HorizonUAM

DLR

THE FUTURE OF URBAN AIR MOBILITY

The integration of air taxis into urban airspace:
Findings from HorizonUAM, a research project
of the German Aerospace Center (DLR)

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Intro

Urban Air Mobility (UAM) as part of Innovative Air Mobility (IAM) is a new air transportation system for passengers and cargo in urban environments. It is enabled by new technologies in the fields of aircraft technology, electric propulsion and air traffic management. A core idea is to integrate UAM into existing multimodal transport systems. The vision of UAM is to achieve safe, secure and sustainable air transport in urban and suburban environments, complementing existing transportation systems and contributing to the decarbonisation of the transport sector.

UAM is expected to benefit users and to also have a positive impact on the economy by creating new markets, employment opportunities for manufacturing and operation of UAM vehicles, and the construction of related ground infrastructure. However, there are also concerns about noise, safety and security, privacy and environmental impacts. Therefore, the UAM system needs to be designed carefully to become safe, affordable, accessible, environmentally friendly, economically viable and thus sustainable.

The German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) combined its competencies in the areas of UAM vehicles, related infrastructure, operation of UAM services, and public acceptance of future urban air transport into a single project: "HorizonUAM – Urban Air Mobility Research at the German Aerospace Center (DLR)". This document outlines key research topics related to UAM.

DLR as the Federal Republic of Germany's research centre for aeronautics and space has the unique ability to investigate UAM holistically, from idea and conception right through to simulation and flight testing.

The HorizonUAM project ran from July 2020 to August 2023, with a financial investment of 9.1 Million Euro. Ten DLR institutes across Germany worked together along with cooperation partners NASA and Bauhaus Luftfahrt.

Overall System Analysis

Can Urban Air Mobility become a reality? Is there a demand for this new type of transportation service? How should a UAM system be designed to be economically promising? Answering these key questions requires a deep understanding of the complex interactions between UAM system components and their impact on system behaviour. The success of UAM is judged by its impact on relevant stakeholders, such as users, operators, and society in general, as well as its impact on the environment. Because air taxis are not yet in operation, models and simulations had to be developed to gather information about the potential pricing of UAM services, assess the global demand, and find out how UAM systems could be optimised.

USE CASES

UAM comprises various potential use cases in passenger and cargo transport. As one of the starting points of the research, the most interesting use cases were selected with regard to prospects of success and technological challenges. The team analysed the characteristics of these use cases in detail: user requirements were compiled, the resulting consequences for the UAM transport system were derived, and scenarios of the technological development up to the year 2050 were derived. The results are incorporated into the vehicle and cabin design and into the development of a system-of-systems simulation.

INTRA-CITY USE CASE

Transport range: up to 50 km
Speed: up to 100 km/h
Seats: up to 4

» Flights on-demand within core areas and built-up urban areas of cities in Germany
» High traffic density and flights in urban environments over short distances
» Flight mission with up to two intermediate stops without need for recharging

MEGA-CITY USE CASE

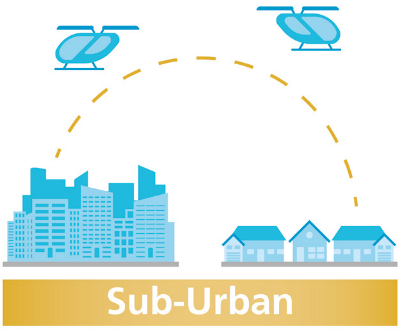
Transport range: up to 100 km
Speed: up to 150 km/h
Seats: up to 6

» Flights on-demand within core areas and built-up urban areas of global mega-cities
» High traffic density and flights in urban environments over large distances
» Flight mission with no or one intermediate stop without need for recharging

AIRPORT SHUTTLE USE CASE

Transport range: up to 30 km
Speed: up to 150 km/h
Seats: up to 6

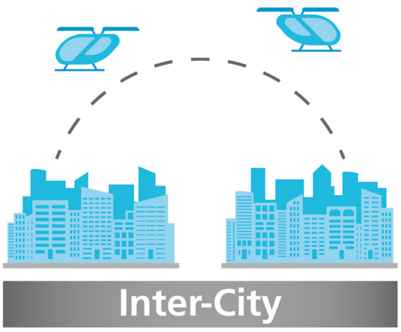
» Scheduled flights between airports and selected locations (e. g. city centre, central business district, CBD)
» Vehicle with higher payload capacity and space to store luggage
» Flight mission between two vertiports with charging capability after each flight



SUBURBAN-COMMUTER USE CASE

Transport range: up to 70 km
Speed: up to 150 km/h
Seats: up to 4

» Scheduled flights between suburbs or surrounding satellite cities and the city centre
» Economically challenging due to high peak demand and low off-peak demand
» Flight mission between two vertiports with charging capability after each flight



INTER-CITY USE CASE

Transport range: over 70 km
Speed: over 100 km/h
Seats: up to 10

» Scheduled flights between two cities
» Vehicle for long distance flights with high comfort for passengers
» Flight mission between two vertiports with charging capability after each flight

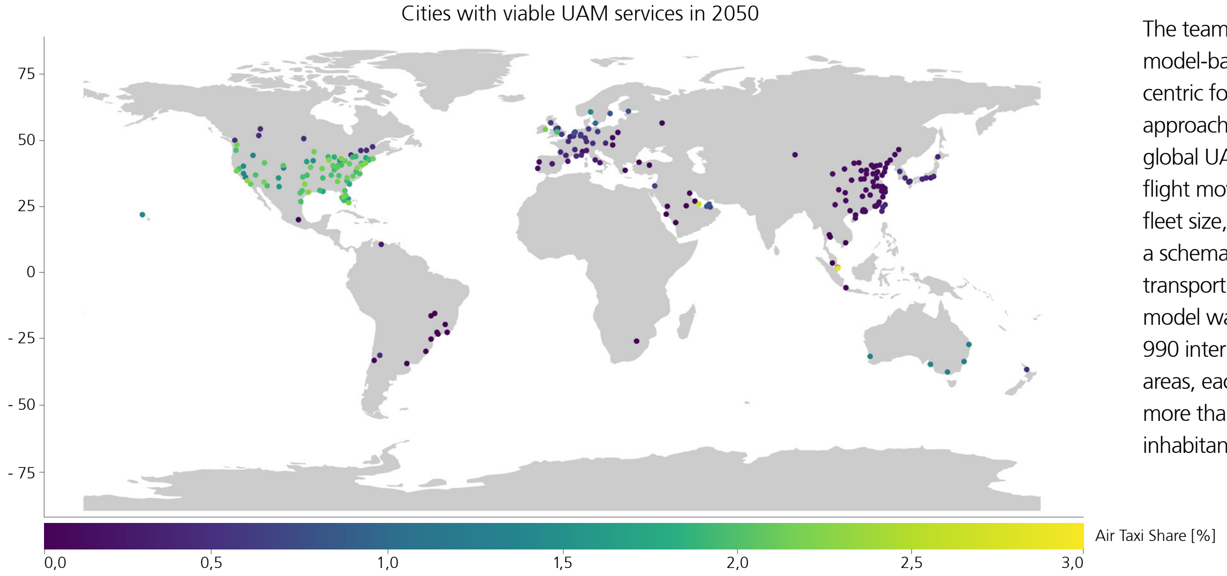
TECHNOLOGY SCENARIOS

	2025	2050
Propulsion technology	Fully electric or hybrid electric based on conventional fuels	Fully electric or hybrid electric, also hydrogen-based
Level of autonomy	Onboard-Pilot / Remote-Pilot*	Highly automated autonomous
U-Space Service Level	U-space Service Level U1 (first U-space services)	U-space Service Level U2 – U3 (advanced U-space services)
Communication	Multilink communications approach relying on existing comm. infrastructure	Multilink communications approach with specific datalink
Navigation	Certified multi-sensor navigation including GNSS	Global Navigation Satellite System (GNSS) and supporting multi-sensor navigation

* For the intra-city and mega-city use cases an onboard pilot is assumed, and for the use cases airport shuttle, suburban and intra city a remote pilot.

