/Advanced Air Mobility at Airports

Shaping the Future of Aviation

Living ideas – Connecting lives

Agenda

Executive Summary

Advanced Air Mobility (AAM) has the potential to significantly disrupt today's landscape of urban mobility with impacts similar to the introduction of the automobile over a century ago. In fact, since the introduction of the concept of so called eVTOLs (electric vertical take-off and landing vehicles), often referred to as air taxis, more than 400 different eVTOL designs with 150 companies competing in the emerging AAM market, have received a total of 7.4 billion US dollars in funding.[1]

The realization of the human dream of flying over congested urban areas seems closer than ever before, but will be heavily dependent on the development of a comprehensive AAM ecosystem. While eVTOL manufacturers can still claim to be driving forces in the market, receiving more than 85% of all AAM funding, further investments in other parts of the ecosystem, especially its landing infrastructure, are required.[2] Investors will need staying power to overcome all hurdles as AAM continues to develop. For example, the required certifications are one of the most underestimated challenges for a successful large-scale AAM deployment. But those who overcome these obstacles could be rewarded as future leaders of a global market that accounts for 5-12% of world GDP.

By 2040, we will see the AAM market having condensed to three major use cases: transporting passengers, transporting goods as well as military and state applications. For airport operators, the most relevant use case will be the passenger transportation, which is expected to generate 50% of AAM passenger revenues from airport shuttle services.[3]

Airport operators can participate in several parts of the extended AAM value chain. Natural choice is the provision of landing infrastructure at existing airports and the erection of new vertiports in traffic-favourable locations. Connected infrastructure like parking, charging services for electric vehicles (EV), as well as non-aeronautical infrastructure help to generate important revenue streams which might be required for a viable vertiport business case. Airport operators can also provide ground handling services, leveraging synergies with their ground handling provider subsidiaries and could also participate in the new fueling market for eVTOLs: the charging and replacement of accumulators.

To enable large-scale commercial AAM operations at airports, airport operators need to integrate eVTOLs into their complex airport ecosystem, confronting them with a variety of interdisciplinary challenges. This report identifies nine key challenges to be solved in order to allow for effective integration of AAM operations.

Finally, this report provides a strategic framework to help airport operators take the necessary steps to establish an economically viable and operationally efficient vertiport at airports.

1 (Lufthansa Innovation Hub, 2021) (The Vertical Flight Society, 2022)
2 (Lufthansa Innovation Hub, 2021)
3 (Morgan Stanley & Co. LLC, 2021)

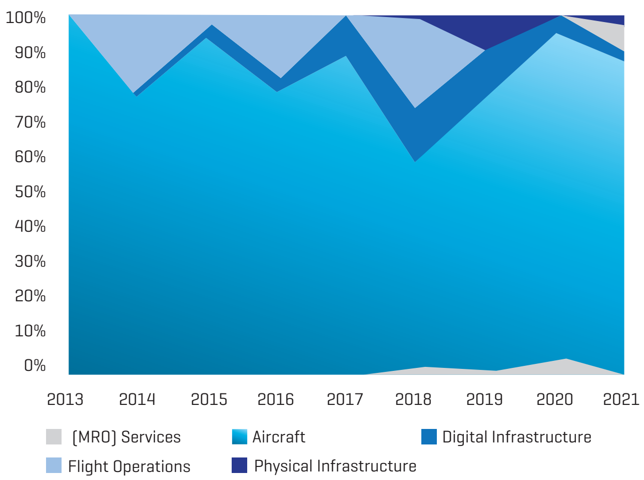
Introduction

What has started as a dream of a few automobile and aviation enthusiasts over a century ago, when aviation pioneer Glenn Curtis debuted his autoplane in 1917, could soon become reality: Flying people and goods in electric vertical take-off and landing vehicles (eVTOL) over congested urban areas has the potential to significantly disrupt today's landscape of urban mobility.

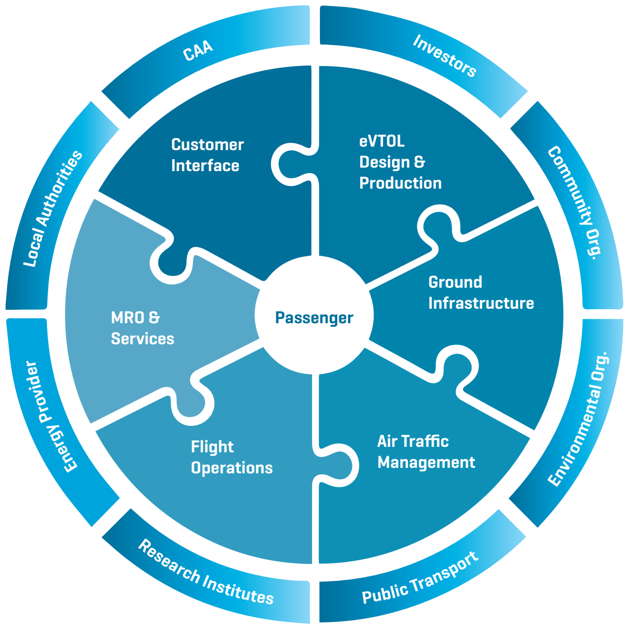
Since the concept of eVTOL has been introduced by AugustaWestland, Opener and Volocopter in 2011, developments have formed around the globe, with most innovations centered in European and North American countries. Up to date, this resulted in more than 400 different eVTOL designs[4] and over 150 companies[5] competing in the emerging Advanced Air Mobility (AAM) market. They are backed by numerous investors, which have injected a total of 7.4 billion US dollars in about 580 founding rounds.[6]

Aircraft manufacturers can still claim to be driving forces in the market
With strong marketing departments, aircraft manufacturers manage to get most of the public attention and seem to be the shining stars of the emerging AAM branch. In fact, eVTOL manufacturers account for up to 85% of all AAM fundings. Nevertheless, during the recent years, venture capitalists also started injecting more capital in other parts of the AAM value chain, e.g. digital and physical infrastructure, as well as flight operations.

Share of historic AAM investments



AAM ecosystem



Joint effort and investments are needed across the AAM ecosystem
Future success of AAM will heavily depend on the development of a comprehensive ecosystem – spanning vehicle manufacturer, fleet operator, ground infrastructure provider, MRO (maintenance, repair and overhaul) and AOG (aircraft on ground) services, as well as air traffic management and digital infrastructure.

