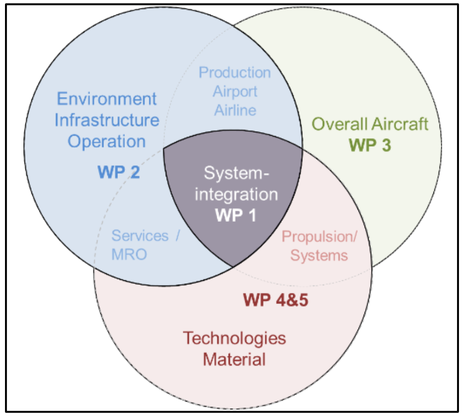
# Short Medium Range Turboprop-Powered Aircraft as an Enabler for Low Climate Impact


G. Atanasov, D. Silberhorn, P. Wassink, Dr. J. Hartmann, E. Prenzel, S. Wöhler, Dr. N. Dzikus, B. Fröhler, Dr. T. Zill, Dr. B. Nagel

# Outline

- Motivation and Background
- Study Boundary Conditions
- Aircraft Design Results Overview
- Aircraft Design Results Breakdown and Analysis
- Environmental Impact Reduction Potential
- Direct Operating Cost Results
- Summary and Outlook

# Motivation and Background




EXACT – DLR internal project.

Goals:

- Identify **aircraft concepts** and **enabling technologies** for climate neutral flight & define respective **technology roadmap.**
- Assess **future air transportation systems** with respect to total energy lifecycle, climate impact, society, infrastructure, value for stakeholders, etc.

**Conventional „baseline aircraft“** featuring only evolved technologies (no radical techno-bricks) serve as a foundation for the roadmap concepts studied in EXACT:

→ The **main baseline** is an **A321-like turbofan** designed for EIS 2040

A study on the **environmental impact** of the baseline **aicraft flight speed** design requirement is currently on-going.

→ A **turboprop baseline** was designed to fully exploit the potential of reduced speed

EXACT Turboprop Baseline D250TP

# Study Boundary Conditions

**Reference A/C:**

A321neo interpretation (EIS2016)

**D239**

## Top-Level-Aircraft Requirements (TLARs)

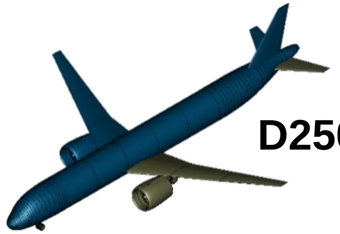
| | | |
|---|---|---|
| Design Range | [nm] | 2500 |
| Design PAX (single class) | [-] | 239 |
| Mass per PAX | [kg] | 95 |
| Design Payload | [kg] | 25000 |
| Max. Payload | [kg] | 25000 |
| Cruise Mach number | [-] | 0.78 |
| Max. operating Mach number | [-] | 0.8 |
| Max. operating altitude | [ft] | 40000 |
| TOFL (ISA +0K SL) | [m] | 2200 |
| Rate of Climb @ TOC | [ft/min] | >300 |
| Approach Speed (CAS) | [kt] | 136 |
| Wing span limit | [m] | <=36 |

**Redesign for EIS2040:**

- TLARS ISO
- Engine Performance: -10% sfc
- Fuselage Mass: -5%
- Wing Structural Mass: -15%
- Empennage Mass: -3%
- Systems Mass: ISO
- Furnishings Mass: ISO
- Operator Items Mass: ISO

The goal of the study is to compare the performance characteristics, the potential impact on the environment and the direct operating cost between the turbofan and the turboprop baseline.

## EXACT Turbofan Baseline

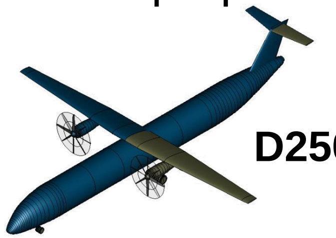


**D250TF**

**TLAR Changes:**

- Range 1500nm
- 250 PAX; Design Payload 23750kg

## EXACT Turboprop Baseline



**D250TP**

**TLAR Changes:**

- Range 1500nm
- Mach 0.62
- 250 PAX & Design Payload 23750kg

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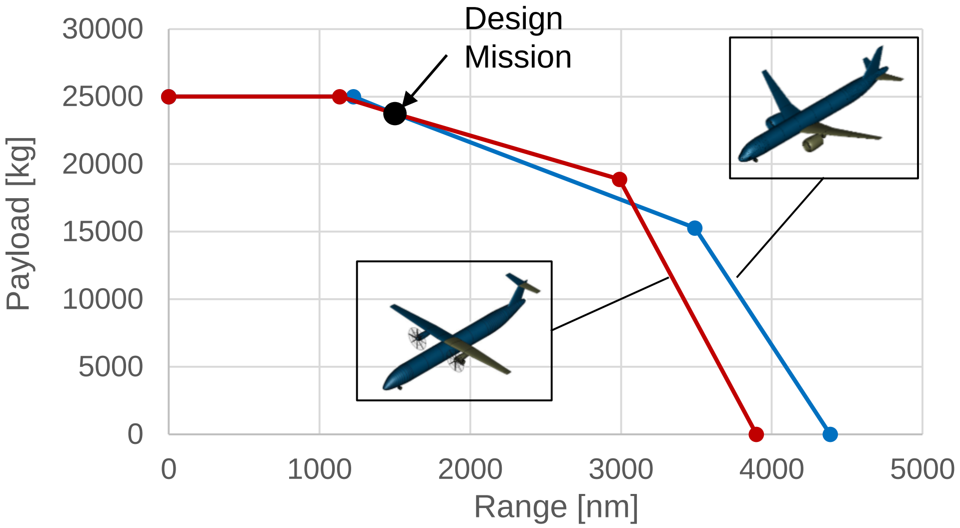
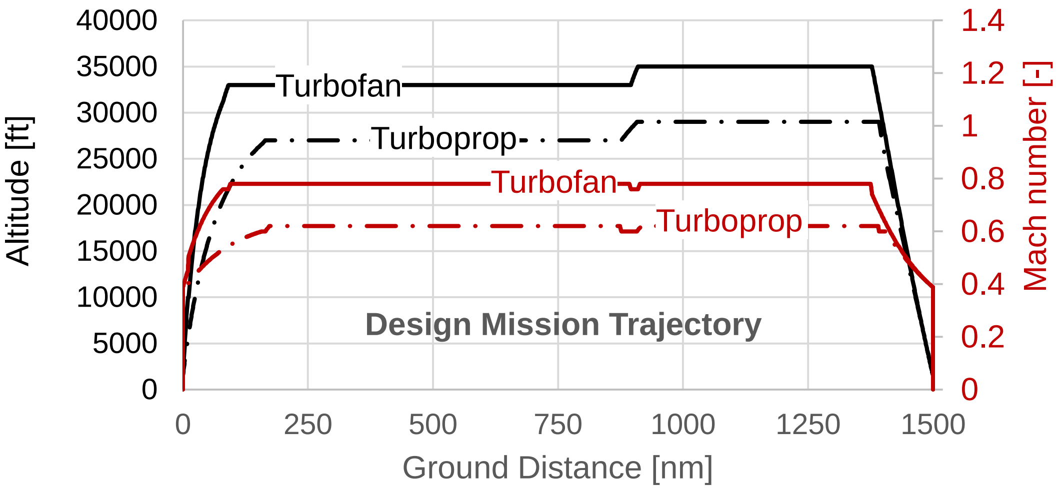
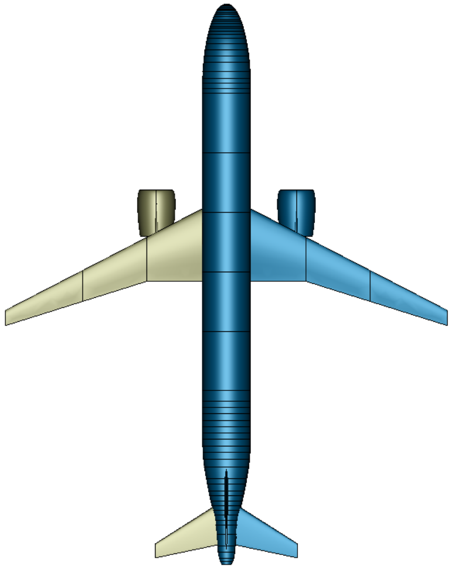
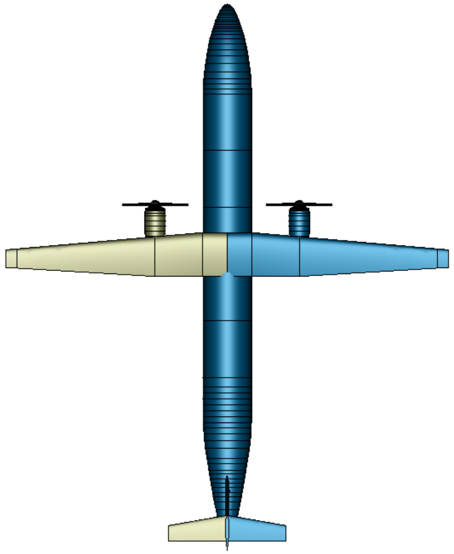
# Overall Aircraft Design Results



