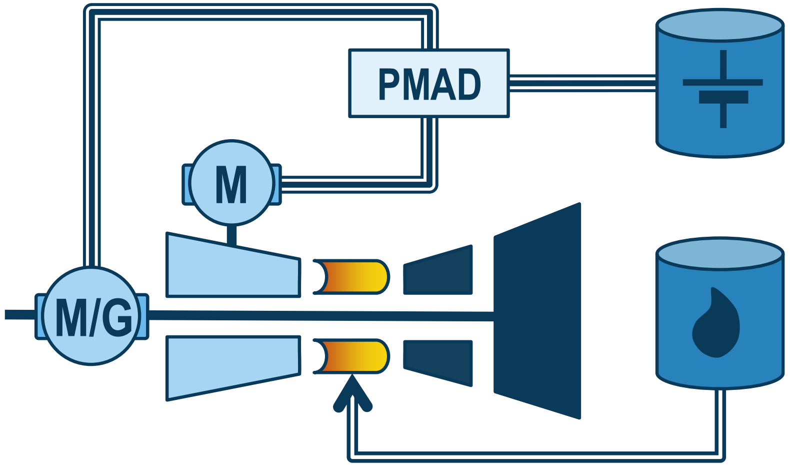
IMOTHEP
GETTING HYBRID ELECTRIC



Performance investigations of a cycle- & mechanically-integrated parallel hybrid-electric turboshaft

P. Maas, A. Seitz, D. Wirth, P. Geiger, M. Hornung

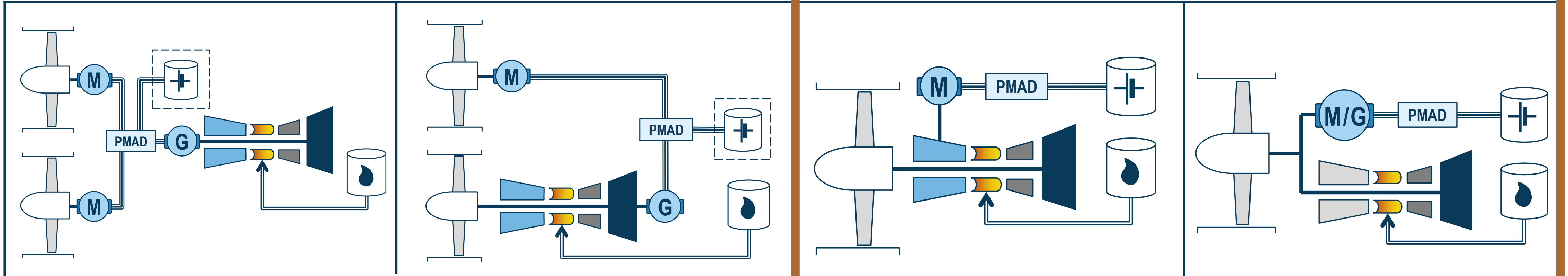
20/10/2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 875006

Basic Approaches to Hybrid Electric Propulsion

Bauhaus Luftfahrt
Neue Wege.

Focus of present study



* „Serial Hybrids" are distinct from „Turbo-Electric" architectures by dual energy storage capacity.

Full „Serial Hybrid" (FSH) / „Turbo-Electric" (FTE)*	Partial „Serial Hybrid" (PSH) / Turbo-Electric (PTE)*	Cycle-Integrated Parallel Hybrid (CIPH)	Mechanically Integrated Parallel Hybrid (MIPH)

Energy Storage: Chemical, Electro-Chemical **Electric Machinery:** M Motor, G Generator

Power Transmission: Mechanical, Fuel Flow, Electrical

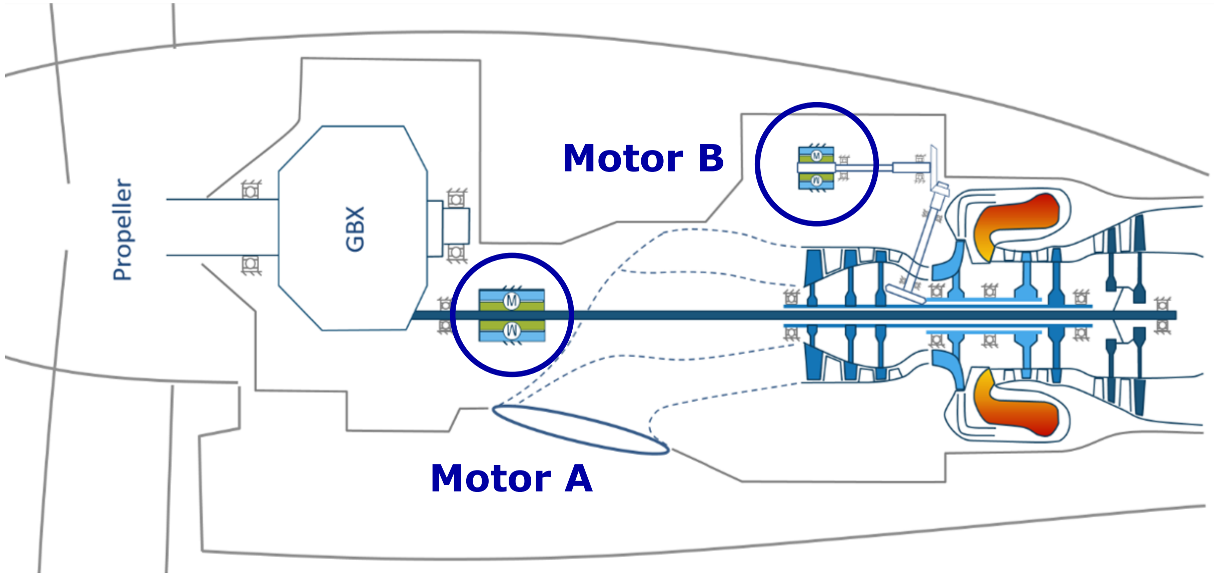
Degree of power hybridization:

