ADVANCING URBAN AIR MOBILITY: COLLABORATIVE EXCELLENCE AND INFRASTRUCTURE INITIATIVES BY DLR

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Abstract

Urban air mobility (UAM) promises transformative solutions to the increasing challenges of urban transport. However, the realization of UAM requires overcoming multiple challenges that include safety, legal frameworks, social acceptance and environmental sustainability. To meet these challenges and support the widespread introduction of UAM, innovative approaches are required for the development and experimental testing of concepts and technologies. Given these requirements and in order to find a holistic solution, close collaboration between different stakeholders is essential. This article highlights the collaboration possibilities of the German Aerospace Center (DLR) in the field of UAM. The HorizonUAM project used an integrated System of Systems approach to model and optimize complex interactions between UAM components. Particular attention was paid to promoting collaborative approaches to vehicle design and the use of model-based systems engineering methods to develop safe architectures for electric vertical take-off and landing systems (eVTOL). DLR also supports the development and integration of UAM technologies by creating experimental spaces and first-class research infrastructures for testing, development and cooperation in the airport environment, namely the National Test Center for Unmanned Aircraft Systems in Magdeburg-Cochstedt. DLR is also working on the realization of a regulatory sandbox for U-space and is investing in the development of vertiport research infrastructures. Projects such as VERTIFIED serve to evaluate and validate new concepts for the integration of air mobility concepts in urban and airport environments. These endeavors promote cooperation between different stakeholders, including government agencies, industry and the public. As a cooperation partner, DLR contributes with its infrastructure and innovative approaches to the realization of efficient and sustainable urban air mobility.

Keywords: Urban Air Mobility, Collaboration, System of Systems Engineering, Experimentation Spaces

1. Introduction

Urban Air Mobility (UAM) emerges as a transformative solution to the increasing challenges of urban transportation, driven by factors such as urbanization, traffic congestion and environmental concerns such as pollution and noise. UAM envisions integrating aerial mobility into urban landscapes, offering the potential to enhance mobility and reduce travel times. However, realizing UAM entails addressing multifaceted challenges such as safety, regulatory frameworks, societal acceptance and environmental sustainability.

Straubinger et al. [1] give a comprehensive overview on UAM research conducted until 2020. Silva et al. [2] provide guidance on exemplary concept vehicles. Airspace integration concepts are investigated by [3], [4], [5]. The adoption of UAM is assessed by Al Haddad et al. [6].

The HorizonUAM project [7], [8] by the German Aerospace Center (DLR) assessed UAM holistically combining research on UAM vehicles, infrastructure, service operations and public acceptance. The project specifically addressed the complexity of UAM, examining the interdependencies of the constituent systems.

Key HorizonUAM findings include estimating high market potential for UAM in over 200 global cities [9]. A telephone survey revealed the varied attitudes toward UAM among the German population [10]. The passenger's experience in an uncrewed air taxi was investigated in a mixed-reality simulation [11], [12]. The project integrated models from different domains into a System of Systems (SoS) simulation, facilitating UAM system analysis [13],[14]. It also designed vehicle concepts suitable for intra-city and suburban use (including detailed cabin design [15]) and developed communication and surveillance technology for drone-to-drone communications [16], [17]. Moreover, it created a 'Safe Operation Monitor' to enhance machine learning certification reliability and established a Vertidrome[1] Level of Service framework for airside operations [18]. Additionally, it assessed Vertidrome integration into airport environments [19] and created a modular model city for UAM demonstrations. The model city was used for scaled flight testing [20].

The HorizonUAM project has demonstrated the technical feasibility of UAM. Despite the far-reaching success of the project, challenges such as profitability, system complexity and social acceptance remain. Innovative approaches for the development and experimental testing of concepts and technologies are required to meet these challenges and support the widespread introduction of UAM. In view of these requirements and in order to find a holistic solution, close cooperation between different stakeholders is essential.

This article aims to demonstrate DLR's collaboration possibilities in the field of UAM. It aims to provide significant added value by informing about the current projects and their results, facilitating the possibilities to form partnerships and networks with DLR, and generally informing about UAM research.

Chapter 2 describes an innovative design approach for UAM vehicles from the HorizonUAM project. This example is used to explain how various design aspects were integrated into the vehicle design at different system levels. This enabled a broad integration of disciplines from different DLR institutes and cross-project cooperation in the research, which led to new findings. The new technologies must be tested in real environments to ensure their practical applicability and prove their operational safety. At the same time, the regulatory framework for new technologies and their applications must be worked out in parallel with their development. Chapter 3 therefore shows the possibilities for DLR to investigate technologies and systems in experimental spaces in the airport environment. DLR's National Test Center for Unmanned Aircraft Systems offers a unique facility for testing, development and cooperation. Previous work as well as future activities and opportunities for cooperation are presented using the example of UAM. The article ends with a summary of the opportunities for cooperation and an outlook.

2. System of Systems Engineering Approach in UAM Vehicle and Fleet Design

2.1 System of Systems Simulation Framework of UAM

System architectures and use cases in aviation are characterized by a complex interaction of different subsystems, systems and operating concepts or strategies. In order to analyze the diverse effects on performance and effectiveness, a holistic SoS approach is required for design and evaluation. An SoS consists of a large number of different, independent and locally separate systems or system elements, which nevertheless interact with each other and can thus achieve capabilities that could not be achieved by the individual systems alone. This approach can also be applied to the field of UAM, as a large number of new systems have to be developed and introduced at the same time.

