Regular Article

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Urban air mobility and flying cars: Overview, examples, prospects, drawbacks, and solutions

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Abstract: Transportation in cities may undergo substantial changes due to two emerging technologies that enable three-dimensional movement of people or cargo. These emerging technologies are urban air mobility (UAM) and flying cars. The present study gives an overview of both technologies, differences and similarities between them, challenges they face, the opportunities they bring, and examples for them with varying stages of readiness from being commercially available to being a concept in development having a small-scale prototype. The models covered here include EHang 216 (UAM aircraft), VoloCity (UAM aircraft), PAL-V Liberty Sport (flying car), and ASKA (flying car). Focusing on air taxis (or flying taxis) in the form of a fleet of piloted or autonomous electric vertical takeoff and landing aircraft operated commercially by a corporation that provides mobility as a service, a discussion about the prospects of this nontraditional mode of transportation is provided, with anticipated drawbacks and proposed solutions.

Keywords: urban air mobility, UAM, flying car, transportation, autonomous, eVTOL, air taxi, MaaS

1 Introduction

According to the Department of Economic and Social Affairs of the United Nations (UN), 55% of the global population is located within cities rather than rural areas, as of May 2018. That proportion of city dwellers is estimated to grow to 68% by 2050 [1]. Megacities are those cities that are highly populated, with more than 5 million inhabitants [2] or 10 million [3] inhabitants. The United Nations Educational, Scientific and Cultural Organization reported 37 megacities with more than 10 million inhabitants in 2018 (such as Paris in France, Beijing in China, and New York in the United States), expecting the number to increase to 47 in 2030 (by adding 10 new megacities, such as Kuala Lumpur, the capital of Malaysia; Dar es Salaam, the capital of Tanzania; and Santiago, the capital of Chile) [4]. Such continuous growth of cities and urban communities brings with it pressure on the infrastructure, including the urban transportation network. Traffic congestions [5] and slower driving speeds [6] are consequences of excessive increases in the urban population.

Some measures can help in reducing congestion in cities, like improving public transportation, real-time adjustment of traffic flow, selection of optimum routes, subsidizing public bus services, establishing safe bicycle lanes, and continuous monitoring of road conditions for early identification of congestion sources [7,8]. However, all these alleviation measures view road transportation as a mostly two-dimensional movement, taking place in only one layer immediately next to roads. A nontraditional method that can help in reducing the traffic load on roads and reducing time for long trips in cities is to utilize the third dimension (the elevation), allowing transportation without restricting ties to the paved ways on the ground. A huge space of the near-ground zone can accommodate aerial routes for the movement from point "A" to point "B," using proper on-demand small-scale aircraft. This concept of three-dimensional ground-free transportation is viable through urban air mobility (UAM) and flying cars (FCs).

The presented work introduces a reader to the two concepts of UAM and FCs, explaining how they differ from each other, lists some obstacles that may postpone their large-scale deployment as a normal transportation mode, and discusses some advantages inherent in them. The work also presents two examples under each emerging-transportation concept with some details, while referring to additional examples briefly. Finally, the idea of providing mobility as a service (MaaS) through UAM electric air taxis that take off and land vertically (without the need for long runways) is discussed further as a good candidate for UAM utilization.

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2 Objective and method

The current study has an objective of providing some answers to a number of questions regarding UAM and FCs. The study contains informative elements that collectively serve as a quick guide to a reader interested in either or both topics. These questions are as follows:
- What is UAM?
- How does a UAM aircraft look like?
- What are FCs?
- How do FCs look like?
- What is the relation between UAM aircraft and FCs?
- What are the advantages of UAM and flying car?
- What are the challenges facing UAM and flying car?
- When can eVTOL air taxis become a common mode of transportation?
- What are the advantages of eVTOL air taxis?
- What are the drawbacks of eVTOL air taxis?

The method followed in this study is the analysis of secondary data available publicly (a small fraction of that data came from personal communication with a flying car company). This analysis included summarizing, organizing, validating, cross-linking, and adding personal viewpoints. The information accessed to conduct the study covers various sources such as research articles, news articles, manufacturer's data, and websites of international or national organizations. Permission was courteously granted to use all the propriety photos displayed in this article by their respective owner companies.

3 UAM versus FCs

3.1 UAM

As the name implies, UAM is a transportation technology that targets urban areas (cities and attached suburban zones) using routes in air. This implies a low-altitude flight [9] because using high altitudes means that time and vehicle energy are lost in large initial ascending and final descending phases, whereas the main goal is horizontal translation during the cruise phase. The following definition is proposed for UAM:
- UAM is a transportation system, which uses low-altitude aircraft that can be either human piloted or autonomous to move passengers or cargo within cities or between cities or suburban zones using aerial routes.

There are other terms related to UAM, such as advanced air mobility (AAM), which is an extension of UAM [10], either geographically or functionally beyond urban transportation, such as serving rural areas and being used in tourism (sightseeing). The term autonomous aerial vehicle (AAV) may also overlap with the aircraft used in UAM. It emphasizes the situation when the flying vehicle does not have a human pilot on board; however, it can still have passengers [11]. The term unmanned aerial vehicle (UAV) or drone is a special case of AAV, where the flying vehicle neither has a pilot nor has passengers. UAVs may also be referred to as unmanned aerial systems (UASs), remotely operated aircraft (ROA), or remotely piloted aircraft (RPA) [12]. The term personal aerial vehicle (PAV) overlaps with UAM. PAV may concern the case where the small aircraft is carrying passengers [13] or when it is a private property, owned by a person. The term electric vertical takeoff and landing (eVTOL) is also an important term in UAM because UAM aircraft commonly (but not always) follow this type of flight, being electrically powered by batteries and electric motors, and able to take off and land vertically without the need for a long runway [14]. Using a helicopter as a UAM aircraft excludes it from the eVTOL category because it is not electrically powered; however, it still has a vertical takeoff and landing capability (VTOL) [15].

Al Haddad et al. [16] realized the lack of understanding of users' perceptions of UAM. They conducted a study with a stated-preference survey for assessing this perception. They found that aspects such as affinity to automation, safety and trust, and social attitude are important.

Straubinger et al. [17] described UAM as a novel mobility concept, enabling the use of passenger drones for on-demand transport in an urban environment. They investigated the distribution of UAM impacts while considering the spatial dimension (suburbs versus cities) and the low-skilled and high-skilled households, by comparing certain socioeconomic variables with and without UAM. Their study covers US-based cities and Europe-based cities. It utilized a numerical simulation with a developed model. Some of their model parameters (such as the working hours per day and the gasoline price) were based on reliable sources. A simulation benchmarking compared model results with empirical values from different sources. As an example for the provided results, wages are expected to nearly remain unchanged after introducing UAM, and this applies to both types of cities (US based and Europe based), both classes of workers (high skilled and low skilled), and both spatial settings (cities and suburbs).

Pukhova et al. [18] considered UAM as synonymous with "flying taxis," which is a reasonable view given that they represent a key potential application of UAM. They developed an agent-based travel demand model for simulating UAM demand around Munich in Germany. Their results suggest that adopting the flying taxis mode of transportation in a metropolitan region with the existing road network and public transit services may not lead to any remarkable time saving. Their model also shows that switching to UAM for transport does not lead to reduction in kilometers traveled by car, which even increase by 0.3% after including access and trips to and from the vertiports (special airports for vertical takeoff and landing, to be used for UAM aircraft). Their study is important in demonstrating the competition expected between UAM and the existing conventional modes of transit.

