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

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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”

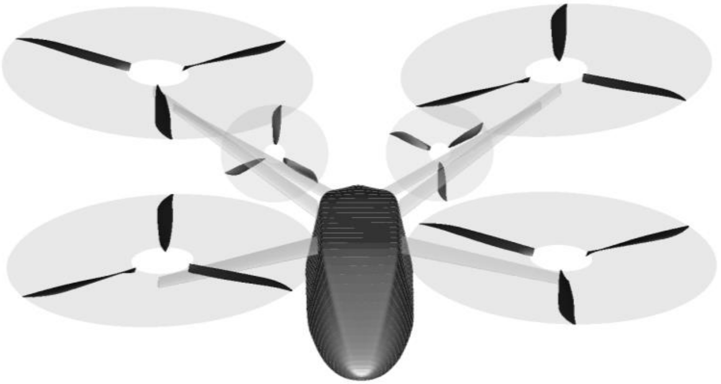
Patrick Sieb

“Maintenance Considerations for Urban Air Mobility Vehicles”

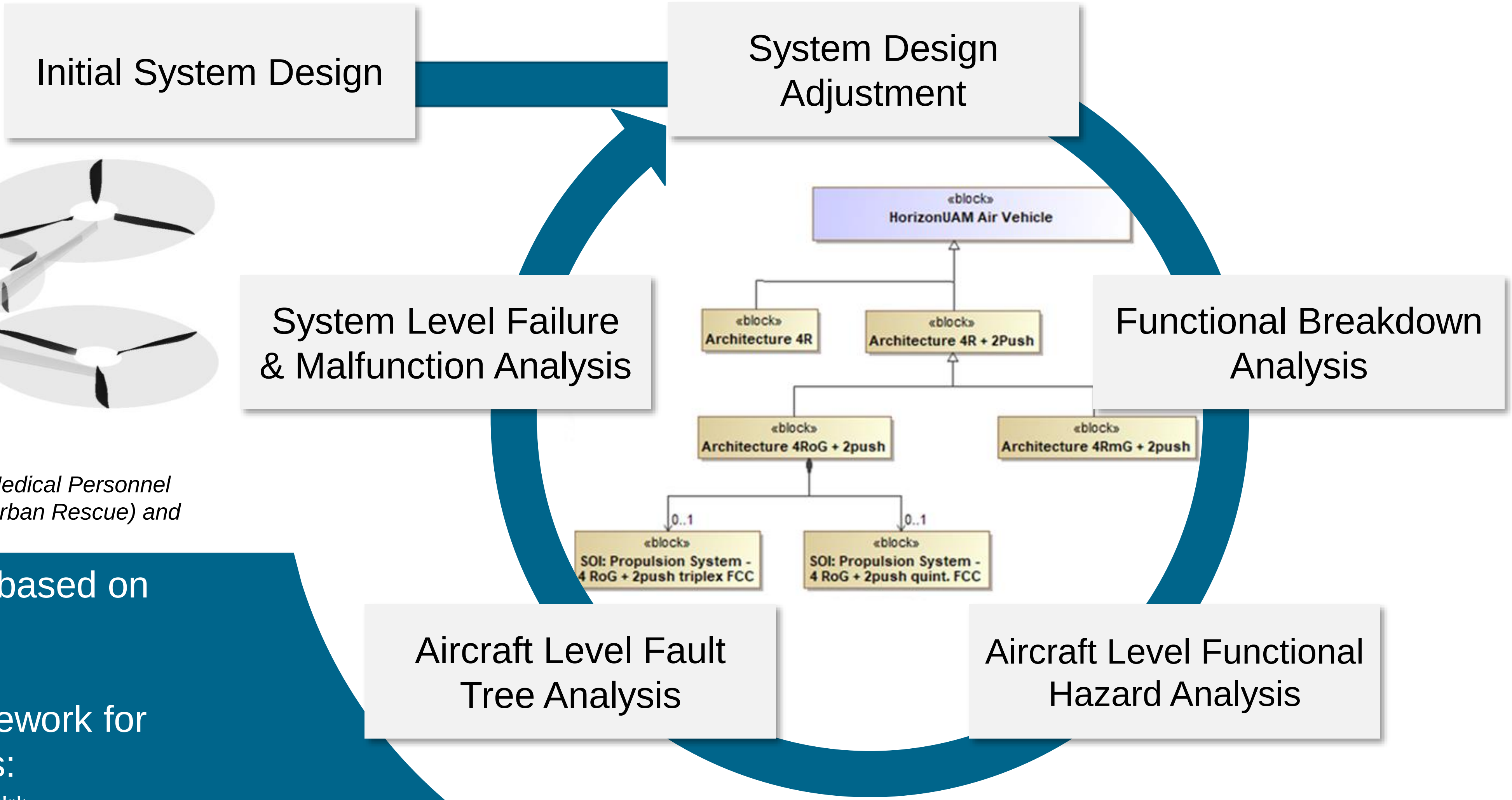
Agenda

1. Design Process for a Safe Powertrain Architecture
2. Design Results
3. Sizing, Modeling and Simulation Results of the Powertrain Architecture
4. Summary & Outlook

