Onboard System Design Challenges of eVTOLs

Oliver Bertram, Florian Jäger,
Viola Voth, Jan Rosenberg

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Corresponding author:

Oliver Bertram
DLR Institute of Flight Systems
German Aerospace Center
Oliver.Bertram@dlr.de

HorizonUAM

- Urban Air Mobility (UAM) is the name for a new branch of aviation
  → Transporting people or goods in an urban environment by air

- HorizonUAM project (07/20-06/23) [1]: Research is being carried out at the German Aerospace Center (DLR) in the field of Urban Air Mobility (UAM)
  → Objective: Assessment of chances and risks of air taxis and UAM concepts

  → Main content
  - Forecast of UAM market share
  - Model-based UAM system simulation
  - **Air taxi vehicle system development**
  - Flight guidance concepts for vertidromes
  - Public acceptance
  - Airport integration of UAM traffic
  - Scaled flight demonstrations in model city

[1] B. Schuchardt. “HorizonUAM-Urban Air Mobility Research at the DLR German Aerospace Center”. In: e-Flight Forum China 2020.

Safe and Certifiable Onboard Systems for UAM Vehicles

Research at DLR - Institute of Flight Systems – Department Safety-Critical Systems & Systems Eng.

- Goal: Definition of an onboard system architecture as a contribution to the air taxi concept

- Main research fields:

State of the art
- Vehicle concepts
- System technologies
- Design challenges
- Safety and certification aspects

System design
- Requirements analysis
- Function and architecture definition
- Safety and reliability analysis

Process and tool chain
- Design methodology
- Conceptual design
- Sizing methods
- Design/feasibility studies

Design Challenges of UAM Vehicles

- Today, many prototypical UAM vehicle concepts exist
  - Only a few concepts are on the way to approval, such as the VoloCity
  - Most concepts still require a lot of research
- Various research areas for UAM vehicles were identified by NASA [2]
- In principle, aircraft design is
  - highly complex and multidisciplinary
  - with a wide variety of interactions and influences between the design disciplines
- Many design challenges also have to be solved for UAM vehicles