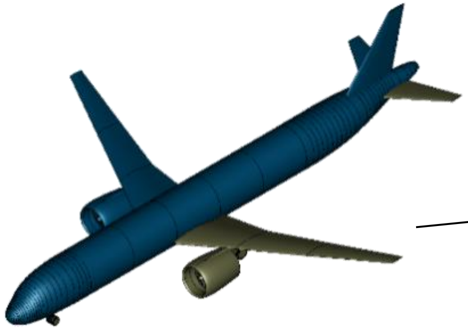





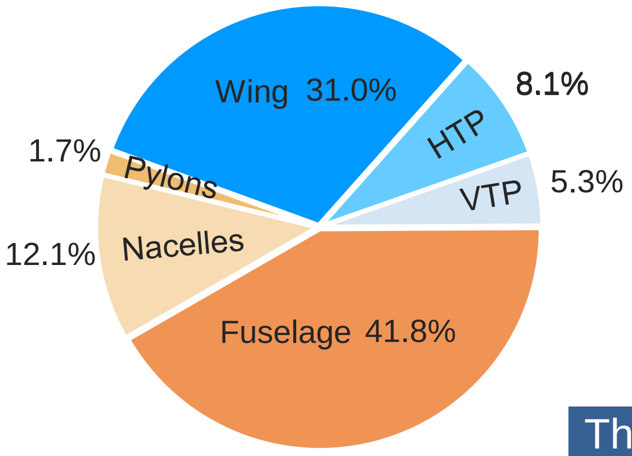
| Parameters | Units | Turbofan | Turboprop |
|---|---|---|---|
| **DESIGN MASSES** | | | |
| Max. Takeoff Weight | kg | 82400 | 71300 |
| Max. Landing Weight | kg | 75400 | 68500 |
| Max. Zero-Fuel Weight | kg | 73500 | 65600 |
| Operating Empty Weight | kg | 48500 | 40600 |
| Max. Fuel Weight | kg | 18600 | 11800 |
| **WING GEOMETRY** | | | |
| Wing Ref. Area | $m^2$ | 121.5 | 96.9 |
| Wing Span | m | 36.0 | 36.0 |
| Wing Aspect Ratio | - | 10.7 | 13.4 |
| Average Rel.Thickness | - | 0.130 | 0.139 |
| Ave. 1/4-Chord Sweep | ° | 27.3 | 3.1 |
| MAC | m | 4.02 | 2.87 |
| **AERO** | | | |
| Best L/D (mid-cruise conditions) | - | 17.2 | 19.2 |
| cL @ best L/D | - | 0.6 | 0.8 |
| cLmax (Full Flaps) | - | 2.9 | 3.3 |
| **MISSION PERFORMANCE** | | | |
| 1500nm Mission Block Fuel | kg | 7700 | 5500 |
| 1500nm Mission Time | min | 228 | 272 |
| 800nm Mission Block Fuel | kg | 4350 | 3026 |
| 800nm Mission Time | min | 135 | 158 |

