Flow Modulation for Rened Control of the Combustion Dynamics Using a Novel Actuator. In Journal of Engineering for Gas Turbines and Power, accepted for publication
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details	

Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Franz.Heitmeir@tugraz.at

Result description Product(s) envisaged, functional description, main advantages, innovations	**Hybrid engine performance model** Validation of the performance model vs. the literature and description of the performance two hybrid engine concepts. Results published in: * Fabrice Giuliani, Andreas Lang, Mohammed Irannezhad, Tomas Grönstedt. Effects of a Controlled Phase-Shift on the Outlet Conditions of a Set of Pulse Detonators. In Proceedings of the 18th ISABE Conference, ISABE-2009-1315, 2009 * Fabrice Giuliani, Andreas Lang, Mohammad Irannezhad, Anders Lundbladh. Pulse Detonation as an Option for Future Innovative Gas Turbine Combustion Technologies: A Concept Assessment. In 27th International Congress of the Aeronautical Sciences, 2010
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Franz.Heitmeir@tugraz.at

Result description Product(s) envisaged, functional description, main advantages, innovations	**Phase shifting of pulsed detonation** Results on the introduction of a phase shift to pulsed detonation combustion. Published in: * Fabrice Giuliani, Andreas Lang, Mohammed Irannezhad, Tomas Grönstedt. Effects of a Controlled Phase-Shift on the Outlet Conditions of a Set of Pulse Detonators. In Proceedings of

	the 18th ISABE Conference, ISABE-2009-1315, 2009 * Fabrice Giuliani, Andreas Lang, Mohammad Irannezhad, Anders Lundbladh. Pulse Detonation as an Option for Future Innovative Gas Turbine Combustion Technologies: A Concept Assessment. In 27th International Congress of the Aeronautical Sciences, 2010
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Franz.Heitmeir@tugraz.at

Turbomeca

Result description Product(s) envisaged, functional description, main advantages, innovations	1/ 3D definition of the blade geometry applied to centrifugal compressors. It increases the centrifugal stage performances. 2/ Definition of Lean combustor technology. It decreases pollutant emissions, especially NOx emissions.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Turbo-shaft engines
Stage of development Laboratory prototype, demonstrator, industrial product …	1/ Compressor demonstrator tested on a compressor test bench. 2/ Full annular combustor test campaign on a combustion rig.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	emilie.basset@turbomeca.fr

University of Florence

Result description Product(s) envisaged, functional description, main advantages, innovations	Evaluation of advanced cooling applications for combustor liner applications (note : publications had been presented in some international congress and Scientific Journal) Heat Transfer phenomena in advanced high cooled components – combustor liner -(note: publications had been presented in some international congress and Scientific Journal and some others will be planned)
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	None
Stage of development Laboratory prototype, demonstrator, industrial product …	None
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	Consultancy for further developments of advanced cooling systems. Contribution for advanced experimental studies and CFD simulations applied to heat transfer analysis for future research programs.
Collaborator details Type of partner sought and task to be performed	Industrial partner
Intellectual property rights granted or published	None
Contact details	bruno.facchini@unifi.it

Karlsruhe Institute of Technology

Result description Product(s) envisaged, functional description, main advantages, innovations	Lean blow out and stability mechanism of PERM especially the influence of outer and inner recirculation zone. (Published in ASME GT2010) Spray characteristics of PERM (Published in SPEIC 2010) Influence of PVC on spray characteristic for PERM (In review for ASME GT2011)
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Nikos.Zarzalis@kit.edu

University of Stuttgart

Result description Product(s) envisaged, functional description, main advantages, innovations	NEWAC TERA 2020 models including analysis, assessments and multi-disciplinary optimization studies.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	Günter Kappler, Universität Stuttgart kappler@ila.uni-stuttgart.de

Technical University of Belfort-Montbéliard

Result description Product(s) envisaged, functional description, main advantages, innovations	Numerical process resulting in estimates for the thermal and mechanical properties of any heterogeneous coating or material, based on micrographs.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Design of novel materials and coatings.
Stage of development Laboratory prototype, demonstrator, industrial product …	Software package currently used in research works at UTBM.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	Consultancy and training can be offered.
Collaborator details Type of partner sought and task to be performed	Any academic or industrial partner involved in material development.
Intellectual property rights granted or published	
Contact details	rodolphe.bolot@utbm.fr