$$H_P = \frac{P_{sup,el}}{P_{sup,tot}} = \frac{P_{Bat,prop}}{P_{Bat,prop} + P_{Fuel}}$$

Source: Seitz et al. (2018) Proc. IMechE Part G, Vol. 232(14) pp. 2688–27122018.

Concept Overview

- **Mechanically- & Cycle-Integrated Parallel Hybrid configuration**
  - 3-spool architecture with cycle-integrated system driving the high pressure (HP) spool
  - Axial compressor driven by intermediate pressure (IP) spool, radial compressor driven by HP spool
  - Use of towershaft for integration of cycle-integrated electrical machine
  - Mechanically-integrated system driving the power turbine (PT) shaft



Power split:

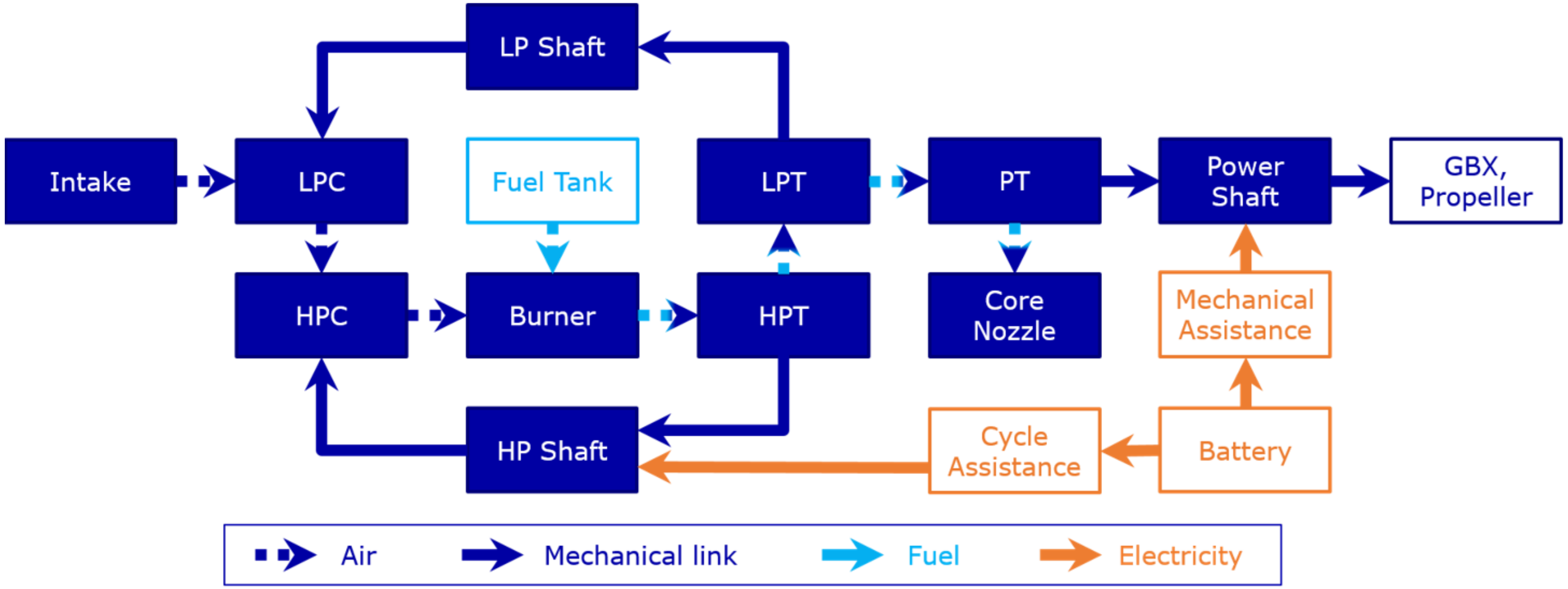
$$S_P = \frac{P_{MotorA}}{P_{MotorA} + P_{MotorB}}$$

Motor A: Mechanically-integrated assistance
Motor B: Cycle-integrated assistance (turboshaft)

Propulsion System Modelling

Bauhaus Luftfahrt Neue Wege.

