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Public perception of advanced aviation technologies: A review and roadmap to acceptance

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ABSTRACT

The aviation industry has seen a lot of innovation over the last 125 years. Advancements such as transatlantic flight and the development of avionics technologies and composite materials have changed how we think about what the future will hold. Advanced aviation technologies such as remotely piloted aircraft systems (i.e., “drones”) and urban air mobility may be the next revolution in the aviation industry. While many in the aviation industry look forward to greater inclusion of these technologies, the public may have a different perspective. This review aims to examine the factors that may influence one’s perception of advanced aviation technologies. First, an overview of the technologies is presented to categorize the different types of drones and how they are used, followed by a discussion on the principles of technological adoption. Next, data from past studies investigating the public perception of drones and air taxis was collected and analyzed to discover if any patterns exist in terms of overall acceptance or mission preferences, and to determine the root causes of hesitancy towards this emerging technology. The trends suggest that drones have become increasingly accepted as public awareness rises, and missions that support the common good are viewed more favourably than commercial uses such as package delivery or air taxi services. The major obstacles include the perceived level of risk, pre-existing judgement as to the technological reliability, as well as the lack of perceived benefits when compared to existing technologies. Each of these topics are discussed and finally, a roadmap towards public acceptance is presented, incorporating the viewpoints of the public, drone users, and regulatory authorities. Together, this review discusses the current state of the field and what must be done to better integrate advanced aviation technologies into everyday life.

1. Introduction

The Industrial Revolution was defined by the development of machines and processes geared towards assisting people perform a variety of different tasks. This led to many positive outcomes for society including greater productivity and yield, higher quality of life, and an increased life expectancy. The advancements made during this period also paved the way for some of the ground-breaking technologies of the twentieth century, such as the automobile, the airplane, and the computer. Technology will play a major role in the twenty-first century as well; however, this will primarily be due to the rise of artificial intelligence (AI), machine learning (ML), and computer vision (CV). One of the major beneficiaries of these technologies will be the transportation industry as vehicles will continuously incorporate more autonomous features, simplifying the task of driving a car or piloting an aircraft, making them safer and reducing the opportunity for human error. At present, automobiles have begun including autonomous features such as adaptive cruise control and automatic emergency braking; however, the market has yet to reach its full potential. In aircraft, commercial flights are flown predominantly by autopilot systems while these same systems are becoming more common in general aviation aircraft.

One major emerging application of CV, ML, and AI technologies in the aerospace industry are remotely piloted aircraft systems (RPAS). RPAS, also known as uninhabited aircraft systems (UAS), unmanned aerial vehicles (UAVs) or more colloquially as drones, are a class of aircraft that do not have a human pilot onboard and are instead controlled by either a human operator on the ground, onboard autonomous systems, or some combination of the two. These vehicles range in size from just a few grams all the way up to thousands of kilograms and can complete missions such as geological surveying, search and rescue, and package delivery. Mass production of some of these platforms in recent years has led to an increase in the number of recreational users who either fly for fun or to take pictures and videos of events and

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Abbreviations

AI	Artificial intelligence
AM	Additive manufacturing
CV	Computer vision
DEP	Distributed electric propulsion
EASA	European Union Aviation Safety Agency
eVTOL	Electric vertical takeoff and landing vehicle
FAA	Federal Aviation Administration
FPV	First-person view
GPS	Global positioning system
ICAO	International Civil Aviation Organization
IMU	Inertial measurement unit
LiDAR	Light detection and ranging
MALE	Medium altitude long endurance
ML	Machine learning
OEM	Original equipment manufacturer
PAV	Personal air vehicle
RPAS	Remotely piloted aircraft system
TAM	Technology acceptance model
UAM	Urban air mobility
UAS	Uninhabited aircraft system
UAV	Unmanned aerial vehicle

landscapes.

Another related emerging market is the field of urban air mobility (UAM) [1]. Generally, UAM refers to the movement of passengers by air in urban (intracity) environments, but can also include intercity transit, and even the aerial delivery of cargo in urban centres [2]. Regarding passenger transport with electric vertical-takeoff and landing (eVTOL) aircraft, the concept is still in its infancy; however, there are some vehicles nearing planned operations. Joby Aviation (United States) appears to be the closest to passenger operations as their S4 prototype received a Part 135 Air Carrier Certificate from the Federal Aviation Administration (FAA) in 2022 (although it has not yet received type certification) [3]. Also in the U.S., Archer is not far behind and targeting passenger operations by 2025 [4]. In Europe, certification is managed by the European Union Aviation Safety Agency (EASA) and Volocopter, Lilium, and Airbus are all making strides with their respective concepts. Volocopter opened a vertiport at the Pontoise-Cormeilles airport with the hope of debuting their air taxi at the 2024 Paris Olympic Games [5] while Airbus announced plans to start manufacturing while anticipating certification in 2025 [6]. China is also poised to become a significant UAM market with EHang, Autoflight, and Aerofugia leading the way. In 2021, Morgan Stanley downgraded their projection for the global UAM market from 1.5 trillion USD to 1.0 $Tn in 2040; however, they project the market share to potentially reach 9.0 $Tn in 2050 [7]. Of course, these projections are based on the advancement of the technology, certification, and safety regulations that can accommodate a rapidly growing market in the aerospace industry.

There has also been an increase in the level of interest in these technologies among the academic community. A search of Web of Science performed on 01 August 2022 yielded over 40,000 results in the past 20 years, with the vast majority of publications coming after 2017 (Fig. 1). Although the word "drone" is popular among the public, UAV or UAS is the preferred term in literature (it should be noted that a drone can also refer to a male worker bee, so these results were filtered out). There is also a growing interest in the public perception of robotic aircraft with the number of publications increasing exponentially since 2015 to a total of 56. Cumulatively, these publications have been cited over 450 times, demonstrating the increased level of attention the field is currently experiencing.

While many may view UAM and RPAS as completely different technologies, they share many similar characteristics. Both vehicle types are designed around their respective payloads, whether it is a camera, geographical mapping equipment, cargo or even a passenger. They need to fly in the same airspace, have the same challenges with energy distribution and storage, and share the same public concerns with respect to safety and privacy. For these reasons, the authors will consider RPAS and UAM together in this review. Additionally, RPAS platforms that are commercially available to hobbyists could be regarded as miniaturized UAM aircraft, as UAM vehicles will eventually become remotely piloted and fully autonomous.

As far as these technologies have advanced, the consensus among those in the UAM field is that public perception is the key barrier to pass before the technology is able to integrate into society. To some degree, RPAS have already become normalized as many survey participants report hearing about drones in movies, television shows, news reports, social media, and in literature [8,9]. On the other hand, there are many people that disclose some sort of noise or privacy-related concern from other individuals using the technology, or if the platform is used by a corporation or government agency [10]. Public perception is also dynamic and can change as the public is presented with new information such as a novel RPAS use case or the news of an eVTOL accident. The purpose of this review is to provide the reader with a snapshot of the public's feelings towards RPAS and UAM in different regions of the world and how those feelings have changed over time as the state of the art has evolved. Included is some background on the capabilities of

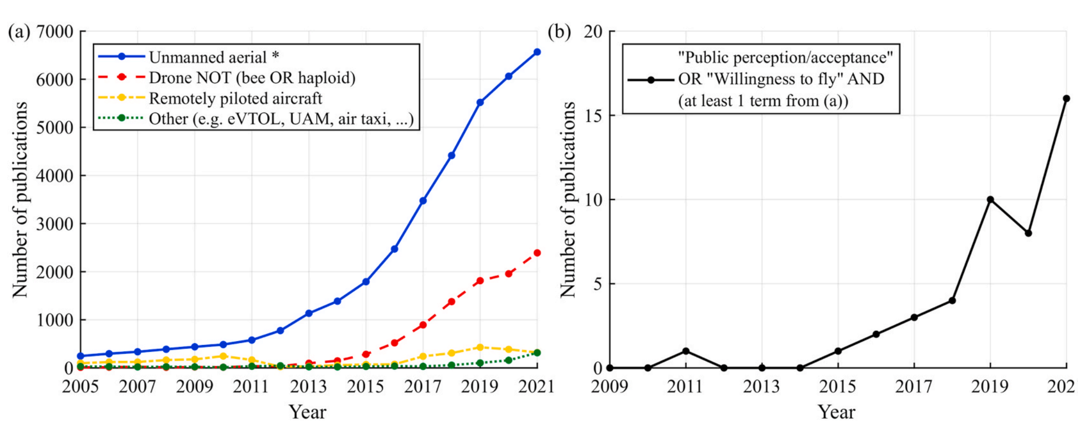

Fig. 1. (a) Number of publications to mention words or phrases associated with RPAS and (b) the number of these publications that also make reference to the public perception field.

