

LEMCOTEC Workshop for the Aeronautics Industry

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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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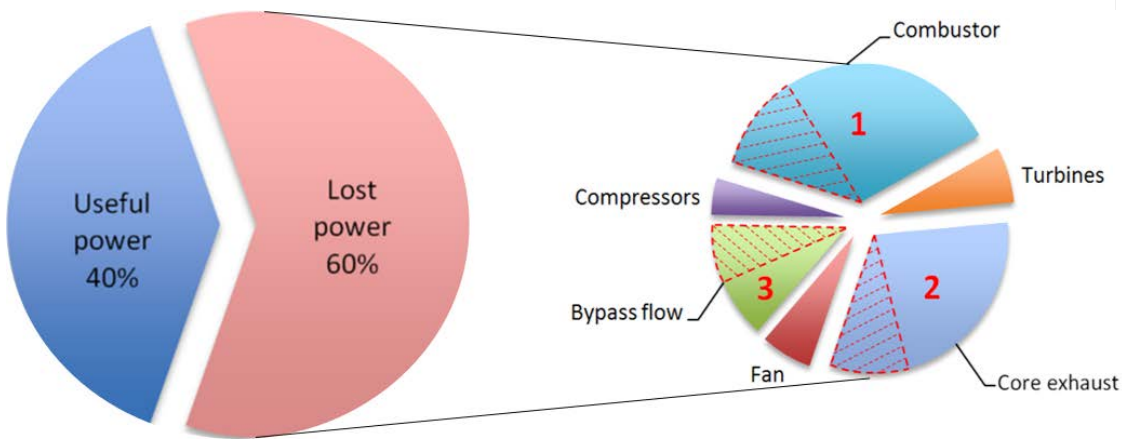
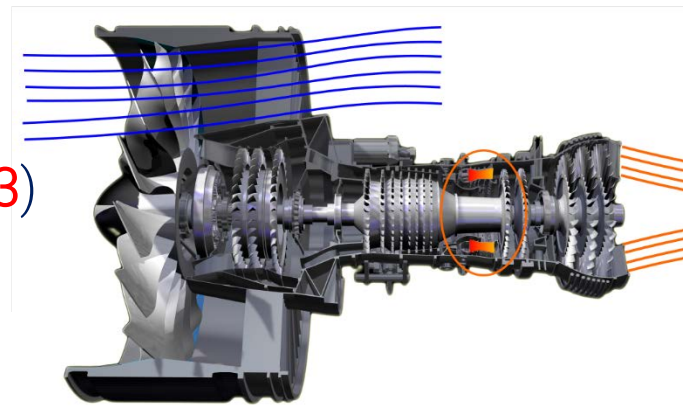


Project Goals

Losses in a 2015 state-of-the-art Turbofan

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 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”

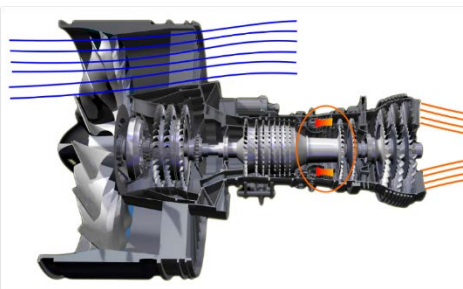
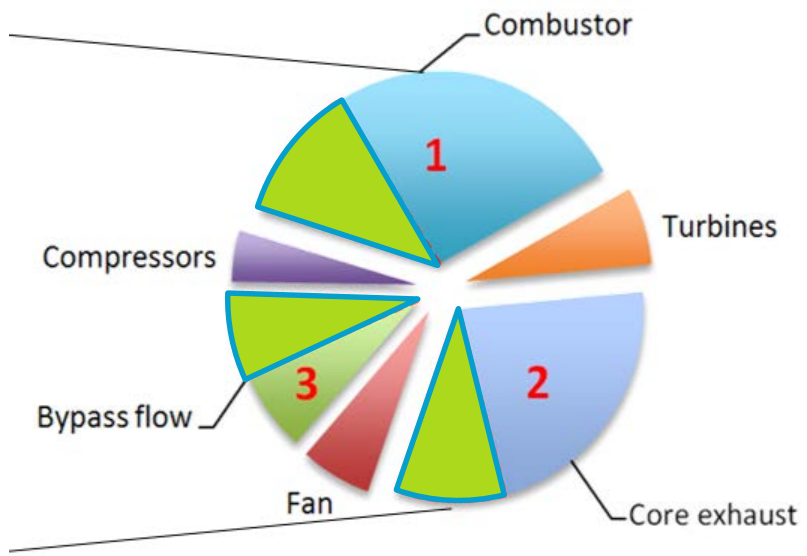
The red cross-hatched areas may be captured –HOW?