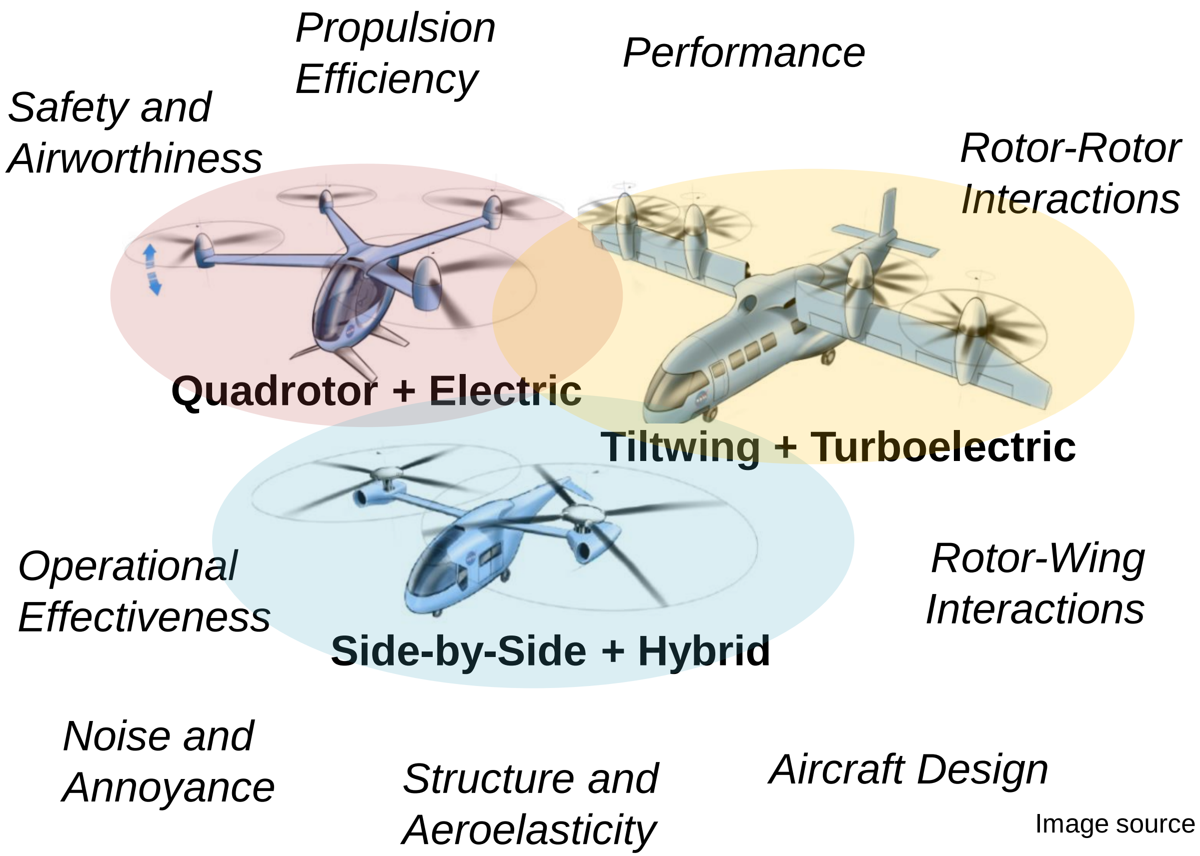


Image source [2]

→ **In this presentation a focus is set on electric powertrains of eVTOLs**
→ **Goal is to give a brief overview of aspects and challenges that need to be considered in the design**

[2] W. Johnson et al. “Concept Vehicles for VTOL Air Taxi Operations”, 2018.

Overview of System Design Challenges

- Power Requirements
- System Technology
- Safety-Critical Design
- Certification Aspects

UAM Vehicle Flight Performance

- **UAM vehicle concepts** can be distinguished in:
  - Cruise architectures with rotary wings (e.g. multirotor, conventional and coaxial helicopters)
  - Cruise architectures with fixed wings (e.g. lift and cruise, tilt duct, tilt wing)

- From a **flight performance-based perspective**, these architectures can typically be characterized by their
  - Hover lift efficiency, i.e. disk loading (T/A) and
  - Cruise efficiency, i.e. lift-to-drag ratio (L/D)

- **Values** for these performance parameters can be found in the literature [3, 4] and can provide an initial estimate for the design space of potential aircraft architectures

