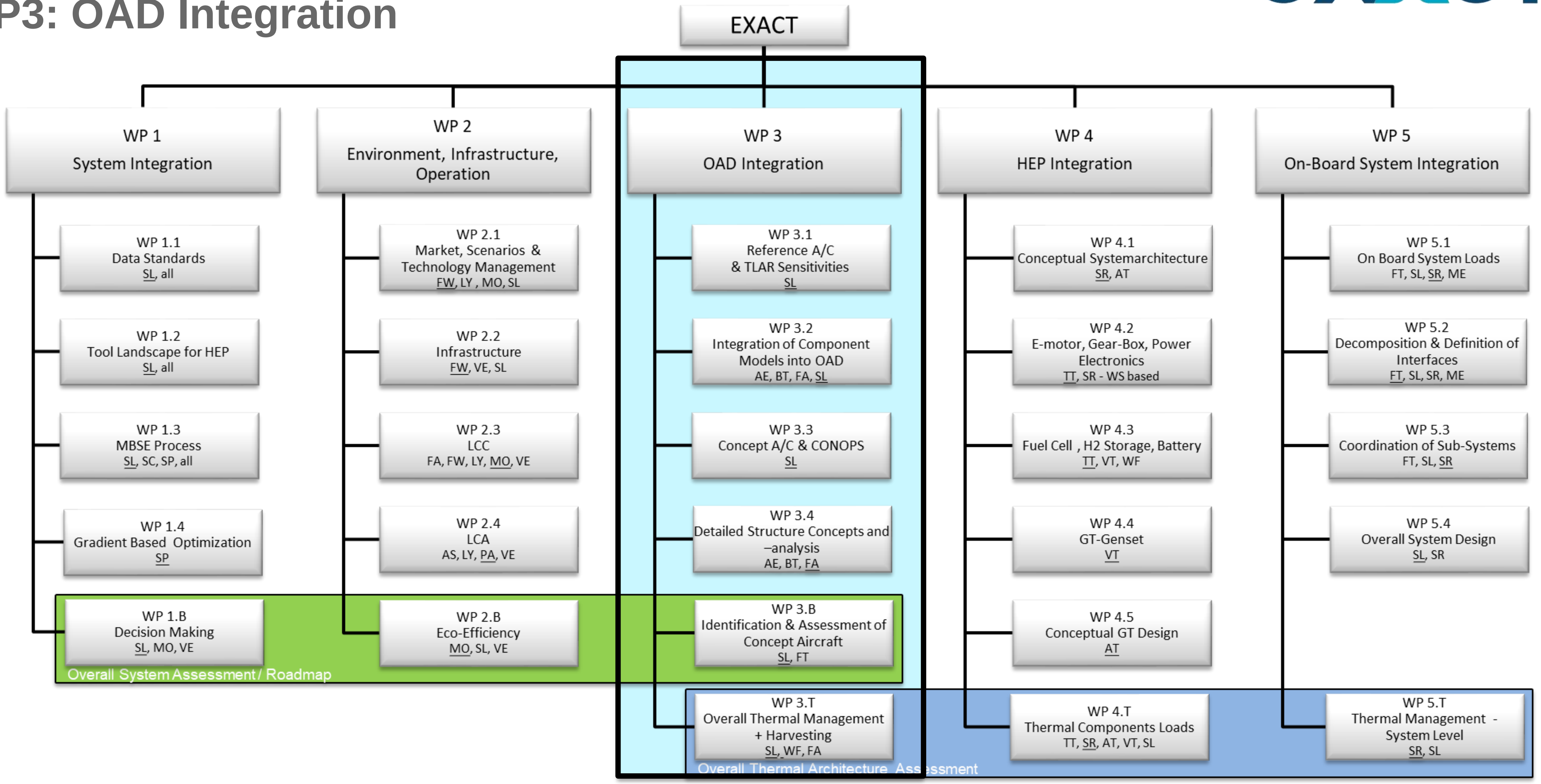
Deutsches Zentrum
für Luft- und Raumfahrt

DLR

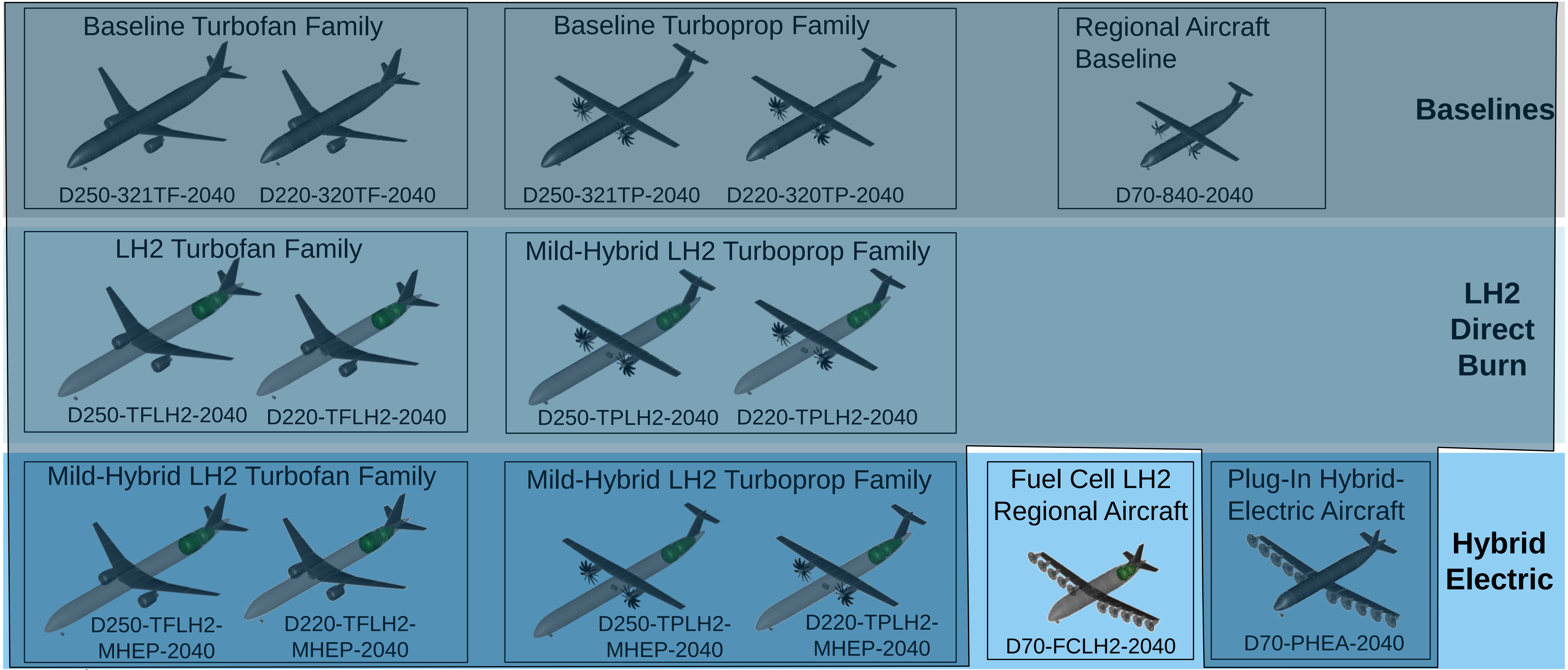
70 PAX Fuel Cell Aircraft
D70-FCLH2-2040