Grönstedt, T., Irannezhad, M., Lei, X., Thulin, O., Lundbladh, A., “First and second law analysis of future aircraft engines”. Journal of Engineering for Gas Turbines and Power”, 136 (3), 2014

Project Goals

Exploring synergistic combinations of radical core technologies

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

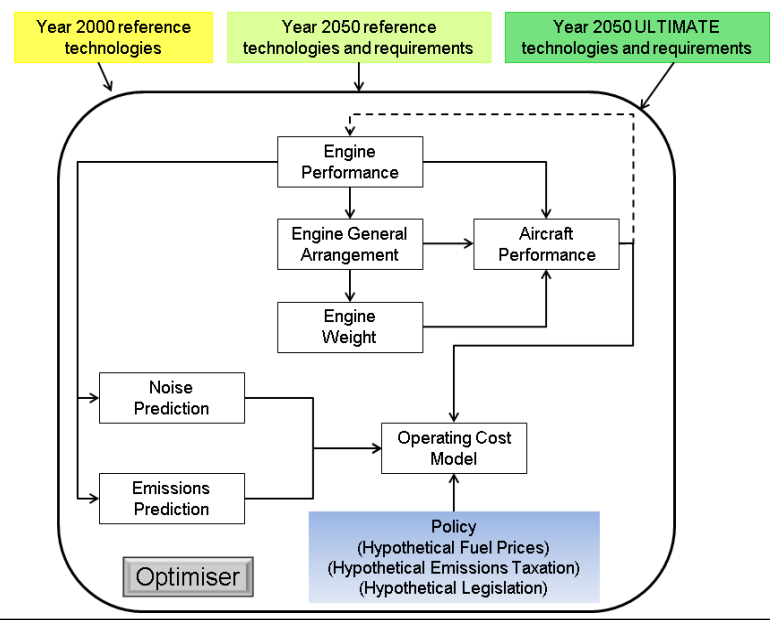


...together with advanced tube and wing configuration

Concept and Approach

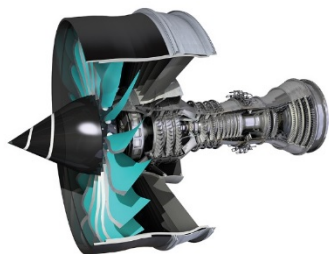
Exploring synergistic combinations of radical core technologies

- **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



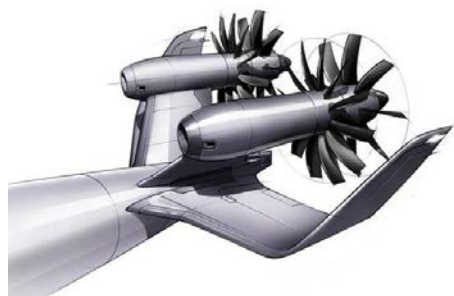
Concept and Approach

Starting point!



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

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



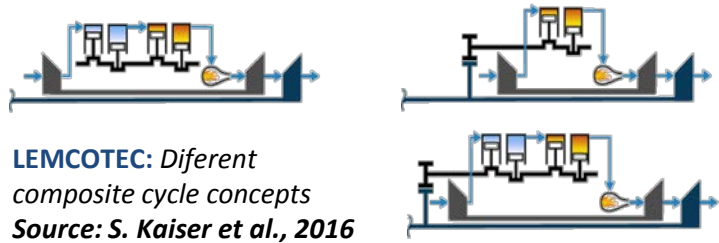
Intra-European configuration



Combustor Irreversibility

Attack loss source #1

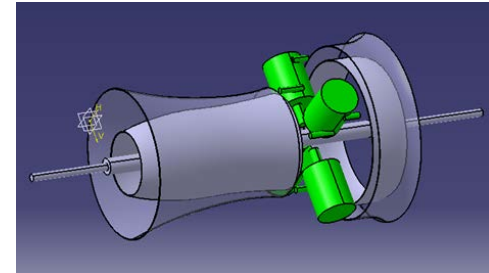
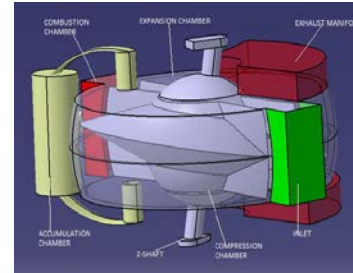
➔ Piston based composite cycles