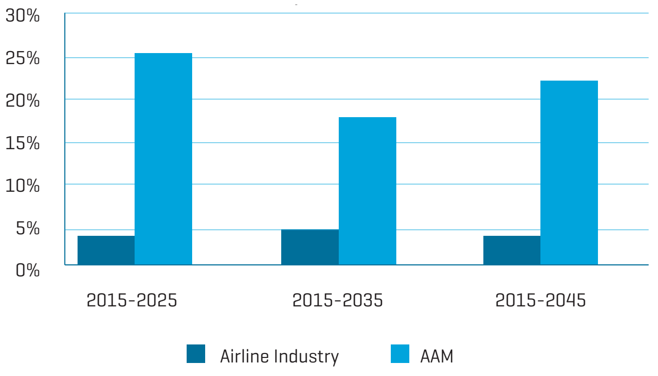
The AAM ecosystem requires interdisciplinary expertise not only from prime function players like vehicle manufacturers and flight operations, but also from supporting stakeholders such as authorities and communities. To fully unlock the potential of AAM, a viable ecosystem with close collaboration between all stakeholders needs to be established. The common vision: to provide passengers with an easy, flexible and safe way to travel via eVTOLs – be it with or without luggage, scheduled or on-demand. A unique customer experience worth repeating.

Building a comprehensive AAM ecosystem not only requires funding for vehicle manufacturers, but needs more investments in other parts of the ecosystem, too. AAM stakeholders therefore need to attract investors with convincing business models, solid partnerships throughout the value chain and good marketing.

[4] (The Vertical Flight Society, 2022)
[5] (Kolin Schunck, 2021)
[6] (Lufthansa Innovation Hub, 2021)

Investments in the AAM ecosystem could pay off
The first eVTOL flights for demonstration and certification purposes have attracted a big audience of investors and have led to high valued SPAC-driven (Special Purpose Acquisition Company) market entries of eVTOL manufacturers. Investors have raised high expectations and are hoping for a quick return on investment. However, projections show that these expectations may not be met in the short term.

CAGR Airline Industry vs. AAM



After the initial hype led to numerous highly valued market entries, it is expected that the Compound Annual Growth Rates (CAGR) of the total addressable market (TAM) declines at first due to the obstacles in the climbing path for AAM: One of the most underestimated hurdles for the large-scale deployment of AAM manifests in regulatory requirements.

They comprise vehicle and infrastructure certification as well as air space and cyber security requirements, which still need to be established. Other obstacles include public acceptance, required advances in battery and propulsion technology for large-scale AAM deployment, as well as infrastructure requirements to build an AAM network.

Overcoming these hurdles takes time. Regulators around the globe are establishing and harmonizing certification guidelines, while industry standards are being developed and infrastructure is being designed and built. In addition, advances in propulsion systems and energy storage are required to increase the range of eVTOLs, create a large-scale AAM network and ensure public acceptance.

Overcoming the obstacles in the initial development phase could be rewarded with big market opportunities. AAM has the potential to replace substantial road trip volumes in densely populated areas and could be a revolution in the mobility sector – comparable to the introduction of the automobile.

Regulatory, infrastructure, and technology hurdles are likely to be overcome by the end of this decade, making commercial deployment of AAM possible at least in the early 2030s.

First movers and early adopters will need staying power, but could be greatly rewarded as future leaders in a global market that accounts for about 5-12% of world GDP.[7] At first glance, this forecast might seem exaggerated when compared to today's aviation industry, which contributes around 4.1% to global GDP.[8] However, this can be explained by the fact that AAM complements and replaces existing auto and shared mobility services, freight transportation, airline services, as well as military and state applications. Besides autonomous drones for cargo transport, which have great potential especially in remote areas, much of the predicted TAM results from the replacement of auto and shared mobility models. Autonomous aircraft are simply far superior economically to such terrestrial models.

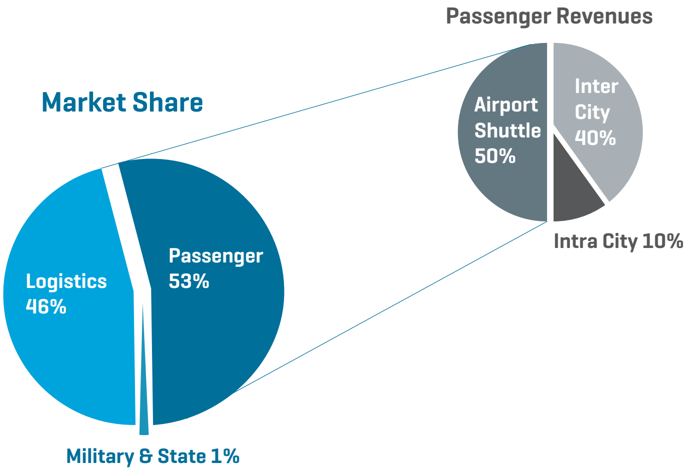
It's not just about the money: AAM creates positive externalities
In just a few years from now, about 60% of the world's population will live in urban regions and megacities. Increasing urbanization poses major challenges for future generations: By 2030, more than 500 million people will be affected by traffic congestions every day.[9] This not only has an environmental impact, as traffic congestion contributes to 20% of the terrestrial transport sector's yearly greenhouse emissions, but also results in lower levels of road safety.[10]

AAM can help solve these challenges. It promises average time savings of 15-40 minutes for city to airport transfers, while reducing local emissions by almost 100%. By adding a third dimension to urban transport, AAM will help to reduce traffic congestions significantly. Smart on-demand mobility solutions will furthermore reduce average commute times and minimize the economic impact of traffic congestion, which is estimated to cause 97 billion US dollars in lost productivity.[11] Alongside these advantages, AAM will have a positive impact on the number of road accidents, as it is expected to be 1500 times safer than current road modes, assuming that AAM will have the same level of safety that is currently mandated for commercial airline transport.[12]

7 (Morgan Stanley & Co. LLC, 2021)
8 (International Civil Aviation Organization, 2022)
9 (Urban Air Mobility: Escaping the Traffic Jam in the Air, 2018)
10 (University of California Transportation Center, 2010), (Marchesini & Weijermars, 2010)
11 (INRIX, Inc, 2018)
12 (European Union Aviation Safety Agency, McKinsey & Company, 2019)

The Potential Use Cases in a Nutshell

Potential AAM market and revenue share



By 2040, we will see the AAM market having condensed to three major use cases: moving passengers, transporting goods, and military and state applications.

The lion's share will be almost equally distributed between passenger and logistics transport. Military and state applications will be important for early acceleration of the emerging AAM branch, but will see a negligible market share in the long run.

Passenger transport

At first, the passenger market can be seen as a niche market that will establish itself as a complement to existing means of transport. Services will be comparable to today's helicopter services and will initially be of particular interest to wealthy travelers and experience seekers who are less price sensitive and appreciate the benefits of AAM. Technological advances, increasing automation and economies of scale will eventually reduce operating costs and enable lower travel expenses, which in turn will attract more price-conscious customers. In the long term, from 2040 onwards, we expect AAM to establish as a premium ride service, comparable to today's taxi services.

The increasing number of eVTOL manufacturers has resulted in numerous different passenger eVTOL designs. Most eVTOLs are designed for a special purpose. The mission profile, in particular the relative proportion of take-off, climb and landing maneuvers, has a major impact on the design trade-off concerning the hover and cruise flight efficiency. While multirotor concepts elevate hover efficiency, they decrease cruise performance. In general, these designs are more suitable for inner city use cases. High cruise efficiency can be achieved with wing designs that also have a positive effect on range. However, these designs result in larger overall dimensions and reduced hover efficiency – a design best suited for longer distances, e.g. intercity flights.