1 Design Process for a Safe Propulsion System



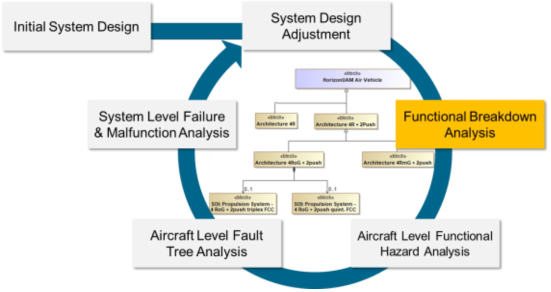
Draft initially developed for a Medical Personnel Deployment Vehicle (Project Urban Rescue) and adapted for HorizonUAM



- Design process based on ARP4761*
- Regulatory framework for safety guidelines: EASA SC-VTOL**

*ARP4761: Aeronautical Recommended Practices
**SC-VTOL: EASA Special Condition VTOL

1 Functional Breakdown Analysis



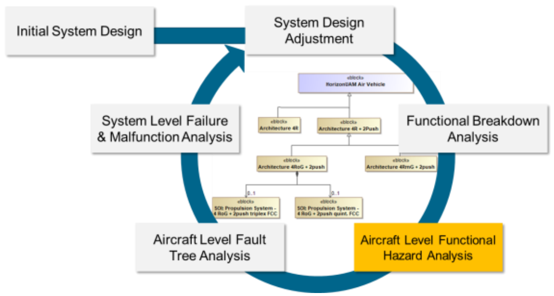
Aircraft Level

- Enable vertical takeoff & landing
  - Provide lift
- Provide controllability & stability of the AC
  - Provide differential thrust for yaw
  - Provide differential thrust for pitch
  - Provide differential thrust for roll
- Enable forward motion
  - Provide forward thrust
- Transport payload
  - Enable passenger boarding
  - Provide space for luggage
- Others
  - Provide situational awareness
  - Control cabin environment
  - Provide communications
  - Provide energy

System Level

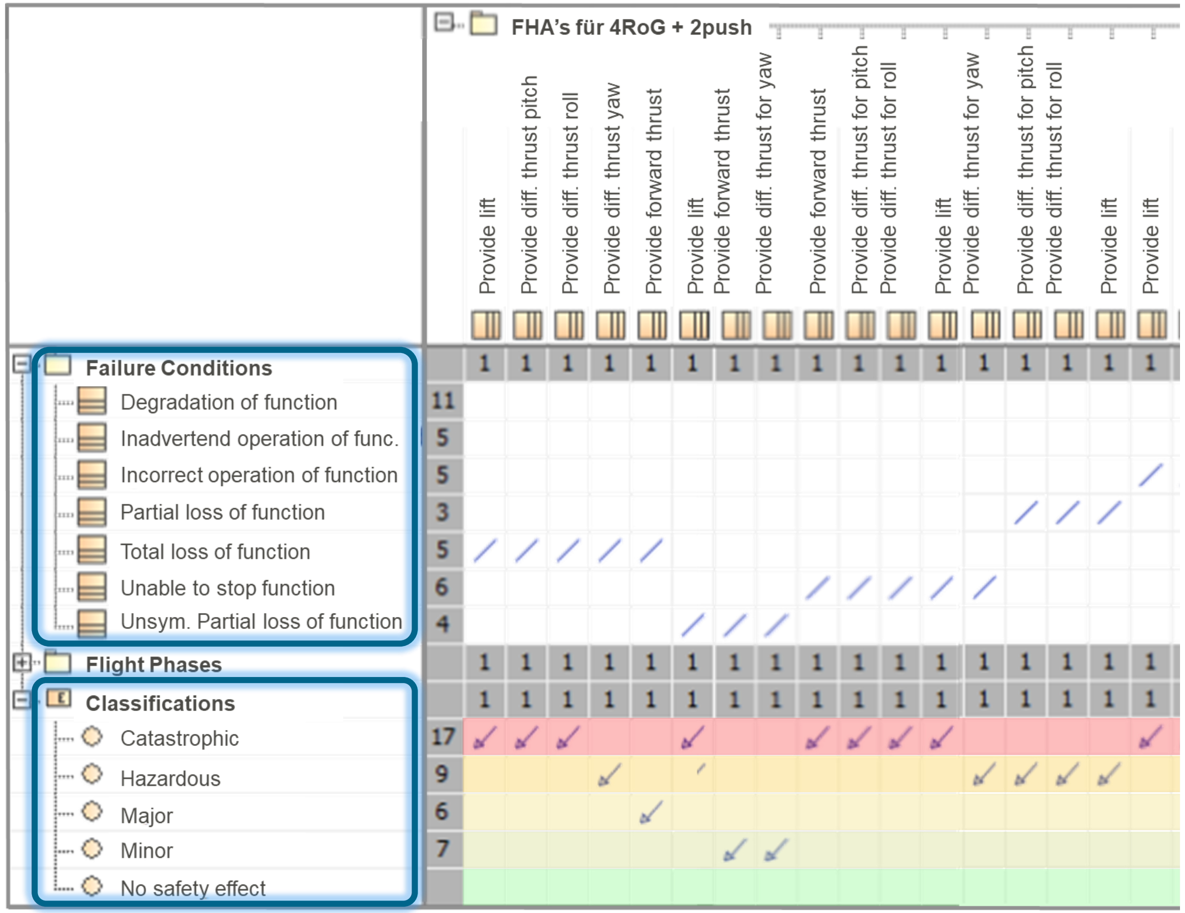
- Adjust rotor lift
  - Provide rotor drive mechanism
- Adjust propeller thrust
  - Provide propeller drive mechanism