Biehle [19] conducted a comprehensive review study about the impact of passenger urban air mobility (pUAM) on the existing urban transportation systems, focusing on Europe. The study addressed social and economic perspectives, through analyzing the expected acceptance of the public to this aerial transportation system (considering safety and noise), its affordability (compared to the existing classical modes of transportation), its inclusivity (suitability to mobility-impaired groups such as pregnant women), its accessibility (being effectively connected to all districts in an urban area), and the level of customer satisfaction (with potential flight issues such as response to a gust wind). Interestingly, the study showed an upsurge in the predicted number of electric aircraft for passengers' transportation in Europe by 2050, jumping from 10,000 in 2016 to 160,000 in 2020. Due to the large number of passenger drones to be in the urban airspace, specialized support services should also be running in parallel to ensure safety and a favorable environment. In general, this concept or framework is called unmanned air traffic management or unmanned aircraft system traffic management [20–22]. In Europe, the regional term is U-space [23].

3.2 FCs

An FC can operate in two modes: (1) a traditional road car and (2) a small aircraft. It can be also called a roadable aircraft. The following definition is suggested for a flying car:

- A flying car is a convertible powered wheeled vehicle that can drive on public roads, be parked in normal parking zones, and uses normal car fuels (if it has an internal combustion engine), while also having the ability to operate as a small aircraft.

A key difference between UAM aircraft and FCs is the use of roads as normal routes for ground transportation (excluding transient short movements like preparing for takeoff). In other words, the presence of a road-driving mode of operation makes the aerial vehicle a flying car. Conversely, UAM vehicles are aircraft, and they are intended to transport through flying only, not through traveling on the ground. The provided distinction between UAM aircraft and FCs is not absolutely agreed upon. FCs may be viewed as a special type of UAM vehicle [24], which can contribute to fulfilling the broad UAM mission. This view is respected and has a logical justification, despite not being followed in the present work.

The idea of a transportation machine that combines two modes of transportation (ground transportation as a car and aerial transportation as an aircraft) goes back about one century, as attributed to the American aviator and noted motorcycle builder and racer Glenn Curtiss. He made a prototype of what was called "autoplane," with three detachable wings, and it was tested in 1917. It was able to make a few short hops, but did not perform a successful flight [25]. The realization of the concept was forecasted long time ago in 1940 by the founder of the American Ford Motor Company, Henry Ford [26]. The earliest dedicated project for building an FC was by the American company Moller International for a model called Moller M400 Skycar, and the project started in 1983. After many years, an experimental car was eventually built, with its first flight being in 2001. After several flights in restricted environments, it was not found successful for deployment in the market and lacked the approval of flying operation from the United States Federal Aviation Administration [27].

Postorino and Sarné [28] reported that 'flying vehicles' (as a more general term than FCs) can reduce travel time compared to conventional ground-only transportation, but this benefit can vary largely depending on the average transportation distance and the number of traveling vehicles between origin/destination locations of a trip. They performed an analysis using simulations of an agent-based model and obtained time savings that ranged from 18 to 71% while considering 12 different scenarios.

Pan and Alouini [29] indicated that FCs offer an opportunity to exploit the near-ground space for transportation. They listed advantages of the FC transportation system (FCTS), which include the possibility of flexible and fast door-to-door transportation. They classified FCs based on four design aspects, which are as follows: (1) take-off and/or landing direction (horizontal or vertical), (2) piloting modes (human piloted, self-piloted, and hybrid), (3) operation modes (airplane, helicopter, and car), and (4) power types (electric, fuel, and hybrid). These design aspects affect the flexibility, comfort, stability, complexity, and environment friendliness of FCs. They also discussed different design issues related to FCTS and challenges that may appear during developing and running FCTS, including safety, commercial performance, and ethical perspectives. For example, they emphasized the importance of the ability of FCs to withstand extreme weather conditions such as thunderstorms and heavy winds, taking this into consideration during the design process.

4 Challenges

Being relatively new technologies, both UAM and FCs face common barriers. Overcoming these barriers has a big influence in deciding when they become a common transportation mode available to the public, competing with cars, buses, taxis, and subways (metros or the underground). The following list summarizes the expected challenges for large-scale deployment of UAM aircraft and FCs in cities.

4.1 Common challenges

Challenges commonly affecting UAM and FCs include:
- Regulation (certification of vehicle by the local authority, either civil or military)
- Pilot training and certification (if there is a pilot aboard)
- Safety standards
- Social resistance

It is possible that a country does not yet have a set of rules that fits the two emerging technologies, which means a new set of rules should be established or existing ones should be adapted. An uncontrolled failure in a flying object within a city can lead to serious damage to properties or personnel. High standards of safety are needed, with redundancy in the powering source and ballistic parachute system (BPS), which forcefully ejects the parachute canopy, thereby resulting in a rapid deployment [30]. Social resistance may stem from concerns about safety, and also the potential breach of privacy by flying at low altitudes over fenced homes with open spaces.

4.2 UAM

It is here assumed that UAM vehicles are not mainly privately owned, but aimed for commercial operation by an operator company. With this assumption, two more challenges for UAM are added as follows:
- Approval of operators (if intended as commercial businesses)
- Public infrastructure (designated landing locations)

4.3 FCs

Compared to an average car, FCs are expected to be expensive, given the more-complex design. This poses a constraint, at least initially before mass production is realized, leading to limiting the technology to wealthy owners. So, the following challenge is added for FCs:
- Profitable sales volume

5 Opportunities

The anticipated opportunities embedded in UAM and FCs are significant enough to motivate progress in their development despite the aforementioned challenges. These opportunities or advantages include:
- Shortest-path travel (possible straight line movement)
- Fast speed (powerful flight propulsion and lack of road obstacles enable high travel speeds)
- Terrain independence (no need for paved roads)
- Wide-view visibility (the traveler can view a wide area during travel, thus conveniently identify the destination)
- Potential for low emissions (electric UAM aircraft and electric FCs do not have direct tailpipe/exhaust emissions; thus, no harmful carbon dioxide is released in the local environment)
- Less traffic on roads (by shifting portion of it to the near-surface atmosphere)

6 Examples of urban mobility

This section presents two examples of UAM aircraft from two different manufacturers, which are viewed here as the two leading companies in UAM technology as of 2021. Both companies have a full-scale model in existence, which passed a trial flight. Therefore, their vision of UAM is tangible and technically valid. One of them has already sold UAM aircraft for revenues.

The interested reader may also examine a third design called Heaviside, which is an eVTOL aircraft with eight electrically powered propellers and a single seat, developed by the American company Kitty Hawk, located in Palo Alto, which is one of the main cities within the Silicon Valley in California [31].