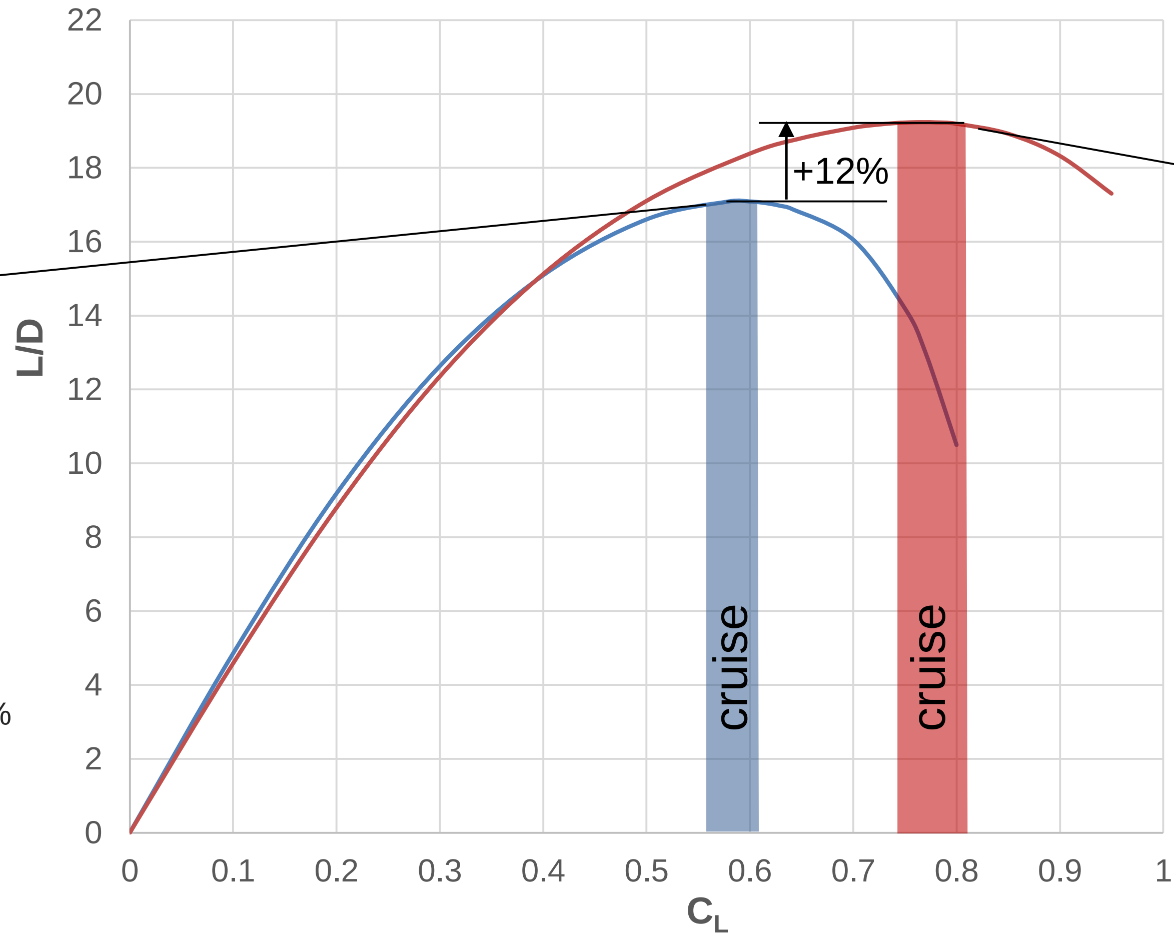
# Aerodynamic Comparison

## Turbofan Baseline

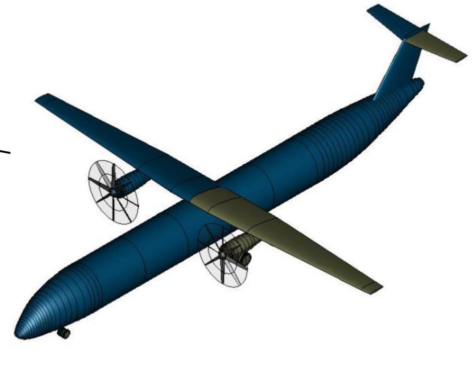


Mid-Cruise (Ma 0.78)
Zero-Lift Drag Breakdown

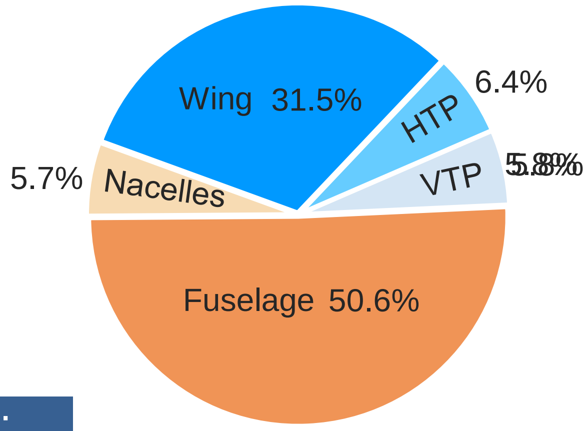



## Turboprop Baseline



Mid-Cruise (Ma 0.62)
Zero-Lift Drag Breakdown




The slower and lighter turboprop achieves better L/D in cruise due to:

- Smaller wing with a higher AR (ISO span) & reduced nacelle drag.
- Significantly higher $C_L$ in cruise (due to milder transonic effects).

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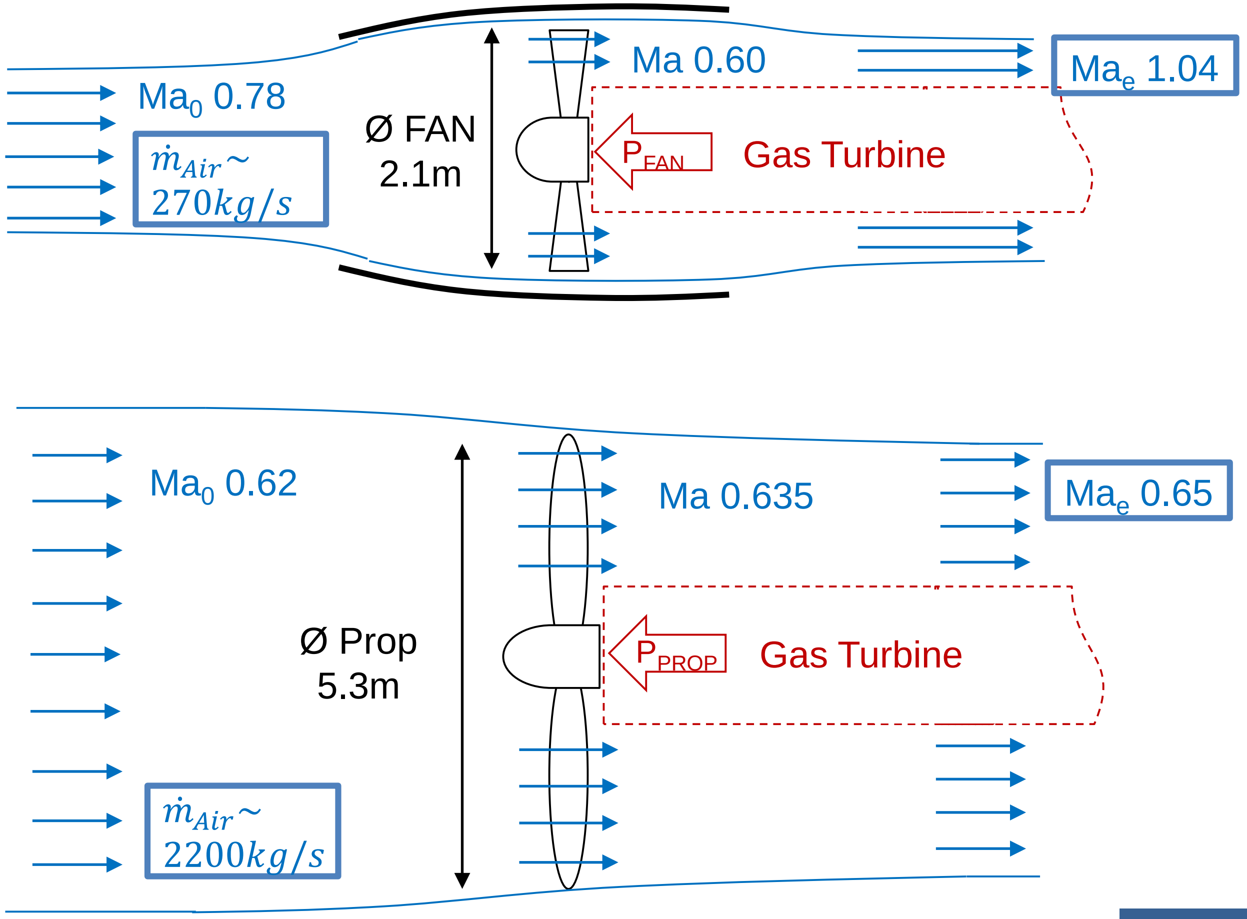
# Ducted Fan vs Propeller




