Comparison of Sustainable Regional Aircraft Concepts

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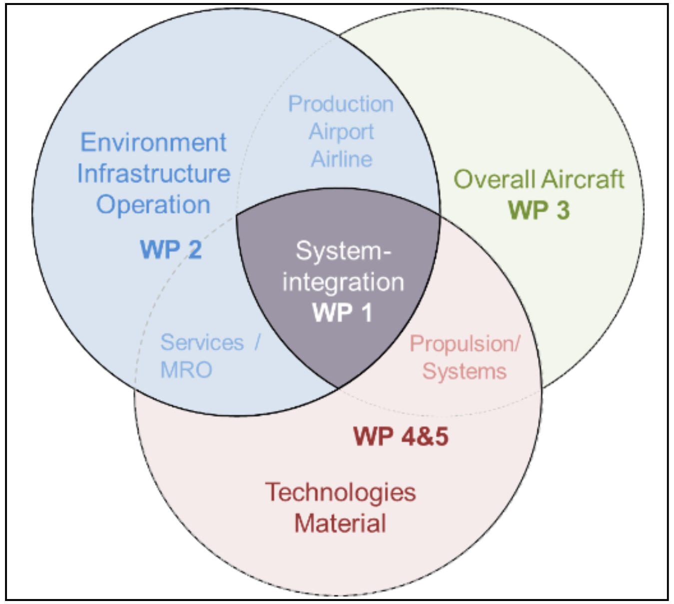
Background

EXACT – DLR internal project



Focus on Short-Range, Mid-Range and Regional Classes

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.

Regional Concepts Introduction

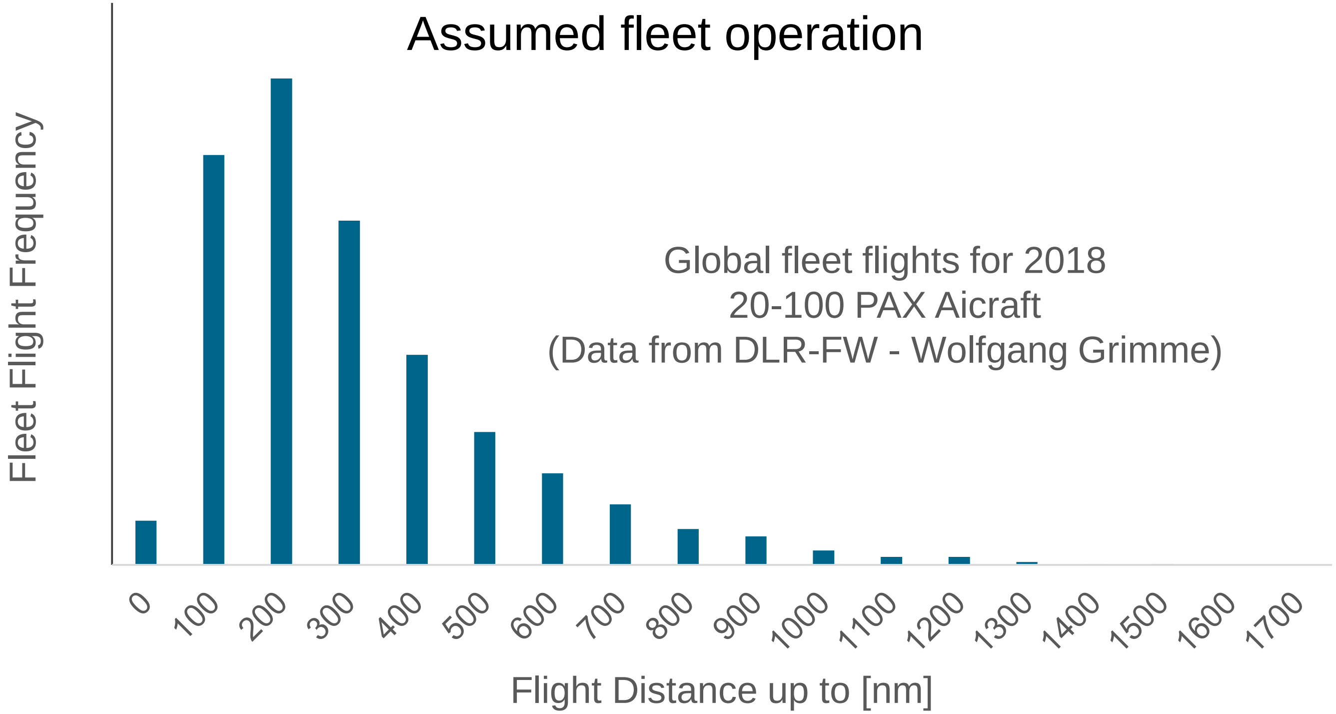
Baseline Aircraft : D70-840-2040 (D70-BL) Energy: SAF (Synth. Air Fuels)	Fuel-Cell Aircraft: D70-FC10-2040 (D70-FC) Energy: LH2	Plug-In Hybrid-Electric Aircraft : D70-PHEA-2040 (D70-PHEA) Energy: Electric + SAF

Baseline Aircraft and Assessment Metrics

Baseline aircraft designation: D70-840-2040 (D70-BL)

Top-Level-Aircraft Requirements (TLARs)

EIS	Year	2040
Design Range	[nm]	1000
Design PAX (single class)	[-]	70
Design Payload	[kg]	6650
Max. Payload	[kg]	7500
Cruise Mach number	[-]	0.55
Max. operating altitude	[ft]	30000
OEI Ceiling	[ft]	8000
TOFL (ISA +0K SL)	[m]	1500
Approach Speed (CAS)	[kt]	<120
Wing span limit	[m]	<=36



