## Contents

- Future Requirements and EU Technology Projects
- Technical Approach
- NEWAC Program
- Subprograms
  - Whole Engine Integration
  - Intercooled Recuperated Core
  - Intercooled Core
  - Active Core
  - Flow Controlled Core
  - Innovative Combustor
Future Requirements and EU Technology Projects
VISION 2020 Targets
ACARE (Advisory Council of Aeronautical Research in Europe)

**Safety & Security**
- Reduce accident rate by 80%
- Zero successful hijack

**Quality & Affordability**
- Halve time to market
- Fall in travel charges

**Air Transport System Efficiency**
- On time arrival/departure 99% within 15 minutes
- Increase movements of aircraft x3

**Environment**
- Reduce CO₂ by 50%
- Reduce NOₓ by 80%
- Reduce perceived noise by half

**Engine Contribution**
- Reduce specific fuel consumption by 20%
- Reduce NOₓ by 60 to 80%
- Reduce noise by 10 dB per operation
- Reduce accident rate by x5
- Reduce operational costs
- Half time to market

Reference: year 2000 in service engine
CO₂ improvements - ACARE objectives versus EU technology projects

Reference: 3rd generation aero engine BPR=5-8 (V2500, CFM56, Trent700)

- 16 %
- 11 %

EEFAE
ANTLE-DDTF
CLEAN-GTF

Innovative Low Spool Technology

TRL 4 - 6

- 7 %

VITAL
DDTF
GTF
CRTF

Innovative Core Technology

- 6 %

NEWAC
IC, AC, FCC, IRA

ACARE 2020 target: - 20%

CO₂ reduction

TRL Technology Readiness Level
1 basic principles observed and reported
2 technology concept formulated
3 critical function proof-of-concept
4 component validation in laboratory environment
5 component validation in relevant environment
6 system/subsystem prototype demonstration in relevant environment
7 system prototype demonstration in real environment
8 flight/production qualified
9 flight/application proven
NO\textsubscript{x} Reduction – Status / ICAO Limits / ICAO Objectives

ICAO: International Civil Aviation Organisation

CAEP: Committee on Aviation Environmental Protection

CAEP/3: all engines (from 2007)

CAEP/4: new engines (from 2003)

CAEP/6: certification date aft 2008
Technical Approach
Thermal Efficiency for Different Engine Cycles

![Diagram showing thermal efficiency for different engine cycles. The graph plots overall pressure ratio on the x-axis and thermal efficiency on the y-axis. The different engine cycles are compared: Conventional, Intercooled, Recuperated, and Active-/Flow Controlled.]

This document and the information contained are property of the NEWAC consortium and shall not be copied or disclosed to any third party without prior written authorization.
NEWAC Key Technologies for New Engine Cycles

- **Ducting**
  - Low pressure loss ducts
  - Advanced IPC outlet guide vane/diffuser

- **Intercooler**
  - Cross-corrogated plate heat exchanger

- **Engine Integration**

- **Radial compressor**
  - Innovative radial compressor suitable for IRA integration

- **Combustor**
  - Injection systems for lean combustion

- **Recuperator**
  - Heat exchanger arrangement and nozzle geometry concept

- **SP3 RR**
- **SP2 MTU**
- **SP2 TM**
- **SP6 Avio, RR, TM**
NEWAC Key Technologies for Compressors

- Tip Injection
- Casing Treatment
- Stall Active Control from bleed valve
- Casing Treatment
- Active Clearance Control

- Non axi-symmetric endwalls
- Aspiration on blade profiles and endwalls
- Rub management
- Passive Clearance Control
NEWAC Project Structure

SP 0
NEWAC Coordination and Technical Management
MTU

SP 2
Intercooled Recuperative Core
MTU
IRA core
- Recuperator
- Centrifugal HPC
- Future innovative core configurations

SP 3
Intercooled Core
RRUK
Intercooler and ducting
HPC technologies for intercooled core operability needs

