Capgemini engineering

ENROUTE TO URBAN AIR MOBILITY

On the fast track to viable and safe on-demand air services

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2025

The year electric vertical take-off and landing (eVTOL) vehicles could become a commercially viable option as air taxis – Capgemini Engineering

By 2050, with the urban population more than doubling its current size, nearly 7 of 10 people in the world will live in cities[1]

Cities consume close to two thirds of the world's energy and account for more than 70% of global greenhouse gas emissions[2]

40%

Estimate of percent of US airline passengers that have some level of anxiety about flying[3]

50%

The amount of public space in the average city dedicated to roads[4]

$5.73

The estimated price per mile of one passenger seat on an air taxi that Uber has announced it plans to launch in 2023[5]

10^{-9}

The failure classification of one catastrophic incident for every one billion hours of flying time, which would be required for eVTOLs with 7-9 passengers by the European Union Aviation Safety Agency[6]

A sustainable radius of life

[noun]
Radius of life

The distance from home or work within which a person performs most of their day-to-day activities; the distance within which a person lives all or most of their life[7].

Today, over four billion people, or more than half the world's population, live in cities. They are at the epicenter of economic activity, with more than 80% of global GDP generated in cities, according to The World Bank[8]. Cities are also vibrant communities that provide residents with accessibility to a diversity of cultural and social activities.

But as urban density increases, it brings a degradation of the quality of life, including poverty, poor air and water quality, waste disposal challenges, and high energy use[9]. A significant contributor to the deterioration of air quality is urban sprawl and the reliance on the internal combustion engine to power the vast majority of vehicles that transport people and goods. According to the US Environmental Protection Agency, vehicles are responsible for 29% of all greenhouse gas emissions, higher than electricity production (28%) and industrial production (22%) in the country[10]. In the European Union, transportation accounts for 30% of total greenhouse emissions, of which 72% comes from road transportation[11].

Buenos Aires, Delhi, Kinshasa, London, New York, Paris, Shanghai, or Tokyo – pick any megacity in the world and the situation is the same. Commuting to work has become a significant time sink for millions of people around the world. In London, the average commuter spends 227 hours a year stuck in traffic, traveling at speeds of just 11 km/h[12][13]. And urban traffic congestion will probably get worse. By 2050, the global population is projected to grow by over two billion to nearly 10 billion, with almost 70% of us living in an urban environment[14].

The search is on for better, more sustainable transportation technologies and models to improve commute times and accelerate the transport of goods across town. Electric cars, e-scooters, ride-hailing platforms, autonomous shuttles, and high-speed trains will be part of our multi-modal transportation network. And to keep pace with the growth of cities, there is another three-dimensional mode of travel that is just now moving from the drawing board to the real world.

Urban air mobility (UAM) offers a new way for us to commute to work and transport goods using electric vertical take-off and landing aircrafts (eVTOLs). Similar to the helicopter, this new breed of aircraft is somewhere between commercial airplanes and remotely controlled drones, configured to carry large payloads and people.

UAM will open traffic lanes in the sky. It represents nothing short of a giant leap forward in transportation, much like the transformation from the horse and buggy to the automobile that began in the late 1800s (see Figure 1).

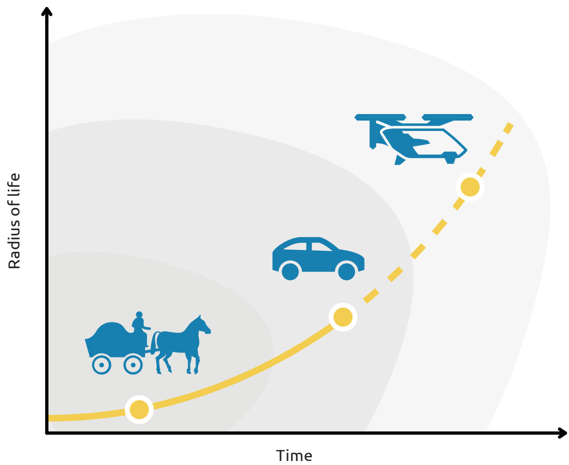


Figure 1: the potential of eVTOLs represents a dramatic and disruptive shift in the way we travel. Just as the automobile transformed the world of horse and carriage in the industrial age, eVTOLs have the potential to fundamentally change transportation in the digital age

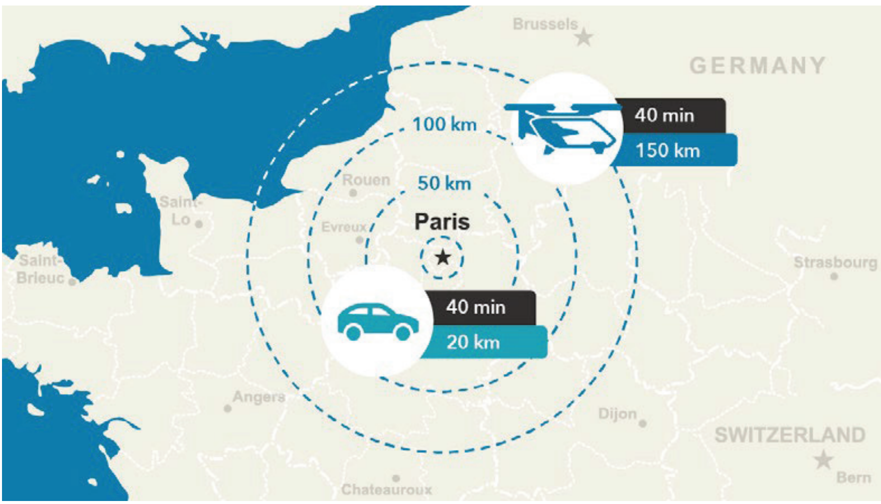


Figure 2: in the time it takes to drive 20 km in a congested city, you could fly 150 km in an air taxi

Three-dimensional travel is an audacious game-changer because it can improve and expand our radius of life in an environmentally responsible way.
For instance, an eVTOL air taxi could transport passengers from Charles de Gaulle Airport in Paris to Orleans – 160 km by road or 133 km by air – in about 35 minutes instead of the two hours it takes by car today (see Figure 2).

