IMOTHEP
GETTING HYBRID ELECTRIC

INVESTIGATION AND MATURATION OF TECHNOLOGIES FOR HYBRID ELECTRIC PROPULSION

Plug-In Hybrid-Electric Regional Aircraft Concept for IMOTHEP

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IMOTHEP – Regional Concepts

BHL Aircraft picture source: https://www.bauhaus-luftfahrt.net/epdf/Bauhaus-Luftfahrt-E-Jahrbuch-2020/#76

REG-REF
Aircraft model calibrated on ATR42 data.
Modelled by BHL

Airframe & propulsion system technology factors for EIS 2035.

REG-BAS
Baseline turboprop
(EIS 2035)
Modelled by BHL

Same config. & TLARS with parallel hybrid propulsion.

REG-CON
Regional-Conservative concept with parallel hybrid architecture.
Modelled by BHL

Same TLARS, with plug-in hybrid architecture & distributed propulsion.

REG-RAD
Regional-Radical concept with plug-in hybrid architecture
Modelled by DLR

Used for aircraft model calibration by DLR for the REG-RAD

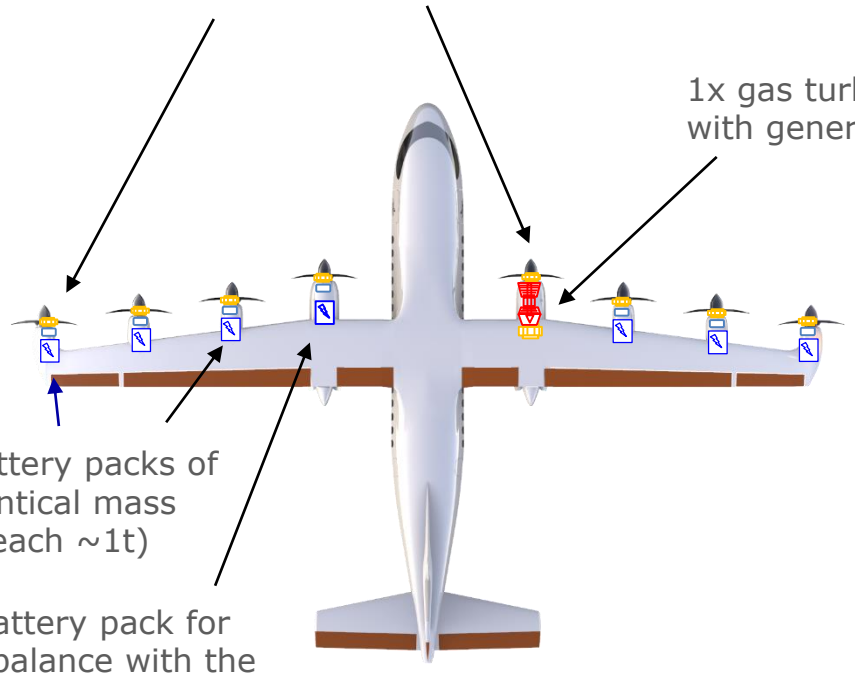
