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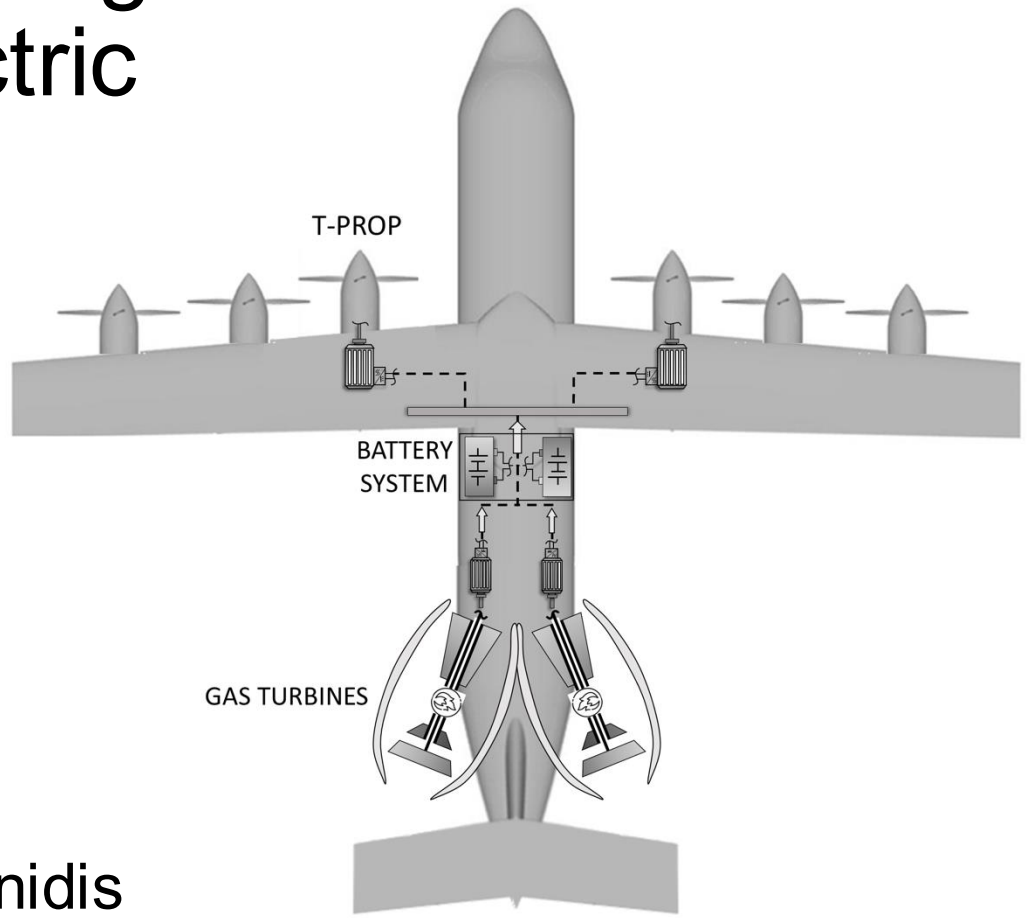
Enabling the Decarbonization of Regional Transport with Series Hybrid Electric Propulsion



Tuesday, October 14, 2025

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Co-authors: Stavros Vouros, Konstantinos Kyprianidis

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Introduction

General context

Motivation:

- Ambitious environmental goals
- Electrification of regional aircraft

Objectives:

- Unified comparison of hybrid electric architectures
- Detailed analysis of **series hybrid** concept

Project / Institution	Aircraft class	Propulsion Architecture					
		Parallel	Series	Series/Parallel	Turboelectric	Fully electric	Synergetic technologies
SUGAR Volt	Single-aisle	✓					
STARC-ABL	Single-aisle				✓		Boundary layer ingestion
NOVAIR	Single-aisle	✓					
Bauhaus Luftfahrt	Single-aisle			✓			Boundary layer ingestion
German Aerospace Centre (DLR)	Regional		✓	✓	✓		Boundary layer ingestion
VoltAir	Regional					✓	Boundary layer ingestion
Georgia Tech	Regional		✓				Distributed propulsion
PEGASUS	Regional	✓				✓	Distributed propulsion
SAFRAN	Commuter			✓	✓		Aft propeller

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Introduction

Hybrid electric configurations

Motivation:

- Ambitious environmental goals
- Electrification of regional aircraft

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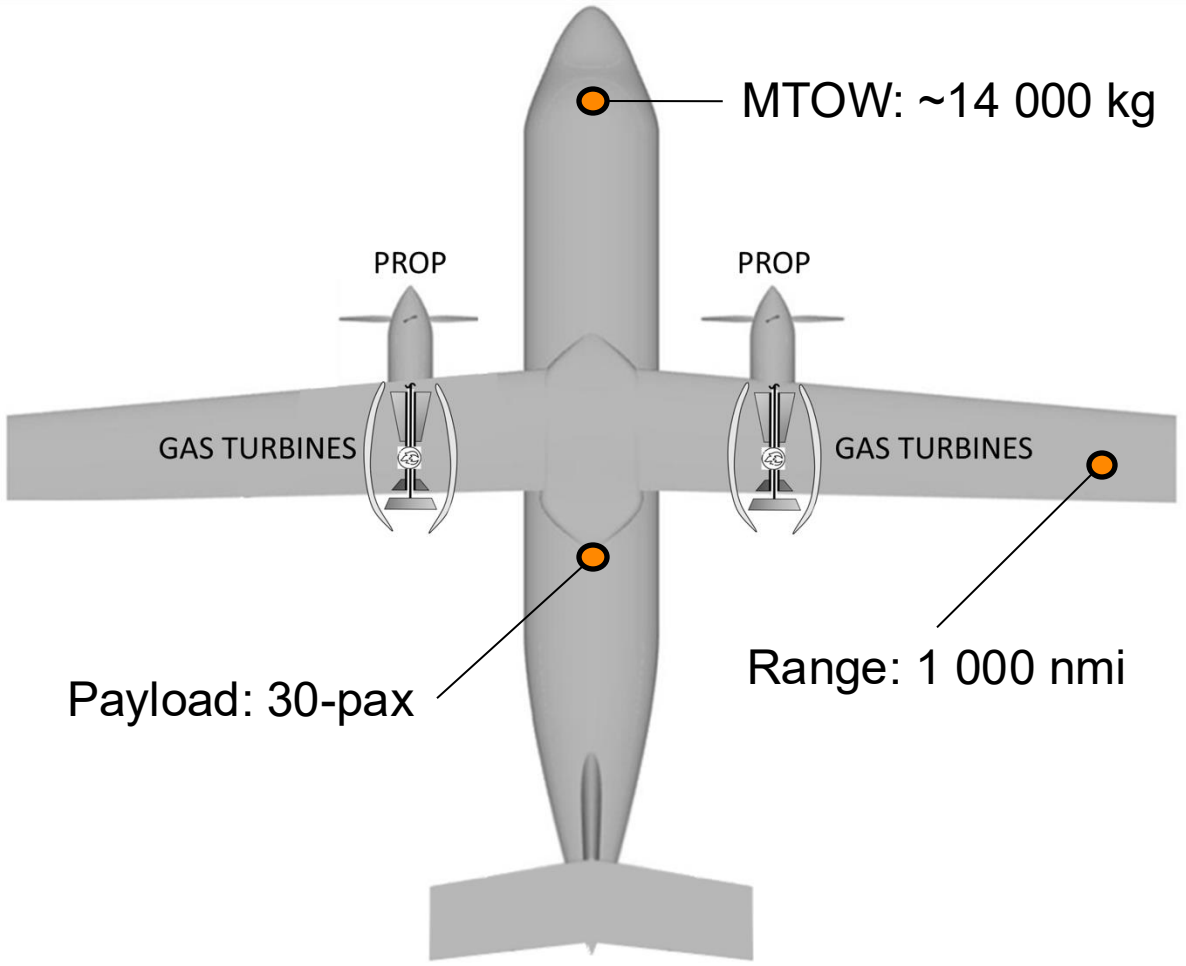
Conventional Aircraft



Entry-Into-Service: 2035

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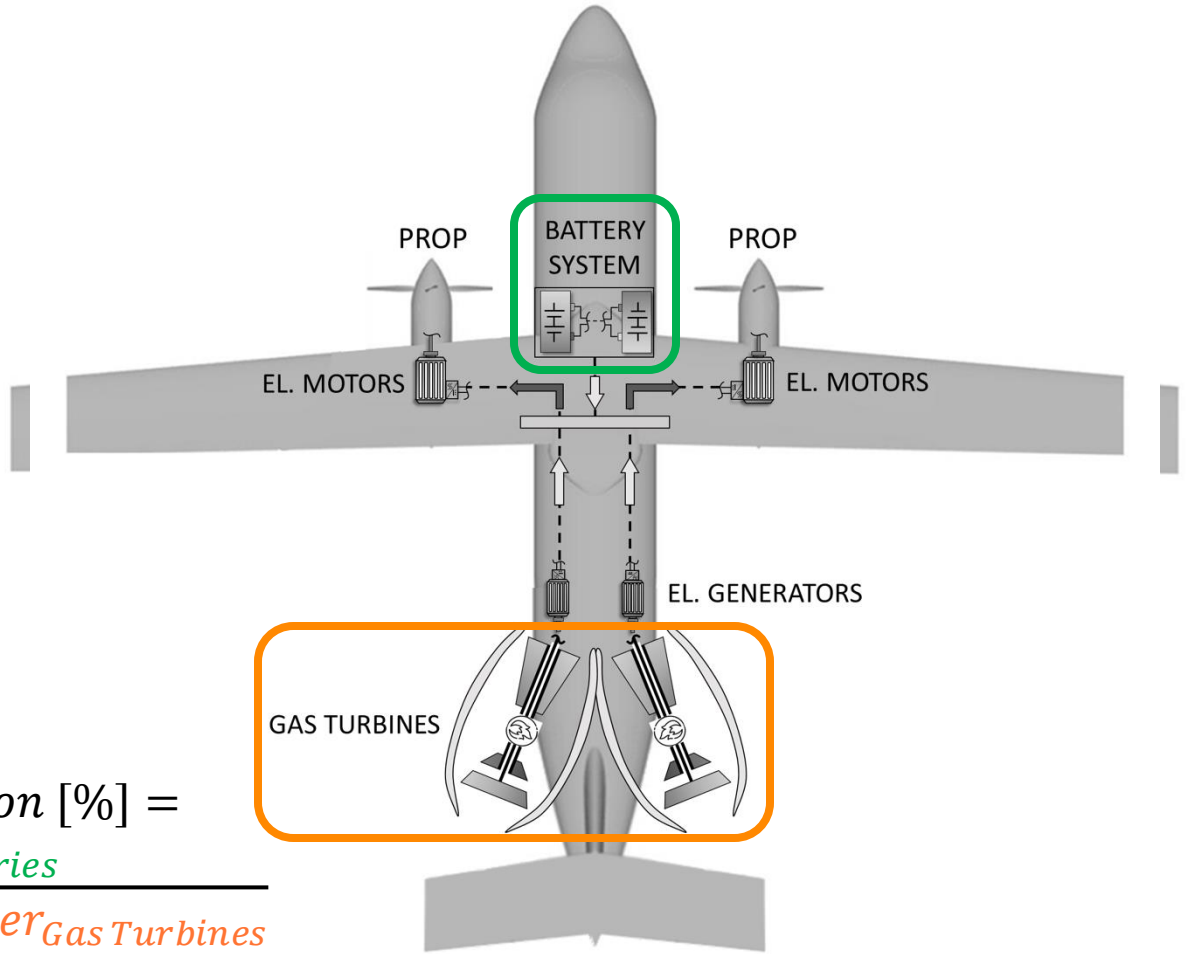
Introduction

Series Hybrid Aircraft



$$Degree\ of\ Hybridization\ [\%] = \frac{Power_{Batteries}}{Power_{Batteries} + Power_{Gas\ Turbines}}$$

Entry-Into-Service: 2035

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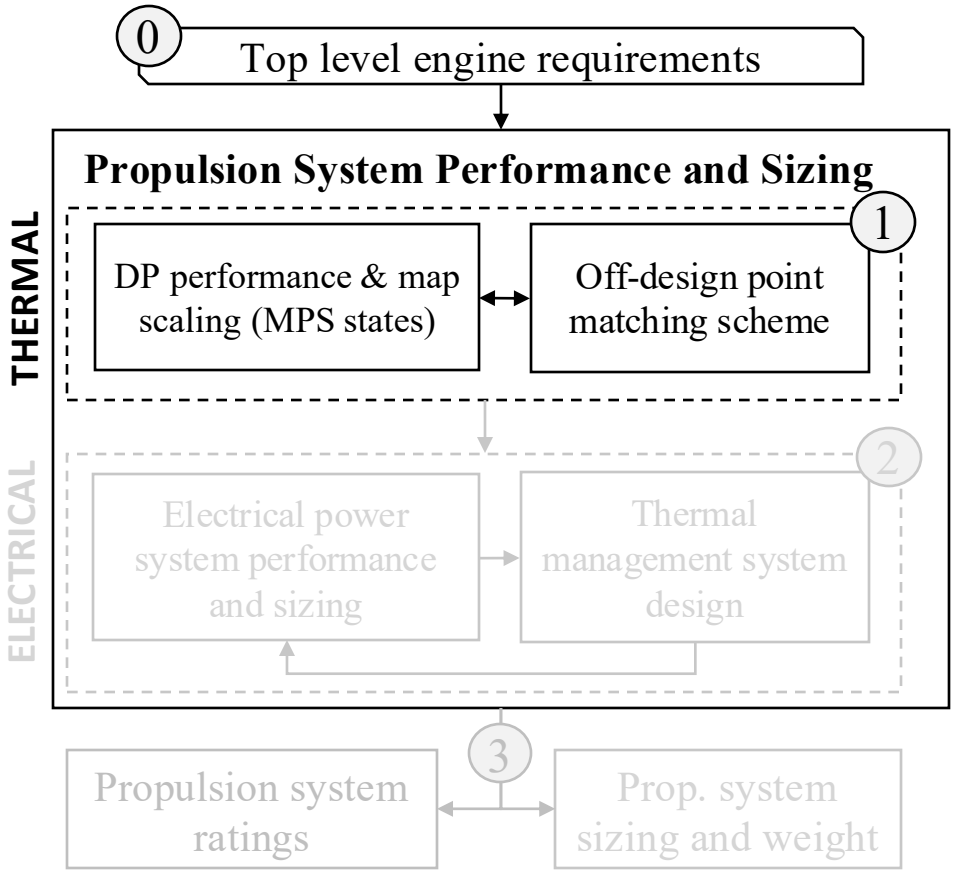
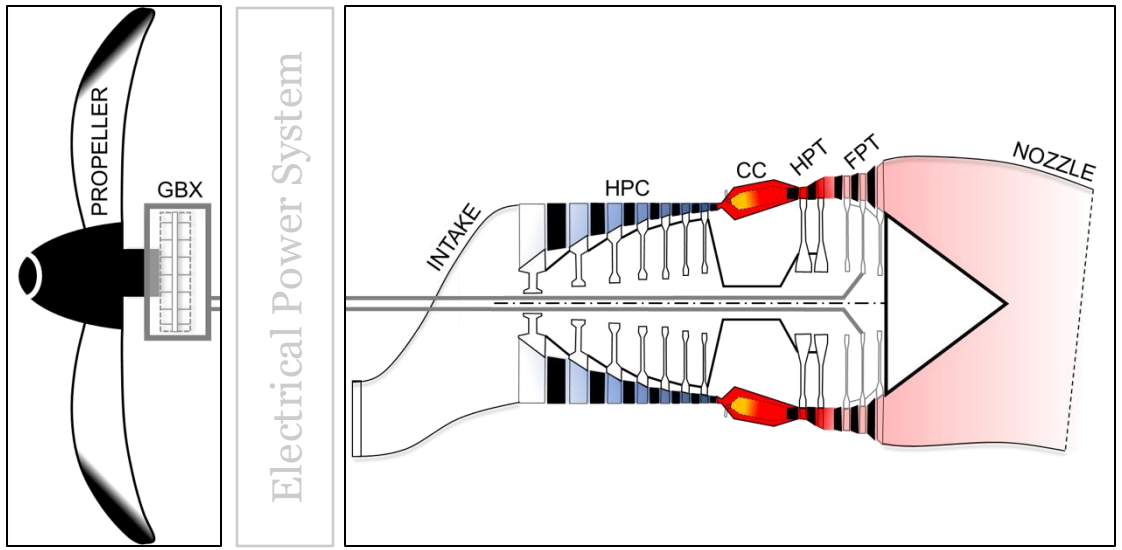
Integrated design methodology