SP 4
Active Core
MTU
Active cooling air cooling
Smart HPC technologies

SP 5
Flow Controlled Core
SM
HPC flow control technologies for highest aerodynamic loading

SP 6
Innovative Combustor
AVIO
Lean direct injection
Partial evaporat. & rapid mixing injection
Lean premixed pre-vaporised injection

SP 1
Whole Engine Integration
RRUK
Project Set-up

40 Partners from
Aero Engine Industry
Small & Medium Enterprises
Research Establishments
Universities

Duration: May 2006 – April 2010 (4 years)
NEWAC Consortium

Target:
6 % CO₂ Reduction
16% NOₓ Reduction

Coordinator:
MTU Aero Engines

40 Partners:
(Engine Manufacturers, Air Frame manufacturers, Universities, Research centres and SME’s)

Project duration:
May 2006 – April 2010

Total budget: 71 M€

EC contribution: 40 M€
NEWAC Project Structure

<table>
<thead>
<tr>
<th>SP1</th>
<th>SP2</th>
<th>SP3</th>
<th>SP4</th>
<th>SP5</th>
<th>SP6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Engine Integration</td>
<td>Intercooled Recuperative Core</td>
<td>Intercooled Core</td>
<td>Active Core</td>
<td>Flow Controlled Core</td>
<td>Innovative Combustor</td>
</tr>
<tr>
<td>RRUK</td>
<td>RRUK</td>
<td>RRUK</td>
<td>MTU</td>
<td>SN</td>
<td>AVIO</td>
</tr>
<tr>
<td>WP1.1</td>
<td>WP2.1</td>
<td>WP3.1</td>
<td>WP4.1</td>
<td>WP5.1</td>
<td>WP6.1</td>
</tr>
<tr>
<td>SN</td>
<td>MTU</td>
<td>RRUK</td>
<td>MTU</td>
<td>SN</td>
<td>AVIO</td>
</tr>
<tr>
<td>WP1.2</td>
<td>WP2.2</td>
<td>WP3.2</td>
<td>WP4.2</td>
<td>WP4.3</td>
<td>WP4.2</td>
</tr>
<tr>
<td>Concept Integration &amp; Optimisation</td>
<td>IRA Components</td>
<td>Whole Engine Integration of Intercooled Concept</td>
<td>Active Cooling Air Cooling &amp; advanced aero</td>
<td>Aspiration concept on blade profiles</td>
<td>Tip flow control &amp; advanced aero</td>
</tr>
<tr>
<td>MTU</td>
<td>MTU</td>
<td>VAC</td>
<td>VAC</td>
<td>SN</td>
<td>SN</td>
</tr>
<tr>
<td>WP1.3</td>
<td>WP2.3</td>
<td>WP3.3</td>
<td>WP4.3</td>
<td>WP5.3</td>
<td>WP5.2</td>
</tr>
<tr>
<td>TERA</td>
<td>Future Innovative Core Configurations</td>
<td>Intercooler Aerothermal Systems</td>
<td>Smart HPC Technologies</td>
<td>Validation test campaign</td>
<td>Tip flow control &amp; advanced aero</td>
</tr>
<tr>
<td>CU</td>
<td>VAC</td>
<td>RRUK</td>
<td>MTU</td>
<td>MTU</td>
<td>SN</td>
</tr>
<tr>
<td>WP1.4</td>
<td>WP3.4</td>
<td>WP3.5</td>
<td>WP4.4</td>
<td>WP5.5</td>
<td>WP5.4</td>
</tr>
<tr>
<td>Improved Blading &amp; Gaspath Design</td>
<td>Stability Enhancement for Intercooled Core</td>
<td>Blade/casing rub management for tight tip clearance</td>
<td>Flow stability control integration</td>
<td>Flow stability control integration</td>
<td></td>
</tr>
<tr>
<td>RRUK</td>
<td>RRD</td>
<td>TA</td>
<td>MTU</td>
<td>SN</td>
<td>SN</td>
</tr>
<tr>
<td>WP1.5</td>
<td>WP3.6</td>
<td>WP3.7</td>
<td>WP5.5</td>
<td>WP5.6</td>
<td></td>
</tr>
<tr>
<td>Technology Validation Rig Manufacture</td>
<td>Technology Validation Rig Test</td>
<td>Technology Validation Rig Test</td>
<td>Compressor rig test validation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RRUK</td>
<td>RRD</td>
<td>RRD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP1.6</td>
<td>WP3.8</td>
<td>WP3.9</td>
<td>WP5.7</td>
<td>WP5.8</td>
<td></td>
</tr>
<tr>
<td>Concept Integration &amp; Optimisation</td>
<td>Technology Validation Rig Test</td>
<td>Technology Validation Rig Test</td>
<td>Compressor rig test validation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTU</td>
<td>RRUK</td>
<td>MTU</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Expected Results**