LEMCO TEC: Different composite cycle concepts
 Source: S. Kaiser et al., 2016

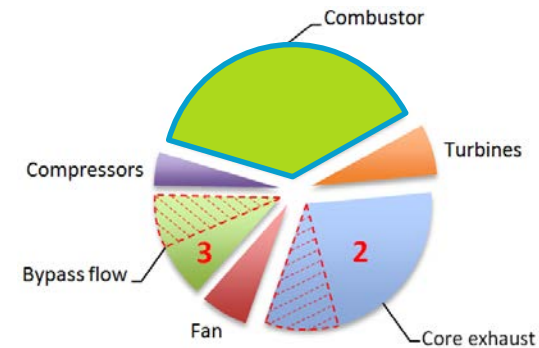
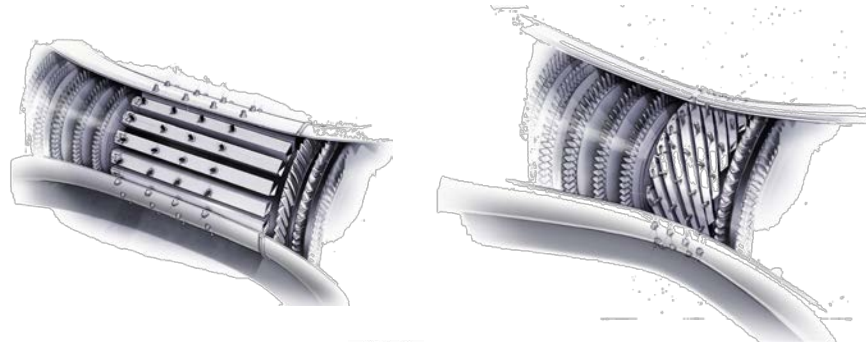


➔ Nutating disc composite cycles



S. Kaiser et al "Composite Cycle Engine Concept with Hectopressure Ratio".
 Accepted for publication in AIAA Journal of Propulsion and Power

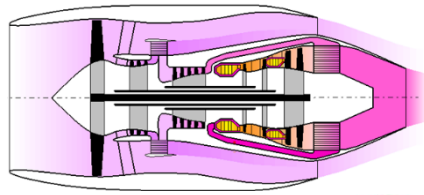
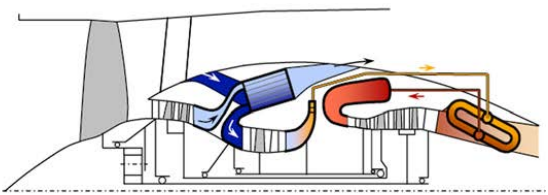
➔ Pulse detonation combustion



Core exhaust heat losses

Attack loss source #2

➔ IC/Recuperation, with inter turbine burning

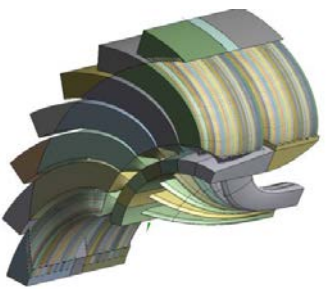


LEMCO TEC: MTU concept for IRA engine

Goulas, A., Donnerhack, S., Flouros, M., Missirlis, D., Vlahostergios, Z. and Yakinthos, K. "Thermodynamics cycle analysis, pressure loss and heat transfer assessment of a recuperative system for aero engines", Journal of Engineering for Gas Turbines and Power, Vol. 137, 041205-1, (2015).



➔ Intercooling

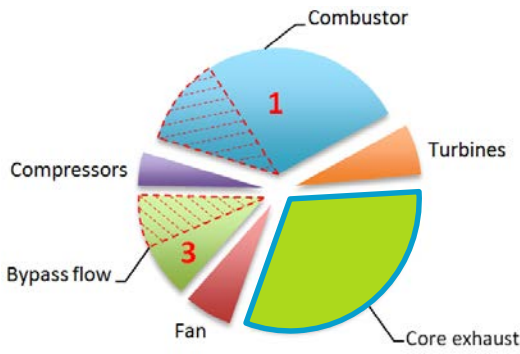
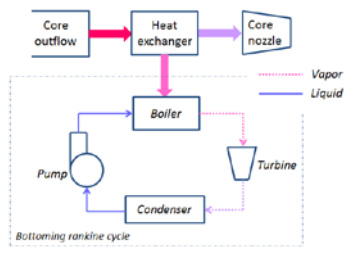