REG-RAD: Configurational Aspects

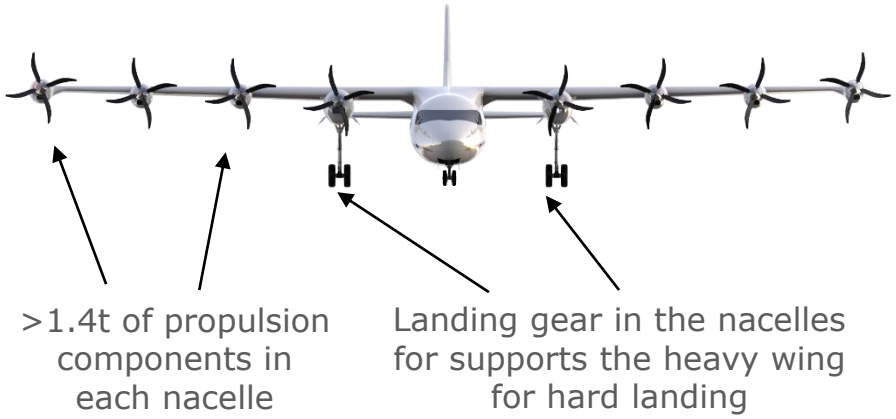
MTOW ~ 22t

Propulsion System (incl. battery) ~9t

Propulsion + Wing ~ 50% of MTOM

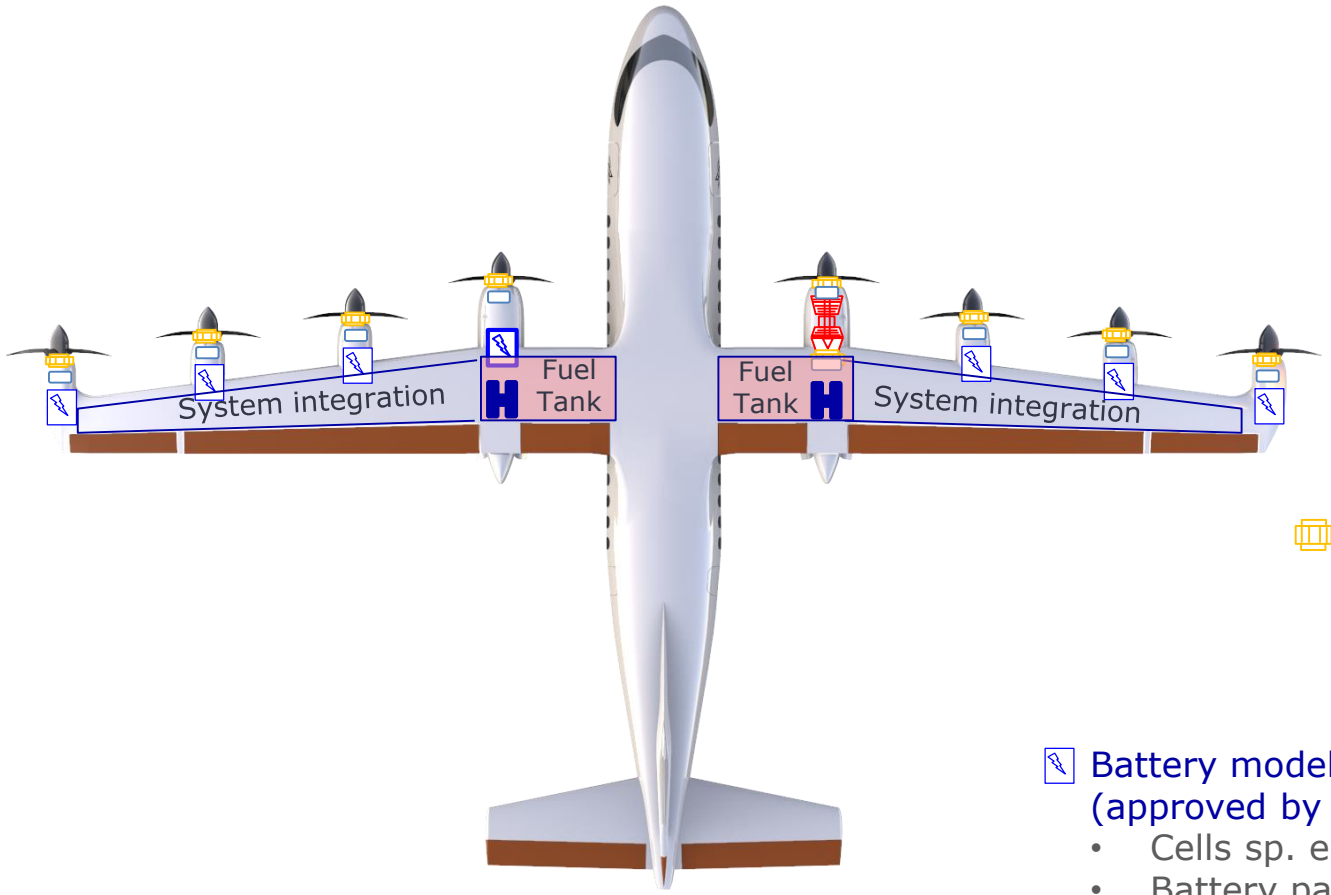
8 x propellers of **identical thrust & rpm map**
Inboard-up rotation.
8 x geared e-motors **of identical power.**





- **Fully electric flight capability**
  - Including take-off and landing.
- **Gas turbine as a range-extender**
  - One gas turbine used in cruise is around 10% more efficient than two smaller gas turbines.
  - Used for mission reserves & longer range capability
- **Distributed electric propulsion for:**
  - Reducing total take-off power requirement.
  - Battery distributed along the wing span to alleviate wing loads.
  - The VTP size is reduced, as the OEI yaw moment is no longer a dominating sizing constraint.

Propulsion System Provided by IMOTHEP Partners



Gas turbine model provided by DLR
(including complete oprational map).