Model Layout



Note: only dark blue components are modelled as part of the present study

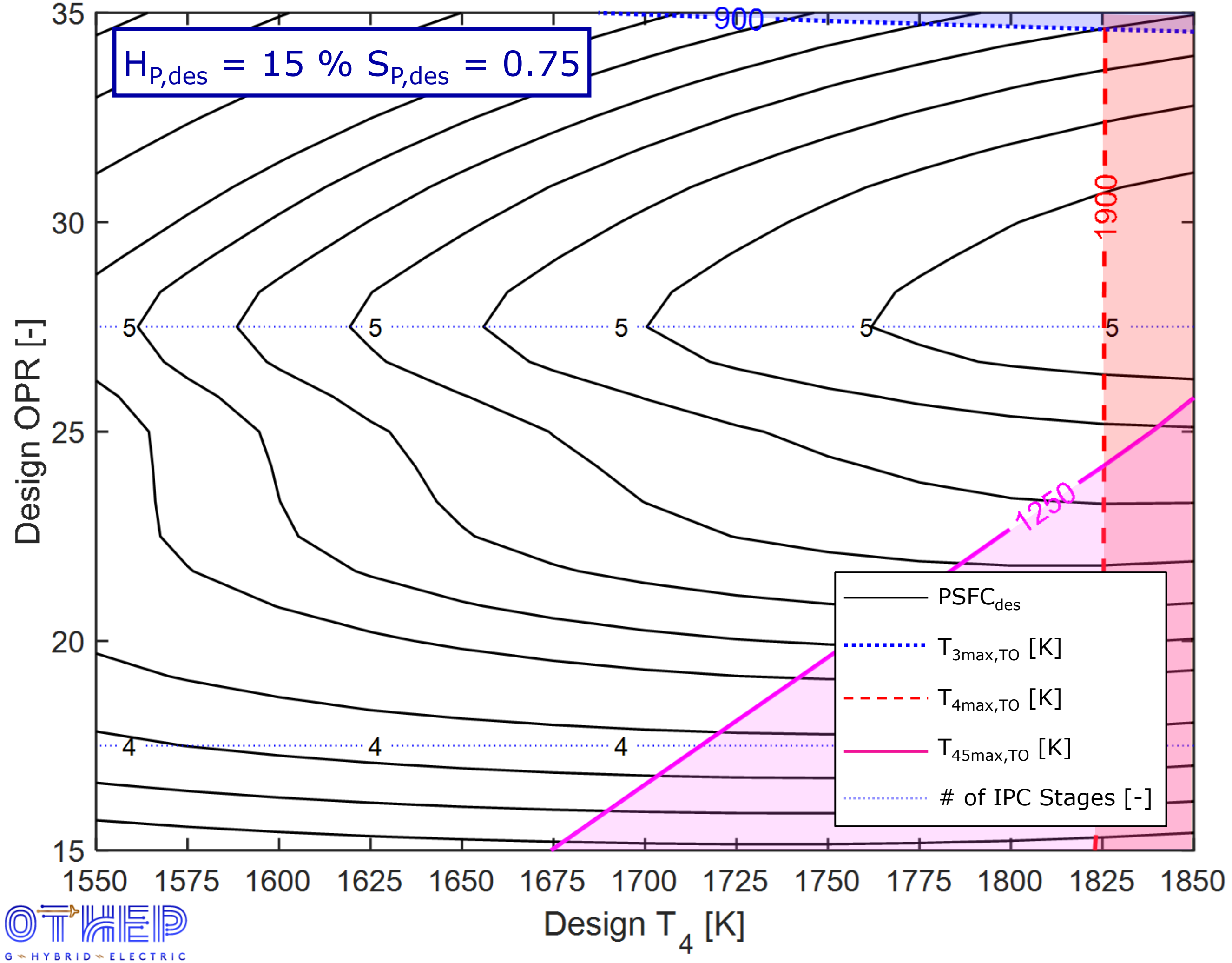
Model Settings

- Use of BHL in-house framework «Aircraft Propulsion System Simulation» (APSS)
- Flow path sizing at TOC conditions (M0.4, FL150, ISA+10)
- Baseline turbo component efficiencies based on expert knowledge
- Typical geometric settings (hub-to-tip ratios, turbo component axial Mach numbers, circumferential speeds)
- BHL in-house flow path sizing laws & cooling air model

Propulsion System Sizing Study

Bauhaus Luftfahrt Neue Wege.