The different application profiles can essentially be summarized into three relevant passenger use cases:

Illustration of different use cases

Intra city air taxis will fly in densely populated urban areas, covering distances of up to 50 km. They will fly from city vertiports to city vertiports and supplement existing urban means of transportation, like cars, taxis, buses and other public transport. Intra city operation is the most demanding passenger use case. In order to exploit its advantages over existing urban transport modes, a comprehensive vertiport network is essential, which means high investment in infrastructure is needed. Since inner city routes tend to be short, intra city air taxis will have more turnarounds than other passenger AAM use cases. And as successful AAM business models require high vehicle utilization, intra city business models may generate less revenues than use cases that cover longer flight routes.

Inter city air taxis comprise flights of up to 200 km between different cities. These services will most likely be scheduled and are most promising in regions with poorly developed public infrastructure. Although the number of inter city flights will be lower, they will cover longer distances, resulting in fewer unproductive turnarounds. This, in turn, will lead to higher revenue per flight compared to inner city flights. Additionally, inter city flights generate greater time savings for users than inner city flights. Since time savings is one of the key promises of AAM, this will result in inter city flights becoming relatively more expensive compared to inner city flights. Inter city flights could be a potential playground for airport operators, as they can be operated from small city airports. Small city airports can already provide most of the infrastructure needed, are often integrated into the public transport network, and could therefore easily be developed into future intermodal transport hubs.

Airport shuttles cover flight routes of up to 50 km and will serve cities with major airports, which are often located distant to city centers. They are expected to be scheduled services on defined routes. Due to long flight distances, vehicle utilization can be almost as high as for inter city use cases, but will still remain lower because of air traffic regulations around dense airport air spaces. Integration of eVTOLs in airport terminal air spaces will be crucial for the development of airport shuttle services and should allow for independent AAM and airline operation. Airport shuttle services could initially target high-density business travel routes to airports which are used by a less price-sensitive customer base. These are business travelers, as well as some financially strong individuals, who are willing to pay a premium for airport shuttle services.

Logistics transport

Emergency and rural delivery are expected to be the first mass-commercializable end-market for drone delivery. First cargo drone operations can already be seen today, covering the last mile of parcel delivery in cities to the end customer with lightweight drones. Initially payload and range are very limited, with ranges up to one mile and payloads of up to 20 kg. In the long term, from around 2030 onwards, as batteries improve and the range and payload of freight drones increase, middle mile deliveries from distribution centers to stores or micro distribution centers in urban areas will be possible. However, large-scale freight eVTOL drones with a range of more than 300 miles and a payload of more than two tons are not expected to be in service before 2040.
Since short-term operations are expected to be for last-mile delivery of lightweight packages only, and middle-mile delivery to rural stores and warehouses will merely begin in 2030, airports will initially play a negligible role in eVTOL cargo operations. Still, there may be promising use cases for modern airports with aerotropolis infrastructure nearby, where AAM drones could be deployed to serve the airport city.

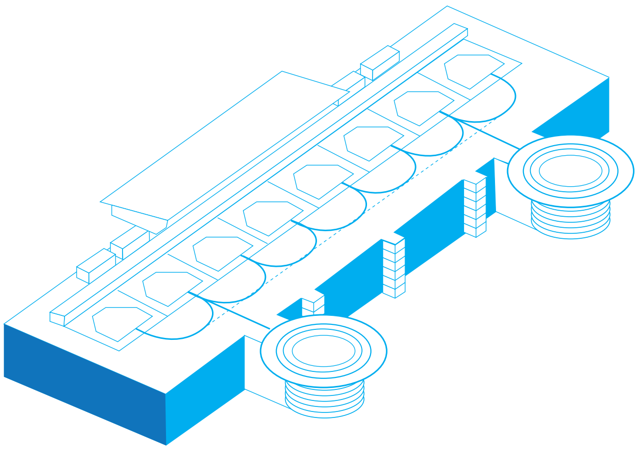
Military & state applications

Military applications are a very important accelerator for technology developments and large-scale AAM operations. Military programs, like the US Air Force's Agility Prime program are seeking to accelerate the development of AAM. They provide manufacturers with testing resources and allow for first government use cases which generate revenues for OEMs. Future military eVTOL applications could be used wherever troops and material need to be moved, replacing costly helicopters. They could also assist in last-mile supply delivery and medivac missions.

State applications could include a variety of different use cases: search and rescue as well as emergency operations appear to be the most promising and are likely to be among the first ever eVTOL use cases (compare to eVTOL orders from SAR operators like ADAC Luftrettung). eVTOLs could also assist in law enforcement use cases, like border patrol and crowd surveillance.

Vertiports are an Important Element of the AAM Ecosystem

Exemplary schematic vertiport design on a car park



The infrastructure components at vertiports are comparable to helicopter landing sites. Vertiports will have at least one Final Approach and Take-Off Area (FATO), a defined area over which the eVTOL completes its final phase of approach to a hover or landing and from which the take-off maneuver is initiated.[13] Besides the FATO, vertiports wil provide at least one Touchdown and Lift-off Area (TLOF). This area needs to carry the dynamic or static load-bearing of the designed eVTOL, dependent on whether the TLOF is located within in the FATO, or collocated with eVTOL stands. Their size, and in particular the size of the protection areas, will differ from current heliports due to the different flight characteris-tics, which may e.g. imply a larger clearway to also allow for winged eVTOLs. Other than that, taxiways and taxi routes, as well as aircraft stands can be integrated into the vertiport infrastructure.

For the vertiport infrastructure design five major guiding principles can be defined:

- **Safety:** Flight operations must always meet the highest safety standards.
- **Slot neutrality:** The capacity of the existing airport's run-way system should remain unaffected.
- **Non-exclusivity:** The infrastructure must be designed for the largest possible number of eVTOL types/OEMs.
- **Scalability:** The vertiport must be able to develop with growing demand.
- **Efficiency:** To fulfill the value proposition, all vertiport processes should be as lean, cost-effective and automated as possible.

[13] (European Union Aviation Safety Agency, 2019)

Future infrastructure size and configuration of vertiports can be condensed into three basic concepts: a Vertistop, a Vertiport (Vertibase) and a Vertihub. All three concepts are characterized by their function and size within an AAM network.

Vertistops consist of one FATO and up to three aircraft parking positions which will in most cases be associated with a TLOF. The number of parking positions is primarily determined by the necessity of battery charging, which highly affects the capacity. More advanced battery technology and systems which do not require re-charging after each eVTOL landing might lead to vertistops without separate parking stands, while still allowing for high throughput. Vertistops will typically be located in urban and inner-city locations and allow only for limited vehicle services, including charging of vehicles and baggage loading. Vertistops will be needed to build a network with sufficient stops and will serve as the network's spokes.