**NEWAC subprojects Exploitable Outcomes**
- SP2: Intercooled recuperative core
- SP3: Intercooled core
- SP4: Active core
- SP5: Flow controlled core
- SP6: Innovative combustor

**NEWAC innovative core configurations**
- IRA + LPP combustor: -2% CO₂, -10% NOₓ
- Intercooled core + LDI combustor: -4% CO₂, -16% NOₓ
- Active core + PERM combustor: -4% CO₂, -12% NOₓ
- Flow controlled core + LDI combustor: -3% CO₂, -12% NOₓ

**Global engine significance**
- IRA + LPP combustor: -2% CO₂, -10% NOₓ
- Innovative core configuration: -6% CO₂, -16% NOₓ

**ACARE targets achievable with other results**
- CO₂: ✔
- NOx: exceed target
- CO₂: ✔
- NOx: close to target
Subprogram
Whole Engine Integration

NEWAC
new aero engine core concepts
SP1 Whole Engine Integration - Introduction

- Ensure overall consistency of NEWAC results and assess the NEWAC engine technologies to prepare the roadmap towards the ACARE objectives at technical and economic levels

- Define and provide detailed requirements and objectives for NEWAC SP2 - SP6

- Compare, assess and rank the benefits of the advanced concepts

- Combine and integrate NEWAC technologies with those developed in VITAL to optimise the environmental performance of aero-engines

- Adapt and develop a previously created software tool (TERA) to compare the environmental and economic impact of various engines and use it for advisory purposes
SP1 Whole Engine Integration - Technical Approach

2 Aircraft Configurations

Short Range

Long Range

4 Engine Configurations
### TERA - Technoeconomic and Environmental Risk Assessment

- NEWAC will build a socio-economic model that will start from a software tool developed within the VITAL program to conceive and assess engines with minimum global warming and lowest cost of ownership. Issues considered will include performance, weight, NOₓ, CO₂, noise, fuel cost, maintenance cost and installation weight, flight path and altitude.

- The ability of the four NEWAC configurations to meet the ACARE 2020 objectives will be assessed. Further advanced configurations will be studied by combining technology elements from the NEWAC and VITAL program.
Subprogram
Intercooled Recuperative
Aero Engine
SP2 Intercooled Recuperative Core - Introduction

- Further development of core components for the IRA engine with aim of SFC and weight reduction:
  - Concept and integration studies
  - Optimisation of recuperator arrangement
  - Design of a radial compressor

- For targets beyond 2020, SP2 will initiate studies on even more innovative core concepts:
  - Variable core cycle
  - Highly innovative combustion
  - Contra rotating core
  - Unconventional heat management
Intercooled Recuperative Aero Engine
SP2 Intercooled Recuperative Core - Objectives

High level objectives

- Further develop IRA core components resulting in
  - 2% SFC reduction in addition to 16% SFC reduction achieved from CLEAN IRA
  - 1% propulsion system weight reduction

- Initiate system level studies on even more innovative core concepts with respect to further challenging targets compared to ACARE 2020 objectives