1 Aircraft Level Functional Hazard Analysis (FHA)



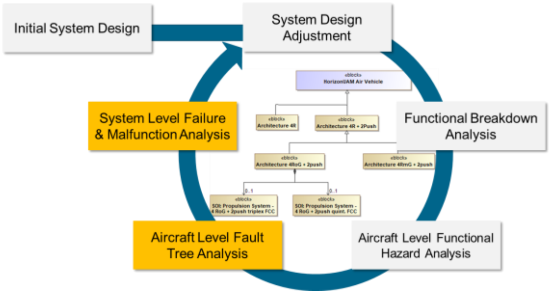
- For each function several ***failure conditions*** are defined
- Each function – failure condition - combination is assigned to a ***failure effect category***
- The failure effect was derived by using the equations of movement and estimating the effect on the vehicle, the passengers and the flight crew
- Each category is then linked to a ***failure probability*** see EASA SC-VTOL Extract:

		Failure Condition Classifications			
	Maximum Passenger Seating Configuration	Minor	Major	Hazardous	Catastrophic
		Allowable Qualitative Probability			
		Probable	Remote	Extremely Remote	Extremely Improbable
		Allowable Quantitative Probability (Note C and D) Development Assurance Level			
Category Enhanced	-	$\leq 10^{-3}$ FDAL D (see Note B)	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL B	$\leq 10^{-9}$ FDAL A