Vertiports (Vertibases) will consist of up to three FATOs and between four and ten eVTOL parking positions. Vertiports provide dedicated infrastructure for maintenance, repair and overhaul services, as well as for eVTOL storage. Typically, vertiports will also have connected infrastructure which serves as a kind of terminal. Connected infrastructure enables operators to generate non-aeronautical revenues, similar to today's passenger terminal buildings at airports. Vertiports will be located at strategically important traffic hubs, like airports, railway stations or ports.

For vertiports however, this might be a difficult, yet not impossible challenge. Especially when placed in limited space, e.g. on roof tops or parking garages, smart concepts are key. Ensuring scalability also requires close monitoring and prediction of technological developments to account for future eVTOL designs. Larger wing designs or even electric STOL for regional air mobility would e.g. need elongated FATOs and TLOFs.

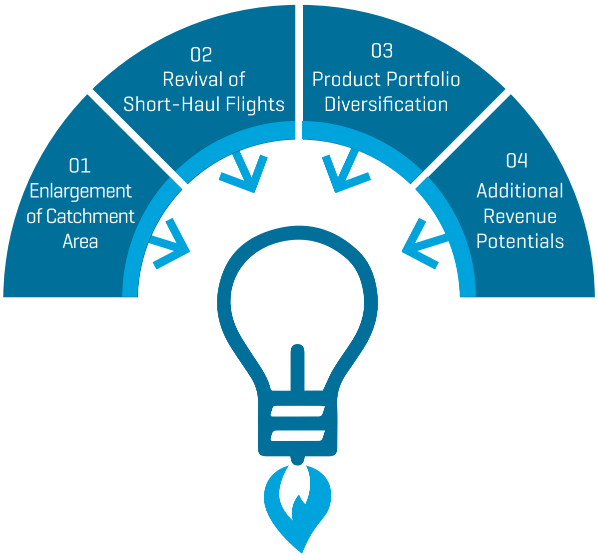
Vertihubs will present the largest configuration of vertiport infrastructure within an AAM network and may have characteristics that can currently be found at regional airports. Therefore, vertihubs consist of minimum two FATOs and at least ten eVTOL parking positions to ensure the highest traffic throughput. Typically, vertihubs can be considered as dedicated traffic and MRO hubs with connected infrastructure that clearly shows characteristics of an airport terminal including office space for fleet operator, MRO service provider, handling agents and concession spaces for generating non-aeronautical revenues.

Similar to conventional vertiports, vertihubs will be located at nearby existing transport infrastructure to guarantee the highest degree of intermodality. Due to the expected space requirements of vertihubs, the integration into the city core might not be possible. Therefore, we expect vertihubs to be located in the periphery of metropolitan regions like today's hub airports. In addition, given their size and complexity, we see the need for vertihubs only in the medium to long term. Over the first ten years, a number of medium-sized vertiports will be able to accommodate all eVTOL traffic within an AAM network.

Benefits for Airports

It is clear from the previous chapters that engagement in the emerging AAM market could bring multiple benefits for airport operators.

Benefits for airports



Enlargement of catchment area
The passenger's airport choice is mostly based on the distance to an airport and its accessibility.[14] To maintain competitiveness as an airport, it is therefore crucial to cover a large catchment area. AAM airport shuttles could help to further increase this catchment area and attract more people to make it their airport of choice. Within the existing catchment area, blind spots that currently are underserved by public transport systems, could be eliminated.

Revival of short-haul flights
With AAM successfully integrated at airports, we could also see a revival of short-haul flights. Short-haul flights, often serving as feeder flights for hub airlines, have just recently come under public pressure because of their environmental impact. Zero emission, low-noise eVTOLs allow airlines to address the environmental challenges associated with short-haul feeder flights.

Product portfolio diversification
Airport business models have come under pressure in recent years. With further growth of low-cost airlines, this trend seems to continue. To balance the effects of declining revenues from aeronautical charges, airports need to diversify their product and service portfolio. Airport operators can develop new business opportunities by managing vertiports on airport property as well as at other locations. Engagement in the AAM market is particularly favorable for airports operating at their capacity limit and helps to enable further organic growth.

[14] (Gelhausen, 2007)

Revenue potential toolbox (excerpt)

Potential Revenue Streams: Cluster	Potential Revenue Streams: Potential Types of Revenue	Exploitation Potential: For Full Service Operator	Exploitation Potential: For Operator with Outsourcing Strategy
Vertiport Charges	Take-off and Landing Charges	Likely	Likely
	eVTOL Parking and Storage Charges	Likely	Likely
	…	…	…
Revenues related to Real Estate	Space Rent and Leasing	Likely	Likely
	Advertising and Sponsorship	Likely	Likely
	…	…	…
Revenues related to »Airside« Service	eVTOL Towing & Pushback Fees	Likely	Questionmarks
	De-Icing Fee	Likely	Questionmarks
	…	…	…
Revenues related to »Landside« Services	Food & Beverage	Likely	Questionmarks
	…		
	…	…	…

Likely Questionmarks

Additional revenue potentials
Vertiport management seems to be a natural choice for airport operator's product portfolio diversification. Landing infrastructure can be provided at existing aerodromes, but airport operators could also erect new vertiports in traffic-favorable locations. Depending on the strategic positioning, the vertiport size and its concept, various sources of revenue are conceivable.

In order to keep total operating cost and therefore ticket prices on a competitive level, it is necessary to define the revenue framework with a strong sense of proportion. A selection of possible main sources of revenue is presented below.

Vertiport charges: It is very likely that vertiport operators will have to cover the investment for construction as well as the operating costs. It can be assumed that usage-based charges will be levied as financial compensation. Similar to today's airport charges, these might cover eVTOL movement related charges (e.g. take-off and landing charges, parking charges, charging fees) and passenger related charges (e.g. security fees, weight check fees for passengers and luggage). These revenue sources are essential for modern airports and will help build a convincing vertiport business case. By splitting these fees into movement and passenger related charges, it is also possible to achieve an appropriate distribution of business risks between vertiport and eVTOL operators as well as an efficient use of infrastructure.

Especially in the early stages of AAM, when the industry is still in its infancy, non-regulated user fees should be preferred. Nevertheless, business models for formal economic regulations of AAM activities at airports should be prepared for the long term.

Real estate related revenues: Space at vertiports will be a rare commodity. However, available space can be rented to different types of stakeholders, such as fleet operators, ground handling agents, MRO service companies or catering providers.

Airside-service related revenues: As part of the eVTOL turnaround, services are required that cannot be handled by the fleet operator or pilot. Vertiport operators should step in and open up potential for revenue. Examples for such services are assisted movement of the eVTOL on the ground (pushback and towing), de-icing service, charging and cleaning.

