LEMCOTEC Workshop for the Aeronautics Industry

Potsdam, Germany, December 6th, 2016

ULTIMATE
core engine technologies

A Search for the "ULTIMATE" Aero- Engine

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The ULTIMATE project is funded by the European Union H2020 programme under GA no. 633436.

- **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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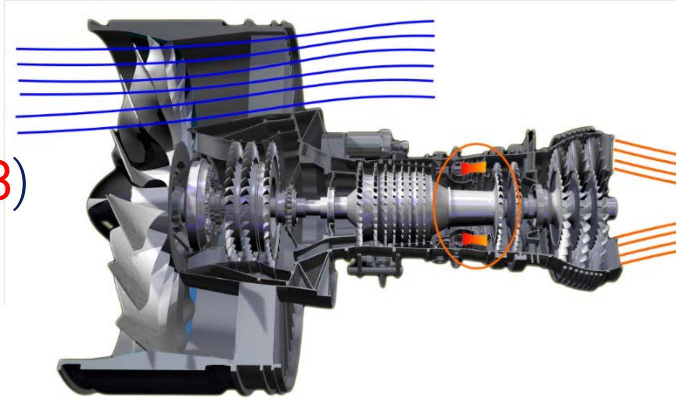
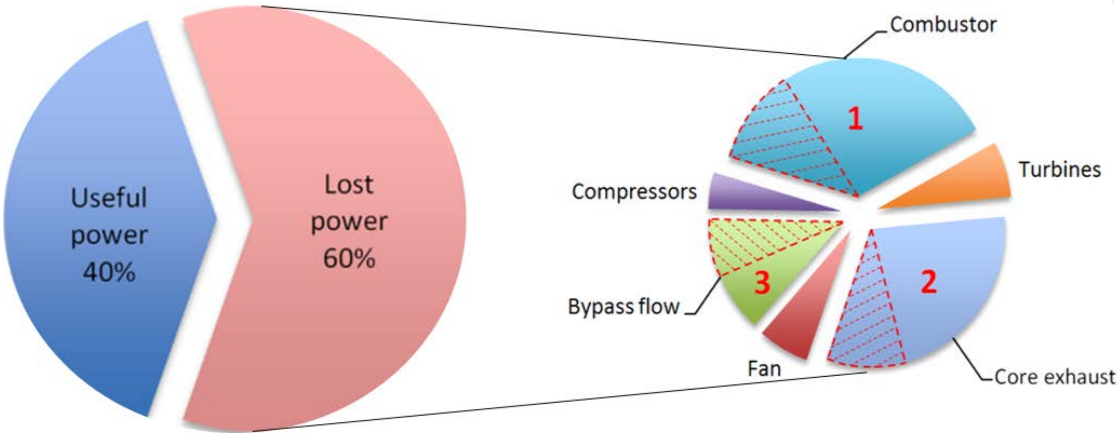
Project Goals

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"

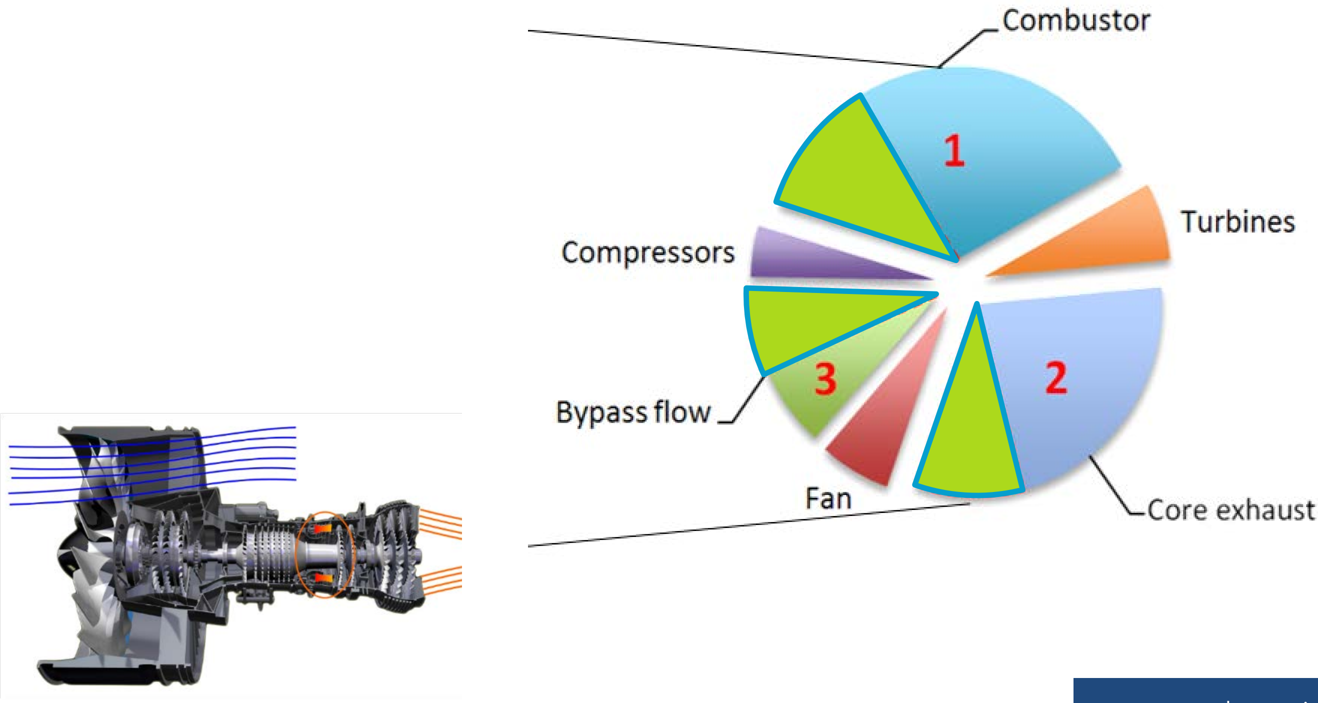
The red cross-hatched areas may be captured –HOW?

