# GENERATIVE DESIGN OF HYBRID-ELECTRIC AIRCRAFT PROPULSION SYSTEMS USING EVOLUTIONARY ALGORITHMS

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# AGENDA

1. **Introduction**
2. **Propulsion concept**
3. **Optimization method (GA)**
4. **Methodology**
5. **Results**
6. **Conclusion & Outlook**

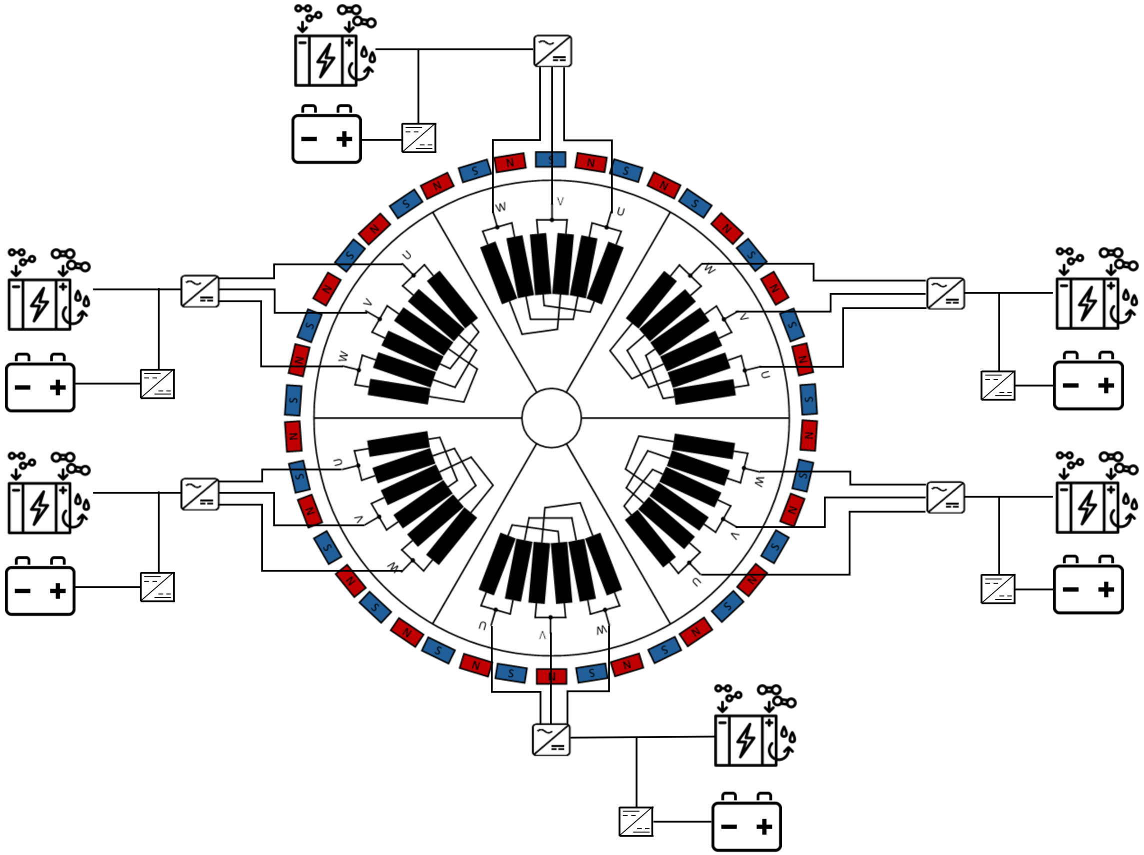

Breezer B400-6[1]

[1] Dirkshof8!, *Breezer B400-6*, Wikimedia Commons, CC BY-SA 4.0.
https://commons.wikimedia.org/wiki/File:Breezer_B400_6_1.jpg