Another UAM example that is not covered here in detail is the seven-seat (one pilot and six passengers) eVTOL model called Lilium Jet, designed by the German aviation company Lilium GmbH, which is located in the Wessling (Weßling) municipality near the city of Munich in the south of Germany. Commercial operations are expected to start in 2024 [32]. Instead of propellers, the aircraft is designed with a special propulsion system relying on multiple small ducted fans (propelling fans surrounded by walls from the sides). A five-seat version has flown in 2019.

6.1 EHang 216 by EHang

EHang Holdings Limited is a Chinese company that is world's leader in AAVs. It is headquartered in the port city of Guangzhou [33], the capital of Guangdong province, in southeast China. The company's key model is EHang 216, which is an eVTOL aircraft having two seats.

On Tuesday, June 24, 2020, EHang announced that EHang 216 completed its first official flight in South Korea in three locations: Seoul, Daegu, and Jeju Island [34]. In the following year, on Friday, June 4, 2021; EHang announced that EHang 216 completed a successful autonomous flight test in Japan, after obtaining a trial flight permit issued by the Japanese Ministry of Land, Infrastructure, Transport and Tourism [35]. EHang 216 reached a mature stage of development and has entered the commercial sales phase with 3 units sold in 2018, 60 units in 2019, and 70 units in 2020 [36,37]. EHang launched other models such as EHang 116 (single seat) and EHang 184 (single seat); however, EHang 216 (two seats) is the dominant model as of 2021, with a unit cost of about $330,000.

Figure 1 illustrates the exterior view of EHang 216. There are eight arms extending from the bottom of the cockpit, and each arm carries two propellers at its outer end. The eight propeller pairs are thus distributed around the cockpit. Figure 2 shows an EHang 216 unit during a flight test.

Table 1 lists some characteristics of the EHang 216 UAM aircraft.

6.2 VoloCity by Volocopter

The VoloCity UAM model by the German company Volocopter GmbH is an eVTOL aircraft, aimed to operate as a two-seat air taxi [38]. Volocopter GmbH was founded in 2011. It has offices in Bruchsal and Munich in Germany, as well as in Singapore. The company attracted multiple investors like the German automotive manufacturer Mercedes-Benz Group AG (formerly Daimler AG), Zhejiang Geely Holding Group (Chinese automotive company, the parent of Volvo Cars), and Intel Capital (a division of Intel Corporation that invests in innovative new businesses). VoloCity has flown in the center of Singapore. The aircraft has two seats. Commercial operation of VoloCity is expected to start with piloted flight (one pilot, one

Figure 1: An illustration of the EHang 216 UAM aircraft (image credit: EHang Holdings Limited, used with permission).

Figure 2: A real view of the EHang 216 UAM aircraft during a flight test (image credit: EHang Holdings Limited, used with permission).

passenger) before shifting to autonomous flight (no pilots, two passengers).

VoloCity adopts redundancy in the battery and the propellers. Losing one or two out of the nine battery packs is tolerable. Similarly, if 1 or 2 out of the 18 propellers fail, a flight can continue safely.

Figure 3 shows a real view of an experimental unit of the VoloCity aircraft. Figure 4 shows the close-up of its cockpit. Figure 5 is an imagined view of that aircraft during flight.

Table 1: Some Characteristics of EHang 216 UAM Aircraft

Characteristics	Value
Number of seats	2
Maximum payload	220 kg (485 lb)
Altitude	975 m (3,200 ft)
Maximum speed	130 km/h (81 mph)
Range (with maximum payload)	35 km (22 mi)
Number of propellers	16 (mounted on 8 arms)
Aircraft height	1.77 m (5.8 ft)
Aircraft width	5.61 m (18.4 ft)
Wing	No
Helicopter-type rotor	No
Autonomous	Yes

Table 2 lists some characteristics of the VoloCity UAM aircraft.

7 Examples of FCs

As a convertible vehicle that acts as a car and as an aircraft, an FC may raise an inherent difficulty during its design due to not being optimized for a single mode of transportation (either terrestrial or aerial). Despite this, having a vehicle that can be driven on roads at some times (which may be preferred when the roads are not congested), while can be flown at other times (which is valuable when crossing a river or trench without the need to seek a far bridge) offers the traveler a power to dynamically choose the optimum mode of transportation.

Some FCs have been adopted, such as AeroMobil 4.0 by the Slovak company AeroMobil [39,40]. It has four wheels and two seats and uses a turbocharged internal combustion engine with 224 kW (300 hp). Its cruise speed as an aircraft is 260 km/h (162 mph), while its top speed as a car is 160 km/h (99.4 mph). This FC is expected to be available in the market in 2023.

Another FC model is Transition by the Chinese company Terrafugia. Terrafugia was founded in 2006 by five alumni of the Massachusetts Institute of Technology in

Figure 3: A real model of Volocopter's VoloCity air taxi, aimed for commercial UAM services (image credit: Volocopter GmbH, used with permission).

the United States [41], as an American company based in the American city Woburn, located in the state of Massachusetts. It was later acquired by the Chinese Holding Group Zhejiang Geely, which works in global mobility technology, and is headquartered in the city of Hangzhou, the capital of the province of Zhejiang, in the east of China [42].

The two example FCs presented in the coming part have a special feature of being open for pre-order online by their manufacturing companies. This establishes a feeling of proximity between the customer and the product. Despite this similarity, one product is at a much-developed stage than the other.

7.1 PAL-V Liberty by PAL-V

In 2008, the Dutch company PAL-V International B.V. was founded. PAL-V stands for "Personal Air and Land Vehicle" [43]. The company is located in the town of Raamsdonksveer in the Netherlands, with representatives in all the six inhabited continents (as of September 2022).

With the country of registration being the Sultanate of Oman, the company offers two models: PAL-V Liberty ME Sport Edition and PAL-V Saqer Edition. As of October 2021 (and again in September 2022), the published expected price by the company for PAL-V Liberty ME Sport Edition was $649,000, while PAL-V Saqer Edition has a higher expected price of $799,000. The Saqer Edition is made specifically for the Middle East and North Africa (MENA) region. For the Netherlands or Germany as the country of registration, the company offers PAL-V Liberty Sport Edition with an expected price of €299,000, and PAL-V Liberty Pioneer Edition with an expected price of €499,000. The PAL-V Liberty Sport model is the standard edition of the PAL-V Liberty flying car, while the PAL-V Liberty Pioneer offers a level of personalization, with a limited number of vehicles to be made under this edition.

Figure 6 shows a view of the PAL-V Liberty Sport model with the rotor (at the top) and the propeller (at the back) being extended, while Figure 7 shows the vehicle in the contracted configuration (folded rotor and propeller). Figure 8 shows an interior view of the vehicle.

Figure 4: A real view of the cockpit of Volocopter's VoloCity (image credit: Volocopter GmbH, License(s): Zur freien Verwendung – for free use, used with permission).

PAL-V Liberty (regardless of the edition) has three wheels and two seats. It does not have a wing. It adopts a gyroplane (gyrocopter) concept for the flight mode, which means it combines a helicopter rotor and an airplane propeller. After the airplane is lifted in the air, the rotor is not powered. It rotates as a reaction to the airflow through it.

Table 3 lists some characteristics of the PAL-V liberty sport edition.