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

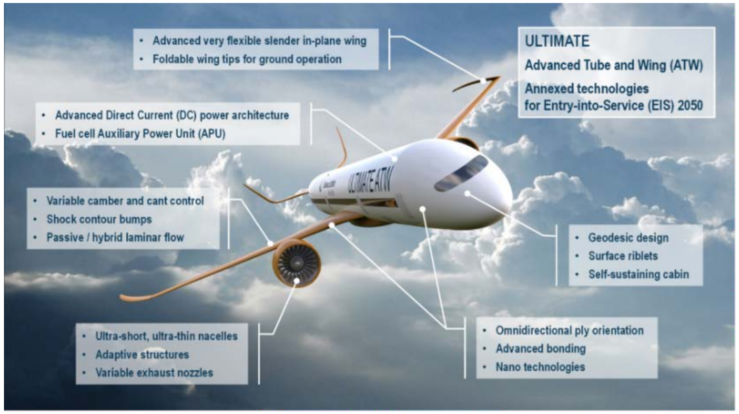


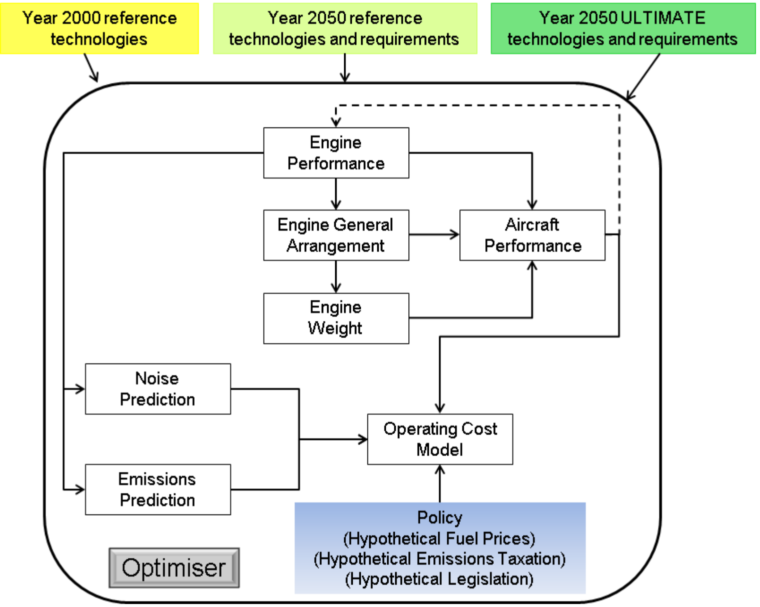
....together with advanced tube and wing configuration

Concept and Approach

Exploring synergistic combinations of radical core technologies

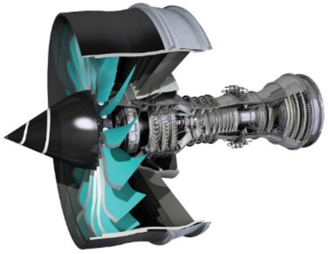
- **Combine and exploit** synergies between radical technologies
- **Attack** all three major sources simultaneously
- **Incorporate** the new powerplants into an Advanced Tube and wing aircraft (TRL1)
- **Create and exploit** multidisciplinary evaluation platform (**TERA 2050**) for powerplant development and optimization





Concept and Approach

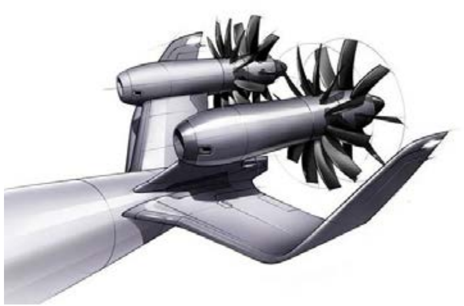
Starting point!