GLOBAL DEMAND

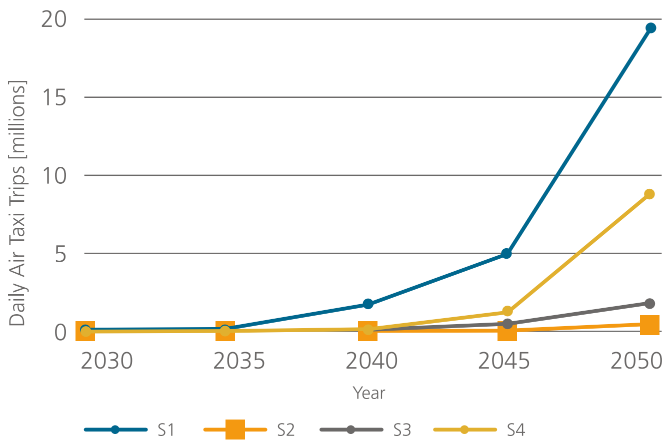
A preliminary estimate of the potential global demand for UAM, the associated aircraft movements and the required vehicles is essential for the UAM industry for their long-term planning, but also of interest to other stakeholders such as governments and transportation planners to develop appropriate strategies and actions to implement UAM. There is a general lack of empirical data on the demand for UAM. Furthermore, cities around the world differ in many ways, including size, economic strength, population, geography, etc.



The team took a model-based city-centric forecasting approach to estimate global UAM demand, flight movements, and fleet size, and created a schematic urban transport model. The model was applied to 990 international urban areas, each comprising more than 500,000 inhabitants.

Considering different development paths for air taxi ticket prices and vertiport densities, four potential market development scenarios (S1-S4) were outlined. A low vertiport density in a scenario reflects the fact that due to political, environmental, or social reasons, only a few vertiports can be placed. Lower ticket prices may be the result of technological advances in vehicle and infrastructure automation. The results show that significant UAM markets are not expected by 2040, regardless of the cost of ticket prices. The results indicate that a low ticket price is more important than a high vertiport density for higher demands. In the best-case scenario, a low ticket price and a high density of vertiports could result in a market potential for UAM of 19 million daily trips in over 200 cities worldwide by 2050. UAM demand varies regionally, with high market shares in larger cities, particularly in North America, Oceania, Europe and Asia, influenced by local market conditions.

	Vertiport Density	Air Taxi Prices
Scenario 1	High	Optimistic
Scenario 2	Low	Conservative
Scenario 3	High	Conservative
Scenario 4	Low	Optimistic

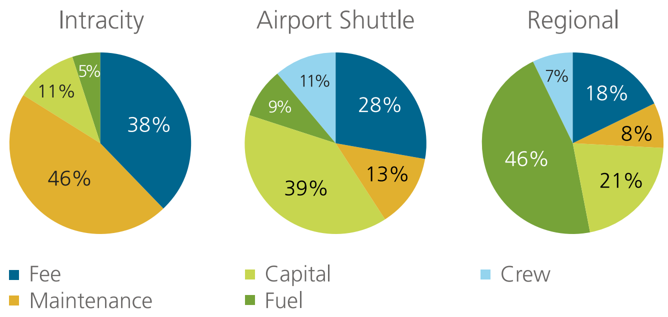


OPERATING COST AND TICKET FARES

The ticket price remains one of the most critical metrics for the success of UAM. As the ticket price is directly linked to the operating costs of UAM, a model for the estimation and forecast of direct operating costs becomes one of the key models that a UAM operator needs to develop. However, many components of the UAM system that contribute to the direct operating cost are not yet known.Therefore, the team created a model of Direct Operation Cost (DOC). This considers the costs involved in landing, terminal usage, air traffic service charges, maintenance and overhaul, capital cost and depreciation, energy, crew, and flight cycles (FC). The parameters for the DOC estimation were based on existing literature, known prices of general aviation, and conclusions by analogies. Ticket fares were determined by prescribing the share of Indirect Operating Cost (IOC) and profit margin.

Use Case	Intra City	Airport Shuttle	Regional
Vehicle name	Ehang 216	Archer Midnight	Lilium Jet
Vehicle seats (passengers + pilot)	2 (2+0)	6 (5+1)	8 (7+1)
Flight distance [km]	12.13	15.11	186.35
DOC per FC [€/km]	62.07	231.30	700.83
Fare optimistic [€/km]	4.1	6.1	1.0
Fare conservative [€/km]	5.7	8.5	1.4

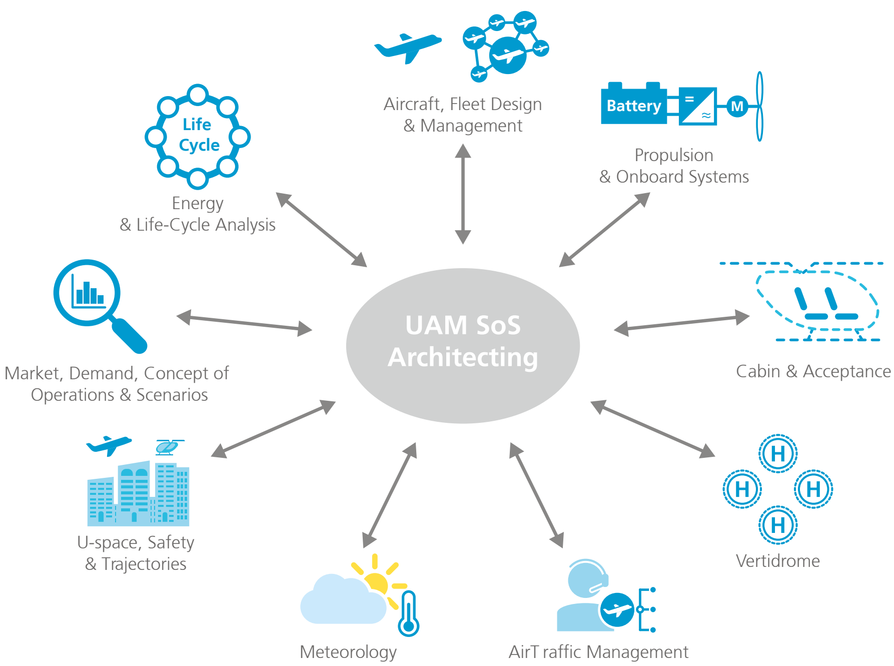
Three applications were taken into account for calculating these price estimates: intra city, airport shuttle and regional trips. For each type of flight, an optimistic and a conservative fee per kilometre were calculated. For intra city trips, the optimistic rate is 4.10 €/km, and the conservative rate is 5.70 €/km. For airport shuttle trips, the optimistic rate calculated is 6.10 €/km, and the conservative rate is 8.50 €/km. For regional trips, the optimistic rate is 1.00 €/km, and the conservative rate is 1.40 €/km.



The results demonstrate that both mission design and vehicle configuration have a significant impact on the total operating cost per flight. UAM operators need to carefully consider different vehicle configurations, particularly when the demand is low and larger vehicles are operating with lower load factors, as reducing operating costs, and thus fares, is critical to generating sufficient demand to be profitable.

OVERALL SYSTEM MODELLING: SYSTEM OF SYSTEMS SIMULATION

Since UAM is a complex system of systems (SoS), with various technical, operational, regulatory, and social components interacting with one another, a holistic approach is essential. The complexity results from the necessary integration of the constituent systems such as aircraft, infrastructure, air traffic management and flight operations into the urban transportation system. In order to create a viable urban transportation system, it is necessary to harmonise the individual system components.



To understand and evaluate the systems of a UAM SoS and their interdependencies, a collaborative agent-based simulation of urban air mobility was developed. The integration of the individual modules (or constituent systems) into the agent-based simulation was achieved through the use of the Remote Component Environment (RCE). RCE served the crucial function of seamlessly connecting the models hosted across several institutes.

The developed collaborative simulation allows studies in any of the participating domains to be performed while capturing cross-domain effects without compromising the modeling fidelity of the other domains. Furthermore, such an approach can also allow the combined optimization of the individual constituent systems and the overall system of systems.

UAM is a highly complex system of systems interacting with each other in intricate ways, some of these potential system interactions are still unknown. Thus, there is significant potential for future research. In order to create a viable urban transportation system, it is necessary to harmonise the individual system components such as vehicles, infrastructure, and the operational framework, including the various air traffic management systems. Reducing operating costs, and therefore fares, and building a sufficiently dense vertiport network are critical to generating enough demand for UAM to be profitable.

Vehicle

The vehicle design was developed collaboratively in accordance with the previously introduced system-of-systems approach. Depending on the use case, different requirements for the vehicle design arise. Comfort requirements of users were identified and taken into consideration for the creation of various vehicle and cabin design concepts.

The cabin and the interior design form the interface between air taxi and passenger. As such, they play a crucial role in shaping the passenger's perception. These aspects are thought to have a substantial impact on public acceptance of future air taxis.