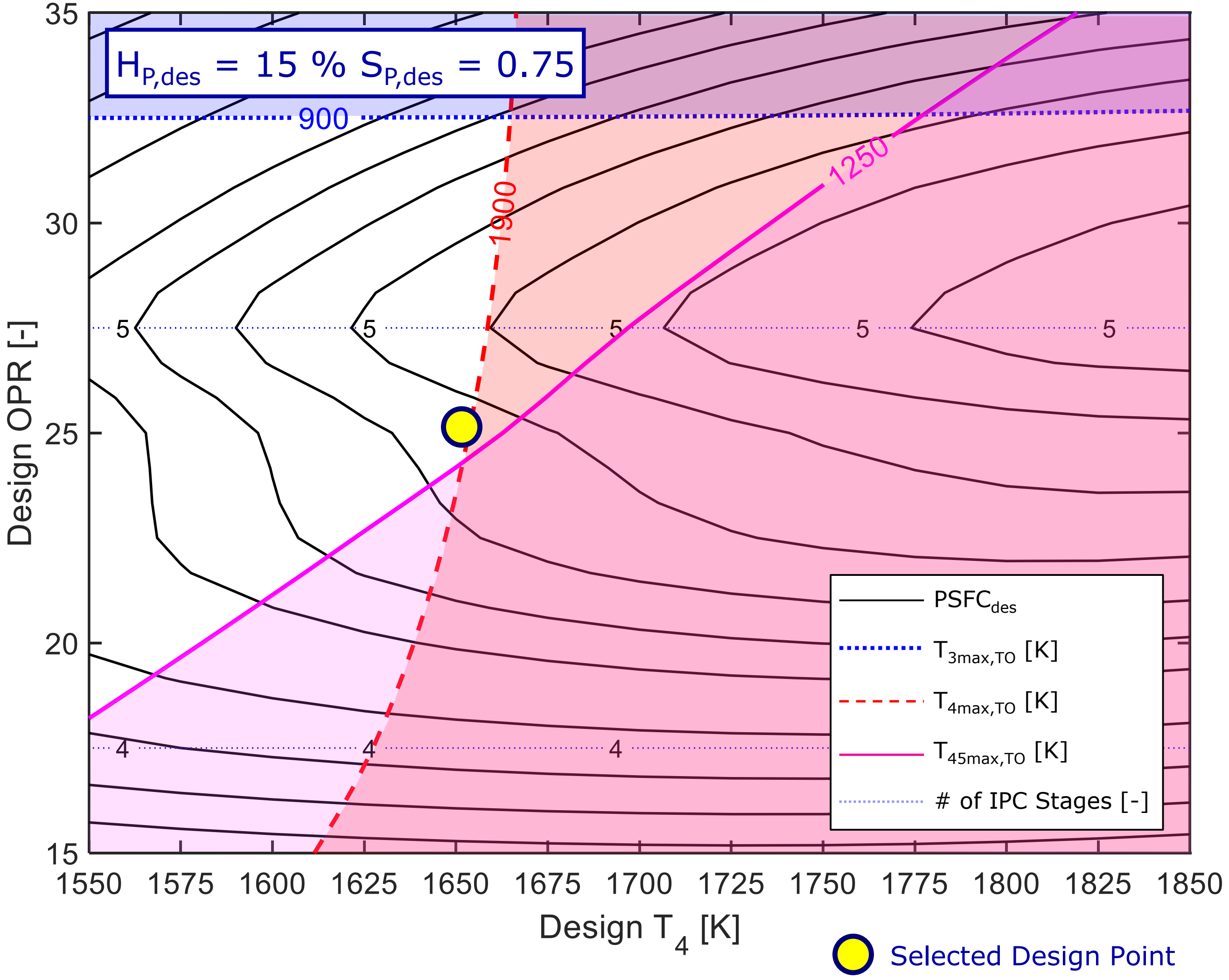
All electric motors operative (AMO), $HP_{TO} = HP_{des}$



- **Study Settings**
  - Multi-point sizing study
  - Variation of design cycle parameters (OPR_{des} & $T4_{des}$)
  - Flow path sizing at TOC conditions (M0.4, FL150, ISA+10)
  - Take-Off rotation conditions (M0.17, SL, ISA)

Propulsion System Sizing Study

All electric motors inoperative (AMI), $HP_{TO} = 0$



- **Study Settings**
  - Multi-point sizing study
  - Variation of design cycle parameters (OPR_{des} & $T4_{des}$)
  - Flow path sizing at TOC conditions (M0.4, FL150, ISA+10)
  - Take-Off rotation conditions (M0.17, SL, ISA)

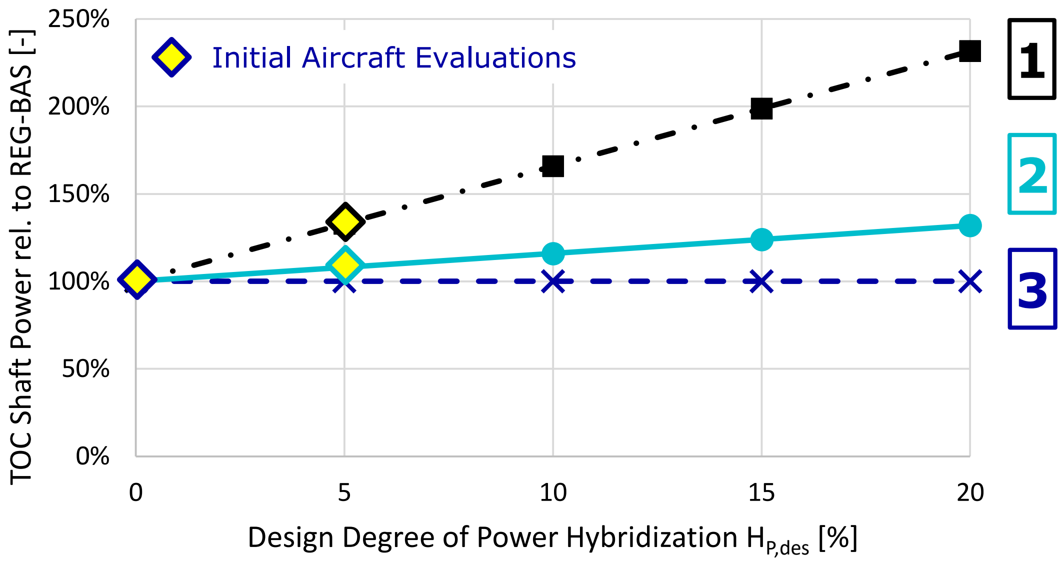
Propulsion system sizing depends on considered failure mode

Most critical cycle limitation during dual failure of electric motors

Design Hybridization Study (1/2)

Bauhaus Luftfahrt Neue Wege.