Landside-service related revenues: Due to its value proposition AAM requires specific passenger related services. Connected infrastructure and good curbside access will allow verti- port providers to offer ancillary services. These services can lead to additional revenue potential for the vertiport operator. Depending on the vertiport classifications and business model, landside passenger services span from parking and access management, over ancillary services such as food & beverage to special VIP/CIP services. The provision of security services and checks depends on domestic legislation and can be part of the airport operator's responsibility. In this case, vertiport operators might also be required to provide security services and at least generate cost-covering revenues from them.

AAM Ecosystem Challenges

To facilitate commercial advanced air mobility services at scale, key challenges across the AAM value chain must be solved.

Technical challenges

Battery technology and advanced propulsion architecture are critical for large-scale commercialization of AAM. For initial AAM deployment this decade, lithium-ion battery technology may be a suitable solution for eVTOLs. The automotive industry is continuously working on improving lithium-ion batteries and their energy density in cells. As soon as sufficient resources are available and supply chains can be stabilized, these advances will also benefit AAM. Since the energy density of lithium-ion batteries is still about two orders of magnitude lower than that of aircraft fuel, a fundamental change in battery technology is needed in the long term. Only then can range and payload be increased and the required charging rates and life cycles be achieved. New battery technologies will also allow all-weather operations, as aircraft deicing systems rely on vast amounts of energy that current lithium-ion batteries cannot provide. These new technologies are still years away from being used in electric road vehicles and even more so in eVTOLs. However, the need for cost parity with existing transportation modes will drive battery development.

UTM (Unmanned Air Traffic Management) is a traffic management ecosystem for unmanned flight operations that is separate from, but complementary to, existing Air Traffic Management (ATM).[15] UTM is essentially the digitalization of air traffic services that until now are transmitted to pilots by voice. Today's ATM is not designed to manage large-scale AAM operations. Instead, a digital UTM network is needed, which is a critical component for secure in-air eVTOL management.

Required certifications for eVTOL operations

Vehicle certification challenges

Certification hurdles are dramatically underestimated by the AAM market and could slow down the emerging industry. eVTOL aircraft must obtain four different certificates to operate commercially:

The type certificate verifies that the eVTOL type meets the safety criteria established by the competent authority and is issued for each different type of eVTOL individually. The leading aviation authorities EASA and FAA take different approaches to this kind of certification. While EASA recently published a Special Condition (SC-VTOL) that serves as a framework for issuing an eVTOL type certificate, the FAA plans to use existing regulations (under CFR §21.17(b)) for a manufacturer-tailored process. In this process, the FAA determines which existing certification standards (from Part 23/25/27/29/31/33/35) are to be used and addresses design differences through collaboration, using consensus standards and topic papers. However, the FAA will now deviate from this course. Details have not yet been published at the time of publication of this paper. The potential issue arising from the different certification approaches is the mutual recognition between EASA and FAA.

Regardless of the certification authority, obtaining the type certificate is far more complicated and costly than for road vehicles. We estimate the cost of type certification to be approximately 700 million US dollars, requiring a time span of more than 3 years. This results in additional financing requirements for a large number of eVToL manufacturers.

[15] (U.S. Department of Transportation: Federal Aviation Administration, 2021)

A production certificate is mandatory for the duplication of type-certified eVTOLs. It ensures compliance with quality standards throughout the supply chain. Maintaining it is a complex process that often leads to delays in aircraft production. Typically, the production certificate should be applied for in parallel with the type certificate to avoid delays in aircraft delivery. It also allows manufacturers to issue the **airworthiness certificate** for each individual aircraft produced.

An air operator certificate (AOC) is required for the safe operation of commercial eVTOL services. This certificate must be obtained by the operator and ensures that an organization, systems, measures and procedures for safe operations are in place.

Public and user acceptance

Public and user acceptance will be a prerequisite for economically viable AAM operations in the future. In general, two dimensions can be distinguished: Public acceptance and user acceptance.

Public acceptance will be critical for large-scale commercial AAM services. Especially since more people will potentially be affected by the adverse effects of AAM than those who will initially benefit from this new mode of transportation.

Most of all, citizens are concerned about safety-related issues, in particular the fear that safety levels could drop compared to today's standards in aviation. Given the high level of confidence in aviation safety, the same standards are needed to achieve public acceptance. Other public concerns include noise and visual pollution issues, along with privacy concerns[16].

Noise pollution from eVTOLs and their ground infrastructure is a sensitive subject because vertiports will be located in the heart of cities and residential areas. Consequently, the noise level of the vehicles and infrastructure must blend into the urban soundscape, which in turn has a strong impact on the vertiport location.

Vertiports could be located near noisy roads or train stations, for example. Concerns about visual pollution and privacy must be addressed through clear regulations limiting the overflight of eVTOLs in certain areas. With regard to the citizens' concern about the impact of AAM ground infrastructure on the cities' heritage[17], vertiport operators need to ensure that the vertiport is integrated into the urban landscape – a challenge, especially when it comes to standardized vertiport designs.

User acceptance poses a major challenge and has to be considered by all stakeholders involved. Empirical studies confirm that the willingness to use AAM strongly depends on the perceived trustworthiness of the eVTOL provider and its security measures[18].

Almost equally important for user acceptance is the central promise of AAM: time savings compared to other modes of transport. All stakeholders have to join forces to develop efficient and lean processes along the entire travel chain. Easy and convenient booking solutions, seamless eVTOL boarding and smooth vertiport integration with other means of transportation, as well as inflight services tailored to individual customer needs are required.

AAM business model challenges

The realization of an AAM transport system is investment-intensive – both in the area of ground infrastructure and in the area of fleet operations and ATM/UTM. As mentioned earlier, this comes with a high degree of uncertainty. A collaborative approach among all system partners is essential to develop a shared vision and roadmap for implementation. To cover the high start-up investments, public-private-partnerships (PPP) would be a solution worth considering.

Additional financing for eVTOL operators will be necessary at all stages of development to support network growth and position them in the mobility market. Similar to ridesharing services such as Lyft and Uber, AAM operators can be expected to initially suffer financial losses as they seek to attract potential users with low fares and expand their network. This will inevitably lead to funding gaps that will have to be closed later with additional capital injections.

Providing the right service on the right route will be key to successful AAM networks. Market studies need to be adapted to regional differences and local characteristics. These include demographic, geographic, and meteorological conditions, the mobility mix, citizens' mobility behavior, existing infrastructure, and general economic indicators. AAM operators also need to further specify the market segments they intend to serve, which requires setting a clear vision and strategy.

16 (European Union Aviation Safety Agency, McKinsey & Company, 2019)
17 (European Union Aviation Safety Agency, McKinsey & Company, 2019)
18 (C Al Haddad., 2020)

Environmental conditions initially have a major impact on the availability of AAM services, posing a significant threat to business models. First eVTOLs will have very limited weather tolerance and will not be able to operate under instrument meteorological conditions (IMC). High wind and gust velocities, low cloud ceilings, poor visibility, and icing conditions prevent AAM operations. Depending on the location, the risks of inclement weather vary and call for specific contingency procedures. These may involve working with other transportation providers to offer on-demand substitute services in the event of hazardous weather.