Propeller efficiency calculated by SSA.
- ~89% in cruise

Geared E-Motors model used for REG-RAD
(provided by SSA):
- Sp. power ~5kW/kg (incl. gearboxes & inverters)
- Total efficiency ~ 96.5% (incl. gearboxes & inverters)

Generator model used for REG-RAD
(preliminary simplified assumption):
- Sp. power ~9kW/kg (incl. rectifier)
- Total efficiency ~ 97.5% (incl. rectifier)

Battery model used for REG-RAD
(approved by AIT):
- Cells sp. energy ~475Wh/kg (for 1C discharge)
- Battery pack sp. Energy ~380Wh/kg (for 1C discharge)

REG-RAD Sizing Strategy

Sizing:

- IMOTHEP regional stream key-performance indicator is the energy consumption @ 200nm
- ~2/3rds of the global ATR42 flights are under 200nm (Sabre Market Intelligence 2022 data).

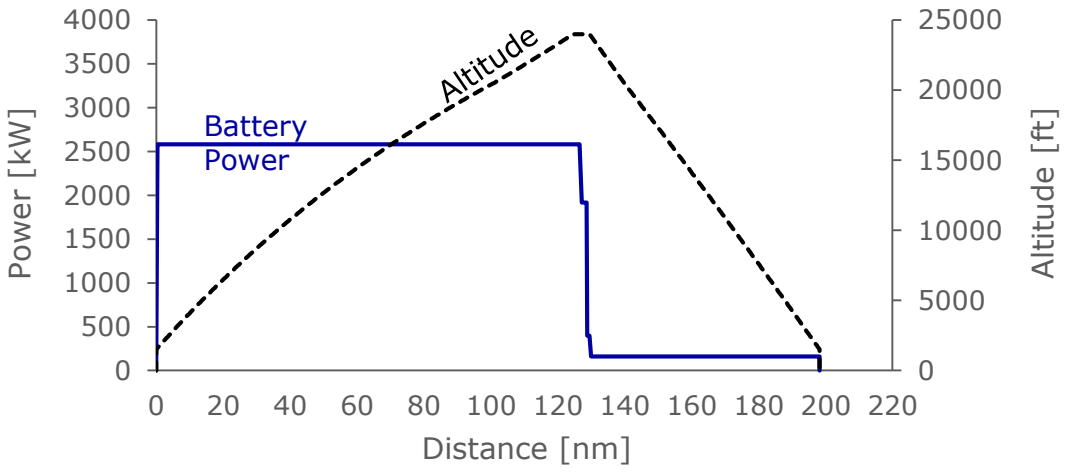
→ **the concept was sized for an all-electric 200nm mission.**

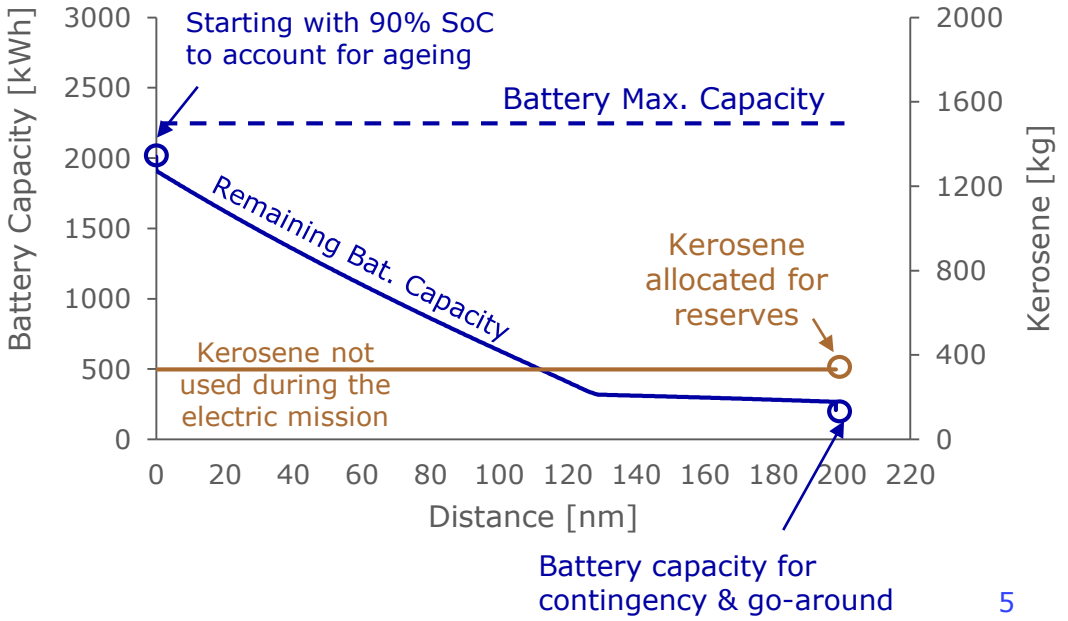
Mission specifics:

- The mission consists mostly of climb & descent.
- Take-off & taxi also performed electrically.