UAM, as illustrated in Figure 1, comprises constituent systems such as the aircraft, the heterogeneous fleet, the vertiport system, the air traffic (trajectory, conflict resolution, safety), the passenger demand and the energy system with its life cycle aspects at vehicle, fleet and network level. These systems are operationally and administratively independent, but together form a SoS that must collaborate for successful, efficient operation or positive emergence. In addition, the individual systems are geographically distributed and developed independently at different times, such as when new vehicles, new energy sources, smart grids, new ATM processes or meteorological phenomena are introduced.

[1] A vertidrome is a UAM ground infrastructure which accommodates only VTOL vehicles

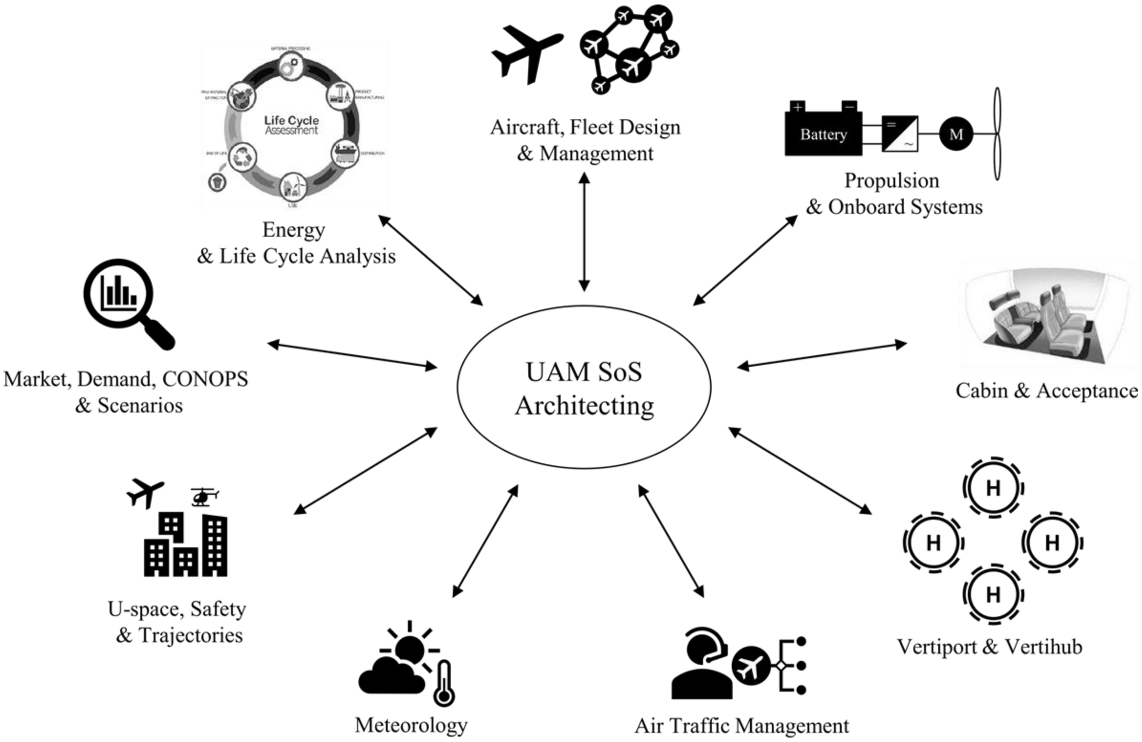

Figure 1 – UAM as SoS [23]

The System of Interest (SoI), on which this chapter focuses, is the UAM vehicle and the associated propulsion system. The design and development of the vehicle and fleet must consider developments in other areas such as passenger demand, infrastructure (vertiports[2]), flight guidance, etc. in order to tailor the concepts to the market and operations. This leads to various dependencies and interactions between the constituent systems, which were considered in the HorizonUAM project.

As part of the HorizonUAM project, an approach was developed to model the interactions between the various systems and to map the sensitivities between subsystems, the overall system or vehicle and the SoS. Specifically, SoS simulations were integrated into the aircraft design process to consider aspects of SoI, i.e. the UAM vehicle design, in the context of the transportation network, fleet planning and operations management.

Given the large number of unknown unknowns in the operation of a UAM network - from projected demand and vertiport locations to aircraft-level parameters such as optimal architecture, speed and passenger capacity - decision-making is difficult. Therefore, the project's approach was to support the decision-making process by simulating the UAM network based on available data and well-founded assumptions. This simulation made it possible to analyze the impact of different parameters on the overall performance of the SoS and to easily integrate new data and assumptions from the literature.

The defined approach for the SoS design and its evaluation on several levels is shown in Figure 2. This approach enabled a comprehensive analysis of the overall UAM system, holistically capturing the influence of the vehicle and its impacts. To model these interactions and interdependencies, an agent-based simulation was developed and used to determine various SoS metrics (e.g. number of passengers transported, passenger waiting time, fleet size, vehicle utilization, number of empty flights, fleet energy consumption, energy consumption per passenger kilometer).