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

GKN AEROSPACE   Rolls-Royce   SAFRAN   MTU Aero Engines

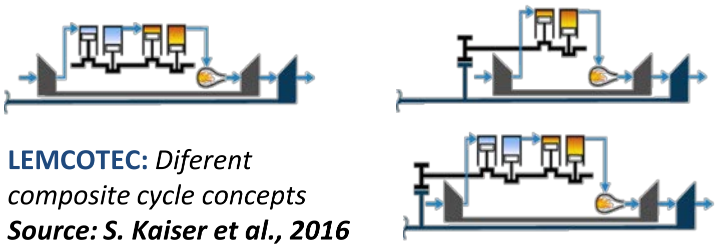


Intra-European configuration

Combustor Irreversebility

Attack loss source #1

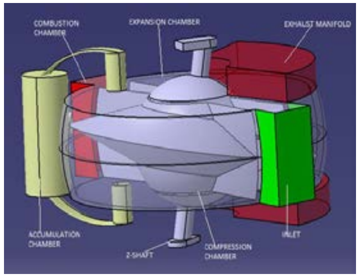
Piston based composite cycles

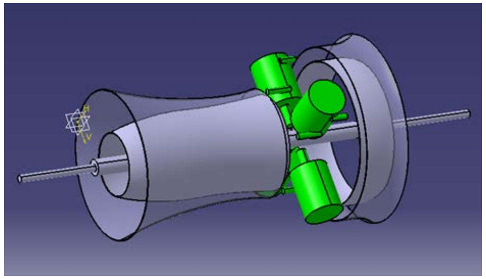


LEMCOTEC: *Diferent composite cycle concepts*
Source: S. Kaiser et al., 2016

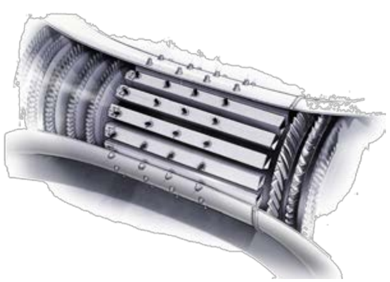
S. Kaiser et al "Composite Cycle Engine Concept with Hectopressure Ratio". Accepted for publication in AIAA Jounal of Propulsion and Power

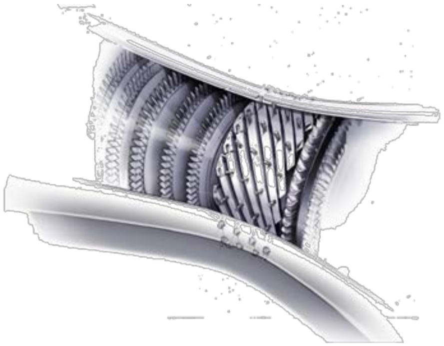
Nutating disc composite cycles

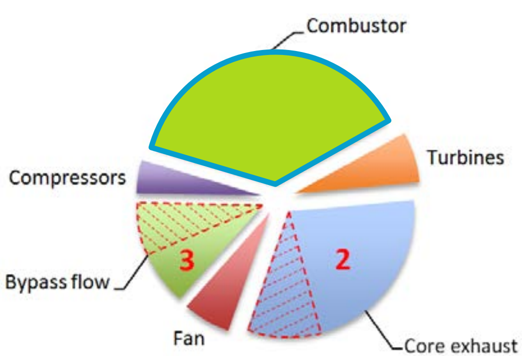




Pulse detonation combustion





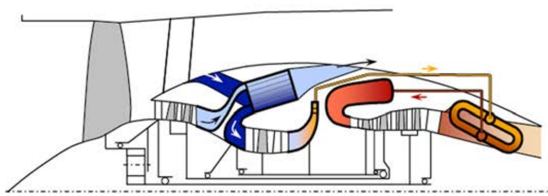


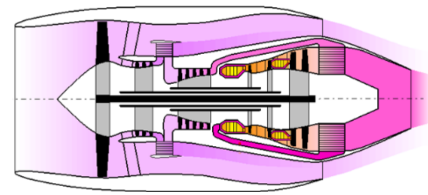
Core exhaust heat losses

ULTIMATE

Attack loss source #2

IC/Recuperation, with inter turbine burning





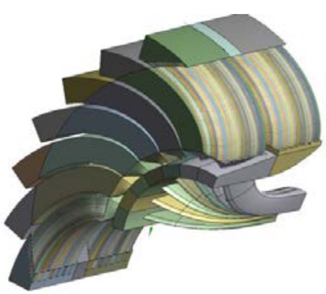
LEMCOTEC: *MTU concept for IRA engine*

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).