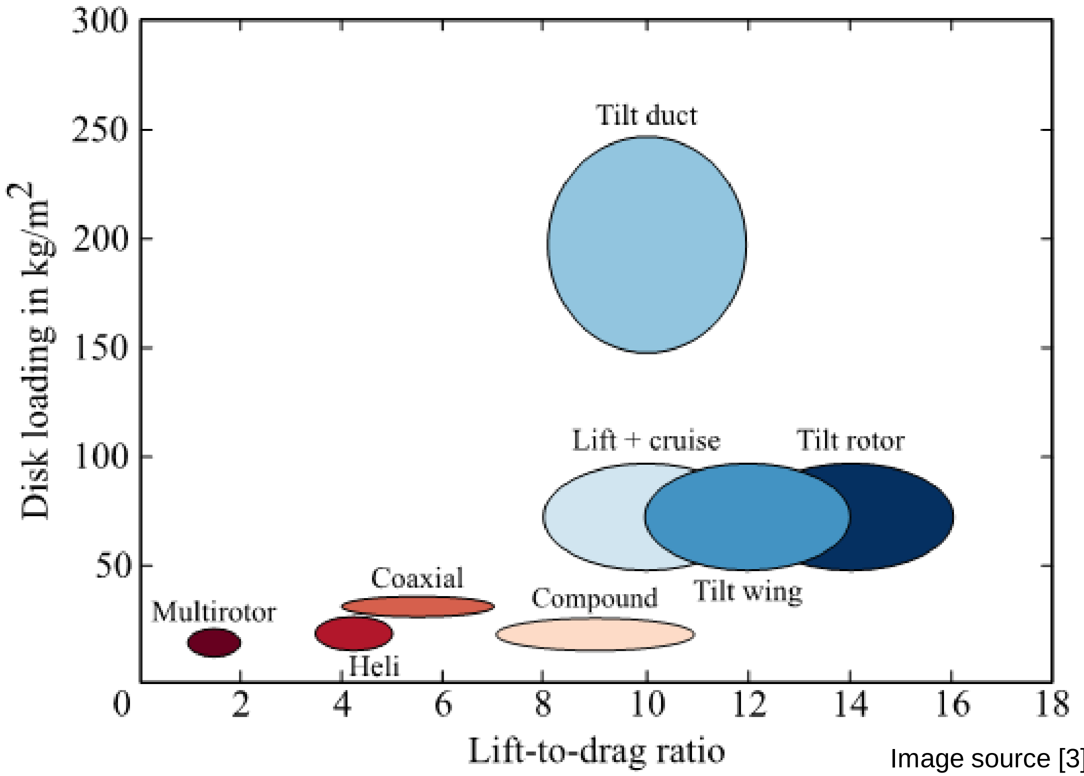
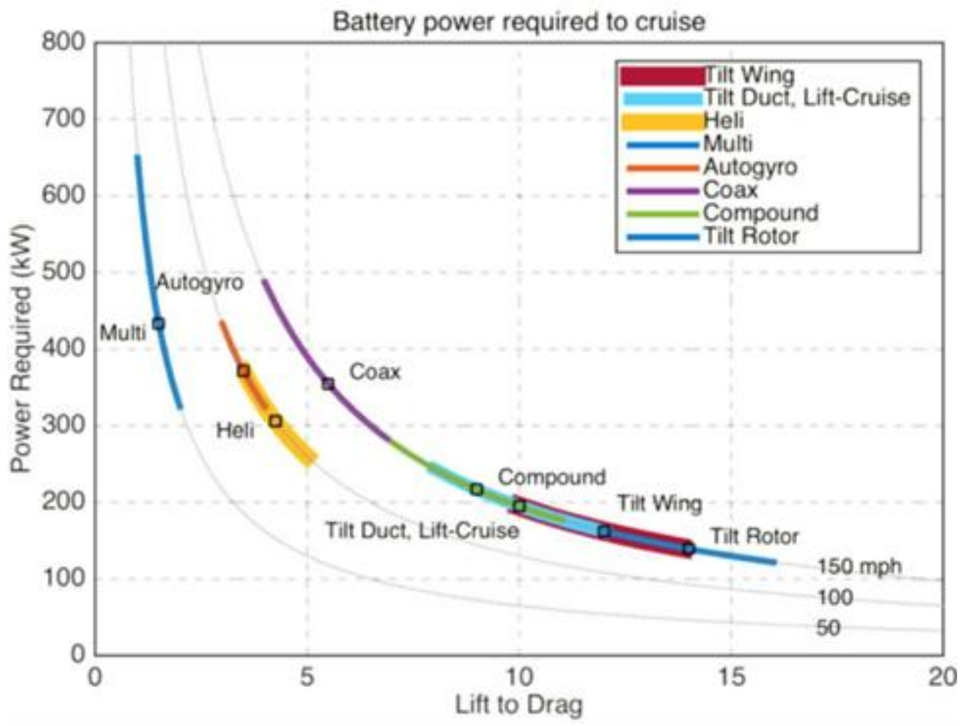
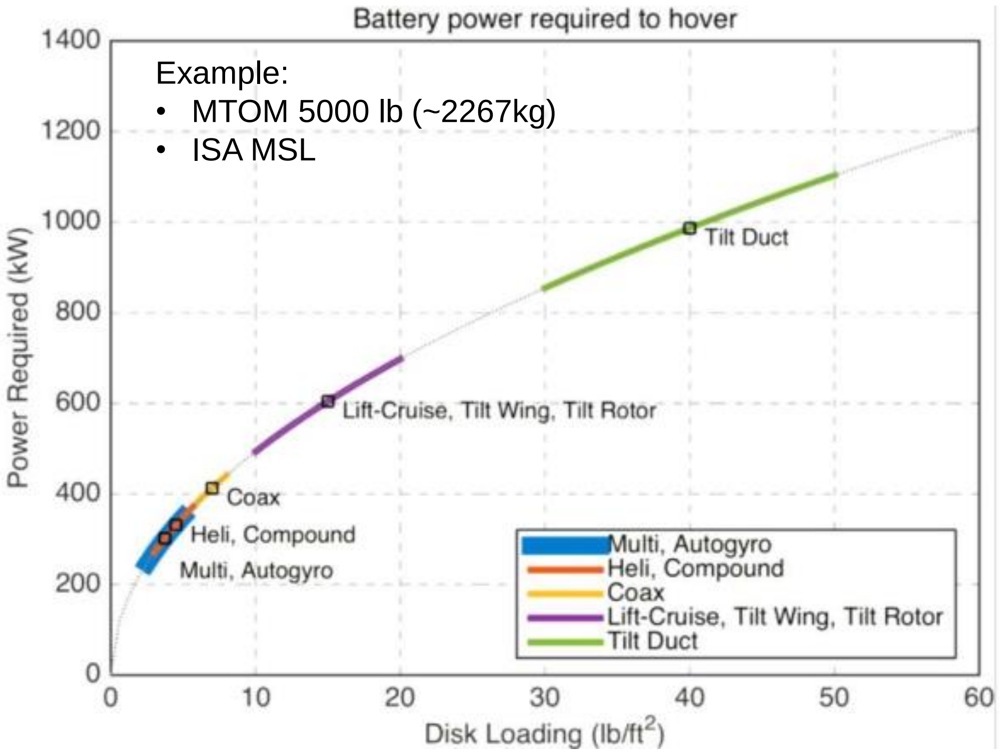