LEMCO TEC: Involute spiral arrangement of IC for space optimization
Source: Zhao et al., 2015



X. Zhao and T. Grönstedt, "Conceptual design of a two-pass cross-flow aeroengine intercooler," Proc IMechE Part G: J Aerospace Engineering, vol. 229, no. 11, pp. 2006-2023, 2015

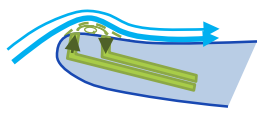
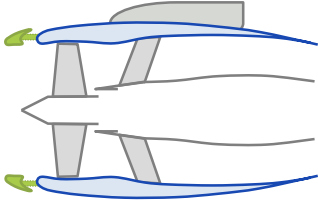
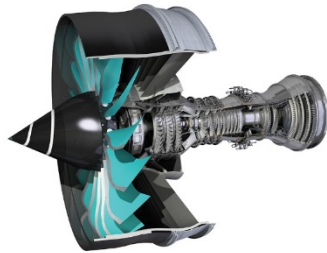
➔ Bottoming cycle



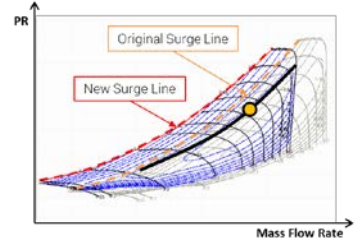
Excess of Kinetic Energy

Attack loss source #3

➔ Ultra-slim nacelle enabling tech.



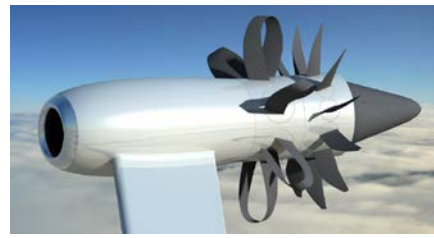
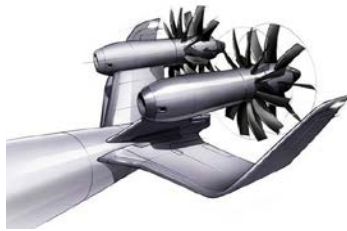
➔ Variable pitch fan & area nozzle



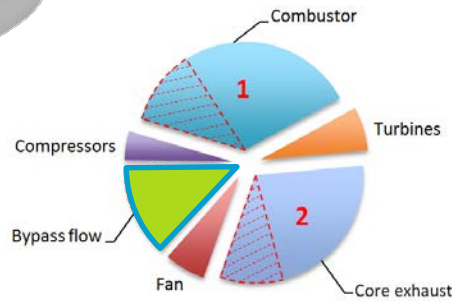
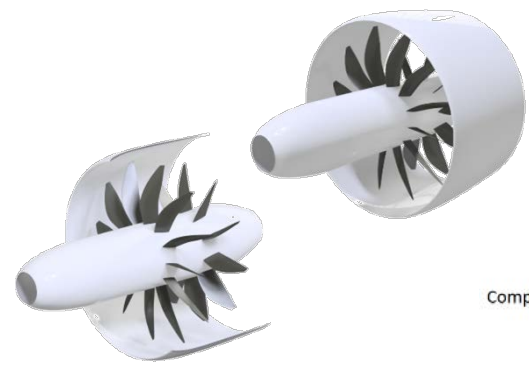
Powerplant for intercontinental configuration
(architecture illustrated by Rolls-Royce UltraFan for 2025)



➔ Boxprop



➔ Retractable nacelle



Intra-European configuration





Combinations!

