DLRK 2024 Presentation

EXACT Sustainable Aircraft Concepts Results and Comparison

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EXACT Concept Exploration

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Which concepts have the potential to drastically reduce aviation's climate impact while maintaining a high economical competitiveness?

Green energy
- Energy carrier production
- Energy carrier transport
- Energy carrier storage
- Airport infrastructure

Climate impact
- In-flight emissions
- Ground based emissions
- Manufacturing / End-of-Life

Future air-traffic demand
- Fleet network optimization
- Maintenance
- Ground handling

Aircraft Design
- Propulsion architectures
- On-board systems
- Structural design

Focus of the presentation

- Funding Volume: 20M€
- Consortium: 20 DLR Institutes

„Overall Aircraft Design Integration“ Task Description

Goals:

- Identify the most promising aircraft concepts for climate impact reduction.
- Provide aircraft models for global fleet analysis of cost and climate impact, including life cycle assessment.

Boundary conditions:

- Focus two aircraft classes: short-range and regional class.
- No limits on the aircraft configuration.
- All energy carriers and propulsion power providers can be considered.

Open and extremely complex task.

„Overall Aircraft Design Integration“ Background

START

At the starting line (2020) :

- ✓ Good level of publically available knowledge and methods on conventional aircraft design & hybrid-electric design of kerosene-driven aircraft.
- ✗ Little available knowledge / capabilities on aircraft modelling with alternative energy carriers and power providers.
  E.g. LH2 aircraft, fuel cell aircraft.
- ✗ Little available knowledge / capabilities on transonic turboprop design
- ✗ Not a usual project practice on consistently comparing multiple concepts of different propulsion technologies & at different aircraft classes – many tool & know-how gaps to be filled.

Many knowledge & tool gaps to be filled for completing the modelling goals.

Overall Aircraft Design

EXACT Final Concepts Overview

Short-Range Single-Aisle		Regional	
250PAX, Design Range = 1500nm		70PAX, Des. Range = 1000nm	
Turbofan (Ma=0.78) 	Turboprop (Ma=0.66) 	Turboprop (Ma=0.55) 	SynFuel
Turbofan Mild-Hybrid (Ma=0.78) 	Turboprop Mild-Hybrid (Ma=0.66) 	Fuel-Cell (Ma=0.55) 	LH2
	Plug-In Hybrid (Ma=0.66) 	Plug-In Hybrid (Ma=0.55) 	Battery + SynFuel

EIS 2040 for all concepts

The best concepts from the project downselection result.

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Propulsion Architecture Overview

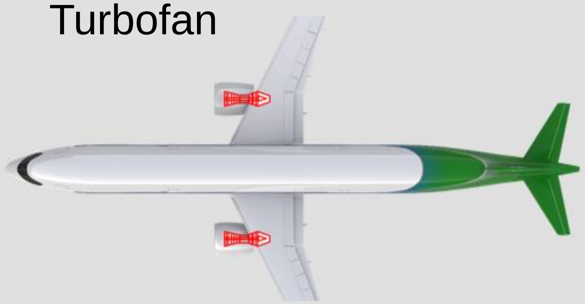
	Short Range		Regional	
	Turbofan	Turboprop	Turboprop	SAF
	Turbofan Mild-Hybrid	Turboprop Mild-Hybrid	Fuel-Cell	LH2
			Plug-In Hybrid	Battery + SAF

SAF

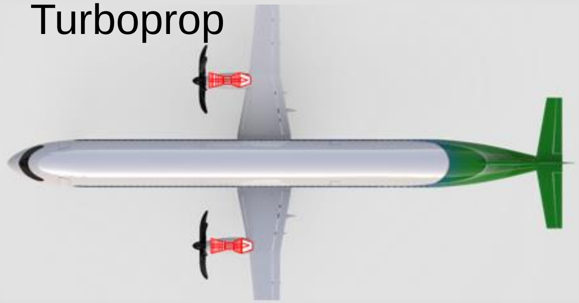
Modelling:

- **Conventional technology (gas-turbine propulsion).**
- **Only Evolutionary advancements**

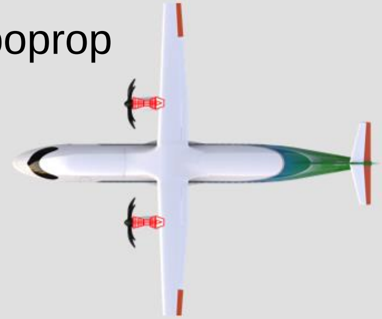
Turbofan



Turboprop



Turboprop



LH2

Tank gravimetric index (including systems):

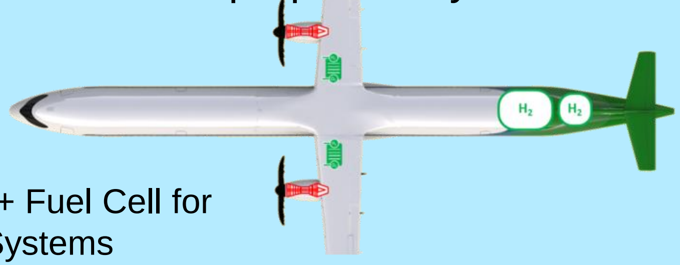
- **Short-range: ~53%**
- **Regional: ~35%**

Fuel cell stacks (500kW class) 1.5kW/kg, efficiency:

- **47% @ Full load**
- **56% @ 20% load**

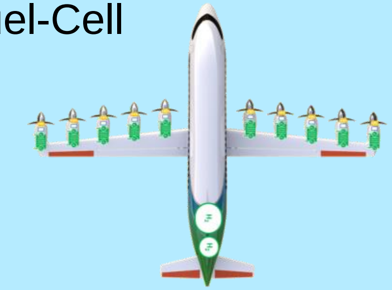
Turbofan Mild-Hybrid

Turboprop Mild-Hybrid



LH2 **Direct Burn** + Fuel Cell for On-Board Systems

Fuel-Cell



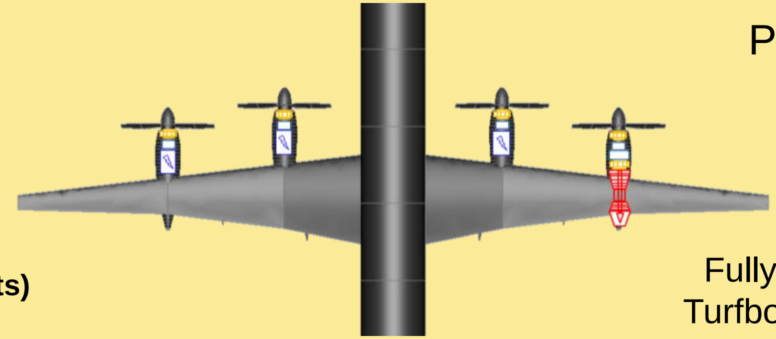
Battery + SAF

Batteries:

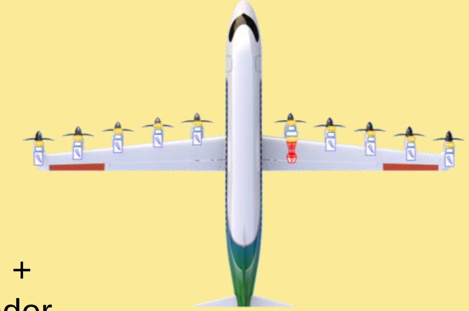
- **500Wh/kg battery cells, 400Wh/kg battery pack**
- **3000 cycles (80% EoL), 100€/kWh cells**

Aircraft:

- **~300nm electric range**
- **Range extender gas turbine for mission reserves & range flexibility (same design range as other concepts)**



Plug-In Hybrid



Fully electric propulsion + Turfboshaft Range Extender

Overal Aircraft Design Loops

Year 1 – concept exploration:

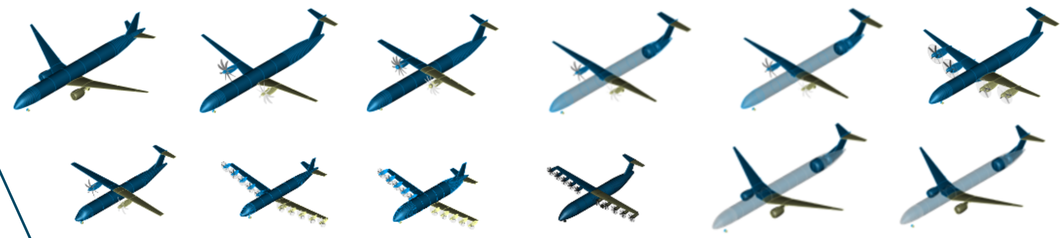
- Conceptual level exploration of different propulsion architectures & aircraft configurations
- Defining interfaces with the participating institutes
- Identifying modelling gaps & development needs

Identifying TLARs & Conceptual-Level Downselection

Year 2 & 3 – setting up the modelling infrastructure:

- Assessing feed-back from the global analysis
- Refine interfaces with the participating institutes
- Creating tools & know-how to ensure consistent modelling of the various aircraft.
- Further downselection

Increasing level of fidelity & further downselection



Year 4 – creating the project results:

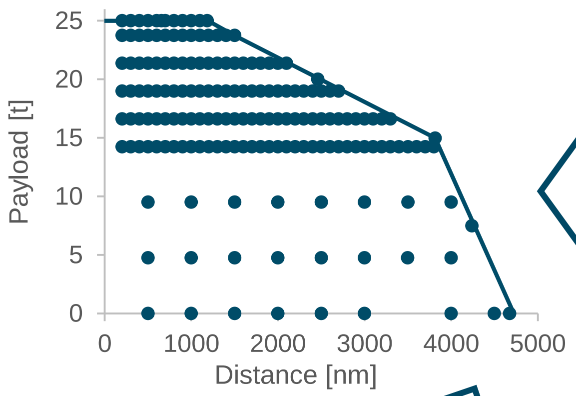
- Final concepts with finalized tools for consistent modelling between the different classes and architectures.
- Optimization in complete loop with the other work-packages.
- Comparison and postprocessing of the results.