Image source [3], values based on [4]

[3] Prakasha, P. S., Ratei, P., Naeem, N., Nagel, B., & Bertram, O. (2021). “System of Systems Simulation driven Urban Air Mobility Vehicle Design”. In AIAA Aviation 2021 Forum (p. 3200), https://doi.org/10.2514/6.2021-3200
[4] R. Gohit et al. Urban Air Mobility (UAM) Market Study - Booz Allen Hamilton. In: UAM Market Study - Technical Outbrief, 2018.

Power Requirements





- Due to the different performance levels, different types of aircraft also have different electric power requirements
- Different mission, environmental conditions etc. will change these power requirements

[4] R. Gohit et al. Urban Air Mobility (UAM) Market Study - Booz Allen Hamilton. In: UAM Market Study - Technical Outbrief, 2018.

System Technology – Full Electric Powertrains

- **Full electric powertrains are key enablers** for the implementation of electric air taxi concepts (eVTOL)
  - Simpler than gas turbines and mechanical drive trains
  - Lower maintenance costs → Lower vehicle costs
  - Emission-free, low-noise* and green (if sustainable energy is used)

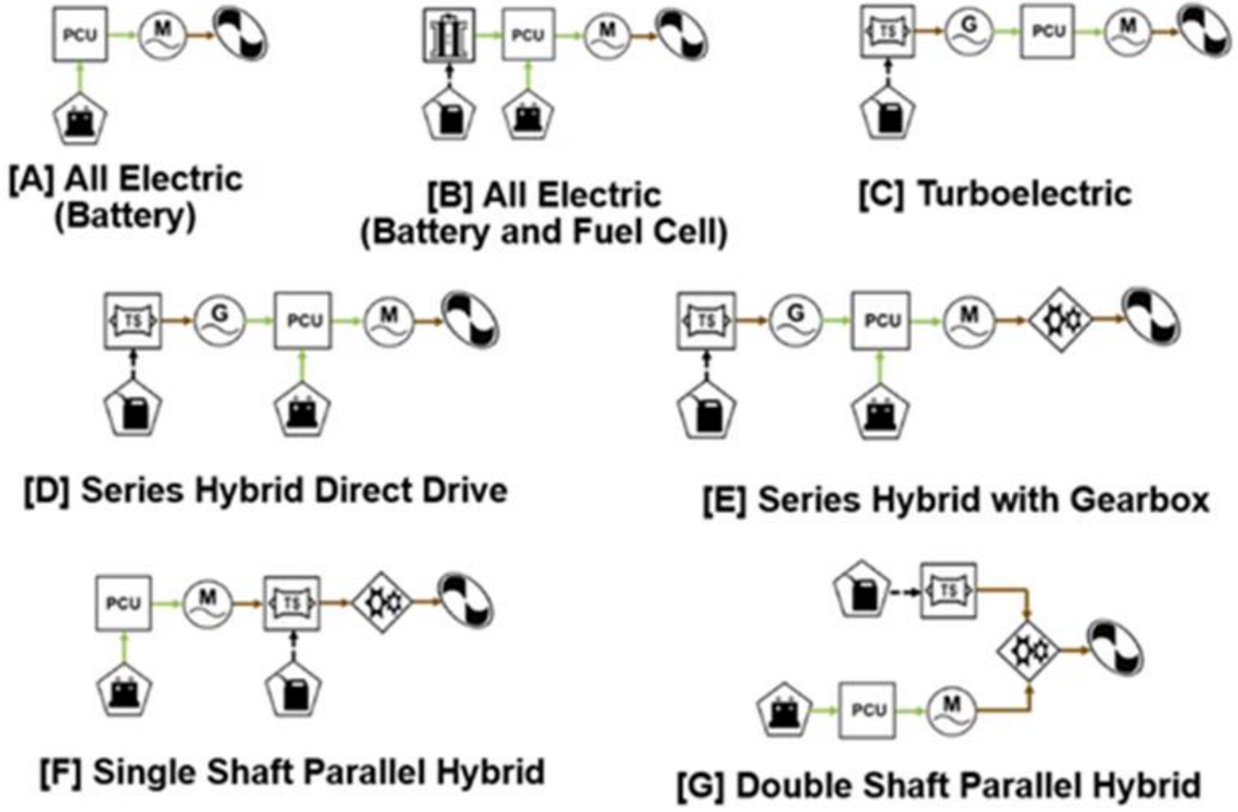
- **Distributed electric propulsion** (DEP) concepts
  - Design flexibility
  - Can play a major role for safety and reliability