Propeller and Gas Turbines



Propeller & Turboshaft



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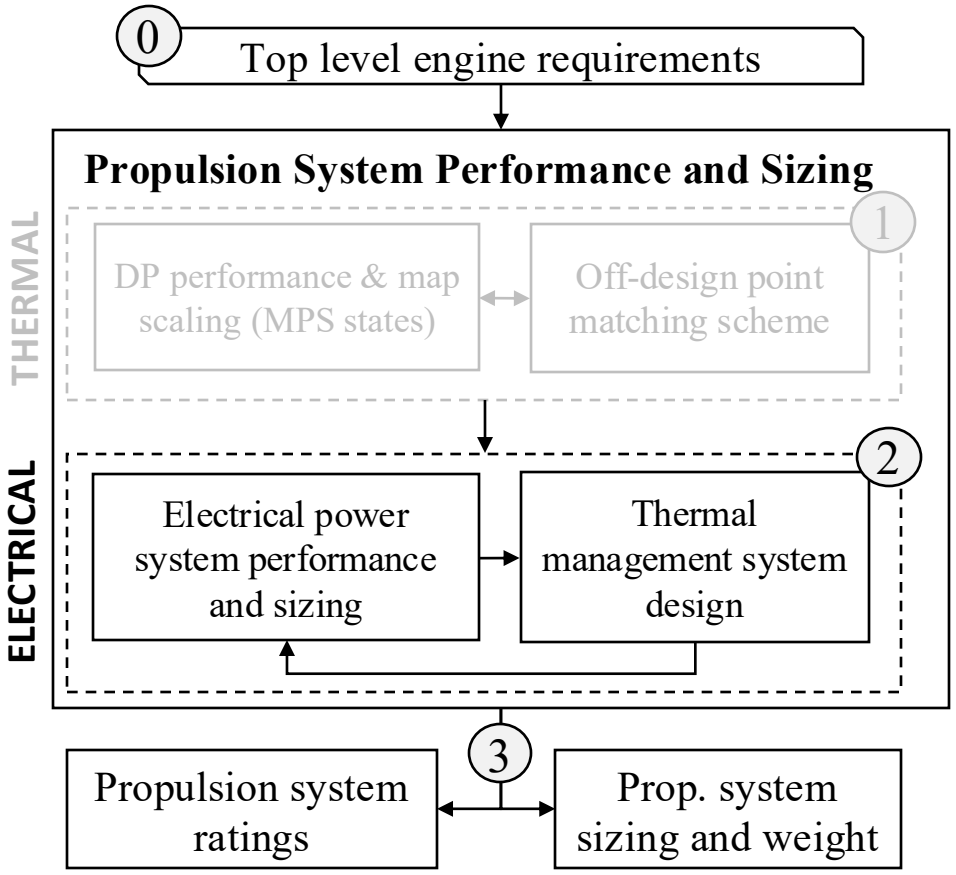
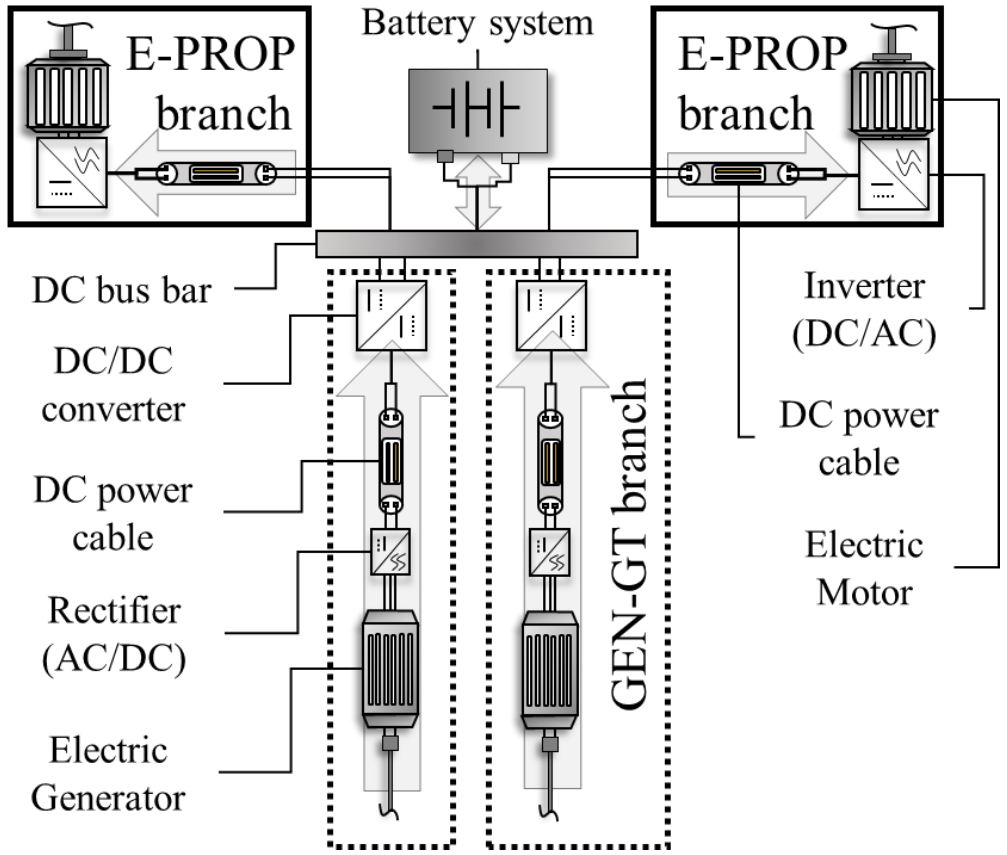
Integrated design methodology

Electrical Power System



Electrical Power System (EPS)



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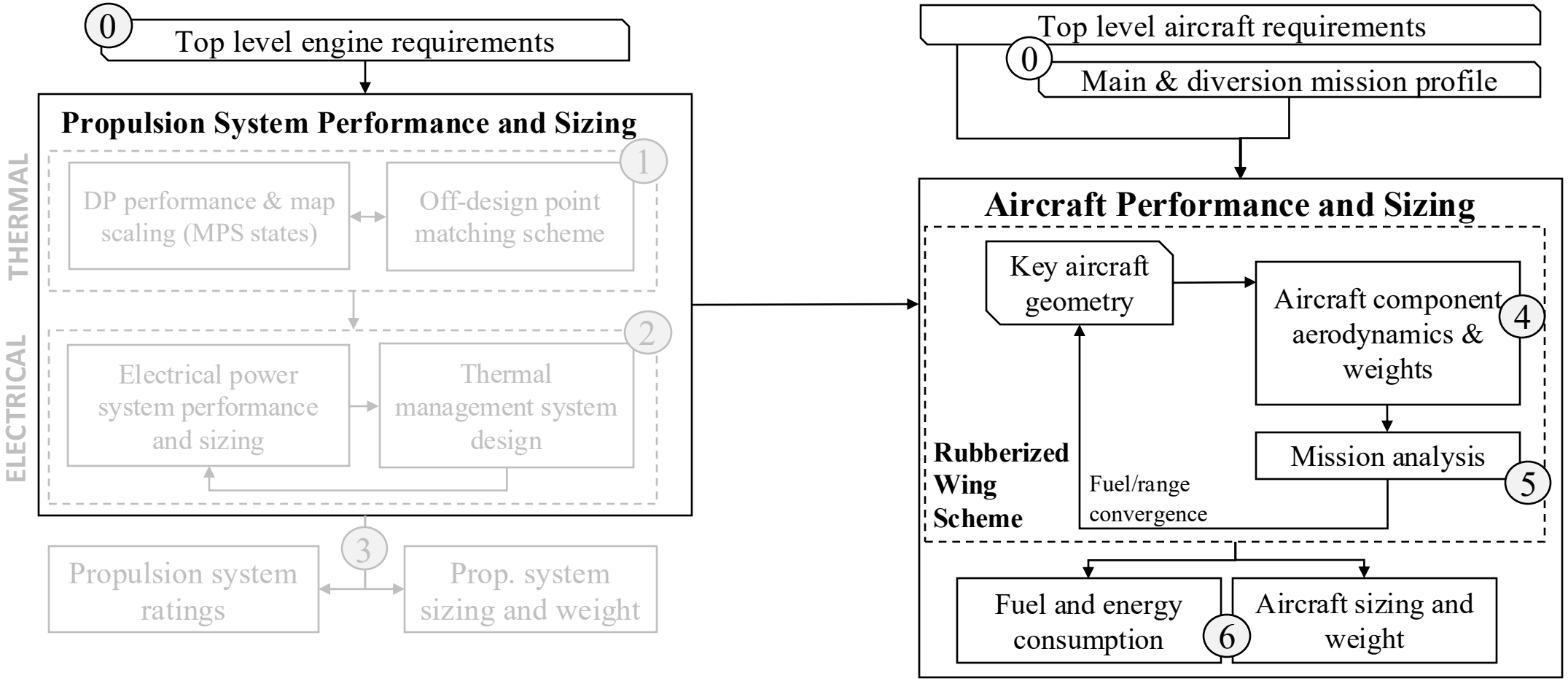
Integrated design methodology

Aircraft and Mission



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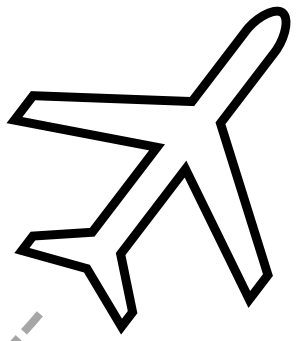
Conceptual design roadmap