Technical objectives

- to optimise and improve IRA engine cycle and configuration
- to study integration issues and structural aspects
- to improve internal losses compared to EEFAE CLEAN results
  - to improve heat transfer by changing HEX configuration and HEX arrangement
  - to improve radial HPC efficiency by 0.8% at 10% lower radial HPC weight
SP2 Intercooled Recuperative Core - Technical Approach

Radial HP Compressor
- Radial compressor efficiency improvement and high hub-tip-ratio
- Optimisation of radial compressor/ducting interface
- Radial/axial compressor comparison

Recuperator
- Improved heat exchanger and nozzle arrangement
- Low loss heat exchanger integration
- Structural and overall IRA integration aspects

Future innovative core configuration
- Variable core cycle
- Innovative combustion
- Contra-rotating core
- Unconventional heat management
Future Innovative Core Configurations

Variable core cycle
e.g. variable HPT capacity by the use of statorless turbine

Innovative combustion
e.g. Pulse detonation / wave-rotor engine cycle

Contra-rotating core

Unconventional heat management
Demand fuel system
Subprogram
Intercooled Core
SP3 Intercooled Core - Introduction

One way to achieve the improvements required by the ACARE 2020 objectives is to utilise a high overall pressure ratio, intercooled cycle. This can be applied in two ways:

- For a given turbine entry temperature, overall pressure ratio and combustor technology, NO$_X$ will be reduced due to the lower combustor entry and flame temperatures.
- For a given NO$_X$ level and material technology, the cycle overall pressure ratio can be increased leading to CO$_2$ reduction.
SP3 Intercooled Core - Objectives

- To validate duct and heat exchanger technologies that allow the utilisation of an intercooled configuration to realize a 2.0% SFC improvement and a 15% NO\textsubscript{X} reduction for an engine with an increased overall pressure ratio.
  - The SFC and NO\textsubscript{X} benefits can be optimized with respect to engine size.
  - The intercooled cycle will also enable a 0.5% SFC benefit through a reduction in turbine cooling air mass flow (reduced cooling air temperature).

- To improve HPC efficiency and hence improve SFC by 1.5%, relative to EEFAE ANTLE design, through the use of advanced design and novel systems.
  - These benefits will be applicable to both conventional and intercooled cycle engines.

- The total benefit that could be achieved just through the intercooled cycle and compressor technologies is 4% SFC and 16% NO\textsubscript{X} reduction for an engine with increased OPR.
SP3 Intercooled Core - Technical Approach

**Intercooler and related ducting**
- Design and test advanced cross-corrugated plate heat exchanger
- Design and validation of low pressure loss ducts
- Advanced OGV/diffuser

**Improved HPC (higher overall pressure ratio)**
- Stability enhancement for intercooled core operability needs
- Improved blading and secondary flow path
- Improved tip clearance design
SP3 Intercooled Core

Preliminary Intercooled Engine Layout

Ducting System

Cross-Corrugated Heat Exchanger Matrix

Cold side
Hot side
SP3 Stability Enhancement for Intercooled Core

Rotor 1 with tip blowing for significant surge margin increase
SP4 Active Core - Introduction

- Active systems open up a new area of technological opportunities, they offer
  - the possibility to adapt the core engine to each operating condition of the mission
    and, therefore, the potential to optimise component and cycle behaviour,
  - additional degrees of freedom in the design, as the core does not need not to be
    designed on a worst case basis,
  - compensation of efficiency and safety penalties due to deterioration to a certain
    degree by adjusting the core to the actual conditions.

- In SP4 the most promising active systems for core engine applications will be
  investigated and compared with passive alternatives:
  - active cooling air cooling system for reduced cooling air consumption,
  - active or semi-active clearance control system for HPC rear stages,
  - active or passive surge control system for HPC front stages.

- The candidates with the highest overall potential will be developed and validated.
SP4 Active Core - Objectives

The overall target of SP4 is to develop and validate a system of active or semi-active core engine technologies which reduce the SFC by 4% due to increased core component efficiencies, core cycle improvements and related overall engine effects.