The approach described above for comprehensive modeling of the interactions between different systems focused on the design of vehicles and fleets. For the development and evaluation of vehicles and fleets for UAM, a flexible and expandable simulation framework for SoS was implemented on the basis of a specially developed agent-based platform (see Figure 3). Expert modules from all participating project partners were developed and integrated into a joint simulation, including the model integration for demand, cost, transport, airspace and flight path management as well as maintenance processes. Iterative loops between different expert modules are illustrated in Figure 3.

[2] A vertiport is a category of a vertidrome. It separates the vehicle’s touch down and lift-off operation from the gate operation and may offer additional services related to the passenger (entertainment, shopping, etc.), the vertidrome (staff-related, offices, etc.) and the vehicle (maintenance, charging)

The framework was developed to enable the capture and modeling of subsystem, system and vehicle level inputs at the SoS level, considering different scenarios and use cases. The vehicle level inputs included parameters such as vehicle architecture, range, airspeed, payload and design mission. At the system level, parameters such as battery and charging technology were considered. At the SoS level, transportation network, operational concept (ConOps), passenger volume, fleet size and handling criteria were defined as inputs.

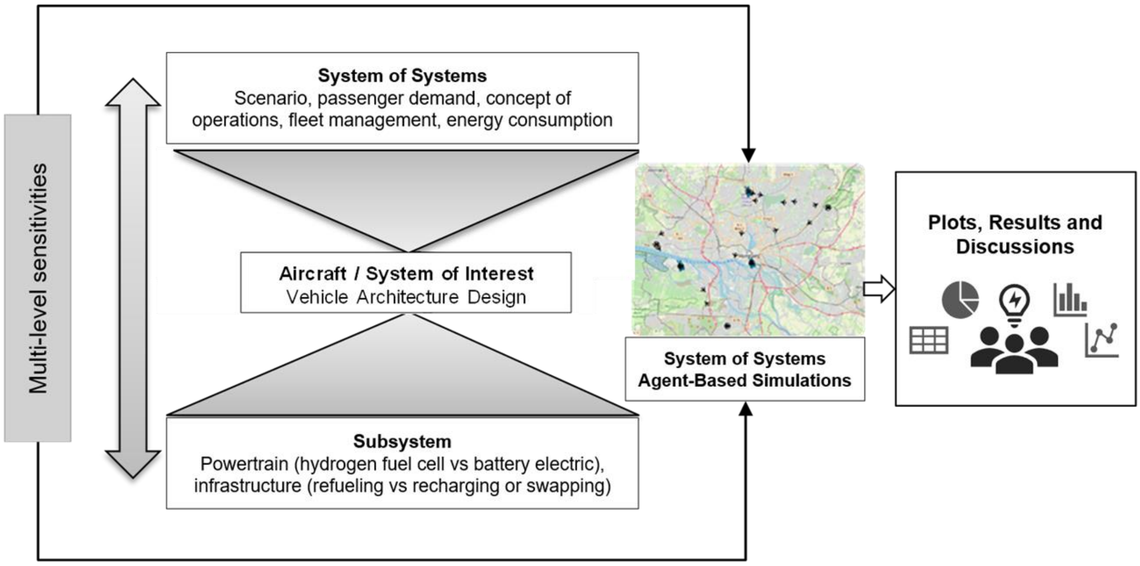

Figure 2 - SoS approach for the design and evaluation at multiple levels [23]

The dimensioning of the vehicle with its subsystems formed the starting point for the simulation. It was first optimized until convergence. The resulting flight performance of the vehicle was passed on to the agent-based simulation, in which each vehicle with its characteristics and together with its flight performance was modeled as an agent. Each vehicle also followed a logic for on-demand air transport, including vehicle allocation with empty flights, flight performance and energy as well as dispatch with recharging.

The actual simulation of the UAM system depicted the flight operations of the fleet over a certain period of time, usually 24 hours. After running various simulation studies, defined metrics for SoS could be evaluated, such as the number of passengers transported versus fleet size. It should be noted that the feedback loop from the SoS to optimize the vehicle design based on the SoS metrics was not automated. Further information on the specially developed agent-based simulation and framework can be found in [21], [22].