Power management:

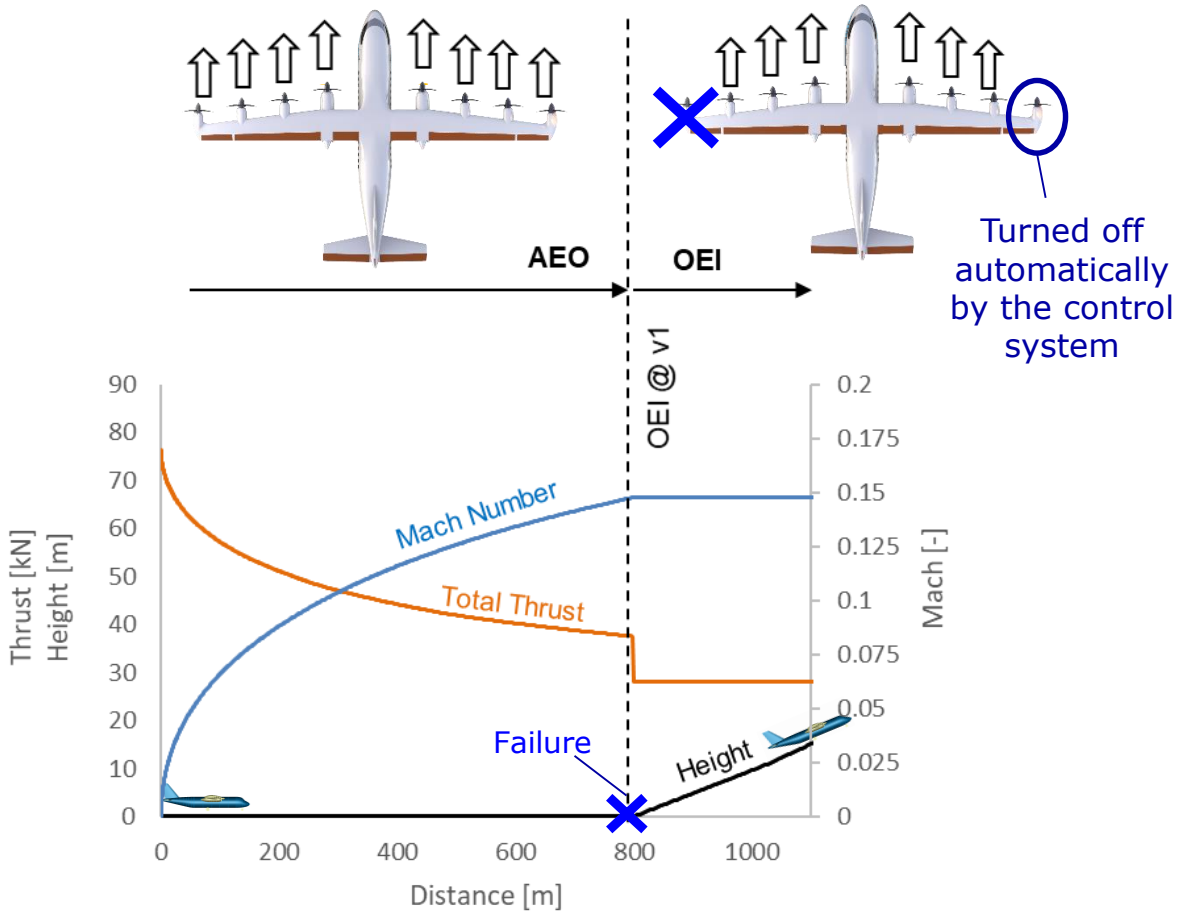
- The battery starts @ 90% capacity to account for ageing.
- Around 10% capacity left at the end of the mission for contingency & go-around capability.