Weather challenges for eVTOL operations

Seamless multimodal integration is expected by AAM users, which adds complexity. For this, AAM operators need to develop and agree on revenue sharing models between mobility providers. Their demand forecasts must encompass the entire travel chain, as they must anticipate delays in other transport modes that may require changes in routing and vehicle positioning in order to keep eVTOL utilization high.

Customer focus is key to all AAM business models as AAM competes with other modes of transportation. Users will expect end-to-end mobility services that not only save time but also offer convenience. This level of comfort is not limited to in-flight service and entertainment, but starts with a user-friendly booking process and extends to the services offered at vertiports.

High utilization of eVTOLs will be crucial to enable profitable business models for vehicle operators. This poses challenges for eVTOL and infrastructure providers as they need to maximize the air time of vehicles. Short turnaround times are necessary, calling for speedy boarding and deboarding, cleaning, charging, and loading procedures. Utilizing all available seats by pooling passengers is another way of lowering travel costs. This requires accurate demand forecasts, transparent Standard Operating Procedures (SOP) and intelligent dispatch systems to respond to irregularities. However, passenger pooling also leads to longer travel times, which reduces a competitive advantage of AAM. eVTOL providers will thus need to find a well-balanced approach.

A shortage of skilled workforce could slow the growth of the emerging AAM market and prevent eVTOLs from taking off soon. This applies especially to a shortage of pilots that could limit AAM operations.

Due to the impact of the Covid-19 pandemic, thousands of commercial pilots are currently available on the market. But while the aviation industry recovers, the question is not whether there will be another pilot shortage, but rather when. Projections show that demand for pilots is expected to exceed the supply by 2023, in some regions even as early as 2022[19].

AAM operators need to develop appealing career paths and attract pilots with competitive salaries. Depending on the applicable regulations, they might find themselves competing for pilots with established airlines – an expensive undertaking that would shrink already low profit margins even further.

Investing in dedicated AAM training programs and pilot recruitment should be considered by eVTOL operators to reduce the overall costs of hiring experienced flight crew.

[19] (Murry, 2021)

Challenges for Vertiport Infrastructure Providers at Airports

Incorporating AAM into an airport's complex ecosystem presents operators with a variety of different challenges. The following nine challenges have to be mastered successfully to enable an effective and smooth integration.

Airspace integration

Existing VTOL operations (mainly helicopters) are embedded in conventional airline traffic flow and thus reduce airport capacity. Helicopters often use the same flight procedures as aircraft (e.g. ILS approaches). Since helicopter traffic at most airports is rather low, their influence on capacity is often negligible. However, for large-scale AAM operations with eventually hundreds of eVTOLs flying simultaneously, different flight procedures will be needed to not compromise airport capacity.

Dedicated flight procedures (including SIDs, STARs, Transitions and Approaches) should be developed to allow for AAM movement independent of other air traffic. This could be initially accomplished through designated AAM flight corridors similar to existing Visual Flight Rules (VFR) corridors in some class B airspaces in the US (e.g. VFR flight corridor through class B airspace around Phoenix Sky Harbor Intl.). In these corridors, eVTOLs could first be operated under visual flight rules, with U-Space concepts implemented at a later date.

Air navigation service providers have an essential role to play in this context. Their cooperation in the design phase is crucial for rapid project progress.

Vertiport planning and certification

The certification regulations for vertiports have not been completely defined yet, but authorities around the world are currently in the rulemaking process.

EASA's technical design specifications prototype for VFR vertiports and FAA's Engineering Brief No. 105 on vertiport design set the direction for vertiport planning and development. However, major parts of the new vertiport regulation will be very similar to existing VFR heliport design regulations as outlined in ICAO Annex 14 Vol II and EASA CS-HPT-DSN.

For the first phase of the market development, it is very likely that traffic will take place at already existing and approved heliports and airports. Yet finding a suitable location for a vertiport is a demanding task, especially at established airports.

One example: The distance between the vertiport and the airport terminal as well as the passenger comfort during the transfer influences the willingness of passengers to use AAM as an alternative to existing modes of transport. If connecting times are long, and convenience during transfer is low, AAM will not offer any significant benefit for its customers which translates to lower revenues. Therefore, a multifaceted assessment process is helpful to narrow down feasible location options at an early stage.

Ensuring the scalability of the infrastructure design is another major hurdle. Usually, airport planners develop a sophisticated masterplan that includes further airport expansions depending on the traffic demand scenarios. Alignment of such an airport masterplan with vertiport planning is important. Future airport capacity expansions will impact vertiport usage and must be considered. They can also greatly affect operational procedures and the capacity of the vertiport itself. Thus, vertiports should be developed and closely coordinated with the airport masterplan.

Smart concepts are vital, especially when it comes to installations in limited spaces, e.g. on rooftops or parking garages. Maintaining scalability entails careful monitoring and forecasting of technology developments to accommodate future eVTOL designs.

Vertiport business case

The business case model should be based on the traffic forecast and include CAPEX, the future OPEX and potential revenues. It should show when and under what circumstances the investment becomes profitable. The challenge is: The market for AAM will be subject to great uncertainties in the initial phase, making it difficult to define a reliable business case.

The cost-effectiveness of vertiport operations cannot be assumed as a matter of course, since demand is difficult to predict and fares are limited by passengers' willingness to pay.

High investment costs for the construction or modernization of the vertiport infrastructure will occur from the very beginning. Later, there will be fix costs and rigid variable costs for operating the ground infrastructure and providing the necessary services. In addition to these expenses, charging infrastructure costs present one of the vertiport's main CAPEX blocks.

Major OPEX cost blocks are personnel costs (determined by type and number of personnel), additional operating costs (electricity, cleaning, waste management, minor maintenance measures), and insurance, if applicable.

To keep total cost of operations, and therefore fares, at competitive levels, a scalable, modest infrastructure design and cost-effective, responsive operations are key to future success. Although vertiports can count on a wide range of potential revenue streams, all planned services and associated revenues must be deliberate and designed according to the market's willingness to pay.

Charging infrastructure

Business models of eVTOL operators will require high vehicle utilization to be profitable. This results in low turnaround times, requiring quick vehicle charging. Fast charging, similar to electric vehicles, calls for the provision of large amounts of energy. With airports already facing increasing energy demands for electric road vehicles, providing energy for eVTOLs, which will be orders of magnitude higher than for an EV, is a huge challenge. Airport operators must therefore develop intelligent load management systems and create accurate energy demand forecasts in order to properly size their grid infrastructure.

Also, when setting up vertiports on existing (high-rise) buildings with helipads, obtaining the necessary power supply often proves to be a difficult undertaking.

Passenger processes

A core promise of AAM is time savings and a seamless, end-to-end passenger experience. Passenger processes need to be streamlined and efficient to allow for fast transfer between different means of transport.

