ULTIMATE - A Chalmers led European effort on ultra-efficient propulsion

ULTIMATE
core engine technologies

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

ULTIMATE

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 Industries, 4 Universities, 1 research institute and 1 technology management company)
- **Coordination:** Chalmers University of Technology

Success Stories

The most recent Success stories from EU Research.

GKN AEROSPACE

AVANCEZ 1829

MTU Aero Engines

Bauhaus Luftfahrt Neue Wege.

ARISTOTLE UNIVERSITY OF THESSALONIKI

Rolls-Royce

Cranfield Aerospace

SAFRAN

ISAE SUPAERO

ARTTIC INTERNATIONAL MANAGEMENT SERVICES

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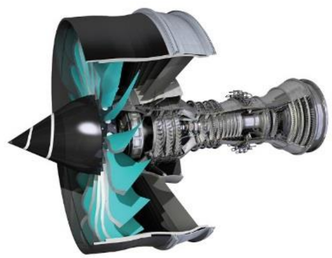
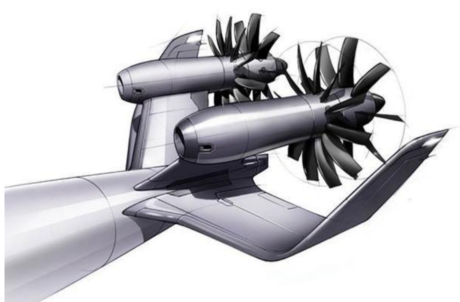
Year 2050 projections



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



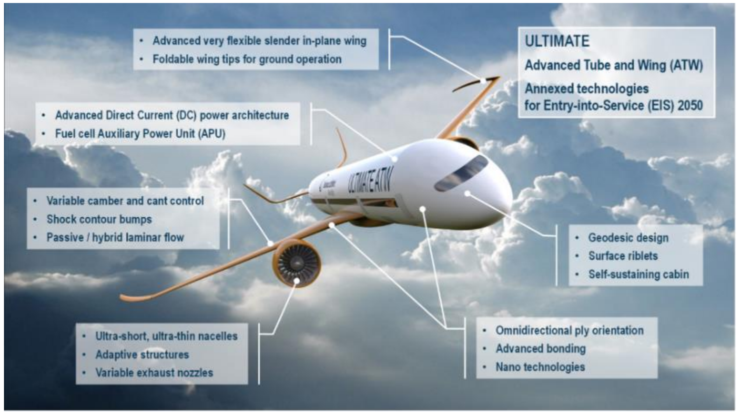
Intra-European configuration

Technology assumptions for 2050

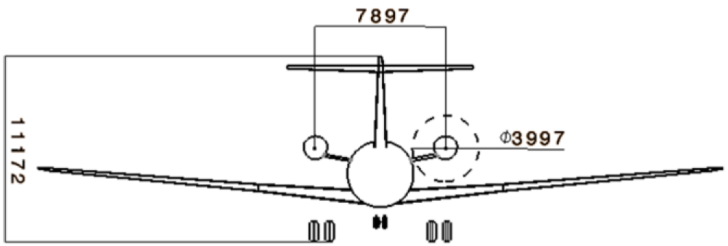
- Turbomachinery efficiency;
- High Pressure Turbine Temperature Capabilities;
- Characterization of Heat exchangers;
- Weight estimation and structural considerations
- Reference cycles

GKN AEROSPACE Rolls-Royce SAFRAN MTU Aero Engines

Year 2050 projections



Intercontinental



Intra-European configuration

- For the intercontinental year 2050 reference, we got a 45% fuel burn reduction to year 2000
- For the intra-European year 2050 reference, we got a 59% fuel burn reduction to year 2000
- ULTIMATE technologies are measured against these reference configurations
- Non-linear trade factors developed to decouple aircraft and propulsion simulations

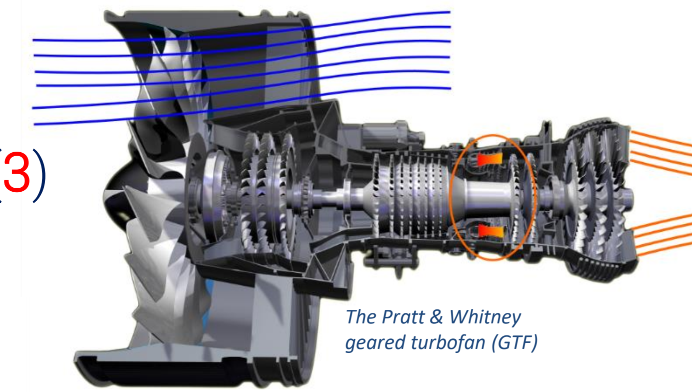
P. Heinemann, P. Panagiotou, Patrick Vratny, S. Kaiser, M. Hornung and K. Yakinthos, "Advanced Tube and Wing Aircraft for Year 2050 Timeframe," in 55th AIAA Aerospace Sciences Meeting , Grapevine, Texas, USA, 2017

