System Design Results for an Air Taxi Concept in HorizonUAM

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01 Dec 2022

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Air Taxi Vehicle, Systems and Cabin Concepts
Presentation Overview

Fabian Reimer, Thomas-M. Bock, Line Winkler, Frank Meller, Björn Nagel

“Urban Air Mobility – Insights into the Virtual and User Centric Design Process for a Future eVTOL Cabin Concept”

Patrick Ratei, Nabih Naeem, Prajwal Shiva Prakasha

“Fleet-Centric Vehicle Design Space Explorations of Urban Air Mobility by System of Systems Simulations”

Oliver Bertram, Florian Jäger

“System Design Results for an Air Taxi Concept in HorizonUAM”

Florian Jäger, Oliver Bertram

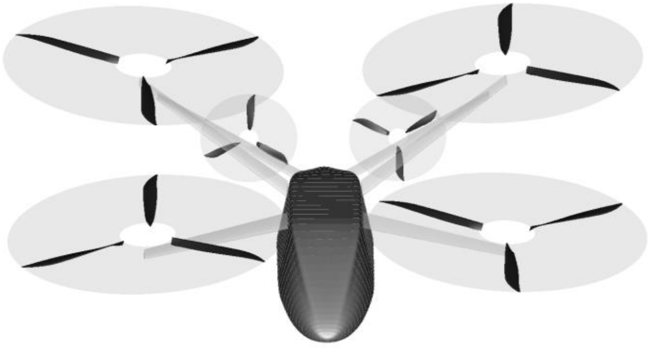
“Development of a Safe Powertrain System Architecture for the HorizonUAM Air Taxi Concept”

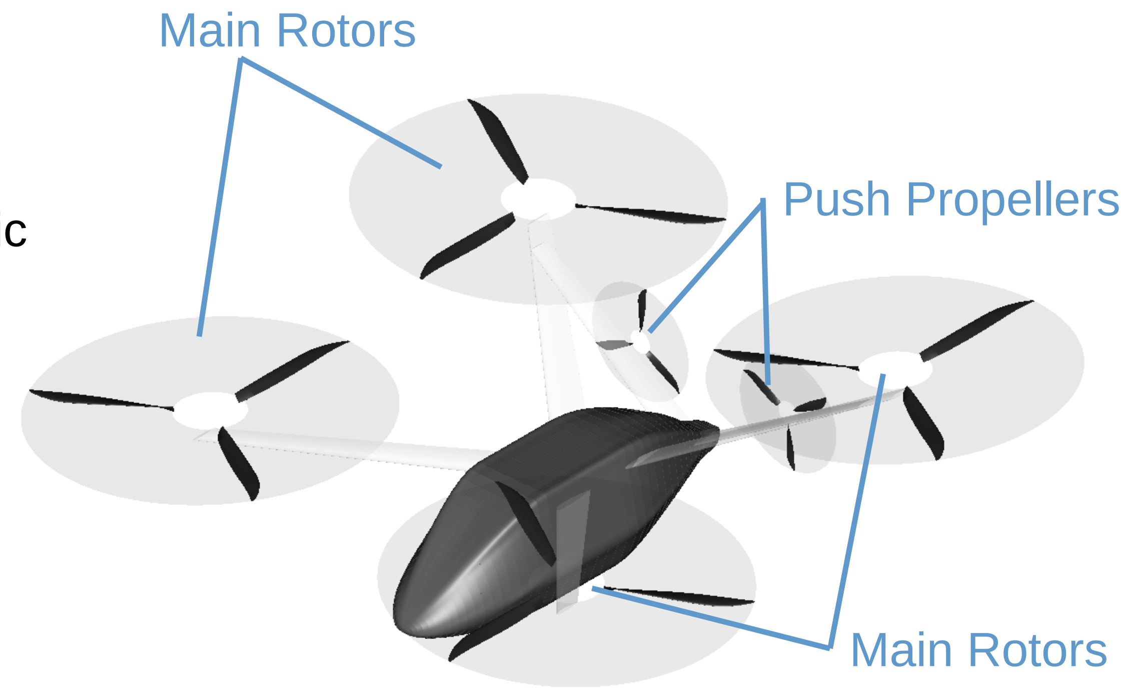
Patrick Sieb

“Maintenance Considerations for Urban Air Mobility Vehicles”