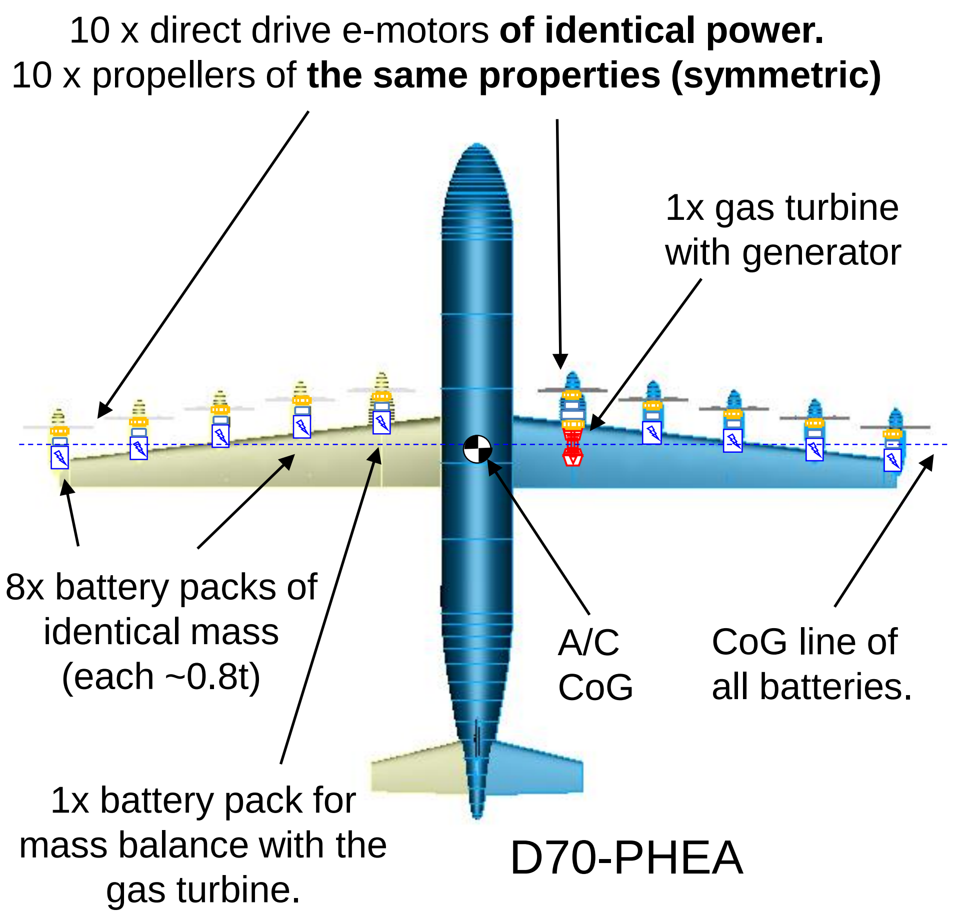
Assessment metric: **Fleet-level energy consumption**

- All three concepts optimized for minimum fleet energy.
- Climate impact not conducted for this study.
- Cost comparison yet to be performed.

Electric Propulsion Modelling

Assumptions for Battery Aircraft Modelling EIS 2040

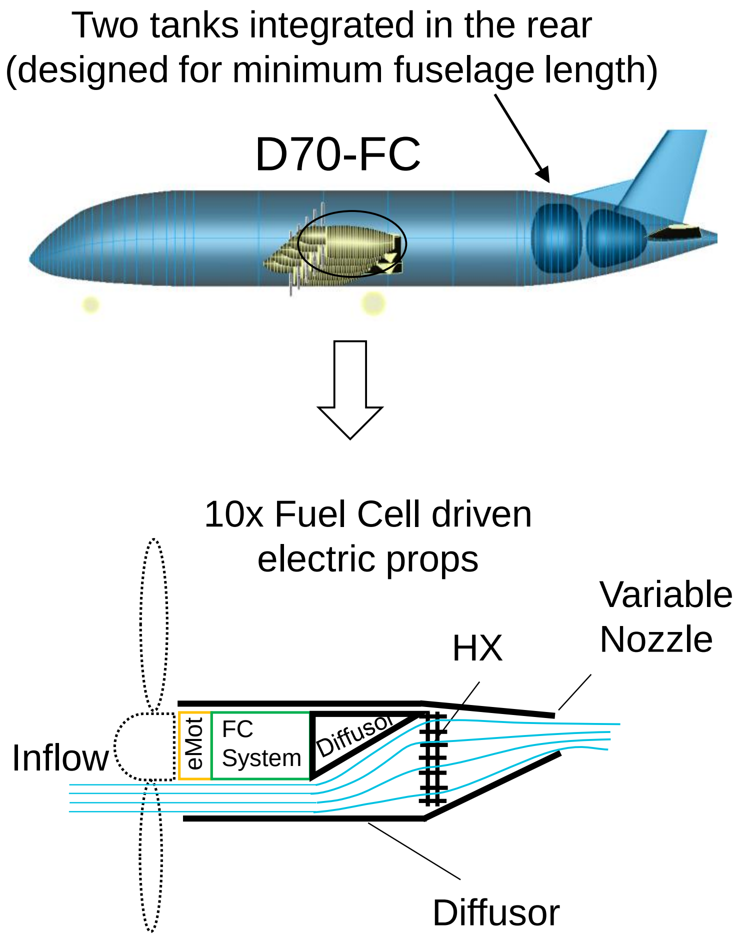
DISCIPLINE/PARAMETER	INPUT	COMMENTS
E-MOTORS & INVERTERS		
Sp. Power e-Motors (incl. Inverter)	10 kW/kg	Direct drive assumed
Efficiency e-Motors (incl Inverter)	97.5%	Direct drive assumed
Sp. Power Generator (incl. Rectifier)	12.5 kW/kg	Direct drive assumed
Efficiency Generator (incl. Rectifier)	98.0%	-
Installation Mass Penalty	10%	-
BATTERIES		@1C discharge (2C discharge capabilty)
Sp. Energy Battery Cells	500 Wh/kg	
Sp. Energy Battery Pack	400 Wh/kg	
1C Charge-Discharge Efficiency	90%	