OEI Considerations

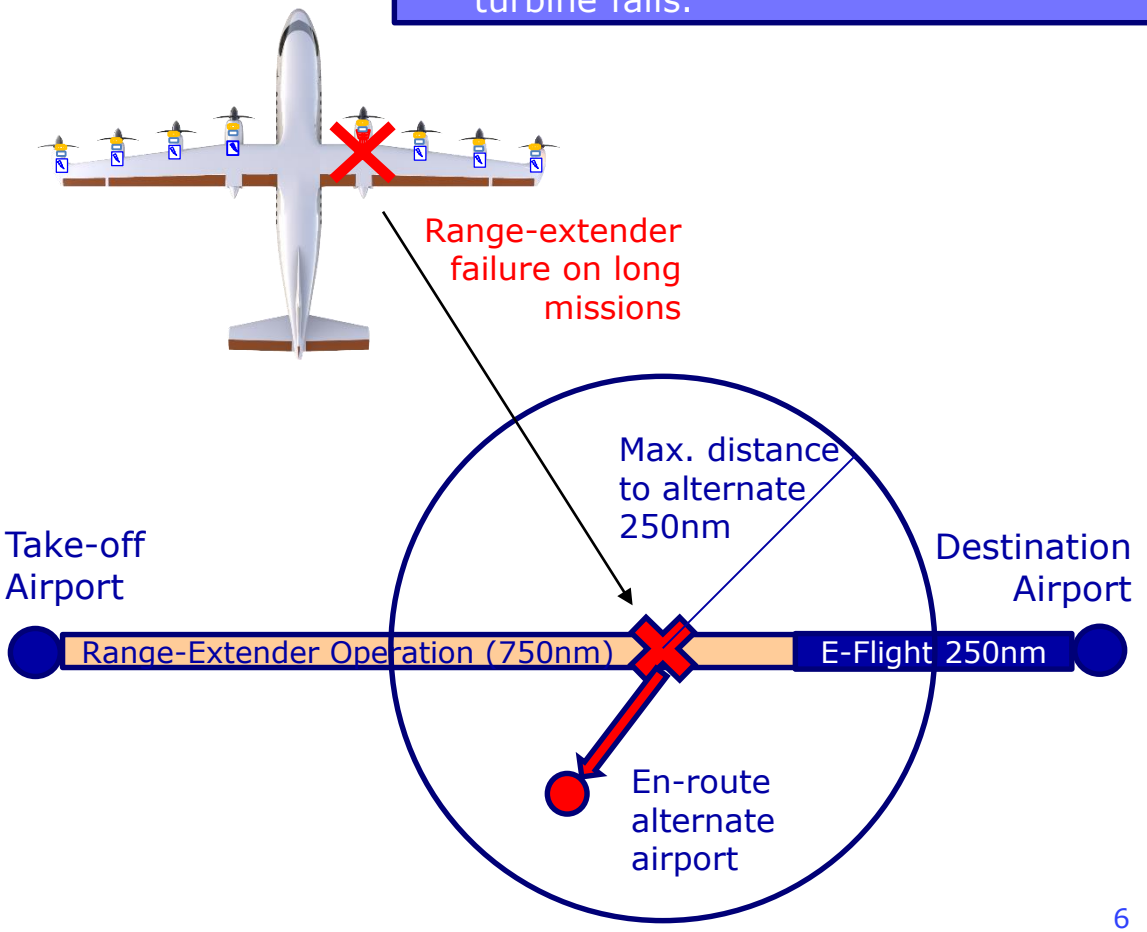
Propeller failure in take-off:



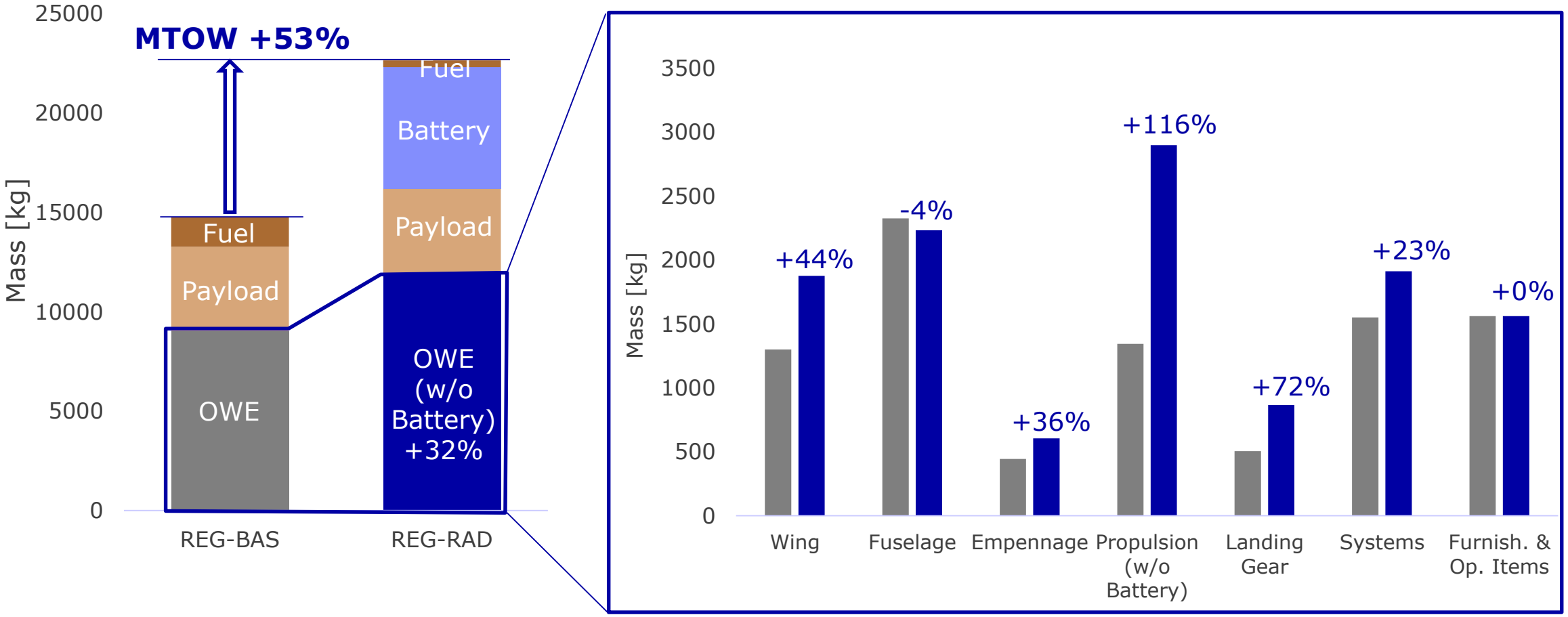
Vertical tailplane not constrained by engine failure.

Gas-turbine / Generator Failure in Cruise

Range-extender operation strategy:
- Kerosene used first so that the battery is full for diversion in case the gas turbine fails.