Meggitt Sensing Systems (Vibro-Meter)

Result description Product(s) envisaged, functional description, main advantages, innovations	Ability to measure individual compressor blade tip clearance of the non-shrouded compressor or turbine blades. Design of microwave tip clearance probe as a Line Replaceable Unit. - Evaluation of the complete microwave tip clearance measurement system.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Active Clearance Control of compressor or turbine in all kind of aerospace engines or industrial gas turbines
Stage of development Laboratory prototype, demonstrator, industrial product …	Product ready to be industrialized.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	Industrial partner.
Intellectual property rights granted or published	
Contact details	Pavol.Rybarik@ch.meggitt.com

Result description Product(s) envisaged, functional description, main advantages, innovations	Ability to measure fast low pressure fluctuations on the high static pressure background and to withstand the harsh engine environment. The pressure sensitivity of the sensor was increased by using a new piezoelectric material. The sensitivity to vibration of the pressure transducer was decreased in the sensitive axis as well as in the cross axis so that the influence of the vibration on the output signal is minimized. Therefore the sensor can be installed on structures having high vibration levels without having a vibration generated signal component in the output signal. The main characteristics of the sensor are: Pressure sensitivity: - 100 pC/kPa (transducer alone) - 200 mV/kPa (transducer with electronics) Sensitivity to vibration: - 2.5 Pa/g (axial)

	- 4.0 Pa/g (radial)
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Pressure monitoring in all kind of aerospace engines or industrial gas turbines
Stage of development Laboratory prototype, demonstrator, industrial product …	Product ready to be industrialized.
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	Industrial partner.
Intellectual property rights granted or published	
Contact details	Pavol.Rybarik@ch.meggitt.com

Wytwonia Sprzetu Komunikacyjnego

Result description Product(s) envisaged, functional description, main advantages, innovations	1.γ-TiAl Conventional Machining Methods – Tool wear and cutting force when rough and finish milling - (note: PhD thesis. Some publications will be presented in some international congress and Scientific Journal) 2. γ-TiAl rough and finish (milling machining influent on surface layer - hardness measurement, microstructure “white layer” and surface roughness. 3. γ-TiAl rough and finish milling, selection of cutting tools and technology process optimization of jet engine blade machining.
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	Consultancy for further developments of γ-TiAl Conventional Machining Methods
Collaborator details Type of partner sought and task to be performed	Industrial partner
Intellectual property rights granted or published	
Contact details	Robert.Haligowski@wskrz.com

Direction Generale de l'Armement - DGA

Result description Product(s) envisaged, functional description, main advantages, innovations	Evaluation of advanced gas analysis probes for high temperature / pressure combustion test applications (note : a publication has been presented at Turbo expo 2011 - Vancouver)
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	Combustion testing
Stage of development Laboratory prototype, demonstrator	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	Consultancy for further developments of gas analysis probes for high pressure/temperature combustion tests.
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	franky.le-mez@dga.defense.gouv.fr

ENGINSOFT

Result description Product(s) envisaged, functional description, main advantages, innovations	CFD Aerodynamic study of the innovative PERM injection system and MOGA optimization of the air distribution layout for the AVIO combustor in the frame of the NEWAC project. ASME IGTI expo 2008. CFD Aerodynamic and reactive study of the innovative PERM injection system for the AVIO combustor in the frame of the NEWAC. XXVII UIT Congress 2009 CFD Aerodynamic and reactive study of an innovative lean combustion system in the frame of the NEWAC project. ASME IGTI 2010 - GT 2010-22465
Possible market applications Sectors, type of use … **or How they might be used in further research** Including expected timings	
Stage of development Laboratory prototype, demonstrator, industrial product …	
Collaboration sought or offered Manufacturing agreement, financial support or investment, information exchange, training, consultancy, other	
Collaborator details Type of partner sought and task to be performed	
Intellectual property rights granted or published	
Contact details	l.bucchieri@enginsoft.it