# INTRODUCTION

## PROJECT BEHYPSY (B4 INNOVATIVE HYDROGEN PROPULSION SYSTEM)

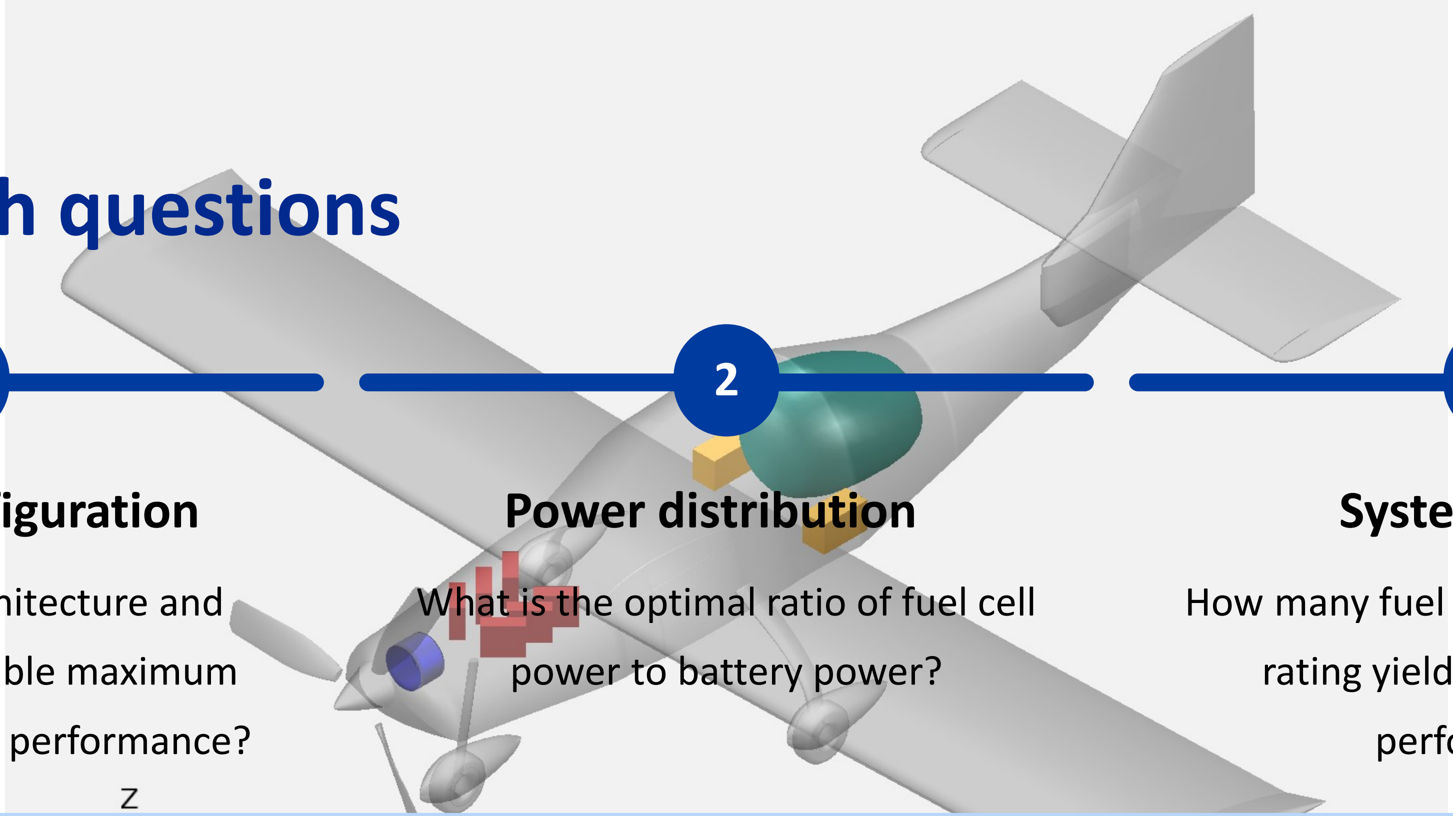
- Target: Development, integration, and testing of a hybrid-electric, multi-string fuel cell propulsion system
- Testing of air-cooled fuel cells
- Combination of an MBSE model with numerical architecture optimization for validation and optimization of the system architecture



Model of a multi-string fuel cell propulsion system

# PROPULSION CONCEPT

## SYSTEM DESCRIPTION & KEY RESEARCH QUESTIONS




# Key research questions

**1**

### Optimal configuration

Which system architecture and mission profile enable maximum efficiency and flight performance?

**2**

### Power distribution

What is the optimal ratio of fuel cell power to battery power?

**3**

### System design

How many fuel cells of which power rating yield the best overall performance?

ⓘ These decision-making foundations form the basis for developing the sustainable aircraft propulsion systems of the future.