**Ducted fan (FPR ~ 1.35) efficiency:**

- Propulsive efficiency: $\eta_P = \frac{2}{1 + v_e/v_0} = 0.86$
- Pressure losses: $\pi_{inlet} = 0.99; \pi_{nozzle} = 0.995$ (empirical)
- Fan isentropic efficiency: $\eta_{is,Fan} = 0.915$ (empirical)

$$\eta_{TOT,Ducted\_Fan} = \frac{T_{FAN} \cdot v_0}{P_{FAN}} = 0.76$$

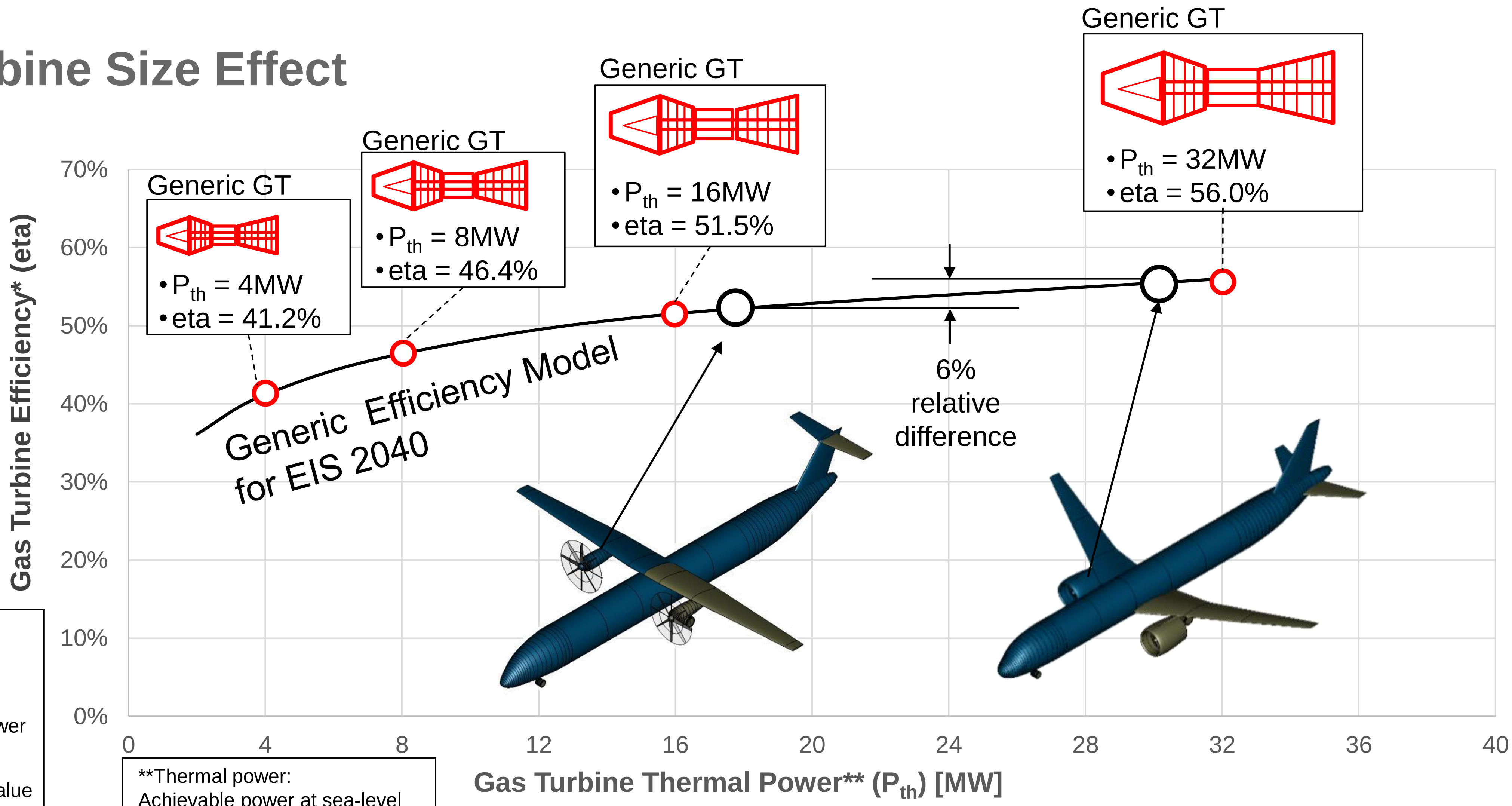
**Propeller (FPR ~ 1.025) efficiency:**

- Propulsive efficiency: $\eta_P = \frac{2}{1 + v_e/v_0} = 0.99$
- Prop isentropic efficiency: $\eta_{is,Prop} = 0.87$ (empirical)

$$\eta_{TOT,Propeller} = \frac{T_{Prop} \cdot v_0}{P_{Prop}} = 0.86$$

Slower flight allows for switch to propeller with 12% (relative) more efficient thrust generation.

# Gas Turbine Size Effect




*GT efficiency:

$$eta = \frac{P_{eq}}{\dot{m}_{Fuel} \cdot LHV}$$

$P_{eq}$ Equivalent power

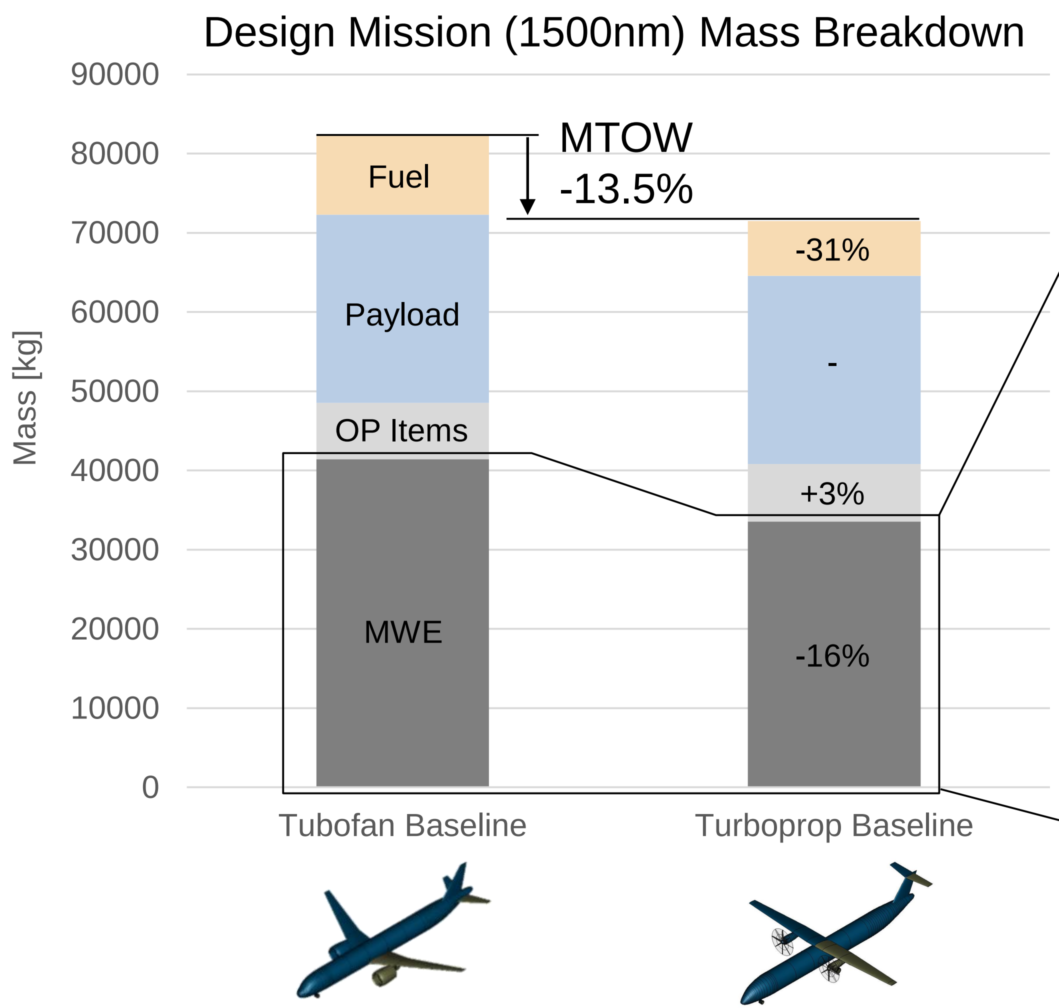
$\dot{m}_{Fuel}$ Fuel flow

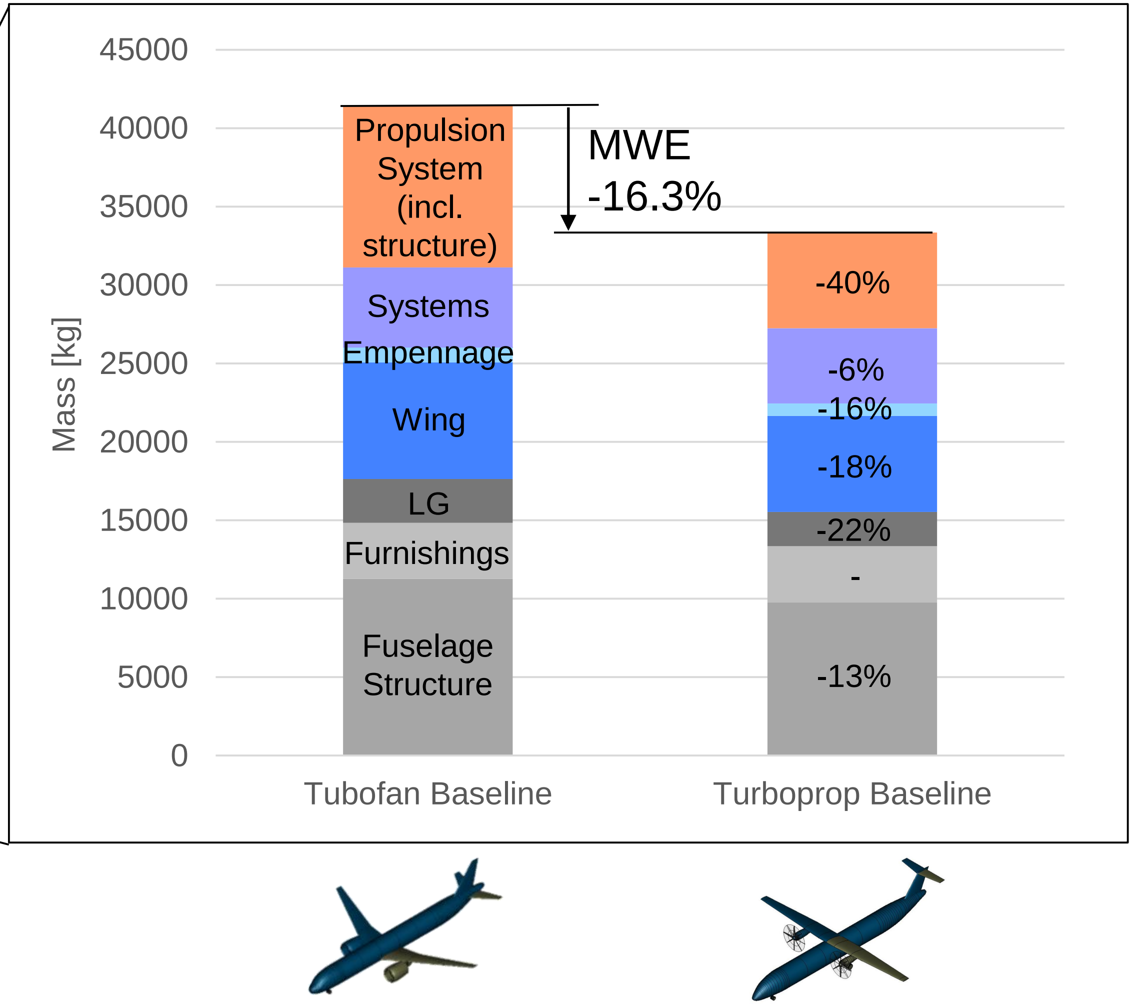
$LHV$ Low heating value

**Thermal power:
Achievable power at sea-level static ISA conditions withtout any power limitations.

**The slower and lighter turboprop needs smaller gas turbines → ~6% less efficient due to scaling effects.**

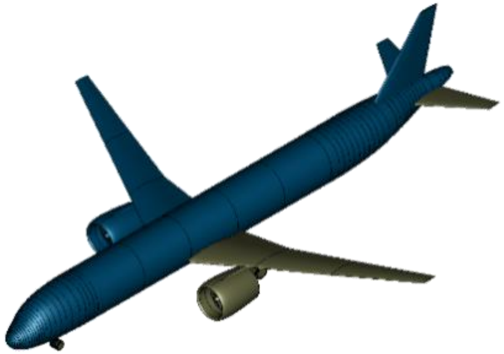