3

Step 3

Integrated aircraft and propulsion design

2

Step 2

Integration of synergetic concepts

1

Step 1

Propulsion system design and assessment

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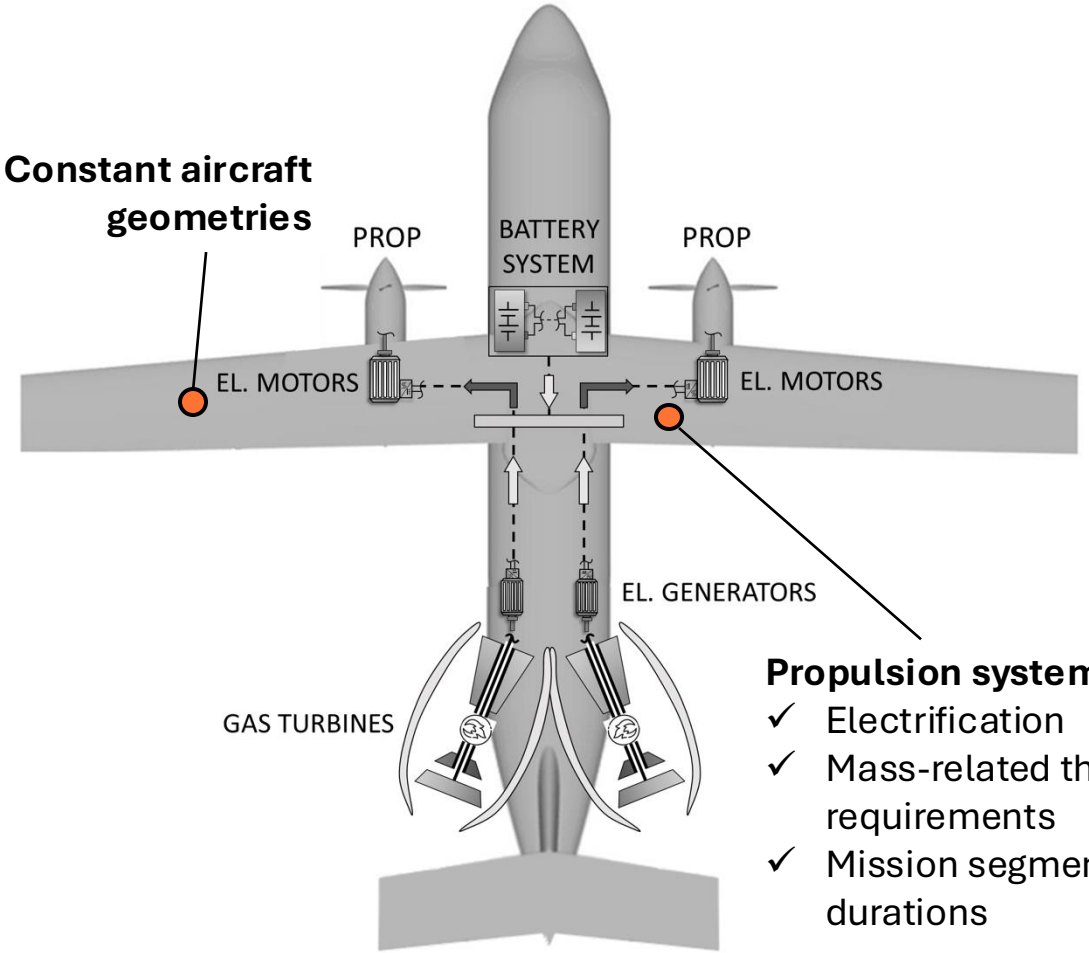
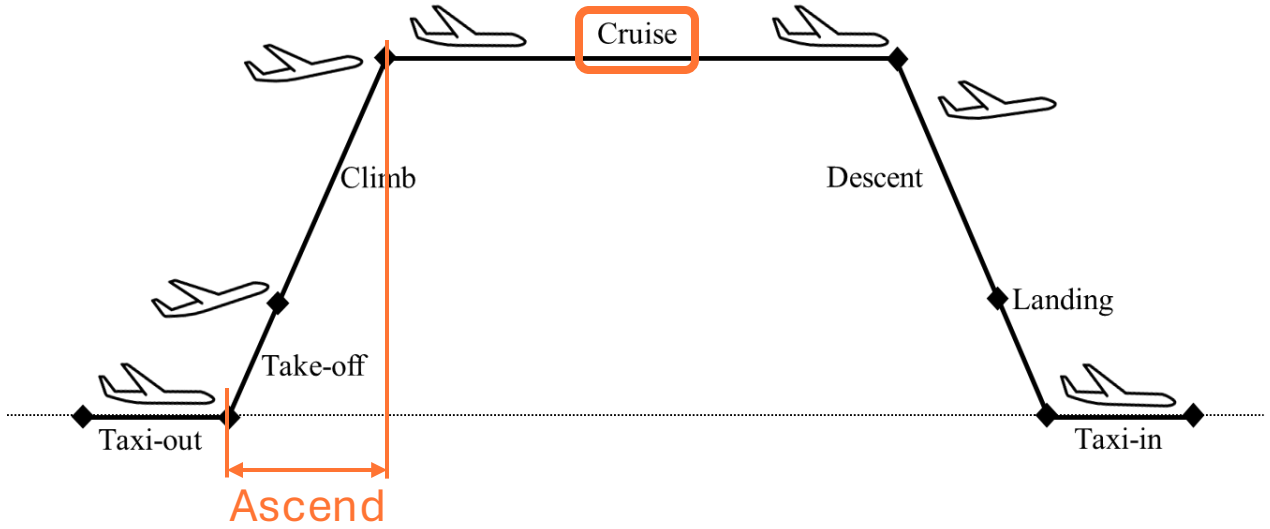
Propulsion design

Design space



Propulsion system design

- ✓ Electrification
- ✓ Mass-related thrust requirements
- ✓ Mission segment durations



Design space variables	Ascend	Cruise
Degree of Hybridization [%]	**0 - 20**	0 - 15
Battery mass [kg]	**125 - 2500**	

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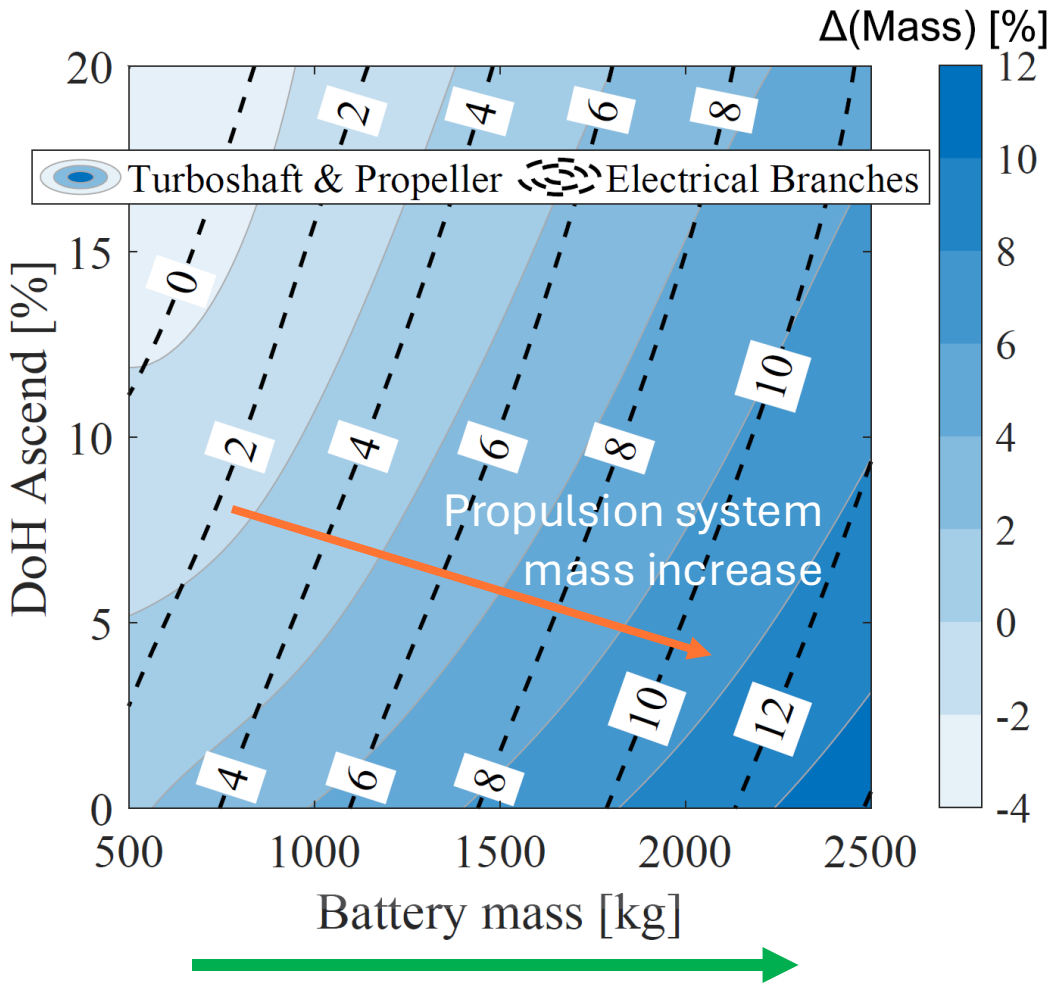
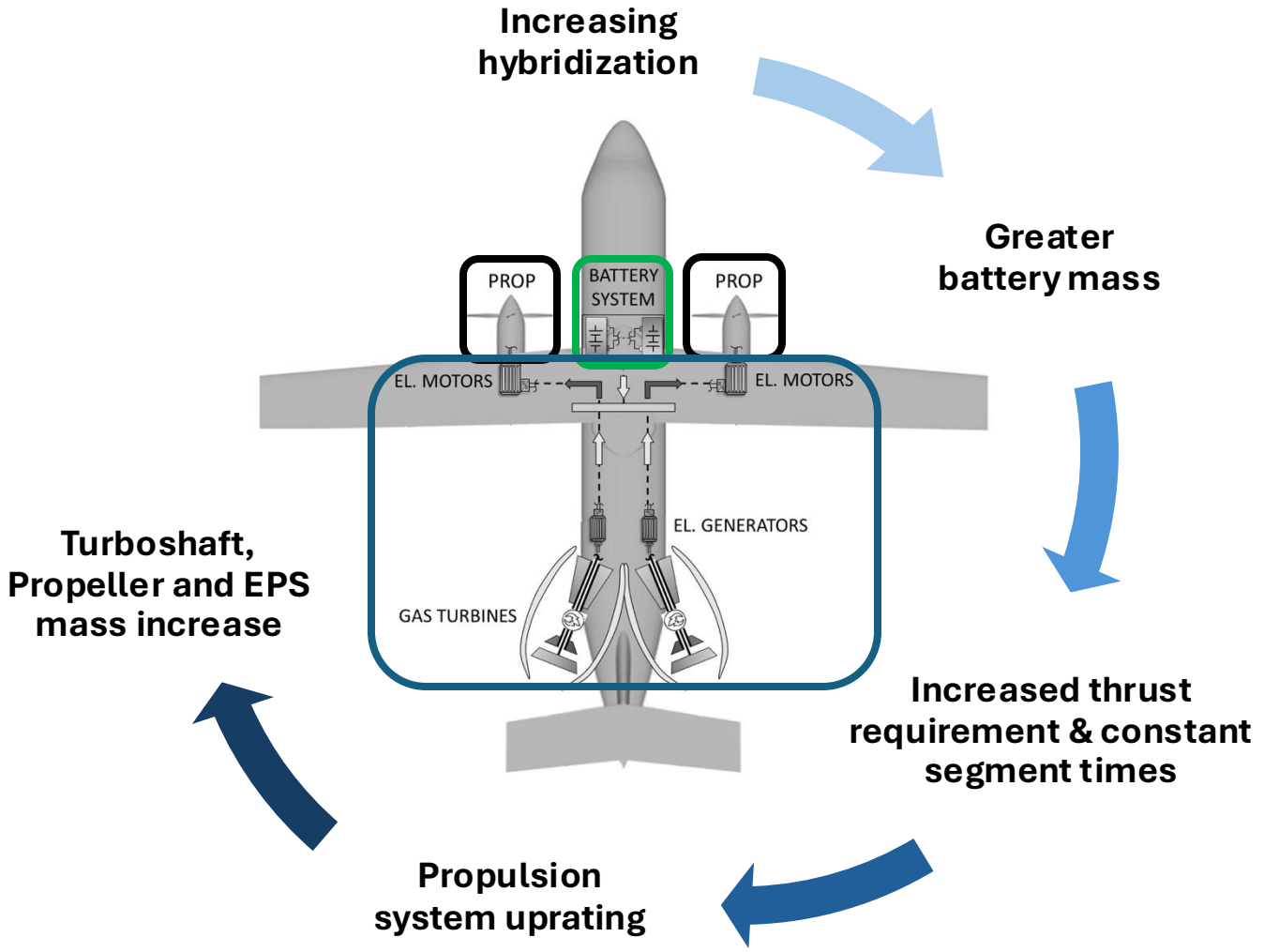
Series hybrid electric aircraft

Sizing aspects





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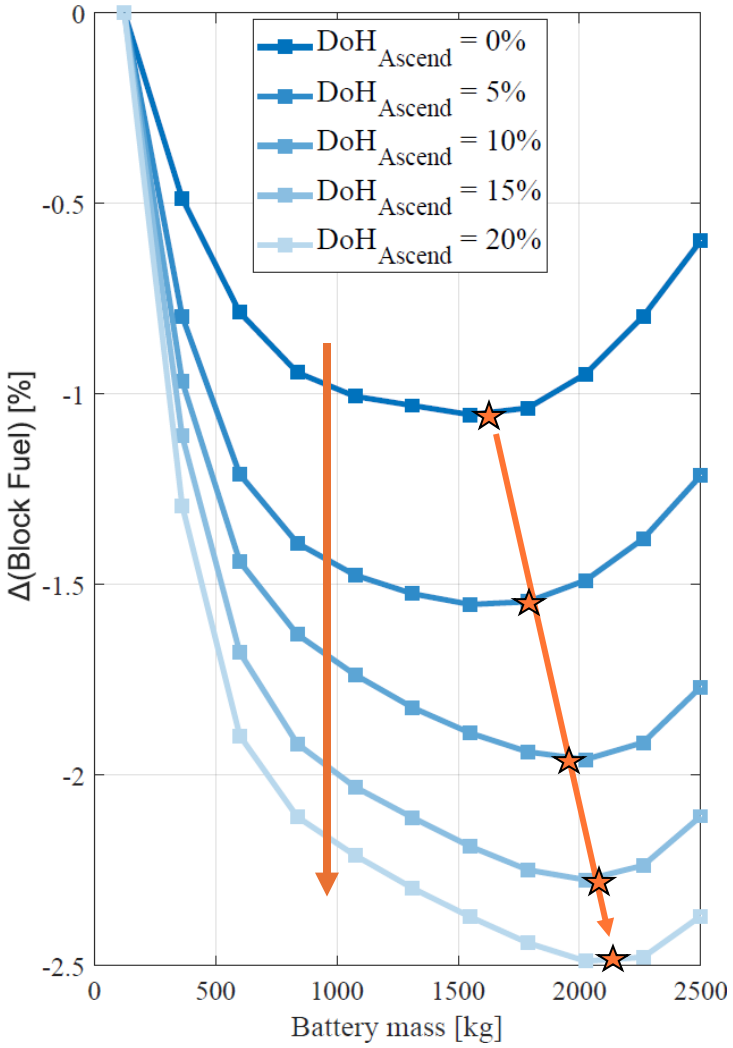
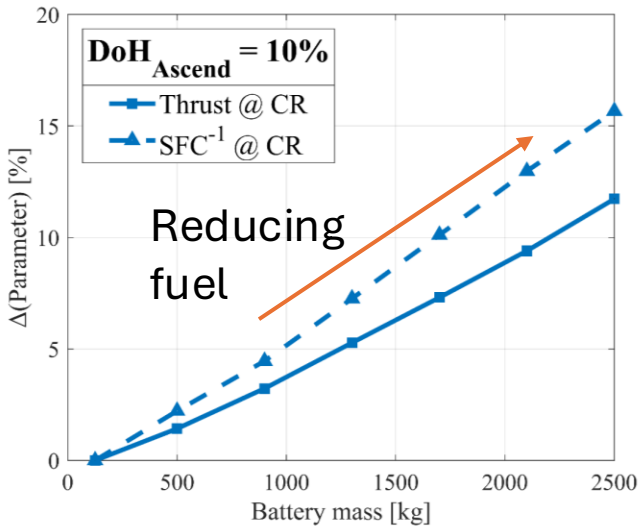
Series hybrid electric aircraft