Fuel Cell Aircraft Modelling

Assumptions for Fuel Cell Modelling EIS 2040

DISCIPLINE/PARAMETER	INPUT	COMMENTS
FUEL CELLS		
Sp. Power Fuel Cell System	1.5kW/kg	Oversized stacks & inc. sub-systems (no cooling)
Stack efficiency @ Full Load (29000ft)	47%	-
Efficiency @ 20% Load (29000ft)	56%	-
Efficiency in Cruise	54%	Stacks oversized to work @ 33% load
LH2 Tanks		
Structure Material	Alu	-
Insulation Type	MLI	-
Containment index	29%	Result from LH2 Subworkflow Calculation
Installation Mass Penalty	5%	With respect to total mass of tank & fuel.
Cooling System		
Sp. Power @ AC Level (with respect to heat losses)	2 kW/kg	Incl. variable nozzle
Cooling Drag	Output from Tool	Negligible in cruise

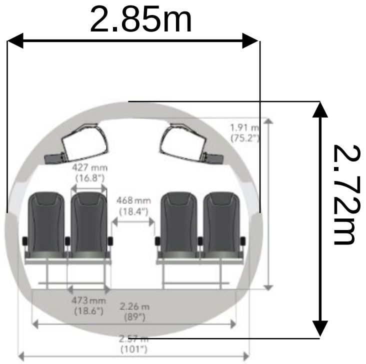


Configurational Aspects

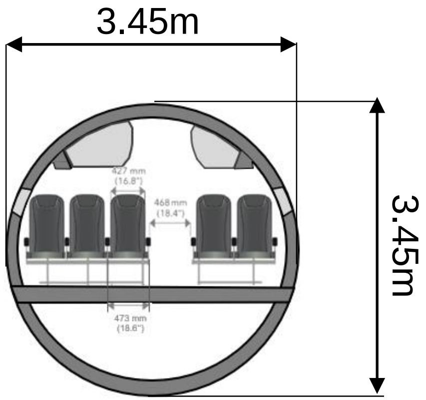
- **10 propellers:**
  - Take-off power reduction due to redundancy and blown wing effect **(certification tbc)**.
  - Battery / fuel cells distributed along the wing span to alleviate wing loads **(hard landing tbc, aeroelastics tbd)**
  - Sufficient area for nacelle-integrated heat exchangers for D70-FC.
  - VTP size reduction due to the reduced OEI yaw-moment constraint.
- **Low-wing enabled by the smaller propeller diameter:**
  - The landing gear supports the heavy wing directly, reducing the strucural loads on the fuselage.
  - The landing gear is integrated in the wing box.
  - Wing dihedral sufficient for 7° banking angle.

Fuselage Design

From the D70-REF (ATR72):
Nose to end of cockpit: 3.4m
Cabin length: 19.5m



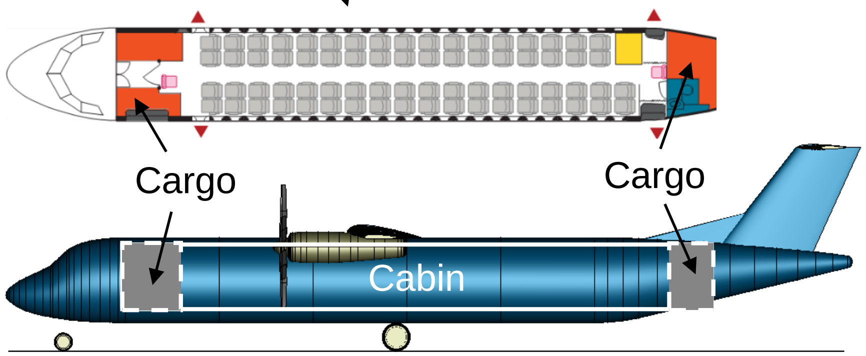
19 Rows



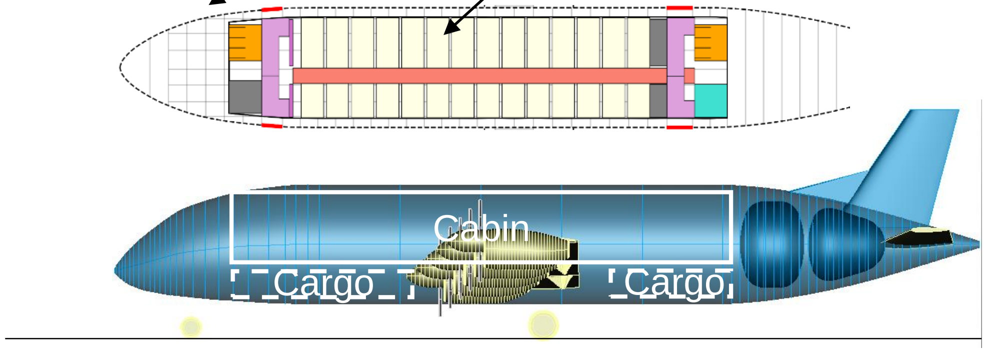
15 Rows

From the Do728:
Nose to end of cockpit: 2.9m

Cabin design by DLR-SL-KNS:
Cabin length: 14.6m
(same seat pitch as Ref.)