# Mass Breakdown Comparison

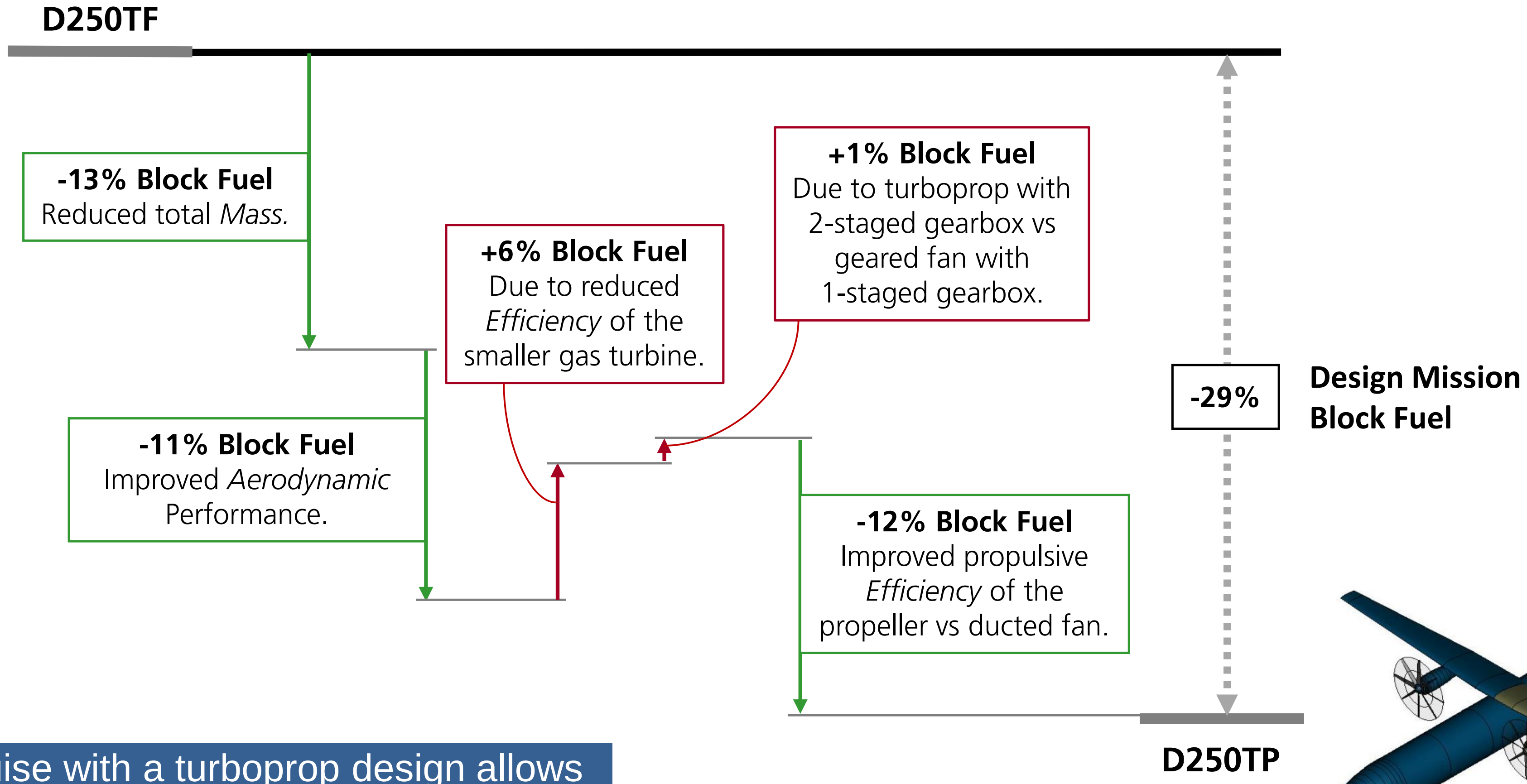


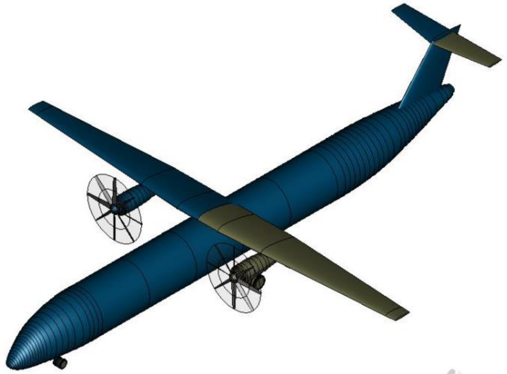




**Mass reduction due to increased efficiency, smaller engines, unswept wing, reduced operating speed & altitude**

# Design Mission Fuel Comparison





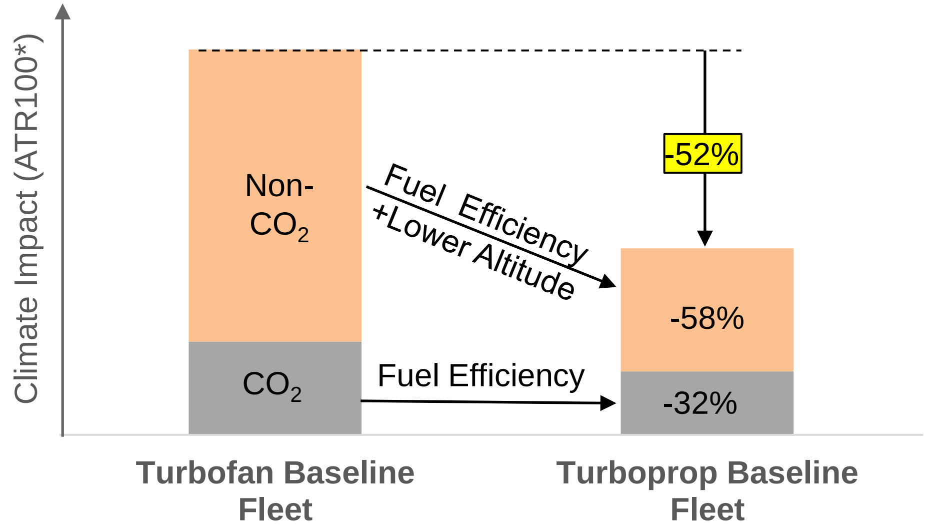



A switch to a slower cruise with a turboprop design allows for a significant shift in overall fuel efficiency.

*The reference aircraft fleet impact scaled proportionally with fuel per PAX from the turbofan baseline model.