Presenter: Georgi Atanasov

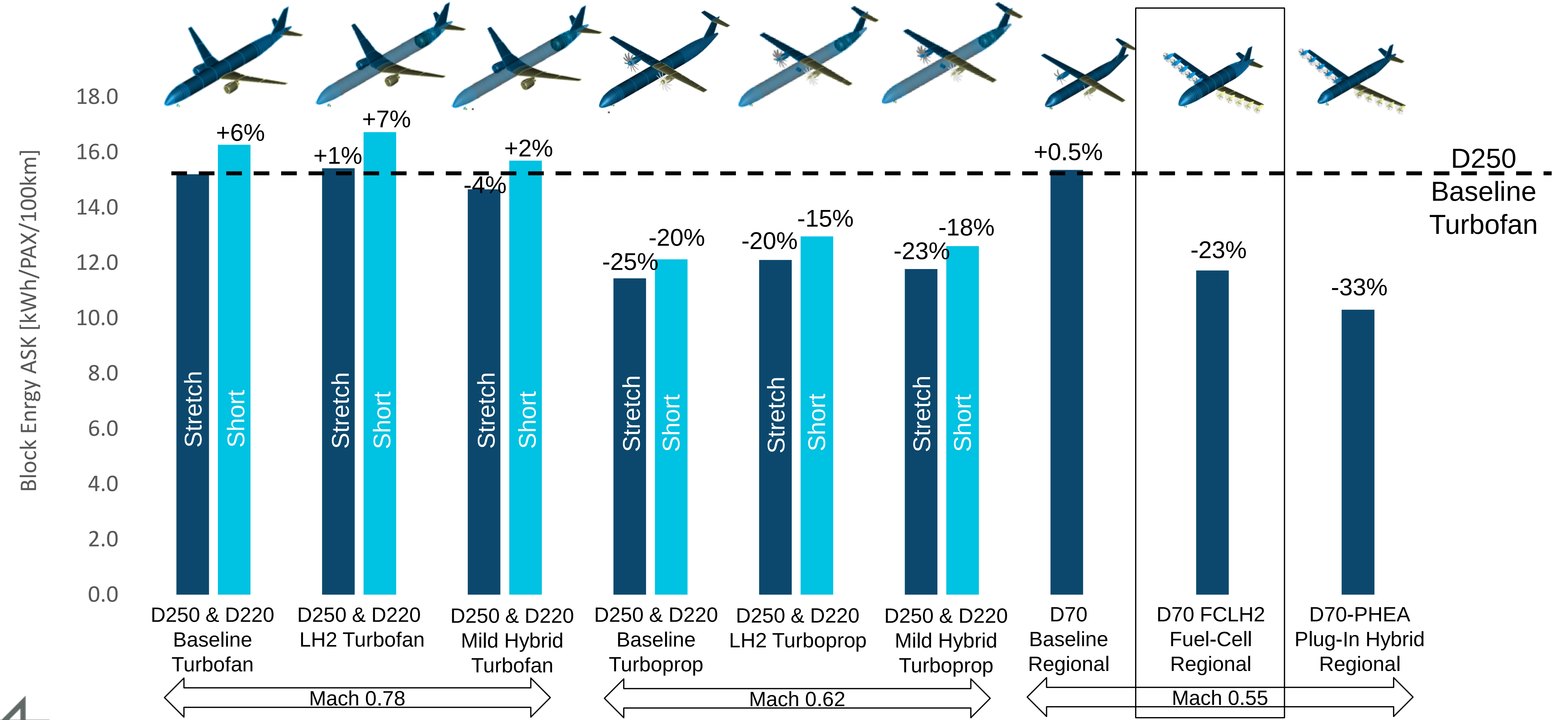
WP3: OAD Integration



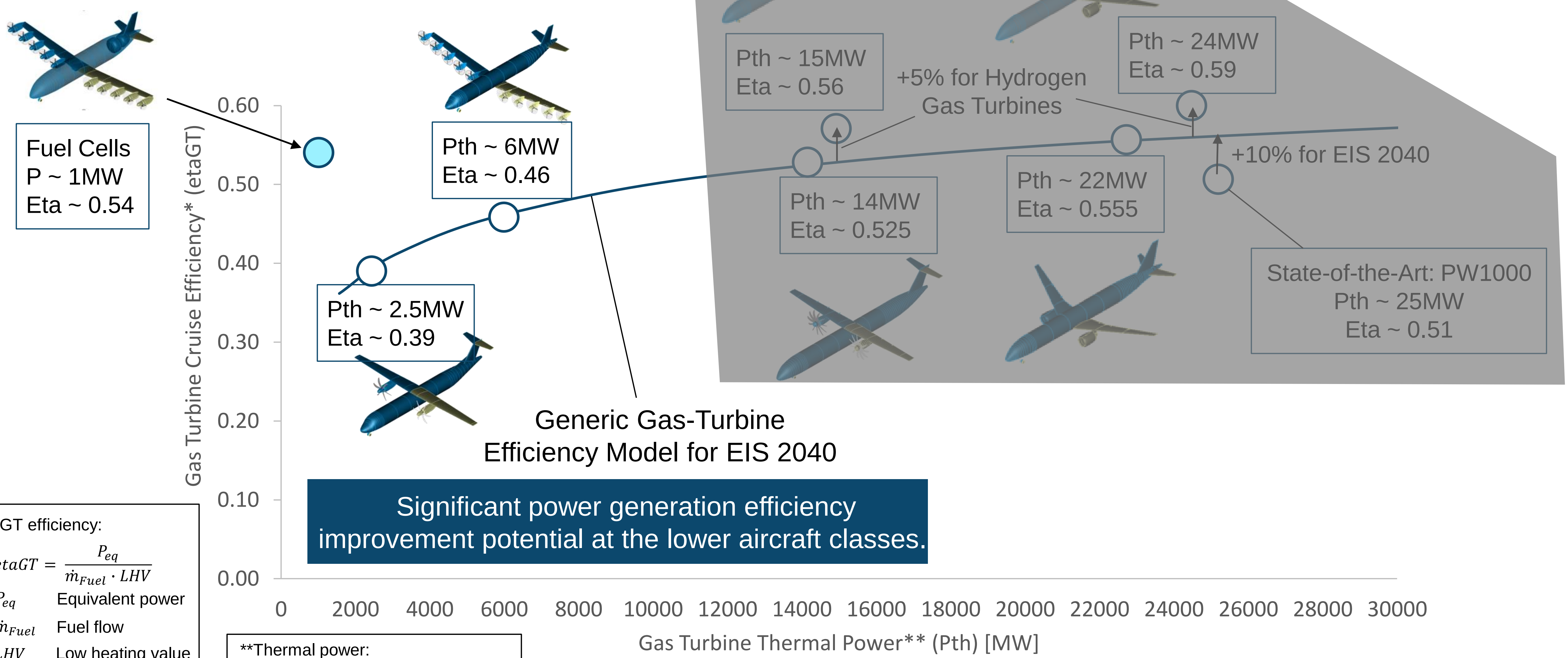
Models Overview



Block Energy Comparison @ 500nm & Standard Payload



Motivation for Fuel Cell Aircraft



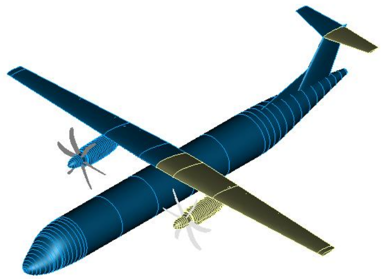
*GT efficiency:

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

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.