RPAS and UAM platforms and a discussion on the adoption process for various technologies. This is followed by a comprehensive review of the public perception studies carried out to assess feelings towards drones and air taxis, and finally a roadmap is presented containing the remaining steps necessary to achieve successful integration of the technology.

2. Overview of the technology

Although the concept of a remotely piloted aircraft has been around since the nineteenth century (the first patent was filed by Nikola Tesla in 1898 [11]), it was not until the 1990s that they were used outside of military or hobby applications, with the FAA issuing the first operations certificate in 2005 [12]. Early usage was limited to research and military applications; however, miniaturization and commercialization of the technology led to drone usage by individuals and corporations. The intended application dictates the type of vehicle used (Section 2.1), the required specifications, and the necessary payloads. An overview of the various applications is presented in Section 2.2, followed by a discussion of the technologies enabling widespread use in Section 2.3.

2.1. Classification of vehicle systems

Although remotely piloted aircraft occupy a vast design space, we will classify them into four major categories as outlined in Fig. 2. The categories include a *nano* category, *off-the-shelf* category, *passenger carrying capable* category, and the *beyond* category. Prior classifications have focused on the technical capabilities such as the mass, range, flight altitude, and endurance [13] or risk [14]; our focus is on the capabilities of the platform and who could be capable of operating it, as public perception studies report that people have different feelings based on who is using the RPAS and what the vehicle is being used for [15]. While there is some degree of overlap between these categories, the logarithmic nature of this classification allows for emphasis to be placed on the capabilities of the systems, rather than the platforms themselves.

2.1.1. Nano aerial vehicles

Nano aerial vehicles are miniaturized commercial hobby drones that weigh less than 25 g and can fit in the palm of one's hand. Systems in this category are either for research or military purposes due to the high costs associated with working at such a small scale. They can be used to monitor an area for a short amount of time (less than 20 min), and they have limited capabilities when it comes to navigation or autonomous flight. An example is the Black Hornet PRS which is used by several militaries for special reconnaissance and weighs just 18 g. Future use of this category will likely still be limited to research and defense sectors as there are no imaginable applications at present of an everyday person requiring a companion flying vehicle that is effectively undetectable by others. Nonetheless, making such vehicles accessible to the public raises significant security concerns that will be briefly explored in Section 5.2.

2.1.2. Off-the-shelf platforms

This RPAS category is the most common and includes both fixed and rotary wing platforms. Wingspans of fixed wing vehicles can range from 200 mm to the 1:13 "giant" scale model of the Boeing 747–400 with a wingspan of 4.95 m and weighing 68 kg. Multirotors are generally smaller and range in size from small racing drones up to octocopters used for cinematography or payload transport, such as the T150 quadcopter produced by Malloy Aeronautics which can carry up to 68 kg [18]. The range and speed are dependant on the type of vehicle with fixed wing platforms being able to travel faster and further than multirotors (except in the case of racing drones, which are small quadcopters designed to fly very fast for a short amount of time).

Payloads for most vehicles include a camera, either to take photographs/video or for navigation via first person view (FPV), and a receiver to receive instructions from the operator. To fly autonomously, the vehicle would also need an autopilot and global positioning system (GPS). For real-time updating of the route and to transmit data between the vehicle and ground station, an internet connection is required, as well as an onboard computer to process the data. More advanced systems can carry specialized payloads to perform missions described in Section 2.2.

Commercial RPAS are used by different entities including individuals, corporations, and government agencies. Small systems are available at hobby stores or online and can cost below 50 USD, making them easy to acquire for home use. Commercial users perform specialized missions and thus require some additional payload capacity, generally up to 25 kg. Government agencies may require additional capabilities and can opt for larger platforms. Overall, future development of off-the-shelf platforms will likely focus on increasing flight times, while reducing cost for hobbyists. Larger platform improvements may consist of including more sophisticated payloads and software for operators to expand their capabilities. This market will continue to grow as one estimate projects the commercial drone market in the United

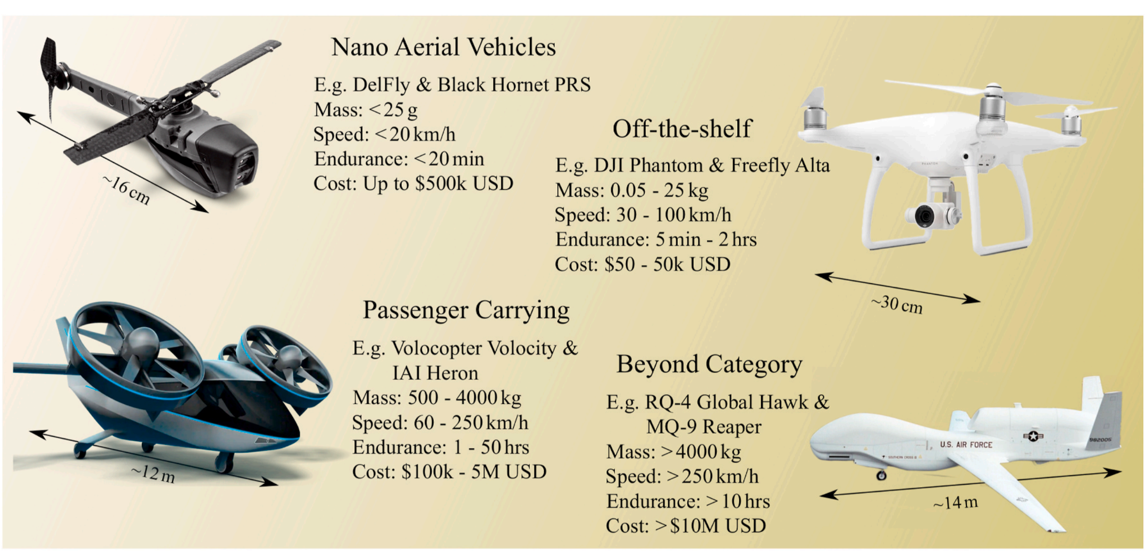

Fig. 2. *Categories of autonomous aerial vehicles. Images courtesy of Teledyne FLIR LLC (Black Hornet PRS)* [16] *and Bell Flight (Bell Nexus)* [17] *while the images of the DJI Phantom and Global Hawk are the author's own.*

States to reach between 31 and 46 billion USD by 2026, up from 40 million USD in 2012 and 1 billion USD in 2017 [19].

2.1.3. Passenger carrying capable systems

The passenger carrying capable category includes vehicles that can carry at least one person, or an equivalent payload. Examples of vehicles in this category include UAM aircraft and the conventional MALE category of RPAS. The design envelope can vary significantly, as UAM vehicles can accommodate anywhere from one to upwards of eight to ten passengers over ranges of 40 km to over 800 km. Payloads in this category for MALE UAVs include airborne radars, infrared line scanners, and satellite communication systems. Operators are all currently commercial or government entities; however, this may change in the future as individuals may begin purchasing their own personalized UAM aircraft similar to individually owned traditional general aviation aircraft and helicopters.

