Bauhaus Luftfahrt
The Aviation Think Tank

Putting Urban Air Mobility into perspective

A White Paper summarising the core aspects of passenger Urban Air Mobility scientific research at Bauhaus Luftfahrt on vehicle, vertiport and transport system level.

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Key Messages on Urban Air Mobility

This White Paper summarises the core aspects of passenger Urban Air Mobility (UAM) research at Bauhaus Luftfahrt. We take the opportunity to make use of the gained scientific evidence from our research on vehicle, vertiport and transport system level to derive the following six key messages:

Key Message #1: UAM shows a potential time benefit compared to car travel only in heavily congested cities if short ground access and egress to vertiports is ensured.
Key Message #2: Most UAM studies present long-term estimates for UAM modal share of around 1%, mainly due to high expected travel cost. Main cost drivers are investment costs for vehicles and infrastructure as well as personnel cost, paired with low vehicle capacities.
Key Message #3: With a market share in the range of 1% UAM will not have a noticeable positive impact on existing modes of transport (e.g. congestions reduction) while resulting in a significant amount of flights (>>tens of thousands of daily flights)
Key Message #4: Vertical take-off and landing aircraft are highly constrained to small payloads (typically 4-6 seats) in the UAM context to be compliant to noise emission requirements and space restrictions
Key Message #5: UAM requires a substantial amount of ground infrastructure. The overall throughput of the UAM system is highly limited by number and size of the vertiports. To allow for a throughput of around 100 passengers per hour, a vertiport of a size of a football pitch is required.
Key Message #6: CO_2 emissions are only reduced if UAM replaces trips by cars with a combustion engine. As vertical take-off and landing is the most energy-intensive way of flying, electric energy consumption and the required installed battery masses are significantly higher compared to electric cars. Therefore, UAM in most scenarios is less resource-efficient than all other modes of transport using direct electric energy.

Overall Message: UAM is no game changer within the passenger transport industry and complements existing transport modes building upon existing relevant use cases of helicopters. For future application, socially, environmentally, and economically sustainable application cases need to be found. Promising applications could be in regions with geographical specificities such as islands or mountains, or for user groups with a high willingness to pay, such as tourists, or as a complementing feeder mode for long-haul aviation. However, sustainable business cases for OEMs and operators are feasible in the future. Even if UAM stays as a niche, eVTOL vehicle production will likely outnumber current helicopter production. Pre-requisites are either lower total costs or noise reductions compared to helicopters. Besides the commercial passenger transport application, there is a diverse range of other applications for small and big drones like for cargo and supporting services, which enable high automation, especially for air traffic management.

Key premises: Our key messages are derived from two fundamental conditions. Urban areas are space-limited or the space within cities is rather valuable, which requires small aerial footprint of transport infrastructure in general and UAM in particular. Otherwise, conventional take-off and landing concepts like Bauhaus Luftfahrt´s CentAirStation and CityBird approach could be better alternatives in terms of passenger throughput, transport costs and cities connectivity to other regions, enabled by range benefits of S/CTOL aircraft. The second fundamental condition is the importance of noise within cities. As there is scientific evidence that higher noise levels affect people´s health and quality of life within cities, it can be expected that different regions deal with the issue of noise in different ways. For European cities, higher noise levels will not be acceptable.

Outlook

As the UAM sector explores novel developments and technologies including (electric) propulsion systems, autonomy, certification, infrastructure, operations, business models, and novel market actors, Bauhaus Luftfahrt continues to monitor and evaluate the transfer potential to the existing commercial aviation.

Introduction to Urban Air Mobility and Bauhaus Luftfahrt´s research focus

Urban Air Mobility (UAM) is often described as a novel mode of transport; however, it is more akin to an evolution of helicopter services within cities based on the technological progress in batteries enabling electric propulsion, sensor, communication, and computing technologies. While there are also other applications like cargo and other service-related purposes, Bauhaus Luftfahrt focuses its research purely on passenger-related transport applications for an early understanding of the overall impact on the mobility sector in general and on aviation in particular, where passenger transport has a dominant role. Passenger UAM research has been conducting at Bauhaus Luftfahrt during the last five years up to and including the year 2022. Our research was embedded and complemented by our extensive network of expertise from academia and industry, enabled by a well-balanced funding through the industry and the public sector at the national and European levels.