Performance aspects

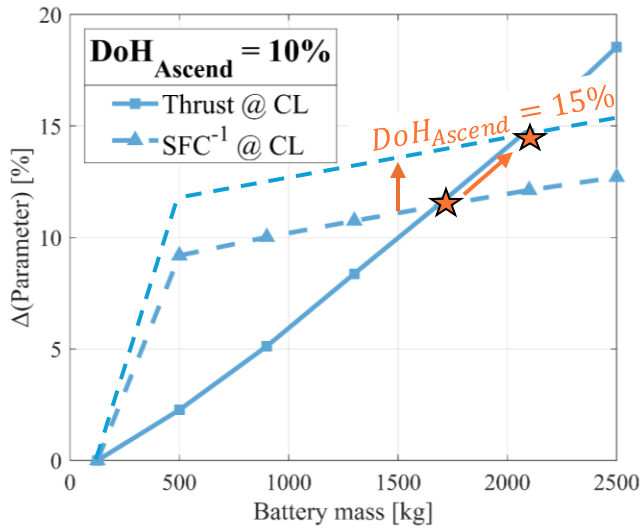
$$SFC^{-1} = \frac{FN}{\dot{m}_{fuel}}$$



Cruise



Climb



- Increasing ascend hybridization is beneficial
- There is an optimal cruise hybridization for each case
- Ascend hybridization shifts optimal cruise hybridization to larger values

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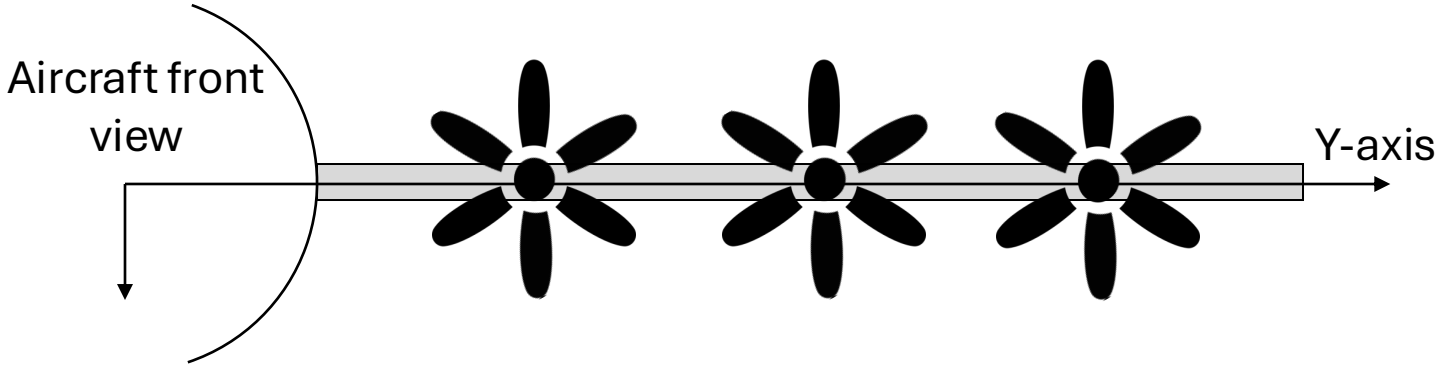
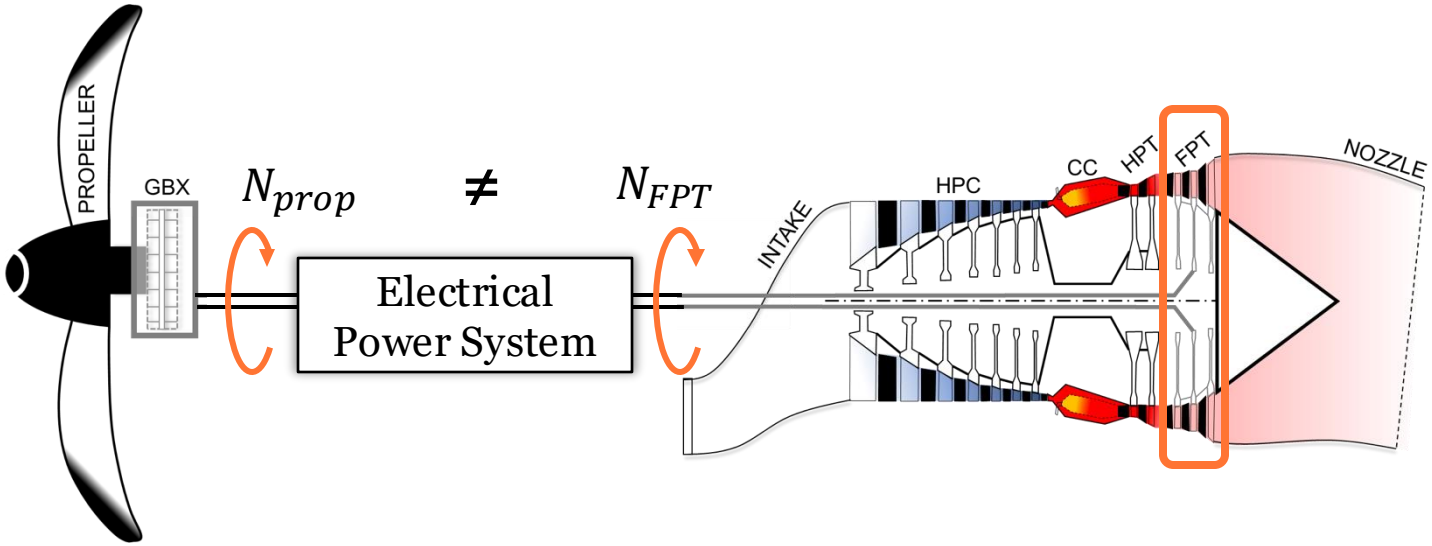
Synergetic concepts

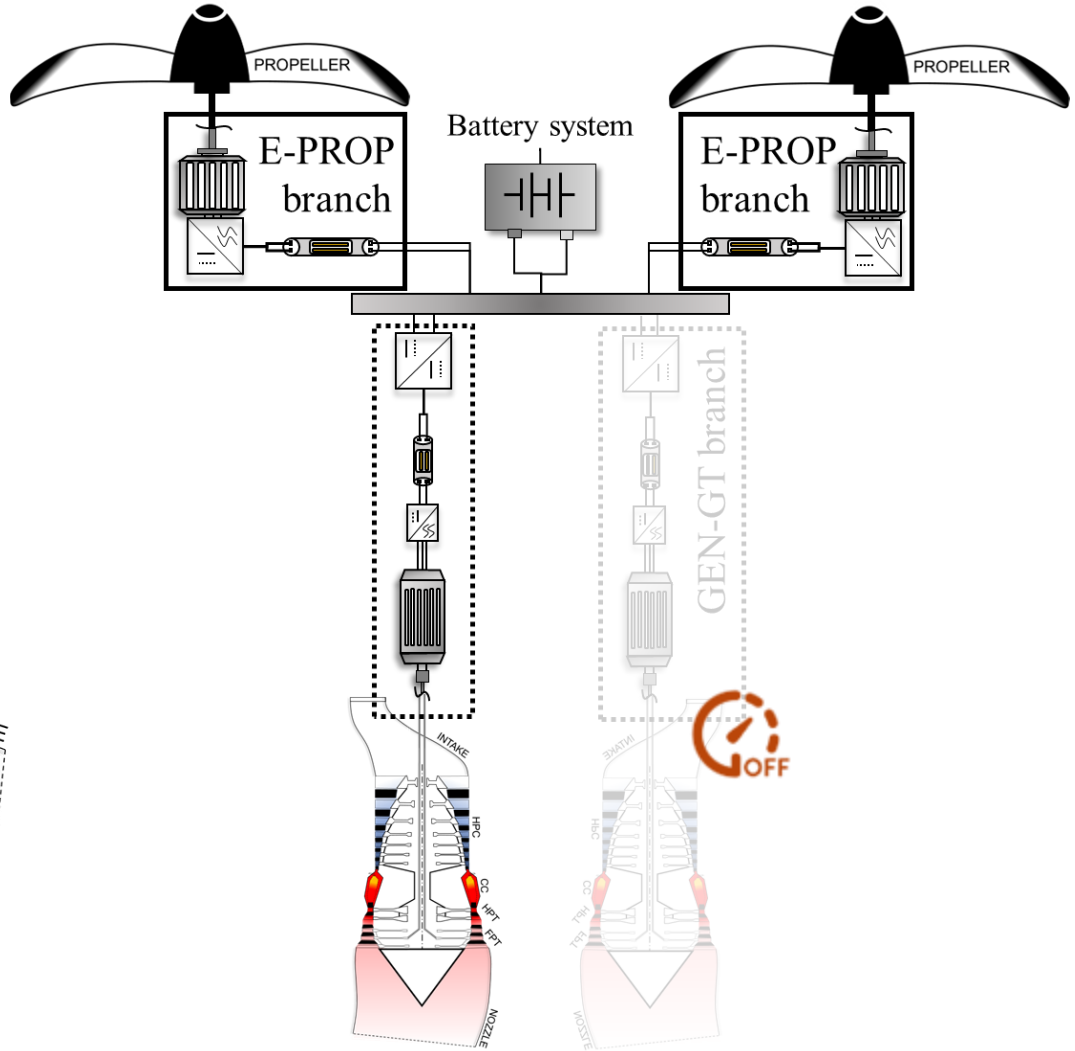
Distributed propulsion



Decoupled FPT speed selection



Descent one-engine-off



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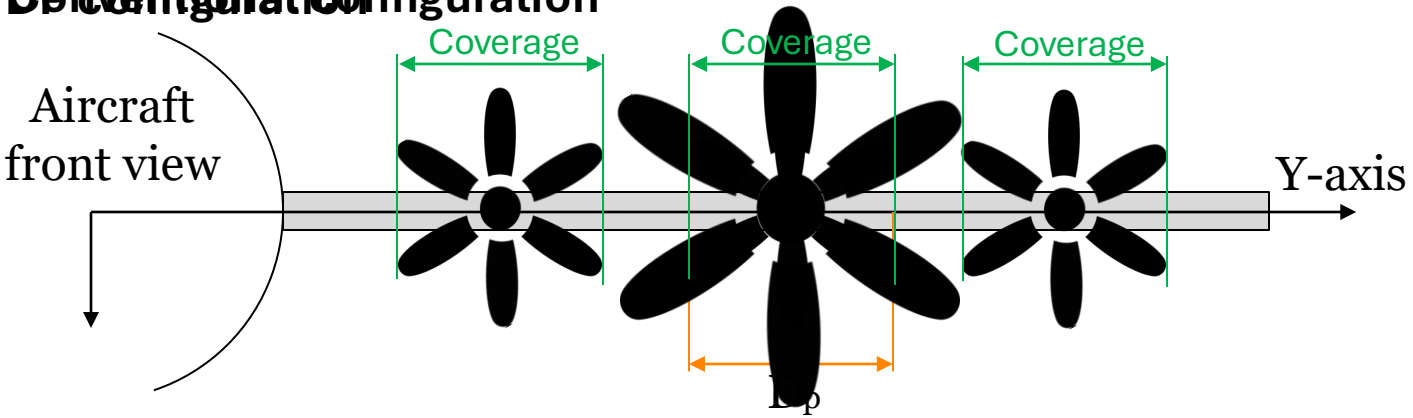
Distributed propulsion