Fuselage Length – 26.9 m

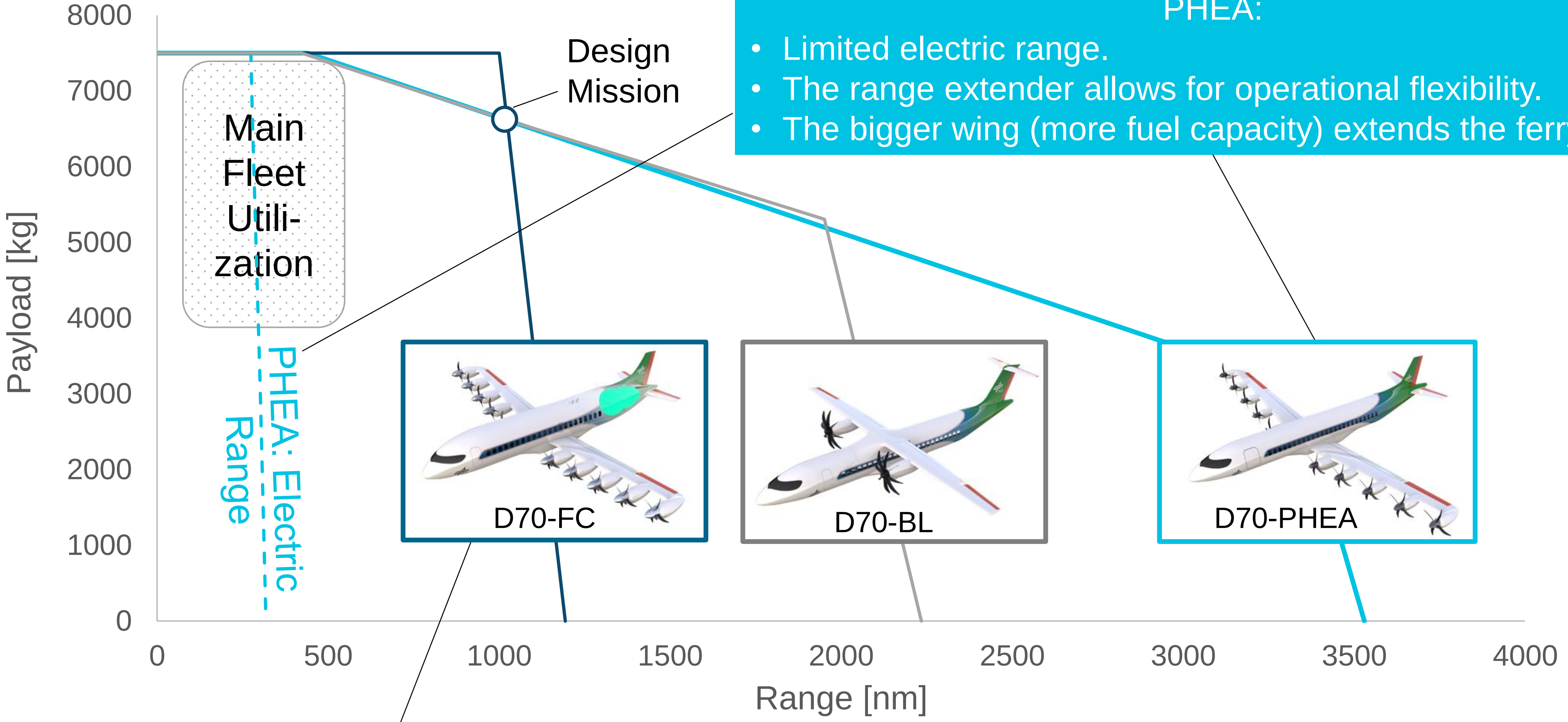


Fuselage Length – 24.9 m

Payload-Range Characteristics

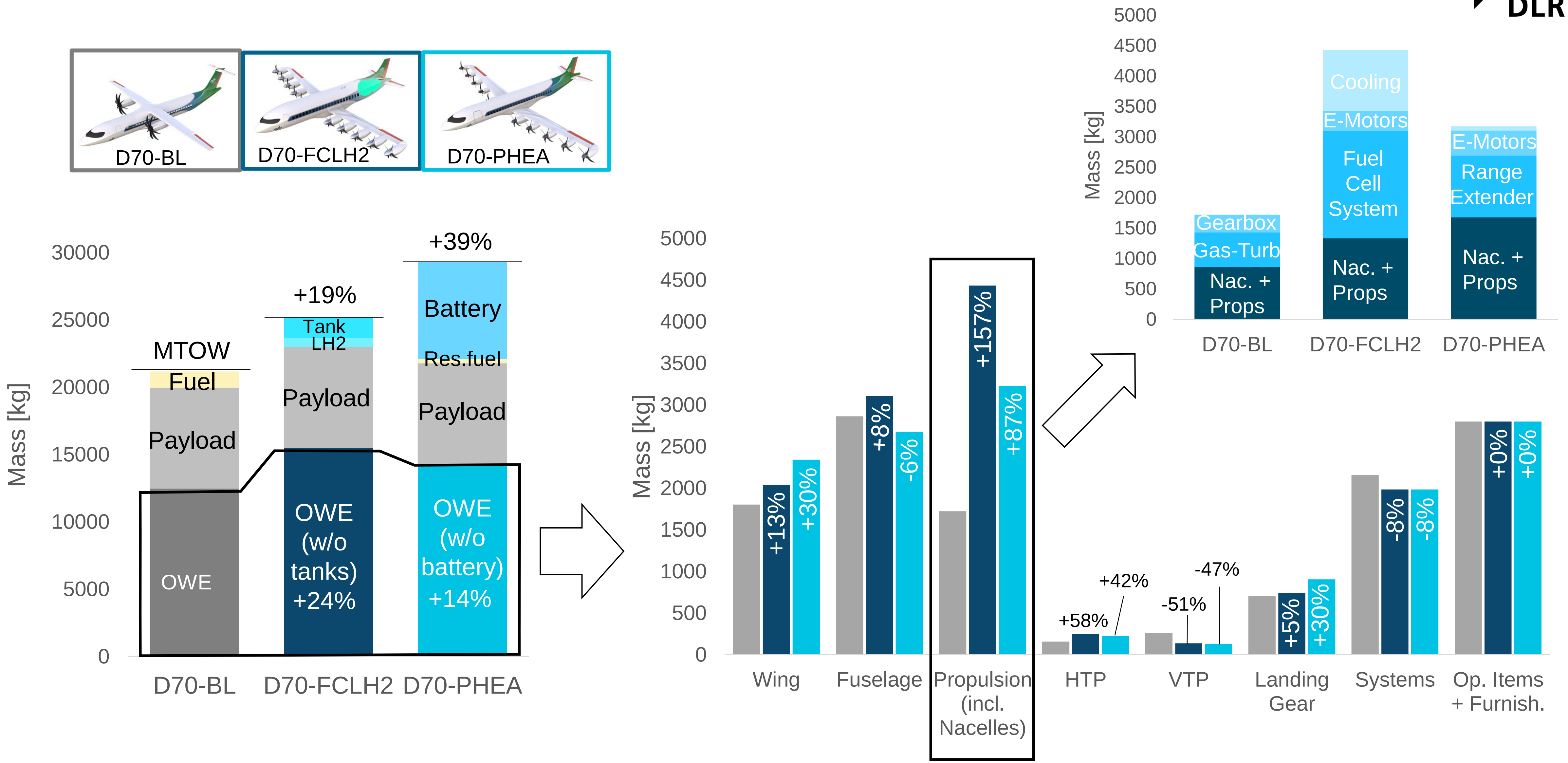
PHEA:

- Limited electric range.
- The range extender allows for operational flexibility.
- The bigger wing (more fuel capacity) extends the ferry range.

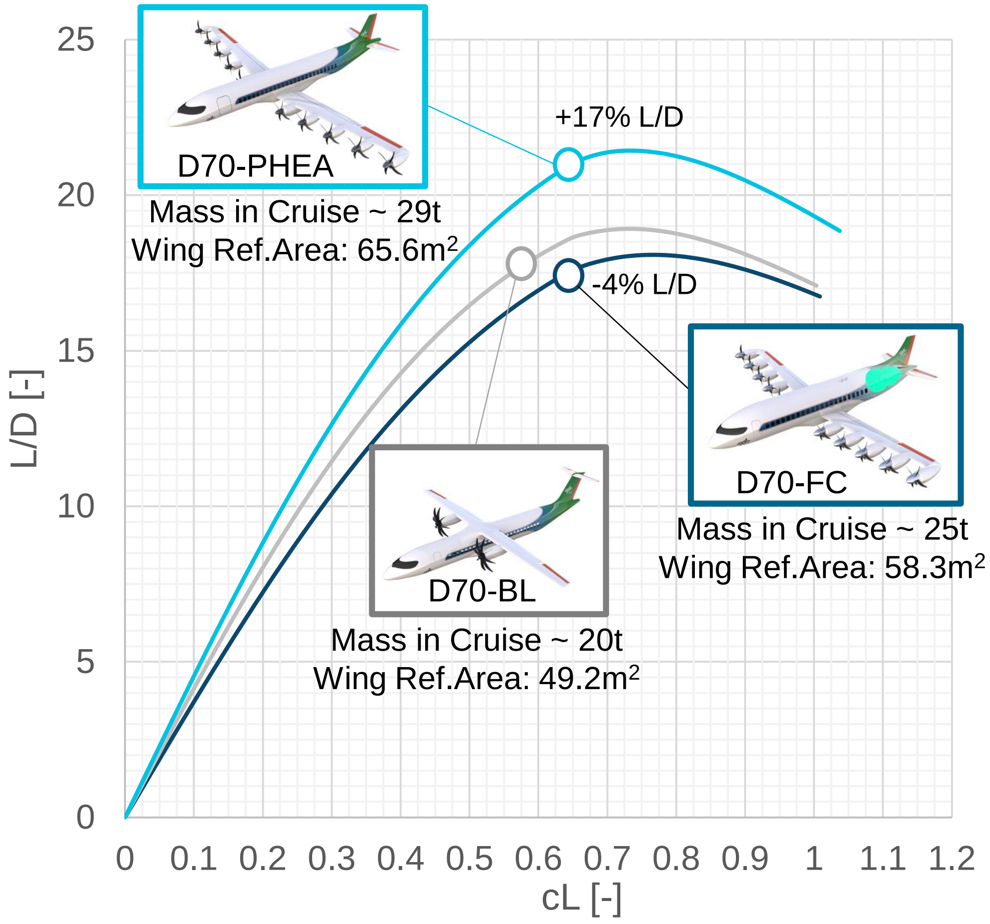


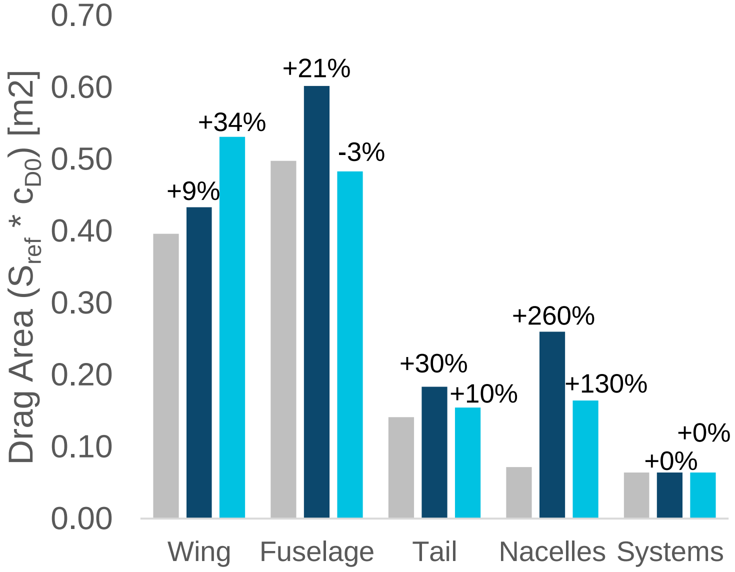
D70FC: The payload-range capability is limited by the max. tank capacity (constrained by the design mission)