• Highly advanced active cooling air cooling system, which aims at a reduction of the high pressure turbine cooling air consumption and an increase of the HPT efficiency.
  ➔ SFC reduction: 1,5%

• Active or semi-active clearance control system for compressor rear stages and an active or passive surge control system for the compressor front stages, with the objective of higher efficiency and improved aerodynamic stability (“smart compressor”)
  ➔ SFC reduction: 1,1%

• Improvement of the engine cycle due to higher overall pressure ratio and bypass ratio
  ➔ SFC reduction: 1,4%
SP4 Active Core Configuration - Technical Approach

Active clearance control system (rear stages)
- Improved tip clearance with active clearance control system (thermal or mechanical)
- Comparison with alternative technologies for tip clearance improvement

Active surge control (front stages)
- Development of an active surge control with air injection
- Comparison to the passive alternative multi stage casing treatment

Active cooling air cooling
- General concept
- Air cooler and control system

- Combustor case cooling air flow path
- HPC rear cone cooling
Active Cooling Air Cooling - Introduction

- In modern gas turbines up to 30% of the compressor air is used for cooling purposes significantly increasing the fuel consumption.

- In known studies cooled cooling air is used for HPT blades only and the amount and temperature of the cooled air is fixed.

- In SP4 a new, highly advanced active cooling air system will be investigated. Not only the rotor blades, but also the stator vanes, the rotor disk and the liner are supplied with cooled cooling air. In addition the cooling air mass flow rate and temperature are actively controlled depending on the mission point. By this, it is possible to reduce the necessary amount of cooling air to a minimum.
Active Cooling Air Cooling - Objectives

- To develop a concept of a highly advanced cooling air cooling system, which aims at
  - a reduction of the high pressure turbine cooling air consumption by 35 %,
  - an increase of the HPT efficiency by 1 % and
  - a significant increase of the specific HPT work
  - resulting in a total SFC reduction of 1.5 %
    (not including the OPR effect and the BPR effect).

- To validate the necessary key components
  - air cooler and control system,
  - combustor case with optimised cooled cooling air flow path,
  - manufacturing technologies for a thinner compressor rear cone, which is cooled by cooled cooling air.
Active Cooling Air Cooling

1. Combustor case
2. Heat exchanger
3. Bypass air
4. Valve
5. Compressor rear cone cooling
6. HPT airfoil cooling
Smart HPC Technologies - Introduction

- Active systems offer the possibility to adapt the core engine to each operating point of the mission and therefore have a significant potential to optimise component behaviour. Furthermore, active systems open up additional degrees of freedom in the design and the possibility of compensating efficiency and safety penalties due to deterioration.

- The two most promising areas of application of active systems in the core are active clearance control and active surge control systems for the HP compressor. They will be investigated and compared with passive alternatives.

- The candidates with the highest potential will be developed and validated in rig tests.
Smart HPC Technologies - Strategy

- Efficiency improvement by active or semi-active clearance control

- Surge Margin
  1. Increased full speed surge margin by active clearance control or casing treatment for rear stages
  2. Increased part speed surge margin by active surge control or casing treatment for front stages
  3. Lifting of working line

  ➔ Reduced compressor size and higher compressor efficiency
Smart HPC Technologies - Objectives

- To develop active or semi-active systems for HP compressors
  - active or semi-active clearance control system for compressor rear stages providing significantly better efficiency and full speed surge margin and
  - active or passive surge control system for compressor front stages enhancing the operability of the engine at part speed conditions.

- Together theses technologies will provide
  - a 1.5 % higher HPC efficiency and
  - a lower HPC size and weight due to lifting of the HPC operating line by 15 %,
  - the resulting SFC reduction is at a value of 1.1 % (not including the OPR and BPR effects).

- To investigate the key issues weight, system complexity and robustness against failure.