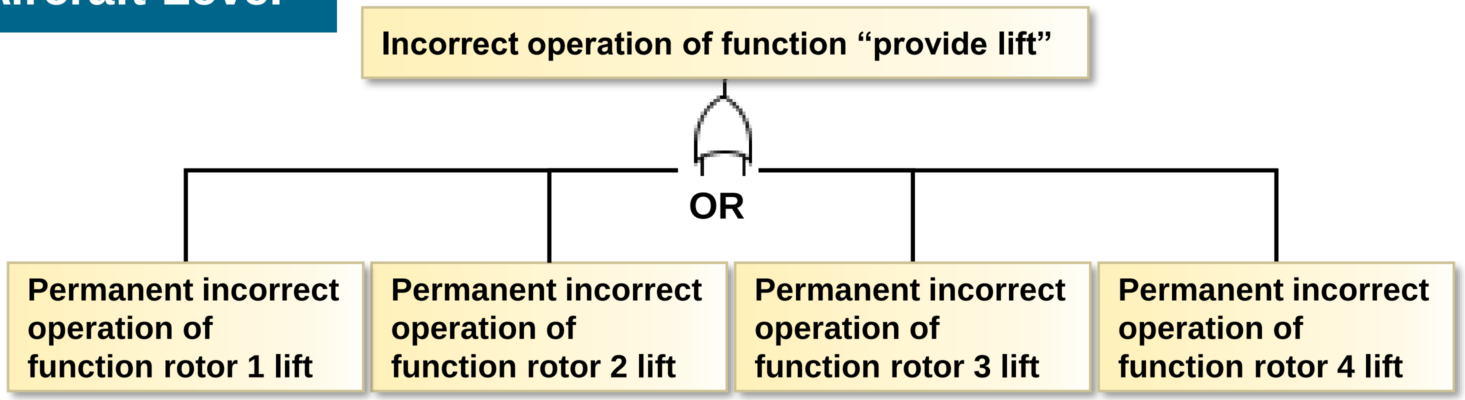


➢ **These failure probabilities define our design goals and need to be proven**

Aircraft Level & System Level Fault Tree Analysis

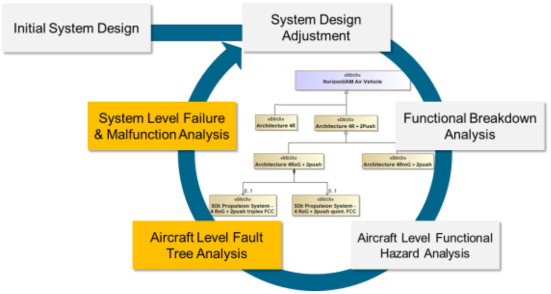


Aircraft Level



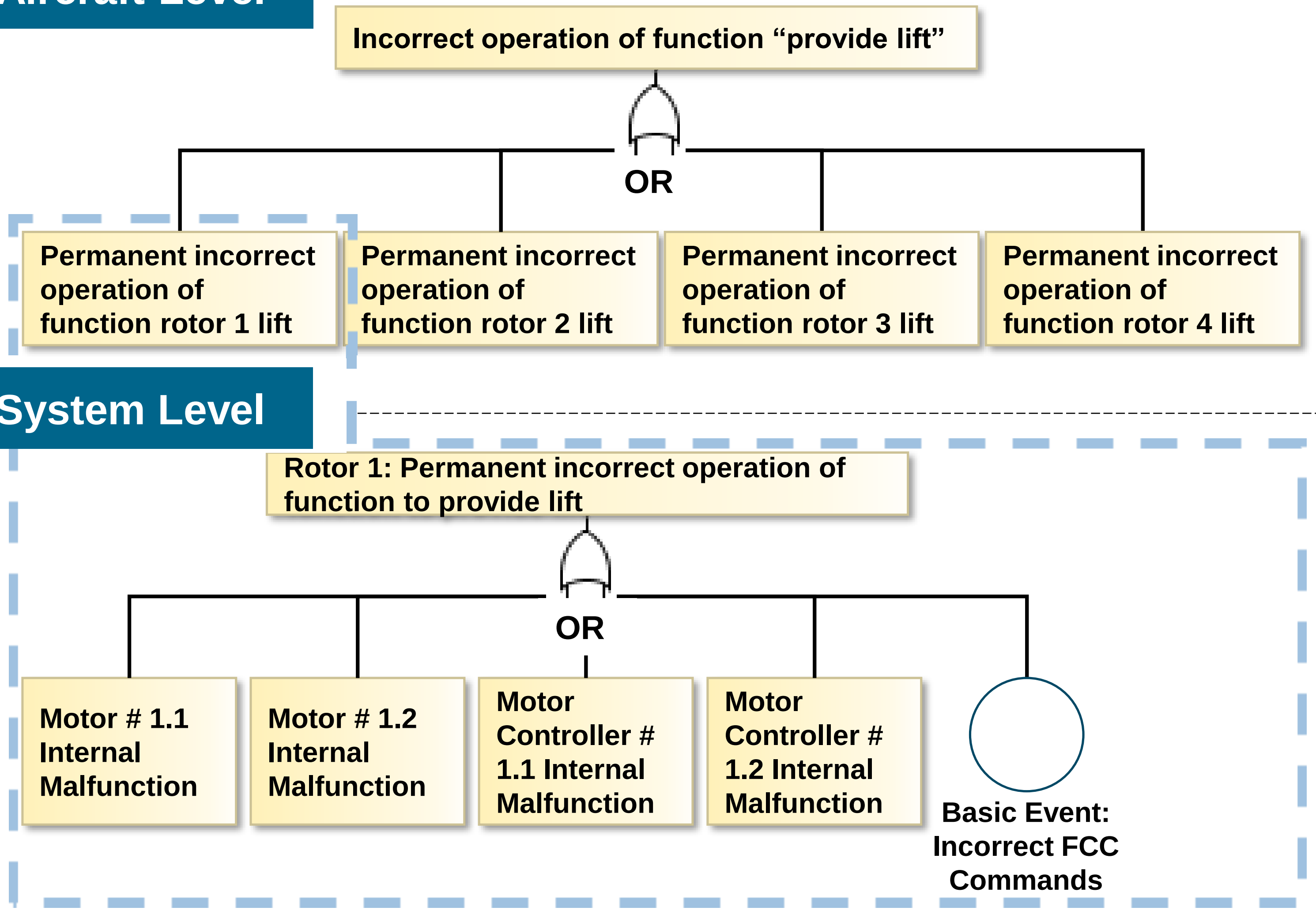
- Deep dive into each failure condition of the previous FHA
- Identifies the ***aircraft sub-functions*** that contribute to the aircraft function failure condition