As with any mass market, the demand for eVTOL services – both cargo and human transport – will increase as the price becomes competitive with ground-based transportation options and consumers gain confidence that these flying cars are safe. If this happens, the worldwide commercialization of eVTOLs could be a reality within 10 to 15 years.

A growing number of players, led by aerospace, automobile, and technology companies, are working on urban air mobility solutions. The first generation of full-scale demonstrators are flying today, and limited commercial flights are possible within the next five years.

Of course, progress is never a straight line, especially in technology, regulatory, and industry transformations as significant as introducing a new transportation system. As a consequence, forecasts of the size of the global market for eVTOLs by 2030 vary widely: MarketsandMarkets puts the figure at $15 billion while Morgan Stanley projects a total addressable market of $322 billion[15][16].

“Electric VTOLs and air mobility will be nothing short of a dream come true. However, success is never a straight line. The big design challenge is to achieve a credible degree of robustness and reliability for a transport system in the sky. We can’t cut any corners.”

WALID NEGM
GROUP CHIEF INNOVATION OFFICER

Moving around in more than one mode

The journey toward a multi-modal urban transportation system that includes air travel has begun.

Meaningful innovation fueled by a significant amount of capital investment in eVTOL prototypes and UAM services is opening a new frontier for urban air mobility services. For example, at the Consumer Electronics Show in January, Hyundai and Bell Textron both announced their visions for integrated urban mobility that includes autonomous ground shuttles and eVTOLs. Also, Hyundai announced it was partnering with Uber to provide mass-production manufacturing services to build the aircraft[17][18]. Ultimately, UAM will become part of the smart-city infrastructure that spans an array of requirements from advanced air traffic management, purpose-built charging stations, pollution-monitoring systems, vehicle-to-vehicle communications, and data-ownership.

And one of the most pressing questions that must be addressed is: how will all the emerging mobility alternatives connect to form a unified, dynamic, multi-modal urban transportation network? Moving around is not just about one mode of travel. It's about connecting cars to trains, planes, eVTOLs, and other MaaS options.

For example, micro-mobility options such as low-cost e-bikes and e-scooters, while not yet mainstream, are making it easier to get around and connect with public transport.

Autonomous shuttles from companies such as May Mobility and Optimus Ride, that operate on fixed downtown routes, promise a low (or zero) CO_2 footprint[19][20]. And autonomous taxis that operate with no human intervention are likely to be commercially available in roughly the same timeframe as eVTOLs. These and other options allow people to opt-out of using a personal car for every trip they take.

Even the brash transit system known as Hyperloop may be part of the multi-modal transport puzzle, connecting smart cities across vast geographies. A Hyperloop future is not that far out. Zeleros, a Spanish Hyperloop startup that got its start at the Polytechnical University of Valencia, is working with Renfe, a Spanish state-owned company that operates freight and passenger trains. The startup is developing a vacuum-sealed tube with a frictionless levitation system. After the test in 2021, Zeleros plans to take cargo by the end of 2022 and people by 2030.

Stitching together all of the various modes of transport into a citywide network will be just as important as the hard work of commercializing each new form of transportation. Indeed, it is going to be counterproductive for a city to optimize on one mode.

Figure 3: within the decade, smart city MaaS transit could include electric bikes, autonomous shuttles, Hyperloop trains, and eVTOLs

Flying packages before people

There are many hoops to jump through before eVTOL air taxis become part of this smart city network. Moving people in the air has its risks, even if planes are safer than cars. Flying cars must be as safe, quiet, environmentally sustainable, convenient, and as efficient as ground-based options. And they need to be as cheap or cheaper than a ride in an autonomous taxi.

To get there means battery size, weight, and recharge time need to improve, communications and regulatory challenges need to be addressed, and the general public must embrace the concept. Today, there are a variety of shapes and sizes of eVTOLs in development, each with different propulsion systems and capabilities, all vying for attention. (See pages 10-11)

A proposed precursor to an eVTOL air taxi service is to use conventional helicopters and existing commercial routes. Companies such as Voom, Blade, and more recently, Uber are testing air taxi services using on-demand helicopter booking platforms[22][23][24]. Another step on the journey to urban air mobility is the commercialization of small, lightweight, pilotless drones used for delivering packages. Pioneers in drone delivery are competing to disrupt the last-mile logistics market. One promising early submarket is the drone delivery of medical and essential supplies to remote locations.

The commercialization of drone delivery is making progress because of the evolution of regulations, and the systematic integration of drone flight paths and approved boundaries into the unmanned aircraft system traffic management (UTM) ecosystem[25]. This year, drone package delivery services are anticipated to begin in earnest in Europe, Australia, Africa, and the US, all in regulated airspace[26][27]. The expansion of drone services has provided a foundation to understand the broader challenges of urban air mobility that encompass an expanded scope of use cases in cargo delivery, search-and-rescue, fire suppression, and air ambulances. (See page 17)

Such an incremental approach is necessary to inform eVTOL companies as they prepare for certification of a new class of aircraft that will replace helicopters, open new routes, and integrate into the transportation networks of smart cities. Uber is one of the companies that is leading the charge by announcing plans to launch an air taxi service by 2023 in Dallas, Los Angeles, and Melbourne with an eVTOL developed by Joby Aviation[28]. (See page 25)

What’s an eVTOL?

Electric vertical take-off and landing (eVTOL) vehicles are light commercial aircrafts that can take off and land vertically like helicopters and fly forward like airplanes. Unlike helicopters, they use batteries instead of fuel for propulsion and are more maneuverable, less complex, and more efficient than helicopters. They are designed to fly at a lower altitude than commercial aircrafts and will be either piloted or autonomous.

Today, there are over 100 VTOL projects under development worldwide, all seeking a stake in the game[29]. However, moving an eVTOL from development to test to commercial production is an investment-heavy endeavor and not for the faint of heart. The use cases for air mobility include delivering packages and cargo, ferrying people above the urban sprawl in sky taxis and airport shuttles, as well as intercity passenger services, and specific applications such as air ambulances, search-and-rescue, and fire suppression.