Baseline Aircraft and Assessment Metrics

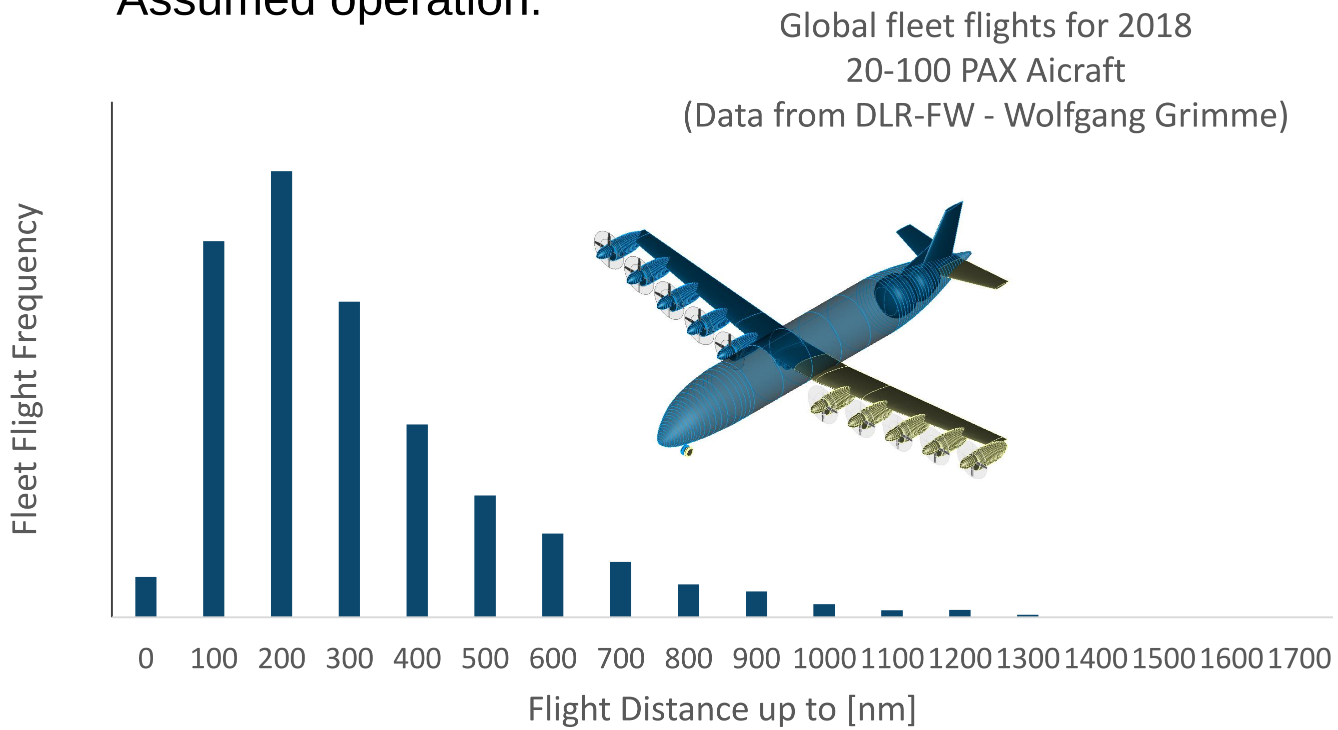


Baseline aircraft designation: D70-840-2040 (D70-BL)

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]	29000
OEI Ceiling	[ft]	8000
TOFL (ISA +0K SL)	[m]	1500
Approach Speed (CAS)	[kt]	<120
Wing span limit	[m]	<=36

Assumed operation:



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

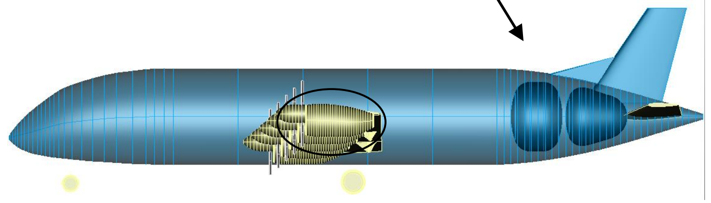
- Assumed that the opeation of the aircraft coincides with the assumed fleet operation profile.
- The fleet-level fuel is determined by multiplying the flight frequency at a given distance with the block energy needed for this distance and integrating across the entire distance profile.

Fuel Cell Aircraft Modelling Assumptions

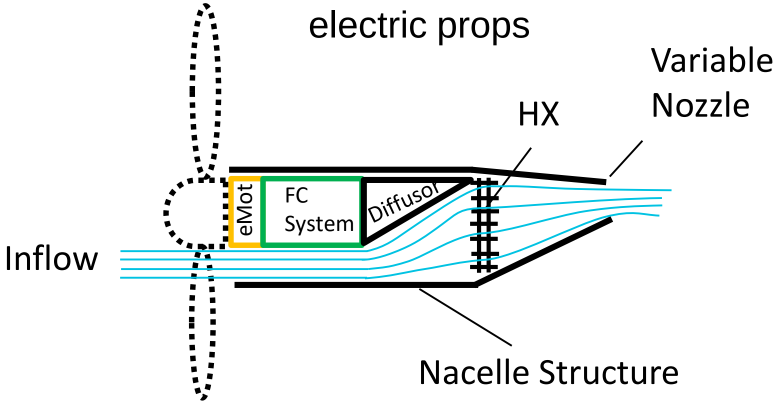
Assumptions for Fuel Cell Modelling EIS 2040

DISCIPLINE/PARAMETER	INPUT	COMMENTS
FUEL CELLS		
Sp. Power Fuel Cell System	1.5 kW/kg	Oversized stacks & inc. sub-systems (no cooling)
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	-
Resulting contrainment index	29%	Result from LH2 Subworkflow Calculation
Efficiency Generator (incl. Rectifier)	97.5%	-
Installation Mass Penalty	5%	With respect to total mass (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

Two tanks integrated in the rear (designed for minimum fuselage length)