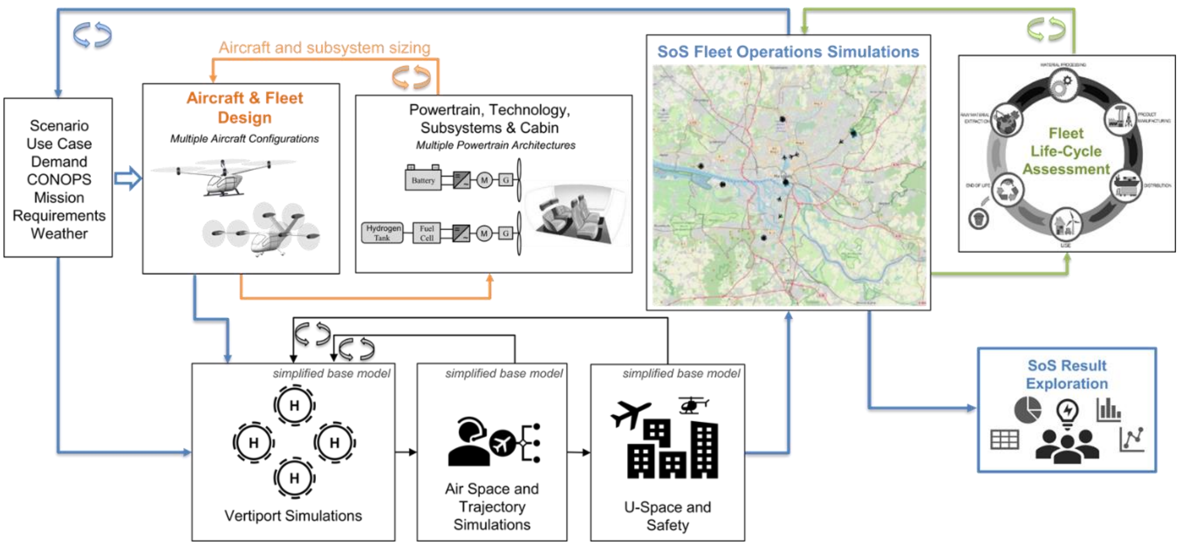

Figure 3 – Agent-based simulation framework for vehicle and fleet design in UAM [23]

2.2 Collaborative and Multidisciplinary Vehicle and Vehicle Family Design

In the field of UAM, eVTOL (electric Vertical Take-off and Landing) in particular are being developed as potential vehicle configurations by start-up companies and established manufacturers. These vehicle architectures differ fundamentally in their typical performance characteristics in vertical and horizontal flight and can be roughly categorized into rotorcraft and fixed-wing aircraft. A more detailed subdivision of architectures includes, for example, multirotor, lift and cruise, tiltwing and tiltrotor. In view of the large number of different applications and requirements in the field of UAM (e.g. "Airport Shuttle", "IntraCity", "Suburban" and "MegaCity" as use cases defined for HorizonUAM), it seems sensible to provide a heterogeneous family of vehicles for different purposes. Each vehicle architecture should be tailored to the respective use case according to its strengths and weaknesses. This requires the ability to cover a wide design space possible in the conceptual studies of the vehicle architectures.

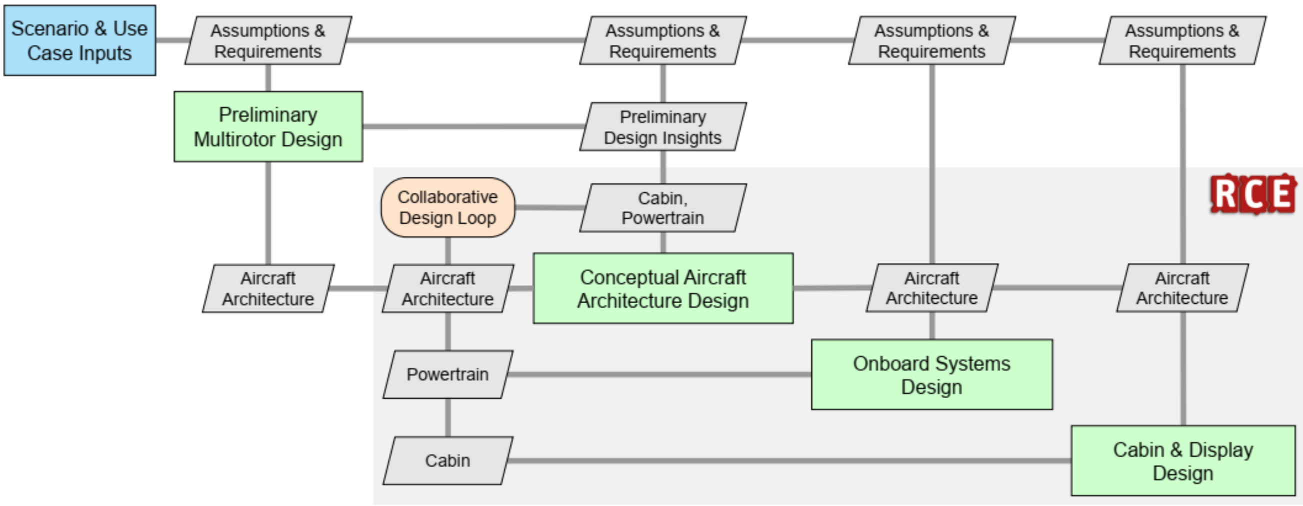

Figure 4 - Schematic workflow of collaborative and multidisciplinary UAM vehicle design [24]

To develop these capabilities, the schematic flow for the collaborative and multidisciplinary vehicle design was defined within HorizonUAM (see Figure 4). The design process was based on top level aircraft requirements and design assumptions that were defined together with the project partners in HorizonUAM [25]. A tool was developed specifically for the design of the vehicle architecture, which considered the various configurations such as rotary and fixed-wing aircraft. A detailed description of the methodology used can be found in [23] and [24].

This tool was combined with another tool for onboard systems design [26],[27] in an RCE[3] process for iterative design. In particular, this tool considered different powertrain architectures in order to examine their effects on the vehicle design and offer further possibilities for holistic optimization of the vehicle design. Furthermore, the process can consider cabin geometry and mass as design inputs or higher-value methods specifically for multirotor design if required. The resulting aircraft performance from the vehicle design was used as input for the agent-based simulation model in the context of the SoS simulation framework, as mentioned above. With the help of the implemented tool chain, different vehicle configurations for a homogeneous fleet could be designed in the UAM system [23], [24].