- **Easy motor control**
  - Instantaneous motor response compared to gas turbines
  - No power degradation with altitude (due to missing combustion cycle)
  - Can lead to challenging requirements for power electronics (e.g. switching frequency, high-voltage / power)

*Rotor noise is not considered here

System Technology – Turbo- or Hybrid-Electric Powertrains

- Alternatively **turbo- or hybrid-electric powertrain** concepts can be seen as bridge technology
    - more complex system
    - less powertrain efficiency



System Technology – Battery Technologies

- Today's available **battery technology** is typically used as **electrical energy source** and is related to the benefits of electric powertrains

- Battery **costs are falling continuously** due to the high demand and production in the automotive industry

- Results in a relatively **high component weight** with reduced payload capacity
  - Power requirements drives the battery size and weight → ~30 to 40% of aircraft empty weight
  - Battery-powered eVTOLs are heavier than conventional ones, but eVTOL concepts are feasible
  - Enables only short flight times and/or ranges in eVTOL applications due to specific energy and energy density
  - Major impact on the vehicle design, on operational aspects of the individual eVTOL and entire eVTOL fleet (→ System of systems)

- **Active thermal management** → Leads to additional components and weight

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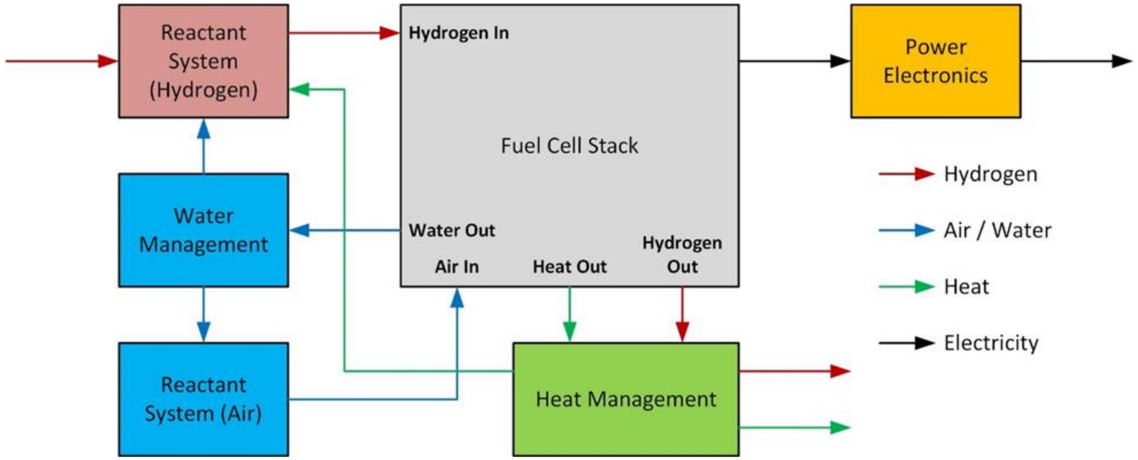
System Technology – Fuel Cell Systems