Much of the eVTOL investment to date has been focused on design – what the aircraft looks like, how it is powered, and how it performs – as well as how to make it as safe or safer than commercial aircraft aviation and how to create an amazing customer experience. The design criteria include:

- **Payload:** the range for air taxis is from a single-person (100 kgs) to a nine-person-plus-baggage (960 kg) payload. Companies such as Lilium and Joby Aviation are focused on a five-passenger eVTOL, while Volocopter and Ehang are opting for a more compact solution. EASA and FAA are recommending setting the maximum take-off weight for eVTOLs at 3,175 kg[30]

- **Safety:** to fly above populated areas, eVTOLs will be required to be at least as safe as general aviation aircrafts. However, with rapid growth expected in the number of eVTOLs operating in city skies, regulators may impose more stringent safety standards than those that apply to general aviation

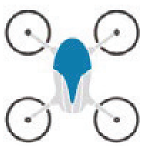
- **Noise:** sound pollution, both at frequency and decibel levels, is a serious issue for operating eVTOLs in urban environments. Uber has a set of requirements specifying that eVTOLs must be 15 decibels (dB) less noisy than existing light helicopters, which is about 70 dB at 500 feet versus 85 dB for a typical helicopter[31]. In comparison, the noise from a commercial jet at 25 meters is 150 dB, while a quiet rural area is 30 dB[32].

- **Cost:** as part of the mobility-as-a-service revolution, eVTOLs will be managed by service providers and will likely not be sold to private customers. The service providers will purchase fleets of eVTOLs that will be part of an on-demand business service. This model will allow them to minimize per-vehicle product costs and drive down the passenger cost-per-mile, which will help drive the success of the commercial eVTOL ventures

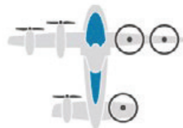
Three key eVTOL configurations

To get an eVTOL to market is a feat of engineering prowess requiring significant capital investment. Much of the focus today is on three propulsion system alternatives that differ dramatically from traditional helicopters

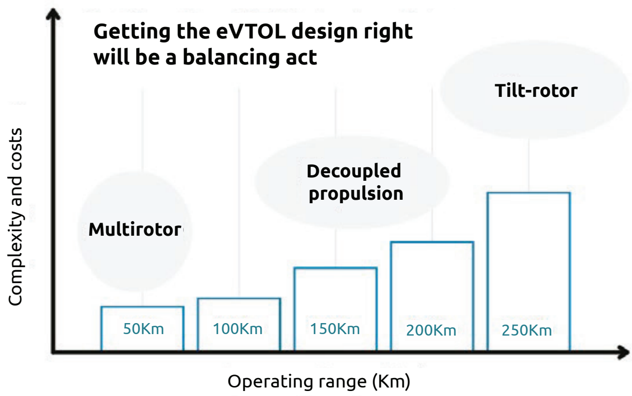
Multirotor eVTOLs are wingless aircrafts. They are very efficient while hovering and suited for low-noise applications. However, they are less efficient while cruising, with a top speed of about 90 km/h and a maximum range of 40-50 km. Still, they are a viable alternative to today's helicopters because they are quieter, cheaper to operate, and have no harmful emissions.



Tilt-rotor or vectored-thrust eVTOLs have multiple propellers or fans that can be tilted to transition from vertical to horizontal flight and can reach speeds of up to 300 km/h and a range of 300 km. Tilting the propellers, and controlling the direction of thrust stabilizes the vehicle's attitude and angular velocity. Tilt-rotors are more complex than multirotors as all the actuators that tilt the engines need to be fully redundant and certified for multiple failures. This redundancy adds weight and cost and requires more time for certification.



Decoupled-propulsive, lift-and-cruise configurations have multiple fixed vertical propellers and a pusher to transition from vertical to horizontal flight. They can reach speeds of up to 250 km/h and have a range of up to 150-200 km. Decoupled propulsive systems can deliver higher performance than multirotors, but lower than tilt rotors.


Getting the eVTOL design right
will be a balancing act
Complexity and costs
Multirotor
Decoupled
propulsion
Tilt-rotor
50Km
100Km
150Km
200Km
250Km
Operating range (Km)

Six factors to drive success

There is an array of challenges and hurdles ahead before eVTOLs are authorized to take to the skies. Here are six that developers and manufacturers need to address.

1 **A sustainable energy source**
Battery weight and recharging time are limitations of the cureent generation of lithium-ion batteries, and next-generation solutions are a few years away

2 **Mobile networks for low-altitude connectivity**
5G will be a boon for eVTOL communications and should be widespread when the first eVTOLs hits the market around 2025

3 **Urban air traffic management**
Managing low altitude drone and eVTOL traffic is a work in progress, with standards for drones comingfirst, followed by eVTOLs in the next few years

4 **Critical safety and certifications**
Compliance with as-yet-to-be formalized standards is a gating factor for eVTOL companies eager to gettheir aircraft and services up and running

5 **Competitive service-based pricing**
The eVTOL mass market will take time to grow, driven in part by the high per-mile cost of an air taxi compared to other forms of urban transport

6 **Social acceptance**
Perhaps the biggest challenge for most prospective customers is a lack of experience with vertical air travel. Fear of flying, noise pollution, and busy skies are deterrents. It might take a generation to get used to eVTOLs.

1. A sustainable energy source

Battery-powered eVTOLs – specifically lithium-ion battery packs – are emerging as the preferred power source over hybrid options that offer longer flight time but are heavier, noisier, and pollute the air. One recent convert is helicopter manufacturer Bell Textron, which recently transitioned to a fully electric eVTOL called the 4EX and showcased it at the 2020 Consumer Electronics Show[33].

However, to be a viable commercial transportation option, especially for longer flights, the electric power source that will be used on commercial eVTOLs in the future must be safer, last longer, be smaller, weigh less, and recharge faster than the current generation of lithium-ion batteries.

The logical next generation is solid-state technology, which is expected to disrupt the battery storage industry by mid-decade[34]. Combined, the solid-state and lithium battery market is expected to reach $1 trillion in 2026, according to Markets and Research[35].