10x Fuel Cell driven electric props



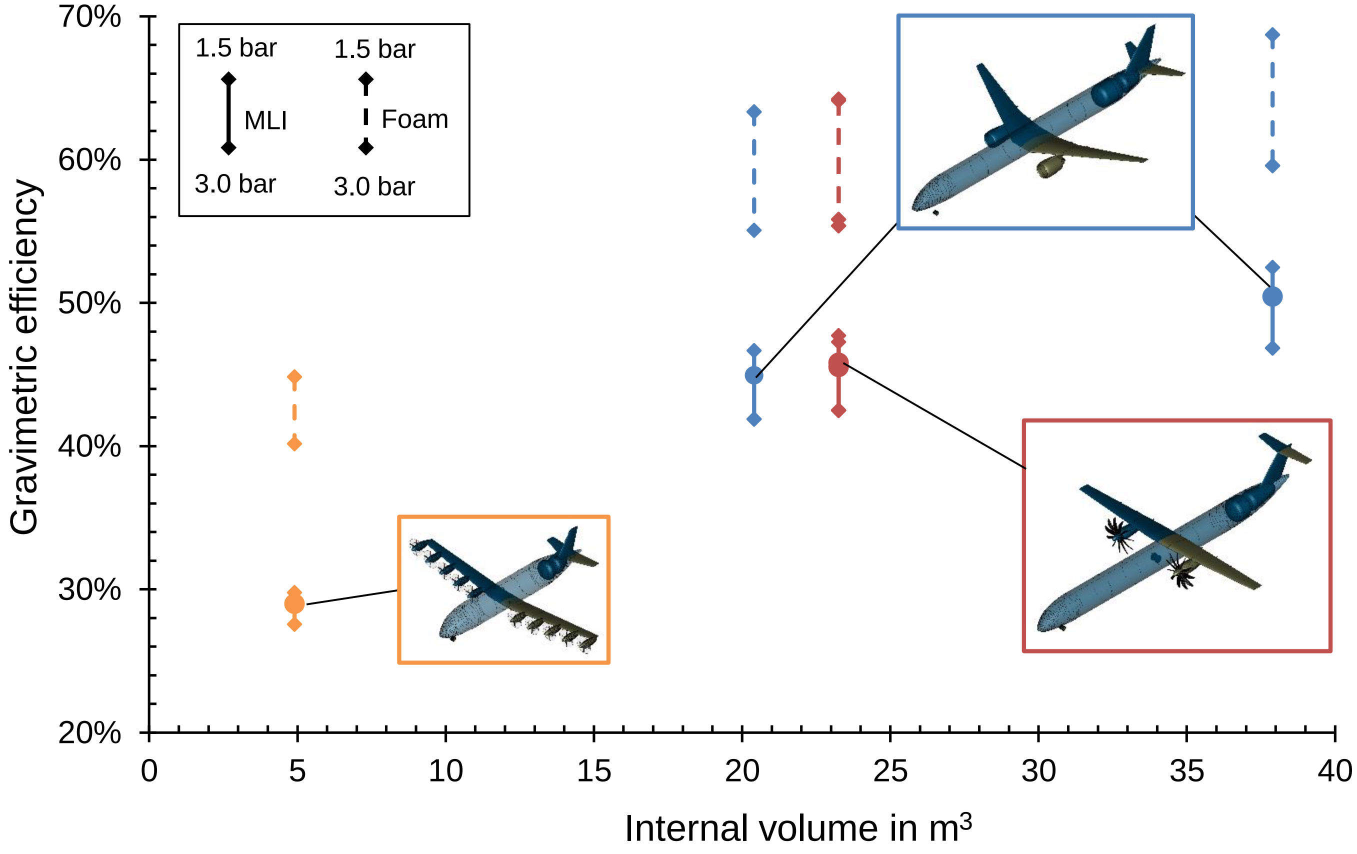
LH2 Tank Mass

Preliminary calculation assumptions:

- Method for minimal wall thickness [1]
- Sizing for external (if vacuum applied) and internal overpressure
- Material: Aluminum AL-2219 T851
- Design stress: 172 MPa [2]
- Load factor: 1.5 [2]
- Safety factor: 1.5 [2]
- Additional system mass from Brewer [2]

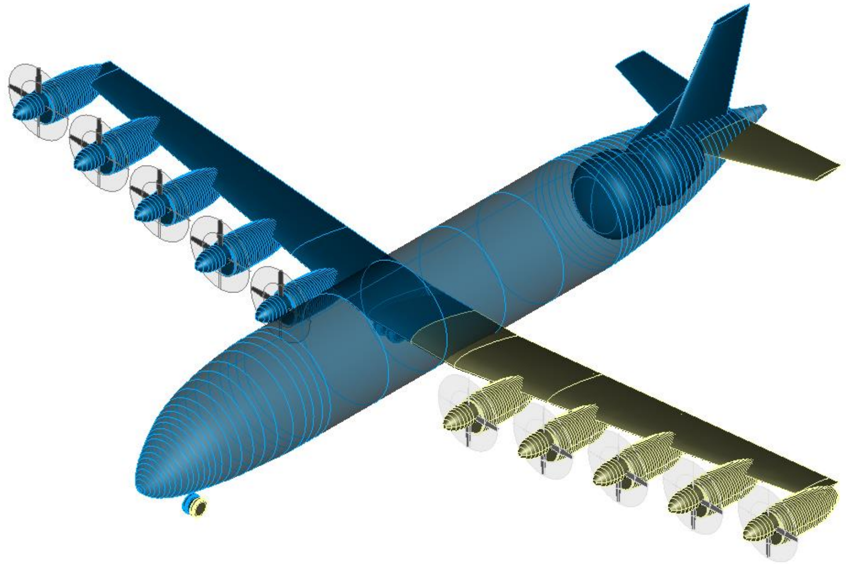
Gravimetric efficiency depends on size, max. pressure and insulation concept

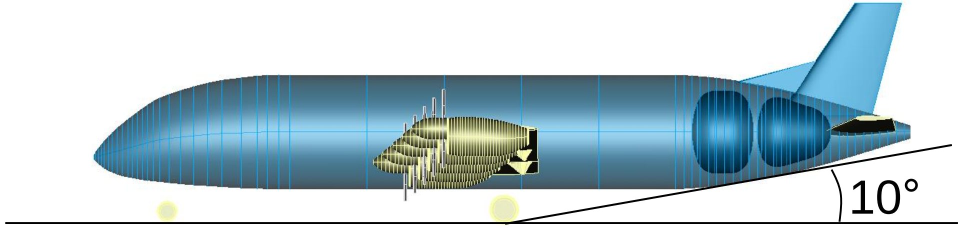
Gravimetric comparison of EXACT LH2 storage concepts

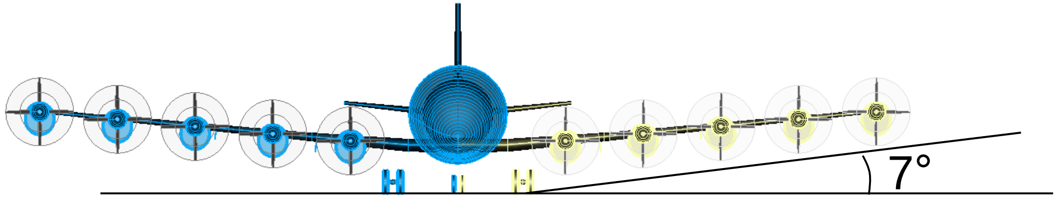


[1] Verband der TÜV e. V., Berlin. „AD2000 Regelwerk“. Berlin. 2016.
[2] G. D. Brewer. “Hydrogen aircraft technology”. New York: Routledge. 1991.