UAM is an emerging transport system with safety level targets derived from conventional aviation. It requires various stakeholders to be involved, and an interaction between them is needed to create a working ecosystem in which a viable business model can be found for each partner. The core UAM ecosystem consists of the vehicle manufacturer, the vertiport operator, the service provider and the public authority. For the implementation of UAM within cities, we see three key requirements:

1) UAM has to be intermodal, requiring integration into the existing transport infrastructure within cities both physical (passenger processes) and digital (single ticketing etc.),
2) UAM has to be competitive in terms of transport cost, passenger throughput, space requirement, and emission levels compared to other transport modes, and
3) social embracement as well as political support have to be ensured.

To get an early understanding about the potential of UAM, the fundamentals of potential supply, largely influenced by vertiport throughput and vehicle capacity, and passenger demand, a function of generalised transport costs in comparison to alternatives, need to be evaluated. Therefore, Bauhaus Luftfahrt focuses its research on transport system modelling, vertiport scaling and vehicle performance analysis.

An intermodal UAM system

UAM adoption rates are affected by UAM service levels (e.g. travel time, ticket fares, safety level, waiting times, service reliability, access and egress times), users' characteristics (age, income, gender, education, country, and household status), and other external factors (Fu et al. 2019; Al Haddad et al. 2020).

While often time savings are stated to be the main advantage of UAM, a closer analysis shows that access to and egress times from the flight as well as passenger process times to change modes have been identified as key drivers of UAM demand. Travel time savings can easily be lost, therefore all parts of the itinerary need to be efficiently designed and operated (Rothfeld et al. 2021). UAM does not offer significant time-saving potentials in urban areas if cities are not heavily congested. Even public transport options are likely to be faster.

Using data from current transport systems and using taxi-service price levels for UAM, most studies converge towards a market share of 1% (Plötner et al. 2020). To enable taxi prices, it is necessary to operate UAM vehicles at maximum capacity while not having a pilot on board (highly to fully automated operation). In the short- to mid-run, significantly higher operating cost and ticket prices are to be expected, which is going to further decrease UAM's modal split.

With a market share in the range of 1% UAM is likely to neither result in significant reductions in congestion for road transport, nor is public transport likely to benefit from a reduction in overcrowding. While the market share likely is too small to have a noticeable positive impact on existing modes of transport it is still going to result in a significant amount of flights. A back-of-the-envelope calculation shows that already in a relatively small metropolis (e.g. Munich) with approximately 1.5 million inhabitants and an assumed three trips per inhabitant and per day and a 1% modal split for UAM, 45,000 flights per day would occur, requiring a relatively large vehicle fleet. So while UAM is likely to be a niche in the overall transport sector, it might still be an economically viable business case for vehicle manufacturers and operators. A scenario-based assessment of the global UAM vehicle market showed a global demand of 0.5 million to 5.5 million UAM vehicles by 2050 (Straubinger et al. 2021a). When contrasting this to current helicopter production numbers, the relevance of this market becomes clear.

While UAM's impact on the overall transport system is expected to be relatively small, it still has the potential to significantly change the way people travel for those using the novel service. Offering a fast and presumably uncongested transport alternative may result in demand shifts induced by changing commuting patterns or induced demand. In the long run, the significantly faster travel alternative could even lead to changes in location choices with people moving to more rural areas with cheaper housing and hence to urban sprawl (Straubinger et al. 2022).

Yet, due to the rather high fares that are expected, different parts of society might be affected in different ways. While households with higher incomes are expected to benefit from the introduction of UAM, households with lower incomes that do not use the service might face welfare losses (Straubinger et al. 2021b). Therefore, it is essential to identify use-cases that benefit large parts of society and keep negative externalities of UAM service provision in mind.

While most UAM vehicles are expected to be operated fully electric, the energy demand for aerial vehicles (especially take-off and landing) is high. Comparing this to the energy demand of electric cars or public transport per passenger kilometre shows that UAM introduction in general does not offer energy saving potentials and hence is not in line with overall transport policies aiming to reduce emissions (Straubinger et al. 2022). Only for specific geographical regions with natural barriers like mountains or water, or regions with no direct transport infrastructure, energy may be saved.