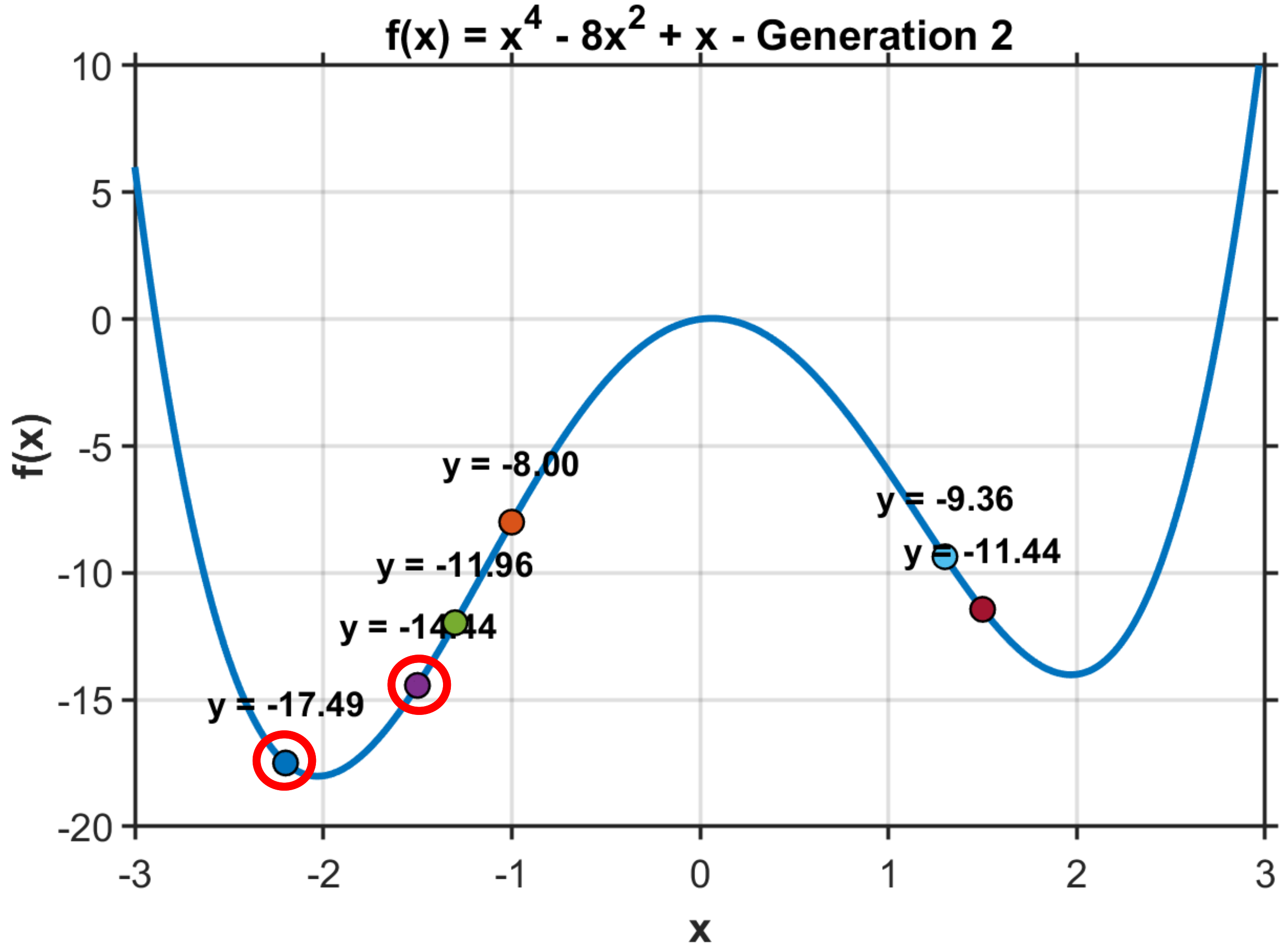
# OPTIMIZATION METHOD

## STOCHASTIC METHODS (GENETIC ALGORITHM)

- ✈ Works with a population of solutions that is iteratively improved
- ✈ Uses mutation, crossover & selection to approach an optimum
- ✈ Effective for non-differentiable or complex functions
- ✈ Robust with respect to initial values, no derivatives required