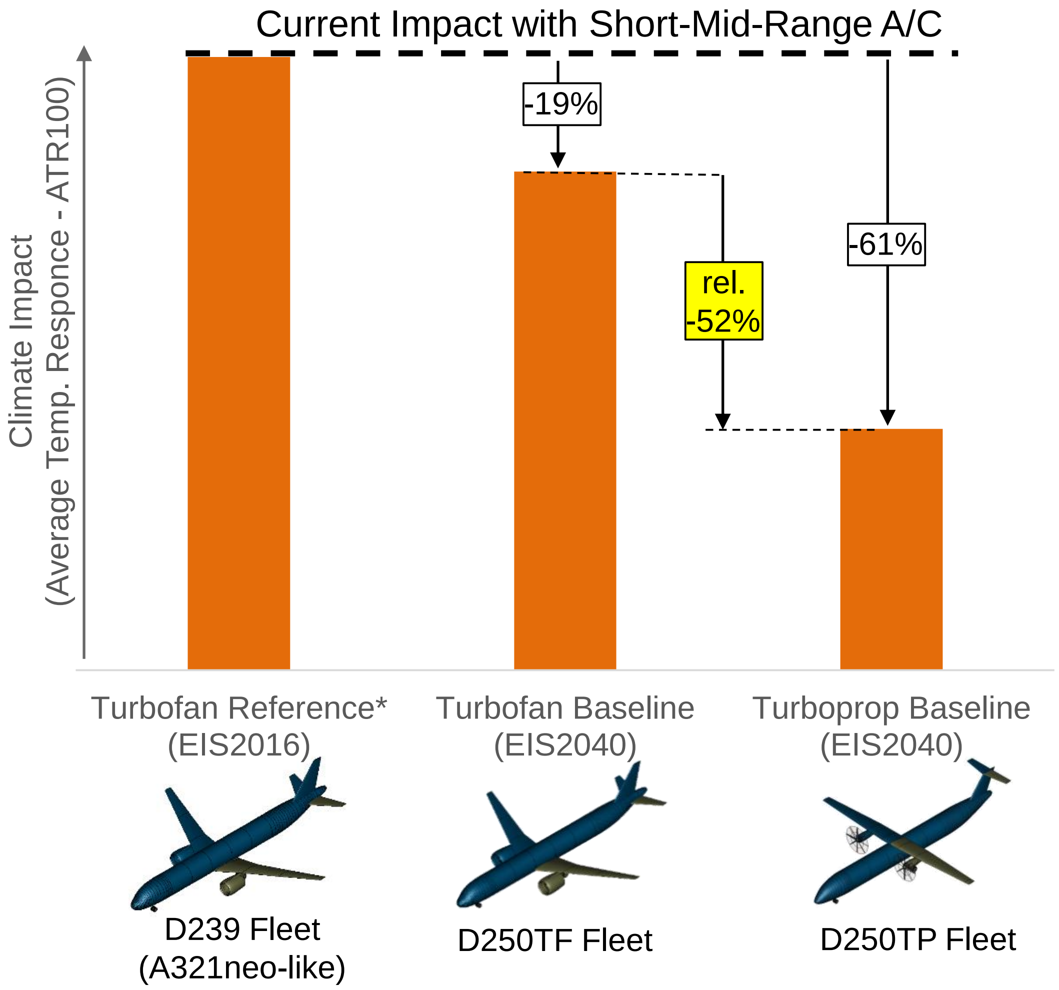
# Environmental Impact

A preliminary result from the EXACT project conducted with DLRs climate assessment capabilities of the „Atmospheric Physics“ Institute




*The average temperature response (ATR100) of a yearly operation of a global short-mid-range fleet:

Both fleet are set up to transport the same amount of passengers per year:
→ the turboprop fleet is larger due to the slower flight speed.




An advanced turboprop can potentially achieve over 60% climate impact reduction compared to current modern short-mid-range A/C even without swiching to synthetic fuels

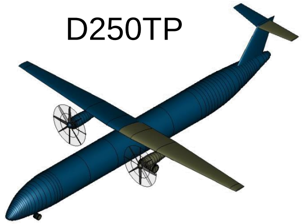
# Operating Cost – 800nm Mission with Kerosene

D250TF

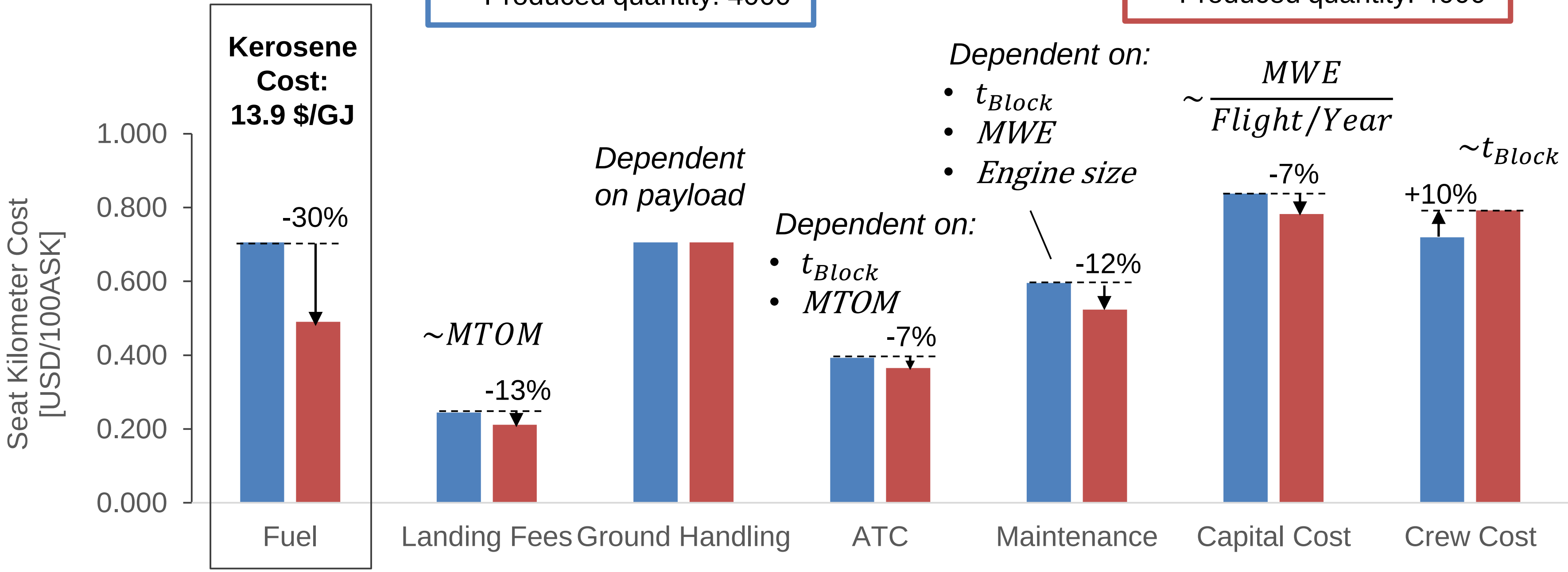
- Flights / year: 1600
- Produced quantity: 4000

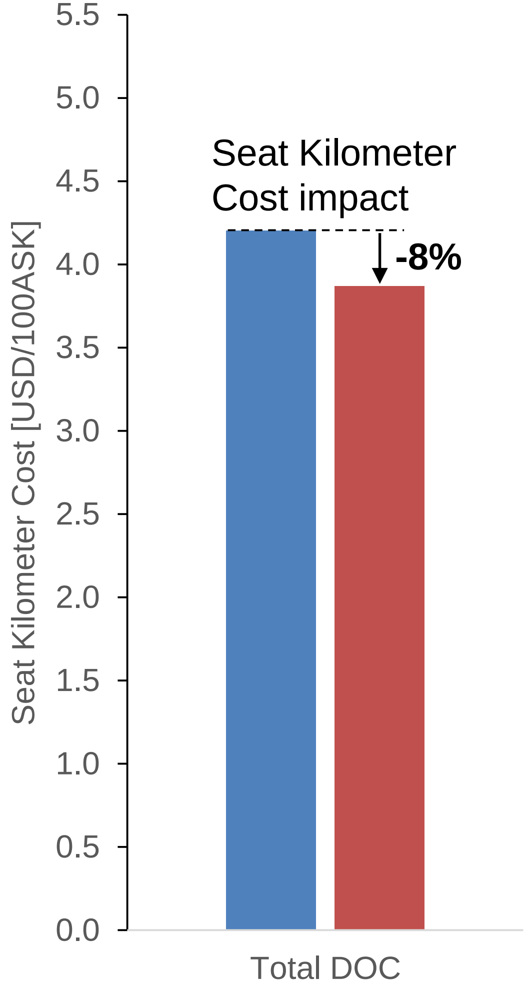
- 13.5% MTOW
- 16.3% MWE
- 30% block fuel
- +10% block time