Combinations

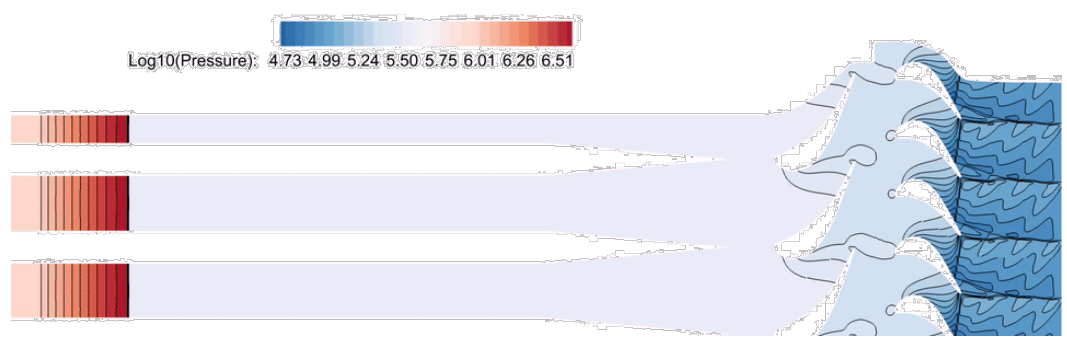
Intercooled Pulse Detonation Core

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

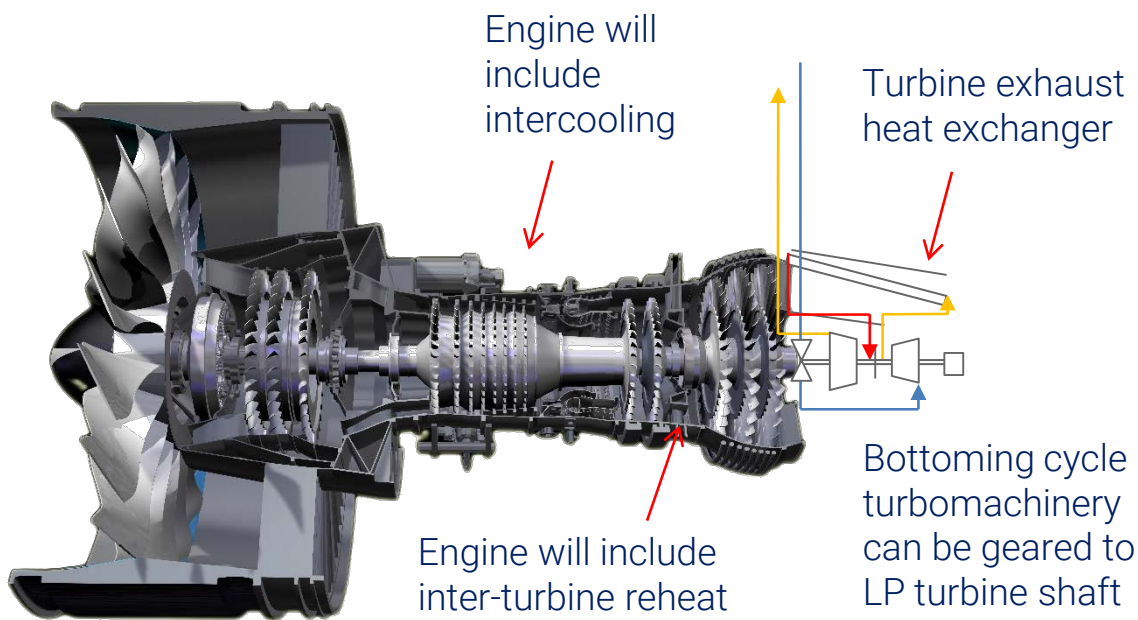
- ➔ Compatibility between HPT and PDC flow
- ➔ NOx emissions
- ➔ Design of cooling system
- ➔ Noise

Combinations

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 NO_x 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

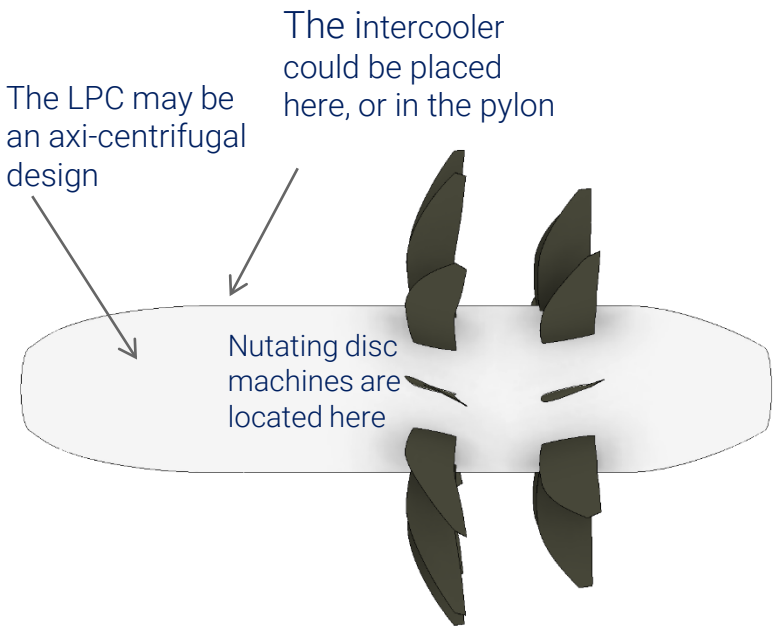
- Accurate simulation of thermal behavior of S-CO₂ heat exchangers
- Realistic prediction of S-CO₂ turbomachinery Off-Design
- Weight estimation of several components