HorizonUAM

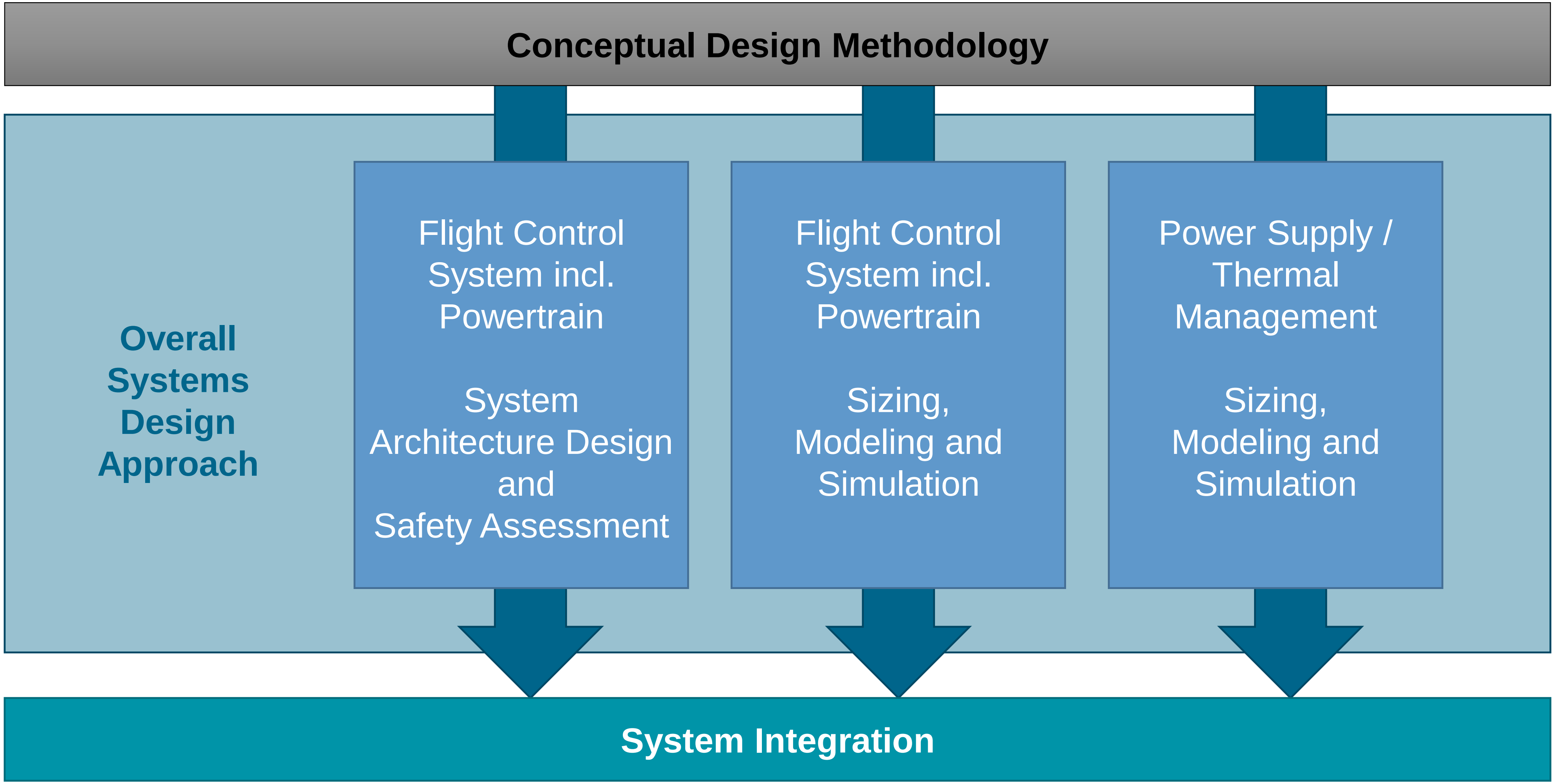
- Within the HorizonUAM project, a concept for an air taxi is being worked on
- The Institute of Flight Systems contributes with research activities in the field of the onboard systems
  - Onboard systems: Vehicle systems and avionics, their interfaces to airframe, cabin, environment, vertiport, pilot, passengers,….
  - During the project a special focus was on the full-electric flight control system (FCS) incl. the powertrain and power supply incl. the thermal management
  - A multirotor with 4 main rotors and 2 push propellers was considered as starting configuration for the investigations
- **Goal: Overview of current status in the system design and its results**