Fuel Cell Aircraft Configuration





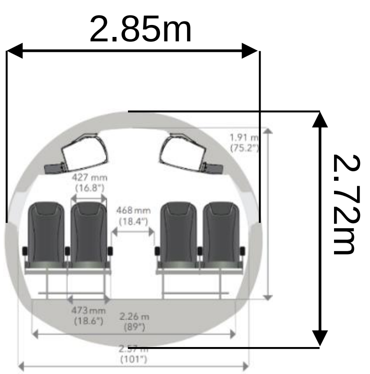


Configuration aspects:

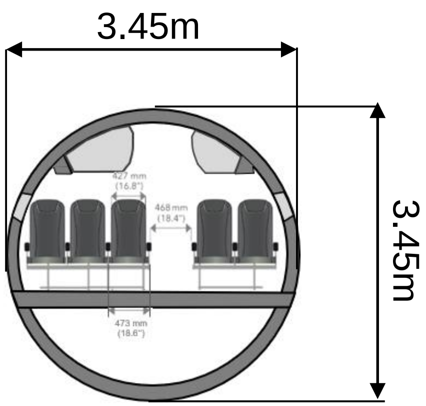
- Switch to a 5-Abreast cabin (vs 4 Abreast of the D70-BL)
- Tanks designed for minimum fuselage length.
- 10 propellers:
  - Take-off power reduction due to redundancy and blown wing effect.
  - Sufficient area for nacelle-integrated heat exchangers.
  - VTP size reduction due to the lack of OEI yaw-moment 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
- 5° wing dihedral for sufficient banking angle.

Fuselage Design

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



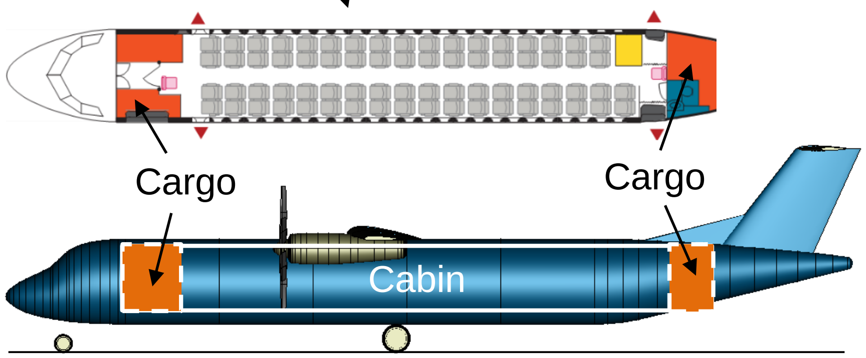
19 Rows

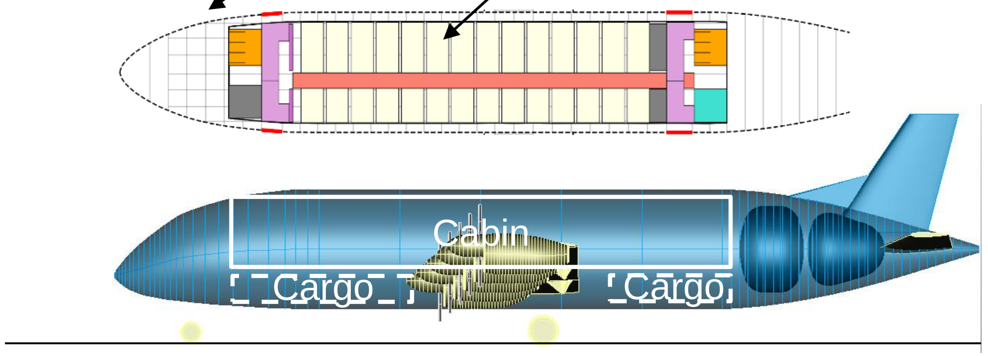


15 Rows

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.)