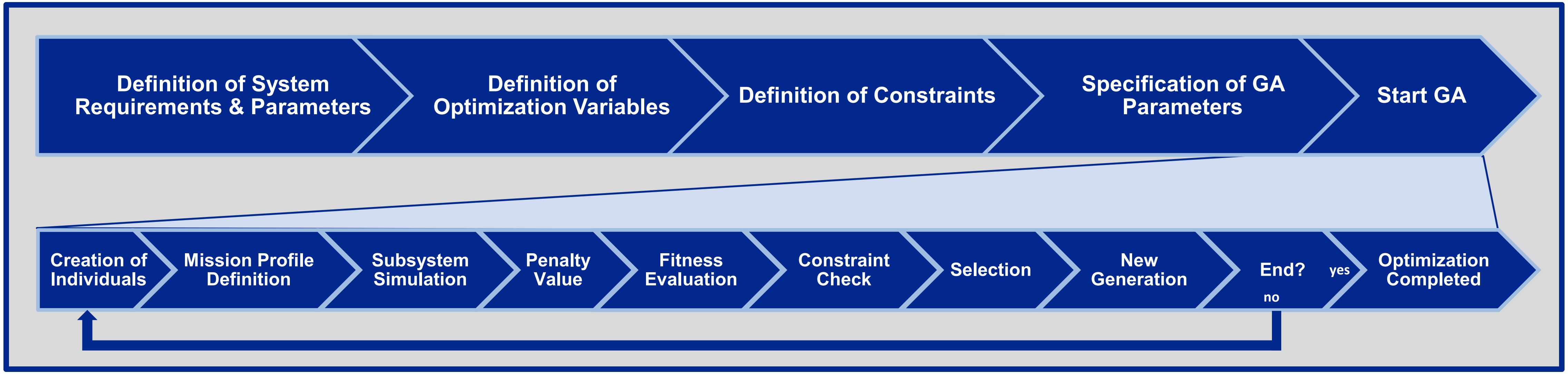
**But:**

- ✈ Slower than classical methods, does not reliably reach the global optimum



# METHODOLOGY

## WORKFLOW OPTIMIZATION PROCESS




Workflow Multi-Objective Optimization (MOO)

# METHODOLOGY

## SUBSYSTEM SIMULATION – BATTERY

- Invocation of the battery function
  - Battery type, $E_{req}$, $P_{req}$, $U_{BAT}$
- Calculation of the number of serial and parallel cells
  - $n_s = \frac{U_{BAT}}{U_{n_{cell}}}$
  - Energy-based: $n_p = E_{req}/(C_{n_{cell}} * U_{cell} * n_s)$
  - Power-based: $n_p = P_{req}/(I_{max_{cell}} * U_{cell} * n_s)$
- Calculation of the total mass and storable energy
  - $m_{BAT} = m_{cell} * n_s * n_p * k_{pack}$
  - $E_{BAT} = V_{cell} * C_{n_{cell}} * n_s * n_p$