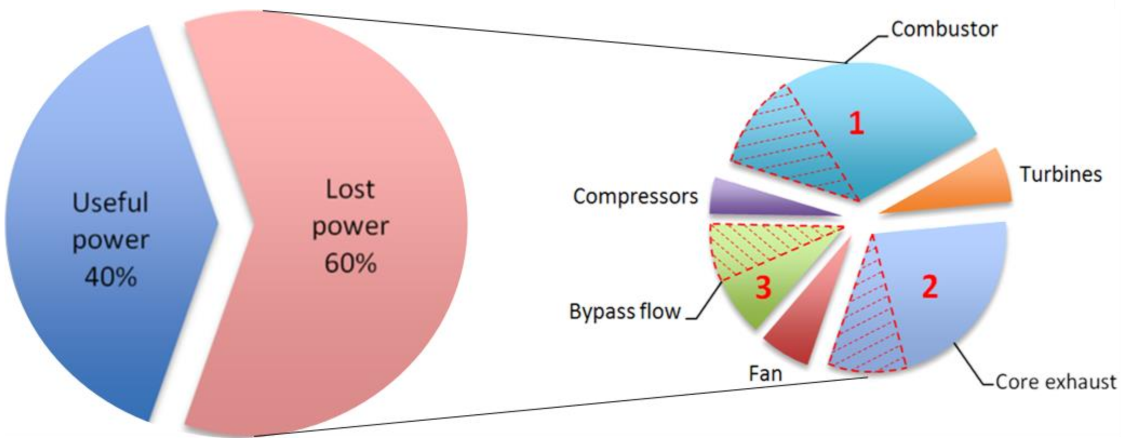
Approach

Losses in a 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)


The Pratt & Whitney geared turbofan (GTF)



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"

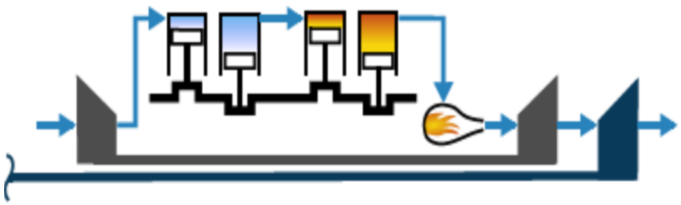
Grönstedt, T., Irannezhad, M., Lei, X., Thulin, O., Lundbladh, A., "First and second law analysis of future aircraft engines".Journal of Engineering for Gas Turbines and Power",136 (3), 2014

Grönstedt, Tomas, et al. "Ultra Low Emission Technology Innovations…" ASME Turbo Expo 2016, GT2016-56123

1. Combustor Irreversibility

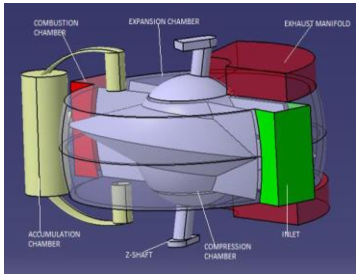
Attack loss source #1

- Piston based composite cycles



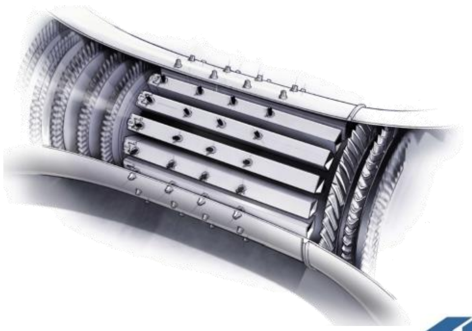
MTU Aero Engines · Bauhaus Luftfahrt Neue Wege.