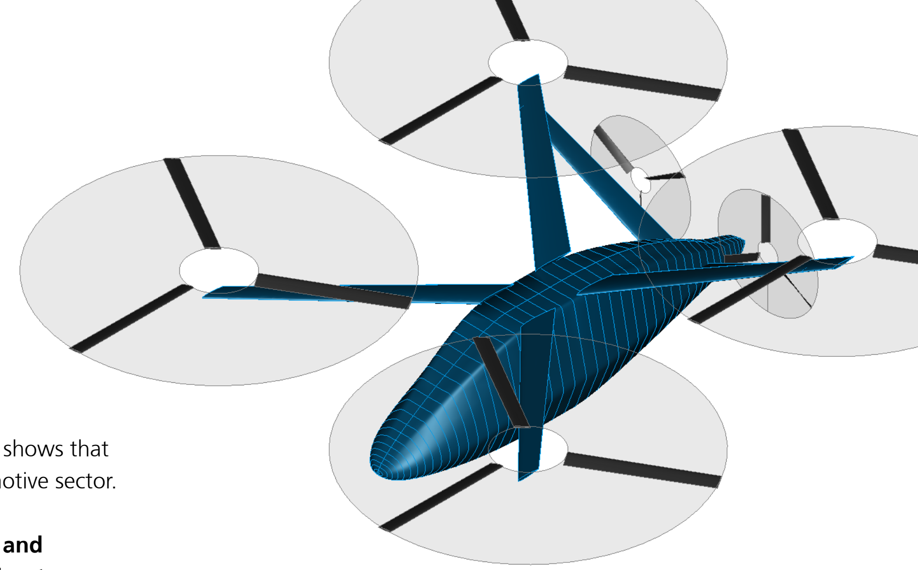
CONCEPTUAL CONFIGURATIONS

The researchers examined various configurations of rotor and wing orientation and evaluated configurational characteristics, such as flight performance and flight stability in various weather conditions. Wherever possible, the design process followed the principles of low-noise design. Based on these investigations, two main vehicle concepts for multiple use cases were proposed: a pusher integrated multirotor configuration and a tiltrotor configuration. The former concept is suitable for shorter distances, whereas the latter is equipped with six tilting rotors mounted on fixed wings to produce thrust in the flight direction, thus achieving higher speeds and covering longer distances. Aside from the conceptual design, a more sophisticated level of design and analysis was performed on the multirotor concept. Here, a flight-mechanical model was created, through which the aero-mechanical rotor analysis and optimisation using blade elements were conducted. An investigation of the initial design limits was also completed.

The quadrotor model is suited to intra-city or airport shuttle transfers, and offers space for four passengers including luggage. The design mission should cover a distance of 50 km, up to a speed of 120 km/h, and include two stopovers.

The tiltrotor model is suited for sub-urban or megacity trips, and offers seating capacity for four passengers including hand luggage. The average trip would cover a distance of 100 km, with a speed of 200 km/h, and include one stopover.

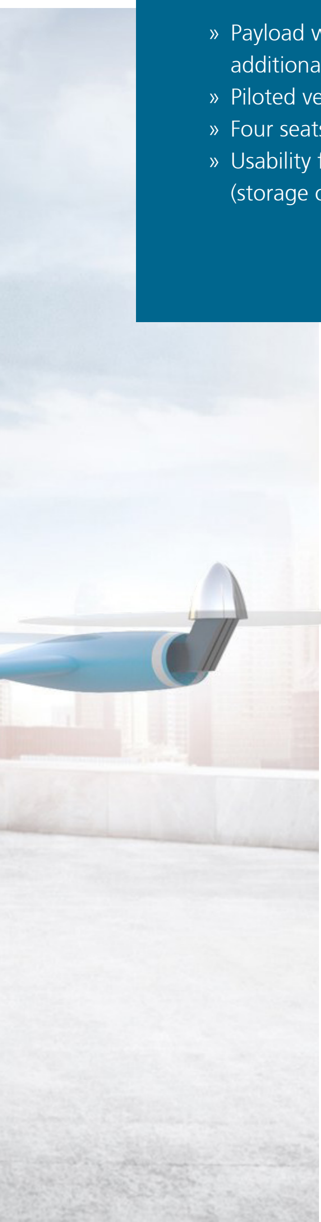
The maximum take-off mass is dependent on payload, range and speed requirements, as well as developments of battery technologies, and will meet EASA Special Condition for small-category VTOL aircraft (SC-VTOL) with a maximum certified take-off mass of 3,175 kg (7,000 lbs) or less.



INTERIOR DESIGN CONCEPTS

Research on existing Urban Air Mobility (UAM) vehicles shows that this industry has learned from innovations in the automotive sector.

The interiors are based on strong colour contrasts and minimalistic design, conveying a sense of connection to the automotive sector. The cabins are given a light and airy feel through large windows, meant to enhance the flight experience. Seats are most often arranged according to the automotive standard, which assists in creating a familiar experience for passengers.



CABIN LAYOUT DEFINITION AND OVERALL PARAMETERS

While defining potential designs for a cabin, in addition to safety and privacy, ergonomic considerations play an important role. Central requirements have been defined:

- Payload weight: 90 kg (+20 kg optional and additional luggage weight)
- Piloted vehicle with autonomous flight option
- Four seats
- Usability for persons with restricted mobility (storage of wheelchair)

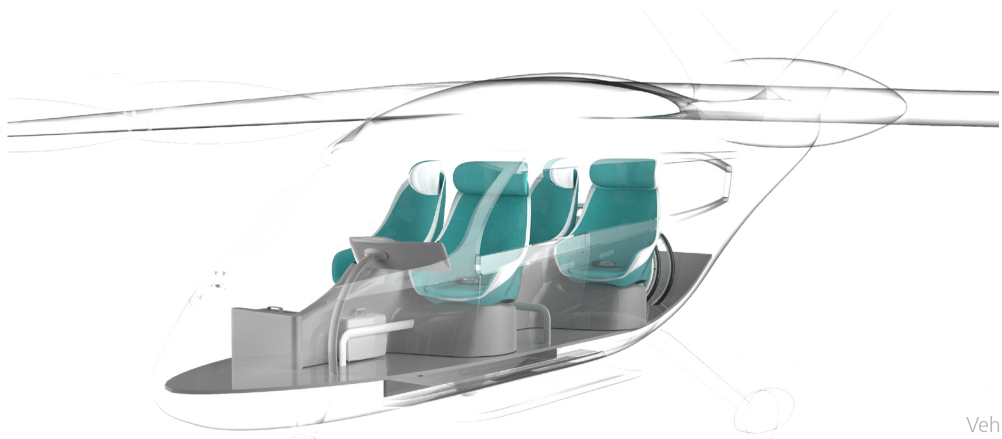
Comfort parameters related to seat spacing and width were derived from dimensions found in business class cabins in commercial aviation. The necessary storage space was defined based on average carry-on luggage dimensions and dimensions for standard wheelchairs.

A cabin layout was designed that meets the requirements of different passengers with the smallest and largest possible physical dimensions. Due to the use case of an airport shuttle, it was determined that at least four pieces of luggage should be carried in the cabin. A seat layout with two rows and two seats per row has been specified.

SEATS

Various seating concepts were evaluated by conducting an online survey in Germany in 2021. In the survey, proximity to fellow travellers, eye contact and level of perceived safety and privacy were investigated. Various seat designs were also evaluated in the survey, with inspiration for the seat designs being taken from the aviation industry (business class seat and first-class seat) and automotive industry, as well as novel seat design concepts.

Seat designs inspired by higher-class airline seats were well received by survey participants. Reasons included expected seating comfort, the presence of armrests, and especially the rotated seating position with U-shaped headrests for increased privacy. Less familiar seat models with novel shapes and no armrests were negatively received.



LUGGAGE AND STORAGE

Survey participants were also provided with different images of luggage storage concepts. The key factors that gained a positive rating among survey participants included sufficient storage space, easy accessibility of luggage during the journey, individual storage options, and secure attachment of the luggage.

To ensure sufficient headroom at a cabin height of 1.60m, no storage compartments or displays are envisioned for above the seating areas.