1 Aircraft Level & System Level Fault Tree Analysis



Aircraft Level

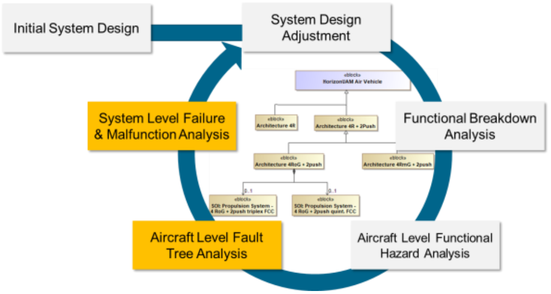
System Level



Allowable Function Failure Probability (EASA SC-VTOL)

Allowable Sub-Function Failure Probability

- Identifies the ***system components*** that contribute to the sub-function failure condition
- Results in iterative refinement of the system architecture
- System design improvement possibilities:
  - Dual channel systems (active / passive), dual / triple modular redundancy



1 Aircraft Level & System Level Fault Tree Analysis

Aircraft Level

Incorrect operation of function "provide lift"

OR

Permanent incorrect operation of function rotor 1 lift

Permanent incorrect operation of function rotor 2 lift

Permanent incorrect operation of function rotor 3 lift

Permanent incorrect operation of function rotor 4 lift

System Level

Rotor 1: Permanent incorrect operation of function to provide lift

OR

Motor # 1.1 Internal Malfunction

Motor # 1.2 Internal Malfunction

Motor Controller # 1.1 Internal Malfunction

Motor Controller # 1.2 Internal Malfunction

Basic Event: Incorrect FCC Commands

Allowable Function Failure Probability (EASA SC-VTOL)

Allowable Sub-Function Failure Probability

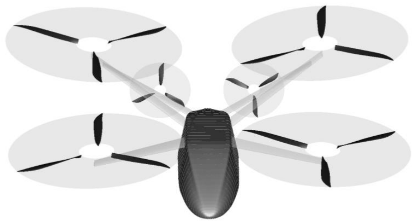
System redesign in case of mismatch

Actual System Function Failure Probability

Allowable System Function Failure Probability

Actual System Component Failure Probability

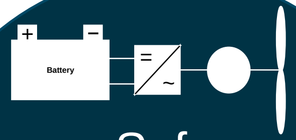
2 Design Results for the Propulsion System



Each main rotor unit must
- be able to supply 50% of total flight power for a prolonged time

Each motor unit must
- be equipped with two parallel emergency disconnect components
- be able to be passivated

Each motor must
- be able to supply 25% of total flight power for a prolonged time