2.3 Model-Based Systems Engineering in eVTOL Systems Design

In the previous sections, it was explained that HorizonUAM has designed and examined various vehicle configurations for the UAM system, considering an SoS simulation. Conceptual considerations were already made for the onboard systems. However, due to the considerable effort involved in designing the system and analyzing the numerous different vehicle configurations, many requirements and design aspects could not yet be considered in detail. Therefore, in consultation with the project partners involved, it was decided to focus on a specific multirotor configuration with four rotors and two push propellers. This decision was based on feasibility studies carried out using the

[3]RCE (https://rcenvironment.de/) is an open source distributed, workflow-driven integration environment. It is used by engineers and scientists to design and simulate complex systems by using and integrating their own design and simulation tools

conceptual design tool [26], [27]. The aim was to design and size a safe system architecture for the battery-electric powertrain, considering the requirements of the vehicle and its operation.

To this end, the design process shown in Figure 5 was defined and implemented. The first two steps included the definition of the ConOps and the analysis of the vehicle requirements (e.g. controllability, handling quality, and noise, etc.), which served as the basis for the subsequent steps. As the configuration and operational concepts were already defined via the RCE workflow (see Figure 4), the focus was mainly on analyzing further requirements and design aspects that caused interactions between the vehicle design and powertrain [29].

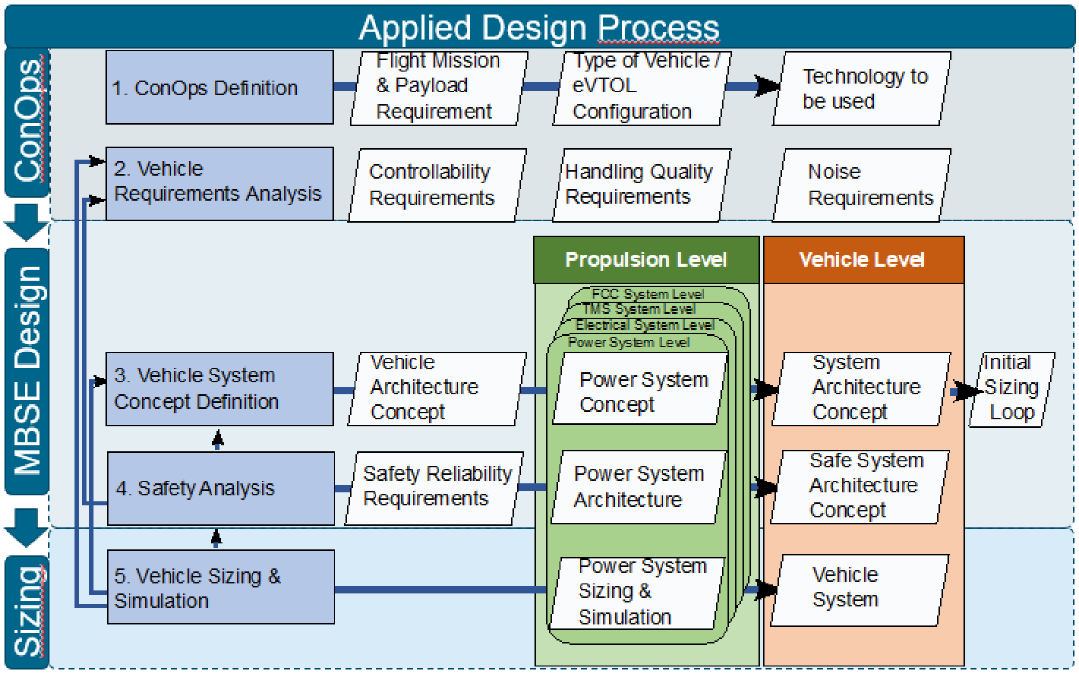

Figure 5 – Applied design process for the multirotor propulsion system [14]

Steps three and four comprised the definition and design of the system architecture (energy supply system, electrical system and thermal management) as well as the corresponding safety and reliability analyses. Any changes resulting from these analyses were iteratively implemented in an adapted system architecture. At the time of the HorizonUAM project, there were no official approval requirements for eVTOL and its systems. However, EASA's "Special Condition Vertical Take-off and Landing" (SC-VTOL) provided indications of possible requirements, particularly with regard to safety and reliability [30]. Given the complexity of technical systems such as air cabs, a systematic approach to control and monitor the design process is essential. Therefore, steps three and four of Figure 5 were performed according to the typical processes for system development and safety assessment [31], [32].

