A Search for the “ULTIMATE” Aero-Engine

Carlos Xisto, Tomas Grönstedt

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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

Tomas Grönstedt
Chalmers University of Technology
Department Applied Mechanics
412 96 Gothenburg, Sweden
e-mail: tomas.gronstedt@chalmers.se
Tel: +46 704 92 33 39
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)

“Exergy, denoted $\varepsilon$, 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”


The red cross-hatched areas may be captured – HOW?
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
  o Turbomachinery efficiency;
  o High Pressure Turbine Temperature Capabilities;
  o Characterization of Heat exchangers;
  o Weight estimation and structural considerations
  o Reference cycles
Combustor Irreversible

Attack loss source #1

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

LEMCOTE: Different 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 Journal of Propulsion and Power
Core exhaust heat losses

Attack loss source #2

IC/Recuperation, with inter turbine burning

LEMCOTEC: MTU concept for IRA engine

LEMCOTEC: Involute spiral arrangement of IC for space optimization
Source: Zhao et al., 2015

Intercooling

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
- Retractible nacelle

Intra-European configuration
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 CO₂ (S-CO₂) bottoming cycle

Opportunities
- Will allow considerably smaller and simultaneously more efficient cores
- Lowered NOₓ and CO₂ 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-CO₂ heat exchangers
- Realistic prediction of S-CO₂ turbinomachinery 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
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

**Challenges**

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

**Potential synergistic combination of the CCE with recuperation**
Scientific Approach

- Development: partially qualitative selection
- Optimization: towards the SRIA 2050 targets
- Exploitation

**TECHNOLOGY DEVELOPMENT**
- Technology downselection
- Share technology simulators
- Common technology parameter assumptions
- Composite piston topping
- Rankine bottoming
- Alternative technology
- Configuration mix and match explore synergies

**CONFIGURATION ASSESSMENT**
- Multidisciplinary evaluation platform
- Aircraft mission analysis
- SRIA 2050 optimization
- Technology parameter refinement
- Advanced integration and propulsor configurations
- Composite piston topping + Intercooled Recuperation
- Nutating disc topping + Rankine Bottoming
- Pulse detonation topping + Intercooling
- Additional configurations

**COMMUNICATION AND EXPLOITATION**
- Industry lead: Roadmapping and exploitation
- SRIA and scenario evaluation

06/12/2016
LEMCOTEC Workshop
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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<th>Mission fuel burn NOx and noise?</th>
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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!