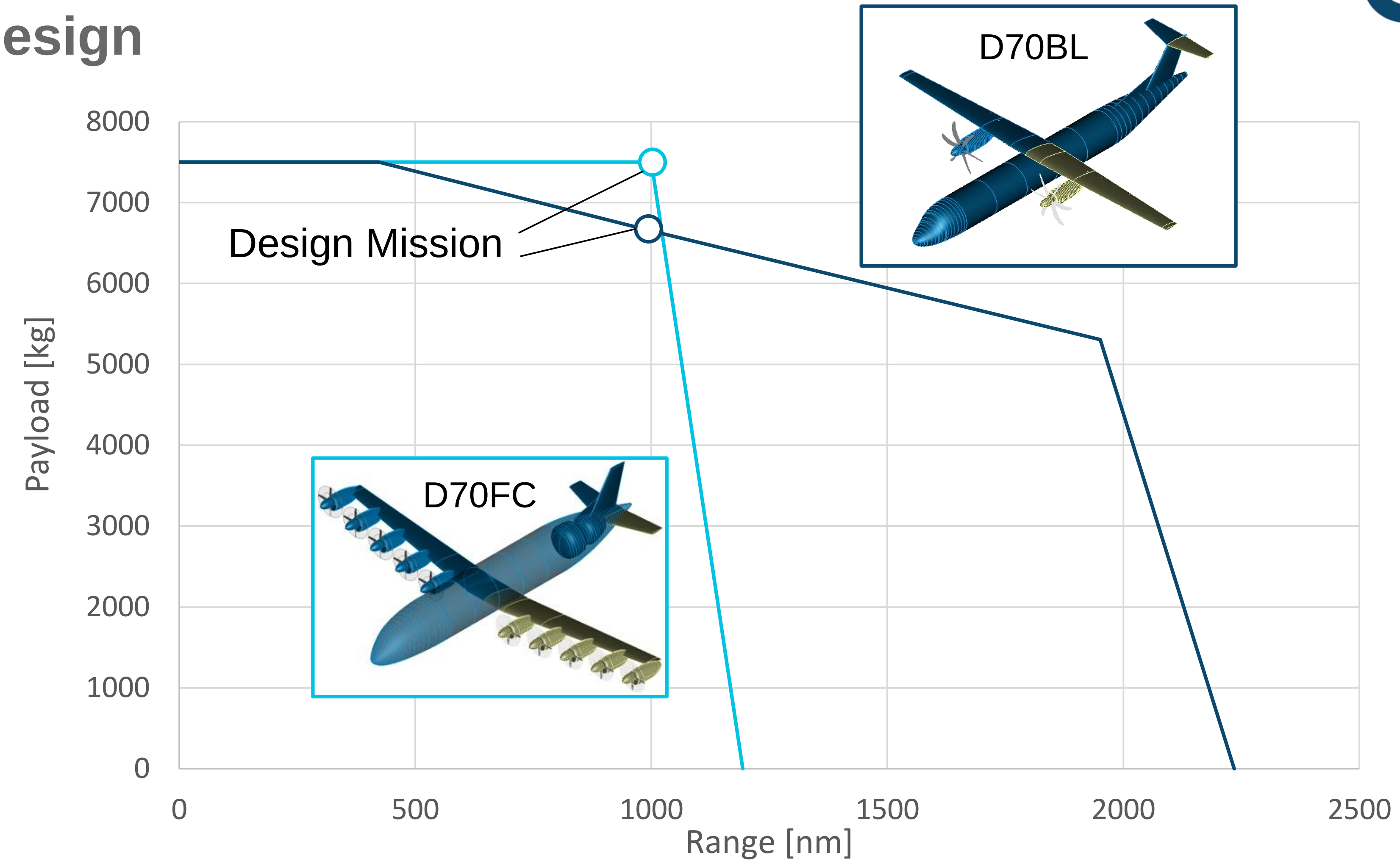




Fuselage Length – 26.9 m

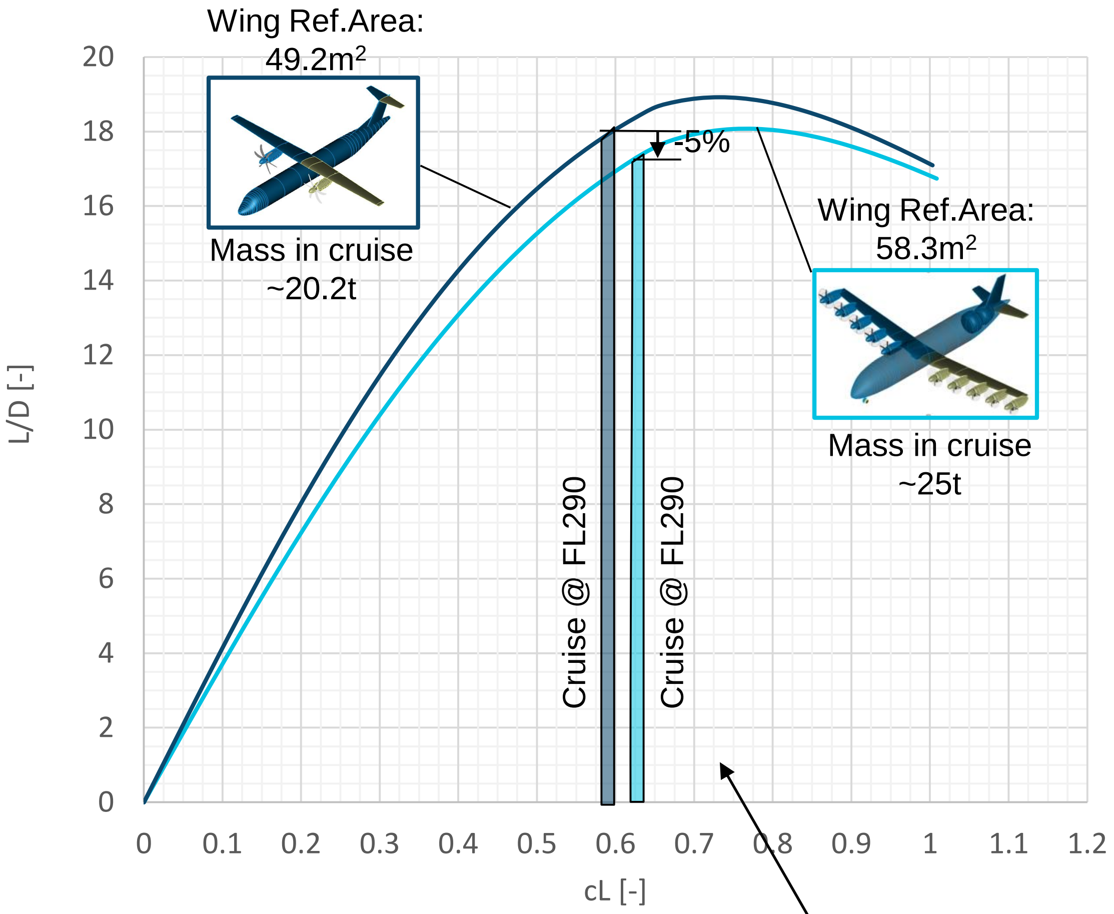
Fuselage Length – 24.9 m

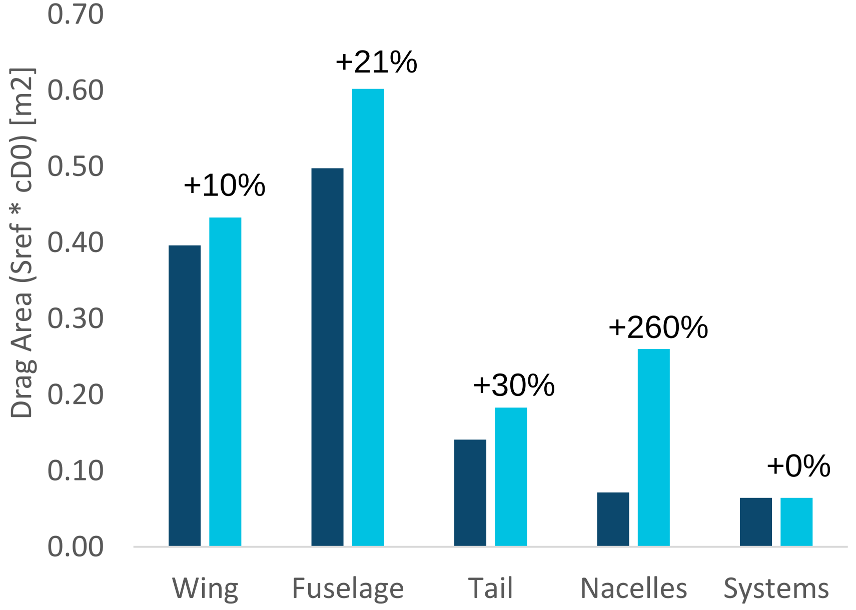
Fuselage Design

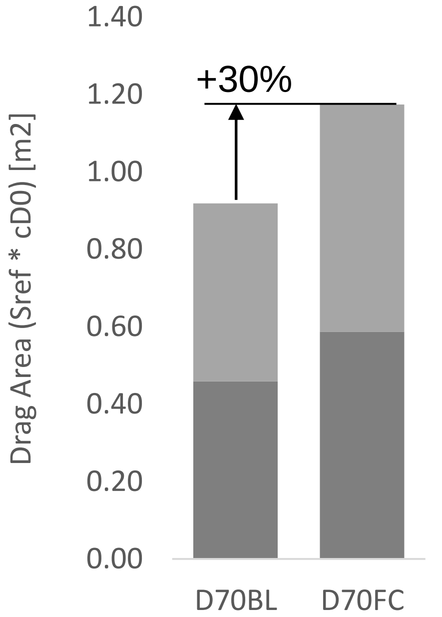


The payload-range capability of the D70FC is limited by the max. tank capability, so the design mission determines the tank size, whereas the conventional turboprop can use the max. volume available in the wing without penalizing the design.