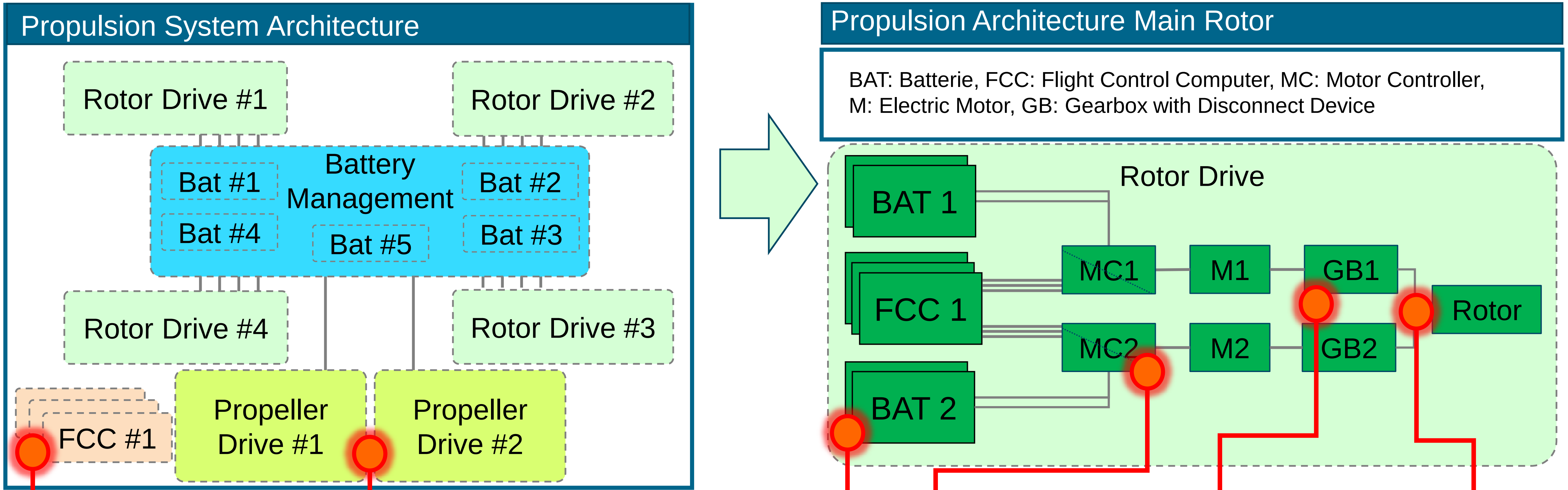
Safe Propulsion Architecture

Each motor controller must
- process FCC commands on its own
- be equipped with a fail-safe fallback mode setting a constant thrust
- be able to switch to an alternate battery

The push propulsion unit must
- be powered by an own battery supply

FCC must
- be triple-redundant
- be fail-operational with voting

2 Design Results for the Propulsion System

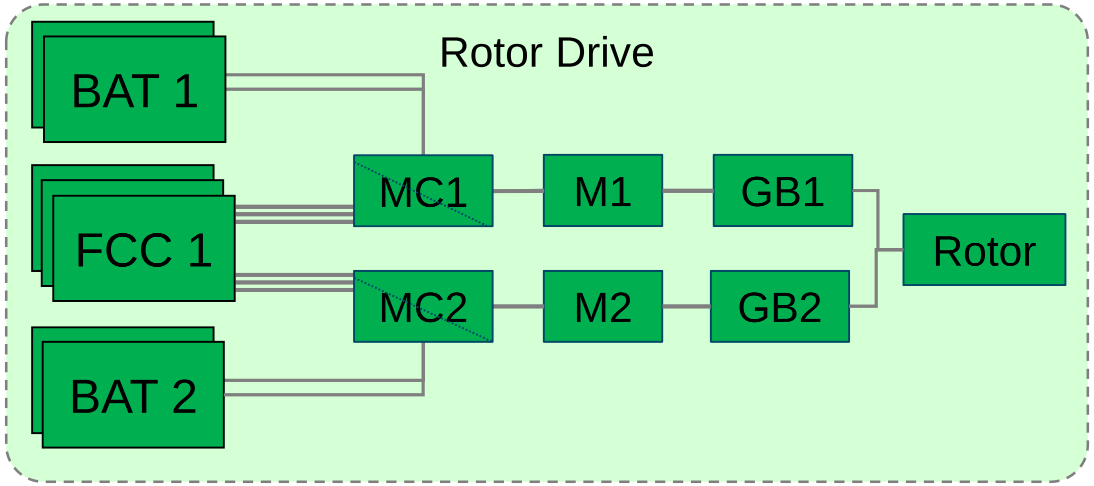


- Triple modular redundant (TMR) flight control computer
- Push propeller to maintain controllability in single rotor drive loss
- Dual modular redundant (DMR) batteries
- Dual channel motor controller (active / passive)
- Segregation of malfunctional drive unit using a disconnect device
- Dual active-active drive system

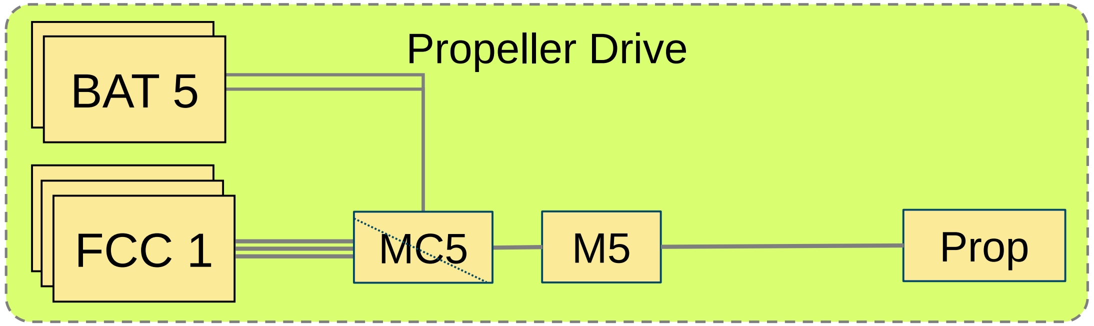
Removal of any single point of failure & implemented ability to segregate malfunctional components

3 Propulsion System Specifications

Rotor Drive Architecture



Propeller Drive Architecture



Sizing Parameters

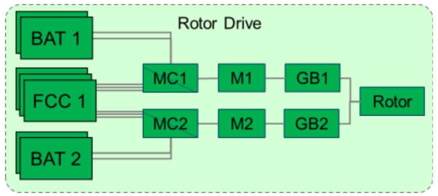
Power Source
- Battery Capacity
- Weight

