EASN 2024 Presentation

Ultra-Efficient Short-Range Aircraft Design

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Facts And Challenge

- About **2%** of global energy-related **CO2 emissions** from aviation
- **5%** of current anthropogenic **climate change** caused by global aviation
- Non-CO2 effects play a major role
- Despite increasing global fleet efficiency, aviation's impact is increasing due to the projected growth in aviation
- Operation is the predominant phase in terms of climate impact
- Long-lifetime of aircraft causing long fleet renewing
- Huge investments and long development times needed for new aircraft
- Challenging technical requirements
- Economically viable solutions

The Project EXACT (2020-2023) – Contents

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

- Ressources: 110 Person-Years (over 4 years)
- Consortium: 20 DLR Institutes

EXACT Aircraft Models

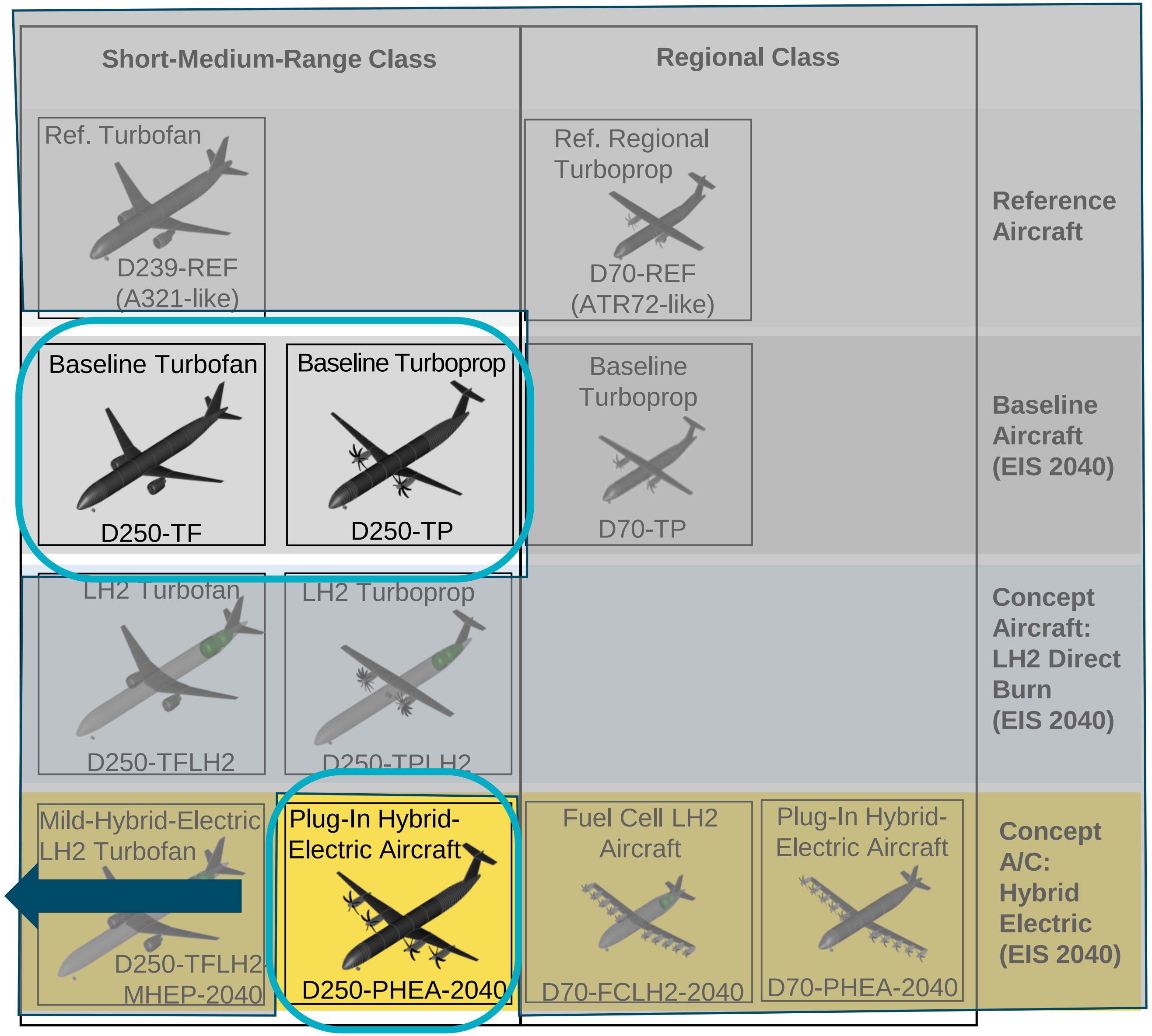
Aircraft Design Work Package:

- Expand tools and know how for consistent aircraft design throughout different aircraft classess and a multitude of concepts.
- Explore aircraft design synergies and market sweet-spots for different power providers and energy carriers at each aircraft class.
- Focus on most fitting concepts for reduced climate impact combined with market competitiveness.

The study **„speed vs sustainability"** lead to improved understanding of the effects and enablers of switching to subsonic flight at the larger aircrat classes!

Battery-electric flight with a range-extender gas turbine to reduce fuel consumption and significantly increase efficiency on short distances.

„EXACT" Project Aircraft Models



Aircraft Design Boundary Conditions

Reference A/C:

A321neo
interpretation
(EIS2016)

Top-Level-Aircraft Requirements (TLARs)

Design Range	[nm]	2500
Design PAX (single class)	[-]	239
Max. Payload	[kg]	25000
Cruise Mach Number	[-]	0.78
TOFL (ISA +0K SL)	[m]	2200
Approach Speed (CAS)	[kt]	136
Wing span limit	[m]	<=36

Redesign for EIS2040:

- **TLARS:**
  - Range 1500nm
  - TOFL (ISA +0K SL) 1900m
  - 250 PAX; Design Payload 23750kg
  - Approach speed <140kts
- **Technology factors:**
  - Gas turbine +5% efficiency
  - Fuselage mass -5%
  - Empennage Mass: -8%
  - CFRP Wing
    with foldable wing tips
  - Bleedless systems architecture