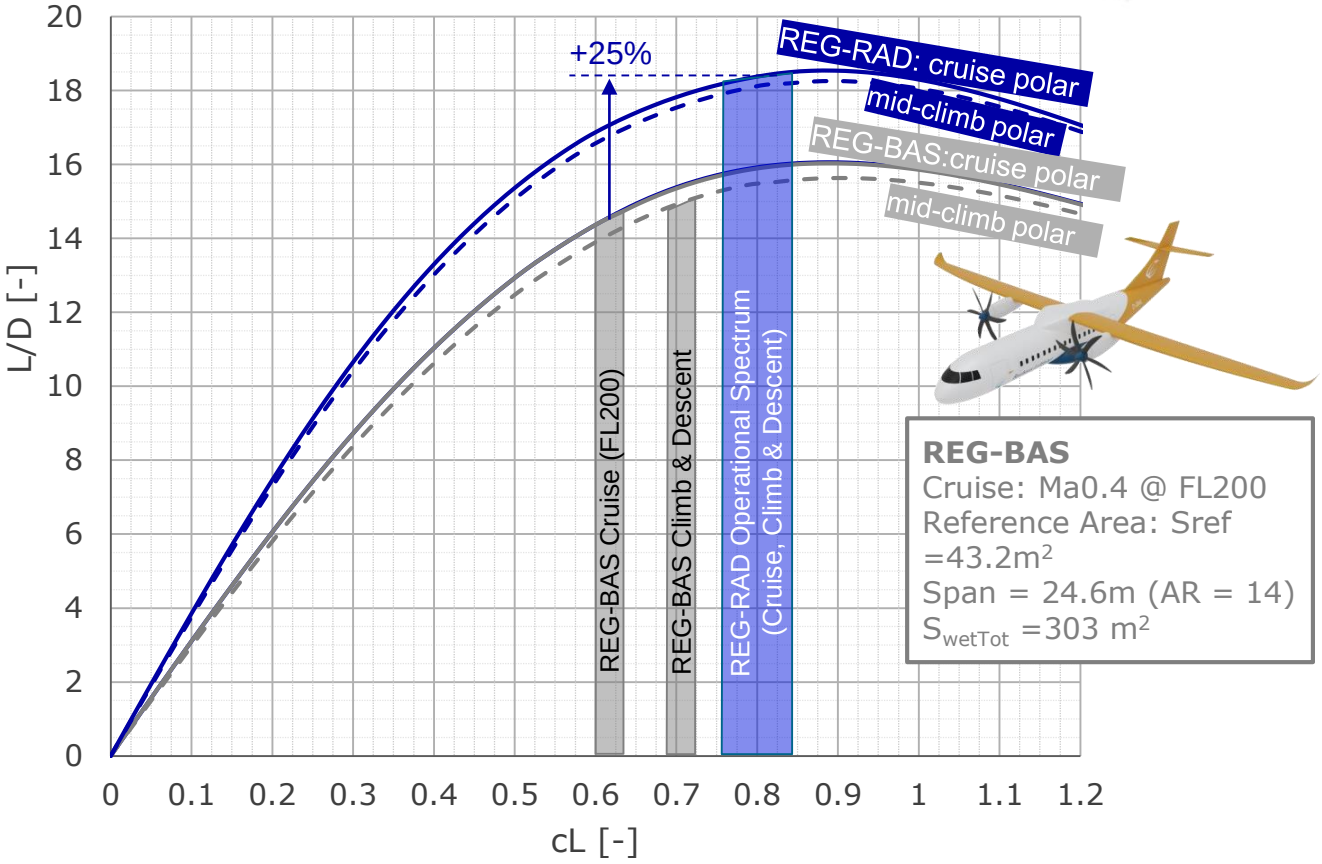


Mass Breakdown

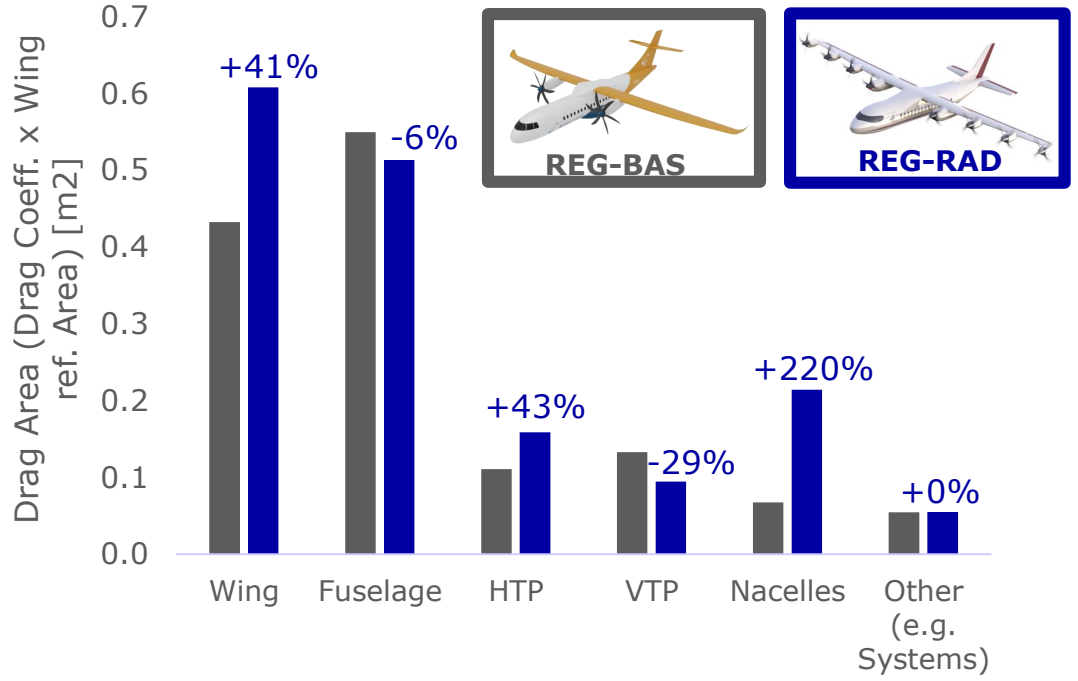


Aerodynamic Performance

REG-RAD
Cruise: Ma0.4 @ FL230
Reference Area: Sref = 65.6m²
Span = 30m (AR = 13.7)
S_{wetTot} = 383 m²