Future efforts will likely see these aircraft become more efficient, provide longer endurance, and increase capabilities and level of autonomy. Corporations may also show interest in these aircraft in the future as they look to transport goods autonomously over long distances. The future for UAM vehicles is less certain due to the state of regulatory affairs and the progress required from each of the enabling technology fields discussed in Section 2.3.

2.1.4. Beyond category type systems

This final category includes systems that are beyond the capabilities of typical MALE UAVs such as the General Atomics MQ-9 Reaper and Northrop Grumman RQ-4 Global Hawk. These types of platforms cost over 10 million USD and are only used by governments or militaries for surveillance or combat applications. These systems are useful in combat applications as they take the human pilot out of the aircraft, reducing the level of risk of the mission; however, ethical concerns slow the adoption of these systems. Some of the capabilities such as speed, range, and endurance may overlap with the passenger carrying capable category; however, the major differences are the size, cost, and who is allowed to operate the vehicles. As countries begin replacing aging aircraft in their military and government fleets, a larger emphasis will be placed on acquiring remotely piloted aircraft due to their improved capabilities over traditionally piloted aircraft. Future developments include improving capabilities, enhancing autonomy, reducing radar detectability, and developing more countermeasures to prevent cyberattacks.

2.2. Applications of remotely piloted aircraft

There are dozens of applications for RPAS platforms, and the number continues to increase with developments in the enabling technology fields. The mission type often dictates the configuration, size, and necessary vehicle payloads. Pictured in Fig. 3 are the major mission types, grouped into eight major categories based on the end goal of the mission. These categories are as follows.

- Aerial photography – acquiring high quality images or video for a number of different interests including ceremonies, events [20], tourism [20], real estate [21], crime scene forensics [22], wildlife/nature documentaries [23], or live streaming. A platform that can fly slowly, equipped with an optical daylight camera are essential for this usage category.
- Agriculture – these missions are centred around assisting the agriculture industry and include bird control [24], crop spraying [25], seed planting [26], crop health monitoring [25,27], and soil analysis [28]. Vehicles are fitted with mission-specific payloads to carry out their necessary tasks and platforms can be small (such as for seed planting) or larger to spray an entire field in a short amount of time.
- Delivery – in a delivery mission, the most important payload is the item(s) being delivered and can include packages [29,30], food [31], humanitarian supplies, blood, organs, medical supplies [32,33], or even people [30,34]. Vehicle size, speed, and range is scaled based on the total weight of the payload as a drone for delivering individual packages can be quite small, while an UAM vehicle must be larger. VTOL capability is not required for all missions; however, it greatly

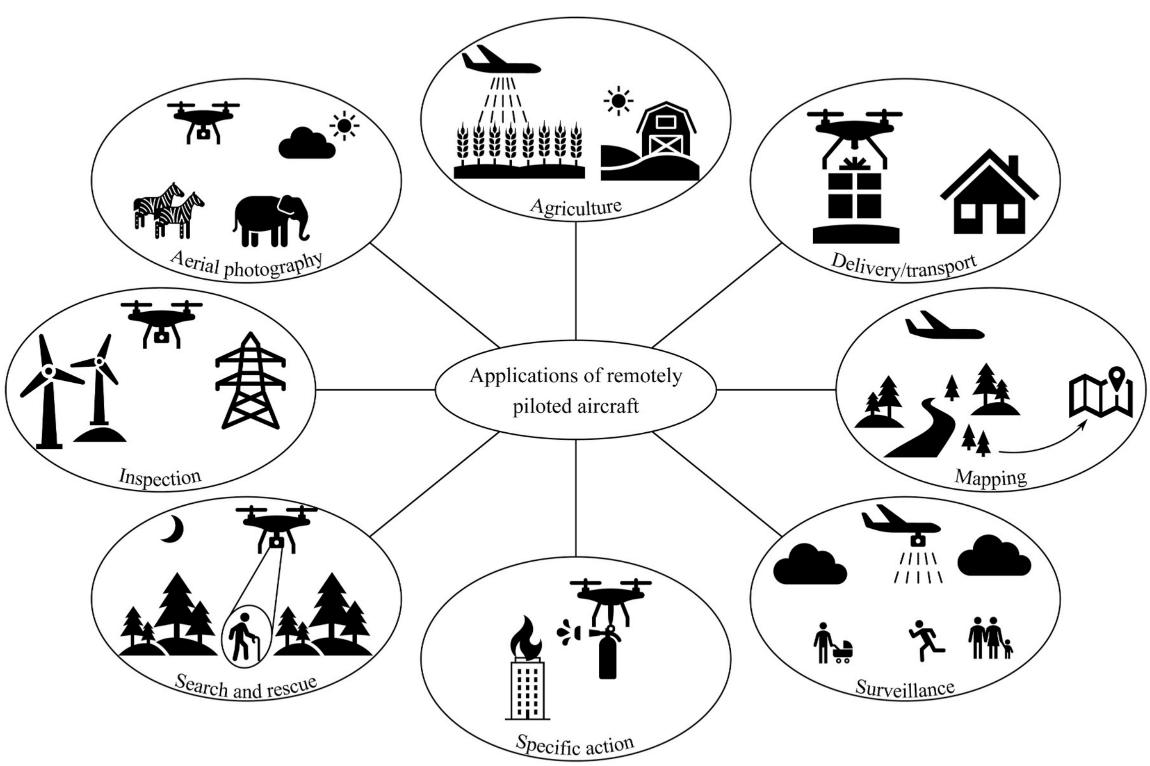

Fig. 3. The eight major mission types for remotely piloted aircraft.

improves the chances that the payload is delivered without being compromised.

- Inspection – platforms used for inspection require a camera and potentially specialized detection equipment based on the type of inspection performed. Missions can involve inspection of structural members such as bridges or towers [35,36], infrastructure such as wind turbines, powerlines, and pipelines [37], and inspections for insurance purposes such as rooftops [38], or regulation compliance monitoring. For all inspection types, a hovering capability is required so vehicles are limited to either helicopter or multi-rotor configurations.
- Mapping – fundamental to mapping missions is the ability to locate and document ground-based features. To do this, a RPAS must take a series of photos or video in order to first detect the objects and then tag the geographical coordinates to the points of interest. Missions consist of geographical/topographical surveys [39], disaster zone mapping [40,41], and 3D reconstructions [41]. The photos collected are typically stitched together to produce one final map of the survey area. If time is of the essence, fixed wing platforms are used due to their faster flight speeds; however, multi-rotors can also be used and are advantageous if a closer look at a specific point of interest is required.
- Search and rescue [42,43] – similar to mapping missions, search and rescue missions also require an aerial survey to locate a person or object of interest. These missions may also use specialized equipment such as thermal imaging or gear to tend to an injured person. One future use case of UAM is medical passenger transport which will be used to locate a person in need of medical assistance and transport them to a hospital.
- Specific action – this mission category is specific to the end user, but the commonality is that they all use an aerial platform to aid ground personnel. Applications can include firefighting [44], mining [44], performing physical construction [45], acting as a mobile internet connection [40], and military strike applications [10]. Vehicles performing these missions are often fairly large as they need to carry heavy payloads.
- Surveillance – surveillance missions involve condition monitoring, whether it be a specific location or person of interest, or even the weather for meteorological purposes [46]. Vehicles can range from being very small (such as the Black Hornet PRS which has a mass of 18 g) or be much larger (such as the 14 tonne Global Hawk).

2.3. Enabling technologies

Technologies enabling the advancement of autonomous and remotely piloted aircraft include electrification and distributed electric propulsion, energy storage and charging, robotics and autonomous flight controls, sensory equipment and CV, software and ML, computational power, communication networks, and composite materials and additive manufacturing (AM). The developments made in each of these fields enable systems with more advanced capabilities than even just six months prior (although there is often a delay in these advancements reaching the broader market due to the safety standards in the aviation industry). Each of these technologies will be briefly highlighted in the following sections.