3 Engine Sizing Scenarios



1. **Linear Extrapolation of initial REG-CON**
   incl. hybridization of holding & diversion
2. **Linear Extrapolation of initial REG-CON**
   no hybridization of holding & diversion
3. **Constant Shaft Power Demand**
   based on initial REG-BAS aircraft

Analysis of Power-Specific Fuel Consumption PSFC vs. Design Hybridization

Analysis of Fuel Flow vs. Design Hybridization

Design Hybridization Study (2/2)

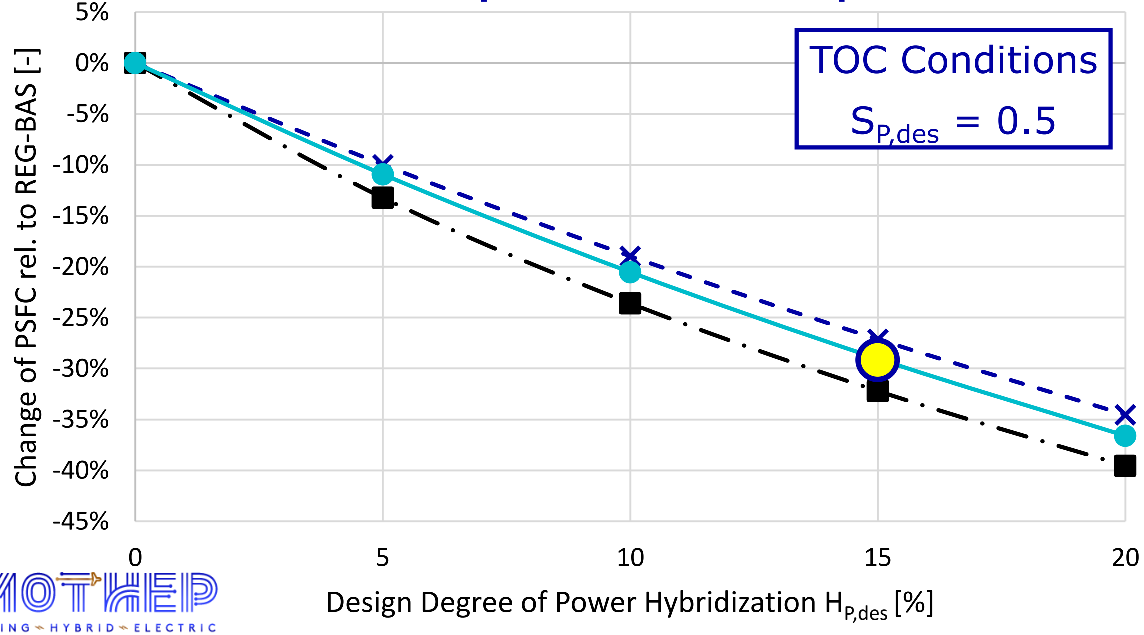
Bauhaus Luftfahrt
Neue Wege.

Good match with overall aircraft level results

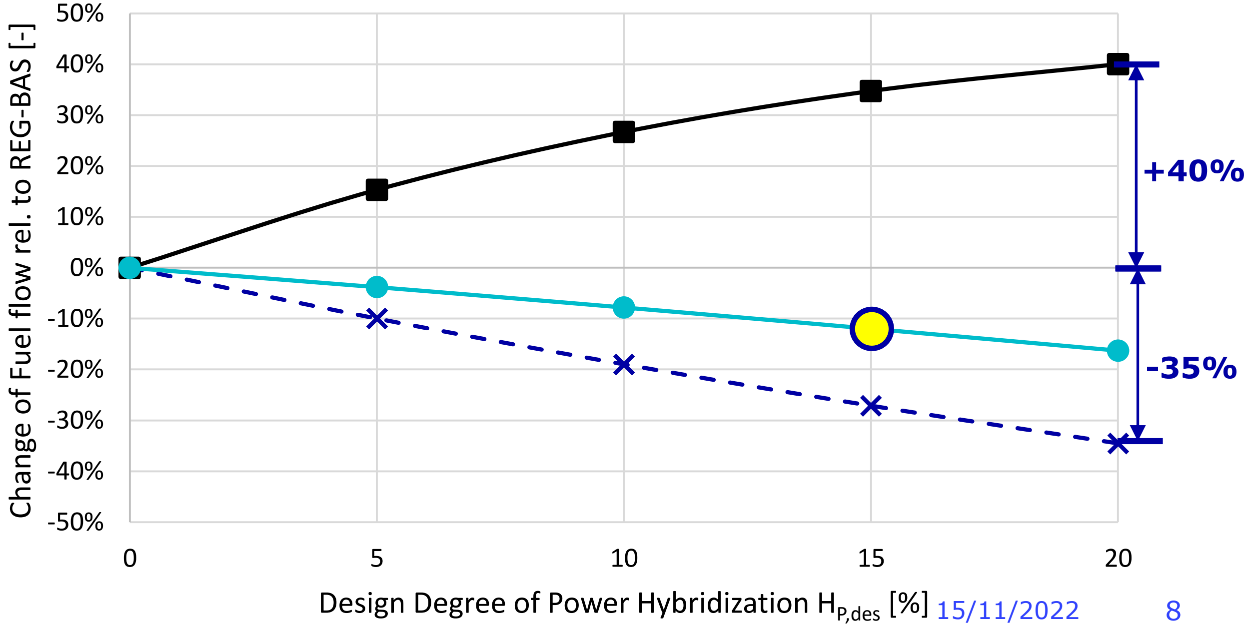
Habermann et al., *Study of a regional turboprop aircraft with hybrid-electric turboshaft assistance*, EASN Conference 2022