- Nutating disc composite cycles



Cranfield Aerospace · Rolls-Royce

- Pulse detonation combustion



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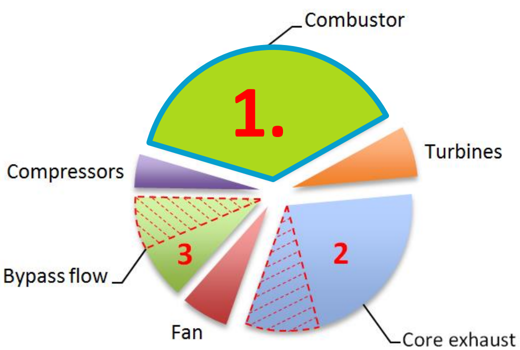
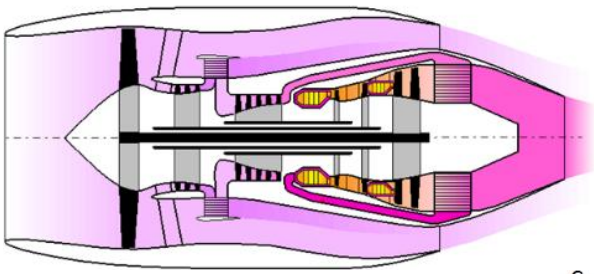


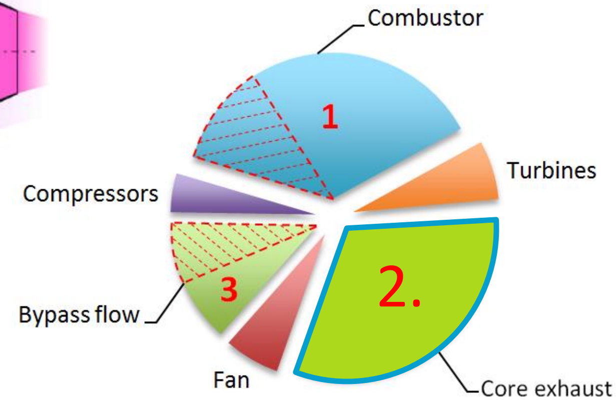
2. Core exhaust heat losses

Attack loss source #2

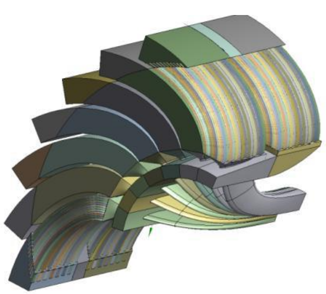
- IC/Recuperation, with inter turbine burning



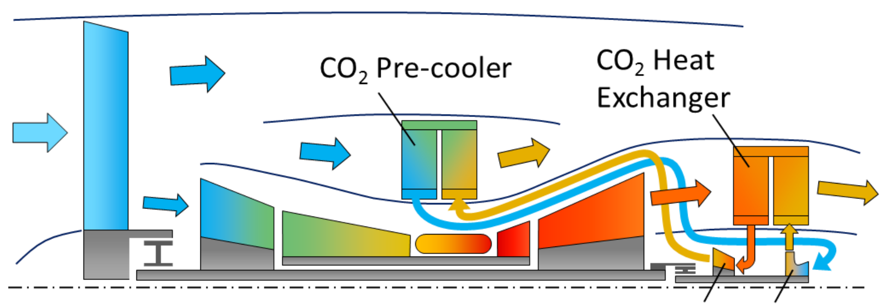
Goulas, A., Donnerhack, S., Flouros, M., Missirlis, D., Vlahostergios, Z. and Yakinthos, K. "Thermodynamics cycle analysis, pressure loss and heat transfer assessment of a recuperative system for aero engines", Journal of Engineering for Gas Turbines and Power, Vol. 137, 041205-1, (2015).