- To validate the technologies in a series of rig tests.
Smart HPC Technologies - Air Injection & Casing Treatment

- Increased part speed surge margin (applied to front stages)

Air injection

- Blade
- Variable nozzles
- Injection ducts
- Air supply

Casing treatment

- Blade
- Air supply

Mass Flow

Pressure Ratio

This document and the information contained are property of the NEWAC consortium and shall not be copied or disclosed to any third party without prior written authorization.
Smart HPC Technologies - Active Clearance Control

- Increased efficiency
- Increased full speed surge margin (applied to rear stages)
Smart HPC Technologies - Active Clearance Control

Example for mechanical clearance control
- Long lever driven by actuators rotates inner ring circumferentially relative to outer carrier ring
- Oblique struts cause radial punch loads between rings.
- Inner ring shows radial shrink relative to stiffness ratio between outer carrier ring and inner flowpath ring
SP5 Flow Controlled Core - Introduction

• To achieve compressor efficiency increase, additional surge margin and reduced in service deterioration, flow control technologies offer new opportunities. These technologies are:
  • Tip flow control technologies including aspiration
  • New advanced 3D aerodynamics
  • Air aspiration applied on stator vane/hubs or blade
  • Blade/casing rub management for tight tip clearance
  • Flow stability control optimised versus engine integration

• The flow control technologies will be investigated by analysis, elementary tests and validated in a compressor rig test.
SP5 Flow Controlled Core - Objectives

Tip Flow Control and Advanced Aero
• + 1.5pt efficiency w/o SM penalty
• Lower efficiency deterioration
• Additional +8% SM from Stall active Ctrl

Blade aspiration concept
• + 0.5pt efficiency
• + 5% SM
<=> equivalent blade loading

Blade/casing rub management
• + 0.5pt efficiency
• + 2% SM
• Lower rub clearance opening

SP5 NEWAC objectives for HPC:
• +2.5% efficiency
• +15% stall margin
• -1/3 deterioration in service
SP5 Flow Controlled Core - Technical Approach

Aspiration concept on blade profiles
- Evaluation and optimisation of aspiration technology on stator vane/hubs or blade
- Identification of potential benefits

Rub management
- Modelling the abradable and its wearing
- Development of improved abradable
- Validation via rub tests...

Tip flow control
- Advanced casing treatment
- Tip rotor injection with/without aspiration

Stall active control system integration
- Studies with thermal, mechanical, technological, hydraulic constraints
- Overview of issued encountered with implementation of each system
Tip Flow Control and Advanced Aero

Concepts for efficiency/operability enhancement

- 3D airfoil design optimized and adapted to the casing environment
- Non axi-symmetric end wall
- Advanced casing treatment
- Casing aspiration
- Tip injection

Flow controlled compressor with tip injection and casing aspiration
Aspiration concept on blade profiles

- To delay separation at high incidence / loading
- To reduce shock/boundary layer interaction

→ Improved blade stability / efficiency / loading
Blade/casing rub management for tight tip clearances

- Engine performances calls for tight tip clearances for the compressor at cruise (efficiency), in transient (operability) and in-service whole engine life (performance).

- Small tip clearances lead to contact between rotor and stator parts which inescapably leads to wider clearances than targeted. Development of new material, robust technologies and new design practices provides opportunities for a better blade / casing rub control.

- Approach
  - Development of a specific methodology, taking into account the entire structure characteristics, modelling the abradable and its wearing, machining loads and thermal effects, with sophisticated contact modelling.
  - Development of an improved abradable, making blisks rub-proof.
  - Tests with blades and abradable in order to validate the methodology, the blade design guidelines and the new abradable characteristics.
Stall Active Control Integration

- CLEAN EEFAE demonstrated a successful implementation of actuators & surge avoidance (fast opening / closing valves, sensors and real time detection system)

- Implementation of the Stall Active Control on real engines requires thorough integration
  - Integration studies for CLEAN-like actuators (fast opening valves) and alternative stall control systems on thermal, mechanical, technological, hydraulic aspects
  - Performance assessment on benefits and penalties to be carried out
Subprogram
Innovative Combustor
SP6 Innovative Combustor - Introduction

