A Search for the “ULTIMATE” Aero-Engine

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Ultra Low emission Technology Innovations for Mid-century Aircraft Turbine Engines

Exploring synergistic combinations of radical core technologies

Call:  MG-1.5-2014 - Breakthrough innovation for European Aviation

Budget:  EUR 3,138,121.88 (100% financed by the EU)

Duration:  36 months, September 2015 – August 2018

Consortium:  10 partners (4 Universities, 4 Industries, 1 research institute and 1 technology management company)

Coordination:  Chalmers University of Technology

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ULTIMATE will attack the major loss sources “the Big Three”

- Combustor irreversibilities (1)
- Core exhaust heat losses (2)
- Excess of kinetic energy in the bypass flow (3)

The red cross-hatched areas may be captured – HOW?

“Exergy, denoted ε, of a steady stream of matter is equal to the maximum amount of work obtainable when the stream is brought from its initial state to a state of thermal and mechanical equilibrium with its environment”

Project Goals

Exploring synergistic combinations of radical core technologies

- Constant volume type combustion
- Intercooling & Recuperation
- Bottoming cycles
- Advanced low pressure system technology

...together with advanced tube and wing configuration
Concept and Approach

Exploring synergistic combinations of radical core technologies

- **Combine and exploit** synergies between radical technologies

- **Attack** all three major sources simultaneously

- **Incorporate** the new powerplants into an Advanced Tube and wing aircraft (TRL1)

- **Create and exploit** multidisciplinary evaluation platform (TERA 2050) for powerplant development and optimization
Concept and Approach

Starting point!

• Technology assumptions for 2050
  - Turbomachinery efficiency;
  - High Pressure Turbine Temperature Capabilities;
  - Characterization of Heat exchangers;
  - Weight estimation and structural considerations
  - Reference cycles

Powerplant for intercontinental configuration
(architecture illustrated by Rolls-Royce UltraFan for 2025)

Intra-European configuration
Combustor Irreversible

Attack loss source #1

- Piston based composite cycles
- Nutating disc composite cycles
- Pulse detonation combustion

*LEMCOTEC: Diferent composite cycle concepts*
*Source: S. Kaiser et al., 2016*

*S. Kaiser et al "Composite Cycle Engine Concept with Hectopressure Ratio". Accepted for publication in AIAA Jounal of Propulsion and Power*
Core exhaust heat losses

Attack loss source #2

- IC/Recuperation, with inter turbine burning

**LEMCOTEC: MTU concept for IRA engine**

Source: Zhao et al., 2015

- Intercooling

**LEMCOTEC: Involute spiral arrangement of IC for space optimization**

Source: Zhao et al., 2015

- Bottoming cycle


Excess of Kinetic Energy

Attack loss source #3

- Ultra-slim nacelle enabling tech.
- Variable pitch fan & area nozzle

Powerplant for intercontinental configuration
(architecture illustrated by Rolls-Royce UltraFan for 2025)

Boxprop

Retractable nacelle

Intra-European configuration

06/12/2016

LEMCOTEC Workshop
Combinations!
Intercooled Pulse Detonation Core

Opportunities

- Pressure rise combustion
- Reduction of combustor irreversibility
- Reduced risk of auto-ignition at higher OPR
- Higher combustion pressure ratio with IC

IC-PDC vs 2050 Turbofan
-11.0% SFC

Challenges

- Compatibility between HPT and PDC flow
- NOx emissions
- Design of cooling system
- Noise
Intercooled cycle with Inter-turbine burning and a supercritical CO\textsubscript{2} (S-CO\textsubscript{2}) bottoming cycle

**Opportunities**

- Will allow considerably smaller and simultaneously more efficient cores
- Lowered NO\textsubscript{x} and CO\textsubscript{2} emissions due to smaller fuel mass flows.
- The main heat exchanger behind the LPT may reduce noise emissions of the core jet.

**Challenges**

- Accurate simulation of thermal behavior of S-CO\textsubscript{2} heat exchangers
- Realistic prediction of S-CO\textsubscript{2} turbomachinery Off-Design
- Weight estimation of several components
Opportunities

- The relatively higher power density leads to a reduced weight penalty as opposed to Piston combined cycles.
- Supposed reduced NOx emissions due to low residence times in the combustion chamber.
- Reduced combustion irreversibility and pressure rise combustion

Challenges

- Accurate simulation of boosted nutating disk engine design point and off-design point performance
- Accurate estimation of the overall weight.
- Accurate prediction of the heat release in the combustion chamber at design and off-design conditions
Combinations

Intercooled Piston Composite Cycle (with inter-turbine recuperation)

Intercooled CCE vs baseline 2050 Turbofan
+3.7% weight | -12.6% TSFC | -17.5% fuel burn

Opportunities

- Pressure rise combustion
- Reduction of combustor irreversibility
- Improves volumetric efficiency
- Reduces piston system weight considerably

Potential synergistic combination of the CCE with recuperation

Challenges

- Demanding operating conditions for the piston system
- Conceptual design of intercoolers (limited space)
- Incorporation of recuperation in the design space
Scientific Approach

- Development
  partially qualitative selection

- Optimization
  towards the SRIA 2050 targets

- Exploitation
Techno-Economic Risk Assessment platform for ULTIMATE

Year 2000 reference technologies
Year 2050 reference technologies and requirements
Year 2050 ULTIMATE technologies and requirements

Engine Performance
Engine General Arrangement
Aircraft Performance
Engine Weight

Noise Prediction
Emissions Prediction

Operating Cost Model

Policy (Hypothetical Fuel Prices)
(Hypothetical Emissions Taxation)
(Hypothetical Legislation)

Optimiser
The race is on - Ultimating

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Fly longer (!) with the best score.

Industry input will **support our “scoring”** of concepts.

Technical feasibility

- How likely is a concept to fly?
- NOx, CO2, Noise
- Methods for assessment

Support on technology roadmapping
The Consortium

4 Universities, 4 Industries, 1 Research Institute and 1 SME

Thank you!