Initially developed as Medical Personnel Deployment Vehicle (Project Urban Rescue) and adapted as an air taxi vehicle for HorizonUAM.

Onboard Systems - Design Streams



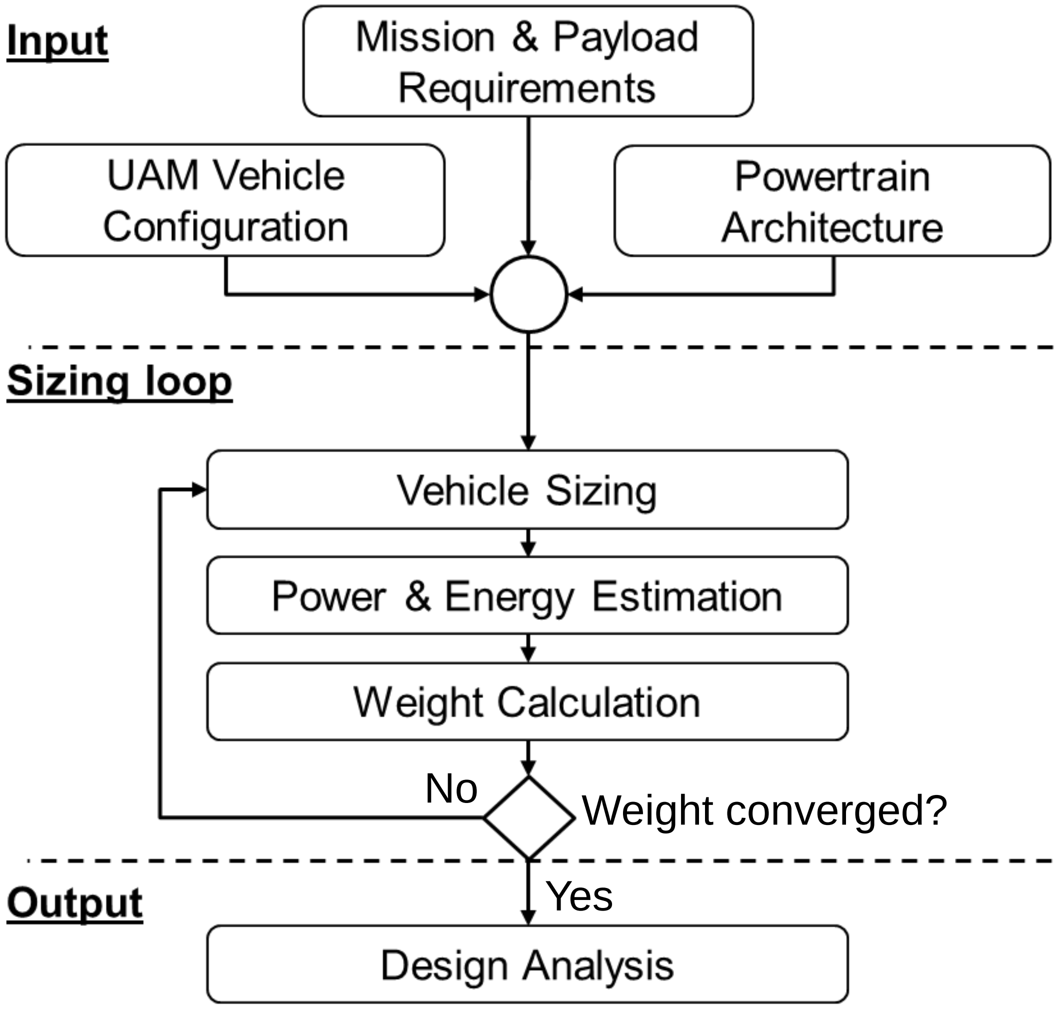
Conceptual Design Methodology

Conceptual Multirotor Design*

- Enables the examination of full-electric, turbo-electric and hybrid-electric powertrain systems
- Based on simple models and assumptions → Uncertainties; results should be used with a certain amount of caution
- Quantitative results and qualitative differences in the results of the various powertrain architectures are credible