EXACT Turbofan Baseline

EXACT Turboprop Baseline

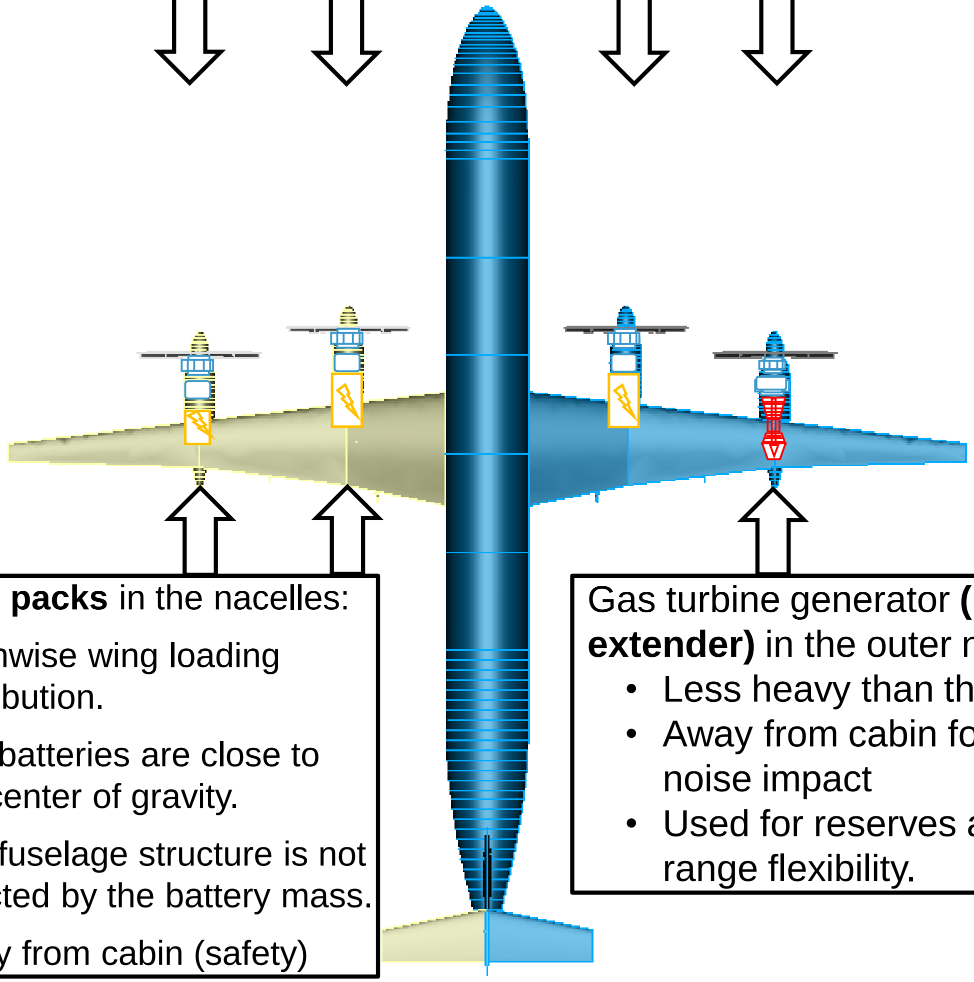
Design specific → Mach 0.66

D250-PHEA (Plug-In Hybrid-Electric Aircraft)

- Ma = 0.66
- Battery size optimized for cost in the sort-range operational network
- Fully electric flight capability

Overall Configuration

4 x propellers of **identical geometry (mirrored).**
D=6m, max. prop area → higher efficiency
4 x geared e-motors **of identical power**
→ designed for fully electric flight



Battery packs in the nacelles:

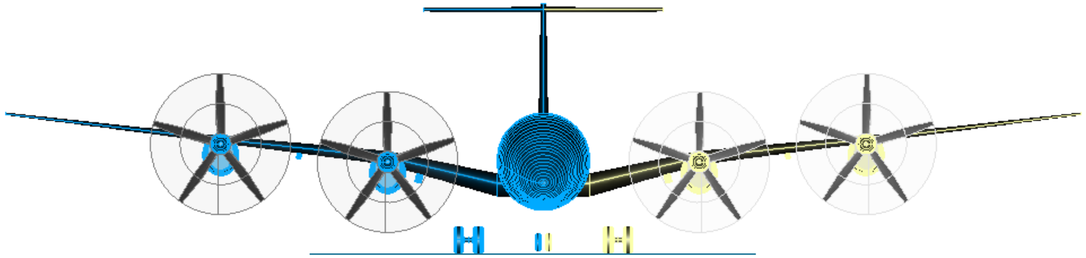
- Spanwise wing loading distribution.
- The batteries are close to the center of gravity.
- The fuselage structure is not affected by the battery mass.
- Away from cabin (safety)

Gas turbine generator **(range extender)** in the outer nacelle:

- Less heavy than the battery
- Away from cabin for less noise impact
- Used for reserves and range flexibility.

A/C Mass: 103t
Propulsion mass: 36t
Battery mass: 27t

Tot. Mass = 5t	**Tot. Mass = 13 t**	**Tot. Mass = 13 t**	**Tot. Mass = 5t**
• Prop: 330kg	• Prop: 330kg	• Prop: 330kg	• Prop: 330kg
• Nac. 720 kg	• Nac. 620 kg	• Nac. 620 kg	• Nac. 720 kg
• E-Mot: 450kg	• E-Mot: 450kg	• E-Mot: 450kg	• E-Mot: 450kg
• Gent-Set: 3500kg	**• Bat: 11500kg**	**• Bat: 11500kg**	**• Bat: 3500kg**



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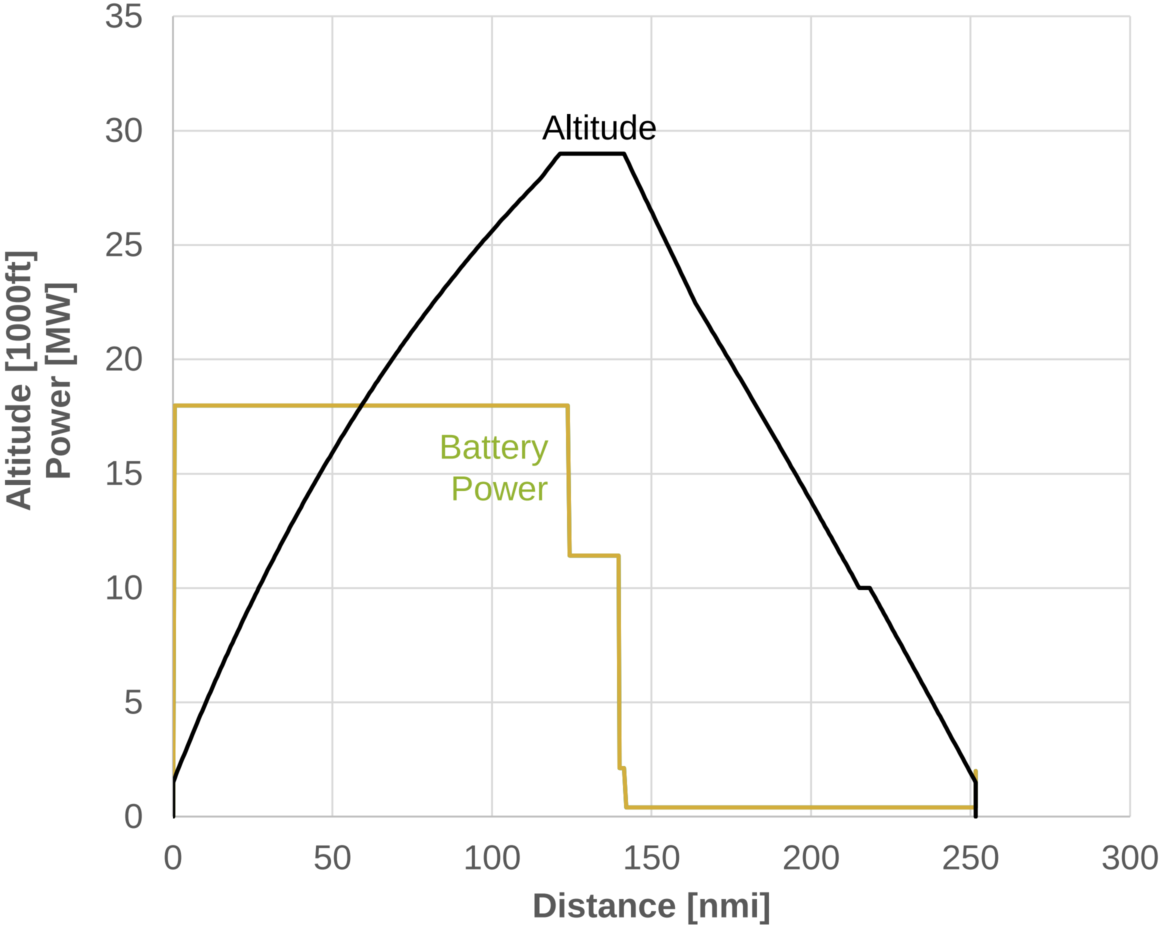
Battery Technology Assumptiont