DP configuration

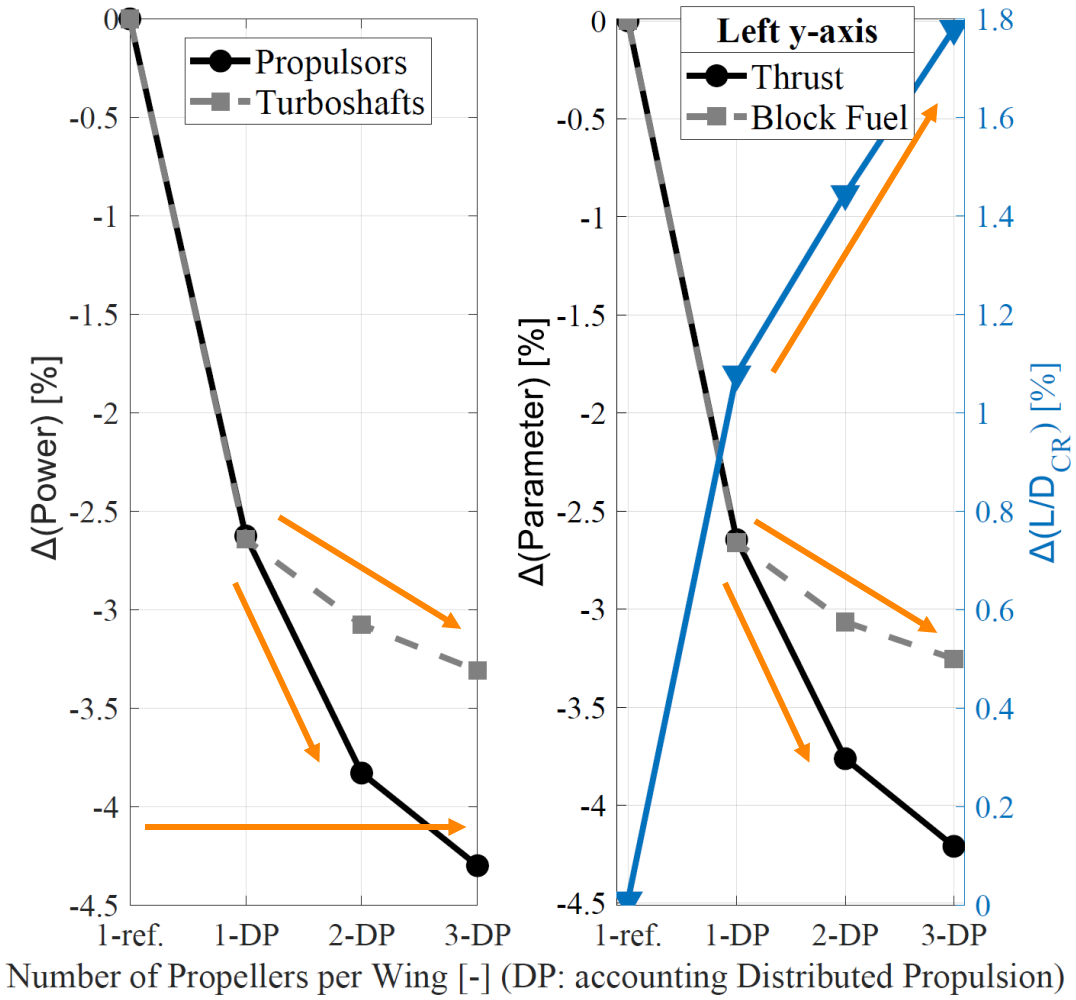


Lift generation

$$Lift = C_L * \frac{1}{2} * \rho * A * V_{fl}^2$$

DP

$$Lift = C_L * \frac{1}{2} * \rho * A * V_{eff.w}^2$$



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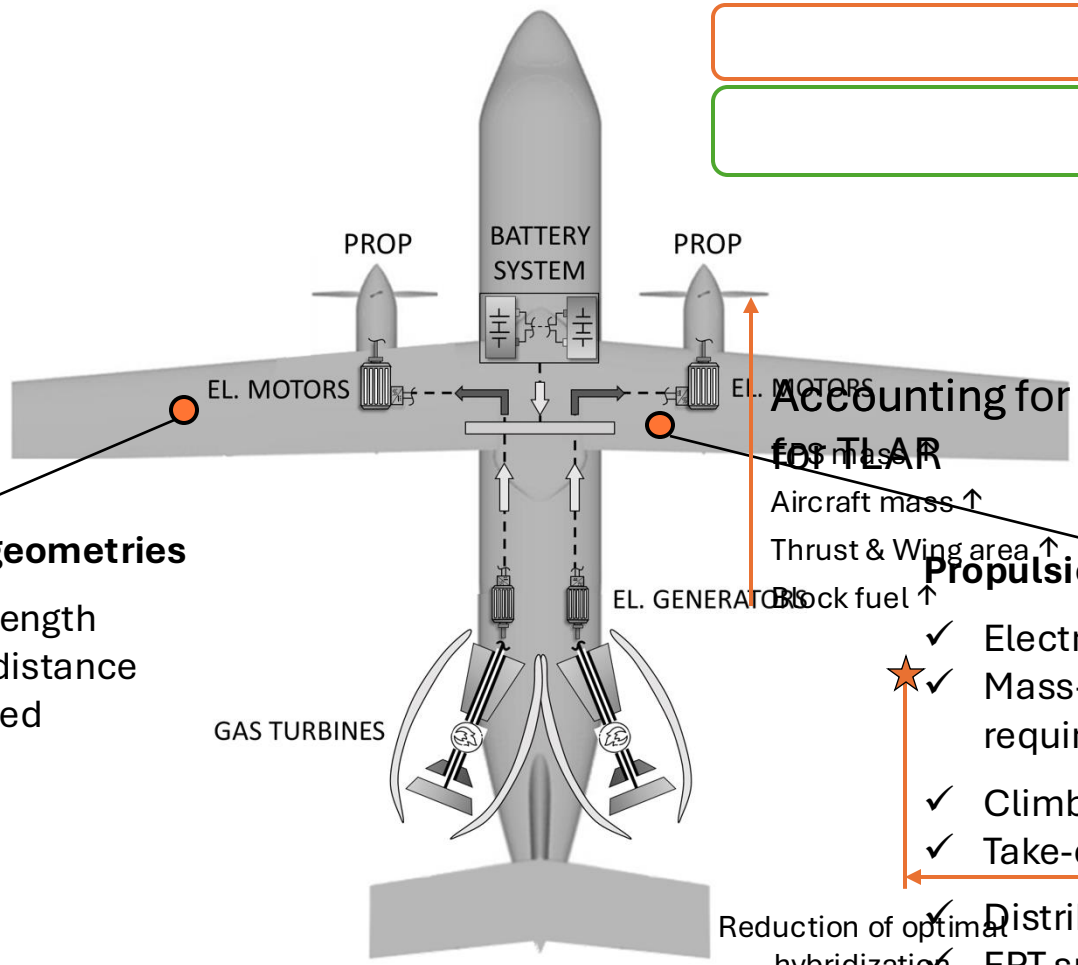
Integrated propulsion & aircraft design



Varying aircraft geometries

TLAR
- ✓ Take-off field length
- ✓ Landing field distance
- ✓ Approach speed
- ✓ Climb rate

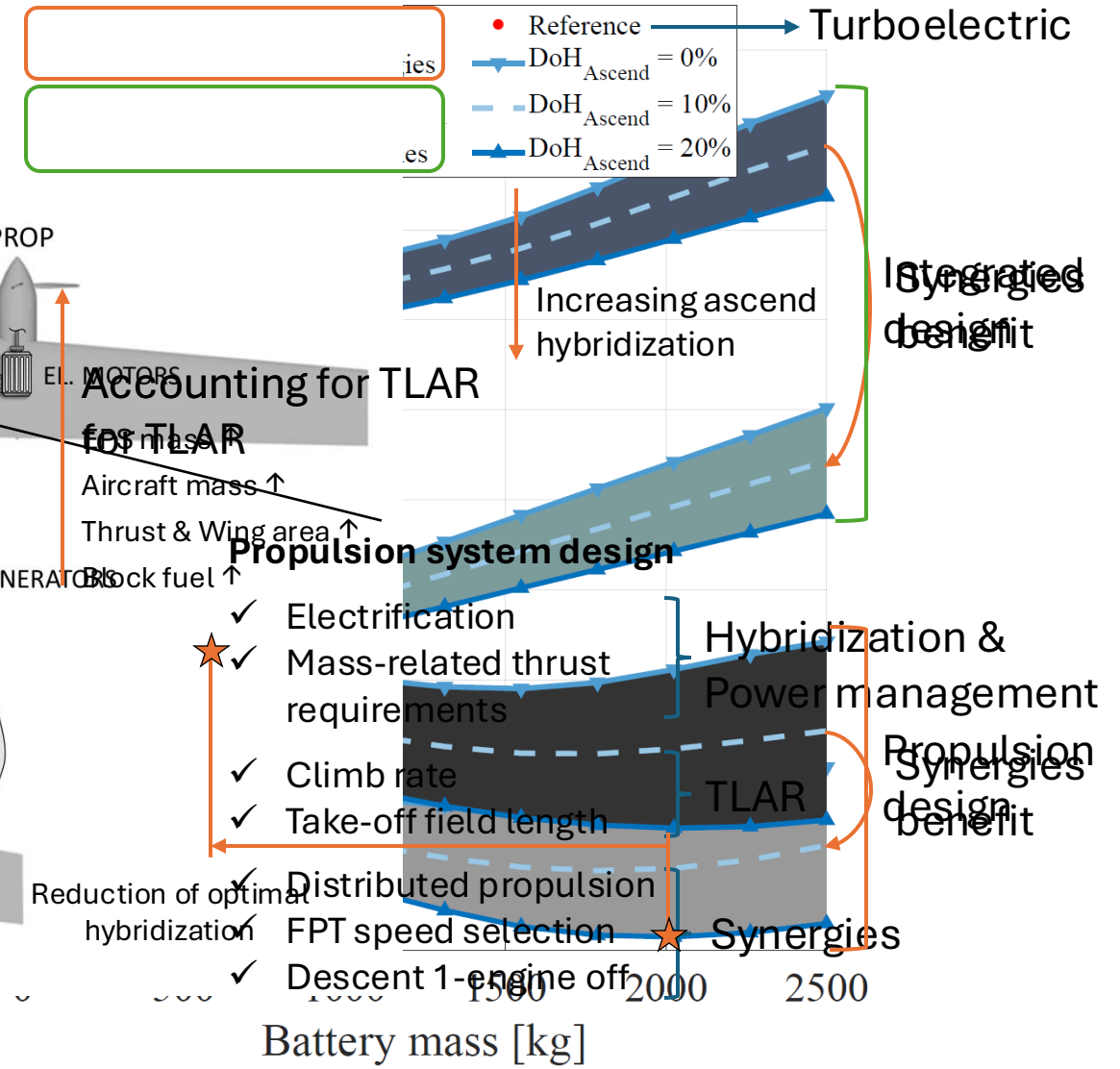
Accounting for TLAR for TLAR

Aircraft mass ↑
Thrust & Wing area ↑
Block fuel ↑

Propulsion system design

- ✓ Electrification
- ✓ Mass-related thrust requirements
- ✓ Climb rate
- ✓ Take-off field length
- ✓ Distributed propulsion
- ✓ FPT speed selection
- ✓ Descent 1-engine off

Reduction of optimal hybridization



*Top-level aircraft requirements

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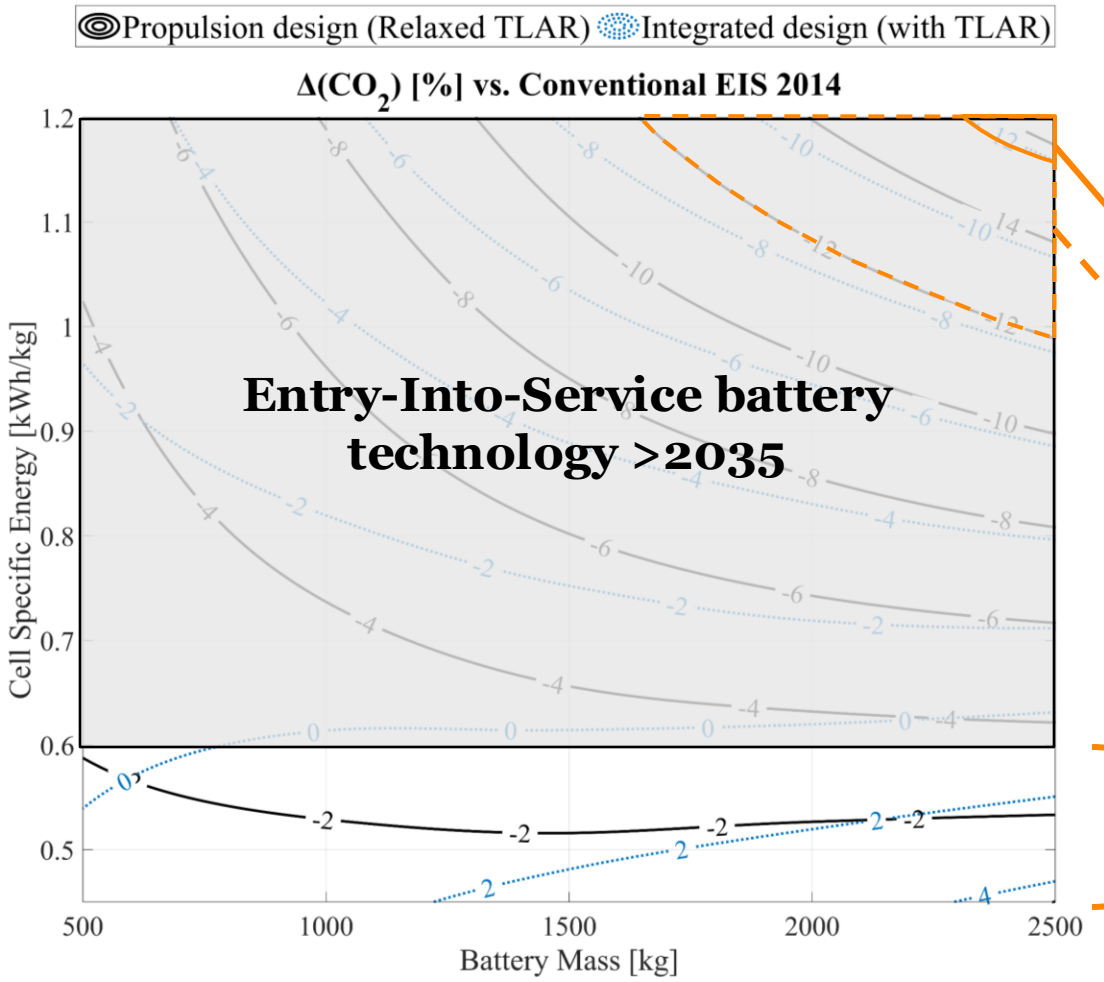
Environmental performance

Battery technology targets



Vs. Conventional EIS 2035 (>12% CO_2 drop)

- Integrated with TLAR: 0%
- Relaxed TLAR: -3%

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Conclusions

- ✓ Optimal environmental and fuel performance
  - ➢ As high ascend hybridization as possible
  - ➢ Cruise hybridization up to the takeover of the mass-thrust snowball effect
- ✓ Synergies to be considered with series hybrid electric aircraft
  - ➢ FPT speed selection through propeller decoupling
  - ➢ One-engine off during descent
  - ➢ Distributed propulsion
- ✓ Cell specific energy above ~1 kWh/kg is required to compete with conventional concepts of same Entry-Into-Service
- ✓ Necessary compromise in some aircraft operation targets

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Thank you for your attention!

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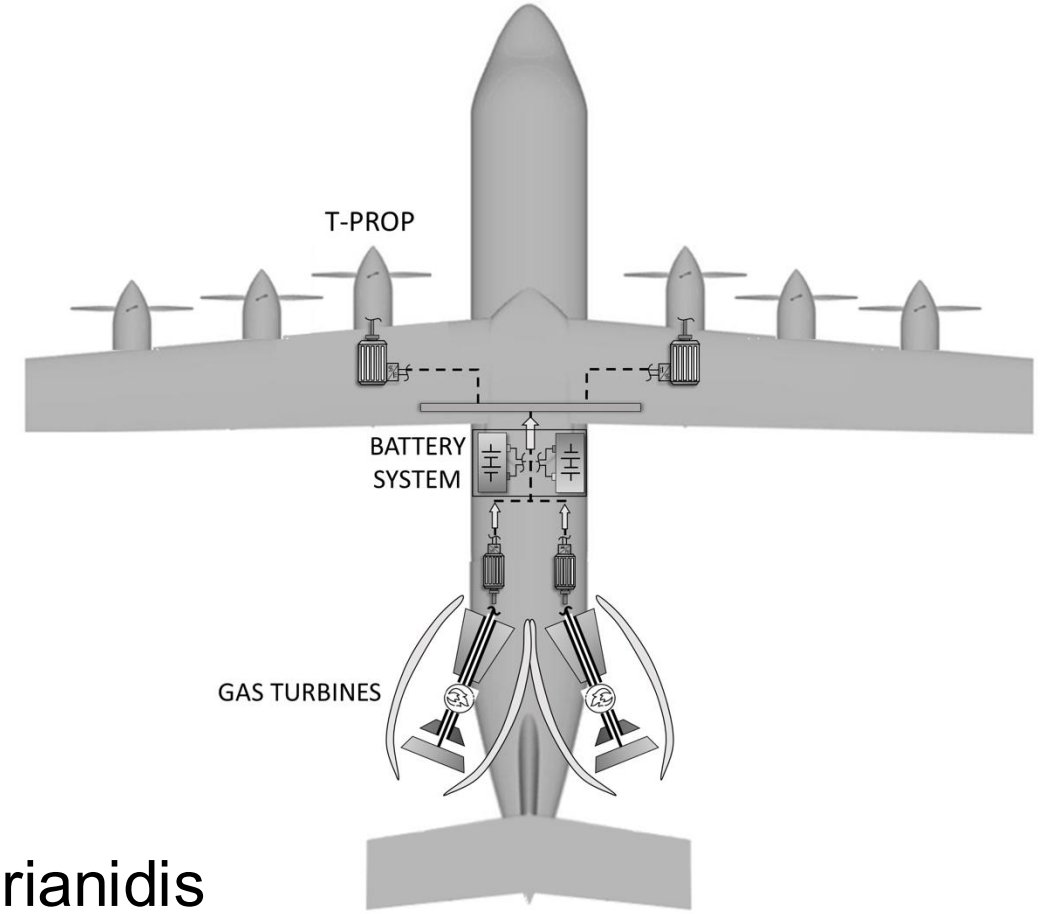