Key results

- Battery and fuel cell systems are important design drivers (Maximum take-off mass, overall efficiency,…)
- 3 most promising architectures were selected:
  - Full-electric with battery,
  - Full-electric with fuel cell system and
  - Hybrid-electric with battery and fuel cell system
- Provide estimated flight performance for system sizing

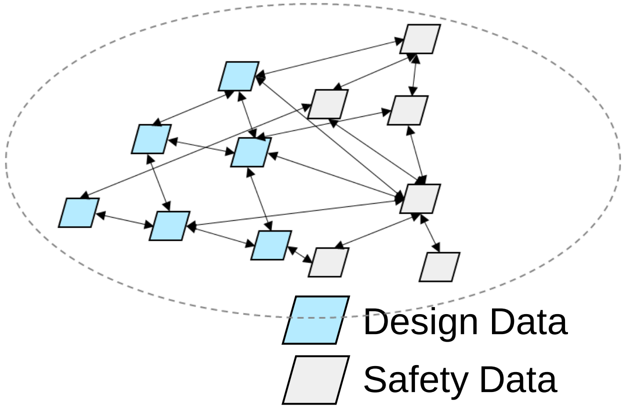


*presented at DLRK 2021 and AIAA SciTech 2022

Overall Systems Design Approach

Model-Based Systems Engineering (MBSE) Approach

- Centralized system model with recursive model structure enables model segregation and distributed, collaborative design
- System architecture design and safety assessment acc. to design standards (e.g. ARP4754A) incl. traceability of requirements
- Integration of analysis models and impact analysis of design decisions