- Intercooling



- Bottoming cycle

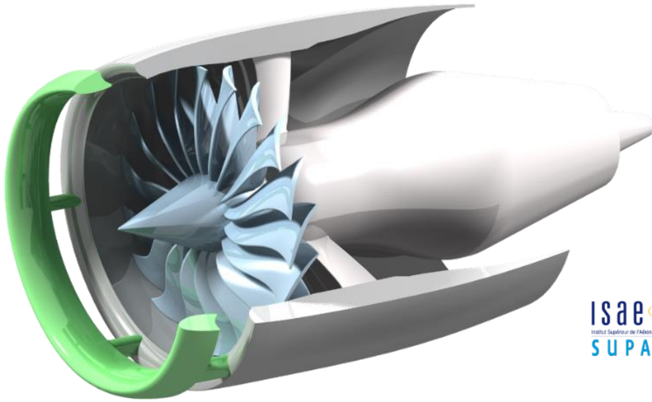


Geared Turbofan Engine with Supercritical CO_2 Turbine + Compressor

3. Excess of Kinetic Energy

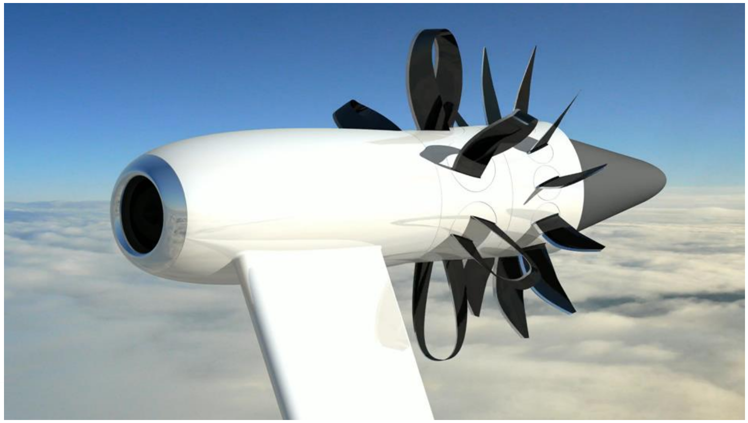
Attack loss source #3

- Slotted nacelle concept



The Boxprop

- Potential to reduce noise, by drastically reducing tip vortex strength.
- Retain propulsive advantages of standard open rotor configuration



Wake energy analysis method applied to the Boxprop propeller concept, Capitao Patrao, A., Grönstedt T., Avellán, R., Lundbladh, A., Aerospace Science and Technology, Aerospace Science and Technology, vol. 79, 2018

Exploring synergies

Synergies and down-selection

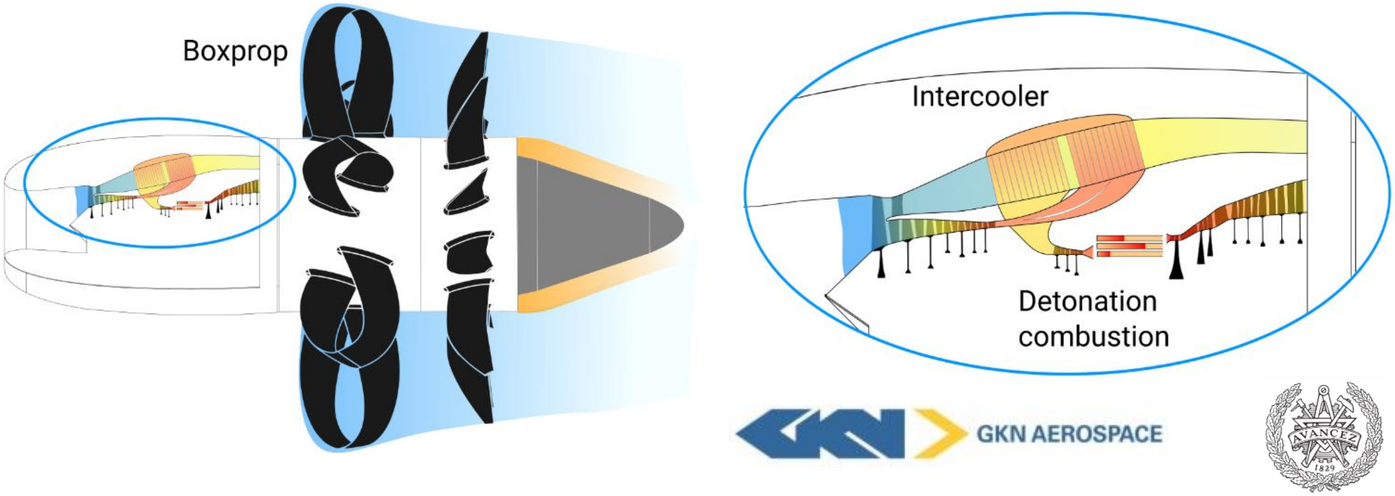
- Combine large loss attackers
- Isolate concepts where synergies exist

	Major cycle variants			Bottoming cycles	
Recuperation	Primary combustion	Intercooled	Secondary combustion	No bottoming	Bottoming
NO	Constant pressure	NO	NO	Reference Brayton	Supercritical CO_2 [13]
			YES		
		YES	NO		
			YES		
	Pressure rise combustion	NO	NO		
			YES		
		YES	NO	Intercooled press. rise [14, 15]	
			YES		
	Pressure rise with power off-take	NO	NO		
			YES		
		YES	NO		
			YES		Air bottoming [12]
YES	Constant pressure	NO	NO		
			YES		
		YES	NO	IRA engine [8, 14]	
			YES		
	Pressure rise combustion	NO	NO		
			YES		
		YES	NO		
			YES		
	Pressure rise with power off-take	NO	NO		
			YES		
		YES	NO		
			YES		