On-time performance will be key to customer satisfaction. A delay of only ten minutes, which is common at many airports, will not be accepted by passengers, causing them to choose other form of transport instead. In fact, the customer's decision to use AAM services is determined by his subjective expectations regarding waiting times for other transport modes or the possibility of traffic congestion on roads. Vertiport infrastructure operators must therefore take a collaborative approach that involves all stakeholders in the customer's travel chain.

Process simulation and optimization tools such as process mining or Lean Six Sigma will be important instruments to ensure efficient processes along the travel chain.

Baggage processes

Passengers expect seamless integration with other modes of transportation. This also applies to baggage handling, with the expectation that baggage will be automatically transferred between different means of transport throughout the travel chain.

Depending on where the vertiport is located at the airport, baggage transfer between AAM and connecting conventional airline flights may also need designated baggage handling solutions; if possible, an extension of the existing baggage handling system (BHS) or even the deployment of a dedicated AAM BHS.

Safety processes

Safety has to remain the number one priority for AAM. Research has shown that safety standards of today's commercial airline traffic should be the non-negotiable basis for large-scale AAM operation. Although some voices, particularly from eVTOL manufacturers, might call for the already existing drone safety standards to be applied to AAM, this approach is considered to be rather critical. At projected flight movements by 2030, this would result in a fatal accident every other day.

Instead, airport operators need to integrate AAM in their existing Safety Management System (SMS). This includes conducting risk assessments, defining mitigation measures, developing effective reporting systems, making employees aware of potential safety and security threats, and establishing a non-punitive safety culture at all hierarchy levels within the organization.

Fire fighting and rescue services (FFRS) requirements for eVTOLs are currently under development. What is already known with certainty is that they will significantly differ from existing standards for conventional aircraft. Since eVTOLs do not rely on Jet-A fossil fuel, some parts of the FFRS will have lower requirements, especially with regard to safety measures during fueling and engine start-up.

However, firefighting demands for large lithium-ion batteries will present challenges for fire services and may require additional equipment for fire stations. Depending on the location of the vertiport, existing fire stations may be insufficient to guarantee the arrival of firefighters at the vertiport within less than 180 seconds. Therefore, automatic extinguishing systems with adequate fire water supply and drainage at the vertiport may be important. It is reasonable to assume that eVTOLs should have similar FFRS requirements as electric road vehicles. Hence, best practices will likely be based on their procedures. In case of constructing a new fire station, a thorough site analysis is needed.

Security requirements

The regulatory requirements for security of AAM have not yet been established. Security demands will have a major impact on process design, infrastructure design and the siting of the vertiport. Existing infrastructure, like security lanes and other terminal infrastructure, could potentially be used for the vertiport. This would not only lead to a reduction in CAPEX, but ultimately also to a reduction in OPEX. A comprehensive vertiport location study will help to identify potential synergies between facilities.

Cargo processes

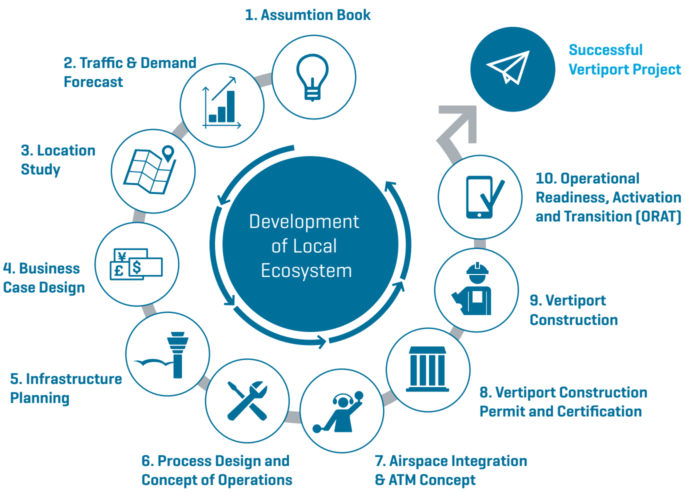
Due to the limited payload and range of eVTOLs, cargo use cases are likely to be insignificant for airport operators for the time being. Large freight drones with a payload of more than two tons and a range of more than 300 km are not expected before 2040.

Integrating smaller cargo drones used for last-mile delivery into the ecosystem of a large hub airport does not seem feasible. It would result in thousands of vehicles flying simultaneously in the already densely used airport airspace. At airports with less complex airspace and infrastructure design or in the case of greenfield development of new airports, however, this may be viable.

Our Approach to Manage Vertiport Projects at Airports successfully

To provide the landing infrastructure for eVTOLs and implement the processes and interfaces needed to successfully integrate AAM at an airport, a number of steps have to be taken.

Roadmap



Assumption book

A vertiport project, especially in an early market phase, is associated with many uncertainties and open questions. Therefore, essential assumptions and definitions of central questions must be addressed at the beginning of each project. The assumption book provides clarity and transparency within the team and builds a solid foundation for the project itself.

Traffic & demand forecast

A comprehensive AAM traffic forecast study forms the baseline for further vertiport planning. The forecasts should be prepared on a year-by-year basis for a period of minimum 30 years and should at least include: AAM movements, fleet mix, assessment of peak hours as well as the transfer and O&D passenger mix. To allow for future facility planning, a design day flight schedule for every five years is recommended.

In general the methodology for traffic forecasts can follow a two-step approach, starting with a status quo analysis. This first step evaluates data on passenger traffic between envisioned AAM routes (often derived from mobile phone data or airport passenger surveys), socio-economic data, and interviews with experts and stakeholders.

Step two consists of the actual traffic forecast. A bottom-up approach can be used for the forecast period of the first ten years, followed by a top-down approach for the following twenty years.

When preparing traffic and demand forecasts, it is important to conduct a comprehensive assessment of the market potential. This includes anticipated trends in passenger experience and air traffic management, as well as trends and solutions in the public transport sector.

For the emerging AAM market, it is particularly important to conduct a thorough assessment of expected technological and regulatory developments and their impact on infrastructure and demand, as the industry is still in the early stages of its lifecycle and is experiencing high volatility across all segments.

The traffic model will be incorporated into the location study and business case.

Location study

Taking into account the results of the traffic and demand forecast, the next step is to identify potential vertiport locations at the airport. Therefore, a strict and continuous alignment with the current airport infrastructure and master planning is required. The derived options are evaluated in a structured approach using over 30 evaluation criteria before a shortlist of suitable sites is created. This list is essential for the following project steps.

To ensure a stable work process, site options for a possible vertiport will be reserved for the duration of the project. Other site users and future corporate neighbors can already be involved at this stage to foster transparency, trust and acceptance.

Business case design

The business case model should include all financial aspects of the vertiport project. It covers the necessary investments (CAPEX), expenditure on facility management, personnel and other operating costs (OPEX), possible revenues in the aeronautical and non-aeronautical sectors, as well as the financing and taxes side. Ultimately, it should clearly show that the invested capital can be recovered through a reasonable profit within a certain period of time. The framework must be defined at an early stage, since cost efficiency and profitability are key elements from the very beginning. The content will then be developed and incorporated step by step as the project progresses.