1. **Linear Extrapolation of initial REG-CON**
   incl. hybridization of holding & diversion
2. **Linear Extrapolation of initial REG-CON**
   no hybridization of holding & diversion
3. **Constant Shaft Power Demand**
   based on initial REG-BAS aircraft

Power-Specific Fuel Consumption



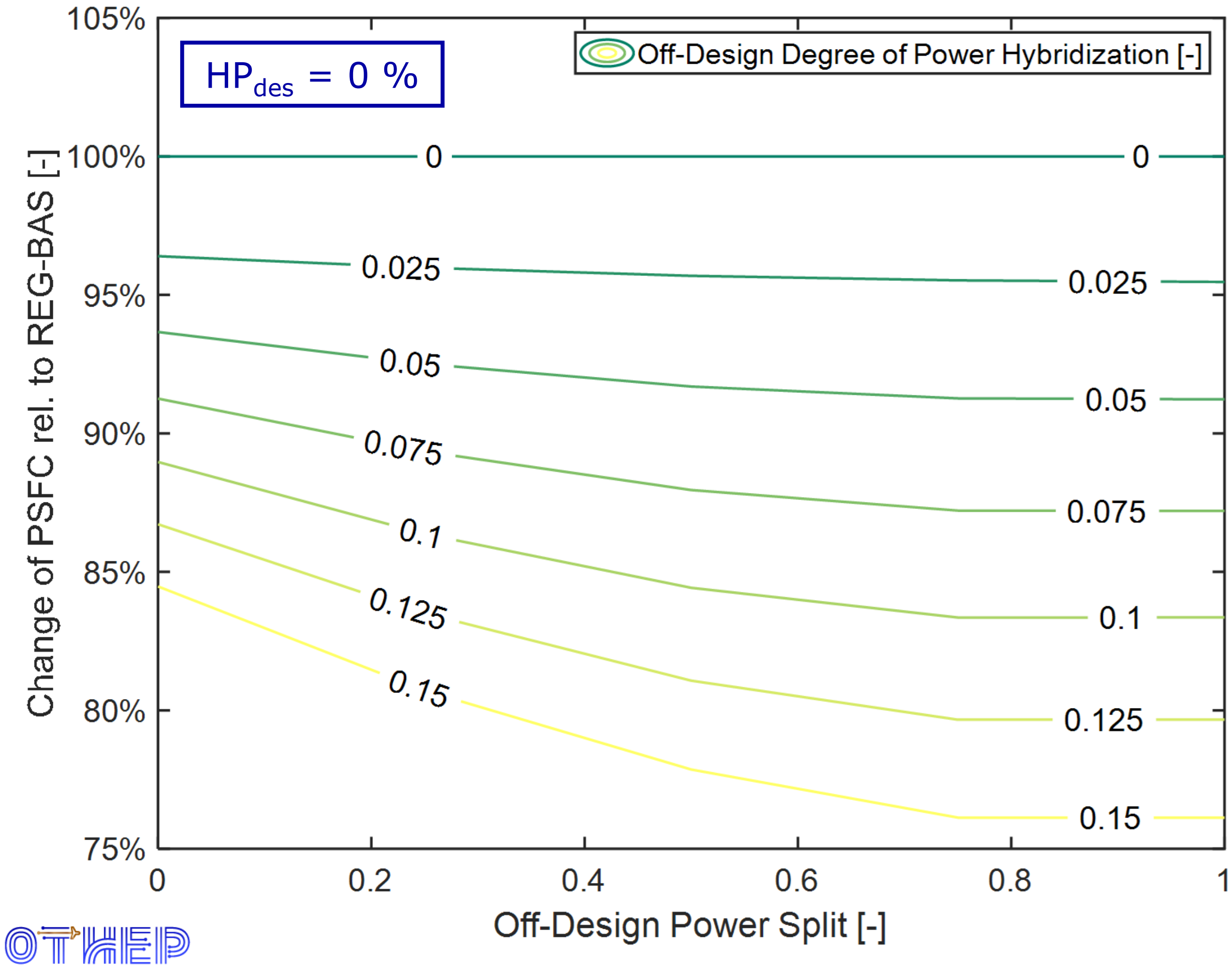
Fuel Flow



Off-Design Hybridization Study (1/2)

Bauhaus Luftfahrt
Neue Wege.