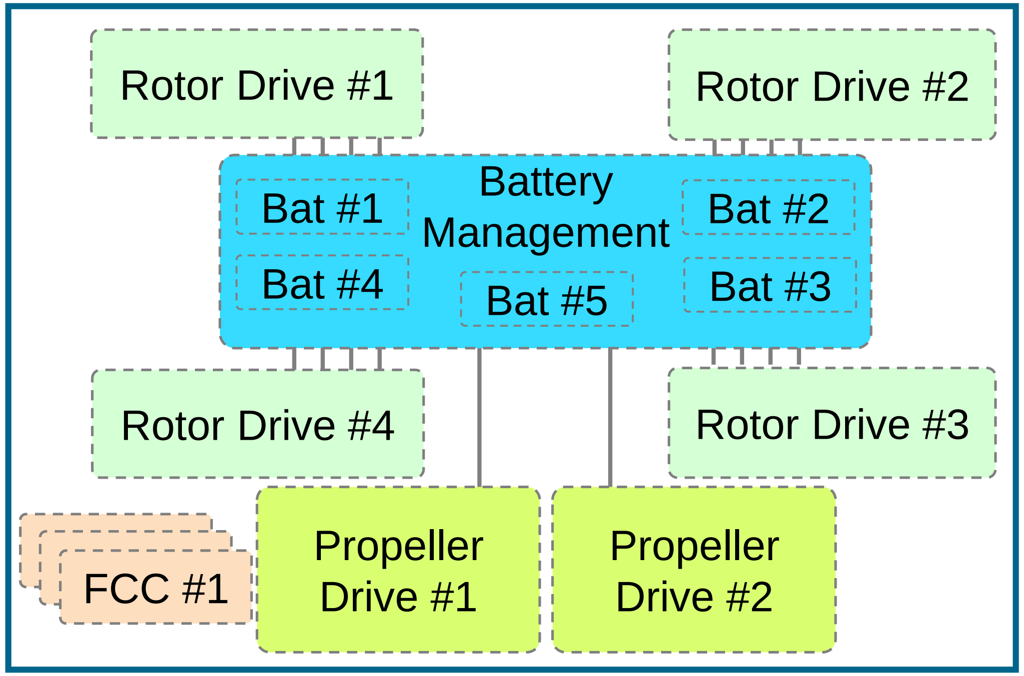


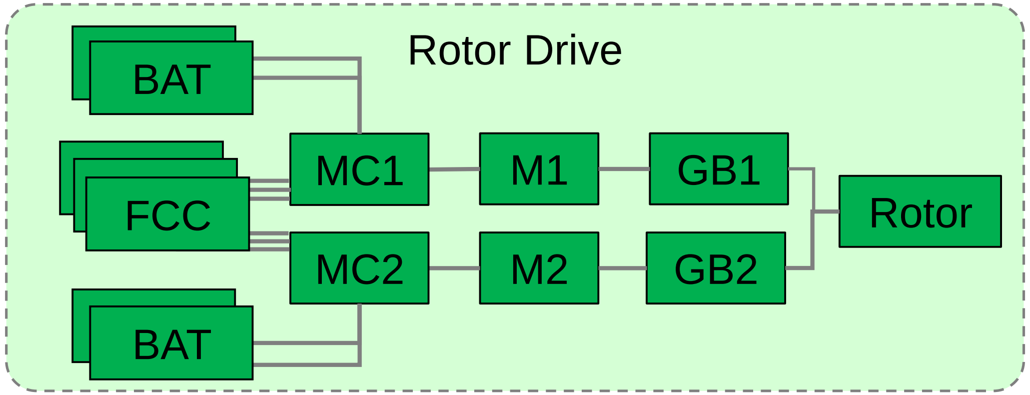
<u>Recursive Model Structure</u> — ***<u>Design Role</u>***

- **Aircraft Level** → Aircraft Architect
  - Analysis
  - Architecture
  - **System X** → Systems Engineer X, Safety Engineer
    - Analysis
    - Architecture
    - **Component 1** → Component Designer 1
      - Analysis
      - Architecture
      - …
    - …
  - **System Y** → Systems Engineer Y
    - Analysis
    - Architecture
    - …
  - Functions
  - Interfaces
  - Requirements

FCS / Powertrain: System Architecture Design and Safety Assessment

- SC-VTOL* / Category Enhanced: “*The aircraft is capable of continued safe flight and landing…*”
  - ➢ Safe and redundant design of each main rotor and
  - ➢ the ability to compensate for the loss of one main rotor with the remaining main rotors and the two push propellers
- **Key results 1**: Safety assessment methods (acc to. ARP4761) were applied to architect the powertrain / flight control system
  - Safety goals are basically achievable and safety mechanisms were identified
  - Different design requirements are derived, e.g. two redundant electric motors per rotor, five battery packs, at least three FCCs,…
- **Key results 2**: Sizing, modeling and simulation
  - Direct rotor drive (w/o gearbox) is possible, but poor efficiency and high heat losses, higher weight
  - Rotor drive with gearbox is more complex and expensive, but increases the powertrain efficiency
  - Propeller drive not yet sized





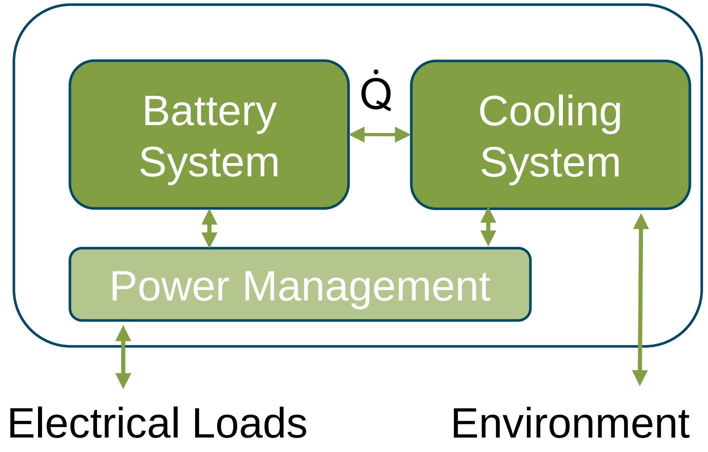
VTOL: Vertical Takeoff and Landing
SC-VTOL: EASA Special Condition VTOL