ARISTOTLE UNIVERSITY OF THESSALONIKI

MTU Aero Engines

Intercooling

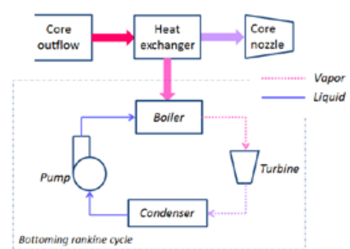


LEMCOTEC: *Involute spiral arrangement of IC for space optimization*
Source: Zhao et al., 2015

GKN AEROSPACE

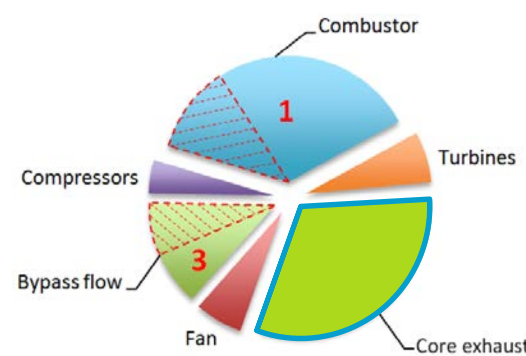
X. Zhao and T. Grönstedt, "Conceptual design of a two-pass cross-flow aeroengine intercooler," Proc IMechE Part G: J Aerospace Engineering, vol. 229, no. 11, pp. 2006-2023, 2015

Bottoming cycle



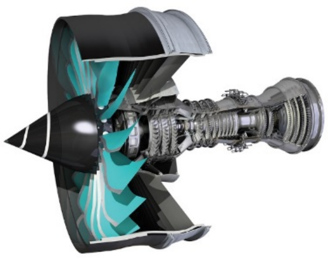
Cranfield Aerospace

Rolls-Royce



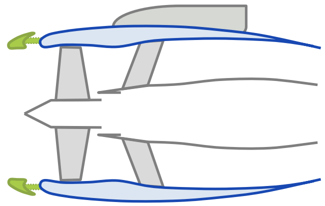
Excess of Kinetic Energy

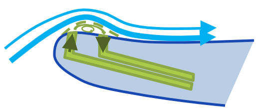
Attack loss source #3



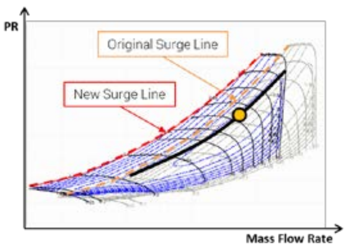
Powerplant for intercontinental configuration (*architecture illustrated by Rolls-Royce UltraFan for 2025*)

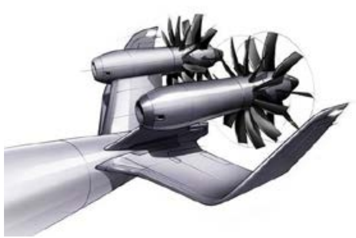
- Ultra-slim nacelle enabling tech.





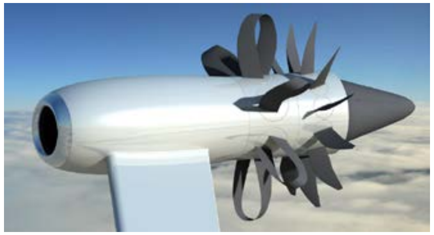
- Variable pitch fan & area nozzle



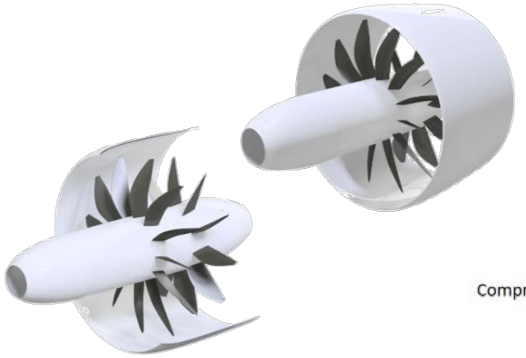


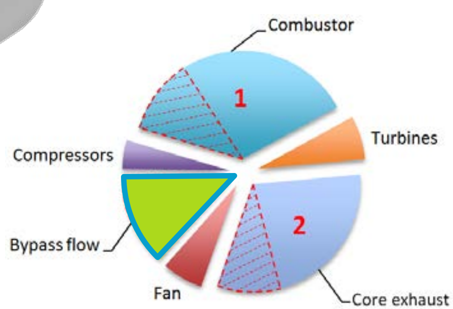
Intra-European configuration

- Boxprop



- Retractable nacelle





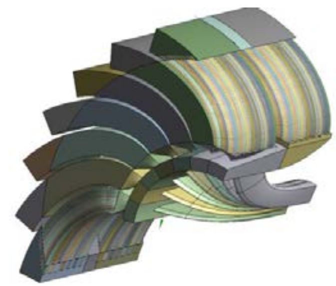
Combinations!