There is a significant investment in solid-state batteries that use solid electrolytes, which has the potential to deliver a 2x performance improvement over lithium-ion batteries. Also, solid-state batteries can be safer because they are non-flammable. Li-ion cells have flammable liquid electrolytes that require mobility applications to use costly temperature controls.

Hydrogen is the only other viable alternative fuel source for eVTOLs in the near term, as the energy density of hydrogen fuel cells is higher than li-ion batteries. This means hydrogen-powered VTOLs can travel further, faster, and carry more weight than their battery-powered rivals. A few pioneers have developed hydrogen-powered VTOLs. One is Alaka'i Technology's Skai VTOL that runs on hydrogen and serves the emergency-response and freight-distribution markets[36]. However, hydrogen-powered aircrafts are still a decade away from being a safe and cost-effective solution. This means that battery-powered eVTOLs are likely to be the first in commercial operations.

"Transportation accounts for about 30% of greenhouse emissions and is a significant contributor to climate change. Capgemini Engineering's engineering teams in Toulouse, France, a city of aerospace pioneers, are helping our clients around the world disrupt air and ground mobility in a safe and sustainable way."

DAMIEN TORTOCHAUX
OPERATIONAL DIRECTOR

2. Mobile networks for low-altitude connectivity

The rollout of 5G communications will be important for eVTOLs, as near-real-time communications will be essential for keeping city skies safe as the volume of eVTOLs traffic grows. 5G will be crucial for situational awareness, and for aircraft-to-aircraft and aircraft-to-ground communication, especially in extreme weather conditions. Just as important, 5G's low latency and high bandwidth will be a must for inflight passenger applications and smart city MaaS applications.

Air-to-ground communications is a primary focus for 5G as indicated by the 3rd Generation Partnership Project (3GPP) efforts to change the specifications for aircrafts. Applications include sharing weather and traffic data at altitudes between aircrafts and ground control, providing more accurate forecasts of cloud formation and turbulence, real-time monitoring of aircrafts for preventive maintenance, and passenger Wi-Fi and entertainment services.

Another possible solution is service from constellations of small satellites that will use unlicensed spectrum for 5G communication service, including air-to-ground service. Small satellites will be part of the broader 5G umbrella and will be able to track aircrafts all over the globe, including in remote areas not well covered by terrestrial antennas. However, it is not clear if small satellites can overcome the challenges of traditional satellites regarding high-latency and low speed.

Presently, direct air-to-ground communication is superior to satellite service due to its lower latency and per-bit cost compared to satellites, which means air-to-ground has the potential to enable a much larger set of applications.

While terrestrial applications are the focus of early 5G rollouts, several telecommunications companies are working to address the aviation 5G market to ensure secure communication and data exchange. One is AT&T, which recently announced a partnership with Uber. The relationship includes AT&T assessing and enabling LTE and 5G connectivity for low altitude autonomous cargo drones and piloted aircrafts[37].

Volocopter recently announced plans for a new 5G-enabled eVTOL called the VoloCity, an urban air taxi that will carry two people a distance of 35 km at a speed of 110 km/h. The 5G capability will allow the aircraft to see around corners, avoid obstacles, and download flight data quickly to enhance performance and safety[38]. Volocopter has reportedly demonstrated these capabilities at trials in Dubai and Singapore.

And in Benidorm, Spain, a consortium of Vodafone, the Advanced Center for Aerospace Technologies and the Polytechnic University of Valencia recently made history by testing the first drone controlled by 5G in an urban area beyond the pilot's line of sight[39]. The demonstration included air traffic control of flights in restricted areas and the resolution of real-time flight conflicts.

All of these early efforts are relevant for 5G for eVTOL aircrafts and their connection with other smart city MaaS services and infrastructure.

3. Urban air traffic management

Unlike autonomous vehicles, eVTOLs will be regulated by air traffic management (ATM) agencies, specifically the European Union Aviation Safety Agency (EASA) and the US Federal Aviation Administration (FAA). These agencies are developing standards for innovative air traffic control (ATC) systems that can manage high-density drone and eVTOL traffic for both passenger and cargo-carrying aircrafts at low altitudes in densely populated urban environments. Complicating the challenge, EASA and FAA already have their hands full managing the rapid growth of global commercial aircraft traffic, which is forecast to double over the next two decades, with the Asia-Pacific region driving the majority of the growth[40].

The European Union's EASA is still in the process of forming recommendations for urban air traffic management that it calls U-Space[41]. The US system is called the unmanned aircraft systems traffic management (UTM) system and is managed by NASA and the FAA[42]. EASA has prepared a worlds-first UTM regulatory package, adopted by the European Commission on 22 April 2021. This package will become applicable in early 2023 and will enable the safe integration of UAS operations in urban environment. While not applicable to eVTOLs, the rules provide guidance for what they might expect[43].

The FAA is tackling this issue differently by abstaining from moving as fast with nationwide regulations but introducing iterative constructs such as the low-altitude authorization and notification (LAANC) service for commercial and recreational operators to access controlled airspace.

It has established a research transition team (RTT) to transform academic knowledge from NASA into operational frameworks and is focusing on use-case development, data exchange and information architecture, communications and navigation, and sense and avoid. Research and testing will identify airspace operations requirements to enable safe visual and beyond visual line-of-sight drone flights in low-altitude airspace[44].

UTM companies are addressing these challenges by conducting drone tests with government agencies, including the FAA's UTM pilot program and NASA's TCL4 trials, which is the final phase of a four-part, multiyear NASA project dedicated to researching, testing, and refining core technologies for UTM[45][46].

Once UTM is integrated into the ATM system, access to the airspace will be managed without human intervention to provide flight authorizations for drones and eVTOLs, while the vehicle altitude is continuously monitored to ensure there is no conflict with the existing aircraft airspace. This is a fundamental requirement for the authorization of cargo eVTOLs, which are expected to be the first generation of eVTOLs to be commercialized.