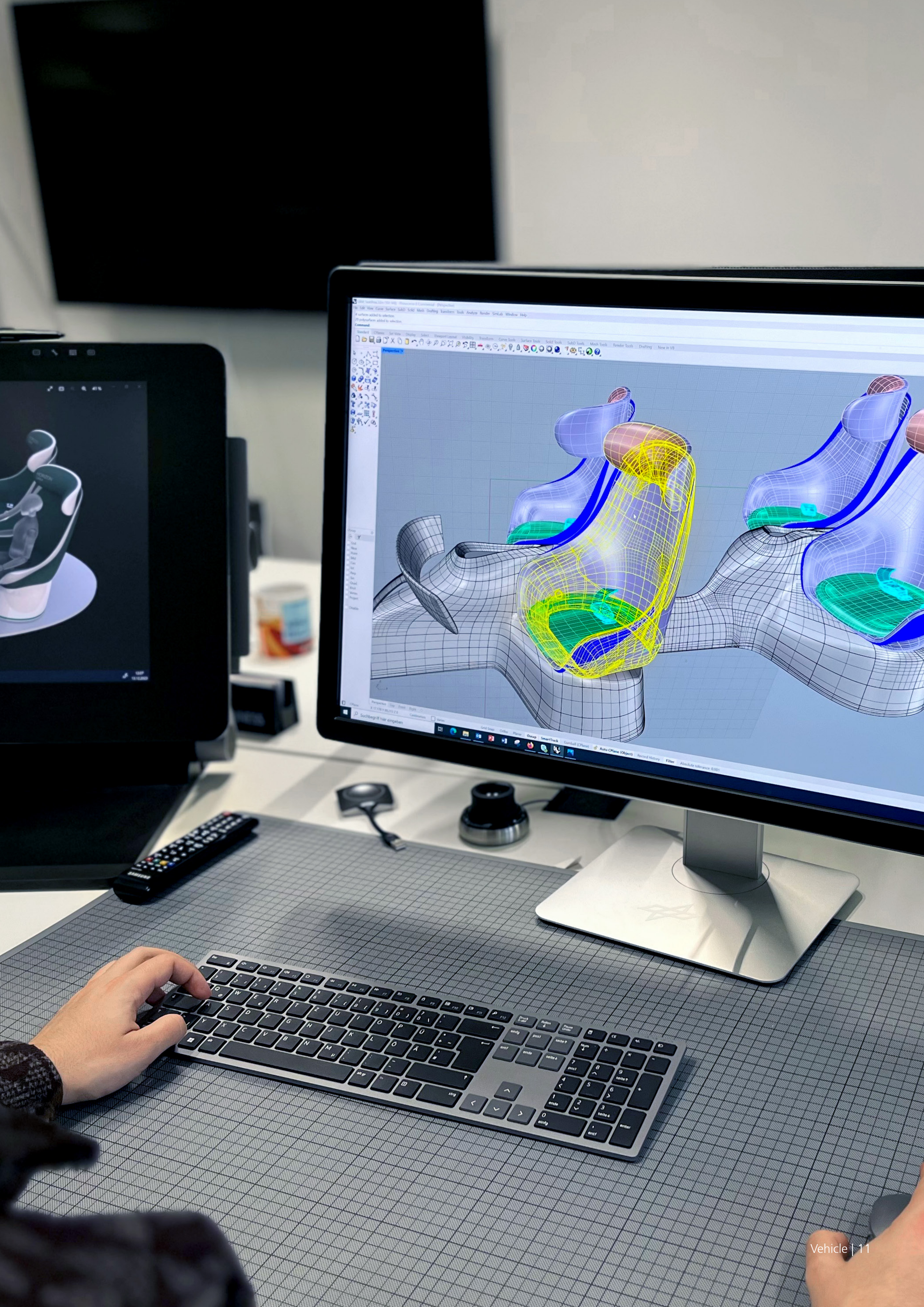
To achieve a barrier-free cabin design, storage of wheelchairs has also been taken into consideration. The storage space in the rear area has been defined for this purpose, and upon landing could be reached via a side flap from outside the vehicle.

Furthermore, different methods of securing the baggage in the cabin have been explored. It was important to ensure that bags do not move during the flight, while allowing simple storage and removal of luggage when passengers embark and disembark the vehicle. Securing suitcases and bags in front of the passengers was preferred so that travellers can access their belongings during the flight. The following image shows a 3D model of the overall view of the concept.

In this concept, three seats have been rotated in the direction of the windows to encourage passengers to look out the window, while the seat in the front part on the right-hand side remains unchanged. In this scenario, a pilot is included, but this concept should already be usable for autonomous operation cabin designs.

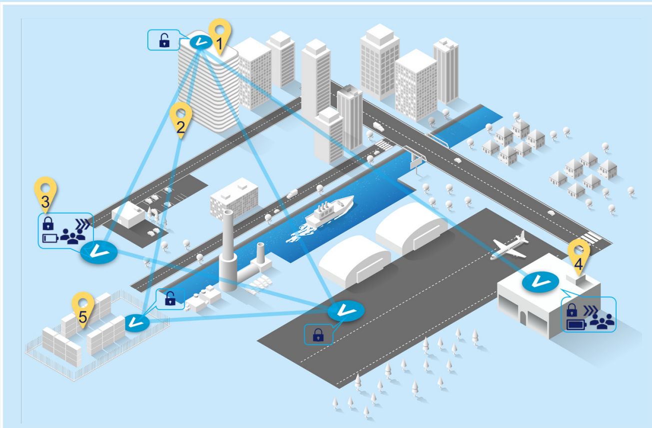
In addition to seating comfort, optimised storage compartments, minimalist design and customisable privacy features, the cabin design incorporates various comfort parameters based on feedback from potential user groups. The deliberate combination of minimalist and easily understandable functions with futuristic and complex design elements enhances the overall comfort and user experience.

The passengers' influence on the design can have a positive impact on acceptance and the perception of safety, leading to a higher willingness to use air taxis among the general population. Moreover, by addressing fears, desires, and concerns directly and incorporating them into the design concept in collaboration with user groups, the development process of autonomously operated air taxis can lead to increased acceptance in society.



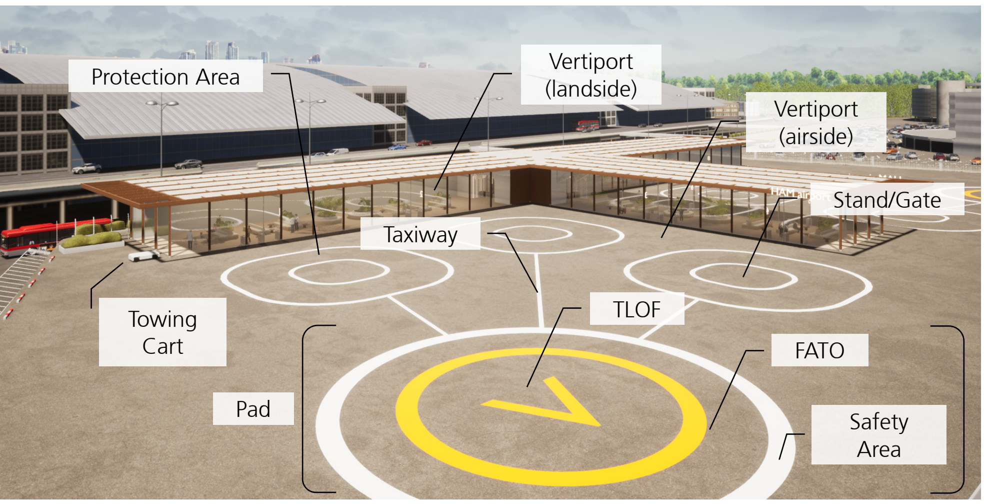
Vertidrome

The functional design and the technical equipment of vertidromes and vertidrome networks are both a challenge and a key driver for the operational deployment of air taxis, as well as the provision of UAM services. In the HorizonUAM project, the generic term "vertidrome" was introduced to describe UAM ground infrastructure used by Vertical Take-off and Landing (VTOL) aircraft. Vertidrome categories can be further distinguished between a vertiport, which is a fully equipped vertidrome with parking and charging spots, and a vertistop, which solely provides safe take-off and landing capabilities. A vertiport might additionally offer maintenance, repair and overhaul services. It can also act as a central "hub" in a hub-and-spoke network with smaller vertistops being located at the outer ends of the "spokes".



The research on vertidromes included the design and operation of individual vertidromes on a micro-level (1), but also extended to the macro-level by addressing vertidrome airspace network management (2) and network optimisation (3). Moreover, the opportunities and challenges of integrating air taxi services and vertidrome operations into an airport environment, thus controlled airspace were studied (4), and the approach of developing a UAM model city (5) in order to validate our concepts in scaled flight trials was introduced.

This image shows an example layout of a vertidrome and explains its surface features.



TLOF – Touch-Down and Lift-Off Area

FATO – Final Approach and Take-Off Area

The number and arrangement of pads, stands and taxi ways can vary. To evaluate the airside performance of a specific vertidrome layout, an assessment framework, named Vertidrome Airside Level of Service (VALoS), was developed. VALoS considers different stakeholder perspectives (e.g. air taxi operator, passenger, and vertidrome operator) and offers the opportunity to quantify a qualitative vertidrome design in strategic planning phases. The VALoS rating can be used to evaluate the performance of a specific vertidrome configuration for a given performance target and demand distribution.

Potential management concepts and procedures for conflict-free airspace operations were also investigated. One of the concepts was based on direct routes between vertidromes represented as four dimensional trajectories. A second concept made use of a rigid route structure and time-slot management. Exemplarily, 20 vertidromes within the city of Hamburg were considered in the networks. Average travel time savings of up to 43% compared to ground-based transportation could be reached.