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Back-up slides

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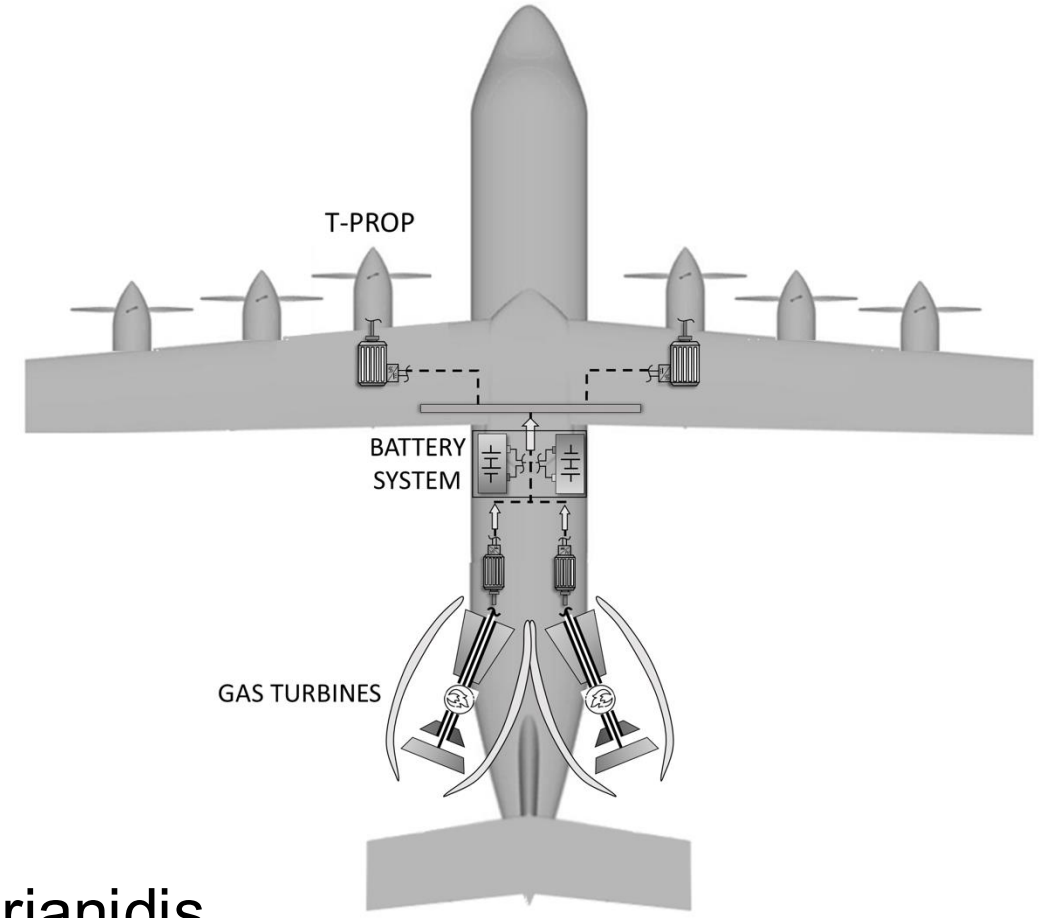

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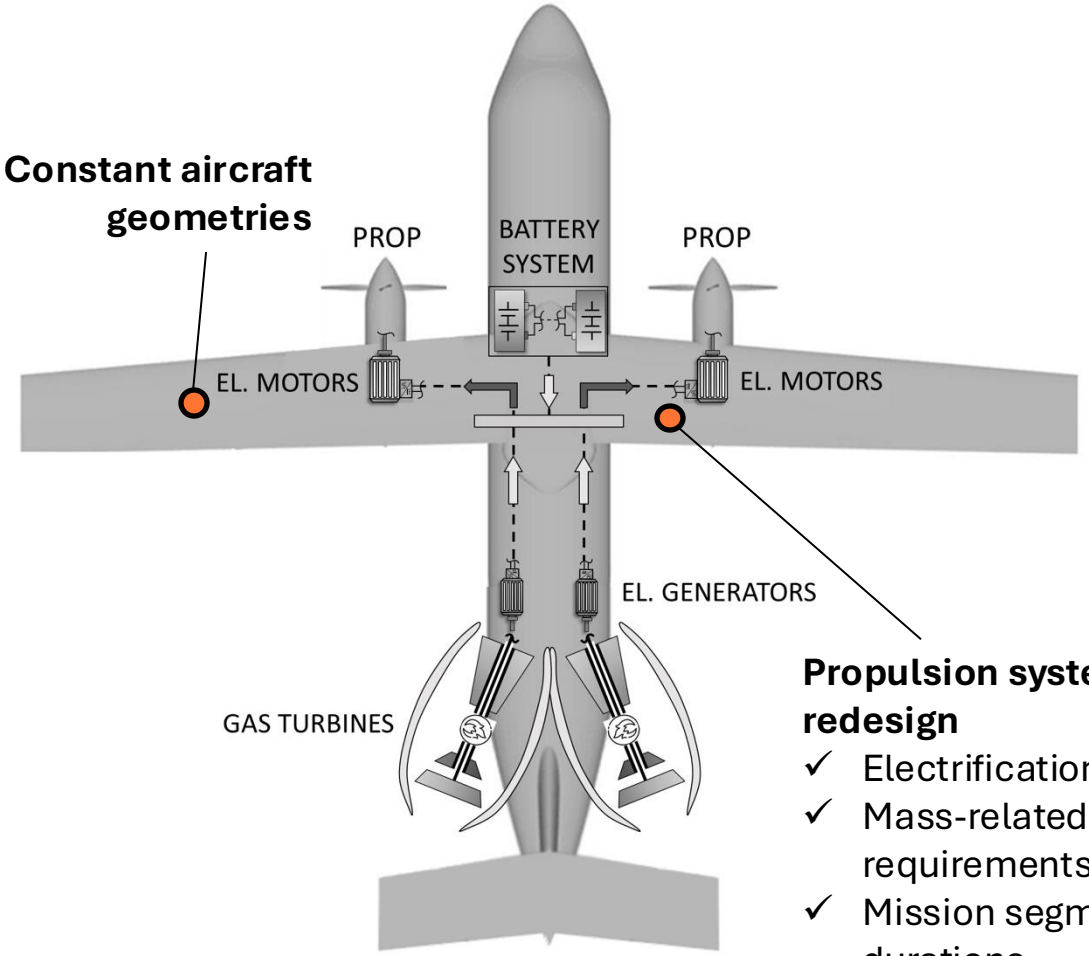
Propulsion design

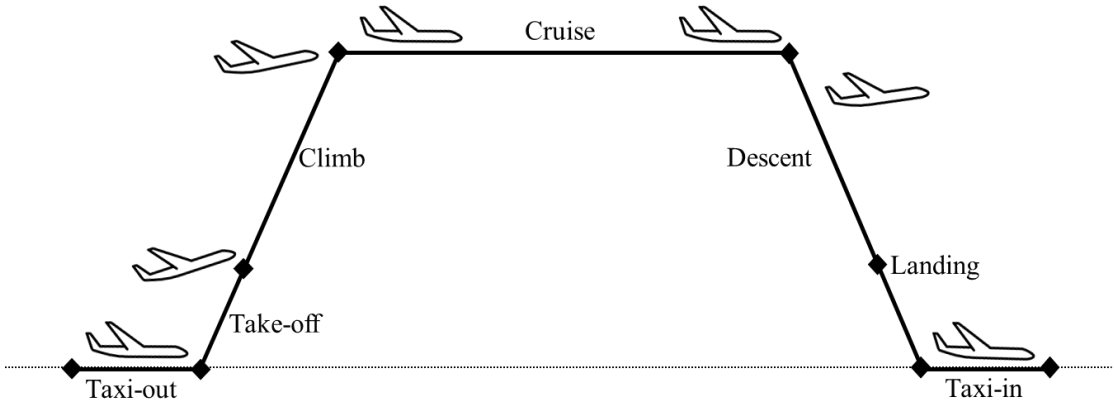
Design space

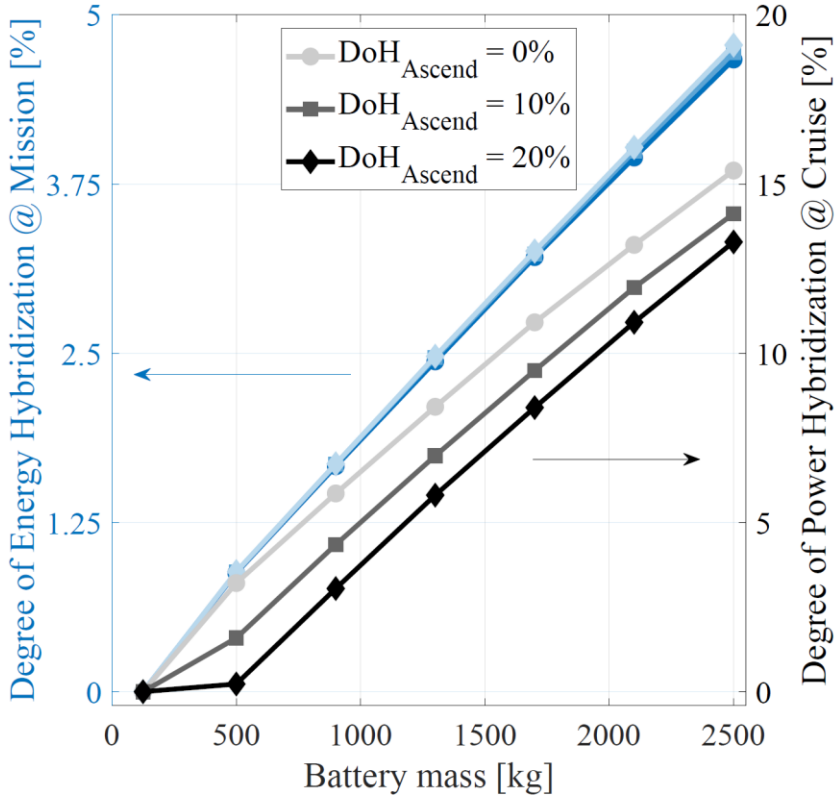
Constant aircraft geometries



Propulsion system redesign

- ✓ Electrification
- ✓ Mass-related thrust requirements
- ✓ Mission segment durations





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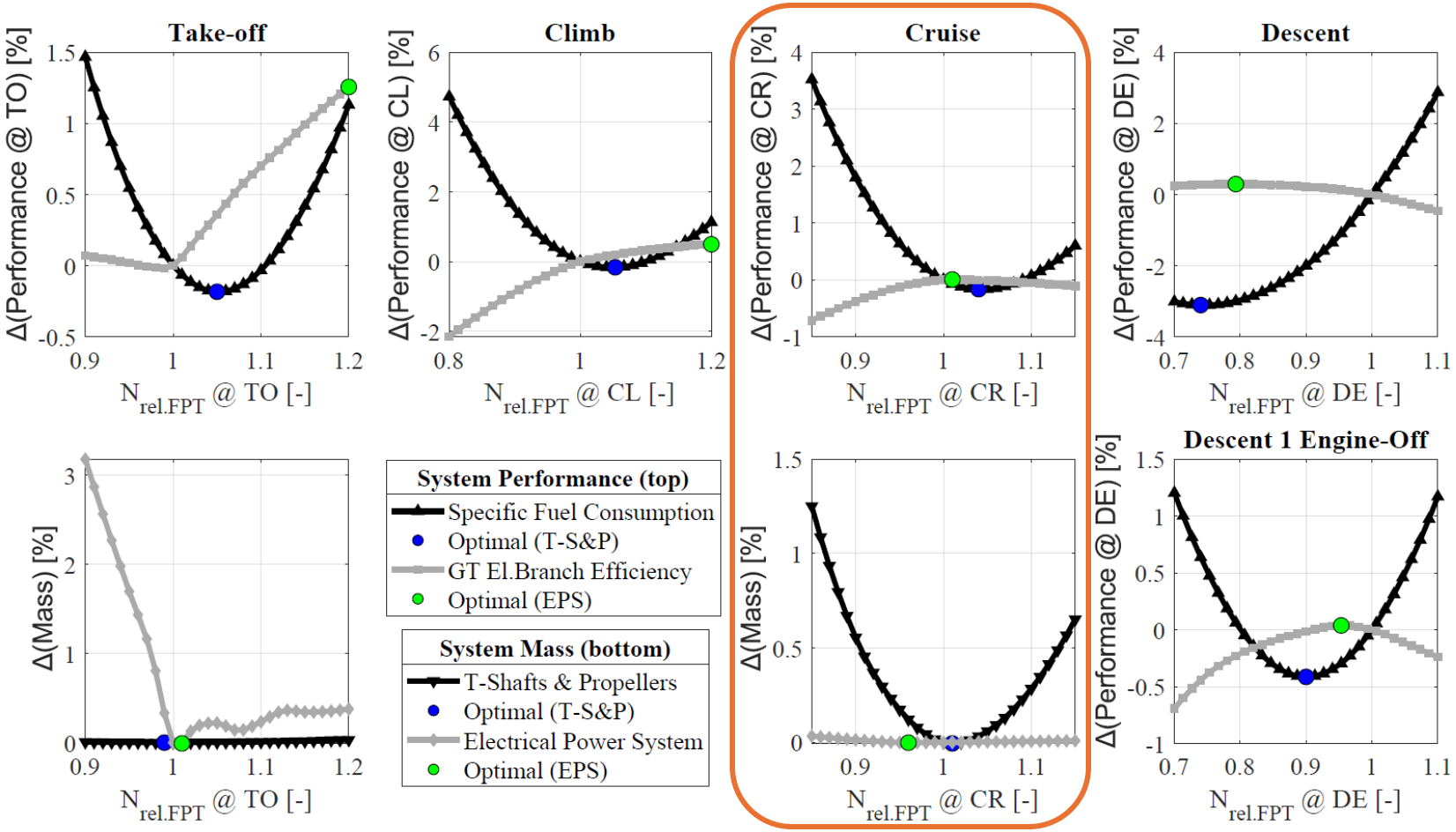
FPT speed selection