Positive synergy exists

Boxprop, intercooling & PDC

- Conceptual design observations
  - **Modest OPR** in the open-rotor configuration results in **substantial fuel-burn improvements** with pulsed detonation combustion alone

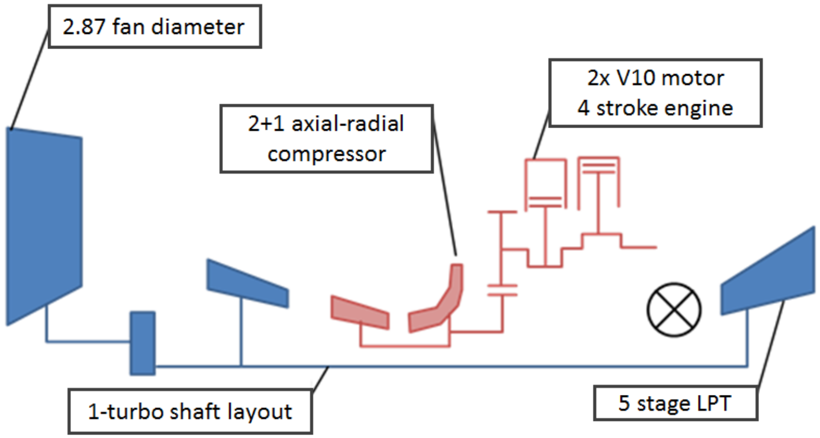


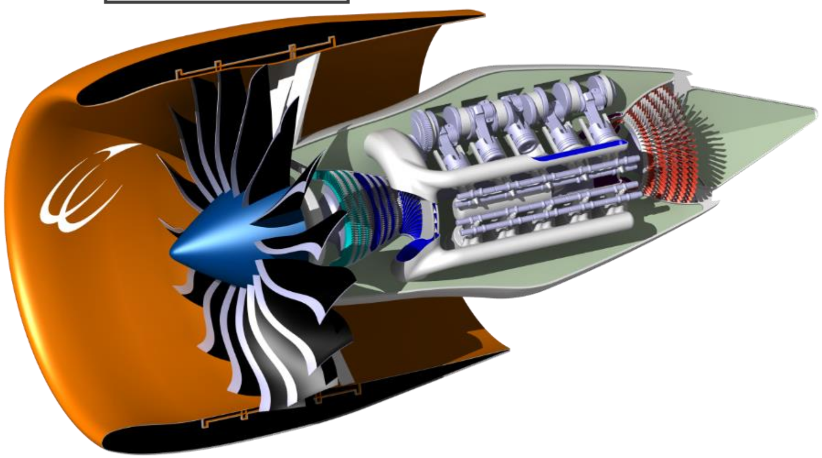
  - Delta fuel burn over year 2050 reference is up to -10.0%

Intercooled composite cycle engine

Key findings:

- Intercooling drastically reduces CCE´s weight and thus improves fuel burn
- Recuperation extensively investigated but no benefit found
- **Two banks** of **four stroke V-10 piston engines** drive the HPC. The piston engines can be fit inside the core engine cowling.
- **Buffering volumes before and after** piston engine section to balance piston engine pressure fluctuations