1.13 List of publications

Author	Partner	Publication title	Conference
F. Giuliani *et al.*	TUG	Using Dual Laser Vibrometry to monitor the stability of gas turbine combustion	ECM 2007
F. Giuliani *et al.*	TUG	TIME-RESOLVED ANALYSIS OF DENSITY FLUCTUATIONS IN A RESONANT AIR-METHANE FLAME USING DUAL LASER VIBROMETRY FOR GAS TURBINE COMBUSTOR QUALIFICATION TESTS	ISABE 2007
A. Andreini *et al.*	DEF	COMBUSTOR LINER TEMPERATURE PREDICTION: A PRELIMINARY TOOL DEVELOPMENT AND ITS APPLICATION ON EFFUSION COOLING SYSTEMS	CEAS 2007
S. Bock *et al.*	MTU	ACTIVE CORE TECHNOLOGY WITHIN THE NEWAC RESEARCH PROGRAM FOR CLEANER AND MORE EFFICIENT AERO ENGINES	CEAS 2007
JL. Seichepine *et al.*	UTBM	Measurements and Numerical Simulation of Thermal and Mechanical Properties of AlSi-Polyester Abradable Coatings	EUROMAT 2007
A.Sachdeva *et al.*	SN	CONTROL OF HUB CORNER SEPARATION ON A STATOR BLADE ROW WITH BOUNDARY LAYER ASPIRATION	AAAF 2008
A. Touyeras	SN	Flow Controlled Core Concept for HP Compressors	AAAF 2008
R. Bolot *et al.*	UTBM	Thermal Conductivity of AlSi/Polyester Abradable Coatings	ITSC 2008
JL. Seichepine *et al.*	UTBM	Mechanical modeling of highly heterogeneous thermally sprayed abradable coatings	ITSC 2008
V. Iliopoulou *et al.*	CENAERO	DESIGN OPTIMIZATION OF A HP COMPRESSOR BLADE AND ITS HUB ENDWALL	ASME 2008
L. Bucchieri *et al.*	ENGINSOFT	CFD aerodynamic study of the innovative PERM injection system and MOGA optimisation of air distribution layout for the AVIO Combustor in the frame of the NEWAC Project	ASME 2008
F. Giuliani *et al.*	TUG	Phase-defined density fluctuation maps of a resonant air-methane premixed flame using laser vibrometry	International Combustion Symposium 2008
A. Lang *et al.*	TUG	ANALYSIS OF A PULSED FLAME AT INTERMEDIATE PRESSURE	International Symposium for Flow Visualization 2008

Author	Partner	Publication title	Conference
S. Bock *et al.*	MTU	"ACTIVE CORE" – A KEY TECHNOLOGY FOR MORE ENVIRONMENTALLY FRIENDLY AERO ENGINES BEING INVESTIGATED UNDER THE NEWAC PROGRAM	ICAS - Sept 2008
S. Colantuoni *et al.*	SP6	Low emissions combustors development for new aero-engines core applications	ECCOMAS - June 2008
L. Bucchieri *et al.*	ENGINSOFT	Studio aerodinamico CFD dell'innovativo sistema di iniezione PERM e ottimizzazione dello schema di distribuzione aria per il combustore AVIO nell'ambito del Progetto Europeo NEWAC	Italian scientific review Analisi & Calcolo
V. Iliopoulou *et al.*	CENAERO	Non Axisymmetric Endwall Optimization Applied to a High Pressure Compressor Rotor Blade	AIAA ISSMO - Sept 2008
V. Iliopoulou *et al.*	CENAERO	MULTI-POINT NON AXISYMMETRIC HUB DESIGN OPTIMIZATION FOR A HIGH PRESSURE COMPRESSOR ROTOR BLADE	ETC - March 2009
E. Colombo *et al.*	EPFL - ECL	EXPERIMENTAL INVESTIGATIONS ON ACTIVE FLOW CONTROL BY ASPIRATION SLOTS ON THE HUB OF AN AXIAL COMPRESSOR ROTOR GEOMETRY IN A NON ROTATING ANNULAR CASCADE	ETC - March 2009
AD. Walker	LOUGH	Duct Aerodynamics Duct Aerodynamics for Low Emission, Intercooled Aero Gas Turbines	Set for Britain - March 2009
F. Giuliani *et al.*	TUG	Mapping the density fluctuations in a pulsed air-methane flame using laser-vibrometry	Journal of Engineering for Gas Turbines and Power
P. Di Martino *et al.*	AVIO	Reactive CFD analysis in a complete combustor module for aero engines application	Combustion Colloquia - April 2009
K. Yakinthos *et al.*	AUTH, MTU	DERIVATION OF AN ANISOTROPIC MODEL FOR THE PRESSURE-LOSS THROUGH A HEAT EXCHANGER FOR AERO ENGINE APPLICATIONS	ASME - June 2009
F. Giuliani *et al.*	TUG	MAPPING THE DENSITY FLUCTUATIONS IN A PULSED AIR-METHANE FLAME USING LASER-VIBROMETRY	ASME - June 2009
A. Ceccherini *et al.*	DEF	COMBINED EFFECT OF SLOT INJECTION, EFFUSION ARRAY AND DILUTION HOLE ON THE COOLING PERFORMANCE OF A REAL COMBUSTOR LINER	ASME - June 2009
SJ. Hiller *et al.*	MTU	STABILITY ENHANCEMENT OF A MULTISTAGE COMPRESSOR BY AIR INJECTION	ASME - June 2009