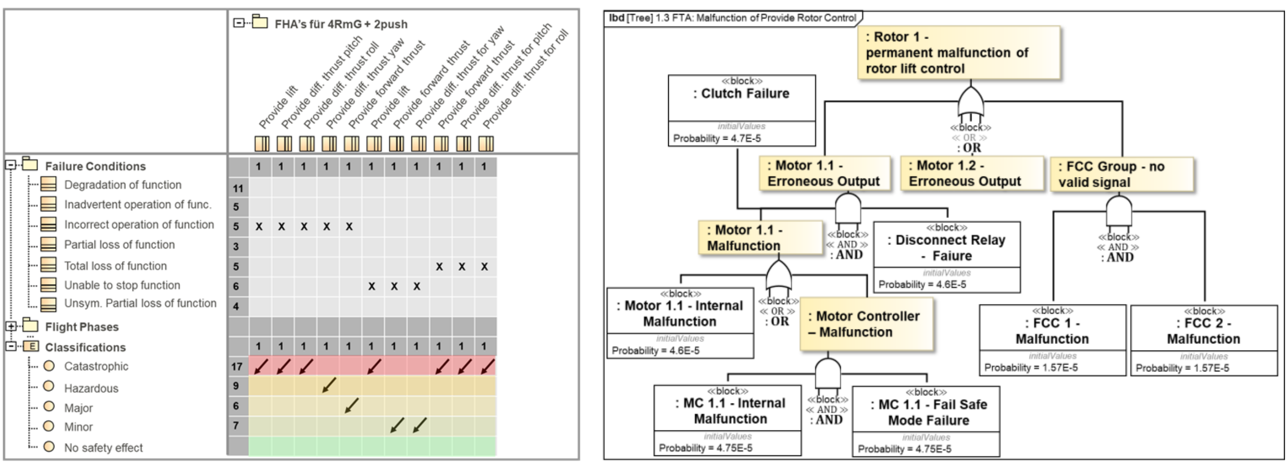

Figure 6 – Aircraft FHA (left) and System FTA (right)

Due to the numerous advantages, such as consistency and traceability of the system design, early detection of problems and effects of design decisions as well as early error and risk reduction, a model-based systems engineering (MBSE) approach was chosen for the implementation of the design process. This enabled various system and safety experts to work together on the model and thus on the system design. This was achieved in particular through a suitable model structure, interface definition and role allocation. The eVTOL system model was modeled using the SysML modeling language in the Cameo Systems Modeler tool. Previously developed profiles for safety analyses [33] (Functional Hazard Analysis (FHA) and Fault Tree Analysis (FTA)) were used. Figure 6 shows exemplary diagrams for an Aircraft FHA and a System FTA.

The last step in Figure 5 describes the design of the system components and, based on this, the dynamic simulation of the designed, safe system architecture. Finally, the suitability of this architecture was validated on the basis of the ConOps definition and the vehicle requirements as well as the general feasibility and functionality. Based on the defined design process, a safe architecture of the drivetrain with its subsystems and components was successfully designed and sized, which also meets the requirements of the SC-VTOL. Detailed information on the architecture and its design and properties can be found in [34].

2.4 Collaborative Studies within the Framework of the HorizonUAM Project

Collaborations played a crucial role in the HorizonUAM project. The UAM systems were considered as SoS and the constituent systems were integrated into it. The conceptual design and investigation of such a UAM system was done by integrating different subject matter experts at different levels, including the SoS, vehicle and subsystem levels.

A particular focus was placed on the vehicle design, considering aspects of both the SoS level and the subsystems. The SoS simulation framework developed made it possible to carry out previously unperformed studies, although the framework itself worked with conceptual design models. Several aspects of vehicle design and operational concepts were considered as part of various studies.

A conceptual exploration of the design space with respect to different vehicle architectures was conducted [24], as well as an SoS study dealing with vehicle architectures in homogeneous and heterogeneous fleet compositions [35], [36]. Sensitivities were demonstrated at several levels, from subsystems to the entire system and the SoS [37]. In addition, SoS simulations were carried out that included life cycle analyses for battery production and operation [38]. Particular attention was paid to the design and operational concepts for multirotor concepts, especially with regard to battery charging and replacement [39]. Another SoS study was used to determine optimal design requirements for vehicle families in homogeneous fleet composition [28] as well as simulation. In addition, systems were designed on the basis of Concepts of Operation, emergency capability and certification requirements [34]. The evaluation was carried out using the various metrics for SoS (see section 2.1). The investigations described enabled the individual disciplines, such as system engineers, aircraft designers and flight guidance experts, to gain new insights and to drive forward the development of their systems or aspects in a targeted manner.

Within HorizonUAM bilateral cooperation were also established between NASA and DLR and between Bauhaus Luftfahrt (BHL) and DLR. The cooperation partners Schweiger (DLR) and Preis (BHL) focused on vertiport research. Their paper [40] reviews systematically existing literature on UAM ground infrastructure, which is essential for safe and efficient operations in urban environments. It categorizes and summarizes 49 scientific publications (2016–2021) covering topics like airspace operation, design, location, throughput, safety, regulation, and more. While certain aspects such as cost and security are under-represented in research, the paper aims to support the harmonization of contributions from academia, industry, and regulatory bodies to advance UAM development. It also discusses regulatory considerations.

The DLR project HorizonUAM was linked to the NASA project ATM-X with the focus on Air Traffic Management eXploration. Abdellaoui et al. [41] explored concepts related to UAM airspace management, focusing on a comparative assessment framework applied to three approaches: Slot-, Trajectory-, and Corridor-based approach. Conducted for exemplary urban areas like Hamburg and Dallas/Fort Worth, the study utilizes simulation platforms at NASA and DLR to analyze the strengths and weaknesses of each concept. The findings emphasize the importance of tailoring solutions to specific cities and highlight the need for further comparative studies to advance UAM airspace management.

Hartman et al. [42] addressed challenges in developing performance models for UAM vehicles, which combine fixed-wing and rotorcraft capabilities for operations in densely populated areas. They propose an interface specification to standardize performance model formats and functionalities, enhancing model development and integration into user applications. The specification outlines model documentation, inputs and outputs in adaptable terms for various programming languages, aiming to facilitate the creation of a UAM performance model database and improve model interoperability across applications.