2.3.1. Electrification and distributed electric propulsion

A lower dependence on fossil fuels and moving towards sustainable energy sources has always been a goal of the aviation industry; however, implementation is typically carried out by incremental increases in engine efficiency (e.g., geared turbofans) or reductions in aerodynamic drag (e.g., winglets). There has been recent renewed interest in electric vehicle technology for automobiles and this has carried over to aircraft; however, the caveat is that it takes a significant amount of energy for an aircraft just to reach its cruising altitude, which is not a limitation for an automobile. Additionally, aircraft always require energy to remain safely in flight, while an automobile can run out of energy without seriously endangering the occupants or bystanders. Regardless, recent advances in electric motor technology stemming from the introduction of axial flux motors, increases in motor efficiency, and some original equipment manufacturers (OEMs) doing away with rare earth metals, will soon make their way into vehicles entering the market. These advances, coupled with the growing political pressure from governments and environmental groups will lead to an increase in the electrification of future aircraft. Remotely piloted aircraft will likely see the bulk of this shift since they do not require the same structural design margins as passenger aircraft.

Distributed electric propulsion (DEP) is another enabling technology in which the higher number of propulsive units increases vehicle safety through redundancy. Other benefits include greater design flexibility, improved propulsive efficiency, and lower noise [47]. Over the past 10 years, multirotors have increased in size and number of rotors – as platforms such as octocopters (8 rotors) are commercially available, and variations exist with 12 and 16 rotors [48]. DEP is also employed in the UAM market as prototypes such as the EHang *216* and Volocopter *VoloCity* rely on DEP to produce lift and thrust. DEP is also being applied to fixed wing platforms such as the Lilium Jet and NASA X-57 *Maxwell* [49].

Noise is a key concern as UAM aircraft will increase the background noise level of a city while in operation. DEP mitigates some of the noise emissions as the additional rotors better distribute the lift forces and leads to a reduction in rotor tip speeds. Research in this area will look to quantify noise emissions from both an empirical and experimental perspective in rural and urban environments, as well as identifying flight routes whose sound profiles impact the fewest amount of people.

2.3.2. Energy storage and charging

While the advancements in electric propulsion have been important, the gains in electrical energy storage have also been crucial. Lithium-polymer (Li–Po) batteries have revolutionized the hobby industry due to their higher energy densities over lead-acid and nickel-metal-hydride batteries [50]. In electric vehicles, battery technology has allowed for increased range as the first-generation Chevrolet Volt had an all-electric range of 56 km (2011) [51], while its successor, the Chevrolet Bolt (2022 model) has an electric range of 383 km [52]. Future research will continue to develop new electrode chemistry options to further improve efficiency and will look to recycling and repurposing them once they reach the end of their useful life.

One of the major barriers to the adoption of electric aircraft is the mass of the energy storage system as present-day battery technologies offer a small fraction of the energy density of fossil fuels [53]. Research will focus on increasing battery capacity above the 400 Wh/kg threshold of lithium-ion batteries of today [54] as well as developing common battery prototypes and charging standards across the industry. Similar to having standard aviation fuel grades, this will ensure that performance standards are adhered to, and operators can have a common set of expectations.

2.3.3. Robotics and autonomous flight controls

Increases in automation and autonomy of aircraft has been one of the reasons why commercial aircraft accident rates have steadily decreased over the past few decades [55,56], such that commercial aviation is now the safest mode of vehicular transport [57]. The commercial availability of open-source autopilots has revolutionized the RPAS industry, increasing the capabilities of various platforms and making them easier to fly. With the increased reliance on autopilots and flight control systems, a major area of interest exists around the response behaviours of those systems. The tuning quality of the autopilot can have a significant impact on the ability of the platform to continue safe operation. Flight simulation will play a critical role in refining response behaviours as the Boeing 737 MAX 8 aircraft accidents demonstrated the consequences of what can happen when the response behaviours of autonomous flight control systems are not well understood. This will be especially important for platforms capable of carrying passengers due to their size and sensitivity of their payloads.

One of the challenges for an increased reliance on autonomous flight is that the certification and acceptance of such technologies by traditional means will not be possible. A collaborative approach between the manufacturer and regulator will be required to address the increase in complexity. Additionally, there will need to be a way to ensure predictable response behaviours in the event of emergencies, such as a return to home feature as there is for RPAS, or auto-identification of emergency type followed by emergency checklist execution. Another problem that may be experienced during the transition between crewed and remote UAM operations is ensuring that pilots do not develop automation dependency and take their hands off the controls [58]. Training pilots for partner operations (where the pilot and autonomous system supplement each other) and ensuring compliance is the key to ensuring success.

While autonomous systems debut in larger industries such as commercial aviation (due to the high development cost), they spillover into other industries such as general aviation with the inclusion of autopilots and introduction of auto-landing features, or the automotive industry with features such as park assist and emergency pedestrian autobraking. The advancement of the automation within the RPAS and UAM market may present a major opportunity to test out features in a niche application before being deployed for wider use in a larger market.

2.3.4. Sensory equipment and CV

CV capabilities and reliable onboard sensory equipment are essential for vehicle autonomy. While early sensory equipment was limited to an inertial measurement unit (IMU), GPS receiver, and a FPV camera, more recent developments include light detection and ranging (LiDAR) and collision avoidance systems. With well-trained CV capabilities (and an accompanying deterministic AI system), aircraft will be able to detect and predict the actions of each other, enabling the ability for fully autonomous operations and swarming.

The CV field has developed rather quickly, and by 2010, tasks such as facial recognition, fingerprint scanning, and autonomous navigation were possible [59], and more recently, UAVs are capable of autonomous takeoff and landing on ships [60] and autonomous aerial refueling [61]. The future research landscape for CV will consist of refining the algorithms in use today and developing new algorithms which decrease the computational cost, incorporate a higher degree of sensor fusion, and can be reliable in a variety of different lighting conditions [62]. Some edge conditions, such as low lighting or bad weather may present major challenges in developing a system that is both consistent and reliable. Finally, an architecture for system certification will also need to be created such that there is standardization across the industry and information surrounding the capabilities of these systems can be relayed to pilots.

2.3.5. Software and ML

While CV developments and sensory equipment enable RPAS to follow instructions, ML optimizes these tasks through pattern recognition of aggregate data. There are several approaches to ML including supervised learning (providing example inputs and desired outputs), unsupervised learning (no information on desired outcomes provided), semi-supervised learning (both labeled and unlabeled data provided), and reinforcement learning (a reward-driven trial and error method) [63]. Together, these approaches enable a variety of problems to be solved including speech recognition, anomaly detection, and vehicle navigation. Recent research in this area has improved the capabilities of RPAS communications [63,64], autonomous flight [65], and collision avoidance [66].

Computer software has also expanded the capabilities of vehicle platforms as specialized applications simplify the technical knowledge required of new users. One major focus of new software development will be decreasing computational power such that applications can be utilized by smaller platforms. One area of particular attention is that there is a lack of ML standards developed for safety critical applications such as the healthcare and nuclear industries. If there is a heavy reliance on AI technologies for UAM, the aerospace field may become the global leader and the standards developed could be adopted by other industries.

2.3.6. Computational power

Advancements in computational power have driven the rise of CV and ML. Although Moore’s prediction for the rate of growth in integrated circuit density was only to apply until 1985, the prediction has held true until today, although progress has slowed in recent years [67]. This increase in circuit density has powered the increases in computational power seen in onboard computers that can control automobiles, satellites, and RPAS. With these advances, some RPAS have begun performing computationally expensive tasks onboard, rather than transmitting the data down to a ground control station for processing [68]. It is expected that processing units will become smaller and more accessible, and that CV and ML will make up a greater percentage of computational requirements. There will also be opportunities to incorporate quantum computing to form a network of quantum drones and include these platforms into the larger Internet of things [69]. Such developments could then be translated to ground vehicles which would improve vehicle-to-vehicle communication and prevent potential collisions.