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



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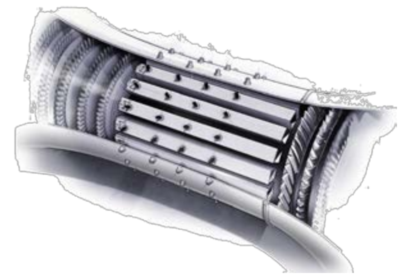
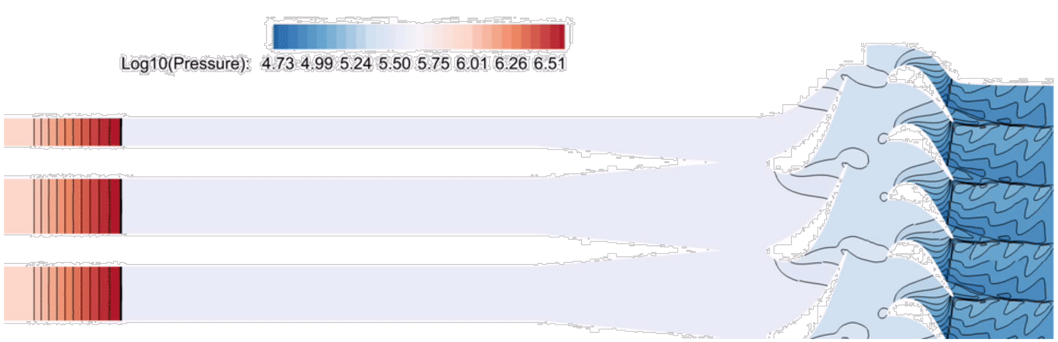


IC-PDC vs 2050 Turbofan
-11.0% SFC



Challenges

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

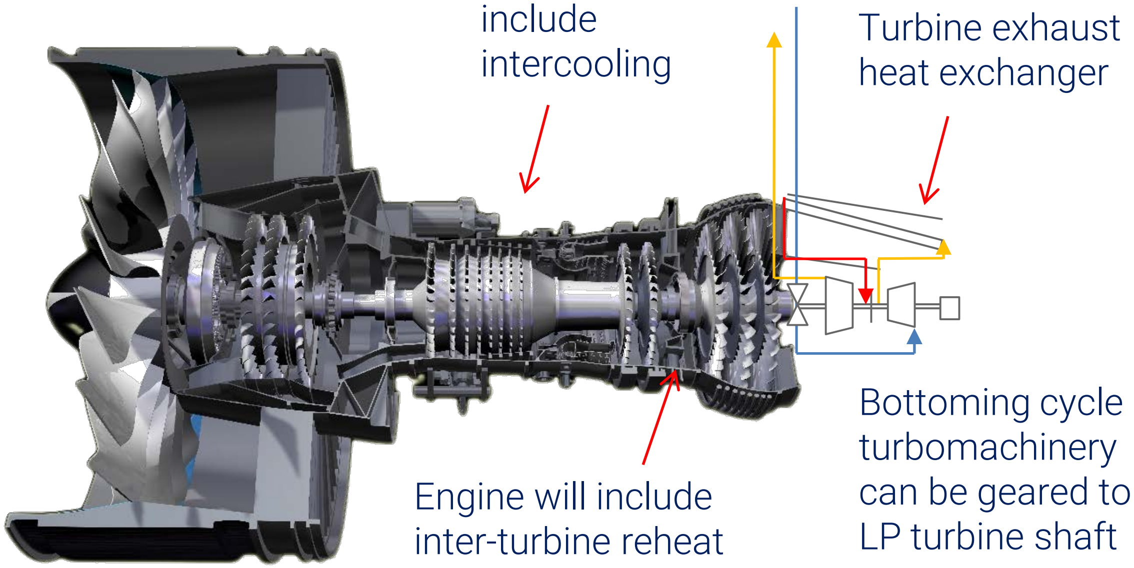
GKN AEROSPACE

Combinations

Intercooled cycle with Inter-turbine burning and a supercritical CO_2 (S-CO_2) bottoming cycle

Opportunities

- Will allow considerably smaller and simultaneously more efficient cores
- Lowered NO_x and CO_2 emissions due to smaller fuel mass flows.
- The main heat exchanger behind the LPT may reduce noise emissions of the core jet.