Variation of Electrical Power Split



- **Study Settings**
  - $0\ \% < H_{P,od} < 15\ \%$
  - $0 < S_{P,od} < 1$
  - TOC conditions (M0.4, FL150, ISA+10)
  - $P_{sh,od} = P_{sh,des}$

For REG-BAS ($H_{P,od} = 0$), electrical power split has no impact on PSFC

For $H_{P,od} > 0$, usage of P_{MotorA} (MIPH system) is more beneficial

Power split:

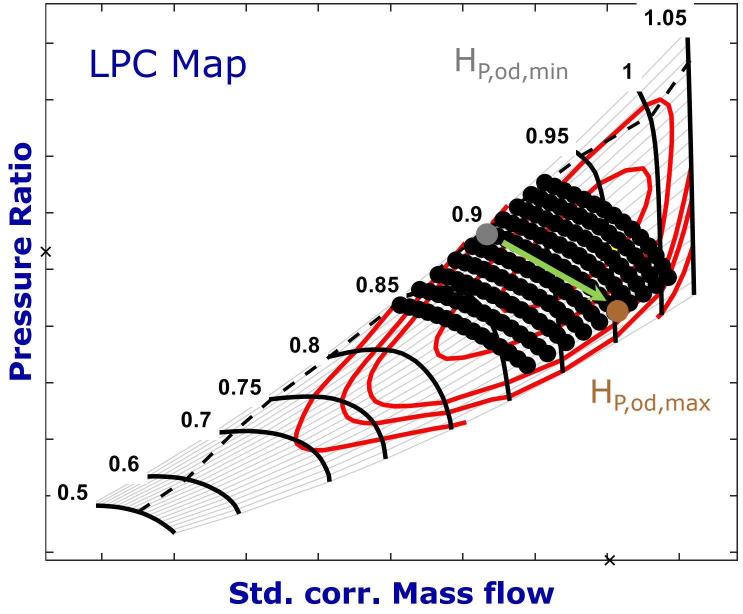
$$S_P = \frac{P_{MotorA}}{P_{MotorA} + P_{MotorB}}$$

Off-Design Hybridization Study (2/2)

Bauhaus Luftfahrt
Neue Wege.

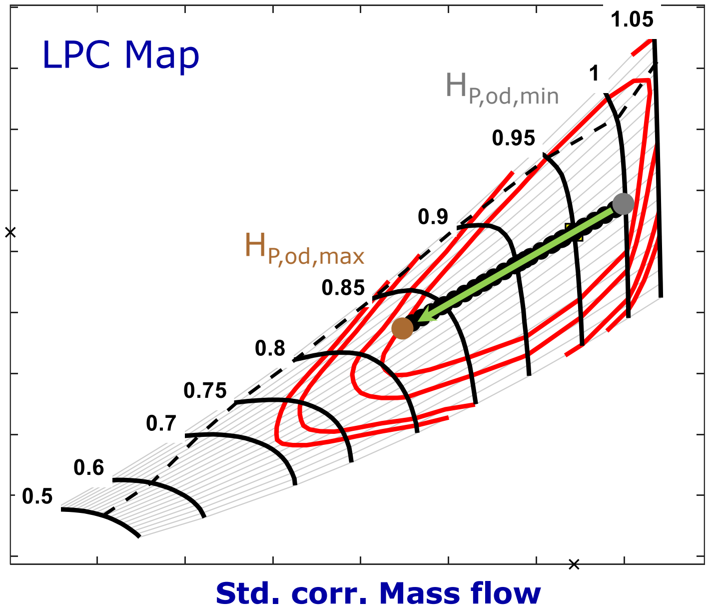
- **Cycle-Integrated Electrification**
  - $S_{P,od} = 0.0$
  - LPC most critical turbo component

NASA-TM-101433



- **Mechanically-Integrated Electrification**
  - $S_{P,od} = 1.0$
  - LPC most critical turbo component

NASA-TM-101433



- **Study Settings**
  - $H_{P,des} = 10\ \%$
  - TOC conditions (M0.4, FL150, ISA+10)
  - $P_{sh,od} = 50 - 100\ \%\ P_{sh,des}$

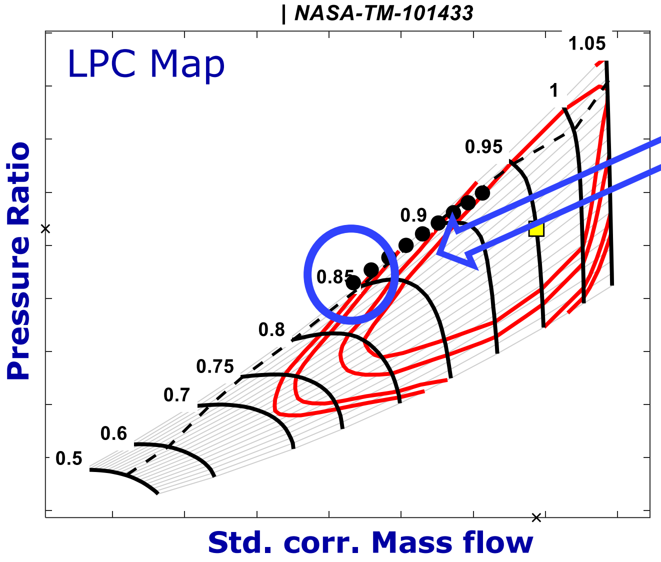
HP electrification limited by LPC choke/surge line