**Li-Ion class battery**

**Properties:**
- CellMass [g]: 48
- NominalCapacity [Ah]: 3
- NominalVoltage [V]: 3.6
- MaxDischarge [A]: 15
- […]

**Methods:**
- evalParallelCells
- evalSerialCells
- evalTotalWeight
- evalTotalCapacity
- […]

**Li-NCA class battery**

**Properties:**
- CellMass [g]: 70
- NominalCapacity [Ah]: 4
- NominalVoltage [V]: 3.6
- MaxDischarge [A]: 45
- […]

**Methods:**
- evalParallelCells
- evalSerialCells
- evalTotalWeight
- evalTotalCapacity
- […]

**Li-NMC class battery**

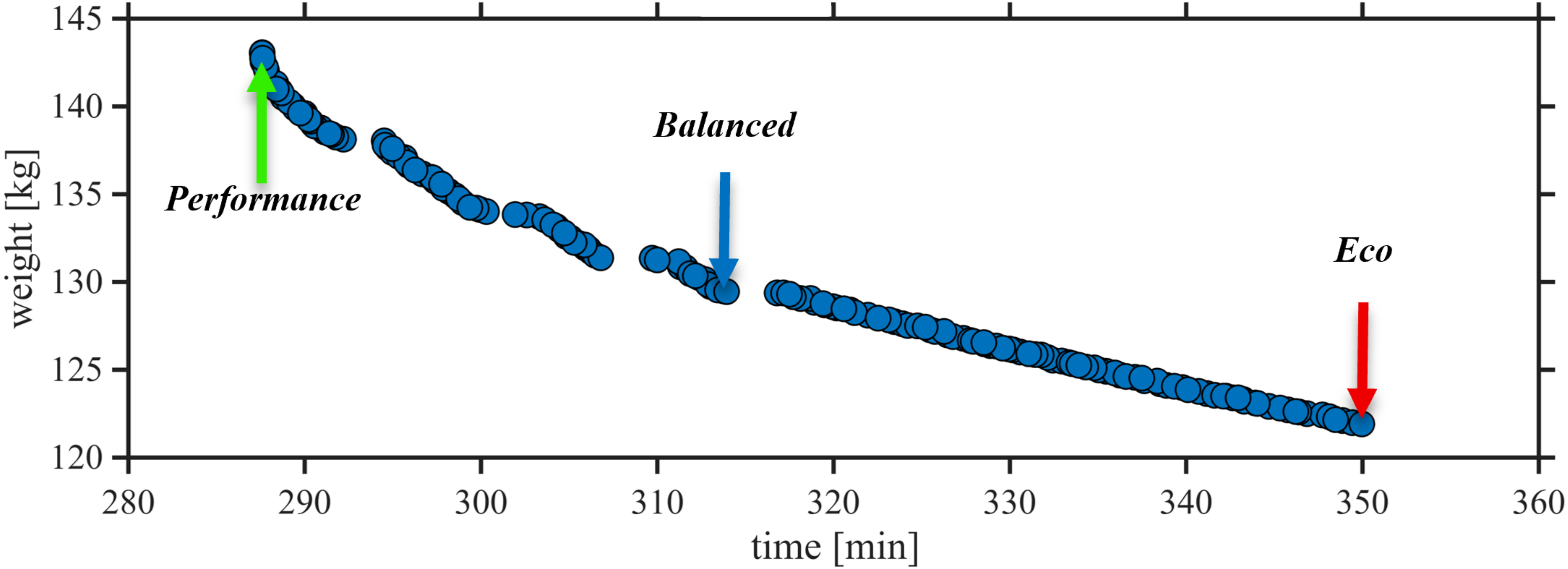
**Properties:**
- CellMass [g]: 72
- NominalCapacity [Ah]: 5
- NominalVoltage [V]: 3.6
- MaxDischarge [A]: 45
- […]