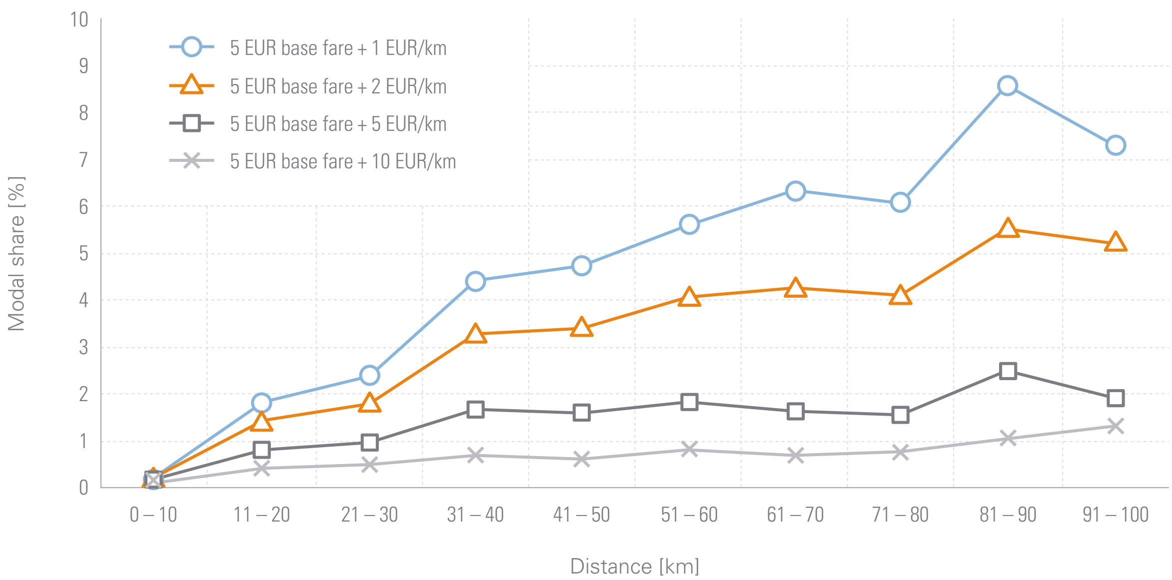

Figure 1
Exemplified on Munich Metro-politan region, UAM gains no relevant market shares at typical urban distances which results in no noticeable impact on existing modes of transport even in case of radical low ticket prices (Plötner et al. 2020).

eVTOL vehicles

Electric vertical take-off and landing aircraft (eVTOLs) are envisaged as transport vehicles for UAM. Compared to the most successful VTOL aircraft type, the helicopter, distributed electric propulsion is anticipated to significantly decrease noise emissions during flight, reduce operating cost and enable aircraft configurations capable of more efficient cruise flight. Furthermore, the use of batteries as an energy source implies the elimination of direct emissions during flight. All these points can be confidently considered as enablers of UAM. However, there are major challenges on the way to a commercially viable aircraft for city operations.

Electric power distribution opens up a large number of different possible aircraft configurations. Accordingly, there is a high number of projects worldwide that develop different kinds of eVTOL vehicles. Generally, the aircraft types can be divided into two classes: Configurations without wings and those with wing-borne cruise flight. The former are usually more efficient in hover flight but have a comparatively high energy demand in cruise flight. Therefore, achievable ranges are well below 100 km even with advanced battery technology assumptions (see also figure 2). Configurations featuring wing-borne cruise flight are more efficient and enable significantly longer ranges. Assuming an advanced battery specific energy of 300 Wh/kg on system level, flights of 100 km and more are achievable (see also figure 2). However, they rely on the shortest possible take-off and vertical climb phases due to significantly lower efficiency in hover flight. In addition, wing-borne configurations are expected to require significantly more certification effort due to the higher system and flight dynamics complexity. Thus, the potential entry into service of these aircraft types may be at a later point in time. Critical to all eVTOL vehicles are the in-flight power reserve requirements. These could significantly limit the operational range and thus prevent numerous use cases for these aircraft.