4. Critical safety and certifications

The single most significant factor that will ultimately determine the widespread adoption of eVTOLs is human safety. All things being equal, for the average commuter, the question comes down to whether the perceived risk of boarding an air taxi to get to work outweighs the stress of enduring bumper-to-bumper traffic. If they don't trust the air taxi, they will endure the stress of driving.

Both the EASA and FAA have established robust safety standards for aircrafts that include certification of manufacturing processes, equipment testing, maintenance, and training. As a consequence, commercial air travel is considered one of the safest forms of transportation. The failure classification for airline aircrafts is one catastrophic incident for every one billion hours of flying time, referred to as the 10-9 standard. This will likely be the standard that EASA and FAA will adopt for eVTOLs.

On February 3, 2020, the FAA proposed new safety standards for delivery drones, classifying them as a special class of aircraft[47]. The final rules requiring remote identification of drones and allowing some flights over people, over moving vehicles and at night under certain conditions went into effect on April 21, 2021.

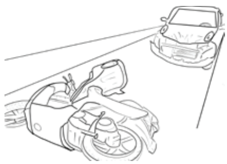
While aviation safety agencies around the world are drafting regulations for eVTOLs to ensure both the safety of vehicles and the software that runs them, the expectation is that they will not be implemented until after the drone standards have been implemented.

To address the perception of higher risk, eVTOL designs include distributed propulsion, with multiple motors, controllers, and batteries, and a redundant battery management system architecture to prevent catastrophic failures[48]. By the time eVTOLs are approved to operate, they will have better navigation sensors, enhanced connectivity, and partial autonomy that will make them at least as safe as today's commercial aircrafts.

It will take time for the EASA and FAA to evolve a comprehensive set of new certification standards for eVTOLs, but they are making progress[49]. One question for companies like Uber, that has plans to go to market in 2023, is: will the regulations that define safety be ready? (See page 18)

A peek into the future: The air ambulance

Today, accessing, treating, and transporting the injured and ill is performed primarily by ground vehicles. In some cases, such as remote, hard-to-get-to areas, helicopters are used. Electric VTOLs would be a faster and more efficient alternative to both. Here's one future scenario.

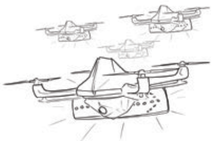


1

A serious accident occurs on a hard-to-access stretch of road in an urban environment injuring the driver of a car and a motorcyclist.

2

A driver who witnessed the accident takes out her smartphone and using a mobile app calls emergency medical services and provides information about the accident.



3

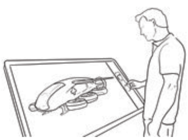
A fleet of drones is launched immediately, and within minutes is placing temporary traffic lights and electronic signage on the road to inform motorists of the accident and regulate traffic.

4

At the same time, a medical drone arrives at the accident site with equipment for the caller to use to assess the condition of the two injured people.

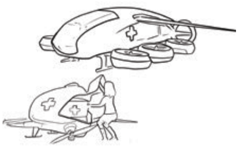
5

The information is compiled and transmitted by smartphone to the medical services team, who analyze the data.



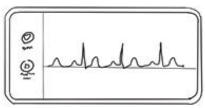
6

A member of the medical team uses a touchscreen to configure an eVTOL flying ambulance with the necessary equipment and medical personnel.



7

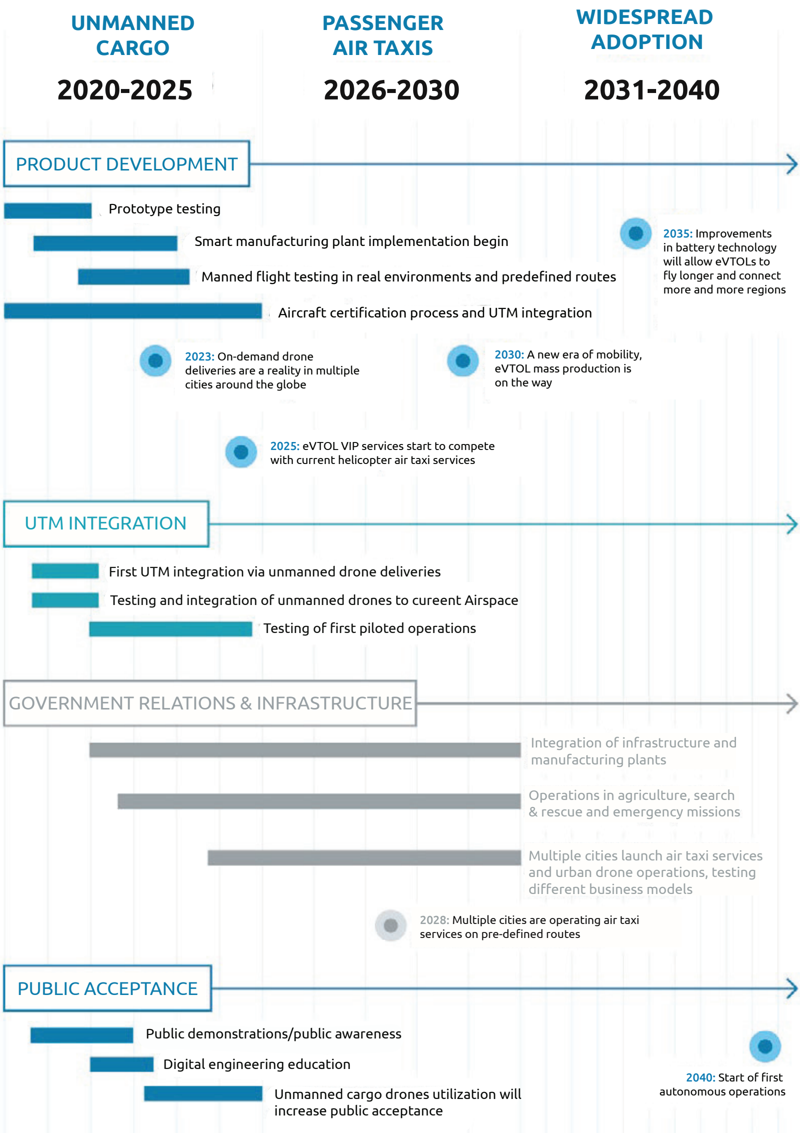
The flying ambulance leaves the medical center with an emergency medical technician (EMT) onboard and arrives at the accident scene within a few minutes to treat the accident victims.