- 500Wh/kg battery cells (next generation technology)
- 400Wh/kg battery pack (25% battery pack mass penalty)
- 90% State of charge at the start of the mission
- 20% State of charge at the end of the mission

→ **280Wh/kg effective battery pack energy**

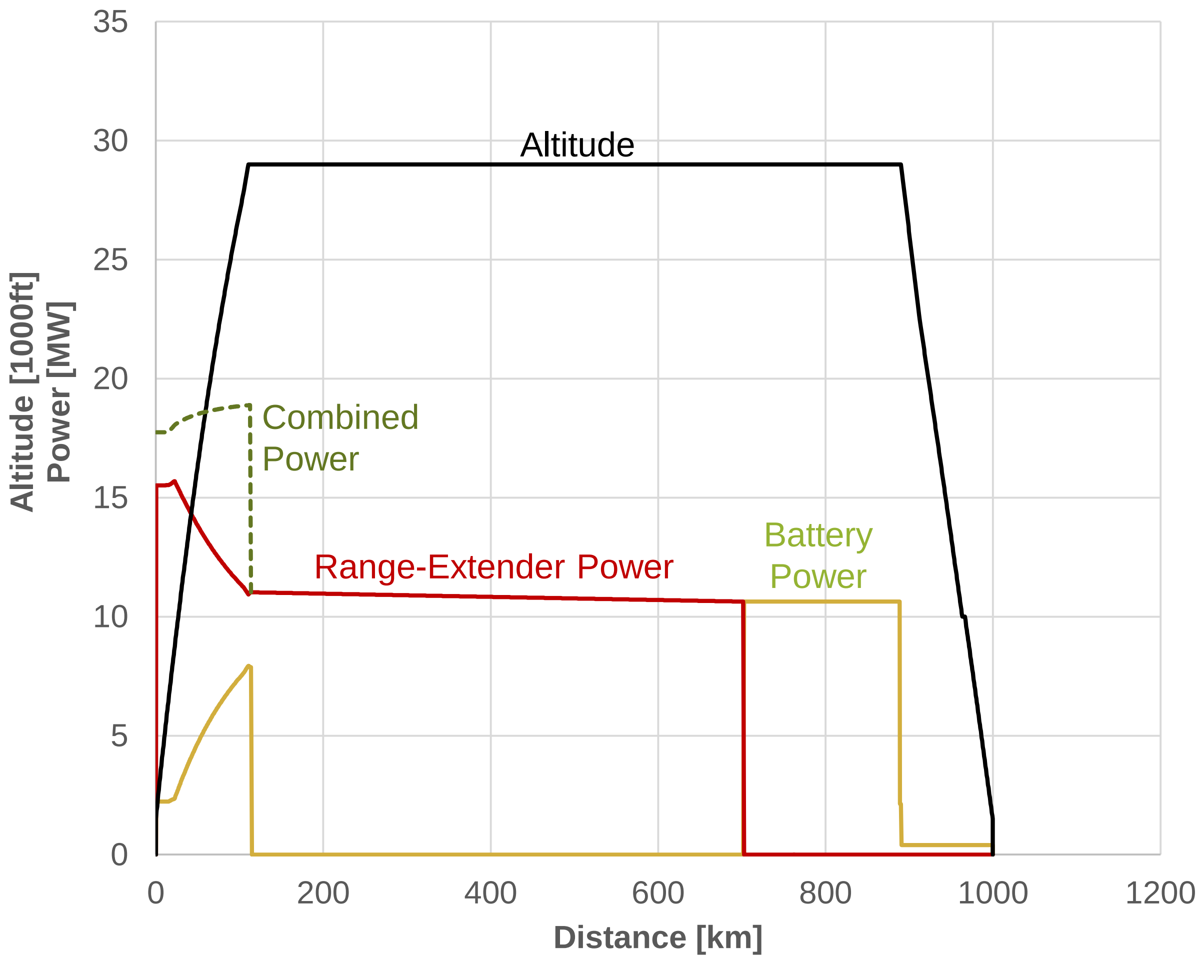
D250-PHEP Power Profile – Electric Mission



- The mission is flown only with battery energy, including taxi, take-off, approach and landing.
- The gas turbine is not used for the main mission but will be started in case reserves are needed.
- Sufficient fuel is carried in case a diversion after the mission is needed.
- ~20% battery capacity remains after the mission

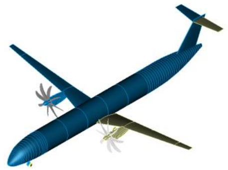
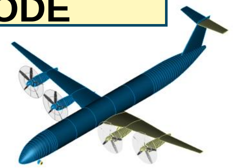
  5% contingency + sufficient energy for electric go-around (to allow starting the gas turbine)

D250-PHEP Power Profile – Range-Extender Mission



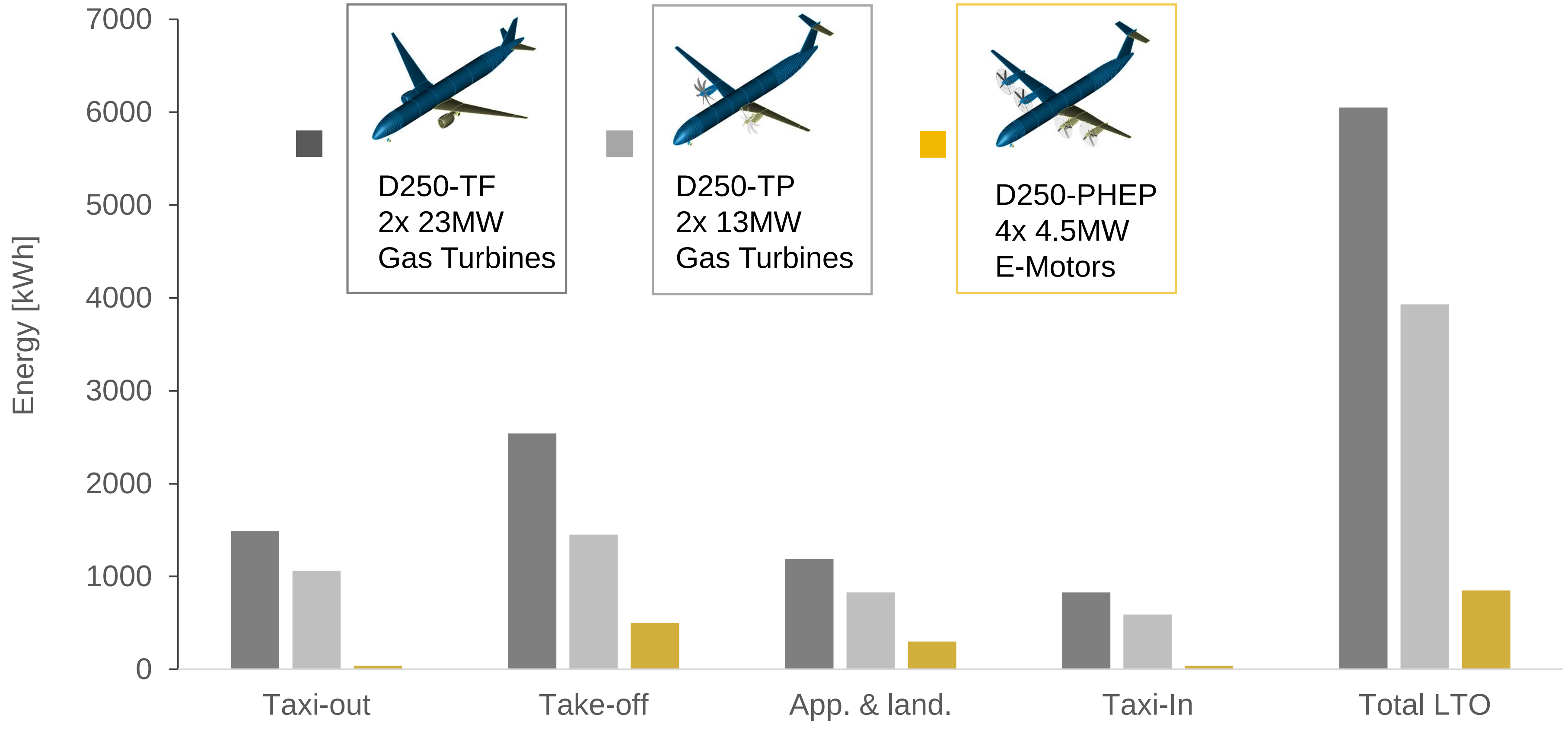
- After electric taxi and takeoff, the fuel is burned, making the aircraft lighter. Sufficient fuel for the reserve mission is spared.
- After the fuel for the main mission is burned, the flight continues electrically without turning on the gas turbine again (except in case of a diversion).
- Should the gas turbine fail during the range-extender phase, the aircraft can divert electrically with ~300nm diversion radius.
- Since the electric flight starts from cruising altitude, the electric distance is around 300nm, which is the possible diversion radius in case the gas turbine fails.
- Sufficient fuel is carried in case a diversion after the mission is needed.
- ~20% battery capacity remains after the mission (contingency + go-around)