Infrastructure planning

Infrastructure planning can be divided in three different phases:

Performance phase I (basic determination) discusses previously delivered work results from a planning point of view, assesses environmental impacts, and analyzes demand and capacity studies.

Performance phase II (pre-planning) sketches an early planning concept with volume models. Initial CAPEX estimations can be made on the basis of the volume model developed. Already at this stage, considerations of future processes are incorporated into the work and contact with approval authorities is usually established.

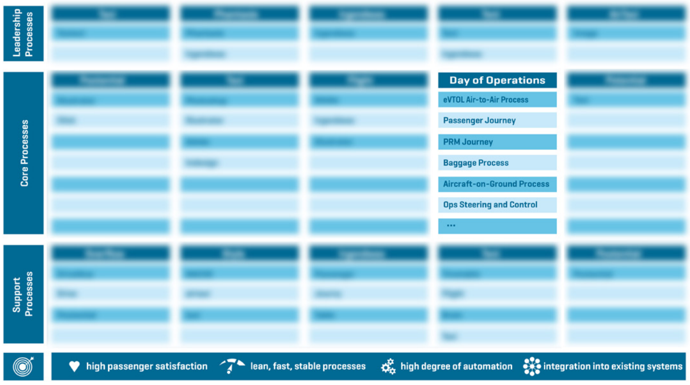
Performance phase III (design planning) comprises the development of detailed designs, the assessment of noise emissions and corresponding noise protection measures.

Process design and concept of operations (ConOps)

The ConOps is a document that describes the operating principles around the vertiport, its infrastructure elements and associated processes, as well as the required roles and interfaces in terms of operational, technological, environmental, economic and legal factors. It may be necessary to begin conceptualizing ConOps prior to the infrastructure planning phase to allow for ongoing mutual coordination.

The ConOps is based on the traffic forecast as well as the location study and adds major operational considerations. Among these are rough infrastructure designs, process descriptions (e.g. eVTOL air-to-air process, passenger process, operations control management) and first ideas for airspace integration. These results form the basis for the development of detailed SOPs and work instructions.

Vertiport Process Map (excerpt)



The concept can be understood as a living document and serves all stakeholders to gain an understanding of the envisioned way of operation. It therefore is not only an operational document, but also an important tool for strategy communication and implementation. It describes how vertiport stakeholders will collaborate and is intended to facilitate a common sense of ideas, challenges and issues about possible solution strategies.

Airspace integration & ATM concept

Together with air traffic control, a concept for airspace integration and flight procedures is developed. Ideally, the air navigation service providers are involved in the project work from the outset, as they can already provide valuable input during the location study.

Vertiport construction permit and certification

All necessary approval procedures with the responsible authorities are initiated and, if possible, completed during this phase. In this context, the preparation of the vertiport certification should also be addressed. This is an ongoing process throughout the construction phase and into the ORAT phase and is a key requirement for the final opening.

Vertiport construction

The construction time of a vertiport depends largely on individual requirements and circumstances. During the construction phase, close cooperation is required between the future vertiport operator and the construction manager. By doing so, preparations for the ORAT phase can be commenced at an early stage.

Operational readiness, activation and transition (ORAT)

In preparation for a smooth vertiport opening, the ORAT phase is of great importance to the landing infrastructure operator. The readiness and activation program is designed to interface with construction, system suppliers and operational stakeholders of the vertiport development project. It aims to support all parties involved in ensuring the vertiport's operational readiness.

The ORAT methodology consists of different phases, starting with the overall preparation set-up, which includes an assessment of the construction site and systems, as well as an analysis of stakeholders and interfaces. In the subsequent readiness preparation phase, all measures are taken to assure operational readiness at the time of vertiport opening, including, for example, updates to SOPs and process improvements.

Familiarization and training of vertiport staff is an essential measure for a smooth opening. Therefore, training concepts need to be established and the trainings need to be coordinated and conducted. Prior to opening, trials are held not only to check processes and systems, but also to best prepare personnel for future operations.

The vertiport activation program does not end with the vertiport opening. It continues to provide targeted hands-on support and additionally offers various shadowing activities for the operational management, involving vertiport and airport management experts.

About Munich Airport International

Founded in 1949, Flughafen München GmbH (FMG) operates Munich Airport and is jointly owned by the Free State of Bavaria (51 percent), the Federal Republic of Germany (26 percent) and the city of Munich (23 percent). With 24 subsidiaries and affiliated companies, FMG employs around 9,000 people across the Group. After starting operations at its current location in May 1992, Munich Airport developed into one of the most important air transportation hubs and firmly established itself among Europe's ten busiest airports. In 2019, it served over 250 destinations worldwide and handled around 417,000 flights with 47.9 million passengers. Bavaria's gateway to the world was the first airport in Europe to be awarded five stars by the London-based Skytrax Institute.

The wholly-owned subsidiary Munich Airport International (MAI) offers airport management, consulting and training services worldwide. Over the past 30 years MAI has evolved from being the leading ORAT service provider to a global airport operator. Today MAI is a trusted partner for smart money and ambitious airports throughout the world. With four subsidiaries and affiliated companies, MAI employs around 100 highly skilled experts globally and has a proven track record of more than 125 successfully delivered projects across more than 45 countries. MAI provides best practice solutions for the entire airport lifecycle, including bid advisory services for airport concessions, airport masterplan and design, operational readiness and airport transfer (ORAT), efficient and sustainable airport operations, optimization of aviation and non-aviation revenues, tailor-made training programs, as well as integrated airport management. Since early 2019, MAI is responsible for the operation, maintenance and concession management of the existing and new Terminal A at Newark Liberty International Airport (USA). In addition, Munich Airport and MAI are acting as airport operator for SOF Connect at Sofia Airport (Bulgaria) and for PIA at Palmerola International Airport (Honduras).

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List of Abbreviations

AAM	Advanced Air Mobility
AOG	Aircraft on Ground
ATM	Air Traffic Management
BHS	Baggage Handling System
CAA	Civil Aviation Authority
CAGR	Compound Annual Growth Rates
CAPEX	Capital Expenditure
ConOps	Concept of Operations
EASA	European Aviation Safety Agency
EV	Electric Vehicles
eVTOL	Electric, vertical take-off and landing vehicle
FAA	Federal Aviation Administration
FATO	Final Approach and Take-Off Area
GDP	Gross Domestic Product
MRO	Maintenance, Repair and Overhaul
OPEX	Operational Expenditure
ORAT	Operational Readiness, Activation and Transition
PPP	Public Private Partnership
SID	Standard Instrument Departure
SPAC	Special Purpose Acquisition Company
SOP	Standard Operation Procedures
STAR	Standard Terminal Arrival Route
TAM	Total Addressable Market
TLOF	Touchdown and Lift-off Area
UTM	Unmanned Air Traffic Management
VFR	Visual Flight Rules

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