2.3.7. Communication networks

One of the keys to expanding the operational envelope of RPAS is being able to communicate with them beyond direct line of sight. Satellite communications have enabled the ability for a pilot sitting at a control station to effectively fly an UAV that could be halfway around the world. Data can be relayed through a series of satellites to the ground control station where it can be processed in real-time. At a smaller scale, UAVs can act as relay points and communicate with each other, extending the useful range of the operation beyond that of the transmitter [70]. UAVs are also projected to play a major role in the modularity of 5G networks as they will be able to act as a mobile communications link. Interesting directions of future research include the interaction between different communication segments, the integration of UAVs into the Internet of things, and data security and protection [71]. From these topics, cybersecurity presents the greatest barrier as drones and their communication networks can be exploited [72].

2.3.8. Composite materials and additive manufacturing

Advancements in composite materials have had a significant impact on the aviation industry [73], enabling lighter and more capable aircraft. Most UAVs in service today have a large composition of composite materials and UAM aircraft will likely include a high degree of composites to reduce structural weight and increase range and payload capacity. Future work will focus on design optimization (similar to design for additive manufacturing seen in the AM industry), performance modelling, lifecycle prediction, and structural repair techniques.

AM technologies have the potential to revolutionize conventional design practices, producing parts with properties that can exceed those of parts produced by conventional means. At present, the FAA has strict guidelines on requirements for parts produced by laser-based AM processes, as there are only a handful of parts approved for service [74], typically for specialized high-temperature applications. Future regulations may not be as strict (especially for autonomous aircraft), as certification authorities are mostly concerned with qualification of AM processes and parts to build a reliable database of material properties. Once this database has been developed, certification authorities can begin to trust OEMs that parts going into service will meet the required specifications. Commercially available platforms will likely have a high percentage of 3D printed plastic parts, as users will be able to print spare parts when needed.

3. Public perception of novel technologies

While there are many types of RPAS that can perform a variety of different missions, not all missions are viewed the same way by the public. This next section will discuss how the public views novel technologies in order to preview the public perception studies that have been conducted for drones and other types of novel aircraft technologies.

The engineering design process begins by investigating a problem, followed by generating a list of requirements, before entering the design loop of product design, evaluation, and verification. Public perception ties into this process at all stages. In the beginning, there may be only a singular person in support of an idea. Eventually the idea will begin to spread and there will be some initial buy-in. That initial hype will lead to support in the community, creating opportunities to acquire funding and thus spread the idea to the masses. Developing a degree of public acceptance during early phases of operation is essential for sustaining full scale implementation in the mid-to long-term. It is also important to monitor public perception throughout the process as a failure during the testing phase or delays in the implementation can lead to losses of support. Finally, at the end it is important to market the product to consumers, which is aided by having some degree of public support.

3.1. Technological adoption models

A popular model for technological adoption is the diffusion of innovations theory, which divides the population into five categories: the innovators, early adopters, early majority, late majority, and laggards, based on how quickly they are to adopt an idea (Fig. 4). The innovators are the most willing to take risks, understand the scientific principles behind an idea, and have the financial means to accept loss if the idea does not pan out. Early adopters are usually well educated and unlike the innovators, carefully choose which ideas to support. The early and late majority make up the bulk of people and adopt a technology when it is convenient and fits their financial situation. Of these two groups, the early majority are more open to new ideas, whereas the late majority are typically older, less educated, and more conservative. The laggards are the last to accept an idea as they are often in opposition to change and only do so after being influenced by close friends and family [75,76].

Another popular model is the technology acceptance model (TAM) which looks at behavioural intention as a function of one's impression of the technology, which is governed by the perceived usefulness and perceived ease-of-use [75,76]. The model was inspired by Davis et al. who investigated the acceptance of computers in the late 1980s. They found that the perceived usefulness was the key variable in influencing people's intentions, while the perceived ease-of-use was significant, but secondary in determining people's intentions on whether to use computers. Over time, the TAM has evolved to incorporate usage intentions from a social image perspective and task suitability [78] and was later included in the unified theory of acceptance and use of technology [79].

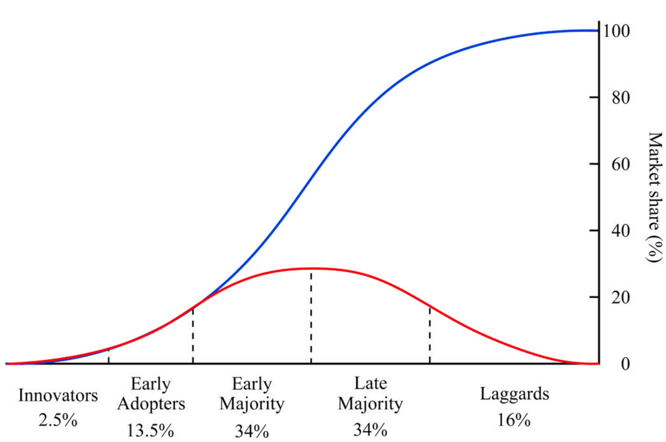

Fig. 4. *Technological adoption according to the diffusion of innovations theory showing the categories of adopters and the cumulative market share. Adapted from* Refs. [75–77].

In the case of disruptive transport technologies, Al Haddad et al. [80] presented a hybrid of the original TAM and the automation acceptance model proposed by Ghazizadeh et al. [81]. This model is pictured in Fig. 5 and retains the influence of perceived usefulness on behavioural intention. Behavioural intention is also influenced by social attitudes toward the technology, the value an individual places on their time, the perceived costs and any direct concerns they may have. Trust is the central part of the model which also affects behaviour and is governed by how the individual feels about the technology and socio-demographic characteristics (such as gender, age, education, and occupation).

For RPAS and UAM, the takeaway from these models is that the technology needs to appear useful to the public, or at least to certain segments of the public. For example, in the case of inspection missions, RPAS should be marketed to inspection companies in a way that highlights their ability to detect and inspect areas of interest, without having to put a person in harms way. Secondary considerations would include the perceived ease-of-use and system cost. From the diffusion of innovations model, larger companies with the financial capital or individuals who are technologically savvy would be the first to implement the technology (innovators and early adopters) and the rest of the industry would follow suit when feasible. The apparent usefulness in one area could also translate to other areas as well. For example, those who have used RPAS for work purposes are more likely to purchase a RPAS for recreational use [82], and vice versa as many RPAS companies were founded by people who got started in the hobby industry. This cascading effect leads to an accelerated timeline for public adoption.

Hype cycles are also a valuable tool for predicting the length of time before a technology matures and becomes ready for public use. A typical hype cycle, pictured in Fig. 6, describes the key milestones a product or technology will see prior to widespread adoption. This particular cycle was introduced by Gartner Inc., a global technology research and consulting firm, and has become known as Gartner's hype cycle [83]. It shows that expectations peak in the early phases of development before reality begins to set in and an eventual rebound paves the way to widespread adoption. The length of time it takes to complete the cycle varies as different issues may arise or the overwhelming complexity of the technology may make users wary.

In 2020, Gartner® published an analysis of connected vehicle technologies and the associated hype cycle is presented in Fig. 7 [85]. Many of these technologies are approaching the slope of enlightenment region, meaning that about 5% of the target population has adopted the respective technology. Although some technologies such as real-time data analytics or driver monitoring systems appear behind on the curve, they are much closer to reaching widespread use in comparison to autonomous vehicles due to the relatively few technological challenges these technologies must overcome. The family of autonomous technologies in Fig. 7 all have an expected adoption time of greater than 10 years. Autonomous vehicle perception systems will be realized prior to both autonomous vehicles and then flying autonomous vehicles (autonomous UAM aircraft); however, as one of the technologies advances, so do the others.

The commercial RPAS industry has been helping pave the way for UAM. Recent years have seen an uptick in drone usage as the general public has begun purchasing these platforms for recreational use. Features such as auto stabilization and follow-me have made RPAS easier to fly and their perceived usefulness has increased due to greater visibility stemming from their popularity on social media. As the public becomes more familiar with, and adopts these individual features, society gets closer to a goal of fully autonomous flying vehicles.