- Significant NO\textsubscript{x} reduction promising approaches are based on lean combustion technology
- EEFAE ANTLE/CLEAN proved NO\textsubscript{x} reduction encouraging progress vs. ACARE 2020 objectives
- Further improvements, mainly on fuel injection technology, are required to enable NO\textsubscript{x} target
- Major challenge is to bring identified NO\textsubscript{x} reduction technologies to a TRL 5 to 6
- Lean combustion is integrated into fuel staged combustion concepts for combustion operability
- Validation of 3 lean combustion technologies (LP(P), PERM and LDI) for different applications up to full annular high pressure test
NO$_x$ Reduction by Lean Combustion

- Lean combustion operates with an excess of air to significantly lower flame temperatures and consequently reduce NO$_x$ formation. Up to 70% of total combustor air flow has to be premixed with the fuel before entering the reaction zone.

- To overcome the narrow operating range of lean combustion fuel staging is required:
  - Staged combustor with two separated zones (additional combustion zone for good stability at low power) either axially or radially staged
  - Internally staged injectors creating a pilot and main combustion zone downstream of the injector installed in a single annular combustor
NO\textsubscript{x} Reduction by Lean Combustion

In NEWAC internally staged injectors will be investigated because of low emissions at acceptable penalties on weight and cost.

- **LPP** (Lean Premixed Prevaporized Injection)
  - fuel is mixed with air by a premixing tube before reaching the combustion region
  - application to reverse flow combustor for IRA engine or small gas turbines
  - risk of auto-ignition or flashback for higher OPR

- **PERM** (Partial Evaporation & Rapid Mixing)
  - fuel is partially evaporated and rapidly mixed using swirler technology

- **LDI** (Lean Direct Injection)
  - fuel is injected directly into the flame zone
  - a concentric internally staged fuel injection system with pilot (stability) and main stage (low NO\textsubscript{x}) is used
SP6 Innovative Combustor - Objectives

- Develop and validate lean fuel injection technology up to TRL 5-6, demonstrating 60% to 70% reduction of NOx emissions in the LTO cycle versus CAEP/2 limit
- Enable combustor full operability

![Diagram showing NOx emission levels versus overall pressure ratio with various combustor technologies and goals compared to CAEP standards.]

**CAEP/2**
- Trent 700
- CFM 56

**CAEP/4 2004**
- ICAO NOx [g/kN]

**CAEP/6 2008**
- ICAO Medium Term Goal
- ICAO Long Term Goal

**NEWAC**
- 60% to 70% rel. to CAEP/2
- 16% rel. to EEFAE

**Reference**

**Intercooled core with LDI combustor**

**Active core with PERM combustor**

**IRA with LPP combustor**

**EEFAE – ANTEL - CLEAN**
SP6 Innovative Combustor Technologies - Applications

3 injection systems

4 core concepts

Engine OPR

LP(P)  PERM  LDI

SP2 (IRA)
SP3 (IC)
SP4 (AC)
SP5 (FCC)
**SP6 Innovative Combustor - Approach**

Development towards a Ultra Low NO\(_x\) lean burn technology single annular combustor (SAC)

- Development of 3 different lean fuel injection systems (LDI, PERM and LP(P)) through CFD and detailed experimental investigations

- Design/adaptation of combustor module demonstrators, integrating advanced validated injection systems, innovative cooling technology, fuel staging concepts, thermal management of fuel injectors, control of thermo-acoustic and combustion instabilities

- Validation of lean combustor technology (TRL 5-6) on full annular combustor demonstrators to assess performance at sub-atmospheric, atmospheric up to high pressure
Advanced Injection System - Approach

- CFD Prelim Design (LDI RRD, PERM UNIKA/AVIO, LPP TM)
- Optical Diagnostics (LDI DLR, PERM UNIKA, LPP TM)
- Combustion Tests (LDI DLR/RRD, PERM UNIKA, LPP TM/ONERA)
- Optical Rigs (TRL 3-4) (LDI DLR, PERM UNIKA, LDI TUG/ONERA)
- HP Single Sector (TRL 4) (LDI DLR, PERM ONERA, LPP ONERA)