8

The EMT assesses the injured, and the return journey of the eVTOL is monitored in real-time by the medical team. Once the injured parties have been treated at the medical center and are in stable condition, the app texts a thank-you message to the person who reported the accident.

The path to commercial air taxis



5. Competitive service-based pricing

There are two ways to look at the price of a journey from point A to B. One is the price of the end-to-end trip that may involve multiple forms of transportation, including a ride in an air taxi. The other is to focus on the mechanics for reducing the cost of a trip in an eVTOL air taxi over time, so the price becomes competitive with other mobility-as-a-service (MaaS) options. Both are important.

Considering the big picture first, the eVTOL industry needs to think about how air taxis will integrate with other forms of public transportation in the MaaS model of smart cities. For many commuters, getting to work may involve two or more types of transportation that an AI assistant has customized to minimize the total commute time. For instance, taking an autonomous bus to a vertiport to catch an air taxi, then a ride-hailing service for the last-mile leg of a journey.

The cost of each form of transportation is less critical than the average price across all of them. Also, consider the convenience of purchasing a single ticket that covers all types of travel. There is a value to saving time and increasing convenience that isn't captured in the cost-per-mile of the journey.

As for the specific price point of an eVTOL trip, there is a long way to go before an air taxi ride becomes a practical alternative for the average commuter. If the choice is between an air taxi or driving to work, the price point of the air taxi needs to converge on the cost of driving a car, which today is about $0.50 a mile for a small sedan[50]. Uber estimates the seat price on its first generation of air taxis at $5.73 per passenger mile but believes the price will eventually drop below $0.50[51].

NASA suggests a slightly higher cost. In the near term, a 5-seat piloted eVTOL will cost about $6.25 per passenger mile. However, in the long run, high operational efficiency, autonomy, and technology improvements will decrease the cost by about 60%, according to a 2018 NASA report[52].

The most likely and straightforward route to competitive pricing will be a business model that prioritizes removing costs across the design and supply chains. For example, lowering battery costs, which will be dependent on the evolution of technology, and reducing the cost of production, which will be based on economies of scale from mass production.

Operational practices for reducing costs include predictive maintenance, which will reduce the need for inspections that take the vehicle out of service. Also, introducing a collaborative piloting model where humans are augmented by auto-pilot software – and eventually replaced by autonomous eVTOLs – will reduce the overall operating cost.

The industry can accelerate innovation and compress time-to-market by using digital twins to help in design, validation, and certification of components and systems. For example, in 2016, Siemens created a digital twin model of the electric propulsion unit of its Extra 330LE aerobatic electric plane to design a powertrain with better performance and reliability, and lower cost. More recently, Siemens engineers developed a holistic model of the aircraft and its major systems – motor, electronics, battery pack, and structure – to design an even better powertrain[53].

Similarly, Twaice uses predictive battery analytics software based on digital twins to help companies develop and use battery systems more efficiently and sustainably while making them more reliable and durable. Cognata helps autonomous-vehicle and ADAS developers improve training and validation solutions using a digital twin of reality with actual roads, infrastructure, learned traffic models, and deep learning-based sensor emulations, to execute millions of scenarios, which significantly reduces the amount of road testing required[54].

6. Social acceptance

Getting the general public to board an air taxi won't be easy. The first step is the assurance of the technical capabilities of eVTOLs and the robustness of regulatory oversight. Another critical issue for winning over urban residents and city planners is to allay concerns about noise, visual pollution, and privacy. Considering the large number of eVTOLs that could be flying above populated areas at any hour of the day, these issues will need to be addressed if air taxi service providers expect to build a sustainable business.

First and foremost, regulators must establish robust certification, testing, and regulatory standards so the eVTOL ecosystem members can confidently design, develop, manufacture, and operate the aircraft. Providing the guidelines quickly will go a long way to accelerate time-to-market.

Second, eVTOL companies should use these standards to inform the general public of the safety of the aircraft, as there is going to be a natural suspicion about such an unfamiliar form of travel. Authoritative sources of impartial information will help reduce suspicion.

A recent study of residents of Stuttgart, Germany, found that the level of knowledge about eVTOLs and the underlying technologies was an indicator of a person's perception of safety. The more knowledgeable, the more likely they are to fly in an eVTOL. As the general public becomes more technology-savvy over time, confidence in the safety of eVTOL is expected to increase[55].

An innovative way to help promote public understanding of vertical transport is through virtual-reality simulations that allow customers to experience a flight and learn about the technologies while safely grounded[56]. The more the potential passenger knows about the experience, the more comfortable they will be to board an eVTOL.

However, there will continue to be a part of the target population that will not be inclined to use air taxis or flying ambulances. About 40% of the general population in the US has some degree of fear of flying, and 2.5% have what is classified as a clinical phobia that causes a person to avoid flying altogether or experience significant distress when they fly[57][58][59].

Even for clinical cases, there is work underway to reduce the fear of flying.
One related example is a study conducted by Oxford VR that found that after receiving VR-based therapy, individuals who suffer from the fear of heights showed a significant improvement in their phobia, which was lowered by 68% on average[60]. The same therapy can be adapted to manage the phobia of flying.

“Rising into the air will radically change the perception that citizens have of their city and open up new areas of services. UAM represents a great opportunity to rethink shared mobility with a more holistic and user-centered approach, by integrating emerging players for smart cities, to lower the environmental impact and re-enchant urban transportation.”

CLEMENT BATAILLE
DIRECTOR, FROG

Collaboration is the linchpin

Building a sustainable market requires an ecosystem of companies and experts that can work together to solve tough problems.

Competition is intensifying in the nascent eVTOL market as large and small companies alike position themselves to take advantage of a potentially huge market. While the commercial viability of the low-cost eVTOL urban air taxi market is still a decade away, a number of interim business models could be operational within the next few years. Among the most likely commercial applications are cargo delivery, air ambulances, fire suppression, and rural passenger services.