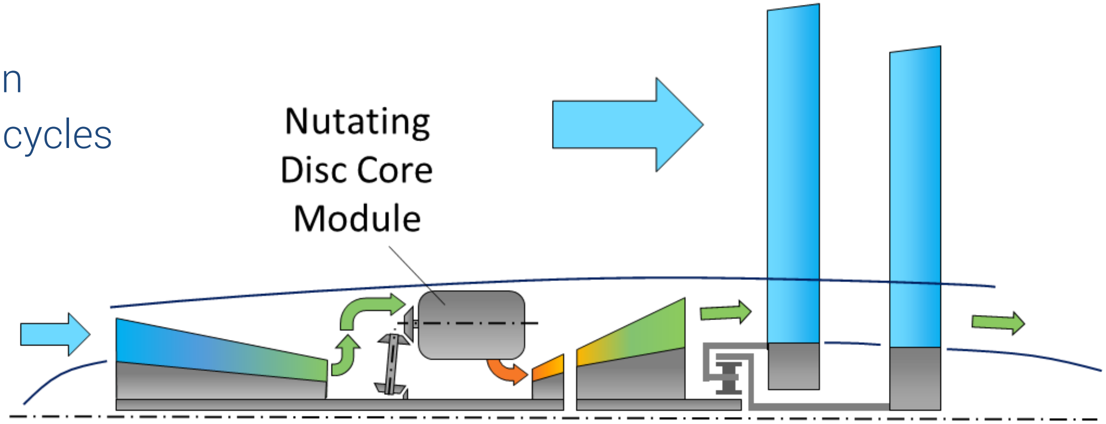




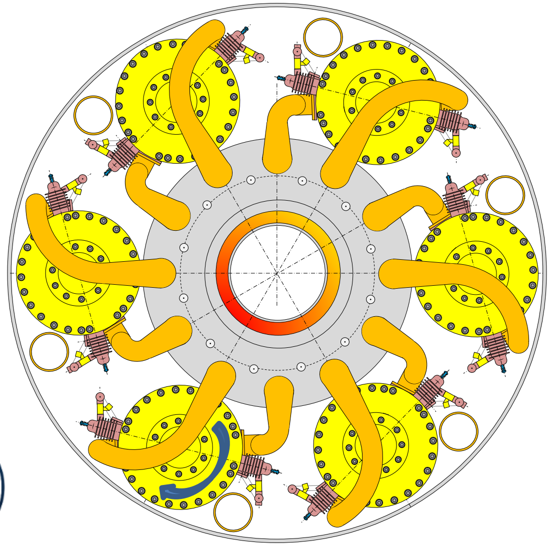
- ***Delta fuel burn over year 2050 reference is 12.5%***

Nutating disc topping

- Nutating disc topping combustor to:
  - Establish pressure rise combustion
  - Constant volume combustor type cycles gives cold core exhaust
- Key findings:
  - Higher power density leads to a reduced weight penalty as opposed to Piston concepts.
  - Intercooler may not provide sufficient benefit to pay its way onto the engine
- Key challenges:
  - Accurate estimation of the overall weight.
  - Accurate prediction of the heat release in the combustion chamber at design and off-design conditions
- Delta fuel burn over year 2050 reference is close to 15.0%



Geared Open Rotor Engine with Nutating Disc Core Modules

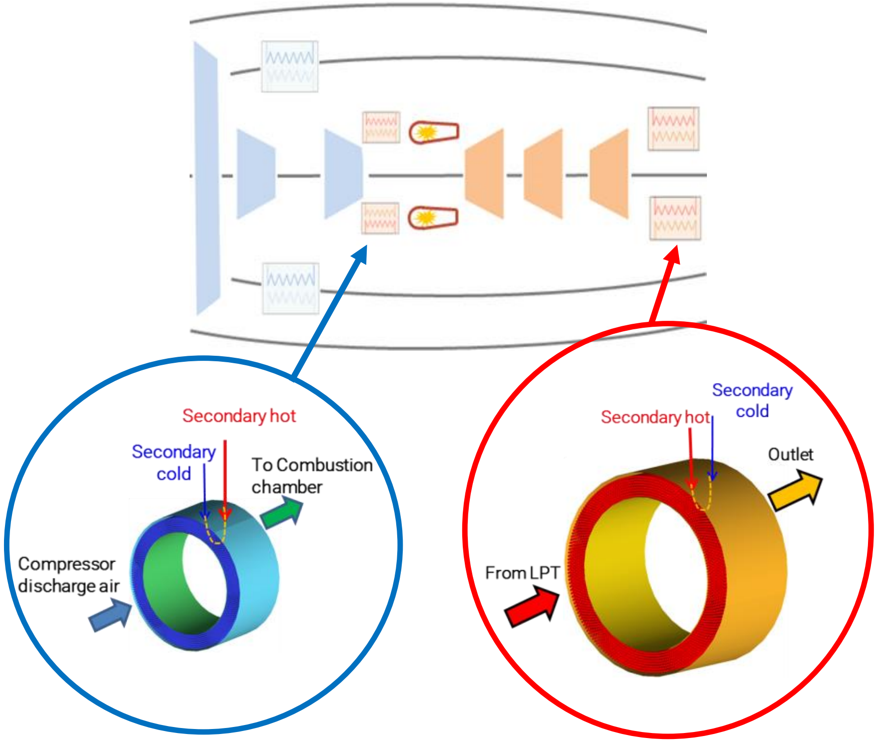


Intercooled recuperation with secondary fluid recuperation

- **Key synergies exploited:**
  - Recuperation using a secondary fluid
  - Intercooling