**Methods:**
- evalParallelCells
- evalSerialCells
- evalTotalWeight
- evalTotalCapacity
- […]

Different battery types represented as classes in object-oriented programming

# RESULTS

## PARETO-FRONT (MASS & FLIGHT DURATION)



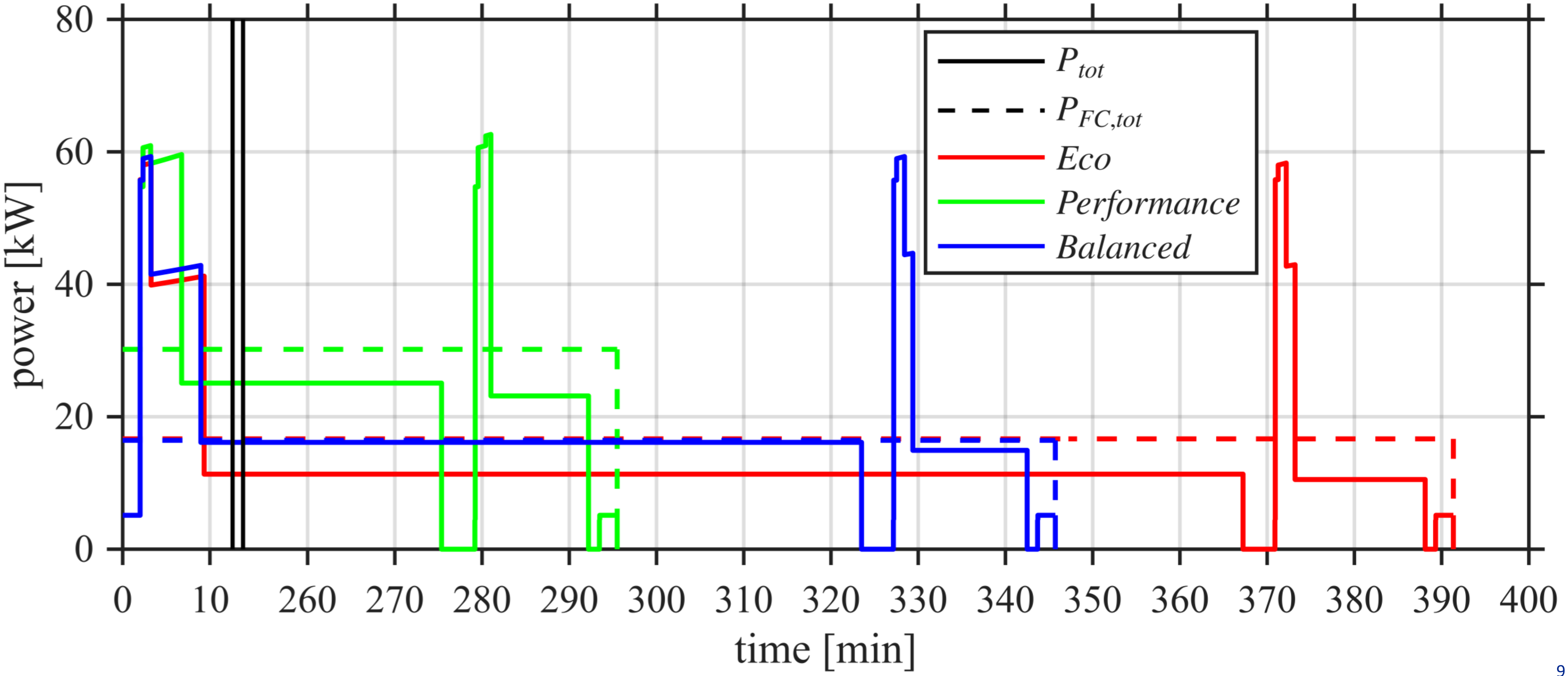
# RESULTS

## OPTIMIZATION PARAMETER

| Optimization parameter | Lower boundary | Upper boundary | Eco | Performance | Balanced |
|---|---|---|---|---|---|
| Power FC total [kW] | - | - | **3,68** | **5,76** | **5,26** |
| H2 mass [kg] | - | 100 | 3,65 | 4,42 | 3,26 |
| Energy Bat [kWh] | - | 100 | 0,838 | 0,762 | 0,645 |
| Number of FC | [1, 3, 6, 9, 12, 15, 18] | | **12** | **18** | **15** |
| Width cell FC [m] | 0,05 | 0,2 | 0,059 | 0,061 | 0,061 |
| C-factor Bat charge | - | 5 | 3,548 | 2,97 | 30,3 |
| C-factor Bat discharge | - | 52 | 24,2 | 36,7 | 3,2 |
| Voltage Bat [V] | 75 | 85 | 76,8 | 76,8 | 77 |
| Length cooling channel FC [mm] | 1 | 5 | 1,51 | 1,53 | 1,57 |
| ΔT cooling exhaust FC [°C] | 35 | 50 | 50 | 48 | 50 |
| Take-off field length [m] | 100 | 400 | 337 | 321 | 248 |
| Landing field length [m] | 100 | 400 | 349 | 321 | 345 |
| Rate of climb (initial climb) [m/s] | 4.2 | 8 | 5,28 | 6,63 | 5,82 |
| Rate of climb (climb) [m/s] | 2 | 8 | 3,26 | 5,65 | 5,59 |
| Airspeed (cruise) [m/s] | 20,3 | 71 | **42,7** | **60,9** | **55,7** |
| Rate of climb (descent + Landing) [m/s] | -8 | -1 | -7,39 | -7,26 | -7,42 |
| Battery type | [1, 2, 3, 4] | | | | |
| **System mass [kg]** | | | **66** | **148** | **112** |
| **Flight duration [min]** | | | **262** | **186** | **202** |

# RESULTS

## RESULTING MISSION PROFILES



# CONCLUSION & OUTLOOK

## FURTHER IMPROVEMENTS/ADJUSTMENTS

- Successful implementation of the optimization method
  - First results are being delivered
- Extensions of the multi-objective optimization
  - Additional optimization objectives (e.g. range, volume, life-cycle assessment, fuel consumption, payload)
  - Additional optimization variables
  - More dynamic mission profiles
- Extension of subfunctions (subcomponents)
  - More detailed models of subcomponents (e.g. hydrogen storage, electrical components, heat transfer via COMSOL look-up table)
- Methodological improvements
  - Further implementation of object-oriented programming
- Long-term goal
  - Comprehensive aircraft design

# THANK YOU

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