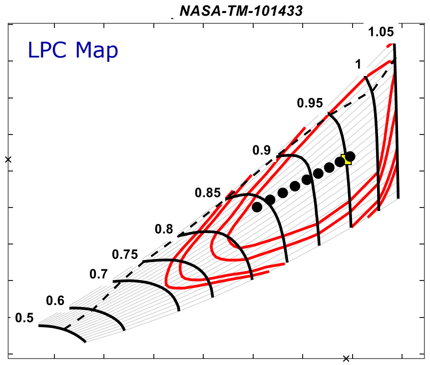
LP electrification limited by LPC spool speeds

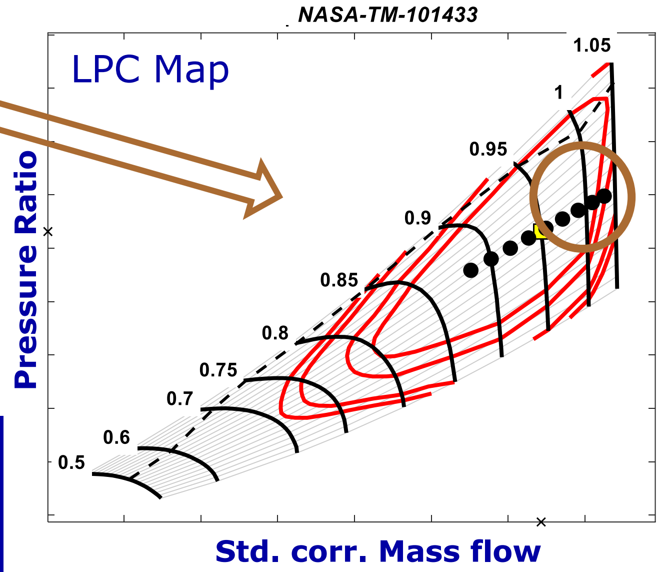
Impact of Electric System Failure

Bauhaus Luftfahrt Neue Wege.

- **Loss of electric assistance to HP shaft leads to critical LPC surge margin values at low part-power points**
- **Loss of electric assistance to power shaft leads to critical LPC speed values (overspeeding) at high power points**







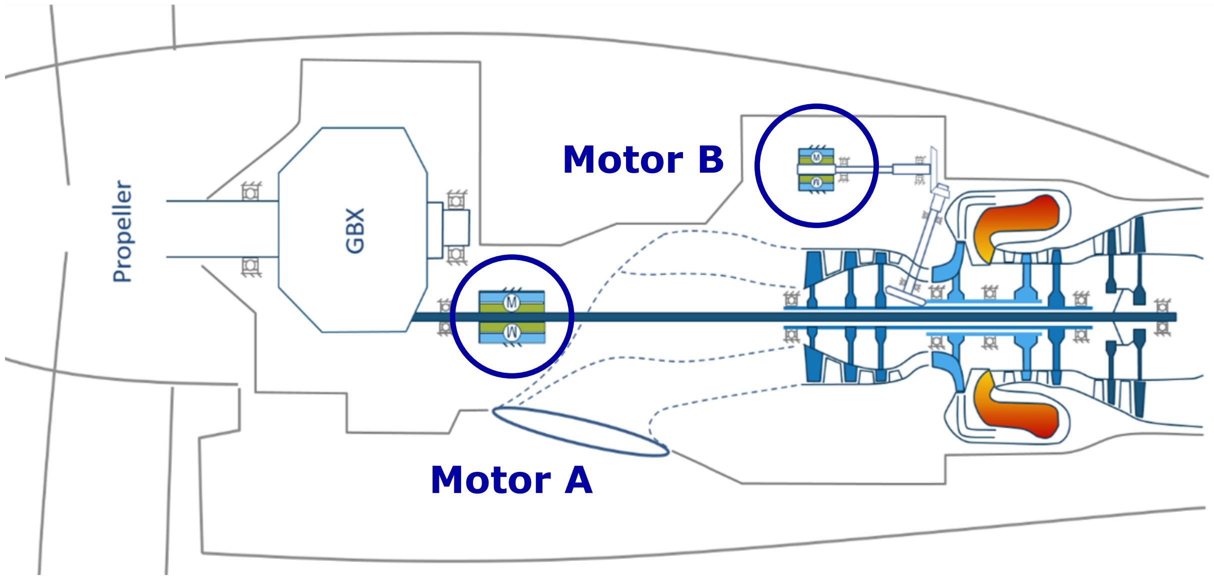
Adjustment of design point position taking into account penalty in efficiency, size and weight

IMOTHEP GETTING HYBRID ELECTRIC

Conclusions

Bauhaus Luftfahrt
Neue Wege.

- **Parallel hybrid-electric propulsion can significantly improve efficiency on propulsion system level**
- **However, electric system failure needs to be considered during propulsion system sizing**
- **For high power degrees of hybridization, electric assistance to the power shaft (Motor A) is more relevant**



Contact:

Philipp.Maas@Bauhaus-Luftfahrt.net

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 875006