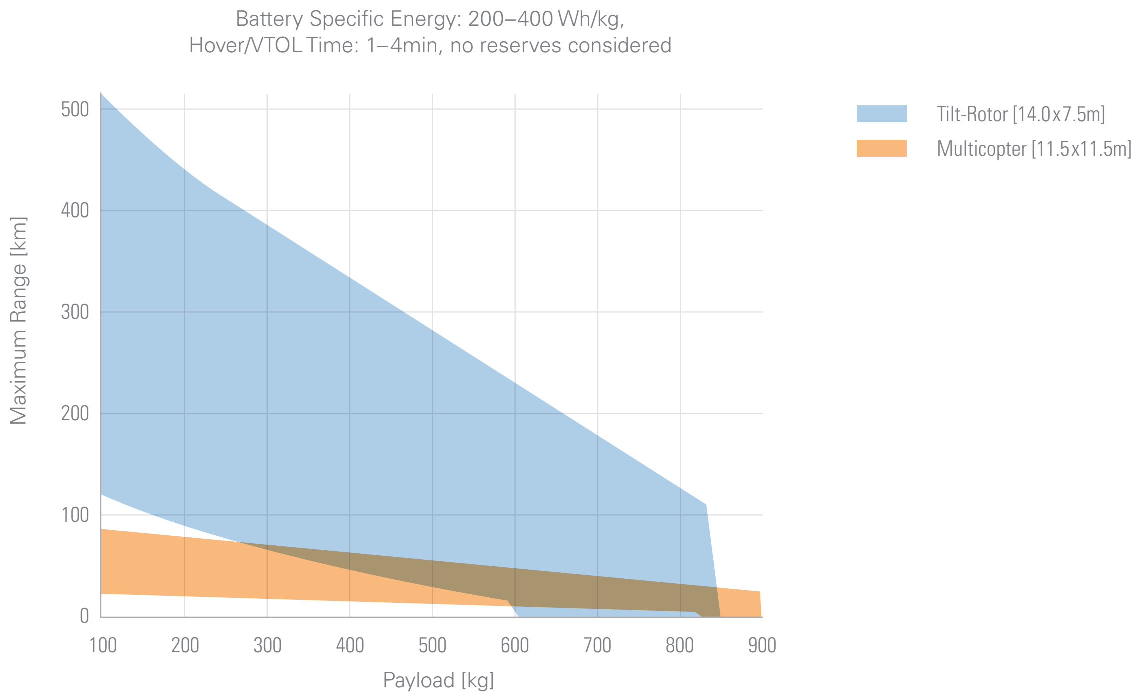

Figure 2
eVTOLs vehicles are highly constrained to smaller payloads (≤ 9 passengers) and battery performance. Tilt-wing configurations show signifcantly better range capabilities due to their lift generation in cruise by fixed wings.

In addition to the operational range, a sufficiently large number of passengers per aircraft is important for numerous specific use cases and transport capacity in general. From a certification perspective, EASA is considering a maximum of nine passengers for this class of aircraft. However, requirements regarding the maximum aircraft footprint and noise emissions in combination with technological restrictions could significantly reduce this number. Power and energy requirements, but also rotor noise reduction potential, significantly depend on a low disc loading of the rotors, i.e. a large available rotor area per kilogram take-off weight. Limiting the maximum dimensions of an aircraft, for example, to meet the requirements of the ground infrastructure (see section Vertiport), directly limits the maximum payload for a given operational range. Assuming again a battery specific energy of 300 Wh/kg and a target range of around 100 km a maximum aircraft box size of 12 by 12 m limits the maximum capacity to four passengers (see also figure 3). In general, lighter eVTOL vehicles with lower payloads are more likely to be able to meet the presumably stringent noise regulations for inner-city operation due to a lower disc loading.