Combinations

Open-Rotor with nutating disc topping

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

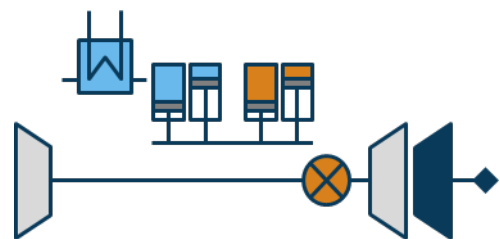


Challenges

- 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

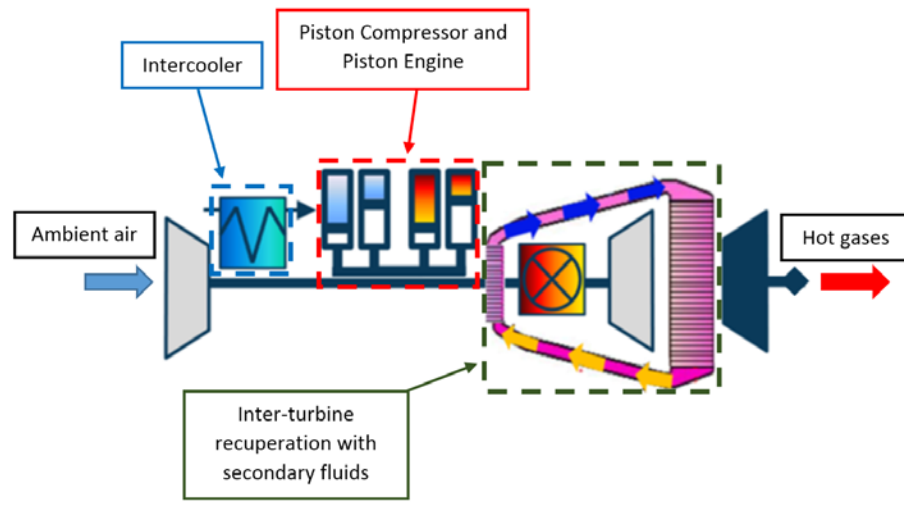
Opportunities