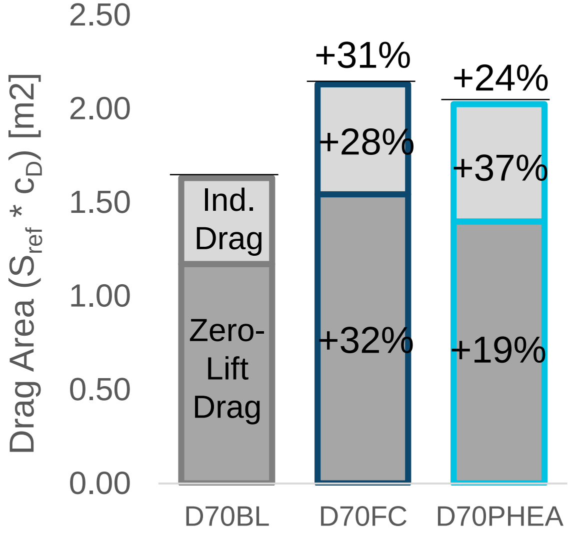
Mass Breakdown



Aero Breakdown







D70-PHEA:

- 19% higher zero-lift drag due to big wing and nacelles
- 37% more induced drag due to mass
- 24% higher absolute drag in cruise but ~45% more lift => higher L/D

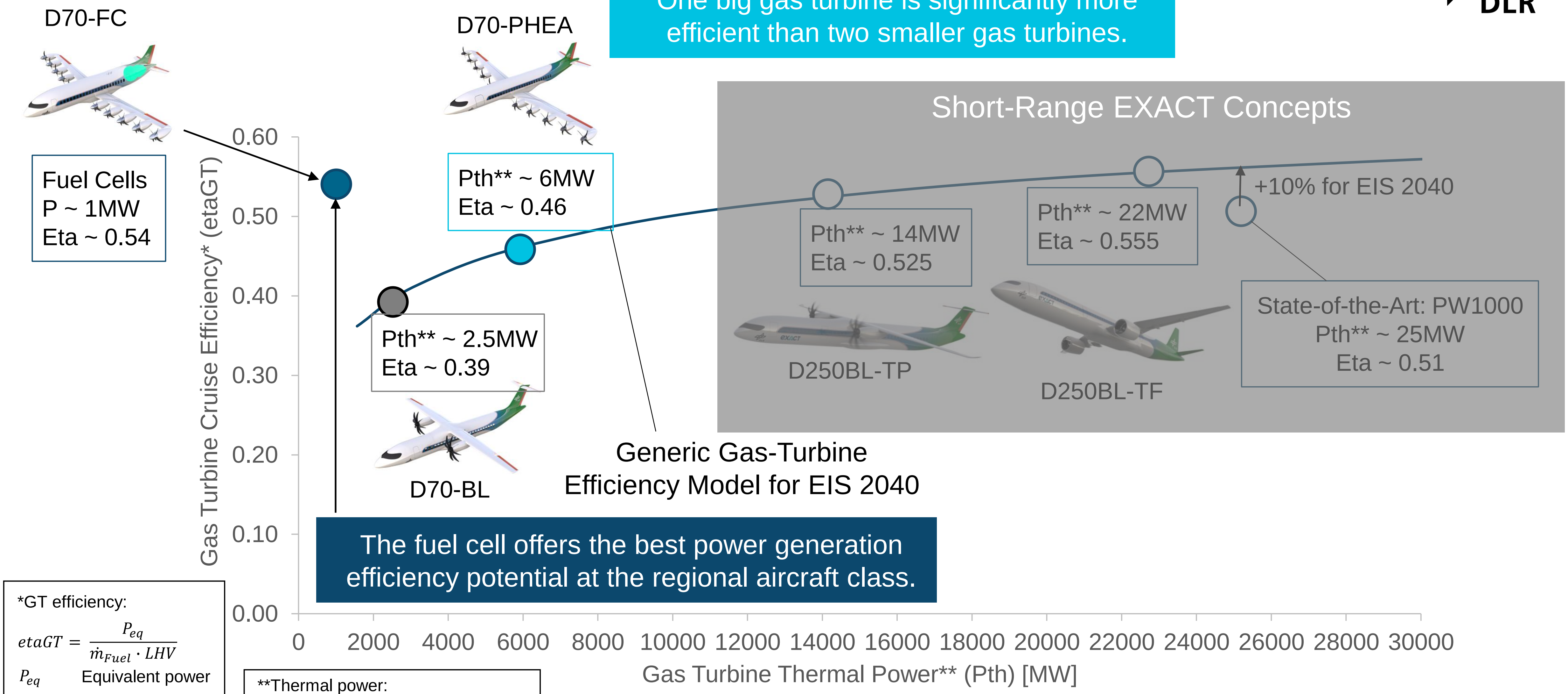
D70-FC10:

- The highest drag in cruise (+31%), mainly due to big nacelles and fuselage.
- L/D slightly less than the baseline due to ~25% more lift in cruise

D70-FC10 & PHEA: ~10% higher wing loading, due to assumed max. lift coefficient improvement in approach due to the „blow-wing“ effect:
→ A higher cruise CL is possible, while still keeping the approach speed TLAR

Power Provider Efficiency

One big gas turbine is significantly more efficient than two smaller gas turbines.



The fuel cell offers the best power generation efficiency potential at the regional aircraft class.