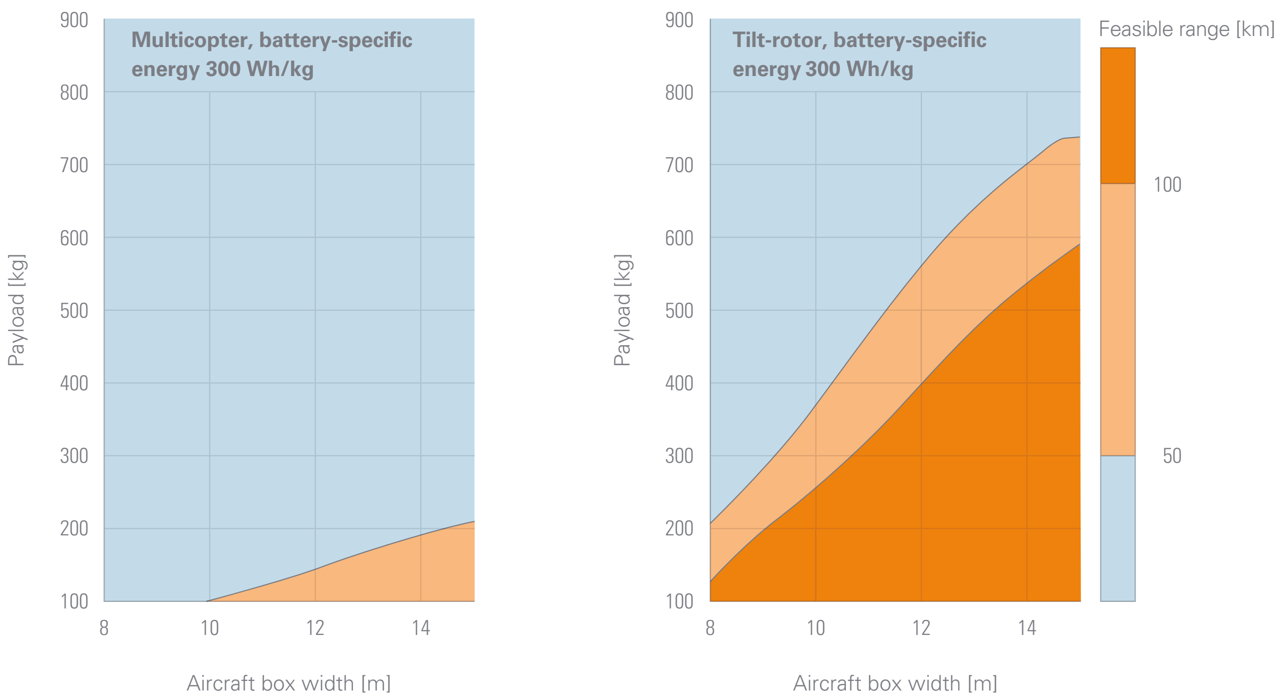

Figure 3
Range capability of eVTOL vehciles are significantly impacted by their size. With same payload and battery larger vehicles are capable to fly longer missions.

Considering the energy efficiency of eVTOL vehicles, the actual range of a representative mission must be taken into account. While on short distances, the penalty due to vertical take-off and landing is large and leads to high energy amounts per passenger-kilometre, the consumption drops significantly on longer distances (Shamiyeh et al. 2018). Under favourable assumptions – again an advanced 300 Wh/kg battery specific energy, a fully occupied aircraft and autonomous flight without a pilot – aircraft types with wing-borne cruise flight can achieve the energy efficiency of the currently most efficient battery-powered cars (with a load factor of 25 %) (see also figure 4). Considering lower load factors, piloted flight or the need of empty flights to relocate aircraft due to limited space at vertiport infrastructure, the energy efficiency of UAM is several times lower compared to battery-powered vehicles on ground.