- **Fuel cell systems** → Alternative electrical energy source
  - Enables a continuous electrical energy output for higher endurance of the vehicle
  - Short-term peak performance (e.g. during take-off or landing) can be provided in conjunction with a battery system
  - Reaction process → pollutant-free, environmentally friendly, noiseless functionality



- **Challenges** of fuel cell systems
  - Requirements for new subsystems (cooling, tank)
  - Crash safety of the hydrogen-carrying components
  - Liquid or gaseous storage of hydrogen incl. A/C integration
  - Fuel cell system control and thermal management
  - Limited service life
  - Higher system weight (for short mission ranges)

Safety-Critical Design Aspects

Electric propulsion systems face aircraft designers and safety engineers with new and unknown challenges

Lithium batteries can fail in seemingly more complex modes

- Main danger: thermal runaway → external fire, toxic gases
- Reasons: deep discharge, overcharging, and internal short circuits
- Crash safety must be guaranteed

Electrical high-voltage systems

- In flight: Energy release through short circuits and arcs → external fire, deterioration in powertrain system performance
- On ground: Pose also a high risk for maintenance and ground handling personnel

Electromagnetic compatibility (EMC)

- Danger for other aircraft systems and passengers
- Through imperfect or faulty behaviour of electrical components

Interconnection of propulsion system with flight control system

- Failure may influence flight control function and lift
- DEP requires intelligent control and power management

Electric powertrain systems offer new potential for **increasing safety**, e.g. DEP

- More tolerant against bird strikes and engine losses
- Failure-tolerant system architectures
- Redundantly designed functional components
- More options of redistributing the power to other drives in the event of a component failure → Simpler, less complicated and more effective system architectures

Certification Aspects – SC-VTOL

- Due to growing numbers of inquiries to air taxi certification requirements EASA released
  - the “Special Condition Vertical Take-Off and Landing (VTOL) Aircraft“ (SC-VTOL) in July 2019 [5]
  - the „Proposed Means of Compliance with the Special Condition VTOL” in May 2020 [6]
  - the „Electric/Hybrid Propulsion System (SC E-19)“ in April 2021 [7]

- **Concept of the SC-VTOL** is analogous to developments in the area of CS-23
  - Performance-based safety goals (“Objective Requirements”) instead of design-specific requirements
  - Independent of aircraft design and adapted to complexity, performance and operating mode
  - Design-specific requirements are located in the (proposed) means of compliance in the form of overarching aviation standards

- Two VTOL categories
  - Category “enhanced” for operation over metropolitan areas or commercial transport of people
  - Category “basic” for all other applications

→ **Air taxis are assigned to the “enhanced” category**

EASA European Union Aviation Safety Agency	Proposed Means of Compliance with the Special Condition VTOL	Doc. No: MOC SC-VTOL Issue: 1 Date: 25 May 2020

Proposed Means of Compliance with the Special Condition VTOL

Statement of Issue

EASA has received a number of requests for the type certification of vertical take-off and landing (VTOL) aircraft, which differ from conventional rotorcraft or fixed-wing aircraft. In the absence of suitable certification specifications for the type certification of this type of product, a complete set of dedicated technical specifications in the form of a Special Condition for VTOL aircraft was developed. The Special Condition addresses the unique characteristics of these products and prescribes airworthiness standards for the issuance of a type certificate, and changes to this type certificate, for a person-carrying VTOL aircraft in the small category, with lift/thrust units that are used to generate powered lift and control.

This Special Condition was subject to a public consultation process and finally issued by EASA in July 2019.

The Special Condition VTOL establishes the safety and design objectives. This approach, previously utilised for the development of CS-23 Amendment 5, is also used for VTOL designs in order not to limit technical innovation by describing prescriptive design solutions as certification standards. The Special Condition does not contain the means that are possible to demonstrate compliance with the safety and design objectives.