Aerodynamic Analysis



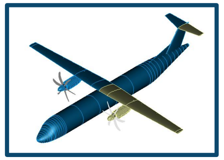


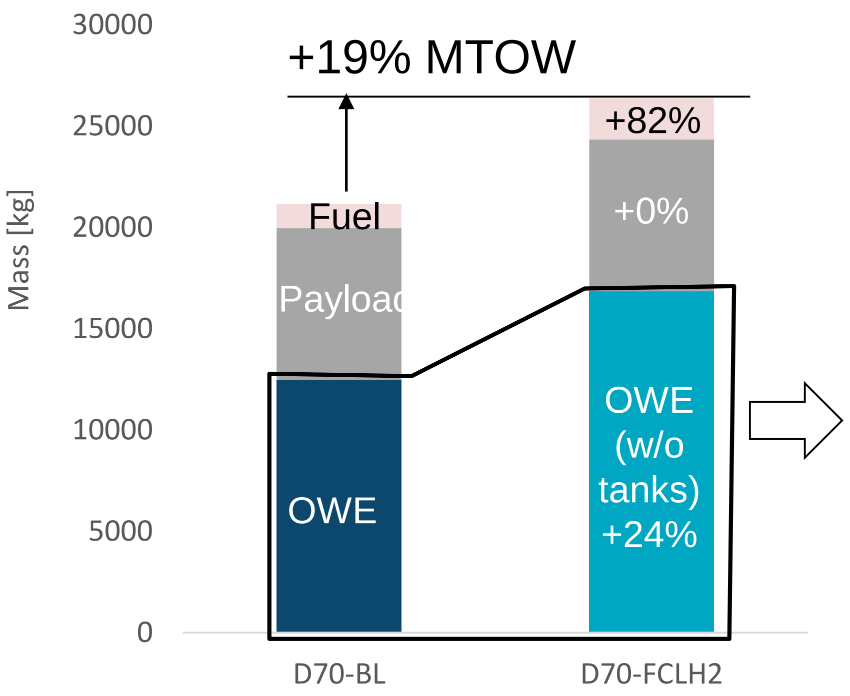


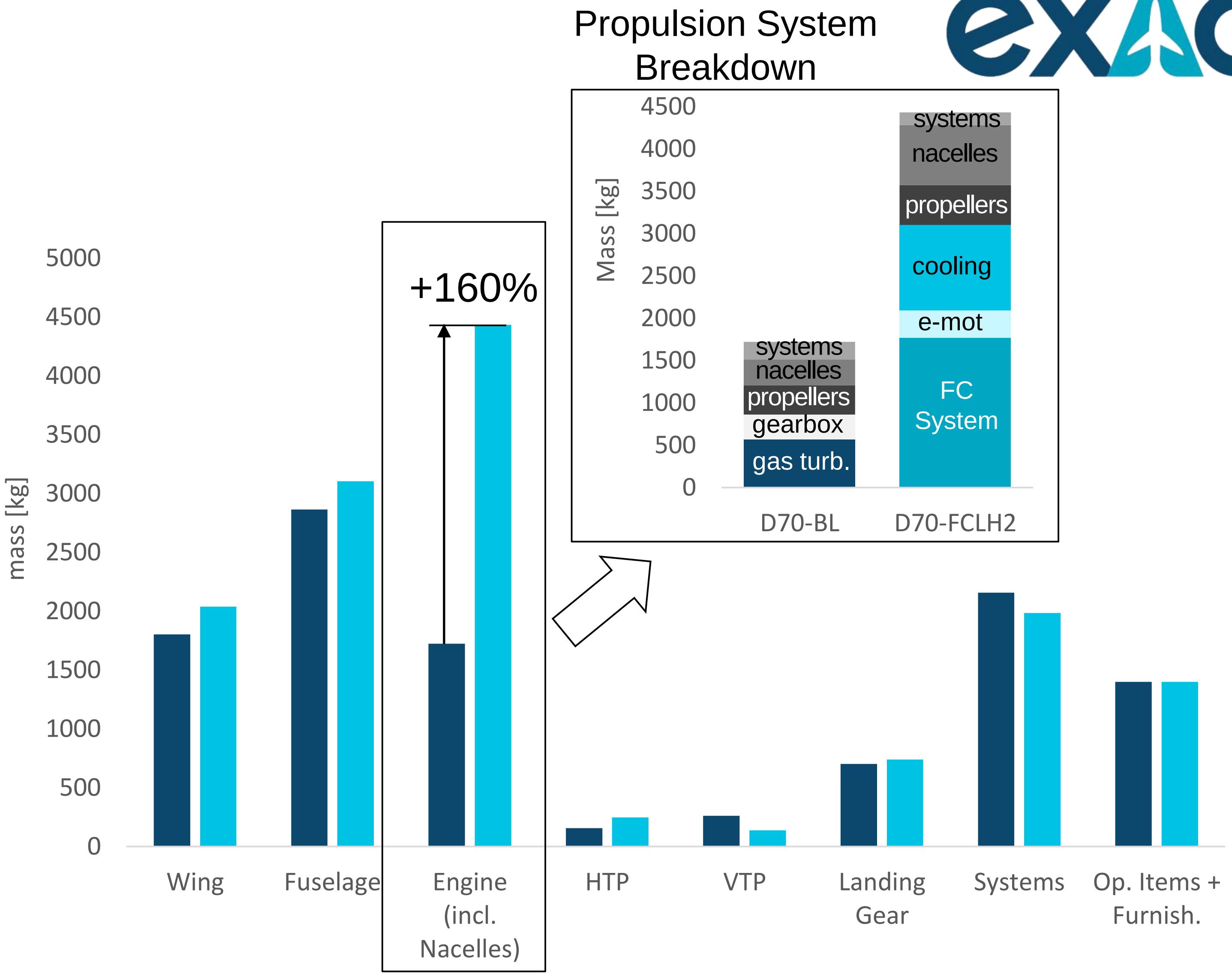
The 30% higher zero-lift drag is compensated by ~25% higher total lift in cruise (heavier aircraft), results in ~5% lower L/D.

Wing loading of D70-FC is ~10% higher, 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