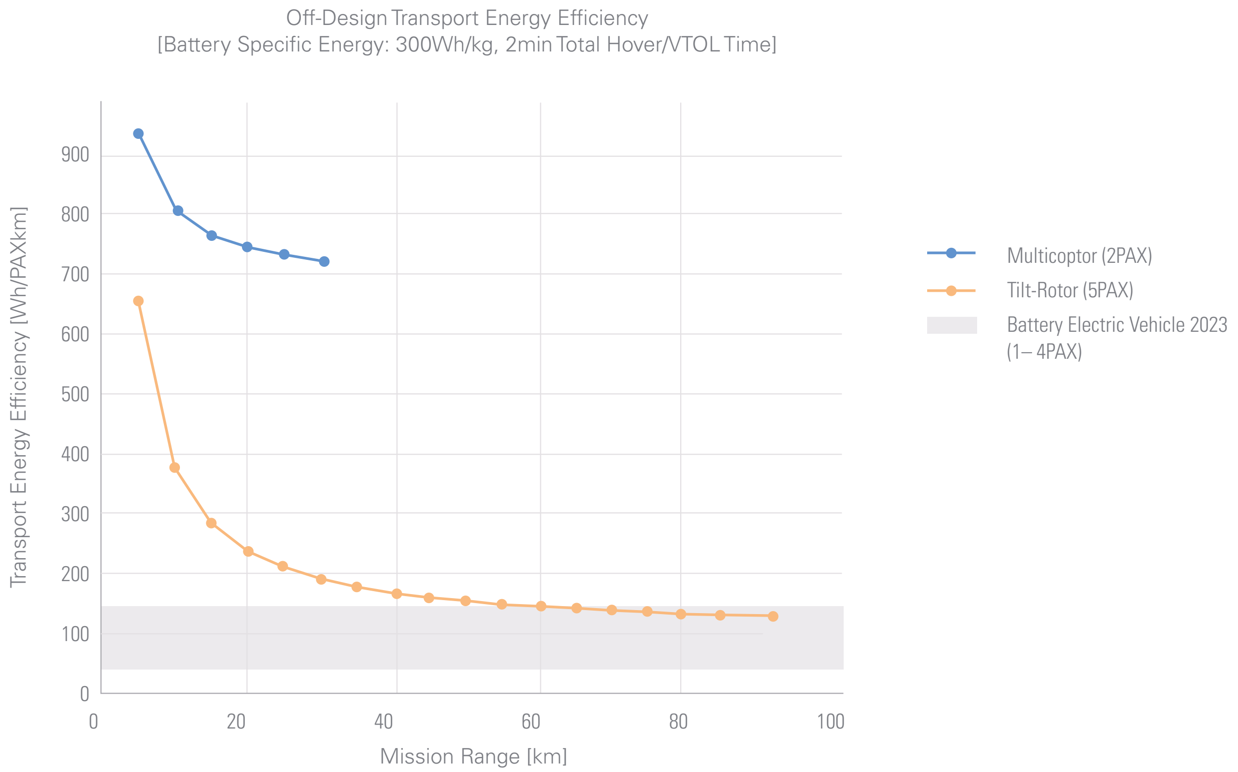

Figure 4
On short routes vertical take-off, landing and hover significantly increases the required transport energy. Only on longer routes, for tilt-rotor configurations and nearly 100 % loadfactor, eVTOLs have same transport energy efficiency on a Wh/PAXKm basis as elctric ground vehicles only if their loadfactor is around 25 %.

Vertiport

UAM ground infrastructure is commonly referred to as vertiport and encompasses three parts: (1) the surrounding airspace, (2) the vertiport airfield, and (3) the passenger terminal (Schweiger and Preis 2022). A major and less frequently addressed challenge is the design and operations of the airfield. With our research on vertiport airfield design, we identified the geometrical and operational dependencies as well as the direct impact by eVTOL vehicles. We could show how the hourly passenger throughput per area as a performance indicator of a vertiport airfield is influenced by different eVTOL designs. Our research shows that vehicles with a small maximum dimension yield the highest passenger throughput capacity (Preis and Hack Vazquez 2022).

Further studies, conducted by means of agent-based simulation, indicate that there are no significant economies of scale regarding vertiport size and achievable throughput per area. They also provide evidence that longer eVTOL vehicle charging times significantly reduce passenger throughput per hour and area. To ensure stable vertiport operations, a balance between arriving, parked and departing vehicles has to be achieved and slight deviations can already result in delays (Preis and Hornung 2022). Therefore, we conclude that UAM requires a substantial amount of land area for its infrastructure.

The passenger terminal is not expected to be a bottleneck for operations due to fast passenger handling similar to regional airports, further accelerated through automated check-in and smart security screening. Vertiports can only handle a limited number of flights per hour, most strongly limited by the available space and the thereby constrained vertiport airfield. In particular inner-city environments will not allow repurposing of large surface areas for air transport even when solving the noise issues. Adding the low capacity per eVTOL vehicle, UAM will either be forced into a niche or high numbers of vertiports will need to be built across a city.