Gas turbine and propeller decoupling



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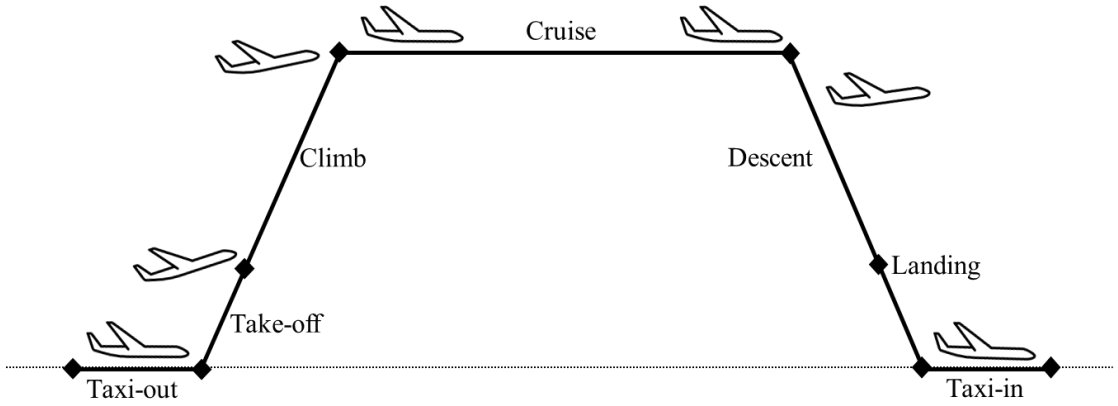
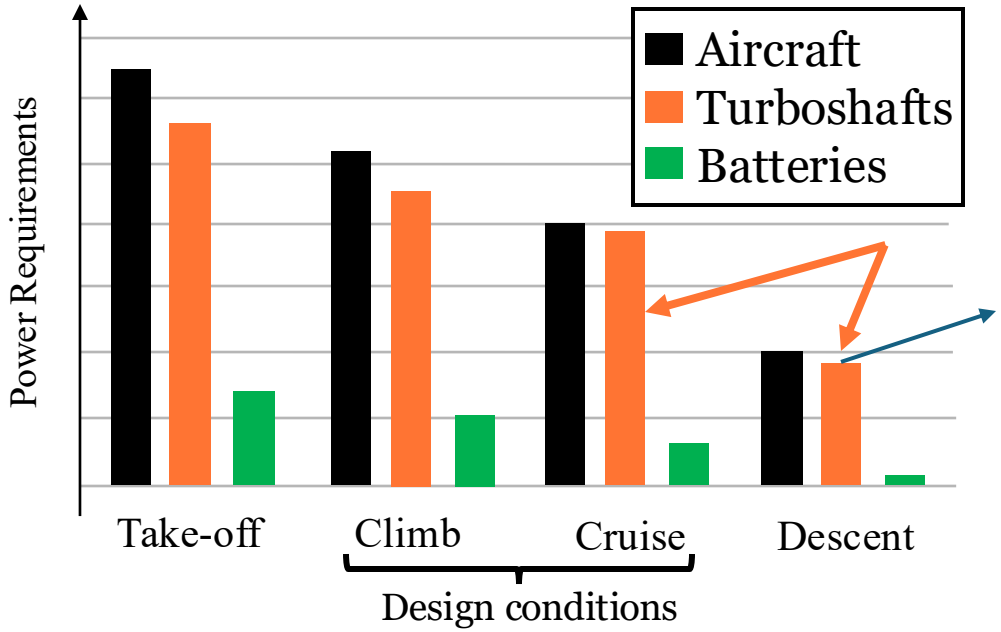
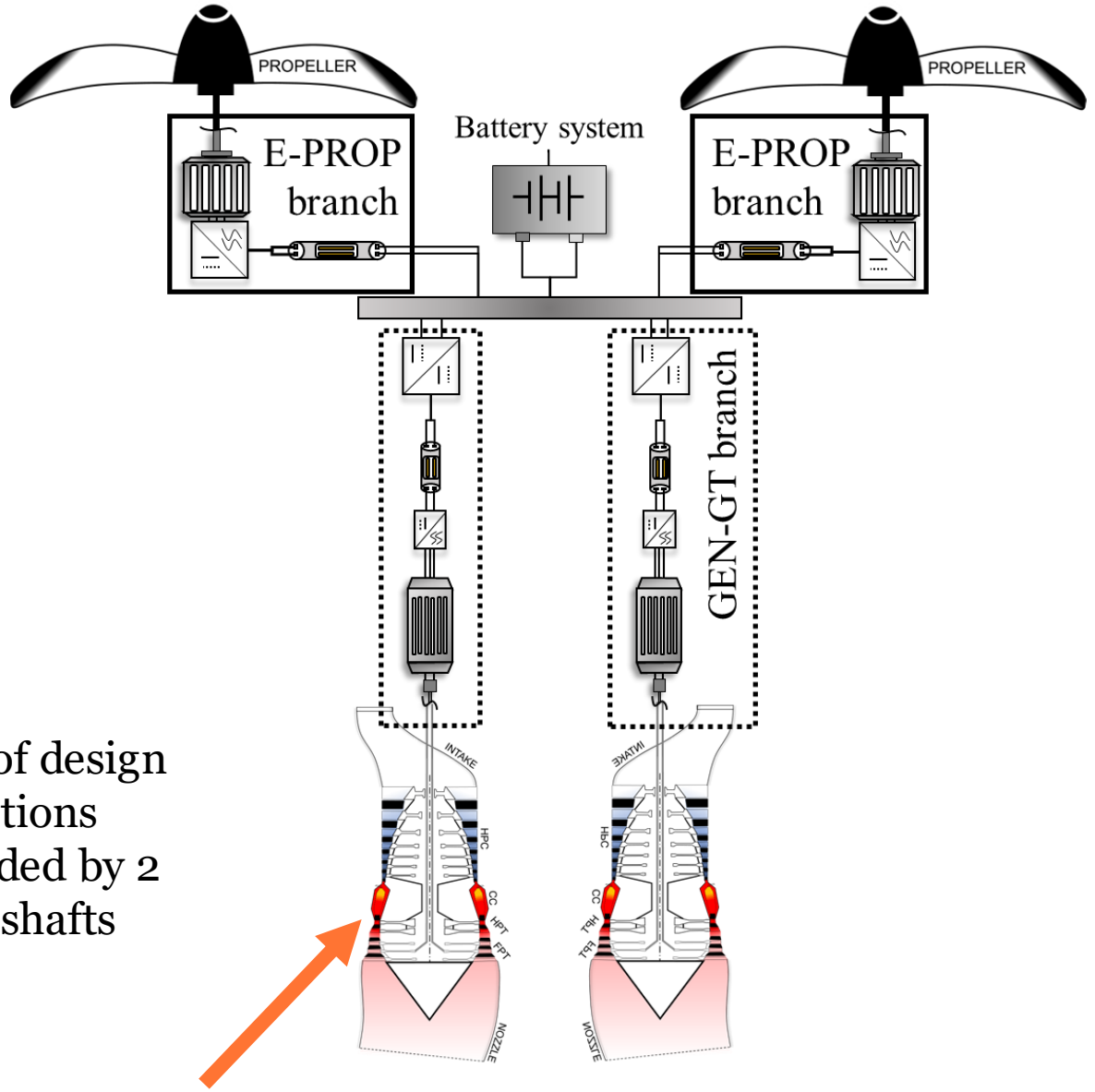
Descent

One-engine off





50% of design conditions provided by 2 turboshafts



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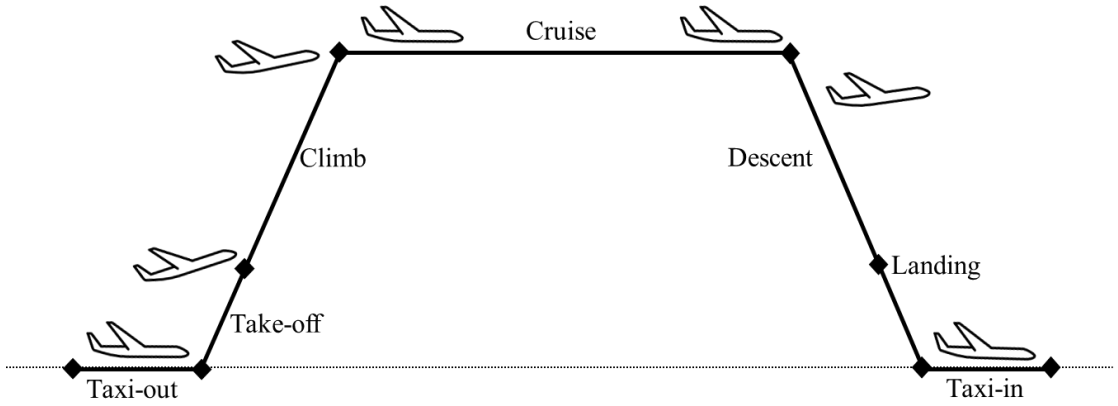