Market success in these initial applications will demand expertise in a multitude of disciplines: aeronautical design and engineering, battery technology, communications and computing, digital security, mass production, vertiport and recharge infrastructure, as well as testing, certification, and regulatory compliance.

The business model to bring eVTOLs to market requires an ecosystem of companies and experts that can work together and solve tough problems. Cross-industry collaboration is a crucial linchpin for success. Aerospace or automotive companies will not be successful on their own. Digital natives may be better positioned to act as the connection between the physical aircraft and the customer's interaction with the service, which is a key part of the customer experience.

The UAM ecosystem

There are four value axes to successful collaboration:

1. **Domain expertise:** producing an eVTOL demonstrator costs millions of dollars and requires a set of core skill sets. Mass producing eVTOLs will be in the billions. Sharing the risk and expense with companies that have expertise in battery technology, materials, propulsion, and other specialties will compress development time and through strategic partnerships and investments, de-risk the development and production challenges

2. **Time to market:** early success in the emerging eVTOL market is about staying in the vanguard and setting the pace. Ready access to technical expertise from a variety of disciplines will help companies maintain an advantage. For example, automobile manufacturers know how to mass-produce vehicles, which is transferable to eVTOLs. Aerospace companies are better equipped to design and develop the aircraft and ensure it is compliant with the testing and certification requirements

3. **Value chain:** private construction companies that build high-rise buildings, parking structures, and helipads, and companies and governments that manage public infrastructure, including train stations and airports, have a vested interest in developing the ground-based infrastructure for eVTOLs. And working with the players within the mobility-as-a-service sector allows niche players to participate and ensure a positive customer experience

4. **Technology innovation:** there's a variety of technologies that are critical for the success of eVTOLs. Chief among them is the development of strong relationships with communications service providers and companies developing next-generation power sources. Both eVTOL developers and infrastructure companies will need to leverage the latest developments in these and other core technology areas

Four primary players in the early stages of the emerging ecosystem include:

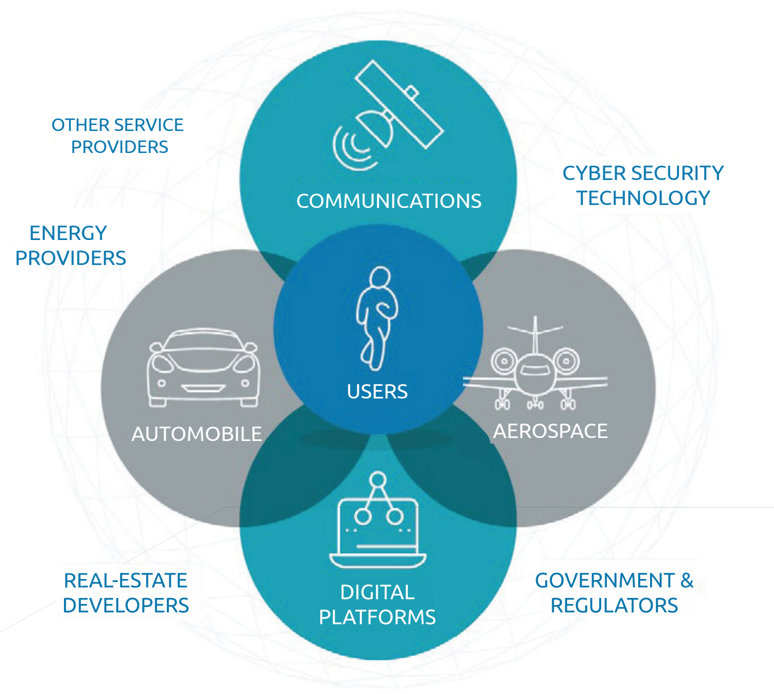
1. **Aerospace companies** have expertise in design, testing and safety standards, air traffic management systems, and relationships with regulatory agencies to approve their eVTOLs for commercial operation

2. **Automotive manufacturers** have expertise in efficient high-volume production and supply chain management, which will be a critical requirement for eVTOL production as the market grows. To be successful, the operating costs of eVTOLs need to be closer to the automotive model than the aerospace model. Also, many automakers today have production experience with lithium-ion battery-powered vehicles, and some have experience with hydrogen cells

3. **Telecommunications** providers are an essential ecosystem partner because eVTOLs will require 5G technology to ensure network reliability, low latency, and high bandwidth to safely and cost-effectively manage flight paths and communicate with other aircraft and drone traffic. In addition, 5G is a requirement for predictive, prescriptive, and condition-based maintenance[61]

4. **Digital platforms** including incumbents such as Uber, will be important partners to create the platforms for scheduling air taxi flights as well as multimodal travel plans across a variety of MaaS transport options, including ground transportation, trains, planes, and even electric bicycles and scooters

Also vital to the build-out of the eVTOL business model are a second set of ecosystem members that includes construction and real-estate companies, city planners, government agencies, and regulators (see Figure 6).


OTHER SERVICE PROVIDERS
COMMUNICATIONS
CYBER SECURITY TECHNOLOGY
ENERGY PROVIDERS
USERS
AUTOMOBILE
AEROSPACE
REAL-ESTATE DEVELOPERS
DIGITAL PLATFORMS
GOVERNMENT & REGULATORS

A collaboration timeline

There have been many cross-industry collaboration announcements in the last 24 months that reflect the multidisciplinary, ecosystem approach to commercializing eVTOLs, and new ones are being announced every week. Here's a timeline of some recent announcements:

- **November, 2021 –** A research team in Texas A&M University is studying the cyclocopter concept and shows it 55-pound cyclocopter in 2021
- **November, 2021 –** After a year of indoor flights, Bellwether in UK acheived its first test flight for its 2-seat Volar eVTOL in Dubai at an attitude of 13 feet and the speed of 40 kilometers per hour
- **February, 2021 –** Joby Aviation, considered a leading eVTOL aircraft developer, is reported to be merging with a blank-check company to go public at a $5.7 billion valuation
- **September, 2021 –** Archer went public through a SPAC deal with Atlas Crest Investment Corp. And it also secured a strategic partnership with United Airlines that would see an equity investment and an order for $1 billion worth of the Maker aircraft. The company completed its business combination in September, 2021
- **January, 2021 –** Ark Invest announced that it would launch a new investment fund to primarily hold publicly-traded companies related to space exploration, including suborbital aerospace technologies such as drones and electric aircraft. As a result, EHang, one of the few publicly-traded eVTOL companies at that time, saw its stock jump after the annoucement of ArkX fund
- **March, 2021** - Beta Technologies flew its fully electricity airplane from New York to Vermont at an altitude of 8,000 feet
- **March, 2021** - German eVTOL developer Lilium made two major announcements in March about his plan to go public with Qell, a SPAC and the deal closed in September. Also, Lilium revealed its new seven-seat Lilium Jet
- **April, 2021** - Beta Technologies secured a deal with UPS that would allow the parcel delivery company to purchase up to 150 of its eVTOL to transport time-sensitive packages. UPS expects to receive its first 10 aircraft from Beta in 2024
- **2021** - A total of 72 fully interchangeable battery modules would power Lilium's seven-seat eVTOL Lilium Jet and allow it to perform 20 to 25 flights per day, covering 95 to 120 kilometers at a time

All paths lead to the sky

Identifying the winning mobility service models for eVTOLs is a work in progress. Developers are prototyping a variety of designs that can be adapted to support a number of applications, including search and rescue, cargo delivery, and air taxi services.

Capgemini Engineering has been researching and developing eVTOL technologies for several years that span a number of use cases. The company's first design was the EVAN VTOL in 2015, equipped with two rotary engines designed to address emergency-response and search-and-rescue applications. The second was ZATA in 2017, which was a decoupled-propulsive eVTOL without movable parts.

Capgemini Engineering's latest proof-of-concept eVTOL is called Viable and based on a ducted, high-lift, multiple-failure-tolerant architecture designed to transport three passengers (see Figure 7). The winged design makes it efficient in cruise flight, with a maximum speed of 250 km/h and a range of 150 km on a single charge. What will make the Viable relevant to the customer is the addition of the digital dimension. This includes 5G ground-to-air communications, digital services that link to the smart-city infrastructure and augmented reality, and digital engineering to test different flight phases to enhance the safety of the aircraft.

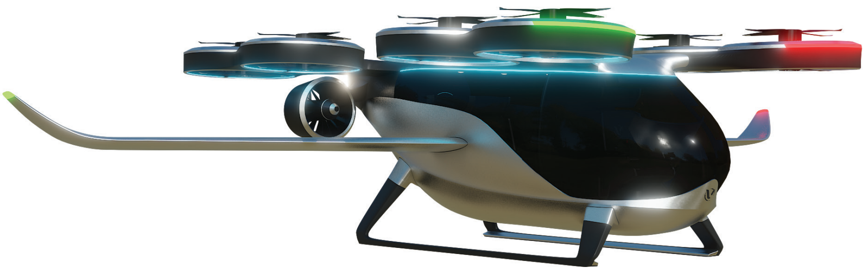


Figure 7: Capgemini Engineering Viable eVTOL, designed by frog, is a concept aircraft to inform engineering and build time-to-market accelerators

Welcome to the vertiport

The vehicle itself is one thing. How and where customers access the service is another. The so-called vertiports will likely take advantage of existing infrastructure, such as helipads, retrofitted public buildings, and unused land. The planning and design involve adequate parking, easy access to public transportation, waiting lounges, take-off and landing pads for multiple eVTOLs, and battery recharging stations, all within a relatively small footprint (see Figure 8).

Rethinking distribution centers

As for cargo terminals, traditional logistics centers will need to be re-engineered to meet the demand for distribution of more than 30 billion individual deliveries by 2030 and up to 90 billion by 2040[73]. While heavy-duty trucks will not disappear anytime soon, the future of intercity delivery will be transformed by aerial and innovative ground-based cargo delivery services.

For example, United Parcel Services has partnered with Waymo in developing autonomous minivans to transport packages from its stores to local sorting facilities[74]. FedEx is investing in battery-powered mobile robots to deliver goods to customers[75]. Both are planning drone operations. UPS has received FAA approval to operate a fleet of drones for pilotless package delivery[76].

Figure 8: vertiports will take many forms, from small neighborhood commuter stations like the one shown here (designed by frog), to large downtown terminals that serve urban centers

You will travel in a flying car

There is a very good chance that we will be flying in air taxis within the decade, maybe sooner. However, eVTOLs are just one piece of the mobility-as-a-service puzzle that will make cities truly smart and transportation more efficient and less stressful. Ultimately, a coherent, networked set of options will be required to connect the dots from a person's front door to their final destination. The air taxi is only one of the dots.

Work to bring this holistic ecosystem to life will be good for all MaaS players. And just like the eVTOL ecosystem, cross-industry collaboration must engage all the stakeholders: city planners, energy providers, regulators, telecommunication providers, infrastructure, and of course, mobility service providers.

As for advancing eVTOL services, there are a variety of challenges ahead. Some are within the control of the companies developing the aircraft and services. But others are outside their direct control, such as advancements in electric and fuel power sources, regulations, and social acceptance – the latter being perhaps the most critical.

Collaboration with all players is the best approach to success. Not only will it speed time-to-market, but it will distribute the risk embedded in the evolution of the new transit ecosystem.

There are no showstoppers that will detail the launch of eVTOLs. It's just a matter of time before you board your first air taxi.

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About Capgemini Engineering

Capgemini Engineering combines, under one brand, a unique set of strengths from across the Capgemini Group: the world leading engineering and R&D services of Altran – acquired by Capgemini in 2020 – and Capgemini's digital manufacturing expertise. With broad industry knowledge and cutting-edge technologies in digital and software, Capgemini Engineering supports the convergence of the physical and digital worlds. Combined with the capabilities of the rest of the Group, it helps clients to accelerate their journey towards Intelligent Industry. Capgemini Engineering has more than 52,000 engineer and scientist team members in over 30 countries across sectors including aeronautics, automotive, railways, communications, energy, life sciences, semiconductors, software & internet, space & defence, and consumer products.

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