Challenges

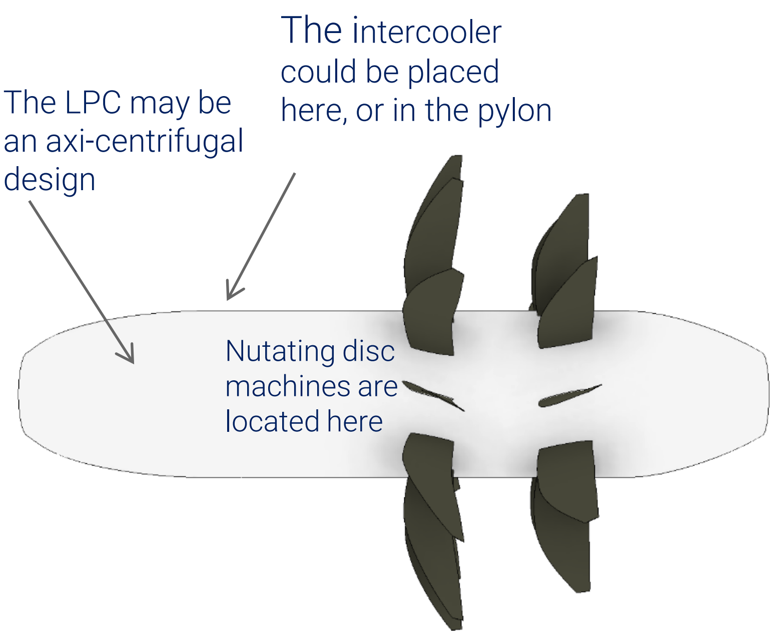
- Accurate simulation of thermal behavior of S-CO_2 heat exchangers
- Realistic prediction of S-CO_2 turbomachinery Off-Design
- Weight estimation of several components