Cruise Efficiency Comparison

	MASS (mid-cruise)	L/D	THRUST	ETA PROP	Different speed	Speed-Independent Parameter: $\frac{P_{shaft}}{V}$	ETA TRANSM	ETA POWER	Energy / Distance
 Turbofan Baseline	76.4 t	19.9	37.7kN	0.76	FL350 Ma0.78	13.7 kWh/km	Gearbox: 0.994	**Gas Turb. 0.526**	**26.3 kWh/km**
 Turboprop Baseline	72.6 t (-5%)	21.7	32.8kN (-13%)	0.84	FL310 Ma0.66	10.8 kWh/km (-21%)	Gearbox: 0.985	**Gas Turb. 0.50**	**22 kWh/km (-16%)**
D250-PHEA  **ELECTRIC MODE**	103 t (+35%)	22.1	45.7kN (+21%)	0.86	FL310 Ma0.66	14.7 kWh/km (+7%)	E-Mot: 0.977	**Battery.: 0.90**	**16.8 kWh/km (-36%)**
RANGE EXTENDER MODE	100 t (+31%)	21.9	44.8kN (+19%)	0.86		14.4 kWh/km (+5%)	Turbo-electric: 0.958	**Gas Turb.: 0.53**	**28.2 kWh/km (+7%)**

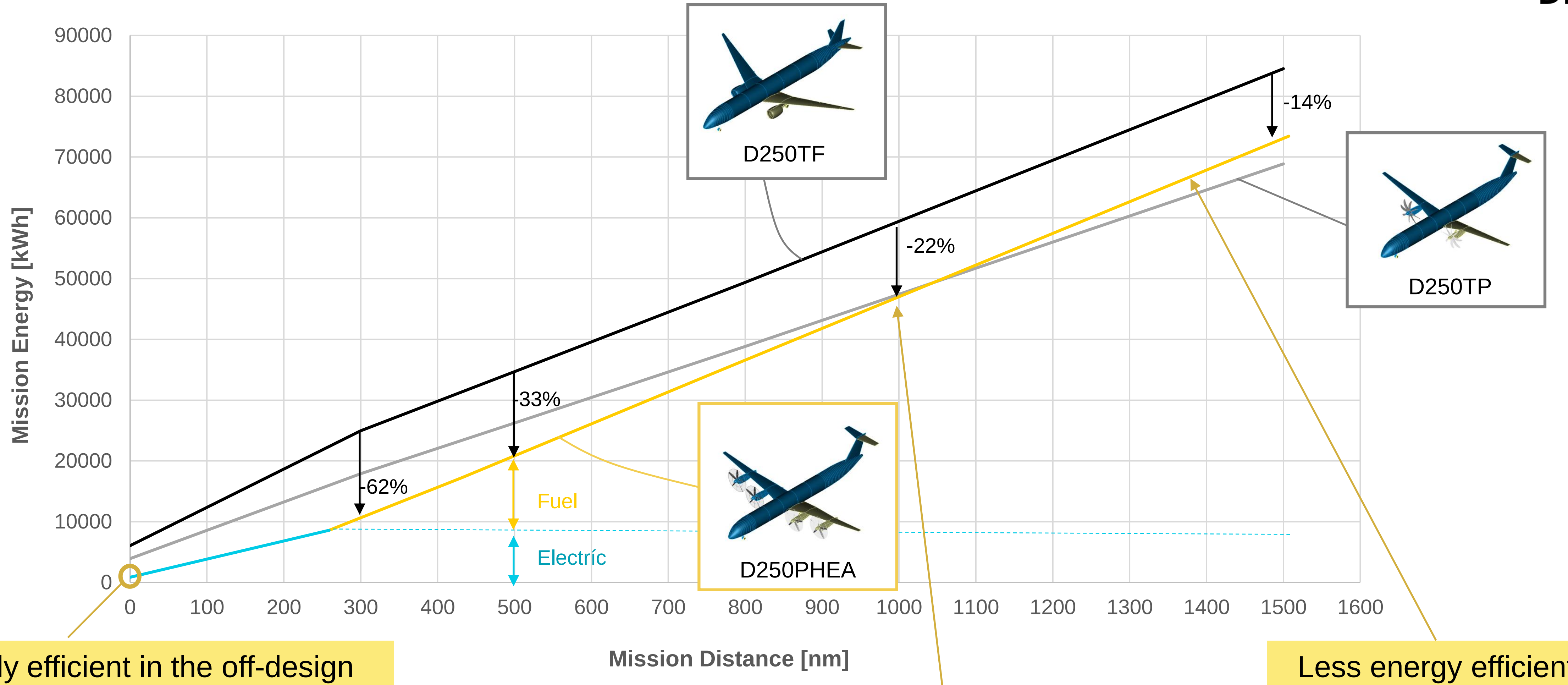
Georgi Atanasov, DLR Institute of System Architectures in Aeronautics, 08.10.2024

Off-Design Performance



The Plug-In-Hybrid concept offers an extreme advantage in off-design performance.
→ Highly relevant for short routes.

Energy vs Range



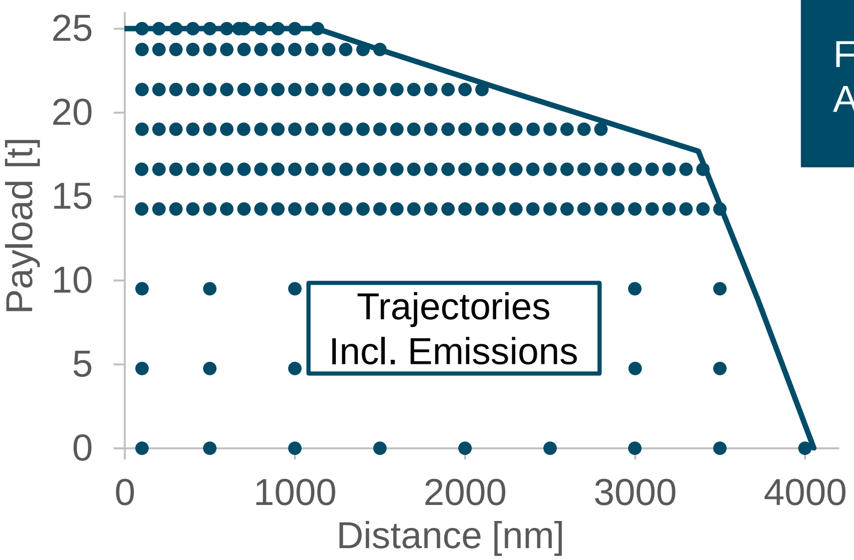
Highly efficient in the off-design phases (e.g. Descent, Taxi, Take-off, Approach and Landing)

Highest energy efficiency below 1000nm, due to high portion of electric energy.