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

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

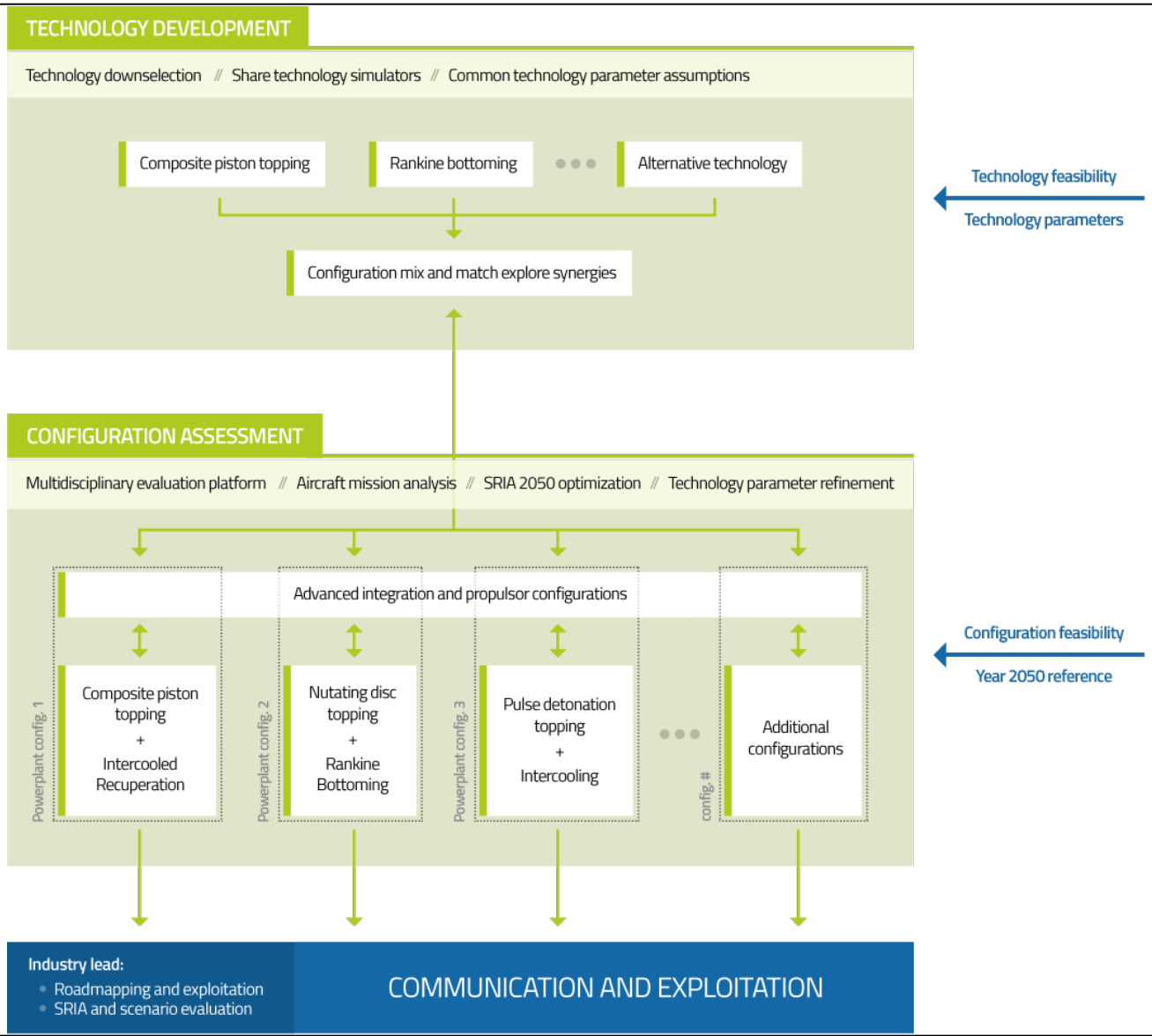


Scientific Approach

➔ Development
partially qualitative
selection

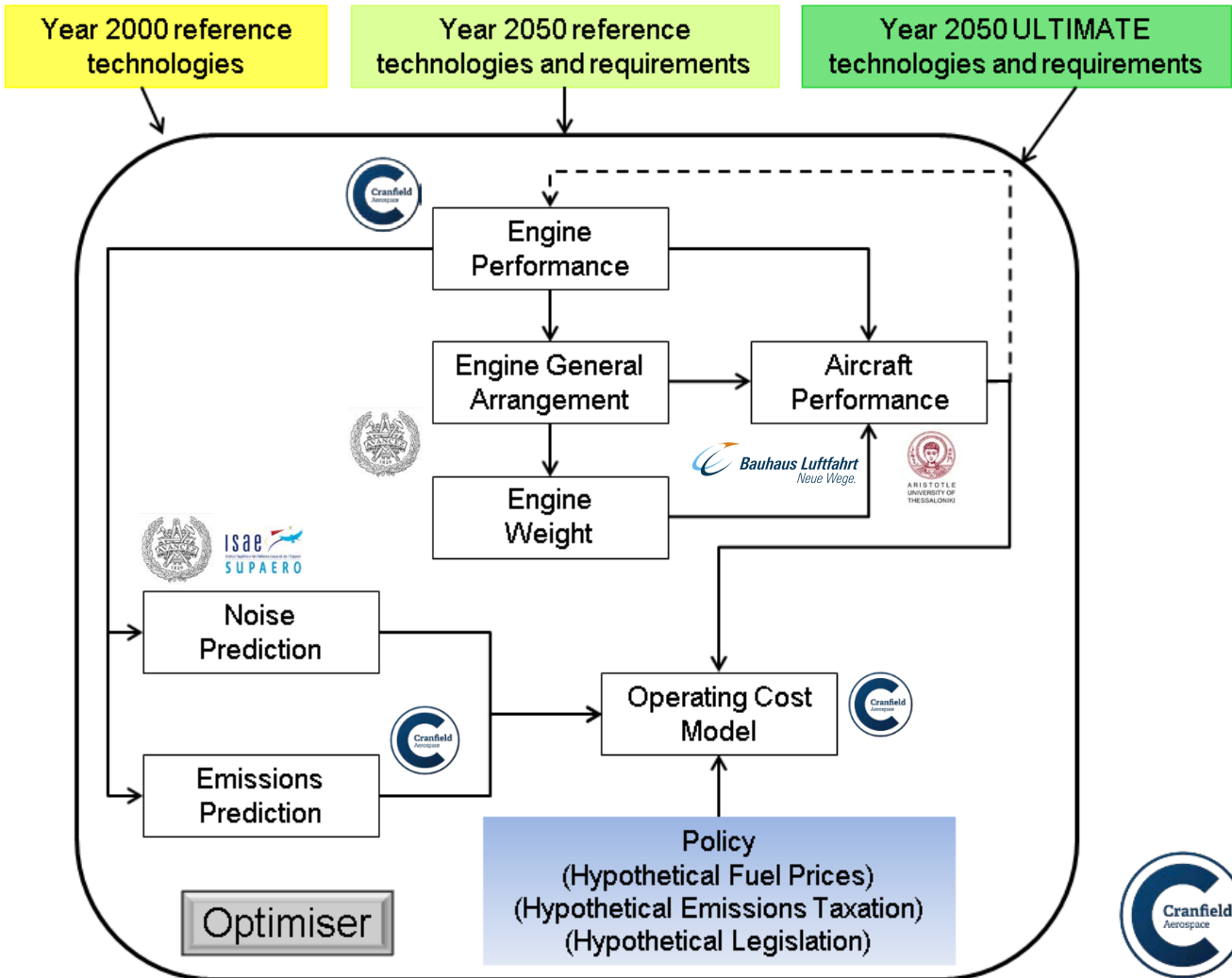
➔ Optimization
towards the SRIA 2050
targets