In addition to urban airspace, vertidrome network capacity is a critical resource of the UAM network that, if optimised, can reduce the required vertidrome infrastructure and fleet size to a minimum. For the exemplary Hamburg network, a commuter scenario with 2,800 missions per day was set up. For efficient fleet management, the number of covered passenger kilometres is used as an optimisation parameter for sequence generation, effectively maximising the total distance traveled by passengers per day, and implicitly rewarding sequences with fewer empty seat kilometres. Simulation results showed that a fleet of 275 vehicles is required to operate all 2,800 missions. When assuming that batteries are swapped instead of recharged, the required fleet size could be reduced to 225 vehicles (-19 %), also resulting in 24 % less parking positions required.

Integrating a vertidrome at an existing airport poses a challenge to air traffic control (ATC). At the airport, controllers' responsibilities include the control and coordination of landing and departing traffic, as well as supervising traffic in the control zone. Adding air taxis to the traffic flow results in additional airspace users with performance characteristics rather different from conventional fixed-wing traffic. Hence, the goal should be to provide them with take-off and landing spaces independent of the runway system, and with favourable independent arrival and departure routes.

The control task itself should be designed in a way that the responsible air traffic controllers can maintain their situation awareness, and that the potential increase in workload remains feasible. The tactical part of the defined processes for the integration of air taxis was tested for feasibility in real-time human-in-the-loop simulations in DLR's Apron- and Tower Simulator with ten air traffic controllers for the reference use case Hamburg airport. In addition to conventional traffic in a peak hour including 44 movements per hour, fifteen air taxis were added per one-hour simulation run. Air taxi routes were visualised and active routes were highlighted on the radar screen in order to support controllers in their tasks. In addition, since air taxis are strongly exposed to the risk of wildlife strike due to the flight and performance characteristics of air taxis, information about critical bird movement in the area was displayed on the screen.

Within the simulation trials, it proved to be feasible to integrate air taxis as well as wildlife information into current airport operations. Even though the introduction of UAM traffic led to an increase in reported workload by 44 % while situation awareness reduced by 18 %, all controllers reported that the changes were all within tolerable limits. Moreover, there was a training effect observed with increasing the number of scenarios, indicating that any negative impact on controllers will decline with additional training. All controllers agreed that a working position dedicated to the handling of UAM traffic should be added in case of increasing UAM traffic. This should facilitate feasibility in higher traffic densities as well.

Safety & Security

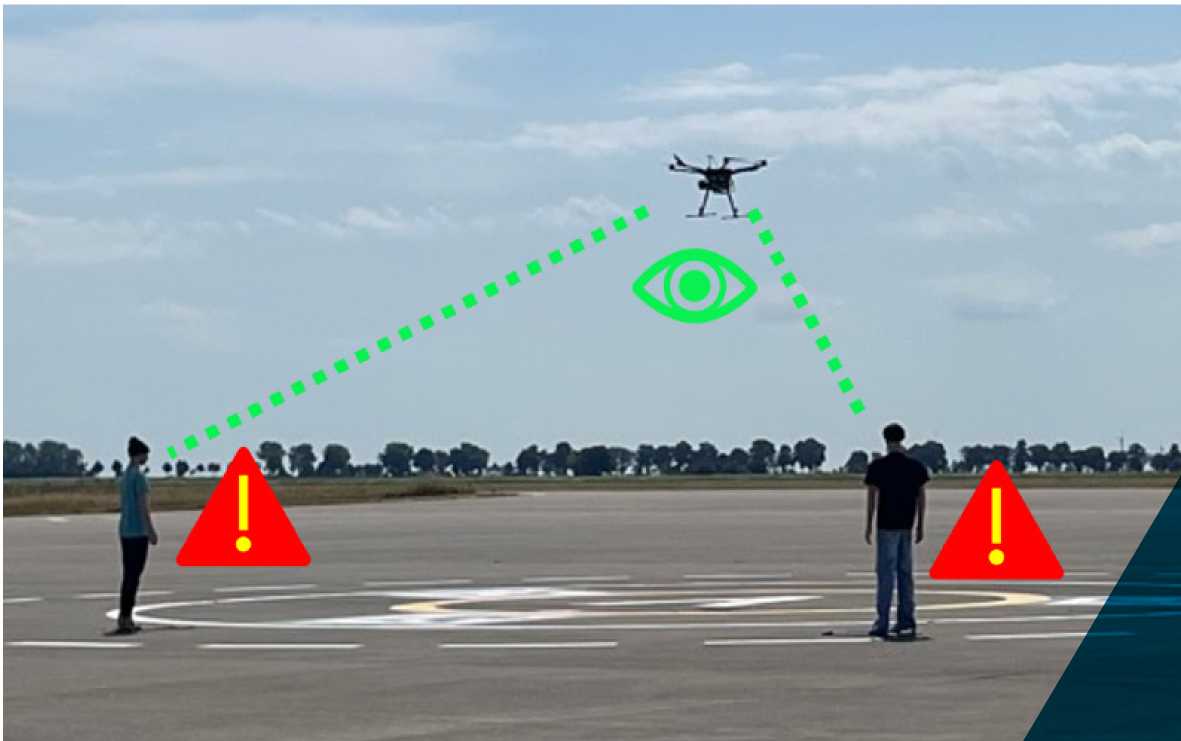
SAFETY

Safety is the main concern in aviation in regards to public acceptance and regulatory approval for new vehicles and use cases for UAM. Other airspace participants and persons on the ground must remain at the same level of safety that has been established today. This is a challenge for upcoming UAM systems. UAM will need to fit into the existing aviation system which has been established and is supported by a large number of regulations and standards. Integrating UAM into this system is expected to be a considerable challenge for many years to come.

SAFE AUTONOMY

With a growing number of air taxis, there will be an increased need for automation and autonomy. Machine learning (ML) technology has seen an immense of growth over the last years, with demand even in safety-critical areas. One example, the detection of persons at a vertidrome during the landing approach. During the HorizonUAM project, this use case of ML technology was developed and demonstrated in flight tests. The detection is performed on board the drone during flight. This would help to ensure that no person on the ground is endangered during landing procedures. This in itself can make the future operations safer. This ML model was developed as one example use case to address the main research: the safe integration of autonomy and specifically ML technology into the safety-critical aviation domain.

The challenge is that ML technology is often considered a black-box system with complete lack of transparency about how they work, and how they calculate results and outcomes. Traditional software is developed based on rules and sequences of commands. On the other hand, ML algorithms are trained by given data, without explicit rules. This is a huge contrast to traditional software. Therefore, it is difficult to comply to existing standards as



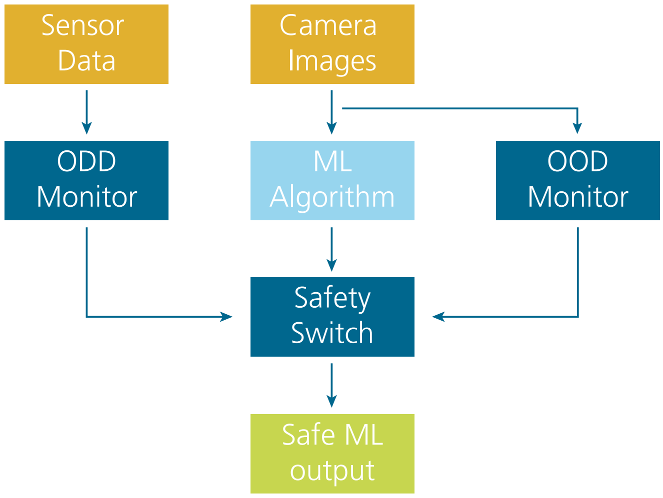
The picture shows the landing approach of a simulated air taxi at a vertidrome. There are two persons detected by the onboard autonomy and the landing approach is aborted.

established in aviation for safety-critical software. Standardisation organisations and authorities are currently developing and establishing new guidelines for the safe use of Machine Learning (ML) in the aviation domain. The European Union Aviation Safety Agency (EASA) has introduced an Artifical Intelligence (AI) roadmap, including first guidance material on how to certify ML systems. Within the project, this process of regulation and standardization of ML was closely monitored and DLR participated in several standardization activities and working groups.

SAFE OPERATION MONITORING

One important finding of this research is the importance of the supervision of the automation functions by an independent safety monitor. When an automation function is carried out by an autonomous algorithm, it is important to verify that the results make sense in the context. The same task is performed by a human pilot, he constantly monitors the situation and checks for any anomalous behaviour. With the Safe Operation Monitoring, DLR developed an automated version of this important supervision task. One important aspect for the utilization of ML is its Operational Design Domain (ODD). This concept describes operating conditions and environmental constraints in which the ML component is expected to operate safely. By supervising the ODD during the flight, the trustworthiness of the ML component can be assessed.