Less energy efficient than the turboprop at longer missions.

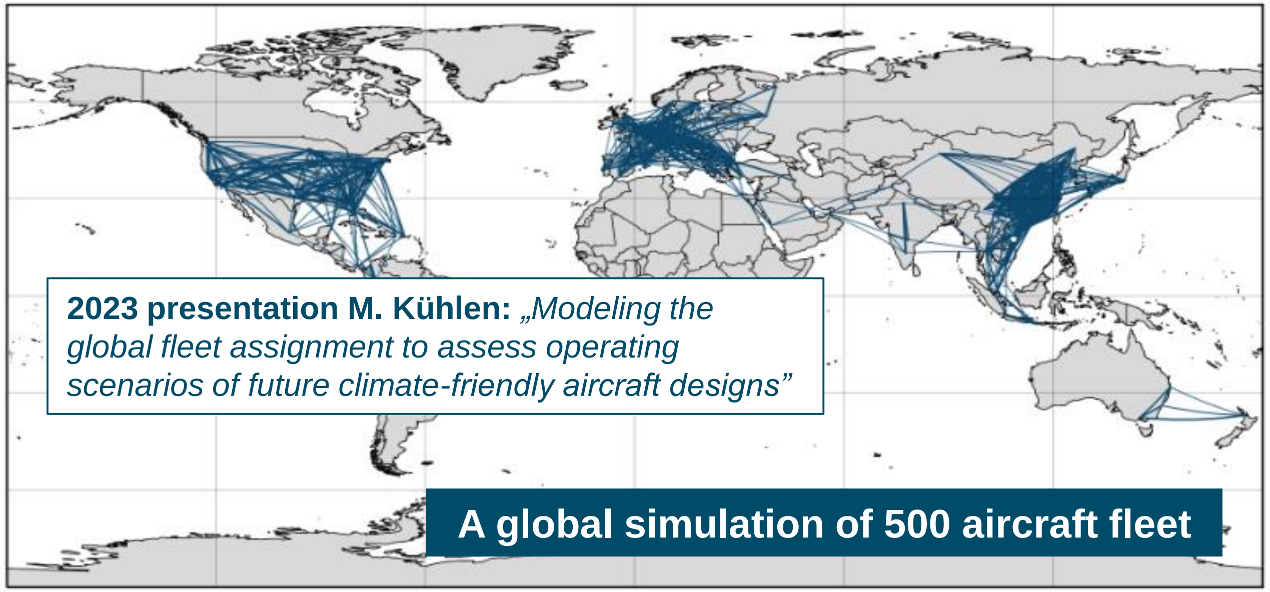
Fleet-Level Assessment

Aircraft Modelling: Generated Trajectories



Feed Global Assessment

Fleet Operation Simulation



2023 presentation M. Kühlen: *„Modeling the global fleet assignment to assess operating scenarios of future climate-friendly aircraft designs"*

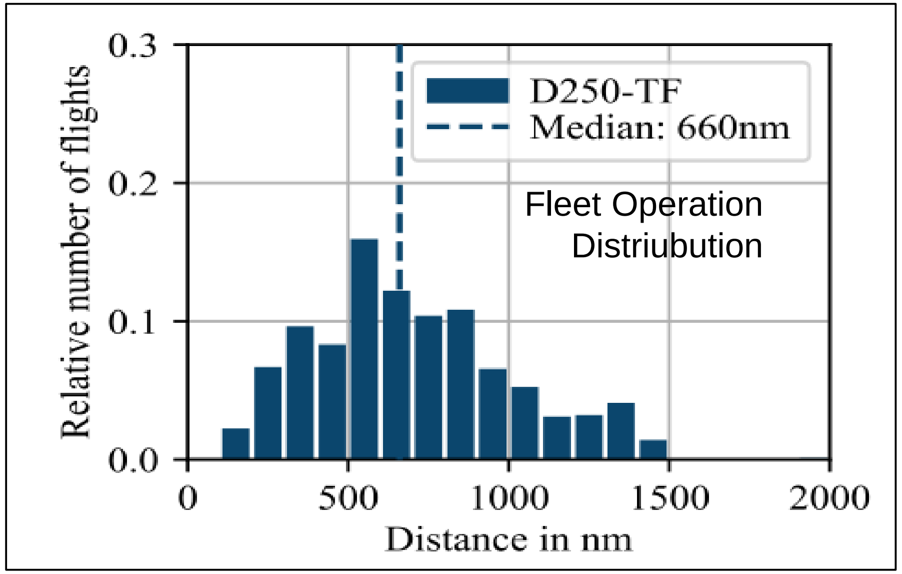
A global simulation of 500 aircraft fleet

- Simulated day-by-day operation of the entire fleet
- Aircraft trajectories (fed by the aircraft modelling)
- Crew working shifts
- Maintenance schedules of each aircraft
- The entire aircraft life-cycle is simulater, including recycling of materials (and batteries)

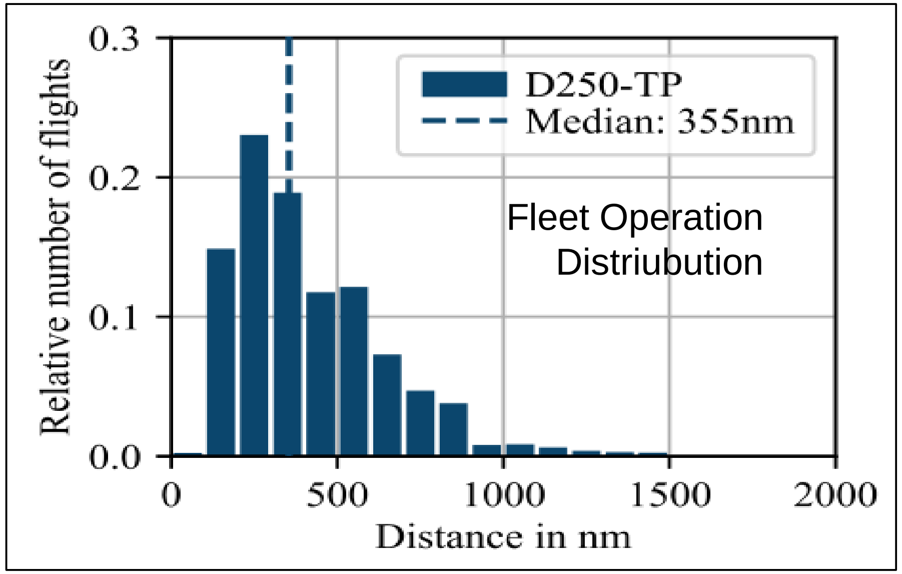
The aircraft are compared in terms of simulated global fleet operation cost and climate impact.

Fleet Simulation: 2 Different Fleet Operators

EXACT global assessment: Two fleet operators of 500x aircraft simulation.