Sievers and Sakakeeny [43] focused on regional air mobility for cargo transport. They evaluated the integration potential of fixed-wing cargo Unmanned Aircraft Systems (UAS) into airspace systems in Europe and the USA. They established a baseline to identify airports suitable for UAS operations in Germany, Texas and California, considering factors like runway capacity and airspace classification. Despite hundreds of potential airports identified, only a few currently have certified landing systems for UAS operations (e.g. Instrument Landing System (ILS), Category III for precision approach and landing in low visibility conditions), although no US operator has approval for that yet. However, ongoing development of alternative landing systems, like vision-based technology, may enhance accessibility for UAS in the future.

3. UAM Experimentation Spaces in an Airport Environment

3.1 Regulatory Sandboxes, Testbeds and Living Labs

New technologies need to be tested in a realistic environment to bring them into practical application as well as to show their operational safety.

Due to the fact that the regulatory framework for new technologies and their applications has to be elaborated in parallel to their development, there is always a gap between the needs of innovators on the one side and the needs of regulators on the other side. A way to close this gap is to conduct tests in spaces designed for experimentation. Here, one can distinguish between three different types: regulatory sandboxes, testbeds and living labs [44]. According to the Commission Staff Working Document of the European Commission published in 2023 [44], testbeds are used for testing and upscaling of a service or a product in a dedicated environment, while regulatory sandboxes are designed as controlled environment in real-world to enable a cooperation with competent authorities. Notwithstanding, living labs enable a technology assessment in an uncontrolled real-world environment.

Depending on the issue to be discussed, a selection of the suitable testing environment has to be defined. While testbeds are suitable to have a look on requirements and performance of a technology, regulatory sandboxes can be used to test modifications and adaptions of the regulatory framework. Living labs have the potential to explore also the effects of a technology on users and the society.

3.2 National Experimental Test Center for Unmanned Aircraft Systems

DLR's National Experimental Test Center for Unmanned Aircraft Systems at the Magdeburg-Cochstedt airport in Saxony-Anhalt offers a unique facility for testing, development and cooperation [45]. It is addressed not only to DLR's research facilities from all over Germany but also to additional stakeholders from the UAS industry, research facilities and legal regulation entities as well.

Since research and development in the UAS sector intensified in the past and is expected to further do so in the coming years, also the need for testing opportunities rises significantly. This not only applies for the simple need for space to operate experimental UAS in a safe environment but also to focus on the regulatory framework to conduct these flight tests. To enable this, the testing facility is established and continuously extended at an operational airport since 2019.

The airport area itself provides a 2.5 km paved as well as an additional grass runway, infrastructure and personnel for firefighting and air traffic control as well as refueling facilities. It is commercially operated during daytime for private and business aviation in a smaller scale.

With its hangar and office spaces around the airfield as well as fully equipped workshops, the test center offers flight test campaigns and their partners perfect conditions to perform their test preparations, flight executions, result evaluation and further tasks in this context. The facility moreover supports the test teams by providing infrastructures such as optical tracking for flight path detection, ground control station equipment and detailed wind measurements applying LiDAR (Light Detection and Ranging), to name just a few available technical outfits.

Besides the technical infrastructure available at the test center, general conditions and different procedures were developed by the team of the test center to facilitate the application process for getting a permission for UAS flights in the specific category. These procedures as well as general conditions are e.g. defined testing areas that can be used also in combination, unified procedures to mitigate the air risk in the environment of the test center, or a description of mitigations to reduce the risk at ground. Based on the requirements of external and internal users of the test center, the procedures and general conditions are developed and improved continuously.

This means that the test can be carried out in a real-world environment. The possible flight areas extend across the area of the airport as well as the surrounding agricultural areas and thus cover an area of several square kilometers to be individually aligned with the flight test requirements. It is one special feature that the test center itself is located at an operational airport. The close link between the airport operation and the test center itself not only ensures a safe execution of flights but furthermore promotes the study of the integration of unmanned aviation in the traditional airport environment.

By these means, there is also the possibility to test the integration of UAS into the manned/traditional aviation environment.

In addition to the aforementioned tests in the existing living lab, there is the opportunity to develop and establish regulatory sandboxes for different UAS tests in the future. More testing possibilities will expand the range of infrastructures in the near future, as the technical equipment is continuously evaluated and extended.

Already conceptualized within the HorizonUAM project and being planned for realization is a scaled model city facilitating research and testing of air mobility concepts, vehicles and processes in an urban environment [46]. Furthermore, a demonstration facility for vertiport procedures will be designed and set up with an upcoming DLR-internal research project (see section 3.4). In summary, the Experimental Test Center for Unmanned Aircraft Systems offers a living lab that can be used to conduct UAS flight tests in a safe manner.

3.3 DLR's U-Space

In terms of regulatory sandboxes, DLR is currently working on the implementation of regulatory sandboxes for U-space[4]. Beginning of 2023, the DLR-internal project AREA U-space [47], [48] started with the aim to implement a U-space at the National Experimental Test Center. The idea is to implement a U-space with certified services on the one side and to establish a regulatory sandbox with experimental services that offer higher automation (U-space level U3 up to U4). These services of higher U-space levels will be developed in-house. The aim is to offer them to external as well as internal users to conduct tests in a protected environment. Here, the vision is to have the possibility to conduct tests with reduced requirements from regulatory side.