7.2 ASKA™ by NFT Inc.

ASKA™ eVTOL drive-and-fly vehicle for consumers is an envisioned product from the American company NFT Inc., which is doing business as ASKA. The company is located in the city of Los Altos, in the San Francisco Bay Area, in California [44].

The flying car is designed with four wheels and four seats. Two propellers are attached to the wing, while the four remaining propellers are attached to four retractable arms. The initial version (signature model) product has a price of $789,000 (the same price was announced in October 2021 and in September 2022). Pre-orders were made possible through a deposit of $5,000, which also enables a share equity in NFT Inc. (if certain legal eligibility conditions are satisfied). This deposit is fully refundable after a year. A full-scale prototype was made (without flight testing). Full-scale flight testing is expected by early 2023, while a small-scale pilotless prototype was already used in flight testing. The product delivery is anticipated by 2026. It is worth mentioning that the word Aska or Asuka is synonymous with (flying bird) in Japanese when uttered [45].

Figure 9 shows how the flying car ASKA™ may look like, with the wing and propeller-carrying arms extended.

Figure 5: A rendering for Volocopter's VoloCity while flying over Singapore (image credit: Volocopter GmbH, License(s): Zur freien Verwendung – for free use, used with permission).

Table 2: Some characteristics of VoloCity UAM aircraft

Characteristic	Value
Number of seats	2
Maximum payload	200 kg (441 lb)
Altitude	1,981 m (6,500 ft)
Maximum takeoff weight (MTOW)	900 kg (1,984 lb)
Maximum speed	110 km/h (68 mph)
Range	35 km (22 mi)
Number of propellers	18 (mounted on a top rim)
Aircraft height	2.5 m (8.2 ft)
Diameter of the propeller rim (circular frame carrying propellers), including the propellers	11.3 m (37.1 ft)
Diameter of the propeller rim (circular frame carrying propellers), excluding the propellers	9.3 m (30.5 ft)
Propeller diameter	2.3 m (7.5 ft)
Propeller's electric motor type	Brushless direct current
Power supply	9 rechargeable battery packs, lithium ion
Battery swapping	Yes (in 5 min)
Wing	No
Helicopter-type rotor	No
Autonomous	Initially no (planned later)

Figure 10 shows how it may look when the wing and propeller-carrying arms are folded. Figure 11 illustrates the orientation of the wing during landing, where the wing tilts to make its two attached propellers in a vertical orientation, generating an upward lift force rather than a forward thrust force. On the other hand, the other four propellers not attached to the wing are always in a vertical orientation when operating, thereby contributing to the lift force to counteract the weight.

The proposed design for this flying car featured the idea of in-wheel motor, with an electric motor attached directly to the wheel itself. This frees some of the interior space to accommodate four seats and also improves the driving experience.

Figure 6: PAL-V Liberty Sport from outside with extended rotor and propeller (image credit: PAL-V International B.V., used with permission).

Figure 7: PAL-V Liberty Sport from outside with folded rotor and propeller (image credit: PAL-V International B.V., used with permission).

Figure 8: PAL-V Liberty Sport from the inside (image credit: PAL-V International B.V., used with permission).

Table 4 lists some characteristics of the designed ASKA™ flying car.

8 eVTOL air taxis

8.1 eVAT model

Based on an insight article dated May 2019 [46] by a team at Deloitte Development LLC, a member company of the London-based international network of professional services Deloitte; people or cargo transportation through UAM at a large scale seems to dominantly utilize eVTOL aircraft, with hybrid-electric vertical takeoff and landing aircraft also considered candidates among the service fleet. In the envisioned UAM system, the MaaS business model was assumed. Instead of privately owned aircraft, these UAM aircraft operate as flying taxis with centralized management under a commercial operator. This section focuses on this business model of UAM, with eVTOL flying taxis (or electric vertically-flying air taxis (eVAT)). The term "air taxi" here is suitable particularly for passenger-oriented UAM. However, cargo shipping can be included within the offered MaaS model. The term "air taxi" here is still used, bearing in mind that it may actually be referring to an aircraft doing air delivery of a shopped item, a document, or a parcel.

The use of fully electric aircraft is advantageous from an environmental perspective due to being zero-carbon-ready (ZCR) [47], which means that there are no emissions of carbon dioxide released directly from them during their operation, since they have electric motors rather than internal combustion engines. However, reaching a zero-carbon status (a better environment-friendly status beyond ZCR) demands that the electricity used for charging the on-board batteries comes from a clean energy source that does not release polluting carbon dioxide (or other greenhouse gases), such as solar energy or wind energy. As a benchmarking value, the average carbon-dioxide emissions from new passenger cars in Europe was 122.3 g CO_2/km in 2019 [48]. According to a released document in 2018 [49], the US Environmental Protection Agency reported an emission rate of 404 g CO_2/mi for the average vehicle in the United States, which is equivalent to 251 g CO_2/km. Thus, an eVTOL UAM system can prevent the release of a large amount of CO_2 to the atmosphere if that UAM system is successful in replacing trips made by engine-powered private cars with trips made by zero-carbon (ZC) UAM aircraft.

In a subsequent study [50] from Deloitte Development LLC, more than 35,000 persons of driving age in 20 countries were surveyed during October 2019 (using an online questionnaire, translated into the local language) to give their opinion about various transportation issues, including UAM. In that study, the perception of potential customers about the eVTOL-MaaS (air taxis) system was assessed in terms of (1) utility and (2) safety.

Table 3: Some characteristics of the PAL-V liberty sport flying car

Characteristic	Value
Number of wheels	3
Flight concept	Gyroplane (gyrocopter)
Number of seats	2
Maximum payload	246 kg (542 lb)
Maximum operating altitude	3,500 m (11,483 ft)
MTOW	910 kg (2,006 lb)
Maximum speed (flight mode)	180 km/h (112 mph)
Economic speed (flight mode)	140 km/h (87.0 mph)
Maximum speed (drive mode)	160 km/h (99.4 mph)
Minimum speed for level flight	50 km/h (31 mph)
Range (flight mode, with 0.5 h reserve fuel and MTOW)	400 km (249 mi)
Range (flight mode, with 0.5 h reserve fuel, single person operation, at mean sea level)	500 km (311 mi)
Range (drive mode)	1,315 km (817 mi)
Endurance (level flight time), (with 0.5 h reserve fuel, MTOW)	4.3 h
Takeoff distance (15 m obstacle clearance, MTOW, mean sea level)	330 m (1,083 ft)
Landing distance from touching the ground to stopping	30 m (98 ft)
Number of propellers	1 (rear mounted)
Engine power (flight mode)	147 kW (200 hp)
Engine power (drive mode)	73.5 kW (100 hp)
Fuel economy (flight mode)	26 L/h (6.9 US gal/h)
Fuel economy (drive mode)	7.6 L/100 km (31 MPG, miles per US gallon)
Fuel type	Euro 95, Euro 98, E10 – Unleaded automotive fuel, with up to 10% ethanol
Fuel tank size	100 L (26.4 US gallons)
Vehicle height (flight mode)	3.2 m (10.5 ft)
Vehicle height (drive mode)	1.7 m (5.6 ft)
Vehicle width (flight mode)	2 m (6.6 ft)
Vehicle width (drive mode)	2 m (6.6 ft)
Vehicle length (flight mode)	6.1 m (20 ft)
Vehicle length (drive mode)	4 m (13 ft)

Also, changes in this perception with respect to a similar older survey in the previous year of 2018 were presented. The perception was found to be dependent on the age and country of the respondents. Overall, about half of the respondents (49% in 2019 versus 48% in 2018) agreed that "Passenger drones/air taxis would be a viable solution to roadway congestion." Thus, they feel that the eVTOL-MaaS system is useful. About one-third of the respondents (32% in 2019 versus 35% in 2018) disagreed that "Passenger drones/air taxis will not be safe," which addresses the safety feature of these air taxis. Respondents in China showed a noticeably higher rating for utility (65% in 2019

Figure 9: An imagined view of the ASKA flying car with the wing and propeller-carrying arms extended (image credit: NFT Inc., used with permission).

