Onboard System Design Challenges of eVTOLs

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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

Safe and Certifiable Onboard Systems for UAM Vehicles

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

• Main research fields:

  - Vehicle concepts
  - System technologies
  - Design challenges
  - Safety and certification aspects

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

  State of the art

  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

→ 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

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


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.

Example:
- MTOM 5000 lb (~2267 kg)
- ISA MSL

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
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

**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

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

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.

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]

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…)
Thank you for your attention!