*GT efficiency:

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

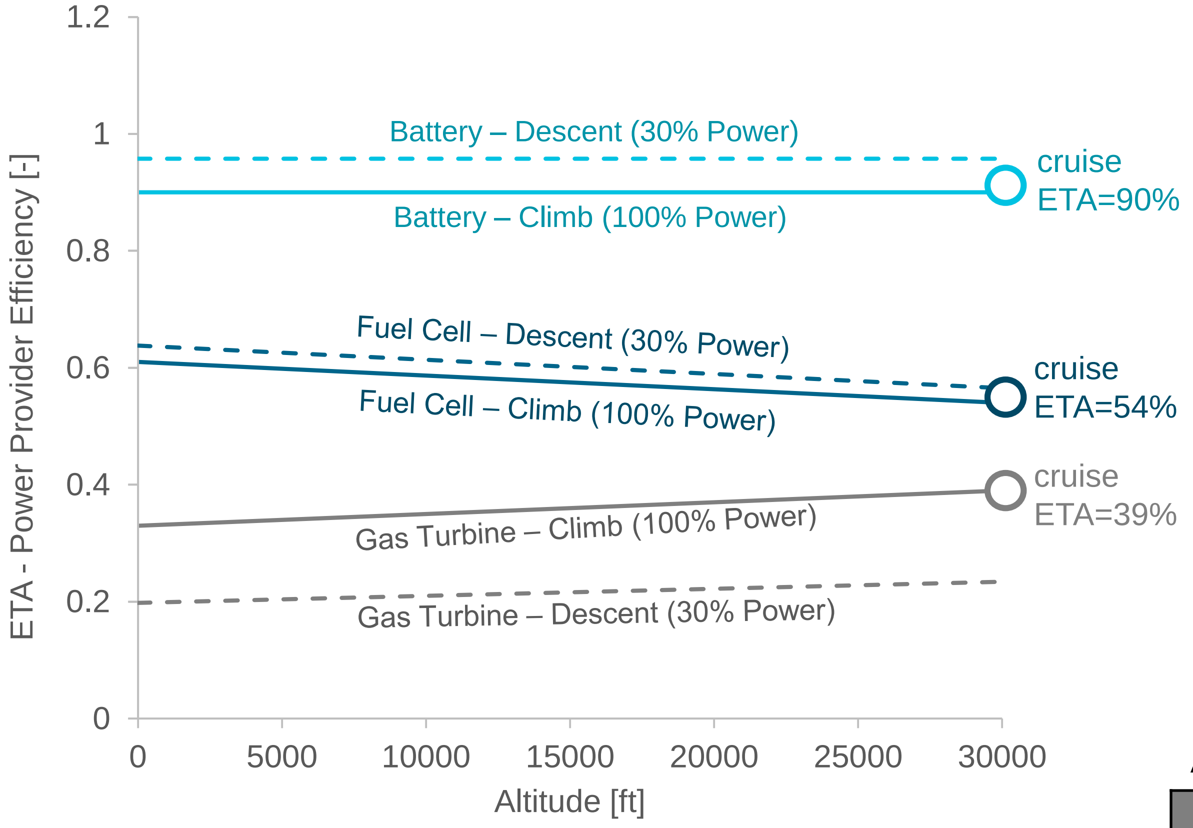
P_{eq} Equivalent power
$\dot{m}_{Fuel}$ Fuel flow
LHV Low heating value

**Thermal power:
Achievable power at sea-level static ISA conditions & TET limit withtout any mechanical power limitations or flat rating.

Mid-Cruise Performance

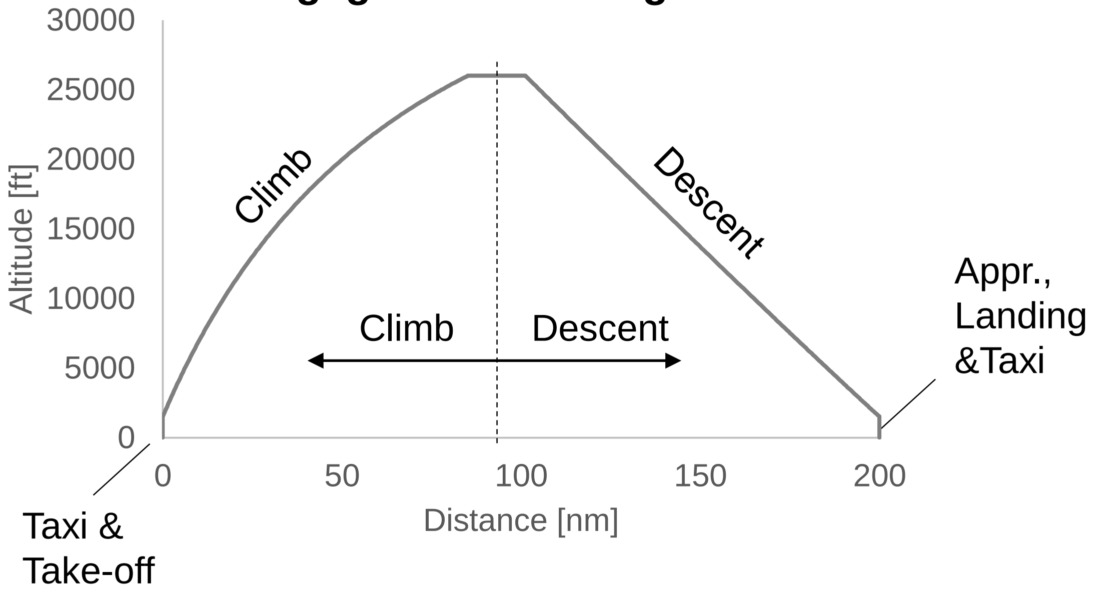
	MASS	L/D	THRUST	ETA PROP		SHAFT POWER	ETA TRANSM	ETA POWER	ENERGY FLOW
 D70-Baseline	20t	18.0	10.9kN	0.903	FL2900 Ma0.55	2030kW	Gearbox: 0.985	**Gas Turb. 0.39**	**5270kWh/h**
 D70-FC10	24.85t (+24%)	17.3	14.1kN (+29%)	0.905	FL290 Ma0.55	2610kW (+29%)	E-Mot: 0.975	**Fuel Cell: 0.54**	**4860kWh/h (-8%)**
D70-PHEA (electric flight) 	29.3t (+47%)	21.0	13.6kN (+25%)	0.920	FL290 Ma0.55	2490kW (+23%)	E-Mot: 0.975	**Battery.: 0.9**	**2840kWh/h (-47%)**
D70-PHEA (range-extender flight)	28.7t (+43%)	20.9	13.5kN (+23%)	0.921		2450kW (+21%)	Turbo-electric: 0.956	**Gas Turb.: 0.46**	**5570kWh/h (+6%)**