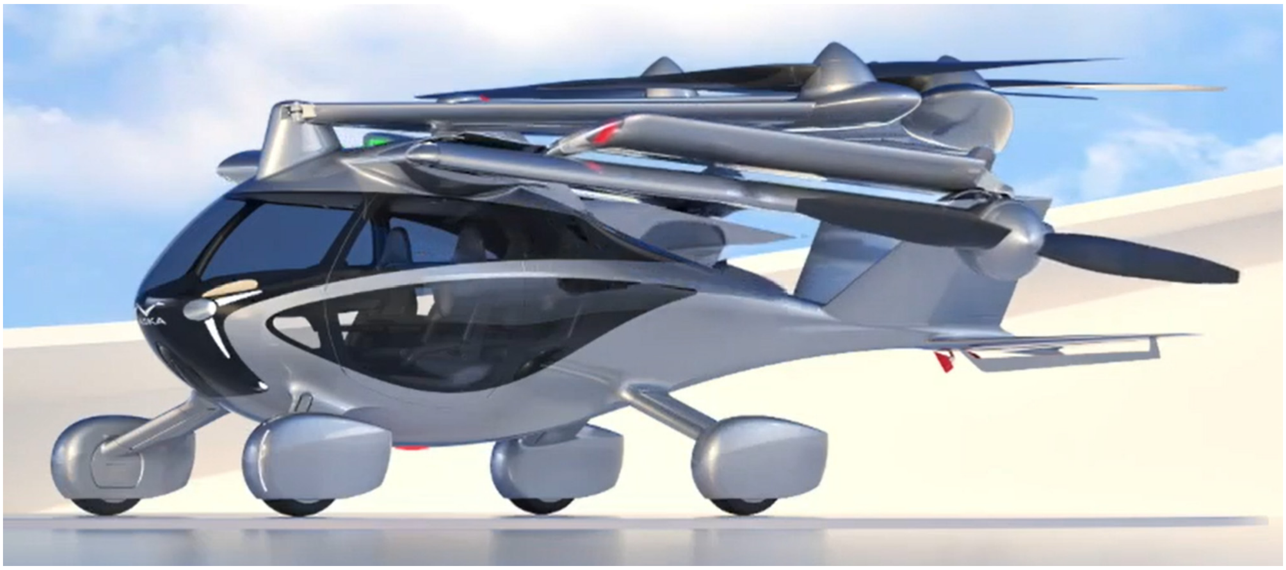

Figure 10: An imagined view of the ASKA™ flying car with the wing and propeller-carrying arms folded (image credit: NFT Inc., used with permission).

versus 73% in 2018) than the average rating, and younger respondents showed also a higher utility rating than older ones.

8.2 Ground infrastructure

According to the Deloitte's insight article, the largest anticipated barrier for the air taxis system (eVTOL-MaaS or eVAT) was designing and building the necessary ground infrastructure. The term "vertiport" was generalized into "vertiplaces," which is the area having landing/takeoff facilities that includes the "vertiports" as well two other types: "vertihubs" and "vertistations." All three types of vertiplaces provide landing and takeoff pads for the eVTOL taxis. However, they differ in the size and the targeted urban environment. Vertiports are aimed to be in the middle of the city, used for both passenger and cargo transportation. They can be placed at the roof of a building. UAM operators should place vertiports at or near primary destinations, such as central business districts, shopping malls, and ground transportation stations (such as those for trains and subways). Integration with the existing ground transportation is important. Vertiports are expected to be large enough to serve multiple eVTOL aircraft at the same time.

Table 4: Some characteristics of ASKA™ Flying Car

Characteristic	Value
Number of wheels	4
Number of seats	4
Range	Up to 402 km (250 mi)
Maximum speed (flight mode)	241 km/h (150 mph)
Number of propellers	6

Figure 11: An imagined view of the ASKA™ flying car during landing (image credit: NFT Inc., used with permission).

They also can have fast charging (or refueling) systems, security checkpoints, and facilities to perform minor repair work. Vertistations are smaller versions of vertiports, with the capacity to accommodate only two or even one eVTOL aircraft. This makes them easier and cheaper to build than vertiports. They also do not need to provide any charging/refueling systems. Vertistations help in expanding the UAM service to suburban areas. Opposite to vertistations, vertihubs are the larger versions of vertiports. They are viewed as dedicated UAM airports. Their suitable location is the periphery of urban or suburban zones. There should be at least one vertihub in each city covered by the UAM service. Vertihubs are the largest ground structure among all UAM components. In addition to landing and takeoff pads, they should have maintenance and repair facilities, as well as a parking area.

8.3 Prospects

The declared period for expected deployment of UAM service in more than one place in the world was around 2025 (2024–2025 for European Union cities, 2024 for the American city Miami, and 2025 for South Korea) [51]. The launch of this service commercially and sustainably depends largely on the readiness of infrastructure, support from regulatory bodies, certification of aircraft and pilots, defining safety procedures at vertiplaces, establishing adequate unmanned air traffic management services, and integration with the existing ground transportation. There is a large disparity among different countries in their capacity with regard to these items, with China, the United States, Germany, and South Korea being in a leading position [52,53]. Thus, the year 2025 is the estimated year to start commercial UAM trips using aircraft at one or more of these leading candidate countries. It is likely that the eVTOL-MaaS UAM system starts with piloted trips, before adding the more complex autonomous ones at a later stage after gaining confidence about the service, from the side of the corporate operators as well as the side of society members.

8.4 Drawbacks and solutions

This section presents some potential drawbacks for the air taxis (eVTOL-MaaS or eVAT) and suggested solutions. These drawbacks are generic and are not specific to a particular location. Thus, some of them may not be applicable in certain urban communities.

8.4.1 High ticket cost

A recent study (2021) showed that a five-seat eVTOL aircraft in the United States is expected to cost (in terms of passenger price per mile) more than all normal ground transportation alternatives, including premium-surface TNC (transportation network company), ground taxis (taxicabs), and private vehicles (ownership). However, traveling by eVTOL aircraft was found cheaper than traveling by five-seat helicopters or limousines [54]. Furthermore, eVTOL aircraft with fewer seats have higher passenger costs (6.25 USD/mi for five seats compared to 11 USD/mi for two seats). The flight was assumed to be piloted, which means that the two-seat air taxi is carrying one paying passenger. Ground taxis, private vehicles, or normal TNC costs less than 3 USD/mi, while a premium TNC costs about 4 USD/mi. A passenger load factor (the number of occupied paying-passenger seats divided by the total number of paying-passenger seats) ranged from 50 to 80%. Random simulation cases (10,000 cases) were made with this range, leading to an average load factor of about 65%. The study showed that increasing the passenger load factor and using autonomous flights can reduce the passenger cost for the air taxi by 60% (which makes the cost of travel by an air taxi less than that of a ground taxi).