BAT: Battery
FCC: Flight Control Computer

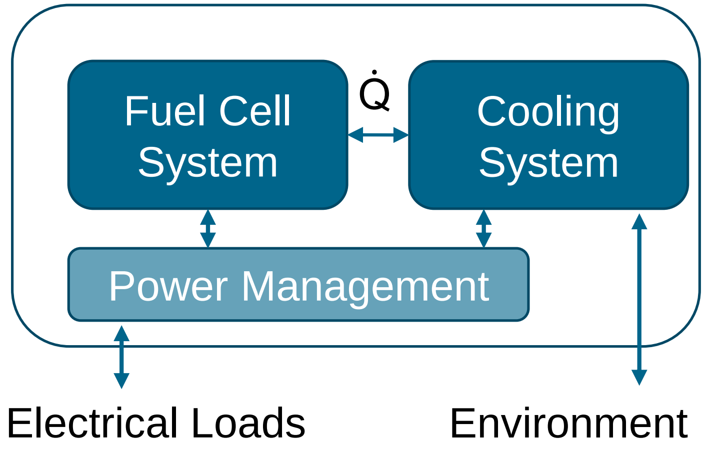
M: Motor
MC: Motor Controller
GB: Gearbox

Power Supply – Architectures and Design Steps

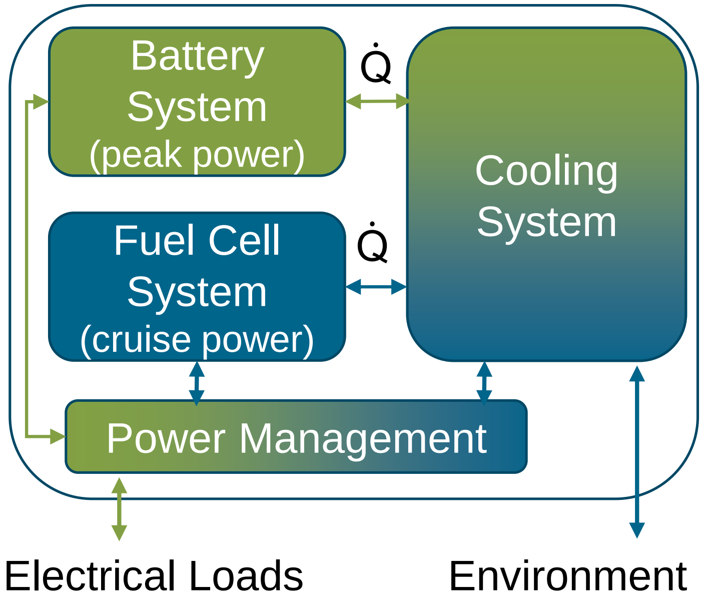
1. Full-Electric with Battery



2. Full-Electric with Fuel Cell System

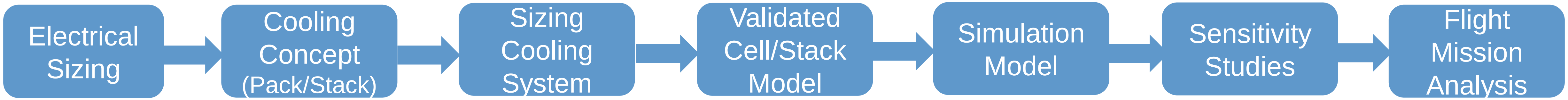


3. Hybrid-Electric with Battery and Fuel Cell System



Three different power supply systems were designed and analysed due to their electrical and thermal behaviour

- Electrical loads were estimated using the flight performance calculation and powertrain architecture efficiencies
- Power management and controller design not yet considered
- Similar design steps for battery pack/system and fuel cell stack/system