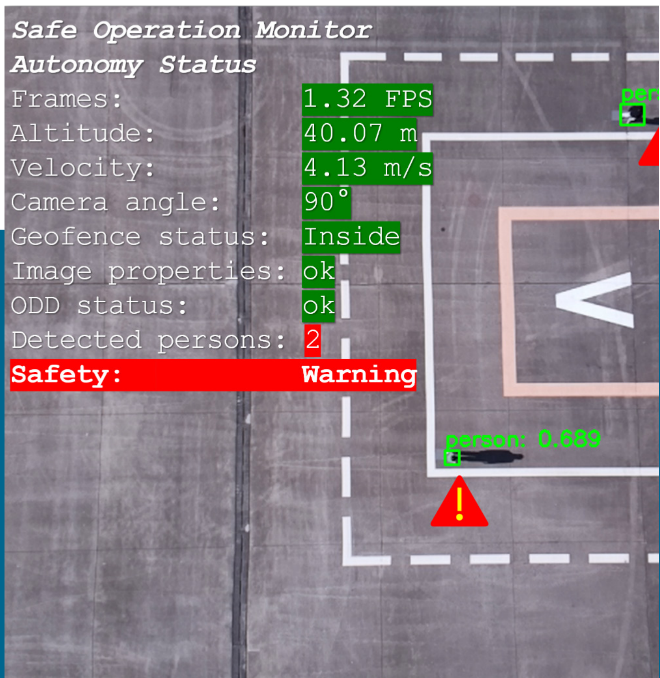
High-level architecture for safe ML operation



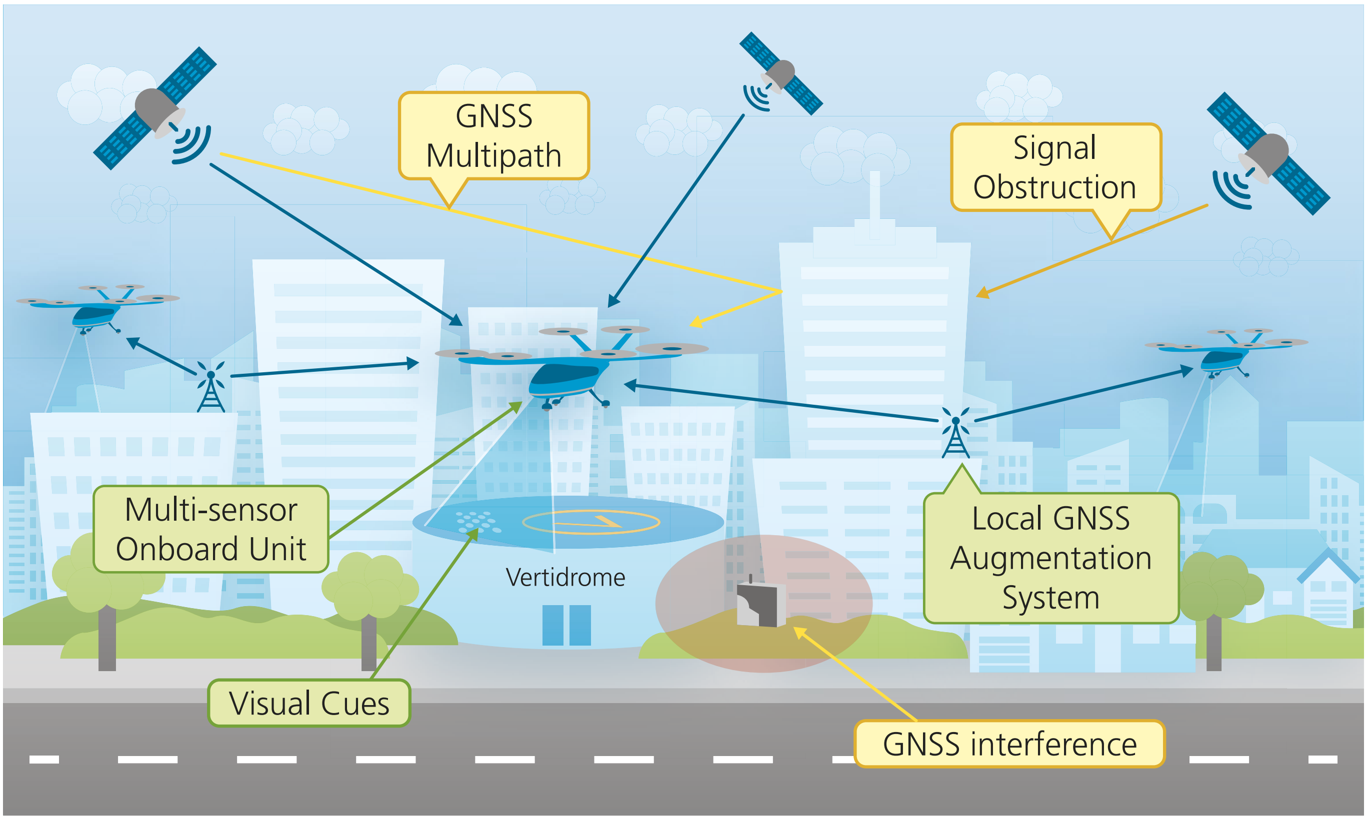
FLIGHT TESTS

Several flight tests were performed during the project. The goal was to generate sets of images that are within and outside the ODD, as well as to investigate the impact of ODD supervision.

The test area includes two vertidromes and a container cluster of six units to represent a scaled down model city. The humans to be detected were represented by mannequins which look very similar to real humans on aerial images. In total, twelve flights have been completed during the flight tests at different times of the day. The altitude, flight speed, camera angle and positioning of the mannequins have been changed between flights. Across all flights, 6993 images have been recorded with the onboard camera.



Visualization of the Safe Operation Monitor (SOM)
This picture shows a video stream of the SOM. It gives the remote pilot or safety pilot all necessary information to assess the situation and assess the status of the onboard autonomy. In this case the autonomy is detecting two persons on the vertidrome.



COMMUNICATION

For the realisation of future UAM, reliable information exchange based on robust and efficient communication between all airspace participants will be one of the key factors to ensure safe operations. Due to the high density of piloted and new remotely piloted and autonomous aircraft, air traffic management in urban airspace will be fundamentally different from today.

Unmanned Aircraft System Traffic Management (UTM) will rely on pre-planned and conflict-free trajectories, continuous monitoring, and existing communications infrastructure to connect drones to the UTM. However, to mitigate collisions and increase overall reliability, unmanned aircraft still lack a redundant, higher-level safety net to coordinate and monitor traffic, as is common in today's civil aviation. In addition, direct and fast information exchange based on ad-hoc communication is needed to cope with the very short reaction times required to avoid collisions and the high traffic density. Therefore, DLR developed a drone-to-drone (D2D) communication and surveillance system, called DroneCAST (Drone Communication and Surveillance Technology), which is specifically tailored to the requirements of a future urban airspace and will be part of a multi-link approach.

As a first step towards an implementation, DLR equipped two drones with hardware prototypes of the experimental communication system and performed several flights around the model city to evaluate the performance of the hardware and to demonstrate different applications that will rely on robust and efficient communication. Furthermore, DLR presented a multi-link approach with a focus on an ad-hoc communication concept that will help to reduce the probability of mid-air collisions and thus increase social acceptance of urban air mobility.

MULTI-SENSOR NAVIGATION

Reliable navigation systems play an essential role in the safe operation of UAM. As a safety-critical application, the passengers expect the vehicles to guarantee safety by not only knowing where they are in order to make operational decisions, but also by ensuring how accurate and reliable this position information is. As a result, the navigation system is required to provide both high accuracy and high integrity.

In the urban environments, multi-sensor navigation is required, since global navigation satellite systems (GNSS) face challenges like low number of satellites in view, multipath propagation due to surrounding buildings as well as radio interferences. However, there are technical and standardisation gaps in certification for multi-sensor navigation, as there are still no standardised navigation performance requirements for UAM operations, and the quantification of integrity remains a technical challenge for some sensors.

Therefore, DLR designed a multi-sensor navigation architecture for reliable vertiport operations. The architecture includes both an onboard multi-sensor navigation unit including GNSS receiver, inertial sensors, cameras and barometers, and local reference infrastructures for the sensors. Additionally, progress is being made on requirements analysis, developments and initial validation of the integrity description for the multi-sensor system towards future standards and certifiable navigation systems for the safe UAM operations.

CYBER SECURITY

UAM vehicles heavily rely on interconnected systems, which increases vulnerability to cyber threats. Thus, vehicles require robust cybersecurity to protect passengers, infrastructure, and data integrity.