Solution:

- Increasing the passenger load factor (through careful choice of vertiplace locations)
- Switching to autonomous flight (thus eliminating expenses related to the pilot)
- Attracting environment-responsible customers who are willing to pay a higher commuting fee given that they support and use a zero-carbon (or ZCR) transportation alternative

8.4.2 Introduced hazard

With UAM aircraft flying over functional urban or suburban areas, a new type of hazard emerges. Any failure of these aircraft leading to its fall can cause costly damages or injuries [55]. This matter causes resistance not only for the traveler to use this mode of transportation [56] but also for the members of the community, even those not engaged in UAM travels.

Solution:

- High redundancy in the eVTOL functions (such as standby propellers and an emergency battery)
- BPS
- Using dedicated airspace routes with minimal human activity or presence on the ground below them

8.4.3 Violated privacy

Being able to hover at low altitudes over visually exposed single-family residential homes can be inappropriate or annoying [57,58]. The matter also extends further to national security (such as unacceptable hovering near military zones) and some business sectors (such as resorts). Distractions and visual pollution are related problems.

Solution:

- Integration with ground transportation, such that the travel mode changes from aerial to ground upon entering areas with possible privacy violation
- Using dedicated airspace routes that bypass areas with possible privacy violation
- Offering top covers (large canopies) free of charge to complaining community members

8.4.4 Noise

From aeroacoustics, UAM eVTOL aircraft can cause noise due to turbulence generated from the propellers. This can cause complaints and poor social perception. Noise can have a negative impact on the eVTOL passengers also. In fact, noise and vibration together were considered a category of passenger concerns [59].

Solution:

- Adapting the design or operation of propellers to reduce induced noise, despite potential penalty in the produced lifting force [60]
- Using the unconventional propulsion technology called "distributed propulsion", where a large propeller is replaced by many small propelling units (propulsors), leading to reduced noise [61]
- Flying at elevated levels to attenuate the noise perceived at the ground level

8.4.5 Processing-time loss

An air taxi has several reasons to complete a trip in less time than a ground taxi. These include following a straight or a nearly straight path, lack of congestions, lack of traffic lights (particularly the red light), lack of road bumps, lack of crossing pedestrians, and the higher flight speed. It was found that the pure travel time using an air taxi can be 50% that of a ground taxi [62]. Despite this promising finding, the total time an air taxi takes from one vertiplace to another should be added to the time of passenger's security checks, boarding, and disembarking. Also, the takeoff and landing phases of travel are not as useful as the main cruising segment in terms of the horizontal traveled distance. Taking these factors into consideration, one finds that an air taxi does not always provide a time saving to the passenger. A recent study has examined this matter in detail, considering the Munich Metropolitan Region, Île-de-France (or "Island of France" in English, which is a region with the highest population density in France [63], containing Paris within it), and San Francisco Bay Area in California. The prospective time saving due to using UAM trips was found to depend largely on the number of UAM stations (vertiplaces) and their spatial distribution in the area to be served by the UAM aircraft. Moreover, short trips do not seem suitable for UAM aircraft when time savings are concerned. A minimum of about 50-min car drive on average is needed for UAM travels to show a time saving. Therefore, UAM should not be viewed as a replacement to mass transport systems, but as an additional system suitable for certain types of trips [64].

Solution:

- Paying more attention to the distribution and accessibility of UAM stations than to the cruise speed of air taxis
- Reducing processing time for passengers using air taxis, especially for short-range trips
- Emphasizing the use of air taxis for long trips, such as between cities or in a large city (including suburbs), where time savings become more viable

9 Concluding remarks

Technology has changed several things in the daily life, and urban transportation is not an exception. This work was an overview of two modern technologies for transportation in cities: UAM and FCs. UAM utilizes the third spatial dimension (elevation) in mobility, allowing short straight-line travel while carrying passengers or cargo, while FCs make this aerial travel an option available to utilize when suitable. These technologies can improve the transportation sector in cities through reduced road traffic with shorter transportation times and also can have favorable environmental impacts due to reduced carbon dioxide emissions (in the case of electric powering).

The work here clarified some acronyms that are related to UAM and flying cars, explained some differences between these two categories of three-dimensional transportation, and discussed some challenges for each category as well as opportunities they can bring. It mentioned a total of 9 specific examples under both technologies together (10 examples if the mentioned use of a helicopter under UAM is also counted), with some details given to four examples (two examples under each category).

Attention was then given to a MaaS business model with eVTOL aircraft, utilized by a commercial operator in a large urban/suburban area (or connecting these areas) for passengers or cargo transportation. This model (also referred to here as eVAT) appears more likely to achieve large-scale operations than private ownership, providing that adequate ground infrastructure is constructed, careful consideration of the needs of local consumers is taken into account, integration with existing transportation systems is achieved, good distribution of the stations is planned, and supportive policies from regulatory bodies are established without delay. Five drawbacks of air taxis in this futuristic commercial UAM system were discussed, guided by relevant studies, and three suggested solutions or mitigating actions were given for each of them.

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References

[1] UN DESA (United Nations Department of Economic and Social Affairs). 68% of the world population projected to live in urban areas by 2050; c2018 May 16 [cited 2021 Oct 3]. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.

[2] Bourdeau-Lepage L, Huriot J-M. Megacities without global functions. Belgeo. 2007 Jan;8(1):95–114. doi: 10.4000/belgeo.11675.

[3] UNESCO (United Nations Educational, Scientific and Cultural Organization). Explanation Note for: I. Megacities Alliance for Water and Climate (MAWAC), and II. Second International Conference. Water, Megacities and Global Change" (EauMega 2022); 2021 [cited 2002 Oct 15]. https://en.unesco.org/sites/default/files/mawac_explanation_note_2021_en.pdf.

[4] UNESCO (United Nations Educational, Scientific and Cultural Organization). Megacities worldwide; [cited 2021 Oct 3]. https://en.unesco.org/events/eaumega2021/megacities.

[5] Vital Signed (for San Francisco Bay Area, California, U.S.A.) - MTC (Metropolitan Transportation Commission). Time Spent in Congestion [cited 2021 Oct 3]. https://www.vitalsigns.mtc.ca.gov/time-spent-congestion.

[6] Department for Transport of the United Kingdom. Road Congestion Statistics - Table CGN0501a - Monthly and 12 month rolling average speeds on local 'A' roads in England [updated 2021 Jul 8; cited 2021 Oct 3]. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1040430/cgn0501.ods.

[7] World Bank. Features Story - Reducing Traffic Congestion and Emission in Chinese Cities; c2018 Nov 16 [cited 2021 Oct 3]. https://www.worldbank.org/en/news/feature/2018/11/16/reducing-traffic-congestion-and-emission-in-chinese-cities.