Author	Partner	Publication title	Conference
AD. Walker *et al.*	LOUGH	DUCT AERODYNAMICS FOR INTERCOOLED AERO GAS TURBINES: CONSTRAINTS, CONCEPTS AND DESIGN METHODOLOGY	ASME - June 2009
T. Leitgeb *et al.*	TUG	COMPUTER AIDED DIMENSIONING AND VALIDATION OF A VERSATILE TEST FACILITY FOR COMBUSTION CHAMBERS AND TURBINES	ASME - June 2009
A. Frassoldati *et al.*	AVIO	Fluid Dynamics and Detailed Kinetic Modeling of Pollutant Emissions from Lean Combustion Systems	6th Mediterranean Comb. Symp. - June 2009
D. Missirlis *et al.*	AUTH	Heat and Fluid Flow investigations on a heat exchanger for aero engine applications	ISABE - Sept 2009
A. Rolt *et al.*	RRUK	Intercooled Turbofan Engine Design and Technology Research in the EU Framework 6 NEWAC Programme	ISABE - Sept 2009
D. Missirlis *et al.*	AUTH-MTU	Numerical development of a heat transfer and pressure drop porosity model for a heat exchanger for aero engine applications	Applied Thermal Engineering
A.Marini et al.	ENGINSOFT-AVIO	CFD aerodynamic and reactive study of the innovative PERM injection system for the AVIO combustor in the frame of the NEWAC Project	XXVII UIT CONGRESS - June 2009
F. Giuliani *et al.*	TUG	EFFECTS OF A CONTROLLED PHASE-SHIFT ON THE OUTLET CONDITIONS OF A SET OF PULSE DETONATORS	ISABE - Sept 2009
X. Lei *et al.*	CHALMERS	A CONTRA-ROTATING VARIABLE CYCLE TURBOFAN ENGINE	ISABE - Sept 2009
A. Lundbladh *et al.*	VAC-MTU-TUG-CHALMERS	Future Innovative Cores for Commercial Engines	ISABE - Sept 2009
K. Kyprianidis *et al.*	CU-CHALMERS	Low Pressure System Component Advancements and ist Impact on Future Turbofan Engine Emissions	ISABE - Sept 2009
M. Babak	PBS	Effective computational procedure for high pressure ratio centrifugal compressor	ANSYS - Sept 2009
T. Grönstedt	CHALMERS	Design and Analysis of an Intercooled Turbofan Engine	Journal of Engineering for Gas Turbines and Power - Sept 2009
D. Missirlis *et al.*	AUTH	MODELING AN INSTALLATION OF RECUPERATIVE HEAT EXCHANGERS FOR AN AERO ENGINE	ASME - June 2010