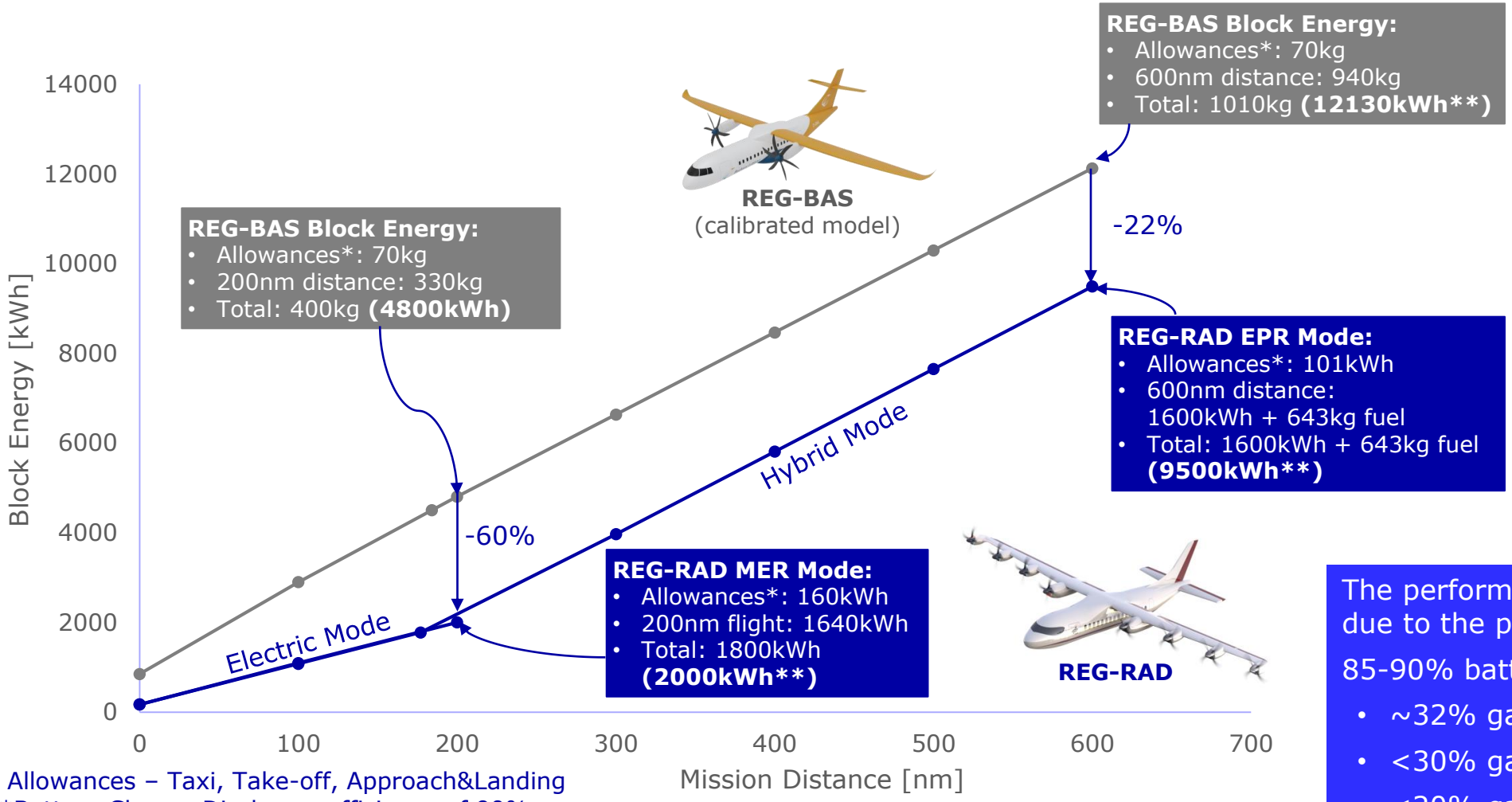
REG-BAS
Cruise: Ma0.4 @ FL200
Reference Area: Sref =43.2m²
Span = 24.6m (AR = 14)
S_{wetTot} =303 m²



Seemingly better aerodynmics REG-RAD:

- ~50% bigger wing with only ~25% increased wetted area, results in a higher L/D.
- The REG-RAD is designed for higher altitudes, resulting in higher CL values in cruise
- ~50% increased mass (lift) in cruise → the absolute drag is ~20% higher despite 25% better L/D

Energy Efficiency Comparison



* Allowances – Taxi, Take-off, Approach&Landing
**Battery Charge-Discharge efficiency of 90%

The performance improvement is mainly due to the power generation efficiency.

85-90% battery-to-shaft efficiency vs:

- ~32% gas turbine efficiency @ cruise
- <30% gas turbine efficiency @ climb
- <20% gas turbine efficiency @ descent

→ The battery is 2-3x more efficient.

IMOTHEP REG-RAD: Conclusions & Outlook

- **Key-performance indicator results:**
  - The highly efficient battery offers ~60% energy reduction potential for all-electric missions up to 200nm.

- **Penalties for the design:**
  - +~50% MTOW
  - +30% empty mass (w/o battery)
  - +~50% bigger wing area
  - +30% wetted area

- **Outlook**
  - Improve level of fidelity of propulsion sizing & integration.
  - Consolidation studies.

Thank you for your attention!

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Renders by: Line Winkler (DLR)

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