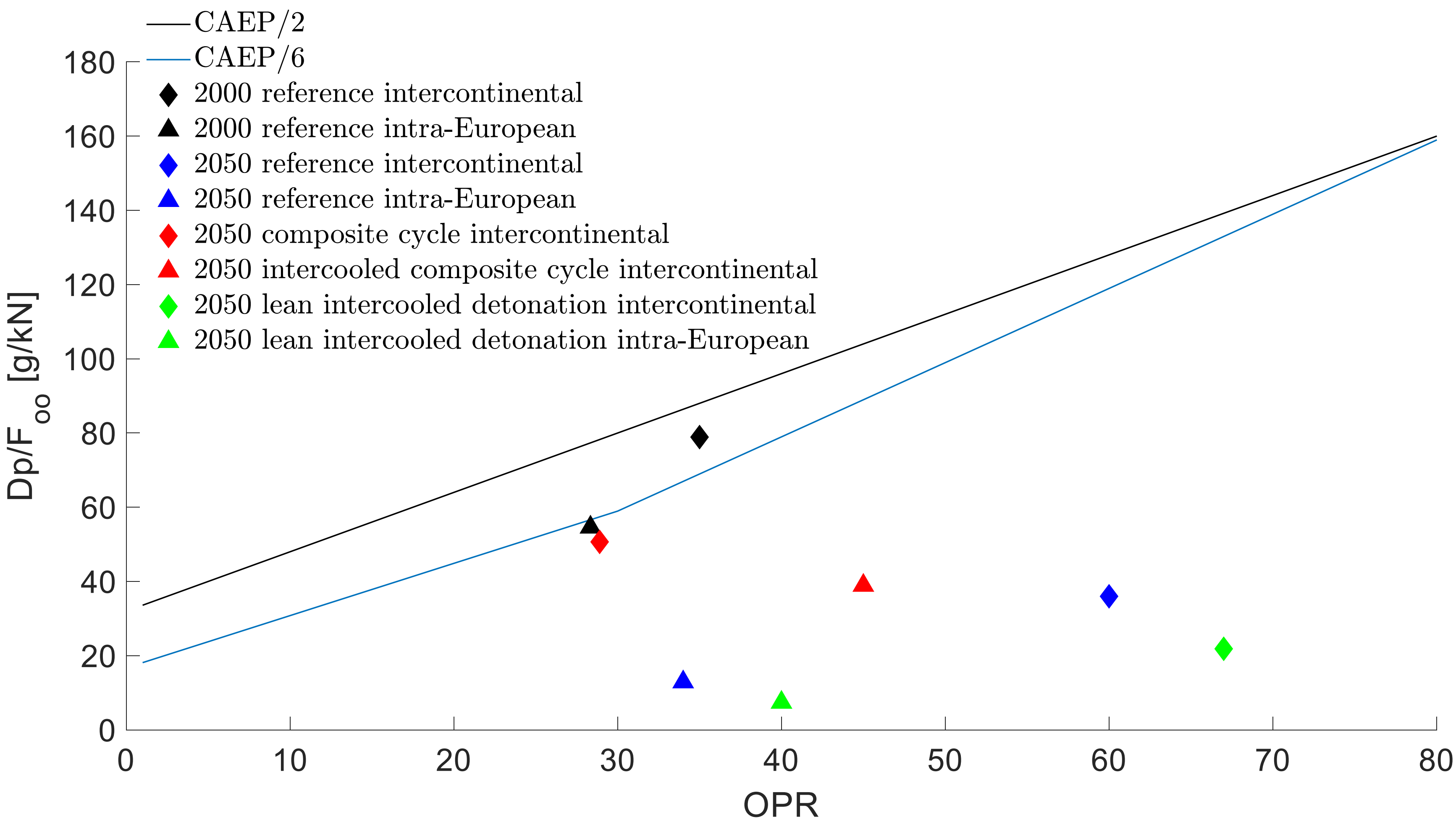
- **Key findings:**
  - Increased heat transfer using a secondary fluid with favourable heat transfer properties
  - Independent optimization of the secondary fluid system for heat transfer enhancement

- **Key challenges:**
  - Secondary fluid compatibility with recuperators materials and safety treatment
  - Recuperators weight and volume reduction