Author	Partner	Publication title	Conference
WJ Calvert *et al.*	PCA	Comparative Studies of Alternative HPC Configurations for the NEWAC IRA Engine	ASME - June 2010
A. Alexiou *et al.*	NTUA	SHORT AND LONG RANGE MISSION ANALYSIS FOR A GEARED TURBOFAN WITH ACTIVE CORE TECHNOLOGIES	ASME - June 2010
S. Marinov *et al.*	UNIKA	ON SWIRL STABILIZED FLAME CHARACTERISTICS NEAR THE WEAK EXTINCTION LIMIT	ASME - June 2010
A. Marini *et al.*	ENGINSOFT	CFD AERODYNAMIC AND REACTIVE STUDY OF AN INNOVATIVE LEAN COMBUSTION SYSTEM IN THE FRAME OF THE NEWAC PROJECT	ASME - June 2010
K. Kyprianidis *et al.*	CU	Assessment of future aero engine designs with intercooled and intercooled recuperated cores	ASME - June 2010
A. Andreini *et al.*	DEF	NUMERICAL STUDY OF AERODYNAMIC LOSSES OF EFFUSION COOLING HOLES IN AERO-ENGINE COMBUSTOR LINERS	ASME - June 2010
B. Facchini *et al.*	DEF	COMBINED EFFECT OF SLOT INJECTION, EFFUSION ARRAY AND DILUTION HOLE ON THE HEAT TRANSFER COEFFICIENT OF A REAL COMBUSTOR LINER - PART 1 EXPERIMENTAL ANALYSIS	ASME - June 2010
A. Andreini *et al.*	DEF	COMBINED EFFECT OF SLOT INJECTION, EFFUSION ARRAY AND DILUTION HOLE ON THE HEAT TRANSFER COEFFICIENT OF A REAL COMBUSTOR LINER PART 2: NUMERICAL ANALYSIS	ASME - June 2010
R. Bolot *et al.*	UTBM	Predicting the thermal conductivity of AlSi/polyester abradable coatings: effects of the numerical method	ITSC June 2010
K. Yakinthos *et al.*	AUTH-MTU	MODELING THE OPERATION OF A HEAT EXCHANGER FOR AERO ENGINE APPLICATIONS FOR REAL ENGINE OPERATING CONDITIONS	ETMM8 June 2010
K. Kyprianidis *et al.*	CU	Assessment of Future Aero Engine Designs with Intercooled and Intercooled Recuperated Cores	ASME Journal April 2010
D. Missirlis *et al.*	AUTH-MTU	FLOW FIELD AND HEAT TRANSFER INVESTIGATIONS IN THE EXHAUST NOZZLE OF A RECUPERATIVE AERO ENGINE	IGTC Oct 2010
A. Rolt *et al.*	RRUK-CU	ASSESSMENT OF NEW AEROENGINE CORE CONCEPTS AND TECHNOLOGIES IN THE EU FRAMEWORK 6 NEWAC PROGRAMME	ICAS Sept 2010
S. Marinov *et al.*	UNIKA-AVIO	Spray Characteristic Investigation of a Kerosene Fuelled Swirl Flame	SPEIC10 June 2010

Author	Partner	Publication title	Conference
A. Frassoldati *et al.*	AVIO-UNIKA-ONERA	FLUID DYNAMICS AND DETAILED KINETIC MODELING OF POLLUTANT EMISSIONS FROM LEAN COMBUSTION SYSTEMS EMISSIONS FROM LEAN COMBUSTION SYSTEMS	ASME June2010
M. Orain *et al.*	ONERA-TM	Measurements of fuel distribution and flame structure in kerosene-fuelled combustors using planar laser-induced fluorescence and OH* emissions	ILASS Sept 2010
K. Kyprianidis *et al.*	CU-RRUK-CHALMERS	Aero Engine Conceptual Design - Part I: Multi-Disciplinary Framework Development	AiAA Journal of Propulsion and Power August 2010
K. Yakinthos *et al.*	AUTH-MTU	Modelling the operation of a system of recuperative heat exchangers for an aero engine with the combined use of a porosity and a thermo mechanical model	Journal of Applied Thermal Engineering August 2010
F. Giuliani *et al.*	TUG-CHA-VAC	PULSE DETONATION AS AN OPTION FOR FUTURE INNOVATIVE GAS TURBINE COMBUSTION TECHNOLOGIES: A CONCEPT ASSESSMENT	ICAS2010 Sept 2010
E. Colombo *et al.*	EPFL-ONERA	INFLUENCE OF BLADE ASPIRATION ON THE FLOW QUALITY OF AN ANNULAR AXIAL COMPRESSOR CASCADE	Europen Turbomachinery Conference March 2011
H. Schrapp *et al.*	RRD	TIP BLOWING FOR STABILITY ENHANCEMENT OF A FIXED GEOMETRY HIGH SPEED COMPRESSOR	European Turbomachinery Conference March 2011
V. Plana *et al.*	DGA (CEPr)	DESIGN OF A HIGH TEMPERATURE WATER COOLED PROBE FOR GAS ANALYSIS MEASUREMENT ON K11 COMBUSTION TEST RIG	ASME June 2011
R. Matzgeller *et al*.	MTU-DLR	INVESTIGATION OF UNSTEADY COMPRESSOR FLOW STRUCTURE WITH TIP INJECTION USING PARTICLE IMAGE VELOCIMETRY	ASME June 2011
C A'Barrow *et al.*	LOUGH-RRUK	AERODYNAMIC PERFORMANCE OF A COOLANT FLOW OFF-TAKE DOWNSTREAM OF AN OGV	ASME June 2011
S. Weichert *et al.*	UCAM-DENG	NEW SELF-REGULATING CASING TREATMENT FOR STABILITY ENHANCEMENT	ASME June 2011
PW Kwan *et al.*	UOXF-RRUK	MINIMISING LOSS IN A HEAT EXCHANGER INSTALLATION FOR AN INTERCOOLED TURBOFAN ENGINE	ASME June 2011
T. Kroeckel *et al.*	RWTH-MTU	APPLICATION OF A MULTISTAGE CASING TREATMENT IN A HIGH SPEED AXIAL COMPRESSOR TEST RIG	ASME June 2011
W. Sturm	MTU	COUNTERING THE ENVIRONMENTAL PENALTIES OF A GROWING AIR TRAFFIC BY MEANS OF ACTIVE CORE TECHNOLOGIES	ISABE Sept 2011
X. Lei *et al.*	CHALMERS	ANALYSIS OF AN INTERCOOLER RECUPERATED AERO-ENGINE	ISABE Sept 2011
F. Giuliani *et al.*	TUG	AIR FLOW MODULATION FOR REFINED CONTROL OF THE COMBUSTION DYNAMICS USING A NOVEL ACTUATOR	ASME June 2011