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

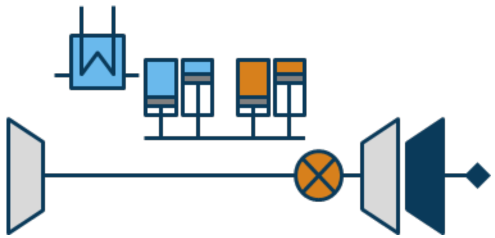


Challenges

- 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

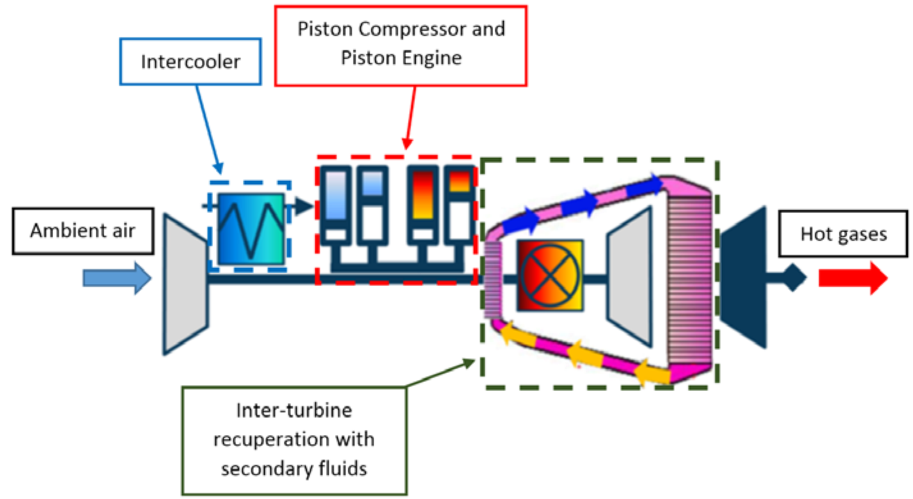
Opportunities

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

Challenges

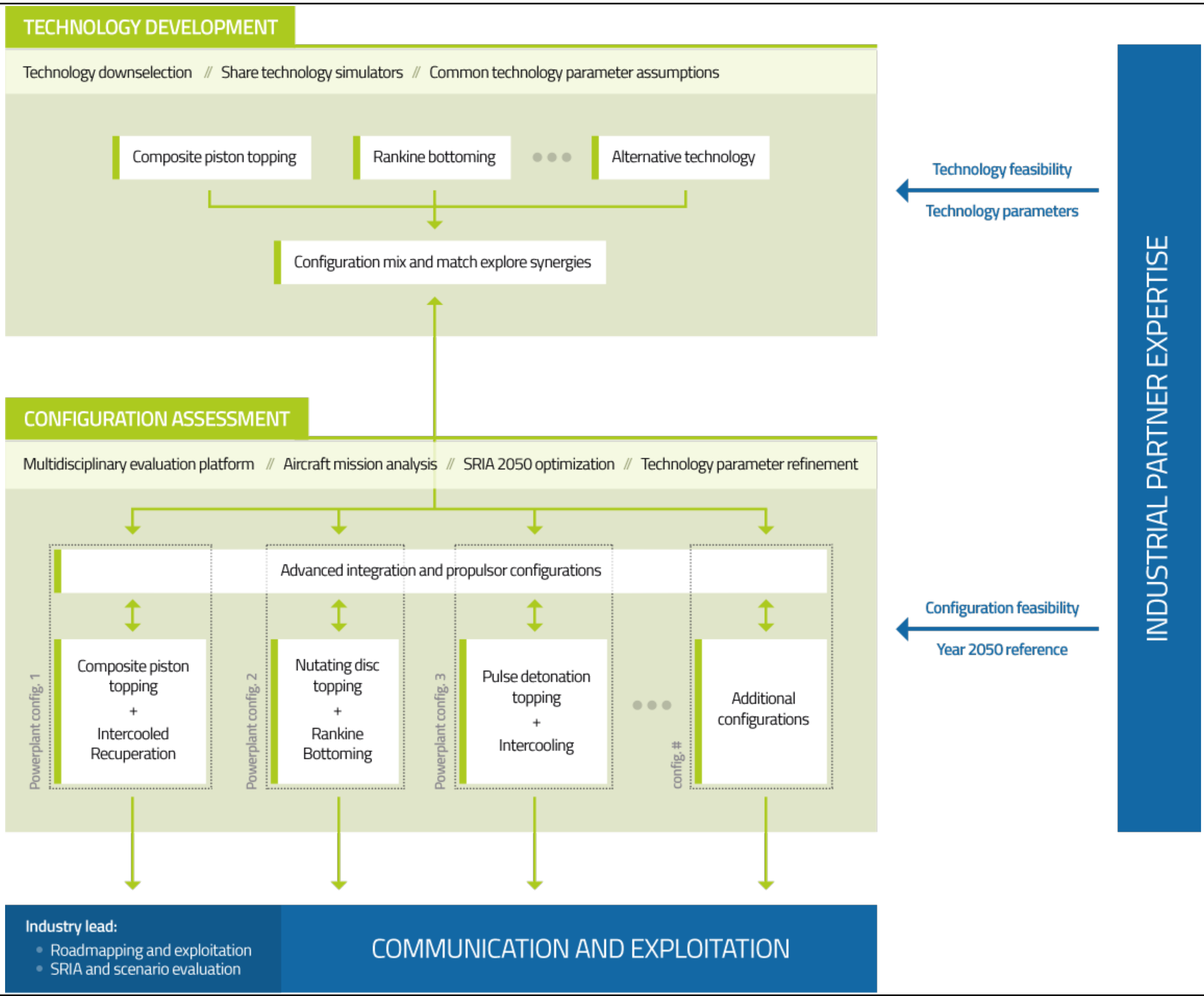
- Demanding operating conditions for the piston system
- Conceptual design of intercoolers (limited space)
- Incorporation of recuperation in the design space