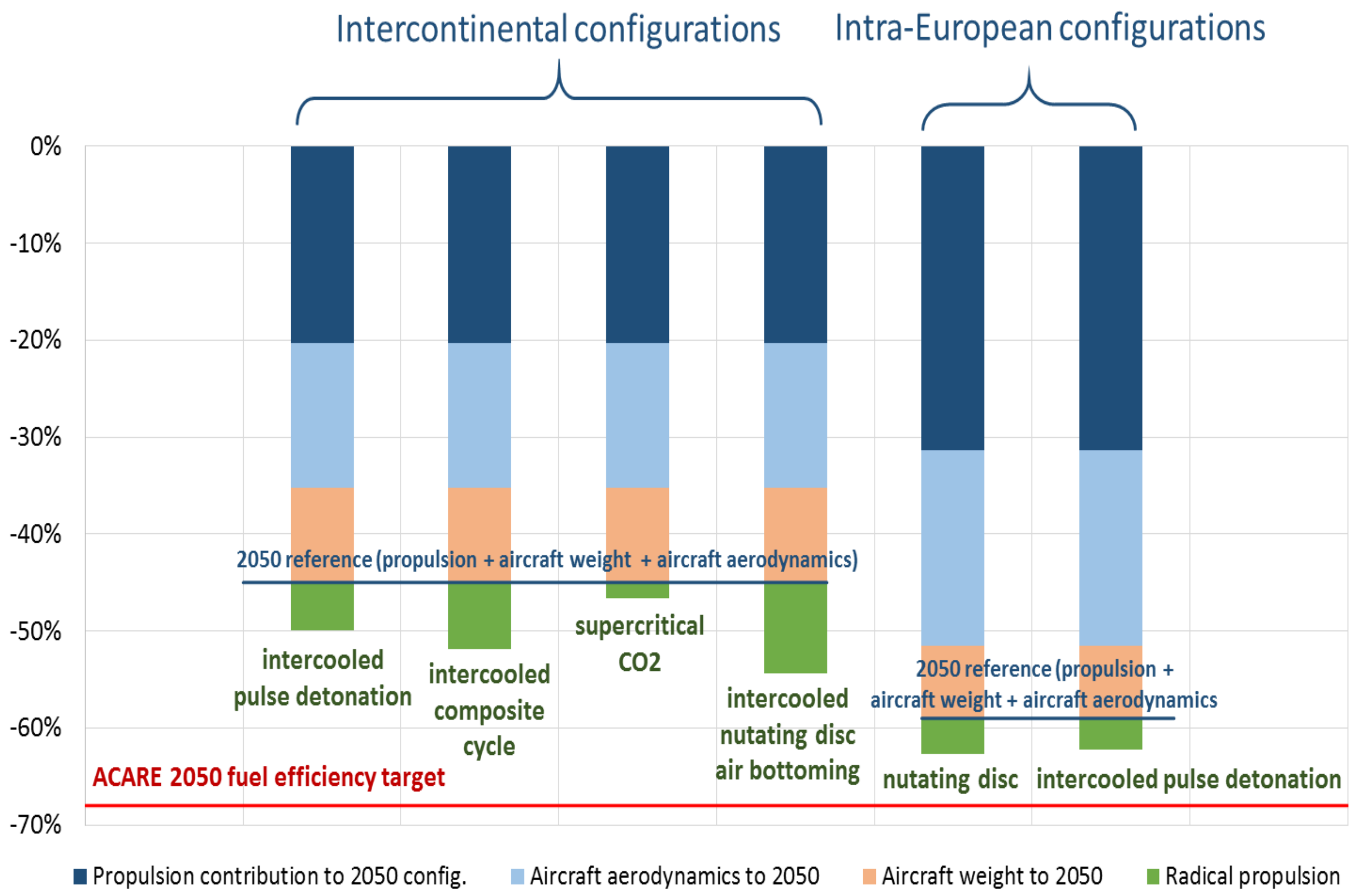


- **Delta fuel burn decrease over year 2050 reference is up to: ~ -5%**

NO_x emissions



CO_2 emissions reductions potential



Conclusions

Liquid fuels will dominate for the better part of 21st century

- Efficient cores are needed for radical airframe-, turbo-electric, hybrid propulsion and cryogenic scenarios as well
- Additionally, increasing fuel price => radical core concepts should be realized

Double digit fuel burn improvements observed for all constant volume variants

- Should be designed to minimize vibration, sealing loss and avoid high heat rejection to oil, and achieve all this at an exemplary reliability.
- Way forward for ultra efficient cores

Despite unprecedented propulsion efficiency & extensive tech. inclusion SRIA2050 not reached

- Will require a more radical airframe.

Thank you!

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

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