[8] Smarter Cambridge Transport. Urban congestion inquiry. 2016 Dec 12 [cited 2002 Oct 15]. https://www.smartertransport.uk/wp-content/uploads/2017/03/Urban-congestion-inquiry_2016-12-09-1e.pdf.

[9] FAA (Federal Aviation Administration) - DOT (United States Department of Transportation). Urban Air Mobility and Advanced Air Mobility [updated 2022 Jun 1; cited 2022 Oct 15]. https://www.faa.gov/uas/advanced_operations/urban_air_mobility.

[10] Tang H, Zhang Y, Mohmoodian V, Charkhgard H. Automated flight planning of high-density urban air mobility. Transp Res Part C Emerg Technol. 2021 Oct;131:103324. doi: 10.1016/j.trc.2021.103324.

[11] EHang Holdings Limited (Chinese company). UAM - Passenger Autonomous Aerial Vehicle (AAV); [cited 2021 Oct 3]. https://www.ehang.com/ehangaav.

[12] Hildmann R, Kovacs E. Review: using unmanned aerial vehicles (UAVs) as mobile sensing platforms (MSPs) for disaster response, civil security and public safety. Drones. 2019 Jul;3:59. doi: 10.3390/drones3030059.

[13] Ansari S, Taha A, Dashtipour K, Sambo Y, Abbasi QH, Imran MA. Urban Air Mobility–A 6G Use Case? Front Comms Net. 2021 Aug;2:729767. doi: 10.3389/frcmn.2021.729767.

[14] EASA (European Union Aviation Safety Agency). Frequently asked questions on UAM; 2021 [cited 2002 Oct 15]. https://www.easa.europa.eu/sites/default/files/dfu/uam_-_faqs.pdf.

[15] Euronews. [Watch: Flying taxi service in Jordan for $77 per trip] [update 2019 Jan 10; cited 2021 Oct 3]. Arabic. https://arabic.euronews.com/2019/01/10/jordan-flying-taxi-been-released-in-october-costs-77-dollars-for-each-person.

[16] Al Haddad C, Chaniotakis E, Straubinger A, Plötner K, Antoniou C. Factors affecting the adoption and use of urban air mobility. Transp Res Part A Policy Pract. 2020 Feb;132:696–712. doi: 10.1016/j.tra.2019.12.020.

[17] Straubinger A, Verhoef ET, de Groot HLF. Will urban air mobility fly? The efficiency and distributional impacts of UAM in

different urban spatial structures. Transp Res Part C Emerg Technol. 2021 Apr;127:103124. doi: 10.1016/j.trc.2021.103124.
[18] Pukhova A, Llorca C, Moreno A, Staves C, Zhang Q, Moeckel R. Flying taxis revived: Can Urban air mobility reduce road congestion? J Urban Mobil. 2021 Jul;1:100002. doi: 10.1016/j.urbmob.2021.100002.
[19] Biehle T. Social sustainable urban air mobility in Europe. Sustainability. 2022 Jul;14(15):9312. doi: 10.3390/su14159312.
[20] Jiang T, Geller J, Ni D, Collura J. Unmanned Aircraft System traffic management: Concept of operation and system architecture. Int J Transp Sci Technol. 2016 Oct;5(3):123–35. doi: 10.1016/j.ijtst.2017.01.004.
[21] Lundberg J, Westin C, Arvola M, Holmlid S, Josefsson B. Cognitive work analysis and conceptual designing for unmanned air traffic management in cities. ECCE'18: Proceedings of the 36th European Conference on Cognitive Ergonomics; 2018 Sep. p. 1–4. doi: 10.1145/3232078.3232082.
[22] Park J-H, Choi S-C, Ahn I-Y. Structure design for unmanned aircraft traffic management system. ICUFN 2019: Proceedings of the 11th International Conference on Ubiquitous and Future Networks; 2019 Jul. p. 118–20. doi: 10.1109/ICUFN.2019.8806075.
[23] Huttunen M. The U-space concept. Air Space Law. 2019 Feb;44(1):69–89. doi: 10.54648/aila2019005.
[24] Cohen AP, Shaheen SA, Farrar EM. Urban air mobility: History, ecosystem, market potential, and challenges. IEEE trans Intell Transp Syst. 2021 Sep;22(9):6074–87. doi: 10.1109/TITS.2021.3082767
[25] Australia Aviation. Flying Cars Throughout The Ages [cited 2022 Sep 15]. https://australianaviation.com.au/2022/01/flying-cars-throughout-the-ages-p-60-61.
[26] Hendricks ES, Falck RD, Gray JS, Aretskin-Hariton E, Ingraham D, Chapman JW, et al. Multidisciplinary optimization of a turboelectric tiltwing urban air mobility aircraft. Proceedings of the AIAA Aviation 2019 Forum; 2019 Jun. AIAA 2019-3551. doi: 10.2514/6.2019-3551.
[27] Send2Press. Moller International Inc. Offers to Sell its Original M400 Skycar; c2017 Jul 17 [cited 2022 Sep 15]. https://www.send2press.com/wire/moller-international-offers-to-sell-its-original-m400-skycar.
[28] Postorino MN, Sarné GML. Reinventing mobility paradigms: Flying car scenarios and challenges for urban mobility. Sustainability. 2020 Apr;12:3581. doi: 10.3390/su12093581.
[29] Pan G, Alouini M-S. Flying car transportation system: Advances, techniques, and challenges. IEEE Access. 2021 Feb;9:24586–603. doi: 10.1109/ACCESS.2021.3056798.
[30] FAA (Federal Aviation Administration) - DOT (United States Department of Transportation). Module 4: Ballistic parachute system familiarization; [cited 2022 Oct 15]. https://www.faa.gov/aircraft/gen_av/first_responders/mod4/presentation_html5.html.
[31] Kitty Hawk (American company). History — Kittyhawk [cited 2022 Jan 22]. https://www.kittyhawk.aero/history.
[32] Lilium GmbH (German company). Investor Relations | Lilium N.V. [cited 2021 Oct 4]. https://investors.lilium.com.
[33] EHang Holdings Limited (Chinese company). EHang | Contact us [cited 2021 Oct 4]. https://www.ehang.com/contact.
[34] EHang Holdings Limited (Chinese company). EHang 216's Korean Flight Tour: The First Step Toward Future UAM Operations; c2020 Nov 24 [cited 2021 Oct 4]. https://www.ehang.com/news/710.html.
[35] EHang Holdings Limited (Chinese company). EHang 216 AAV Conducted Trial Flights in Japan; c2021 Jun 4 [cited 2021 Oct 4]. https://www.ehang.com/news/774.html.
[36] EHang Holdings Limited (Chinese company). EHang Reports Fourth Quarter and Full Year 2019 Unaudited Financial Results; c2020 Mar 24 [cited 2021 Oct 4]. https://ir.ehang.com/news-releases/news-release-details/ehang-reports-fourth-quarter-and-full-year-2019-unaudited.
[37] EHang Holdings Limited (Chinese company). EHang Reports Fourth Quarter and Full Year 2020 Unaudited Financial Results; c2021 Apr 16 [cited 2021 Oct 4]. https://ir.ehang.com/news-releases/news-release-details/ehang-reports-fourth-quarter-and-full-year-2020-unaudited.
[38] Volocopter GmbH (German company). eVTOL brought to life by Volocopter [cited 2021 Oct 4]. https://www.volocopter.com/solutions.
[39] AeroMobil (Solvak company). AeroMobil | Facebook [cited 2021 Oct 4]. https://www.facebook.com/aeromobilcom/about.
[40] FutureFlight. AeroMobil 4.0 Meets Airworthiness Targets in Flight Tests; c2021 Mar 4 [cited 2021 Oct 4]. https://www.futureflight.aero/news-article/2021-03-04/aeromobil-40-meets-airworthiness-targets-flight-tests.
[41] Terrafugia (Chinese company). Who We Are | Leadership, Culture, Innovation [cited 2021 Oct 4]. https://terrafugia.com/who-we-are/#company.
[42] Zhejiang Geely Holding Group (Chinese group). Locations [cited 2021 Oct 4]. http://zgh.com/locations/?lang=en.
[43] PAL-V International B.V. (Dutch company). Flying Car: Explore the PAL-V Liberty | PAL-V [cited 2021 Oct 4]. https://www.pal-v.com/en/explore-pal-v.
[44] NFT Inc. (American company). ASKA™ 4-seater drive & fly vehicle for consumers [cited 2021 Oct 4]. https://www.askafly.com.
[45] Wiktionary. Asuka (Japanes term) [cited 2022 Sep 16]. https://en.wiktionary.org/wiki/%E9%A3%9B%E9%B3%A5.
[46] Lineberger R, Hussain A, Metcalfe M, Rutgers V Infrastructure barriers to the elevated future of mobility - Are cities ready with the infrastructure needed for urban air transportation? Deloitte Insights article; 2019 May 30 [cited 2002 Oct 15]. https://www2.deloitte.com/content/dam/insights/us/articles/5103_Infrastructure-barriers-to-elevated-FOM/DI_Infrastructure-barriers-to-elevated-FOM.pdf.
[47] Johnson S. The green house effect: We all know the climate is changing, and so must our homes and how we build them. Eng Technol. 2021 Nov;16(10):1–4. doi: 10.1049/et.2021.1011.
[48] EEA (European Environment Agency). CO_2 performance of new passenger cars in Europe; c2022 Sep 26 [cited 2022 Oct 15]. https://www.eea.europa.eu/ims/co2-performance-of-new-passenger.
[49] EPA (United States Environmental Protection Agency). Greenhouse Gas Emissions from a Typical Passenger Vehicle. Michigan: Offce of Transportation and Air Quality - document EPA-420-F-18-008; 2018 Mar [cited 2002 Oct 15]. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100U8YT.pdf.
[50] Lineberger R, Hussain A. Urban air mobility - What will it take to elevate consumer perception? Deloitte publication; 2020 [cited 2002 Oct 15]. https://www2.deloitte.com/content/