Motor Controller
- Power
- Continuous and Peak Current
- Weight

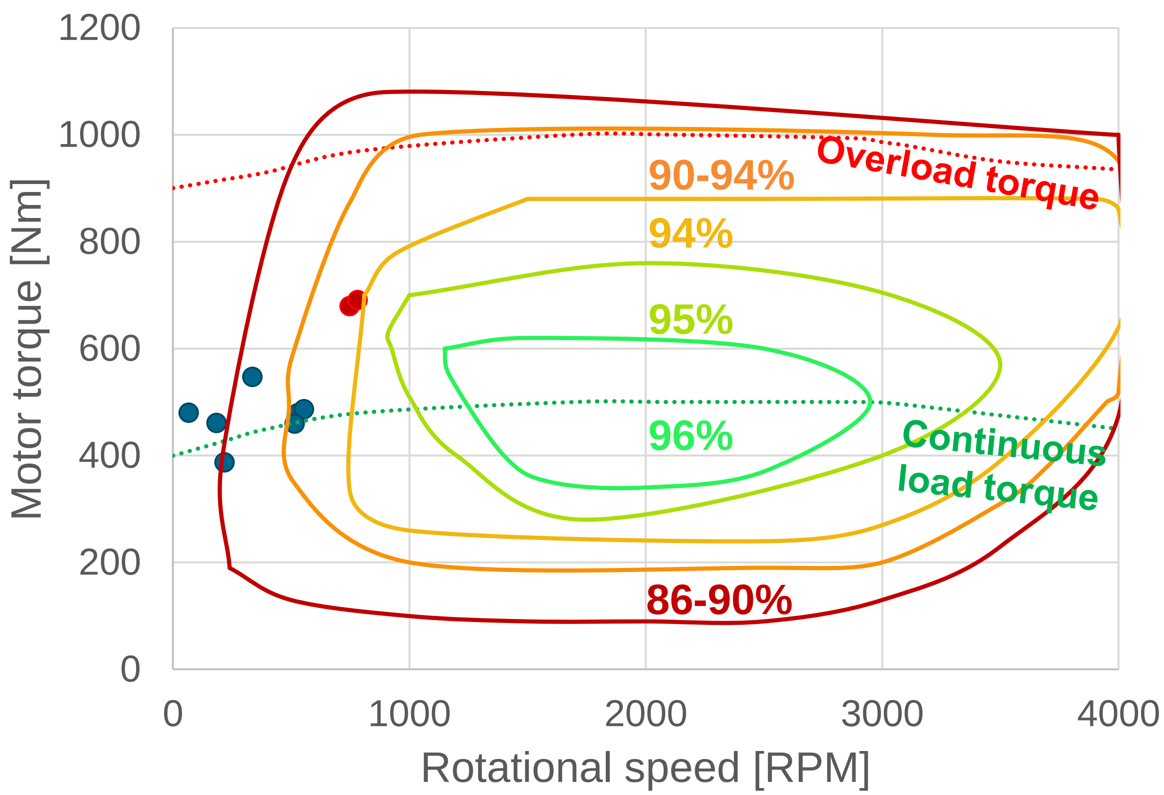
Motor
- Continuous and Peak Torque
- Continuous and Peak Current
- Weight