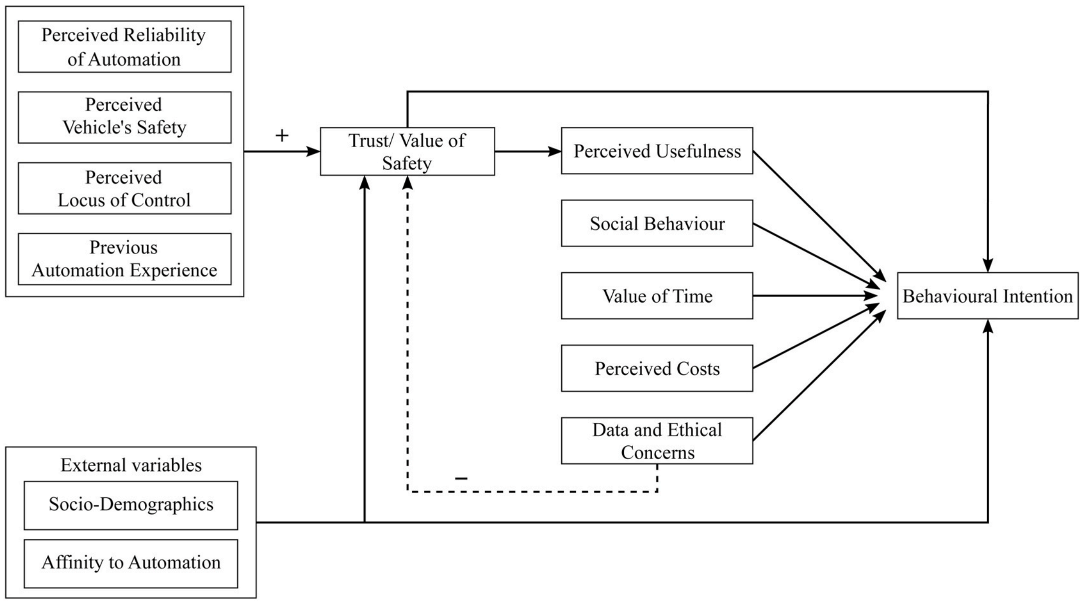

Fig. 5. *Disruptive transportation technologies adoption model* [80]. *Reproduced with permission from Elsevier.*

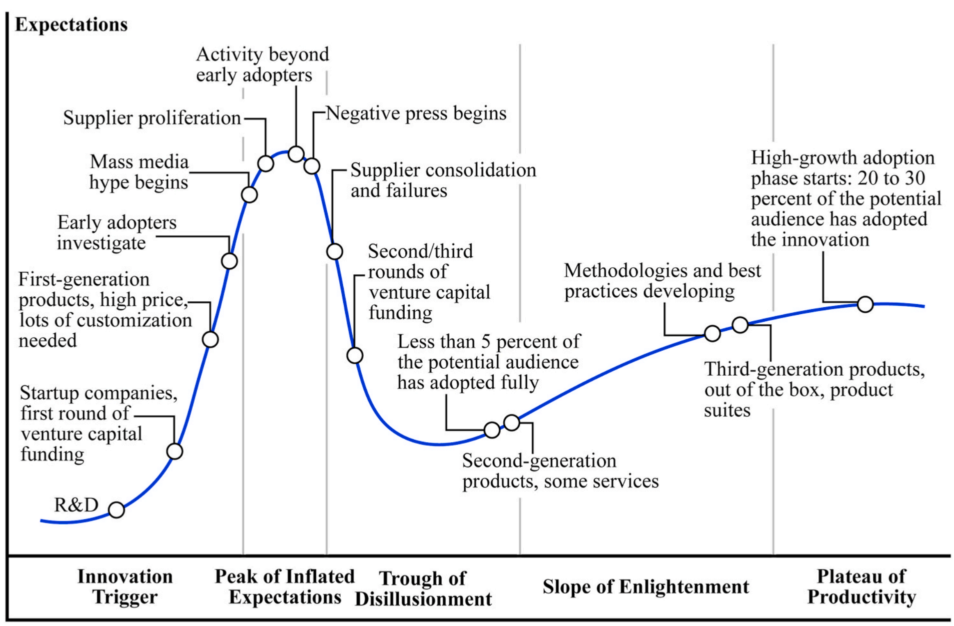

Fig. 6. *Stages of the hype cycle. Adapted from* Ref. [84] *and reproduced with permission from Elsevier.*

3.2. Technological integration into society

The World Economic Forum identified seven principles that are vital to the adoption and long-term success of UAM as a public transportation mechanism. These principles are safety, sustainability, equity of access, low noise, multimodal connectivity, local workforce development, and purpose-driven data sharing [87]. While these principles are presented in the context of UAM, they apply more broadly to the development and adoption of any new product. For example, the cell phone would need to be safe for it to be widely adopted, and as such, the portion of the electromagnetic spectrum they use has not been deemed an issue by health regulators. Mobile phones are also increasingly required to be sustainable, meaning that they can be used for a number of years and can be recycled following the useful life. Equity of access is achieved by different models, each with different features, costs, and usage pricing, while the low noise element can refer to the device annoyance level, or the perceived usefulness (benefit) to drawback ratio. To satisfy the multimodal connectivity element, the product would need to integrate into existing infrastructure – which cell phones do through USB and Wi-Fi connectivity; although some manufacturers such as Apple require add-ons unique to their devices such as charging cables, it does not necessarily dissuade customers from purchasing the product. With local workforce development, the product would need to create a market for product interaction, and this can include anything from purchasing the product to maintaining or inspecting it. Lastly, cell phone manufacturers have established mechanisms for data collection ranging from direct user feedback to online forums and rating systems to better understand how users perceive their product and what features they would like to see during their next purchase. These next subsections outline some key considerations for each of these categories when it comes to RPAS and

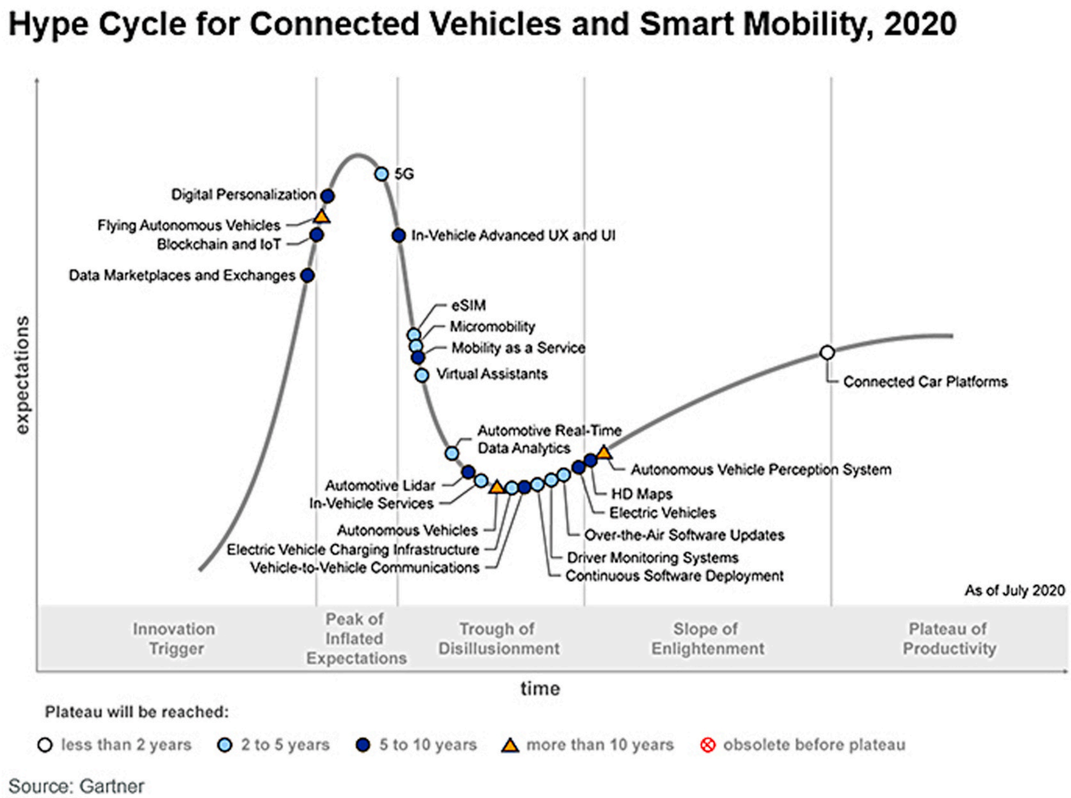

Fig. 7. *Gartner hype cycle for connected vehicles and smart mobility (2020)* [86]. *Image reproduced with permission of Gartner®. GARTNER is a registered trademark and service mark of Gartner, Inc. and/or its affiliates in the U.S. and internationally and is used herein with permission. All rights reserved.*

UAM.