➔ Exploitation



INDUSTRIAL PARTNER EXPERTISE

Techno-Economic Risk Assessment platform for ULTIMATE



The race is on - Ultimating



M12

M36

IC + PDC + BP	 <i>Mission fuel burn NOx and noise?</i>	1
IC + PT + OR	 <i>Mission fuel burn NOx and noise?</i>	2
IC + ND + OR	 <i>Mission fuel burn NOx and noise?</i>	3

The Champ (s)!

Fly longer and better!

- ➔ 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

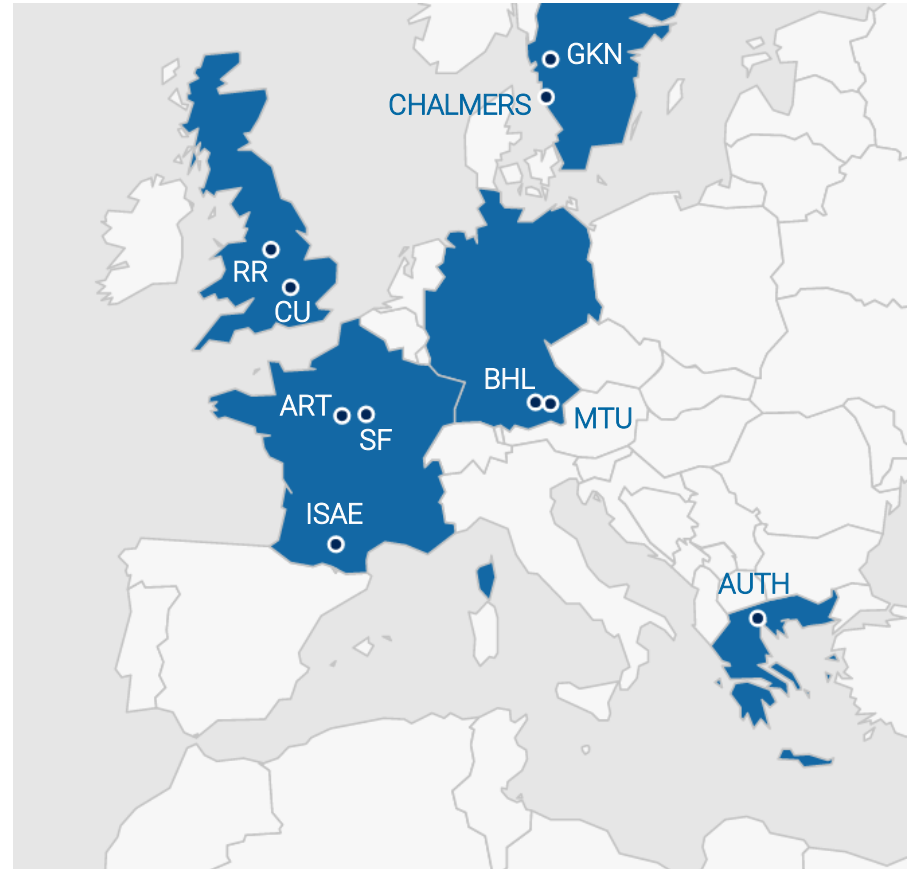


The Consortium

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



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Thank you!