Mass Breakdown

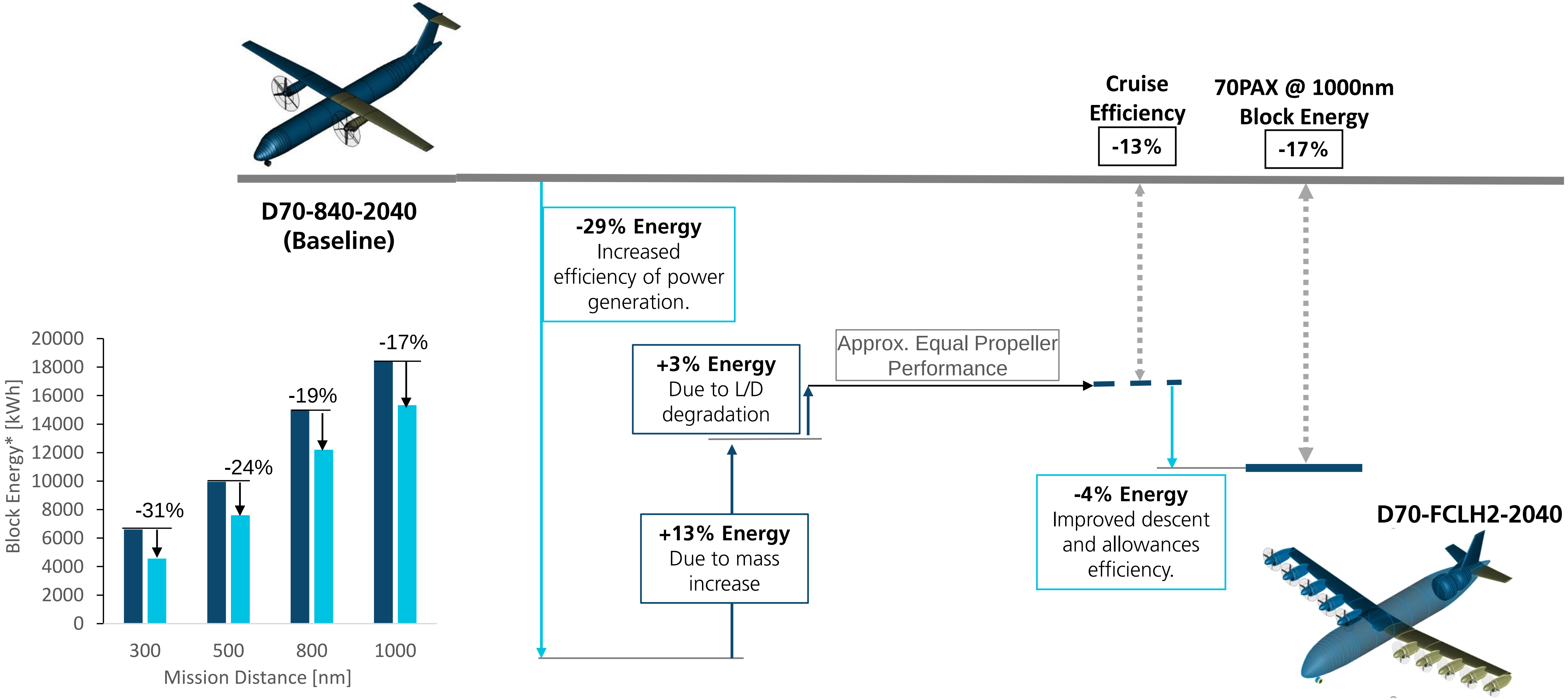






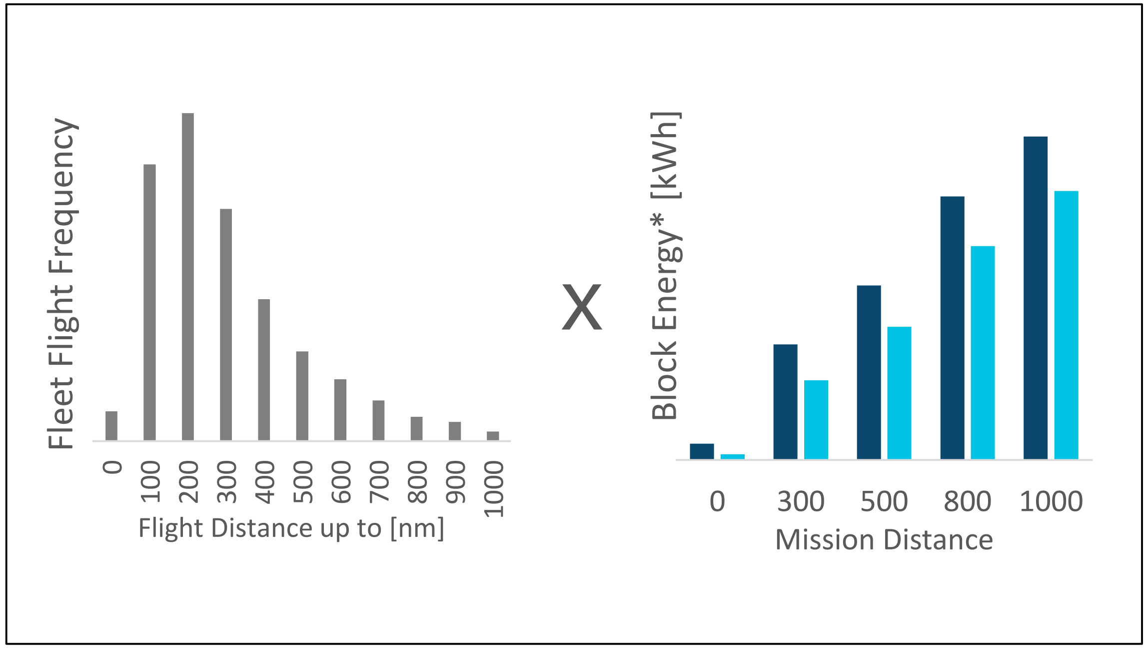
~20% higher MTOW, mainly due to the mass penalty from the fuel cell-based propulsion system.

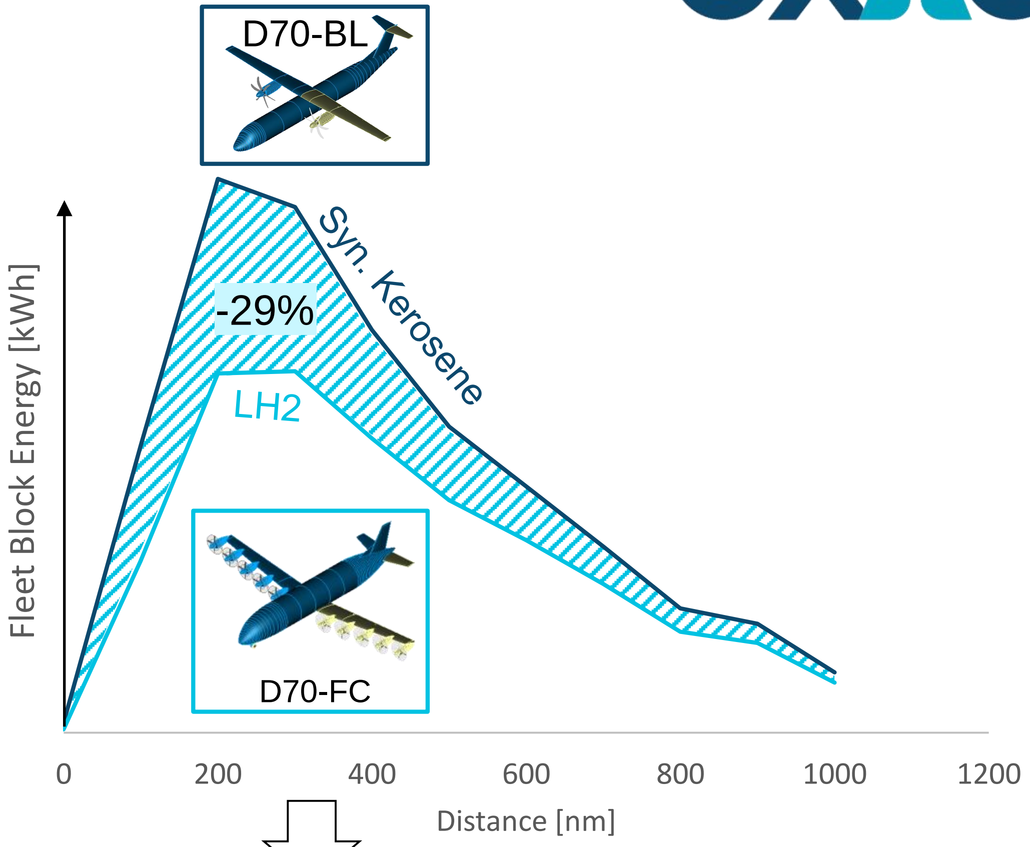
Fuel Cell Aircraft Performance Assessment @ 1000nm



*Based on energy density:
Kerosene: 12kWh/kg
LH2: 33.3kWh/kg

Regional Aircraft Fleet-Level Assessment





EXACT energy cost assumptions:
- Synthetic kerosene: 0.125€/kWh
- LH2: 0.13€/kW

Fleet-level energy reduction of ~29%
Energy cost reduction ~27%

Potentially, a significant energy cost reduction is possible for the regional aircraft class.

Summary

- The assessment of the current loop shows that the fuel cell are uncontested in terms of power provider efficiency at the regional aircraft classes.
- The drawback is a significant mass of the propulsion system.
- An unconventional aircraft configuration, synergetic with the tank integration and propulsion system integration counteracts the mass drawback and can successfully make use of the propulsion efficiency advantage.
- An overal fuel energy reduction of ~30% for the average regional aircraft operation seems possible with the fuel cell concept.

Outlook:

- The configuration will be looped with the other work-packages in the next stage of the project.