dam/Deloitte/us/Documents/energy-resources/urban-air-mobility.pdf.
[51] Archer Aviation Inc. Archer Announces Commitment to Launching its Urban Air Mobility Network in Miami by 2024 [cited 2022 Sep 15]. https://archer.com/news/archer-announces-commitment-to-launching-its-urban-air-mobility-network-in-miami-by-2024.
[52] Research and Markets. World Urban Air Mobility Market 2022: Ridesharing Companies are Projected to Dominate the Market from 2025 to 2030; c2022 Jun 24 [cited 2022 Sep 15]. https://www.businesswire.com/news/home/20220624005427/en/World-Urban-Air-Mobility-Market-2022-Ridesharing-Companies-are-Projected-to-Dominate-the-Market-from-2025-to-2030—ResearchAndMarkets.com.
[53] Chung K. (Korea Aerospace Research Institute). Presentation Material of K -UAM Grand Challange Industry Day: K-UAM grand challenge; c2022 Feb 18 [cited 2022 Oct 15] https://en.kuam-gc.kr/35/?q=YToxOntzOjEyOiJrZXl3b3JkX3R5cGUiO3M6MzoiYWxsIjt9&bmode=view&idx=10439763&t=board.
[54] Goyal R, Reiche C, Fernando C, Cohen A. Advanced air mobility: Demand analysis and market potential of the airport shuttle and air taxi markets. Sustainability. 2021 Jul;13:7421. doi: 10.3390/su13137421.
[55] Thompson EL, Taye AG, Guo W, Wei P, Quinones M, Ahmed I, et al. A survey of eVTOL aircraft and AAM operation hazards. Proceedings of the AIAA AVIATION 2022 Forum. AIAA; 2022 Jun-Jul. p. 2022–3539. doi: 10.2514/6.2022-3539.
[56] Littell JD. Challenges in Vehicle Safety and Occupant Protection for Autonomous electric Vertical Take-off and Landing (eVTOL) Vehicles. EATS 2019: Proceedings of the 2019 AIAA/IEEE Electric Aircraft Technologies Symposium. AIAA; 2019 Aug. p. 1–16. 2019–4504. doi: 10.2514/6.2019-4504.
[57] Villasenor J. Observations from above: Unmanned aircraft systems and privacy. Harv J Law Public Policy. 2013;36(2):457–517, https://www.scopus.com/record/display.uri?eid=2-s2.0-84876822417&origin=inward&txGid=5fdb6baaea441dd3c59490fe28c41bff.
[58] Lee D, Hess DJ, Heldeweg MA. Safety and privacy regulations for unmanned aerial vehicles: A multiple comparative analysis. Technol Soc. 2020 Nov;71:102079. doi: 10.1016/j.techsoc.2022.102079.
[59] Edwards T, Price G. eVTOL Passenger Acceptance. NASA (National Aeronautics and Space Administration) - Contractor Report (CR) NASA/CR—2020–220460; 2020 Jan [cited 2002 Oct 15]. https://ntrs.nasa.gov/api/citations/20200000532/downloads/20200000532.pdf.
[60] Weitsman D, Greenwood E. Parametric Study of eVTOL Rotor Acoustic Design Trades. Proceedings of the AIAA Scitech 2021 Forum. AIAA; 2021 Jan. p. 2021–1987. doi: 10.2514/6.2021-1987.
[61] Kim HD, Felder JL, Tong MT, Berton JJ, Haller WJ. Turboelectric distributed propulsion benefits on the N3-X vehicle. Aircr Eng Aerosp Technol. 2014 Sep;86(6):558–61. doi: 10.1108/AEAT-04-2014-0037.
[62] Naser F, Peinecke N, Schuchardt BI. Air Taxis vs. Taxicabs: A Simulation Study on the Efficiency of UAM. Proceedings of the AIAA Aviation 2021 Forum. AIAA; 2021 Aug. p. 2021–3202. doi: 10.2514/6.2021-3202.
[63] Britannica, The Editors of Encyclopaedia [Internet]. Île-de-France; c2019 Aug 22 [cited 2022 Sep 15]. https://www.britannica.com/place/Ile-de-France-region-France.
[64] Rothfeld R, Fu M, Balać M, Antoniou C. Potential urban air mobility travel time savings: An exploratory analysis of Munich, Paris, and San Francisco. Sustainability. 2021 Feb;13:2217. doi: 10.3390/su13042217.