After the planned demonstration of selected use cases in a prototypical U-space system in 2026, it is intended to allow also external users the utilization of the created U-space test environment.

3.4 Vertiport Demonstration Facilities

As it is the case for the entire field of UAM, testing and demonstration are among the most important issues for the implementation of these future mobility concepts. As already cited in [40] "To take off, flying vehicles first need places to land" emphasizes the need for testing UAS infrastructures to safely (and securely) be operated when taking onboard passengers.

As a follow-up project to HorizonUAM, DLR will invest in the vertiport research infrastructure in VERTIFIED. The project focusses on conceptualizing, building and validating use case oriented vertiports as an extension of the facilities at the Experimental Test Center for Unmanned Aircraft Systems in Cochstedt. A stakeholder forum will be established consisting of vertiport manufacturers, vertiport operators, UAM and air taxi manufacturers, UAS operators and authorities, among others. The focus here is on regular exchanges between the project participants and the relevant stakeholders in order to incorporate their views and perspectives into the project.

Starting with an extensive collection of requirements from a variety of stakeholders and based on the work that has already gone into the project HorizonUAM, the objective is to provide a holistic view of the complex issue of vertiport (design, operations, etc.) by continuously gathering various feedback from stakeholders. This will also create synergies with the existing UAS test field network initiated by DLR. The project aims to design a building concept for different vertiport use cases, such as urban or

[4] U-space is a geographically defined airspace in which U-space services enable conflict-free operation by several drone operators.

inner city as well as at an airport site. During the three-year project period, these concepts then will be transferred to realization at DLR's test center. Finally, tests and public demonstrations are performed on the one hand to highlight the capabilities of the new infrastructures for the UAM community. On the other hand, also the effects on the integration at the vehicle side can be investigated and showcased.

Figure 7 – Vertiport design visions, DLR's HorizonUAM project [40]

It is one aim of VERTIFIED that future projects in the field of UAM as well as the regular users and customers of the test center will benefit from these developments. The VERTIFIED infrastructure is envisioned to provide an assessment capability for new concepts for external cooperation partners, in particular with regard to

- Approach and departure procedures at vertiports,
- Vertipad design and configuration and their impact on safety, capacity and flexibility,
- Validation of software-based support systems for airside and landside processes (incl. passenger trajectories, ground handling),
- Integration capability/compatibility of vertiport systems with airport systems and U-space,
- Benchmarking of DLR systems to proprietary/prototypical commercial systems,
- Validation and investigation of the extension of IFR (Instrument Flight Rules) to UFR (U-space Flight Rules),
- Validation and investigation of RNP (Required Navigation Performance) and approach procedures from Vertical Take-off and Landing (VTOL) Capable Aircraft (VCA) to vertiports
- Connection analysis of vertiports to multimodal modes of transport.

4. Summary and Outlook

Urban Air Mobility (UAM) faces many challenges, but also offers transformative solutions to the growing problems of urban transportation. The HorizonUAM project of the German Aerospace Center (DLR) has comprehensively researched this topic, considering aspects such as safety, legal framework conditions, social acceptance and environmental sustainability. The project identified a high market potential for UAM and investigated various key factors such as passenger experience, vehicle design and communication technologies. Innovative approaches and experimental tests are still essential to promote the broad acceptance of UAM.

As part of the HorizonUAM project, a holistic SoS approach was pursued to model, analyze and optimize the interactions between the various components of the UAM system. One focus was on collaborative vehicle design and the development of a flexible simulation framework for evaluating different vehicle configurations. In addition, MBSE was used intensively to design a safe system architecture for eVTOL systems. Collaborative studies emphasized the cooperation between different disciplines and institutions to find and investigate innovative solutions and drive the overall development of the UAM system.

DLR is particularly involved in creating experimental infrastructure in the airport environment, which makes it possible to test new technologies under realistic conditions and adapt regulatory requirements. DLR's National Test Center for Unmanned Aircraft Systems at Magdeburg-Cochstedt Airport offers an outstanding infrastructure for testing, development and cooperation in the UAS industry. This facility can support flight test campaigns and provide technical equipment and advice for approval procedures. Furthermore, DLR is working on the implementation of a regulatory sandbox for U-space in order to conduct tests with reduced requirements from the authorities. In addition, DLR is investing in the development of vertiport research infrastructures to explore and demonstrate the integration of air mobility concepts in urban and airport environments. Projects such as VERTIFIED aim to evaluate and validate new concepts, including approach and departure procedures at vertiports, vertipad design and configuration and integration capability with existing airport systems and U-space.

In the future, close cooperation between different players will be crucial to overcome the challenges and realize the vision of UAM. Technological advances in areas such as battery technology, electrification and autonomous flight will improve the performance and safety of UAM systems. At the regulatory level, clear guidelines and standards are essential to ensure the safety and integration of UAM systems. Close cooperation between government authorities, aviation organizations and industry will be crucial to develop appropriate certification procedures and operating rules. Investments in infrastructure, including vertiports and charging facilities in urban areas, will facilitate the integration of UAM systems into urban transportation. Cooperation between public and private partners and careful planning considering environmental impacts and urban development are crucial. DLR will contribute as a cooperation partner with its infrastructure and innovative approaches.

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