3.2.1. *Safety*

Both RPAS and UAM platforms will need to satisfy public safety standards. Smaller RPAS models pose less of a risk than larger platforms due to their smaller size and lower speeds. Level of risk is one of the commonalities between most global certification authorities as regulations in the United States [88], Canada [89], and European Union [90] permit the use of vehicles under 250 g to be flown without a license (subject to some other restrictions such as not flying in Restricted Airspace). Licensing of RPAS pilots ensures some general level of understanding as to the safe operations and inherent risks of vehicle use. As RPAS get larger and heavier, government regulations become increasingly stringent as to the purpose of the operation and level of training of the operator. Like RPAS, there will need to be a system in place to ensure safe UAM operations. At present, the FAA and EASA have taken the lead in certifying individual vehicles; however, standards for air traffic management will need to be developed to ensure adequate separation [91]. Flight training and vehicle maintenance standards will need to be adopted prior to the introduction of any air taxi service. This all assumes that early UAM vehicles will have a pilot on board as switching to a remote or autonomous operation would require the development of standards for sensing and inter-vehicle communication capabilities. Additional safety and security considerations for UAM are presented in Ref. [92]. To guarantee public support, safety standards should be in line with those in place for commercial aviation, as many individuals recognize the overall safety record of the aviation industry.

3.2.2. *Sustainability*

RPAS and UAM platforms would need to demonstrate their sustainability through operation. There are many RPAS applications that promote sustainability including weather and climate monitoring, wildlife observation, and pollution monitoring. However, for cargo and passenger applications, the high energy demand required to reach cruising altitude can pose a challenge. Many UAM companies are planning to use sustainable fuel sources such as hydrogen or electricity, which would result in zero greenhouse gas emissions in flight. Since these fuel sources will likely be used for ground-based transport modes as well, demonstrating sustainability will then be less about the greenhouse gas emissions and more about the total environmental impact of how the vehicles are built and maintained as well as the energy demand in flight. Even when considering traditional aircraft comparison metrics (such as energy required per passenger mile), RPAS and UAM platforms can only outperform ground-based transport modes for some use cases. Amongst them are trips that are more direct (e.g., to remote areas, islands, or mountainous regions) and trips that either reduce the wear and tear on ground infrastructure or make new infrastructure investments superfluous [93]. Finally, when considering life cycle assessments for drones, one can look to traditional aircraft as they have long lives due to their intensive maintenance schedules which ensures continued airworthiness, and this lesson can be adopted by the UAM industry.

3.2.3. *Equity of access*

RPAS and UAM also need to be accessible to the public. For RPAS, only off-the-shelf sized platforms are available for public use, whereas nano and larger platforms are only for commercial and government use. Within the off-the-shelf category, there is a spectrum when it comes to cost, capabilities, and level of experience, so the platforms can be accessed by almost anyone; however, to increase the operational complexity requires additional financial investment and training. For UAM, the greatest barrier to equitable access is cost. Although the technology will be expensive to operate in the early stages, cost comparable to taxi fares should be the long-term goal so that a large user base can be developed. Yet, early studies show that even with prices comparable to or below taxi fares, UAM will induce a welfare loss for low-income households and will mainly benefit wealthier individuals [94]. Additionally, vertiports locations should be selected as to not concentrate noisy near-ground UAM operations in poorer neighbourhoods. There are also opportunities for UAM to service those with disabilities or special mobility needs in ways that conventional transportation or general aviation cannot. The industry will need to adopt accessibility standards similar to public transit to ensure ease of access. Ensuring riders are comfortable and able to board/disembark is another important design consideration.

3.2.4. Low noise

Noise is a significant issue for RPAS and UAM use. Prior to making visual contact with an aircraft, people on the ground will first hear the vehicle traveling in their direction. Vehicles with rotating propellors produce a pulsing sound wave known as thickness noise, which is caused by the air being displaced by the rotor blade surface. As the rotor spins faster, both the frequency and sound pressure level increase, causing a greater level of annoyance to people on the ground. Data from Christian and Cabell showed that participants had indicated a higher level of annoyance when exposed to noise from small UASs in comparison to cars or trucks at the same sound exposure level [95], indicating the importance of controlling the blade passing frequency. Testing conducted by Torija et al. identified that electric motors of drones introduce significant sound content in the high audible frequency range (above 4 kHz), and this noise does not easily dissipate into the soundscape (i.e., it can be easily recognized) [96]. This additional noise increased the level of annoyance in study participants by a factor of 1.3 in areas with relatively loud background noise (e.g., along busy city streets) and a factor of 6.4 in quieter areas with less traffic noise. Uber recommended limiting noise levels of UAM aircraft to 62 dB(A) at 500 feet (152 m) above ground level [97]. Test data from Joby Aviation suggests these levels are possible, with their aircraft achieving a sound pressure level below 65 dB(A) during the takeoff and landing profiles, at a distance of 330 feet (100 m) away, and 45.2 dB(A) during flyover at an altitude of 1640 feet (500 m) [98]. The low noise principle is related to the perceived ease of use, meaning that commercially available RPAS should be easy to fly, and UAM should carefully consider the user experience to minimize the potential for annoyance.

3.2.5. Multimodal connectivity

RPAS and UAM must also integrate into existing transportation systems. This is easier for commercially available RPAS due to their size and intended purpose as a consumer product. Off-the-shelf RPAS can be equipped with cameras and other sensory payloads to collect images or data of interest to the user. They also need to use commercially available software or components so they can be controlled and repaired without having to involve an OEM. Due to the complexity and level of sophistication in larger RPAS and UAM platforms, the OEM will have some control over approved maintenance and repair procedures so that airworthiness can be maintained. For maximum efficiency as a transit service, UAM vehicles would conduct flights to heavily transited areas and allow people to deplane nearby. Locating vertiports near public transit stations would make it easier for people to use an air taxi service and ensuring connections to the airport would maximize the potential ridership. The possibility of a drive-fly-drive joint transport model would ensure the first and last mile of the trip would be accounted for in case walking to the nearest vertiport is not feasible. In the early days of commercial UAM operations, there will be very few vertiports, and thus integration with public transportation services or providing ease of access for private vehicles at vertiports will be essential to the overall customer experience. First studies using agent-based simulations show that multi-modal connectivity is a key for successful UAM [99].

3.2.6. Local workforce development

Any demand for a service develops the local workforce by creating jobs. For RPAS, this would include direct-to-user retailers in hobby stores, repair personnel, and payload specialists. The advancement of the RPAS field more generally would also encourage people to take up skills like programming which increases the overall employability of an individual. With UAM, jobs can span from the construction industry which would be required to build the vertiports to pilots that would operate the vehicles. There will also be opportunities for retraining and reskilling workers from industries facing decline such as traditional automotive manufacturing and maintenance, as they could secure employment in similar roles within the UAM field. However, the necessity of these jobs is based entirely on local demand, and thus public perception is required to assess local UAM viability.