Author	Partner	Publication title	Conference
AD Walker *et al.*	LOUGH-RRUK	Aerodynamic Design of the Cooling Flow Duct System for an Intercooled Aero Engine	ISABE Sept 2011
AD Walker *et al.*	LOUGH-RRUK	Aerodynamic Design of the Core Duct System for an Intercooled Aero Engine	ISABE Sept 2011
M. Kern *et al.*	MTU-USTUTT	EFFECTS OF TIP INJECTION ON THE PERFORMANCE OF A MULTI-STAGE HIGH-PRESSURE COMPRESSOR	DLRK Sept 2011
M. Kern *et al.*	MTU-USTUTT	PROOF OF CONCEPT OF A MECHANICAL ACTIVE CLEARANCE CONTROL SYSTEM	ISABE Sept 2011
U. Meier *et al.*	DLR-RRD	Characterisation of the Combustion Performance of Low Emission Fuel Injectors with Laser Measurements	DLRK Sept 2011
B. Facchini *et al.*	DEF-AVIO	EXPERIMENTAL INVESTIGATION ON THE EFFECTS OF A LARGE RECIRCULATING AREA ON THE PERFORMANCE OF AN EFFUSION COOLED COMBUSTOR LINER	ASME June 2011
T. Kroeckel *et al.*	RWTH-MTU	Experimental investigation of advanced multistage casing treatments in a 2.5 stage high pressure compressor test rig	ISABE Sept 2011
P. Sellers *et al.*	RRUK-CU-AVIO	AERO-ENGINE VOLCANIC ASH RELATED RESEARCH: AN OVERVIEW OF WORK CARRIED OUT IN THE NEWAC WORK PACKAGE 1.4	ISABE Sept 2011
S. Freitag *et al.*	DLR-RRD	Study of an Airblast Atomizer Spray in a Lean Burn Aero-Engine Model Combustor at Engine Conditions	ILASS Sept 2011
T.J. Uihlein *et al.*	MTU	COMPARATIVE MEASUREMENTS TO DETERMINE THE EFFECTS OF VOLCANIC ASH AND SAND ON COMPRESSOR MATERIALS	DLRK Sept 2011
G. Radkowski et al.	WSK	WSK „PZL-Rzeszów” S.A. experience in processing of γ-TiAl	V.Conference on Science at Industry Sept 2011
F. Giuliani *et al.*	TUG	Air Flow Modulation for Refined Control of the Combustion Dynamics Using a Novel Actuator	Journal of Engineering for Gas Turbines and Power - Sept 2011