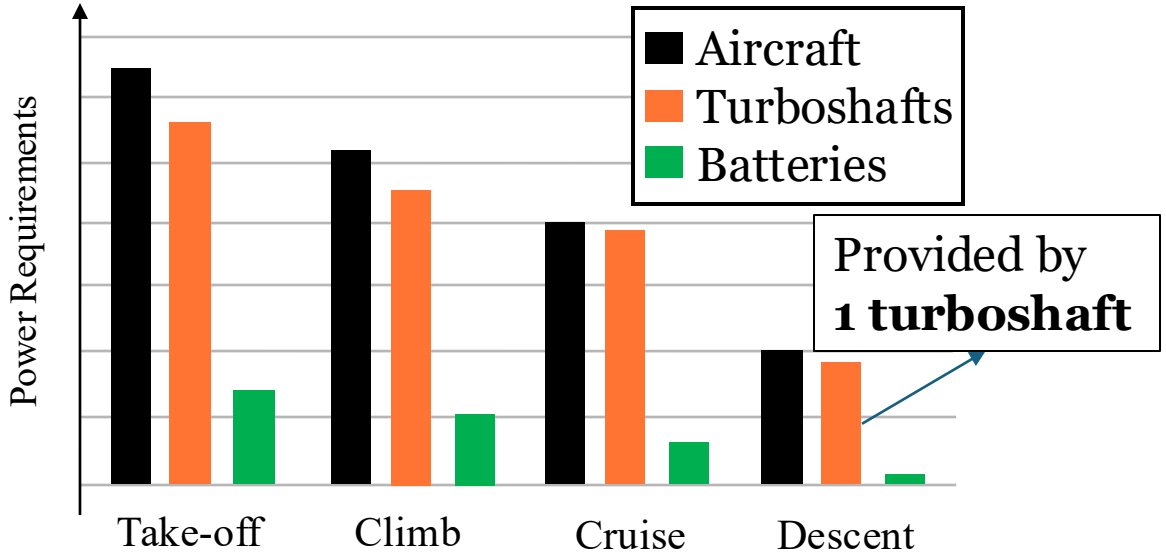

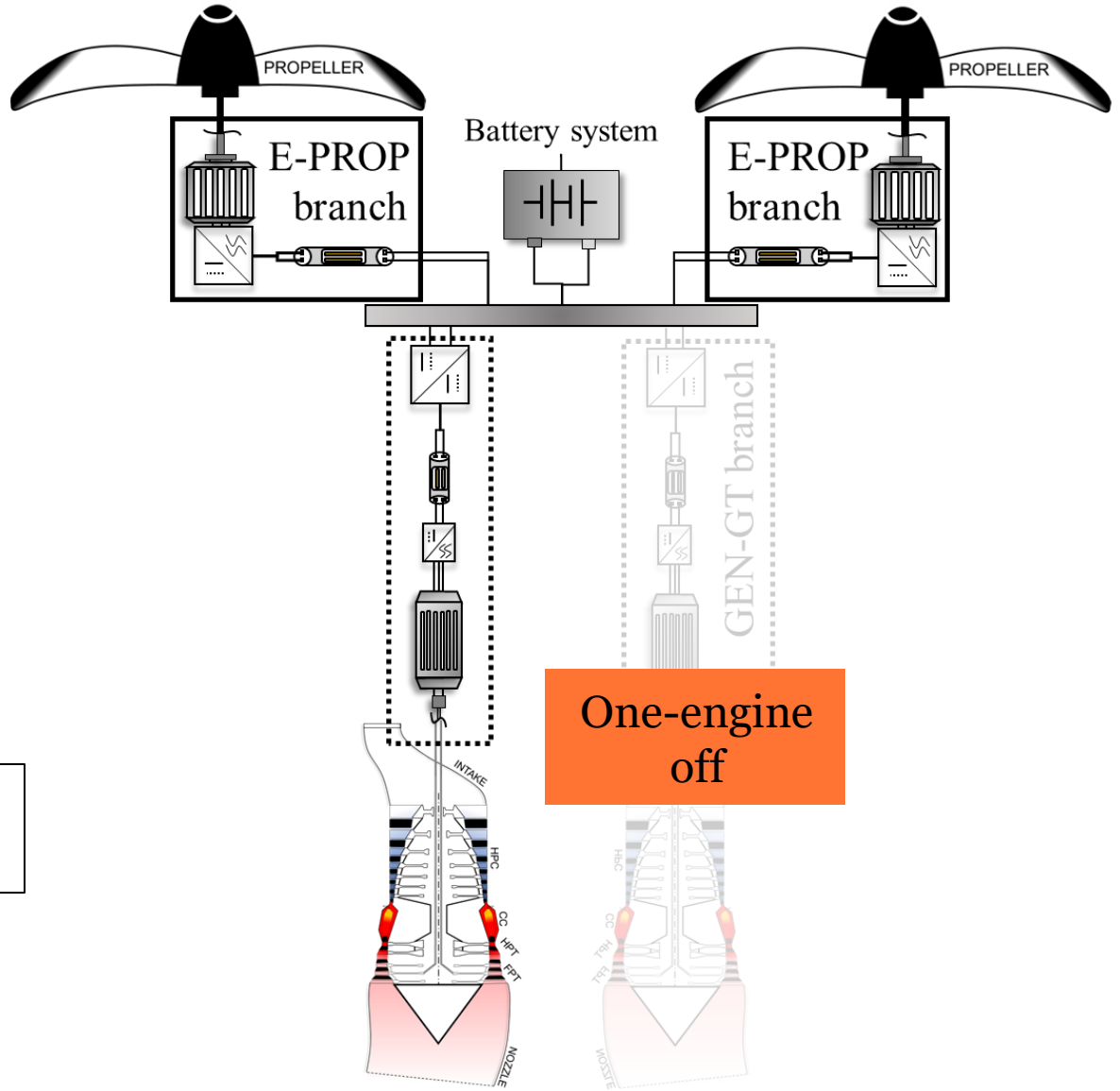

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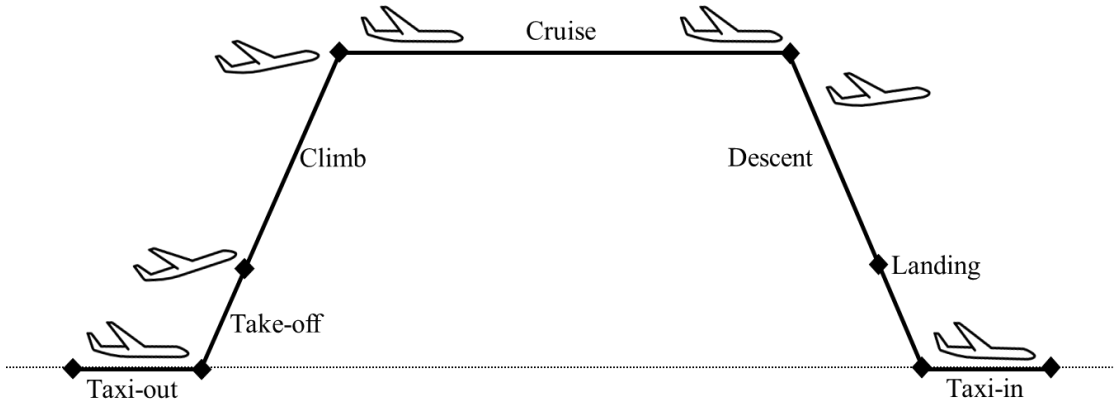
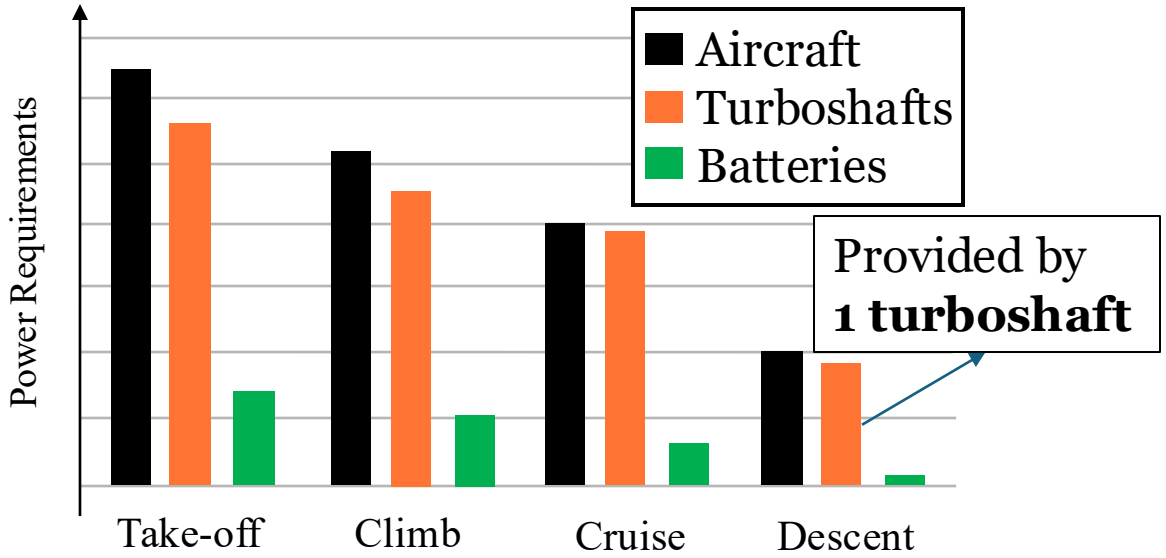
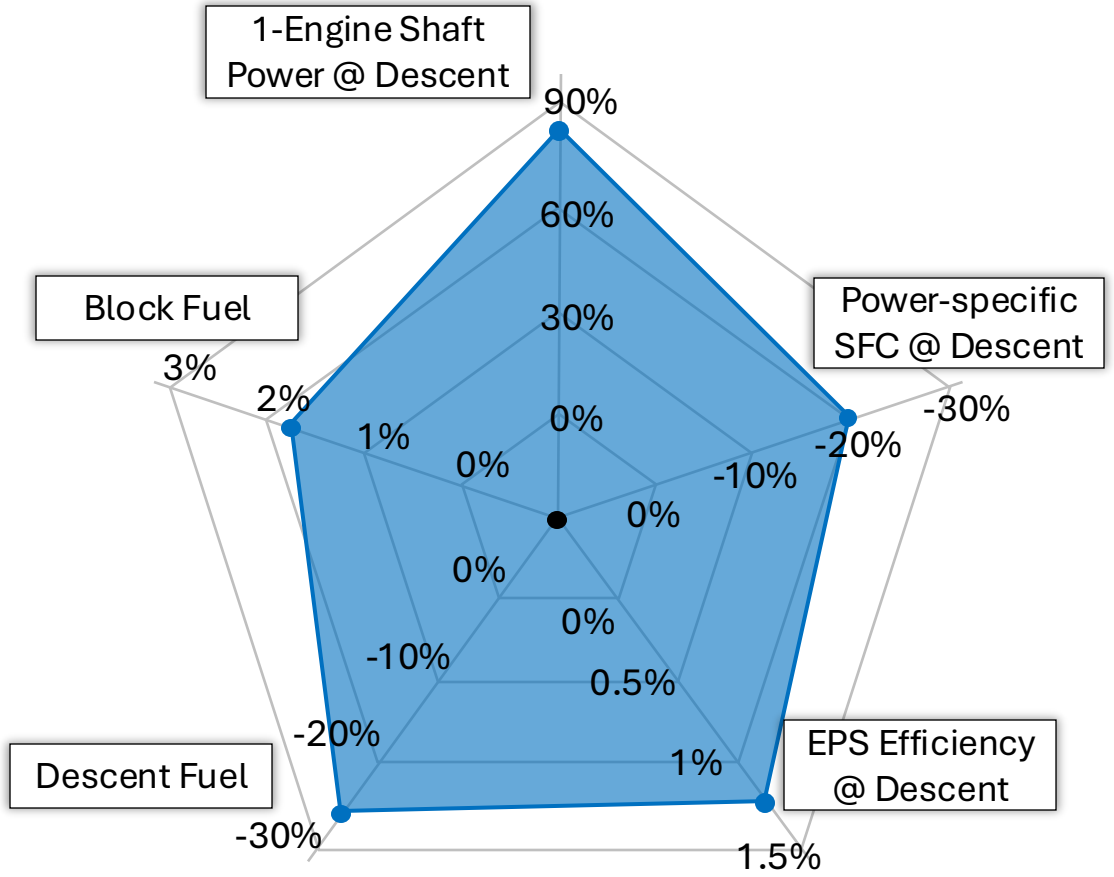
One-engine off





1 Engine-off during Descent Operation



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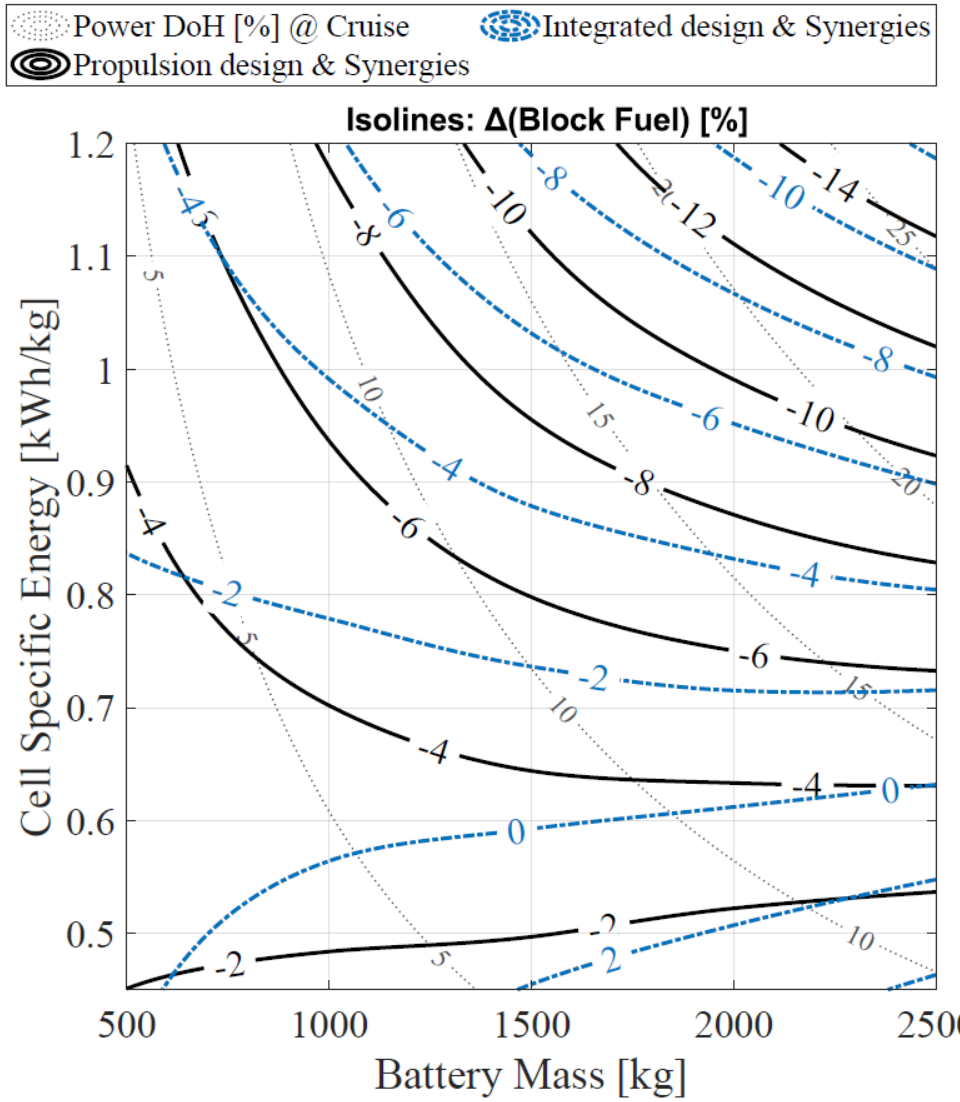
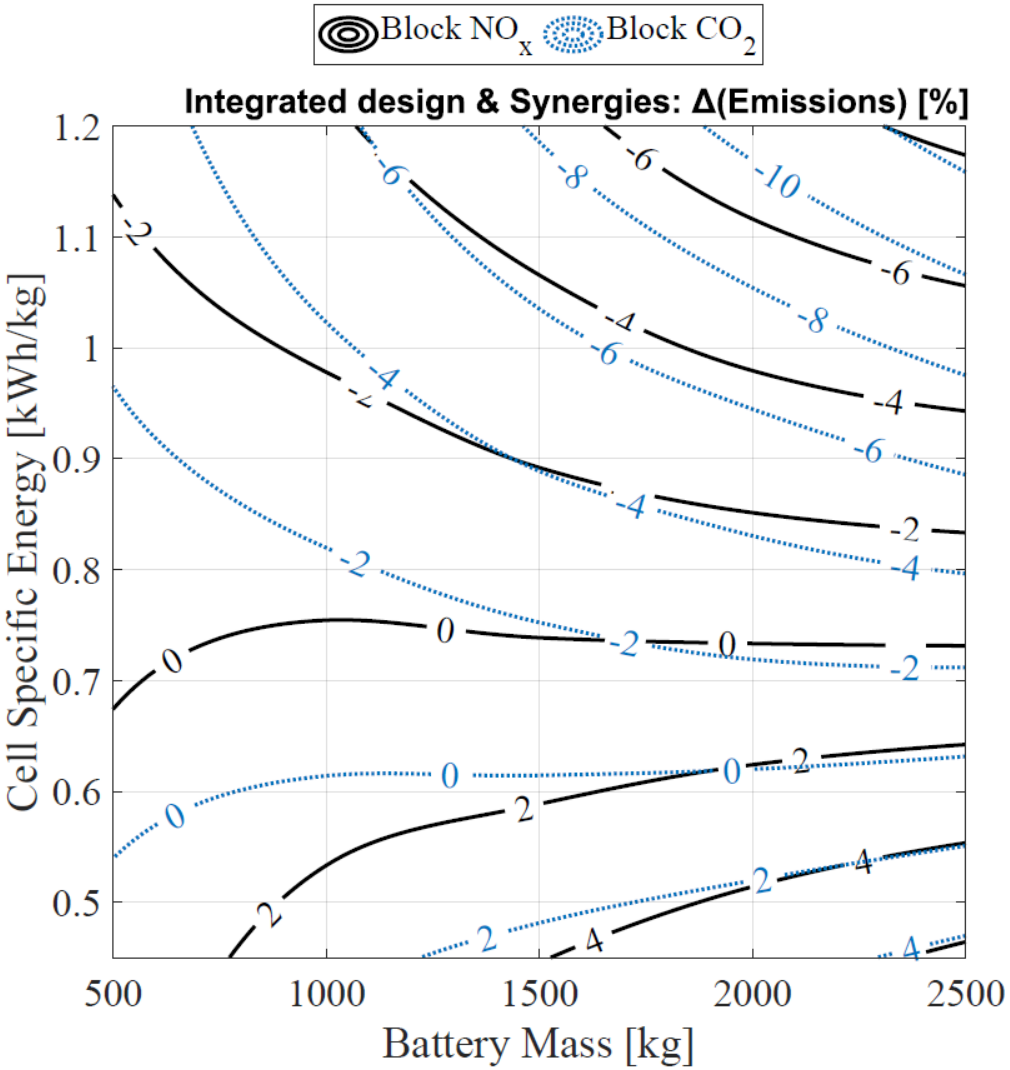
Technology targets

Comparative block fuel, and emissions





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Flight and operational conditions

Cruise speed, altitude and business range