D250TP



- Flights / year: 1450
- Produced quantity: 4000




*USD value of 2021

**Despite the longer flight time, a the turboprop baseline shows an 8% operating cost improvement potential compared to a turbofan even without taking into account emission fees.**

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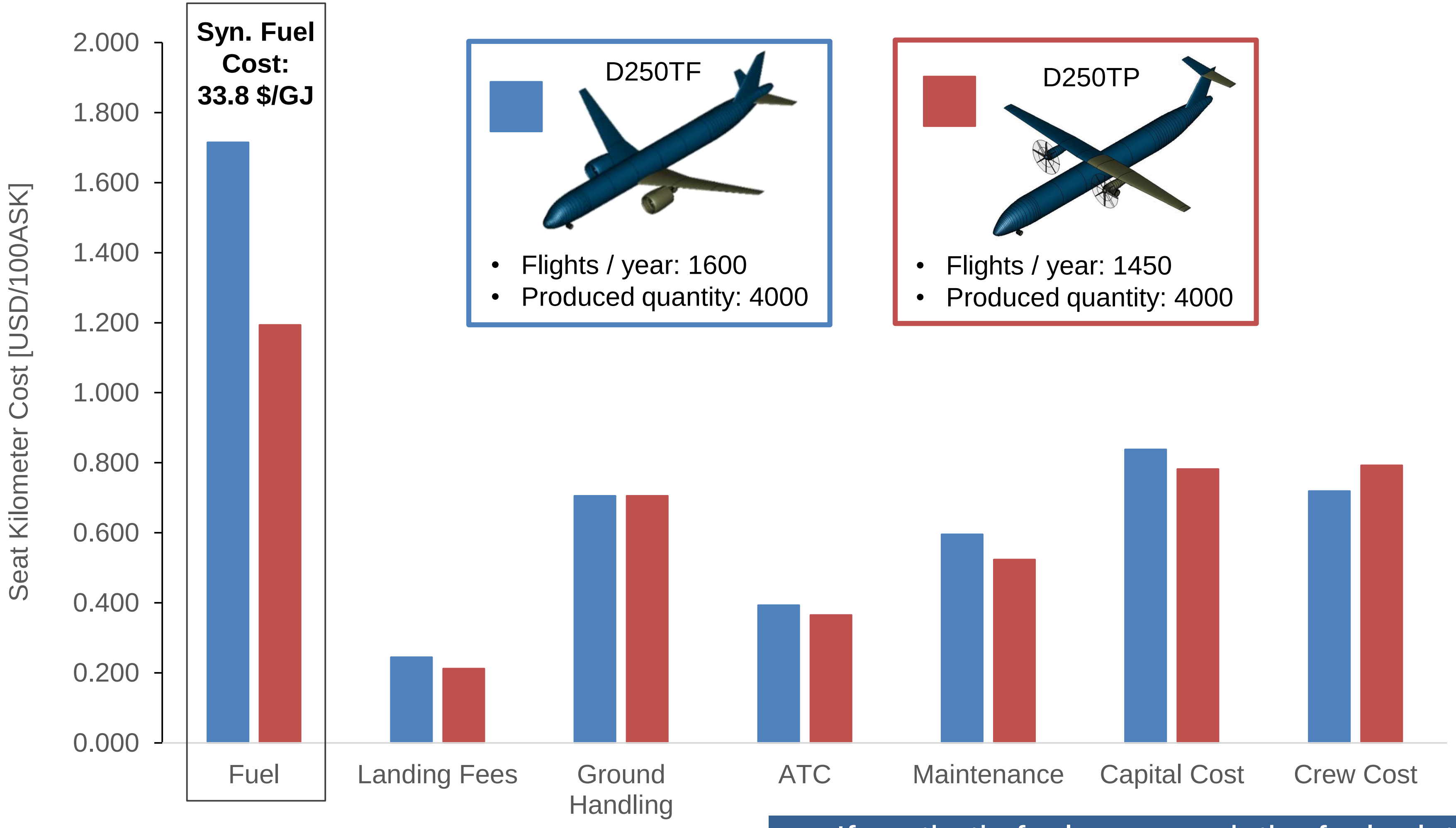
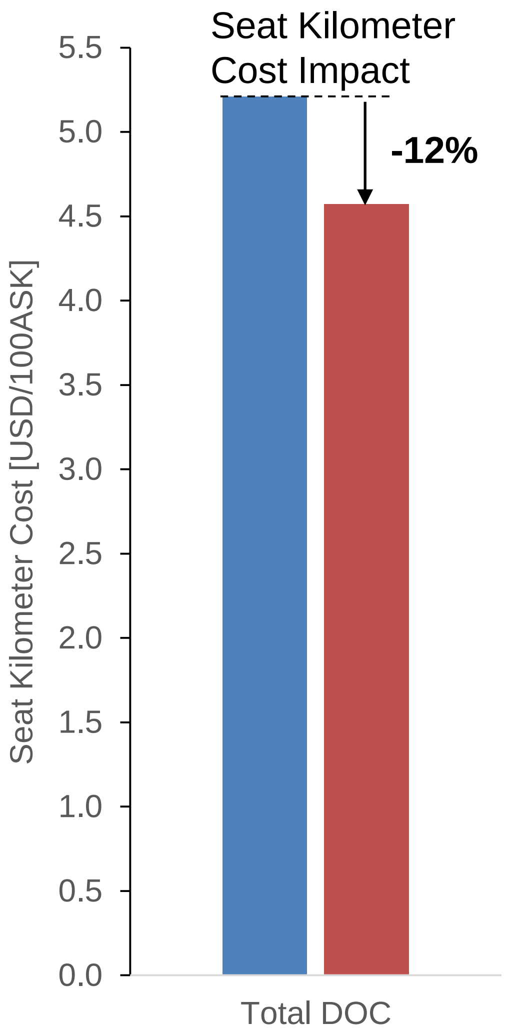
# Operating Cost – 800nm Mission with Synthetic Fuel




*USD value of 2021

If synthetic fuels are used, the fuel-related costs increase significantly
→ the potential cost advantage of the fuel-efficient turboprop rises to 12%

# Summary and Outlook

**Design Mission**
- 250PAX, in high-density layout
- Mach 0.62; 1500nm range

**Features:**
- Single-Aisle
- Low-risk (conventional) technologies
- 36m wing box limit

**Comparison vs. Turbofan Baseline (D250TF):**

| | |
|---|---|
| Fleet fuel consumption | -32% |
| Fleet climate Impact | -50% |
| Seat mile cost | -8% |
| MTOW | -14% |

| | |
|---|---|
| Climate Impact vs Today (without switching to syn. fuels) | -60% |


**Planned studies:**
- Mach sweet-spot analysis for D250TP
- Lower & slower design trade-off study for D250TF
- Expanding the analysis for the aircraft family fleet → stretch version with 250PAX and base version with 200PAX

**Thank you for your attention!**

**Reach out to: georgi.atanasov@dlr.de**

All renderings by Line Winkler (DLR)