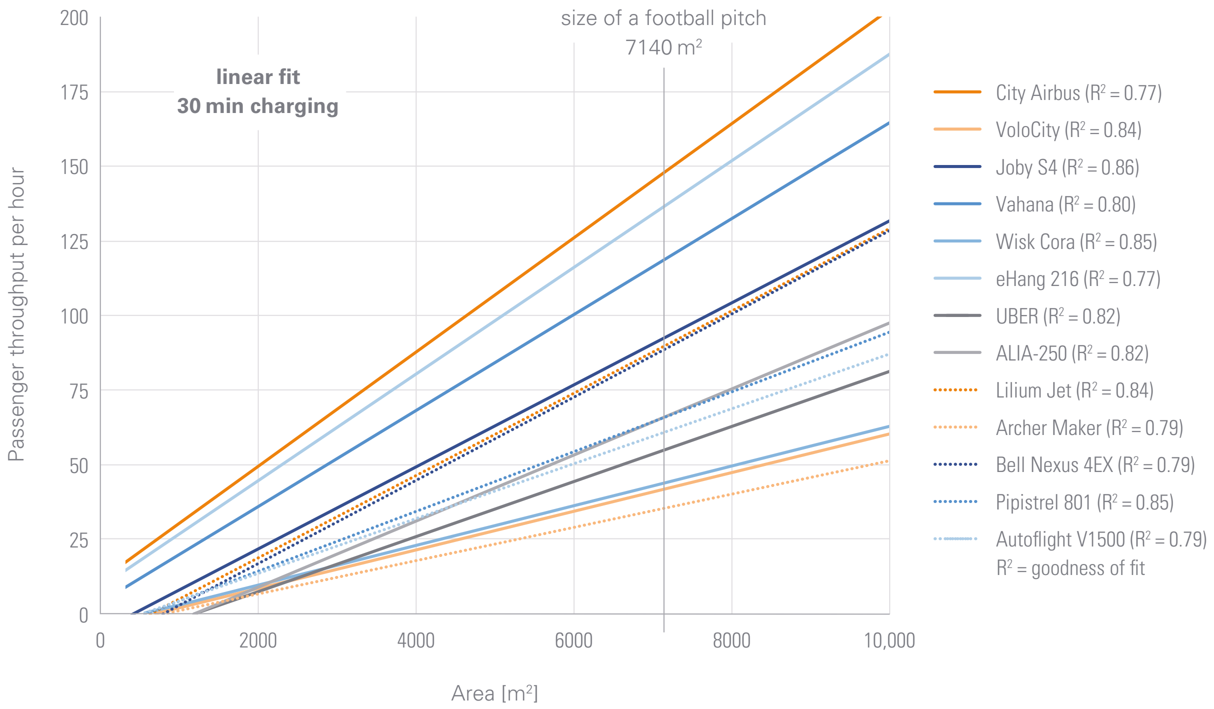

Figure 5
UAM requires substantial amount of land area for the vertiport airfield to transport a rather small amounts of passengers; eVTOL vehicle design plays a major role (Preis and Hack Vazquez 2022).

Conclusion

The research conducted within Bauhaus Luftfahrt between 2017 and 2022 allows the conclusion that UAM will not be a game changer for (urban) mobility. Nevertheless, there can be successful business cases within the UAM and civil drone sector (cargo, supporting services or medical and emergency applications). For these socially, environmentally and economically sustainable application cases need to be found. UAM should aim at complementing existing transport modes and building upon existing relevant use cases of helicopters. Promising applications for UAM could be in regions with geographical specificities such as islands or mountains, or for user groups with a high willingness to pay, such as tourists, or as a complementing feeder mode for long-haul aviation.

We believe that European applications of UAM should be designed through co-creative processes with the aim of creating an equitable and sustainable transport system improving the connectivity between rural and metropolitan areas. Other areas around the globe face different challenges such as hypercongestion in mega cities. Additionally, the relevance of concerns such as privacy, noise or equity might be perceived differently across cultures.

As the UAM sector continues to explore and harness novel developments and technological advancements in the areas of propulsion systems, autonomy, certification, infrastructure, operations, business models and novel market actors, Bauhaus Luftfahrt is continuing to take a realistic perspective on the novel sector while evaluating the transfer potential to and from the conventional aviation markets.

About Bauhaus Luftfahrt e.V. – The Aviation Think Tank

Bauhaus Luftfahrt is an internationally-oriented think tank and independent interdisciplinary research institution. The non-profit organisation is funded by the Bavarian Ministry for Economic Affairs, Regional Development and Energy, by the German Aerospace Center (DLR) and the four aerospace companies Airbus Group, Industrieanlagen-Betriebsgesellschaft (IABG), Liebherr-Aerospace and MTU Aero Engines. The team of around 50 employees deals with the future of mobility in general and with the future of air travel in particular. The goal of the research work is to consider the complex system of aviation from different points of view holistically, including the technical, economic, social and ecological aspects.

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