Potential synergistic combination of the CCE with recuperation



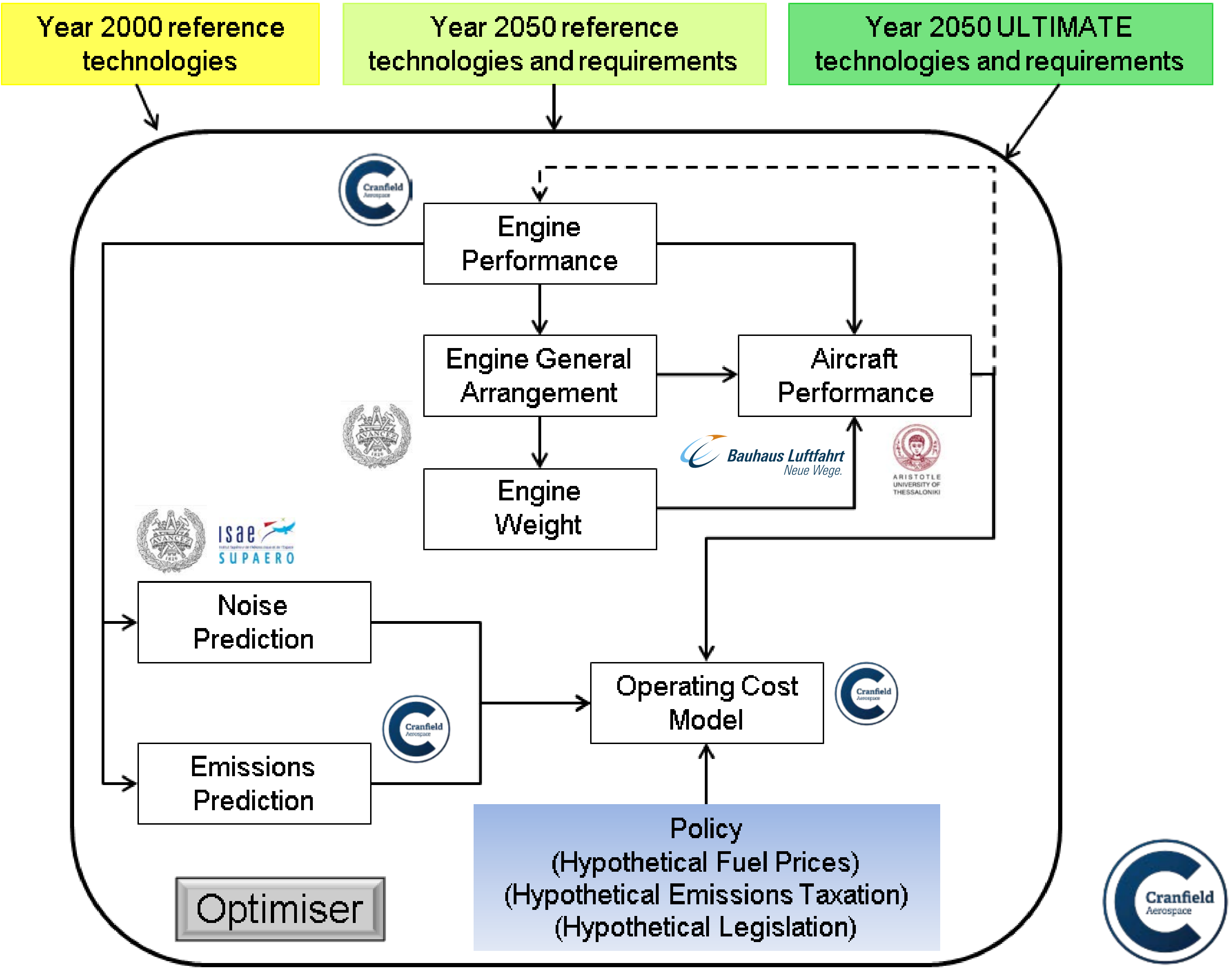
Scientific Approach

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



TERA 2050

Techno-Economic Risk Assessment platform for ULTIMATE



The race is on - Ultimating

	M12		M36
IC + PDC + BP		*Mission fuel burn NOx and noise?*	1
IC + PT + OR		*Mission fuel burn NOx and noise?*	2
IC + ND + OR		*Mission fuel burn NOx and noise?*	3

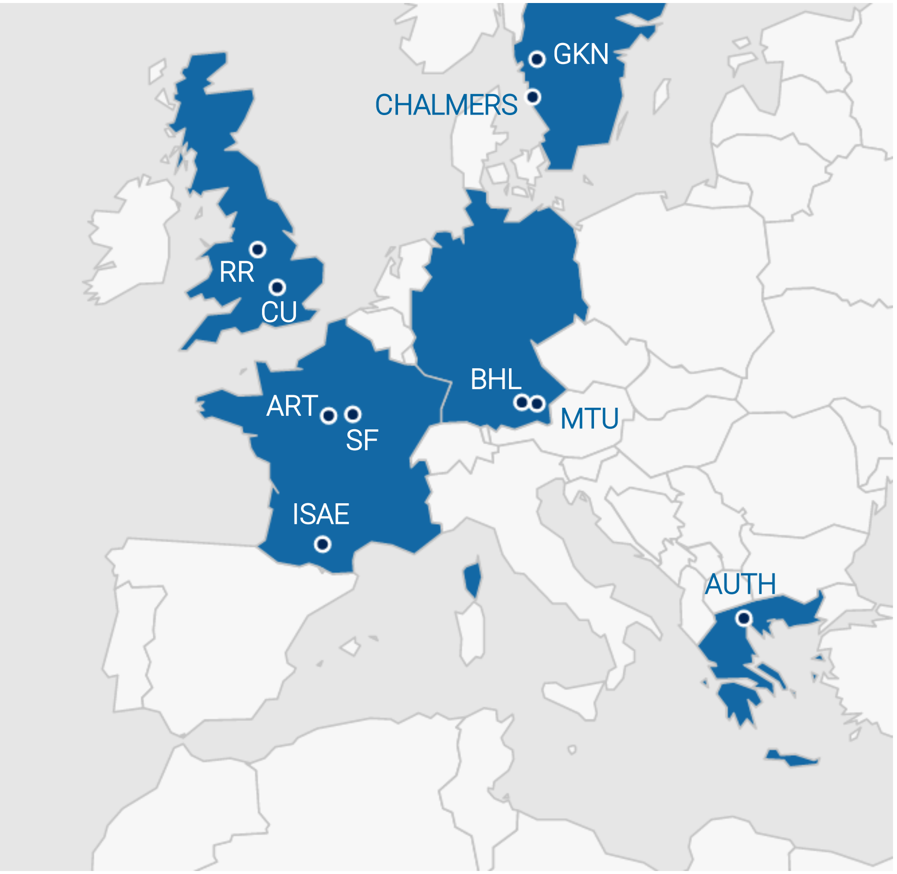
The Champ (s)!

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, CO_2, Noise
  - Methods for assessment
- Support on technology roadmapping

The Consortium

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



Thank you!