Off-Design Performance



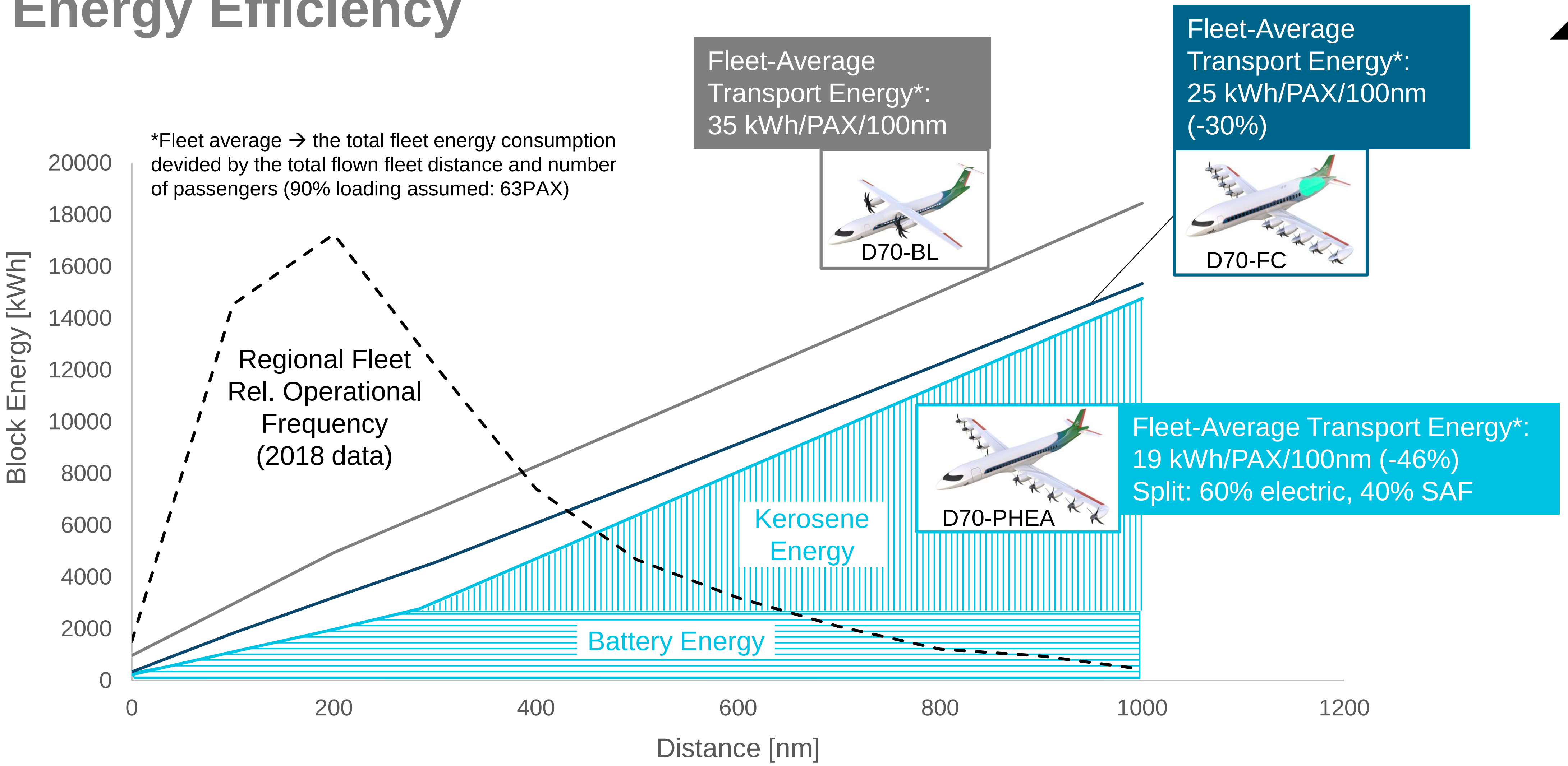
The fuel cell & battery tend to perform significantly better in off-design conditions than the gas turbine.
➔ A considerable advatage on short missions.

200nm Mission Trajectiory:
Negligible cruise segment!



Aicraft	Climb Energy [kWh]	Descent Energy [kWh]	Allowances* Energy [kWh]	Tot. (Block) Energy [kWh]
D70-BL	3080	900	970	4950
D70-FC	2580	300	330	3210 (-35%)
D70-PHEA	1600	180	190	1970 (-60%)

Energy Efficiency



The D70-PHEA offers the highest efficiency for all operational ranges. Its best performance is at missions up to 300nm, due to fully electric flight, which is also where the fleet mostly operates. Resulting in almost halving the energy consumption.

Summary

Fleet-Average Transport Energy:
35 kWh/PAX/100nm

Pros:
- Mature, low-risk technology
- Lightest MTOW & airframe mass

Cons:
- Highest fleet energy consumption of the three concepts

Fleet-Average Transport Energy:
25 kWh/PAX/100nm

Pros:
- **~-30% fleet energy**

Cons:
- ~+20% MTOW
- ~+25% Airframe & Propulsion mass (before LH2 tanks)

Fleet-Average Transport Energy:
19 kWh/PAX/100nm

Pros:
- **~-46% fleet energy**

Cons:
- ~+40% MTOW
- +14% Airframe & Propulsion mass (w/o battery)

Outlook for the next loop of EXACT:
- Dedicated fleet operation model.
- Cost & climate impact comparison in the next loop of EXACT

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THANK YOU FOR YOUR ATTENTION!
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All renders by Line Winkler (DLR)