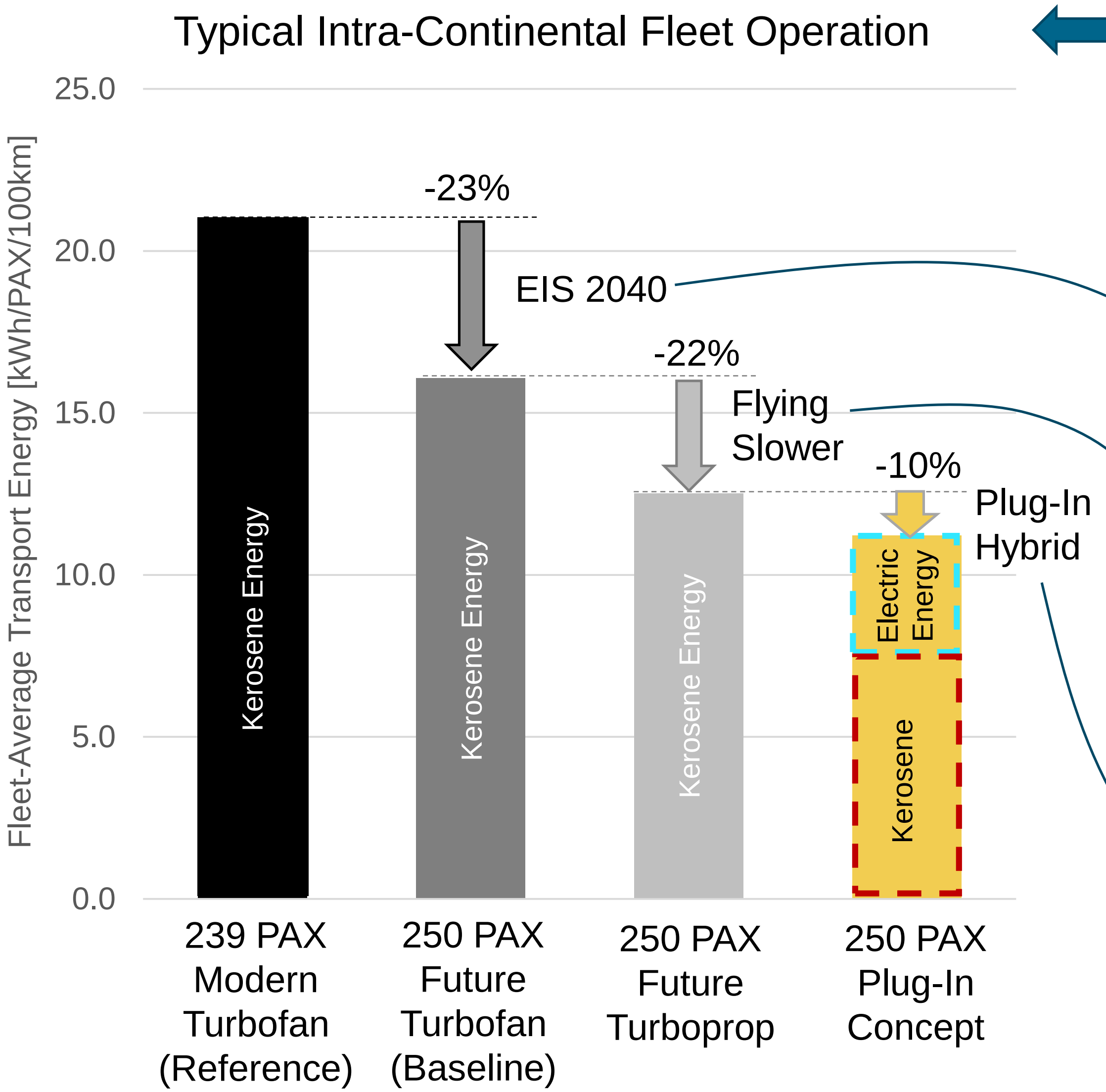


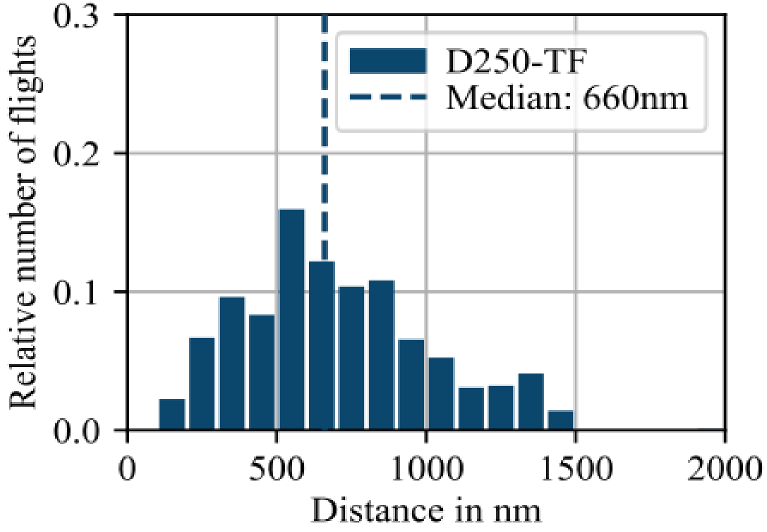
Operator 1: Typical Intra-Continental Routes



Operator 2: Shorter Routes (more advantageous for slower aircraft)

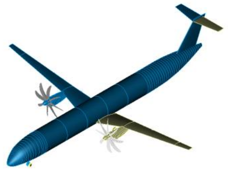
Fleet Energy Consumption – Typical Operator





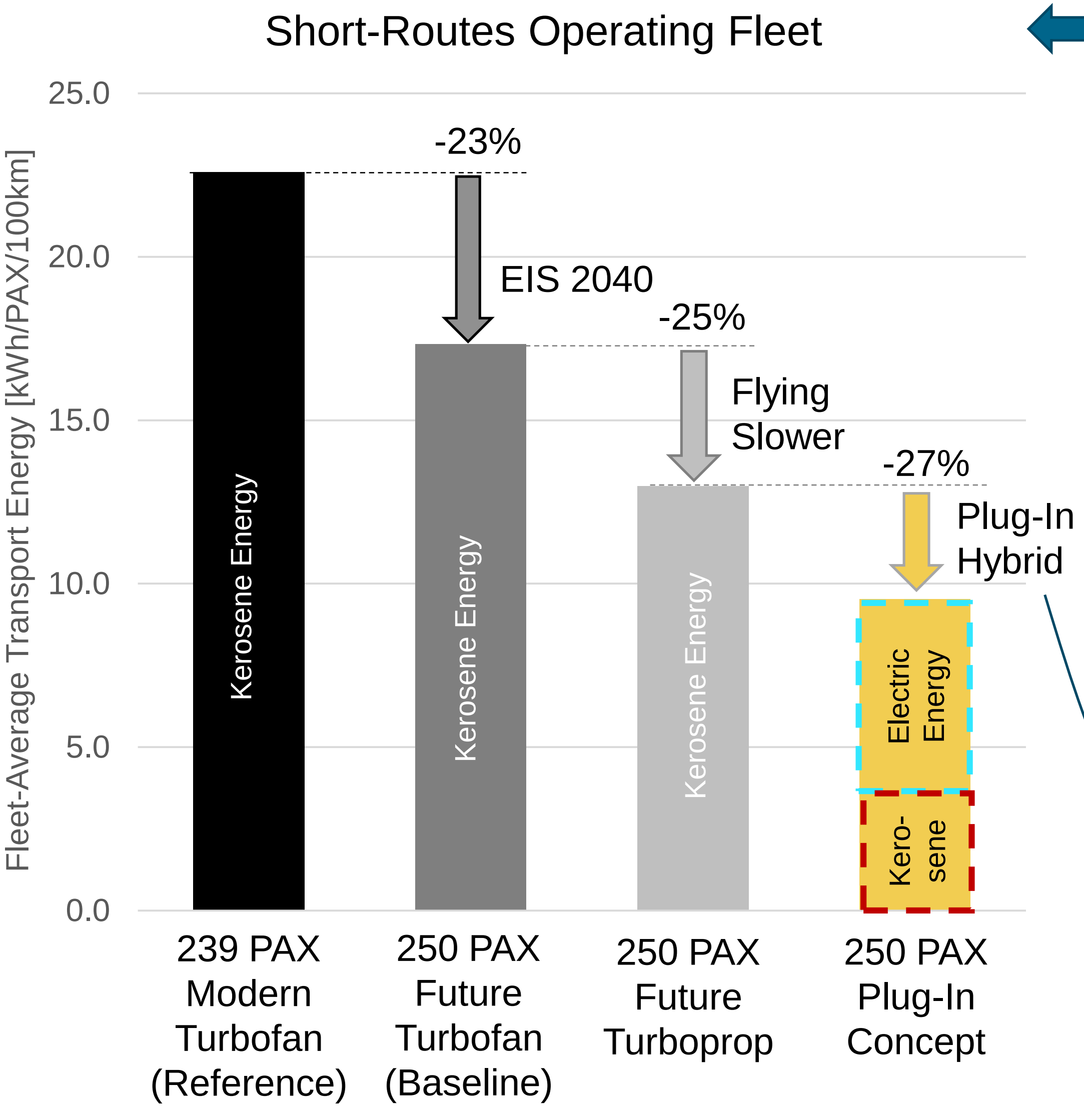
Evolutionary advancements offer a significant improvement potential.