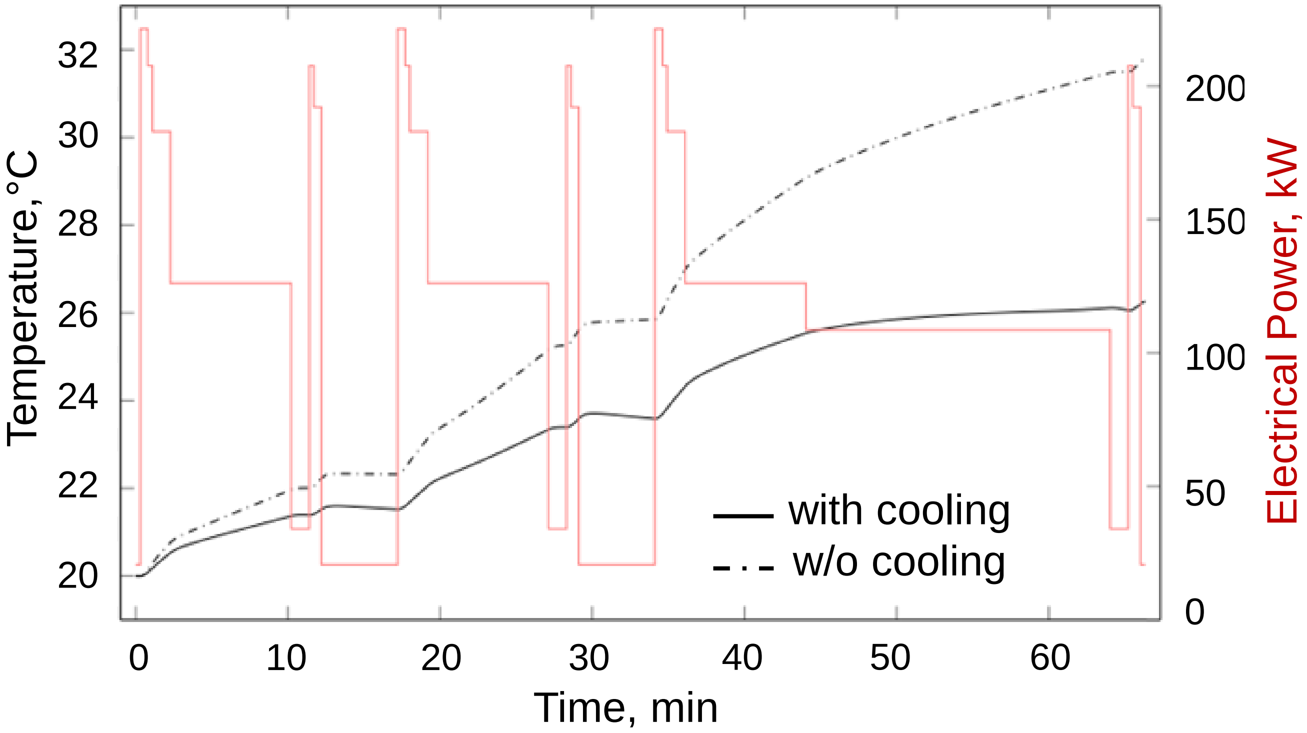
$\dot{Q}$: Heat Flow

Power Supply – Results

Key Results

- For normal conditions the systems are adequately dimensioned: The cooling system lowers the temperature for the entire mission
- The ambient temperature has a significant impact on the cooling performance
- The temperature can be easily regulated with the volume flow of the air
- The water flow will influence the temperature distribution in the battery pack (more detailed investigations needed)
- Based on sensitivity studies a specific cooling geometry for the battery pack and fuel cell stack could be defined
- Similar results for battery cooling in the hybrid-electric power supply system
- Fuel cell system without cooling is not possible, it heats up too fast and too much

Example: Flight mission analysis with and without battery cooling



→ **Feasibility of the different power supply systems was checked and verified**

Summary and Outlook

- Onboard systems are an essential part of the air taxi concept which is under investigation in the HorizonUAM project
- A special focus was on the flight control system incl. the powertrain as well as the power supply incl. the thermal management concept
- The designs and results shown were reached in different parallel design streams
- Each design stream could verify the basic feasibility of the system
- Although an attempt was made to proceed from same assumptions, this was not always possible
- The "System Integration" will harmonize the different system designs (and models) to reach consistent design results