Additionally, the interconnected UAM system creates numerous vulnerabilities, with each connection point serving as a potential entry for cyber-attacks. Securing communication channels via encryption, secure protocols, and regular audits is vital to mitigate risks of data breaches and system compromise.

Moreover, the collection and transmission of sensitive data by UAM vehicles raise privacy concerns. Protecting passenger information and ensuring compliance with privacy regulations is essential. Employing data encryption, access controls, and minimisation techniques can mitigate privacy risks and build passenger trust.

Additionally, integrating UAM into urban infrastructure creates new attack surfaces, demanding securement of charging stations and air traffic management systems. This entails applying security-by-design principles and collaborating among UAM developers, regulatory bodies, and cybersecurity experts to set industry-wide standards and best practices. HorizonUAM addressed the first development steps of a security perimeter for UAM to already consider security in a holistic and system-wide manner during the design phase and beyond.

The main success of the security investigations was an extensive list of primary and supporting assets, as well as listing the threats on these assets, and the possible vulnerabilities which could be exploited by the threats. These lists provide an overview of the main security concerns in UAM.

CONCLUSION

The goal is to retain the high level of safety in aviation, while enabling new types of UAM operation. This is a challenge as UAM sets new requirements in autonomy, communication, navigation, and security. The research done by DLR facilitates the use of new concepts and technology to establish safe and secure UAM operations.

Social Acceptance

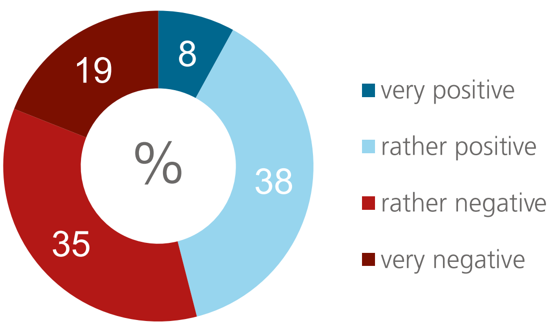
Public acceptance is seen as the key to a successful implementation of UAM. In order to assess current social acceptance levels, and to help people to imagine a future where urban air mobility is part of everyday life, a large-scale telephone survey and immersive air taxi simulator experiments were conducted.

At the end of 2022, computer-assisted telephone interviews were conducted within the German population. A total of 1001 interviews took place, each lasting on average 21 minutes (carried out by BIK Aschpurwis+Behrens GmbH). Survey participants were asked about their attitudes towards civilian drones in general and air taxis in particular. Overall, civil drones tended to be evaluated rather positively, while no such trend was evident for air taxis in the survey. Answers regarding the attitude towards air taxis ranged from very negative to very positive. **46% of participants had a positive attitude towards air taxis, 46% would be willing to use an air taxi within a rural area, and 46% would be willing to travel with it between a rural area and a big city.**

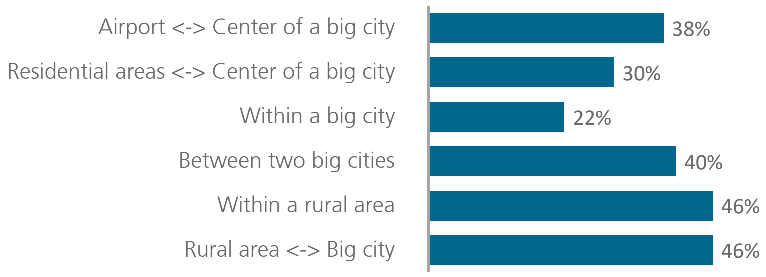
Furthermore, a virtual reality study on the well-being of passengers in an autonomous air taxi was conducted. 30 participants experienced an airport shuttle flight in the city of Hamburg in a mixed-reality air taxi simulator. The influences of a flight attendant on board and a re-routing of the flight on perceived well-being were assessed. The results show that the presence of a flight attendant had no statistically significant influence on the well-being of participants. 16 out of 30 participants stated that an attendant on board is not necessary. Nevertheless, eight found it reasonable for the introduction phase and nine remarked an increase in perceived safety due to the flight attendant. Furthermore, the results show that with an attendant on board, the re-routing scenario was rated better compared to the scenario without an additional crew member on board. With respect to information needs, the three most relevant pieces of information were travel time, changes of flight route due to obstacles or other traffic, and flight route.

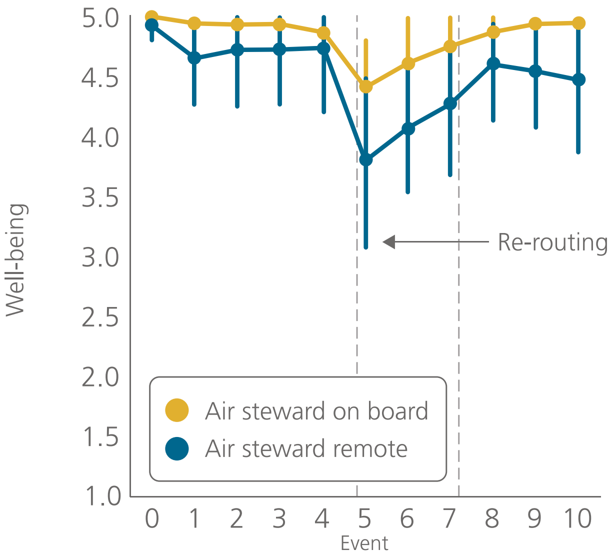
A second virtual reality study focused on the well-being of passers-by when air taxis were simulated in the airspace. 47 participants experienced civil drones flying above Braunschweig, as well as an air taxi landing from the perspective of a pedestrian walking through the city.

Attitudes towards air taxis



Willingness to use an air taxi





The study showed that well-being was at a higher level when fewer drones were visible and when they were flying at higher altitudes. Well-being was slightly reduced when drones or an air taxi were visible as compared to conventional traffic only. Further important factors for social acceptance will likely be safety and security, affordability, accessibility, how environmentally friendly the mode of transport is, and the noise levels it creates.

SAFETY AND SECURITY

Concerns about safety and security may be an initial barrier to the adoption of UAM. There are concerns that UAM users, other airspace users, and persons on the ground may be endangered. Regulations and standards need to be tailored towards the safe and secure implementation of UAM.

AFFORDABILITY

There are concerns that UAM may not be affordable for lower- and middle-income households. As part of the drive to increase social acceptance, UAM services should not be limited to the "wealthy few". Since operating costs and ticket prices are closely linked, the challenge is to reduce operating costs. Failure to achieve significantly lower operating costs compared to helicopters will jeopardise the affordability and, thus, market acceptance.

ACCESSIBILITY

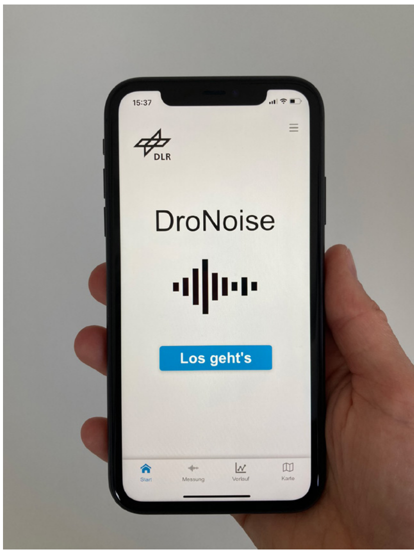
This refers to the ability to quickly reach the departure vertidrome from the origin of a trip, and to reach the destination of a trip from the arrival vertidrome. Analyses have shown, that access and egress times to and from the vertidromes (as well as processing times to change modes of transport) strongly influence the attractiveness and, thus, the demand for UAM. Accessibility can be improved by locating the vertidromes closer to centres of high demand or by reducing travel time to the vertidromes. The placement of vertidromes is an optimisation task: a balance must be found between site requirements, costs and other issues, such as nuisance to neighbours from noise and visual pollution to avoid threatening social acceptance.

ENVIRONMENTALLY FRIENDLY MOBILITY

The goal of environmentally friendly mobility is to maintain and ensure the mobility of people and goods without placing excessive burdens on people and the environment in terms of greenhouse gas emissions, air pollutants, noise, land use, wildlife, and resource consumption. Noise is perceived as a risk of UAM. This includes the noise generated by the vehicles during take-off, landing, and flight.

A smartphone app, called DroNoise, has been developed and trialled. This app makes it possible to measure and assess the noise and subjective annoyance levels of unmanned aerial vehicles. This app was tested during live drone flight demonstrations in Cochstedt in 2023. This app could serve as the basis for creating noise pollution maps. Based on such maps, it would be possible to adapt flight routes and profiles such that drone noise could be distributed as equally as possible among residents.