Optimizing & Comparing the Final Concepts

Global Fleet-Level Optimization

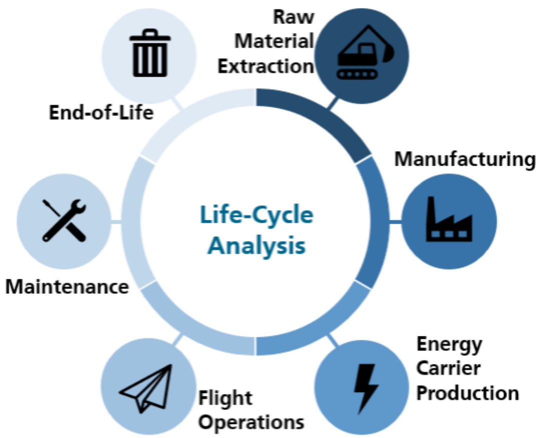
Optimization loop

Aircraft Modelling

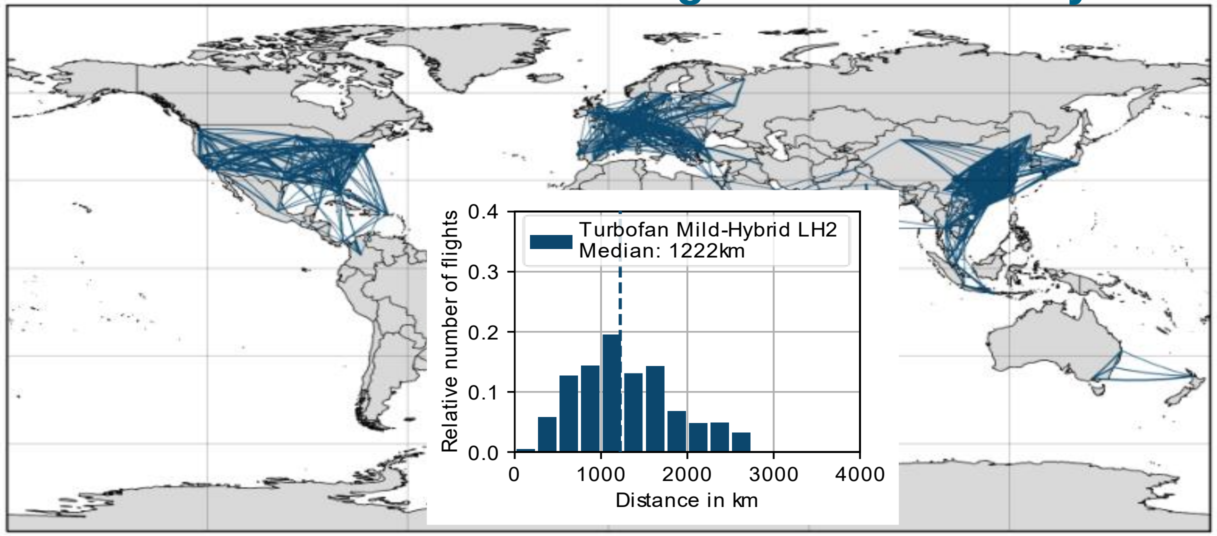


Trajectories including fuel burn and emissions

Materials breakdown



Global Flight Network Analysis



Simulation of global fleet operation

Global-Fleet Analysis:

- **Environmental Impact**
- **Operating Costs**

Collaboration effort of 14 institutes

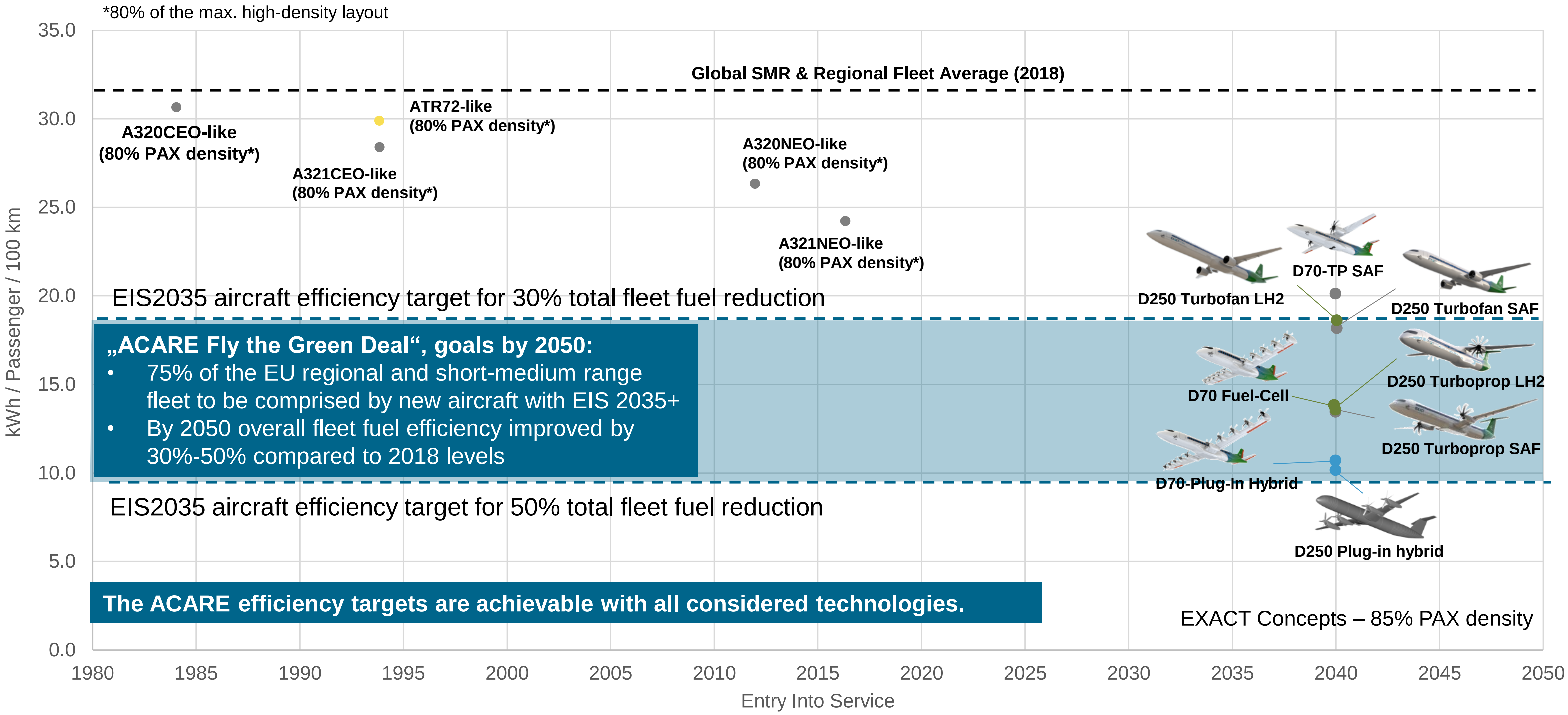
Results and Achievements

WP3 Achievements

At the finish line (2023) :

- The aircraft modelling developed for EXACT achieves fast, consistent and reliable results across different aircraft classes & propulsion system concepts at low-medium level of fidelity & easy to feed back higher fidelity results.
- Achieved a closed-loop hollistic assessment of multiple propulsion concepts, energy carriers and for different aircraft classes.
- The LH2 modelling advanced to complete analysis of the main physical effects and aircraft integration optimization.
- Developed capability in DLR for modelling and optimization of fuel cell and plug-in hybrid aircraft.
- Developed viable battery-driven (plug-in-hybrid) concepts for next-generation battery technology for both the regional and the short-range class.
- The final concepts offer an excellent starting point for the higher-fidelity studies planned in EXACT 2

Aircraft Modelling Results – Efficiency Comparison



Overall Aircraft Integration: Main Take-Aways

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ACARE Efficiency Targets
The ACARE „Fly the green deal“ efficiency goals can be potentially achieved with any energy carrier or propulsion system concept.

SAF vs LH2
SAF concepts are slightly more block-energy-efficient than LH2 concepts. However, LH2 can be a good solution if H2 is significantly cheaper than SAF.

Fuel Cell Aircraft Applications
The fuel cell offers exceptionally high efficiency for the regional aircraft class and is a good option for the mild hybrid concepts of the short-range class.

Battery as the Main Power Provider
The battery as the main energy carrier (combined with a gas turbine range-extender) achieves the best results in terms of energy efficiency and operating cost for both the regional and the short-range class according to the EXACT modelling.

Way Forward → EXACT 2

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Include the Mid- and Long-Range Class in the Studies
A more complete model of the global fleet should further improve the global life-cycle and climate impact analysis

Increase the Systems Architectures Integration Detail Level
The separate elements of the on-board and propulsion systems will be modelled in increased level of detail to decrease the modelling uncertainties.

Increase the Disciplines Level of FIdelity
- Include CFD analysis of the most uncertain configurations.
- Improve the transonic propeller modelling.
- Use higher level of fidelity engine design.

Analyze the Main Uncertainties

Increase the effort of quantifying the technological and modelling uncertainties coming from novel concepts, e.g. the LH2 and the plug-in hybrid designs.

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Thank You for Your Attention!