The Means Of Compliance (MOC) contained within this document address the applicant´s requests for clarification of EASA’s interpretation of these objectives and of possibilities how to demonstrate compliance with them. Some of these MOCs contain material which should be considered to be guidance material to assist the applicant with an understanding of the objective rather than providing a definitive means of compliance.

In the preparation of these MOCs EASA has followed the same principles, and pursued the same objectives, as with the Special Condition. First, to provide sufficient flexibility to address different architectures and design concepts, although it is acknowledged that all possible cases cannot be considered in these MOCs and alternatives can be proposed by applicants to address some particular design features. In addition, the proposed MOCs should enable an equal treatment of all applicants, by establishing a level playing field and ensuring that a comparable level of safety in the compliance with the objectives of the Special Condition is achieved by all designs.

EASA is committed to continue supporting the industry in the development of safe VTOL aircraft. To this end EASA has decided to prioritise the publication of MOC with the Special Condition VTOL and to issue them in a sequential manner. This approach will allow EASA to focus its resources where the greatest safety impact will be achieved and where the need for clarity is more urgently required. It will furthermore allow the industry to gain an early insight into EASA’s interpretation and expectations from the design objectives of the Special Condition which could have an important effect in the design decisions, instead of waiting until exhaustive guidance for the Special Condition is developed.

Consequently, the first issue of the MOCs mostly concerns subjects that are considered to drive basic design choices and have a higher safety impact on the overall VTOL aircraft architecture. Successive issues of this MOC document will include new MOCs as well as supplements to the existing ones.

Finally, it is recognised that the experience gained during the certification of these new products and their entry into service will allow to increase the knowledge in their certification. It is possible that a better insight into the particular characteristics of these products is gained, which might result in modifications of particular elements

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[5] EASA. “Special Condition for VTOL Aircraft”. 2019
[6] EASA. “Proposed Means of Compliance with the Special Condition VTOL”. 2020
[7] EASA. “Electric/Hybrid Propulsion System (SC E-19)”. 2021

Certification Aspects – Safety Requirements

- Safety requirements correspond to those for civil aircraft

- **Failure condition classification „catastrophic“**
  - Failures that lead to one or more deaths or the incapacity for work of a cockpit crew member in connection with a crash of the aircraft
  - All failures that prevent the aircraft from safely continuing its flight and landing

- **No single failure can lead to a catastrophic event**
  - Evidence through the application of established processes for safety assessment
  - (→ ARP4754A, ARP4761)

- Systems whose failure condition could lead to a catastrophic or hazardous event must be able to be monitored by means of **suitable monitoring during operation**.

		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
Category Basic	**7 to 9 passengers (Basic 3)**	$\leq 10^{-3}$ FDAL D (see Note B)	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL B	$\leq 10^{-9}$ FDAL A
	2 to 6 passengers (Basic 2)	$\leq 10^{-3}$ FDAL D (see Note B)	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL C (see Note A)	$\leq 10^{-8}$ FDAL B (see Note A)
	0 to 1 passenger (Basic 1)	$\leq 10^{-3}$ FDAL D (see Note B)	$\leq 10^{-5}$ FDAL C	$\leq 10^{-6}$ FDAL C (see Note A)	$\leq 10^{-7}$ FDAL C (see Note A)

[Quantitative safety objectives are expressed per flight hour]

The failure rates to be verified and the "Function Development Assurance Level" (FDAL) to be used for the individual failure categories can be found in the safety objectives table [6]

[6] EASA. "Proposed Means of Compliance with the Special Condition VTOL". 2020

Summary

- In HorizonUAM an air taxi system concept will be developed
- Goal was to give an overview over system design challenges with emphasis on electrical powertrains
- Electric powertrains and battery technology are key enablers for eVTOLs today
- In addition to the benefits and potentials, aircraft designers and system engineers are faced with new and unknown challenges
- Safety and other requirements must be met in accordance to the SC-VTOL (and others SCs) and its proposed MoCs
- There are, of course, a lot of more design challenges related to other onboard systems (e.g. avionics…)

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Thank you for your attention!

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