Our flight tests have shown that the smartphone app can be a way of involving the public in the design processes for unmanned drone traffic.



CONCLUSION

Within the German population, the perception of air taxis is balanced between positive and negative ratings. Thus, crucial to the future of the potential UAM market are thoughtful approaches to the design of the vehicles and vertidromes, the configuration of the transport system, and integrating it into existing systems. To achieve a positive reception, it is necessary to consider the far-reaching impacts of a new transport system on citizens.

6

Demonstration

WHAT IS U-SPACE?

U-space as defined by the European Commission is a set of new services relying on a high level of digitalisation and automation of functions and specific procedures, designed to provide safe, efficient and secure access to airspace for large numbers of unmanned aircraft, operating automatically and beyond visual line of sight.

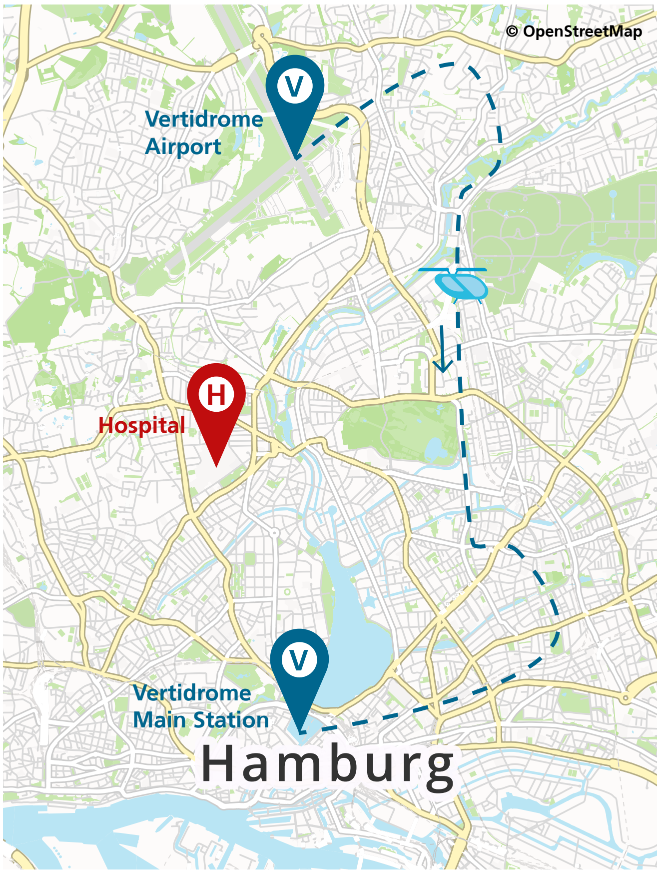
Thus, U-space, also called UTM (Unmanned aircraft system Traffic Management), is the future of airspace integration for drones and air taxis in Europe. U-space services are under development, but are not yet commercially available. For demonstration in the project HorizonUAM, a central U-space cloud service was simulated through a local messaging server.

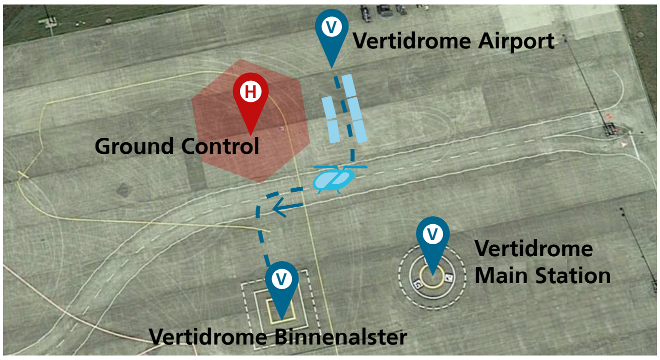
VERTIDROME MANAGEMENT

A prototypical vertidrome management tool was created to demonstrate the scheduling and sequencing of air taxi flights. The vertidrome manager is fully integrated within U-space and receives real-time information on flight plans, including requests for start and landing and emergency notifications. Additional information coming from other U-space services (e. g. weather information) can be accessed on request. The U-space cloud services were simulated through a local messaging server using the protocol MQTT (Message Queuing Telemetry Transport). The integration was demonstrated in a scaled flight test environment with multicopters (< 15 kg) representing passenger-carrying air taxis.

THE POWER OF AUTOMATION

The demonstrated vertidrome management tool relies on a human controller to manage incoming requests. Future developments envision a higher degree of automation on the vehicle side, but also on the controller side. In future research, the integration at existing airports and the interface to conventional air traffic management will be investigated as well.





SCALING DOWN A HAMBURG USE CASE

The vertidrome manager and its integration into a prototypical U-space environment were successfully tested in live demonstrations conducted between May and July 2023 at the National Experimental Test Center for Unmanned Aircraft Systems located near Cochstedt, Germany. A model city on a scale of 1:4 was erected from shipping containers, and vertidrome landing pads were built on the ground. An airport shuttle use-case was selected for demonstration, similar to a scenario that previously had been evaluated in a virtual reality passenger study.

The demonstration also included a scenario where a flight was rerouted to an alternative landing site due to a blocked landing pad at the destination vertidrome. Another aircraft detects a passenger on the landing pad, aided by a runtime monitored machine learning algorithm for the detection of persons in image data. Multi-sensor navigation algorithms were in use for navigating in urban canyons. The demonstrations successfully proved the prototypical vertidrome manager to be functional.

CONCLUSION

A limited number of air taxis could be managed by conventional air traffic controllers. However, the use of U-space for vertidrome management, as shown above, has the advantage of being scalable for high-density air taxi operations. The advantage of U-space is the high degree of digitalisation inherent in the system.

Future Perspectives

The DLR project HorizonUAM has contributed to two aspects of UAM research, the development of individual components as well as their harmonisation for use in an optimised overall system. Expertise on UAM vehicles, related infrastructure, operation of UAM services, and public acceptance of future urban air transport was drawn together. In particular, the complexity of Urban Air Mobility with its interdependencies has been addressed by the project.

The results of HorizonUAM indicate that UAM could become technically feasible in the near future. However, the following key challenges need to be addressed before UAM can be widely implemented:

Profitability: For their widespread adoption and acceptance by users, manufacturers and investors, it is essential to ensure that air taxi services are economically viable even with low ticket prices. The requirement, therefore, is to minimise direct and indirect operating costs of the UAM transportation system. Suitable business models need to evolve to enable UAM to appeal to more than a niche market. The evolving regulatory framework for UAM needs to be matured and harmonised internationally in order to ensure safety, security, and environmental sustainability, but also scalability in order to make UAM financially feasible.

Complexity of the UAM system: Managing complexity and filling existing knowledge gaps to remove uncertainties is necessary to achieve a highly efficient UAM system. This results in a complicated distribution of responsibilities among UAM stakeholders including users, industry, governments, public institutions, regulators and communities. All of these stakeholders must work together to shape the transportation system of the future. In particular, the interactions of the individual UAM system components, its interdependencies and the effects on the feasibility of the overall transportation system need to be further investigated to develop an economically viable and scalable UAM system that maximises the benefits not only for the users, but for society in general.

Social acceptance, particularly community acceptance: Acceptance may be one of the critical factors in UAM implementation in many societies. Appropriate measures will need to be taken to address the key concerns of noise, actual and perceived safety and security, high energy consumption, visual pollution and land use. In order to offer seamless transportation, the integration of UAM into existing transportation networks is essential and can improve the efficiency of the overall transportation system with benefits for users and society. It is of highest importance to keep the general public informed about urban air mobility and its implications. Communities have to be actively engaged in the design of a potential future transportation system to make it a success. Therefore, information based on scientific analysis, but tailored towards a nonscientific audience, should be provided by the UAM community. Real-life demonstrations are recommended to increase the familiarity with UAM in the general public.

In conclusion, it has been shown that UAM might complement existing transportation systems in the future. Ultimately, it is a matter of the constituent systems working together in a way that the overall system is both economically feasible and socially acceptable.

DLR will continue to work on the idea of Urban Air Mobility. Future research will be extended by considering new multimodal and regional use cases. Thus, the initial urban scope will be extended to evolve from Urban Air Mobility to Advanced Air Mobility, and furthermore to Innovative Air Mobility, with the overall goal of integrating drone and air taxi services into existing transportation systems.

THIS PROJECT IS THE RESULT OF THE COLLABORATION OF THE 10 DLR INSTITUTES:

DLR Institute of Flight Guidance (Coordinator)
DLR Institute of Combustion Technology
DLR Institute of Flight Systems
DLR Institute of Air Transport
DLR Institute of Communications and Navigation
DLR Institute of Aerospace Medicine
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