Gearbox
- Reduction Gear Ratio
- Nominal Torque
- Weight

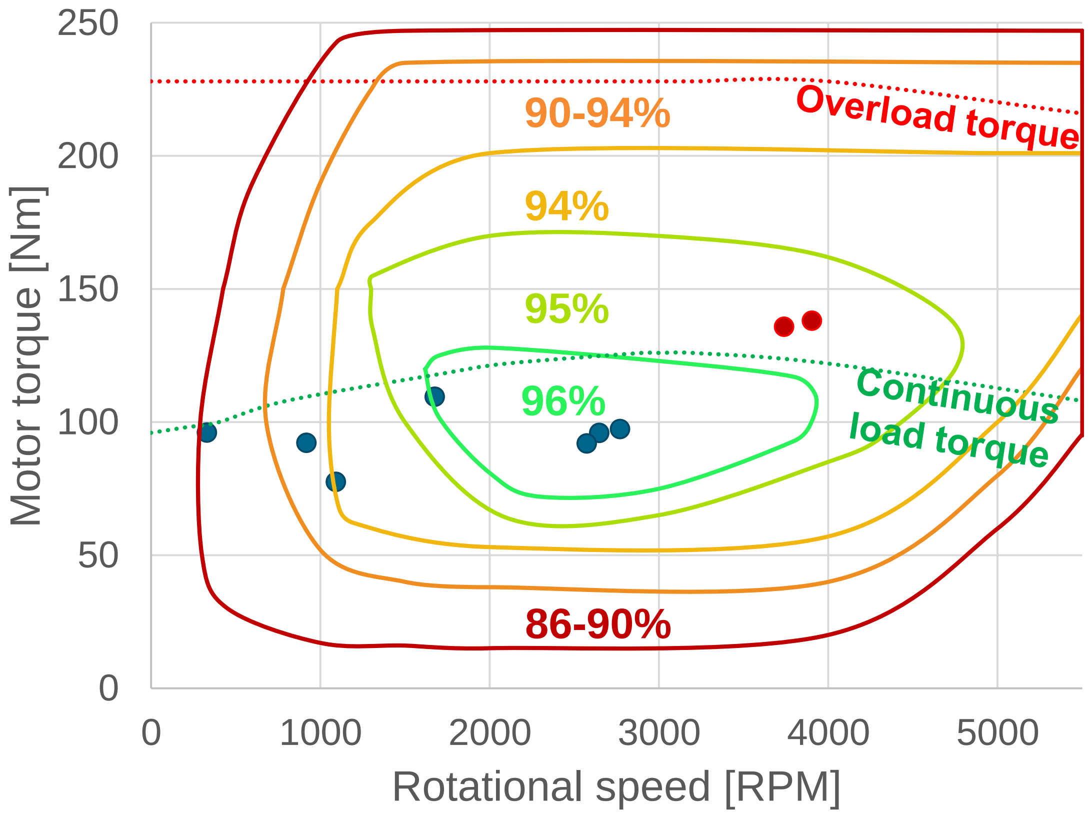
3 Sizing the Powertrain



Main Rotor Direct Drive



Rotor Drive Using a Reduction Gearbox Ratio of 5:1



- Using a reduction gear significantly improves the motor efficiency
- Requirements for the thermal management are far less demanding compared to direct drive

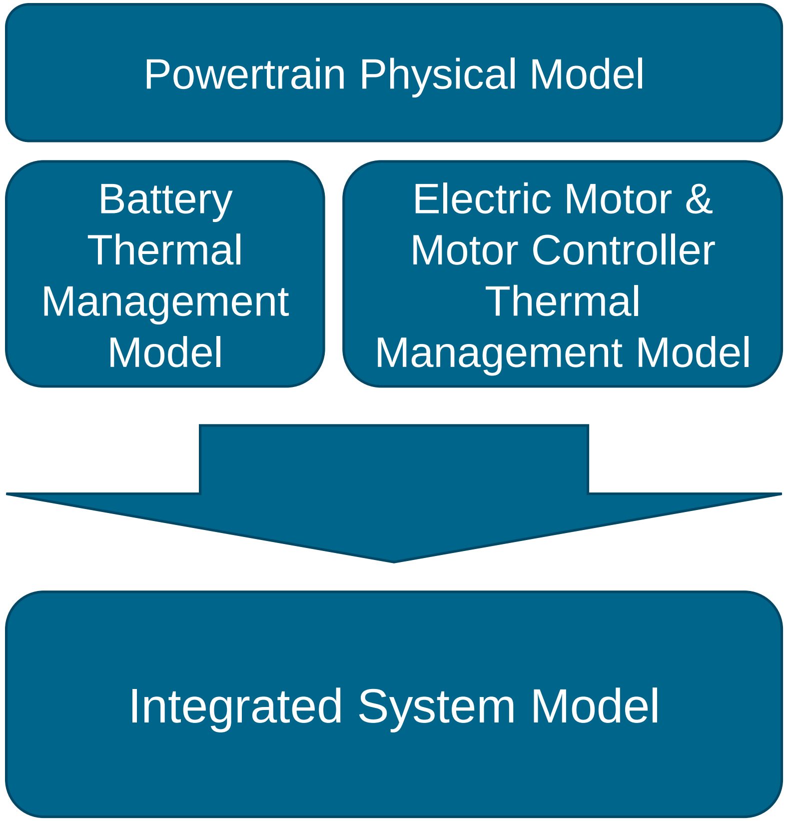
4 Summary & Outlook

Summary

- An abbreviated safety design process based on ARP4761 was conducted
- Several system designs were developed and analysed
- A potentially safe propulsion system architecture for a quadcopter could be derived
- The propulsion system architecture may incorporate a gearbox for the rotor drive system
- The architecture using a gearbox is beneficial in terms of system weight and efficiency, however may be more complex and more difficult to integrate into the vehicle

Outlook

- Integration of the different developed system models into an holistic integrated system model



THANK YOU FOR YOUR ATTENTION

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