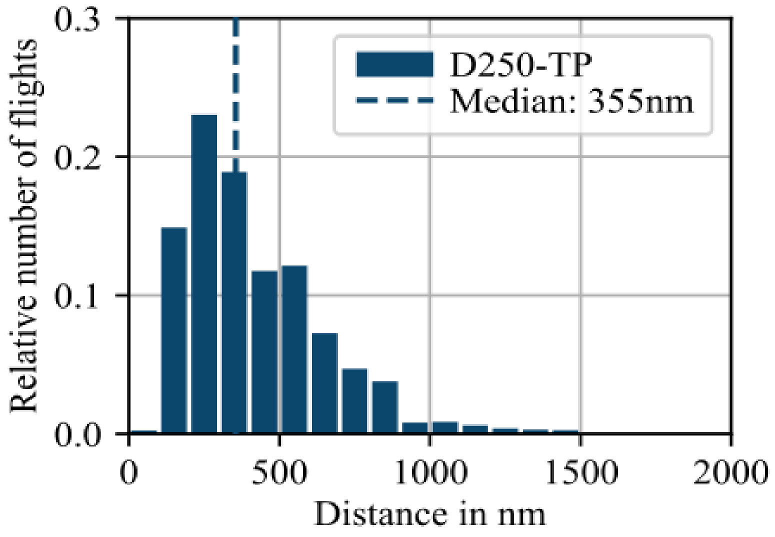
Flying slower can further significantly boost energy efficiency.



Flying slower & plug-in-hybrid propulsion:
- **-45% energy consumption**
- **-65% kerosene comsumption**

Fleet Energy Consumption – Shorter-Routes Operator

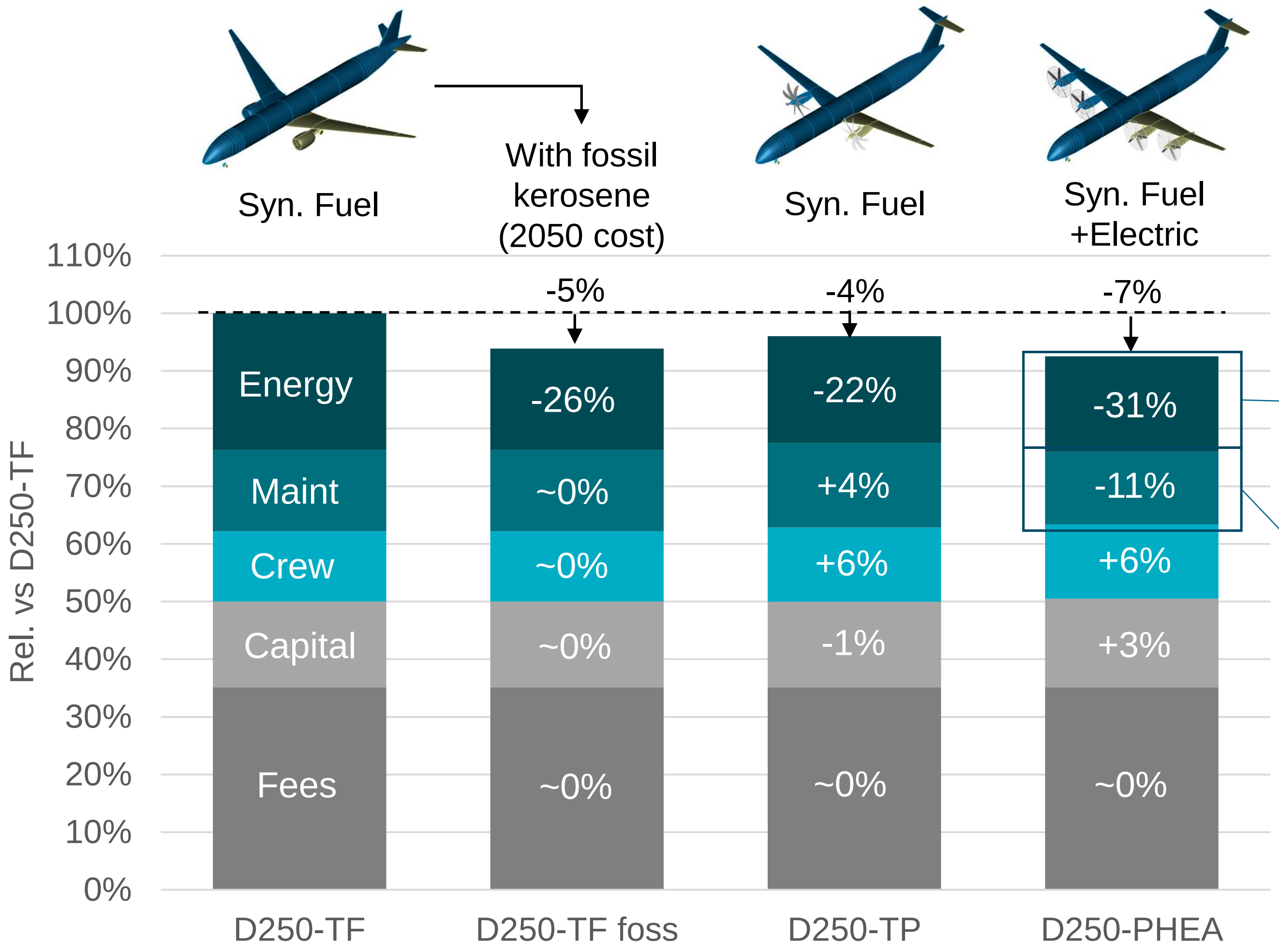


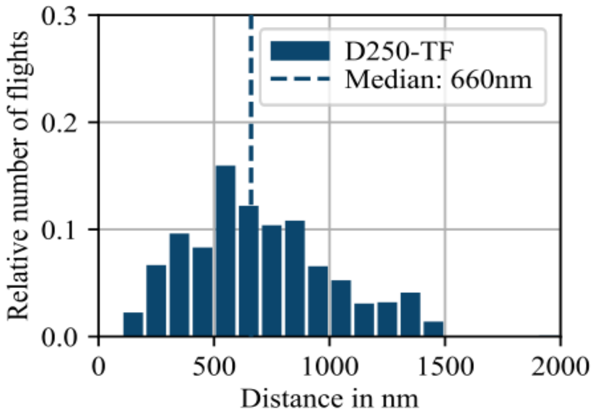


Shorter routes operation → more fully-electric flights:

- **-60% energy consumption vs modern airliners**
- **-85% kerosene comsumption vs modern airliners**

Cost Comparison – Turbofan Network





Incl. battery replacement costs of 3ct/kWh (300 cycles & 100€/kWh)

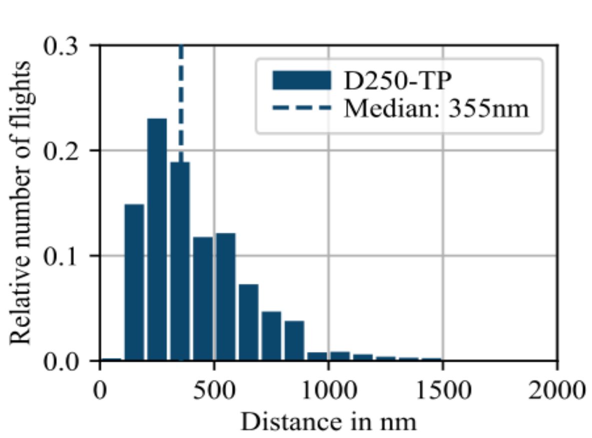
Significantly less engine maintenance:

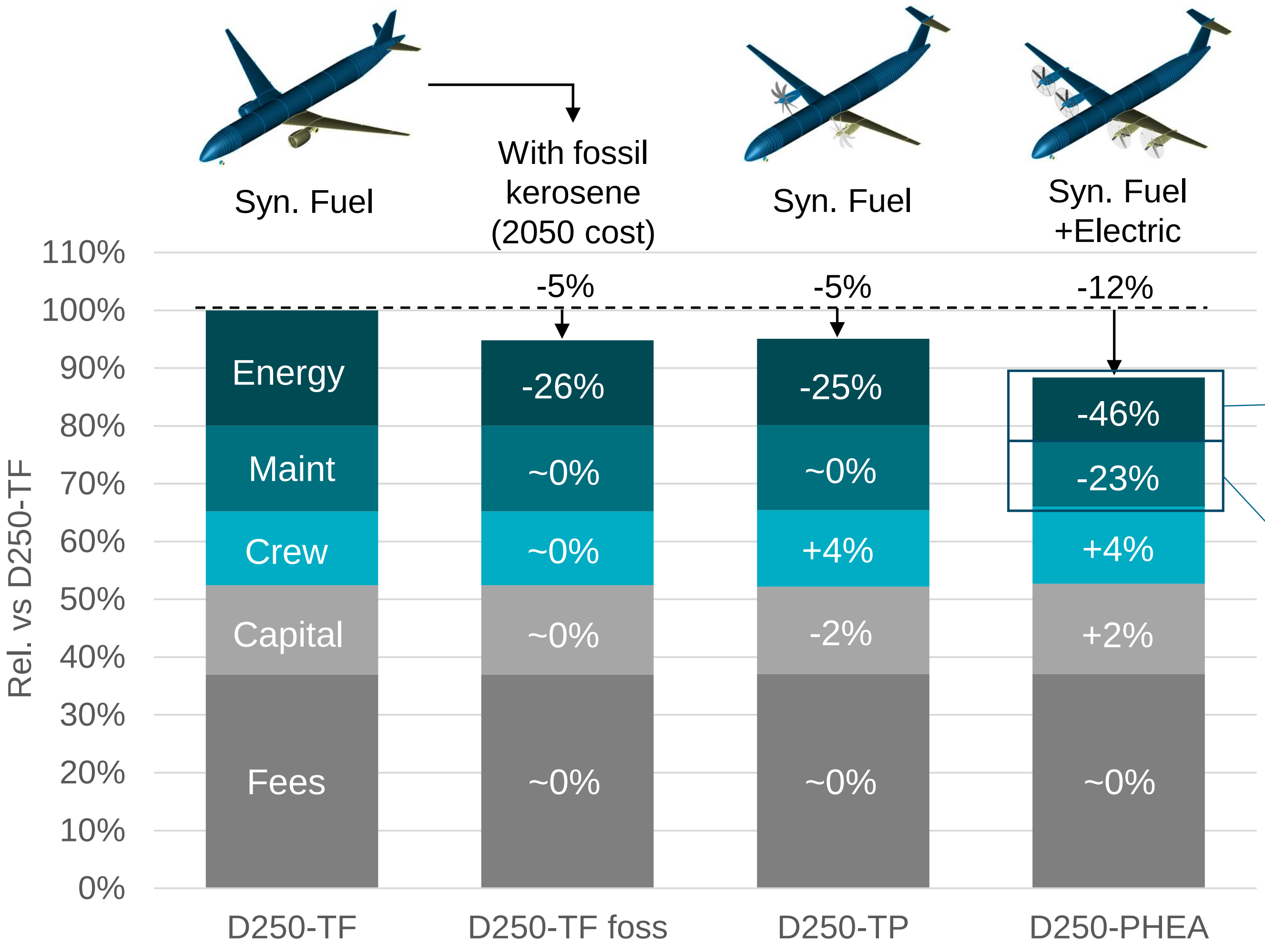
- Only one gas turbine
- Least installed total power (4 large props & no power lapse)
- The gas turbine only used for electric missions and only partially used for range-extender missions (climb & cruise).
- Geared e-motors (single-stage gearbox) maintenance expected significantly cheaper than turbofan or turboprop maintenance.

Base 2050 Energy Costs Projections

~8 cent/kWh Syn Fuel
~6 cent/kWh Fossile
~4 cent/kWh Electric Power

Cost Comparison – Turboprop Network





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Base 2050 Energy Costs Projections → ~8 cent/kWh Syn Fuel
~6 cent/kWh Fossile
~4 cent/kWh Electric Power

Results Summary

EXACT fleet simulation results comparison to a fleet of modern airliners operating on fossile kerosene.

250PAX Turbofan EIS2040

Fleet energy demand	-20%
For Fleet Operation with **Fossil Kerosene**	
Climate Impact Reduction	~20%
Seat Mile Cost	~15%
Fleet Operation with **Synthetic Kerosene**	
Climate Impact Reduction	-40-60%
Seat mile cost	<=10%

250PAX Turboprop EIS2040

Fleet energy demand	-40-45%
For Fleet Operation with **Fossil Kerosene**	
Climate Impact Reduction	~40-50%
Seat Mile Cost	~15-20%
Fleet Operation with **Synthetic Kerosene**	
Climate Impact Reduction	-65-75%
Seat mile cost	-10-15%

250PAX Plug-In Concept EIS2040

Fleet energy demand	-45-60%
For Fleet Operation with **Fossil Kerosene**	
Climate Impact Reduction	**~70-75%**
Seat Mile Cost	-20-25%
Fleet Operation with **Synthetic Kerosene**	
Climate Impact Reduction	**-85-90%**
Seat mile cost	-15%-20%

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Way Forward

- The current study focused on finding the potential of slower flight & plug-in hybrid.
- Further studies will focus on reducing the modelling uncertainties by:
  - Increasing the aircraft & propulsion system modelling level of detail
  - Defining further technology scenarios
  - Analyzing needed airport infrastructure
  - Analyzing impact of different turn-around strategies on operating costs
  - More detailed energy production analysis

Thank you for your attention!