3.2.7. Data sharing

Successful UAM integration also requires data sharing among localities and operators so they can learn from each other and develop standards and best practices. While UAM operational characteristics such as traffic density, average trip distance, and ghost trip percentage (the percentage of flights without a paying customer on board) will vary by location, much of the logistics behind the operations will be the same and operators can greatly benefit by sharing non-secretive information with each other. The composites industry offers a successful example of such an approach, where aerospace OEMs shared knowledge and worked with regulators to develop standards and improve safety in the aerospace industry [100,101]. Data sharing is much easier with consumer products such as off-the-shelf RPAS as customers can have direct lines of communication to sellers to provide product feedback and they can interact with each other through direct encounters and online forums.

3.3. Perspective of the customer

Customer perspectives can vary significantly based on the intended use of the platform. The following sections will discuss the key considerations from each type of customer base.

3.3.1. Individuals

Individuals are most concerned with how a product/service they purchase meets their needs. Recreational users prioritize cost and user experience as the consumer cares about enjoyment of the product. If purchasing a RPAS to make money (such as for farming or photography), cost and capabilities are most important. Users with more experience can make modifications or incorporate their own payloads to further expand capabilities. When purchasing services, the factors that matter most are cost, capabilities, and reputation. For drone services, customers would be looking for a reputable service provider that can offer what they are looking for at a reasonable price. If looking at an UAM service, some additional factors may arise including safety reputation, environmental impact, time savings, route plan, environmental considerations (vehicle noise level, passenger/security policy, etc.), past experience, and personal preference [102]. Straubinger et al. presented four different UAM passenger categories looking at demographics and anticipated travel behaviours [103]. Wealthy individuals may also purchase an UAM aircraft for personal use as a substitute for an automobile. This personal air vehicle (PAV) market will develop as a by-product of the success of UAM service providers and individuals looking for these aircraft may prioritize acquisition and operating costs, range, passenger capacity, and convenience.

3.3.2. Commercial users

Commercial RPAS and UAM users prioritize the system meeting their operational requirements. Different applications, such as agriculture, delivery, inspection, and mapping each have specific needs in terms of payloads and mission objectives. Cost is not a major concern as very few manufacturers or operators can meet some sets of mission requirements, so there is often little competition for a contract. As vehicles get larger, additional safety standards are to be met which govern who can fly in certain locations, the nature of the flights, and what is able to be carried on board. For UAM, service providers are interested in recruiting a client base, and thus need to attract individual clients whose considerations are listed above. UAM service providers will also need to consider how to tailor the choice of UAM platform to the specific flight, developing flight routes, scheduling flights, airspace coordination, and collaborating with different levels of government to select vertiport locations [102].

3.3.3. Government and national agencies

Government agencies prioritize the public interest; however, RPAS client perspectives vary by agency type and potential use case such as search and rescue or forensic photography missions performed by police departments, or surveillance and strike applications for military operations. Some clients such as research agencies or police departments may hire outside contractors to provide a service, whereas militaries require secrecy in terms of the operational details. Military units using RPAS are concerned with the operational capabilities of the platform. Every time troops are on ground for an operation, the safety of those troops is at risk, hence they depend on the effective use of RPAS to collect intelligence and support the ground operations. While RPAS platforms can be replaced (some at great cost), the safety of ground forces is paramount, so there are no major considerations other than operational effectiveness. Most technologies are also developed in-house (or by supporting members in an alliance) so they are purpose-built for the specific application and undergo a significant amount of testing prior to deployment.

For UAM, all levels of government will be involved. Regulatory decisions typically come from federal governments and regulatory agencies through internationally developed standards such as the International Civil Aviation Organization (ICAO). Land usage and flight routes will be dictated by local and regional authorities. For successful UAM integration, all levels of government will need to work hand in hand with UAM service providers to ensure that the proposed operation meets the needs of the public in an equitable manner.

4. Review and analysis of past surveys

To date, many studies have been conducted to evaluate the public perception of technologies such as RPAS and UAM to collect a snapshot of feelings experienced by the demographic. These snapshots vary in time, along with the method of data collection, the wording of different questions, the target population, intended applications of the technology, and their level of previous experience. In this section, we summarize the key findings from these studies and highlight some of the major differences.

Papers selected for inclusion in this analysis were identified by searching Google Scholar for a variety of keywords, including at least one of "public perception," "acceptance," "adoption," or "willingness to fly" and at least one of "drone," "remotely piloted aircraft," "unmanned aerial," "unmanned aircraft," "pilotless aircraft," "autonomous aircraft," "urban air mobility," or "air taxi." While the search was not an exhaustive one, the focus was on finding studies with a larger sample size and reported results as either a percentage or on a Likert scale. Relevance to the specific research questions presented in the following sections was also important. These questions focused on awareness of the technology, awareness of the different RPAS terms, the overall favourability of RPAS, the favourability of RPAS for specific applications, and the willingness to fly on an UAM aircraft or air taxi.

4.1. Technological awareness

Knowledge about a technology is one of the key factors in determining if one will implement it in their life, previously described as the familiarity hypothesis [104]. While many have experienced conventional aircraft (whether it be by flying or seeing pictures of them), there is a lower level of interaction with remotely piloted aircraft. Presented in Table 1 is a summary of studies that ask about the public awareness of the use of RPAS and important findings surrounding usage. Furthermore, some terms referring to RPAS are more recognized than others, thus Fig. 8 shows the change in the recognition of these terms over time in different regions of the world.

The awareness of drones increased throughout the 2010s, especially in the United States due to their usage in military conflicts. This has led to some surveys making the distinction between military and civilian drones, such as in Eißfeldt et al. [114]. Drone is the most recognized word due to its use in the media [115]; however, RPAS, UAS, and UAV are terms known and used by some RPAS users. While some such as Legere [116] and Wild et al. [117] suggest that the term "drone" has a more negative perception, PytlikZillig et al. used a vignette survey and found that there was no change in level of support due to the terminology [118].

There is also a regional distinction between developed and developing countries, as those with greater wealth have a higher degree of access to information and would thus have more knowledge about drones. In the Hardy et al. study, the majority of participants were unaware of drones even after being presented with a picture of one (specifics not provided, but likely a small civilian drone given the study context) [109]. The authors noted that many participants were from rural areas and without access to the internet, leading to television being their most prominent source of drone-related information. A contrasting study in a neighbouring country found that all 46 Rwandan farmers and community members interviewed had knowledge of drones being used for various applications within Rwanda [119].

In addition to these surveys, a number of others have been conducted to assess acceptance of drones/RPAS in Africa [119–121], Australia [117,122], Europe [123–125], India [126], Japan [127], and the United States [128–134]. These studies were excluded from being presented above as they either do not directly ask about drone awareness and/or term familiarity or do not accurately represent their respective

Table 1
Awareness of RPAS usage.

Author	Year	Country	Findings
Monmouth University [105]	2013	USA	Public is more aware of drone usage for military applications in comparison with domestic law enforcement agencies.
Miethe et al. [106]	2014	USA	Most adults in the US have heard about drone usage with 91% being aware of their use for military applications.
Thompson and Bracken-Roche [15]	2015	Canada	Low degree of awareness of UAV usage in comparison with traditional piloted aircraft. Greatest level of awareness is in applications of aerial photography (survey did not ask about military applications).
Aydin [107]	2019	USA	Public is more aware of drone usage for military applications (97%) in comparison to most other applications (<50%).
West et al. [108]	2019	USA	Over 81% of the American public claim to have "some" or a "good deal" of knowledge about drones, whereas less than 5% have not heard of drones or their uses. Women are less aware than men, and younger individuals, those with higher education, ties to the military, or an interest in politics are more aware.
Hardy et al. [109]	2022	Zanzibar (Tanzania)	Only 41% of participants aware of drones, even after being shown a picture of a drone.

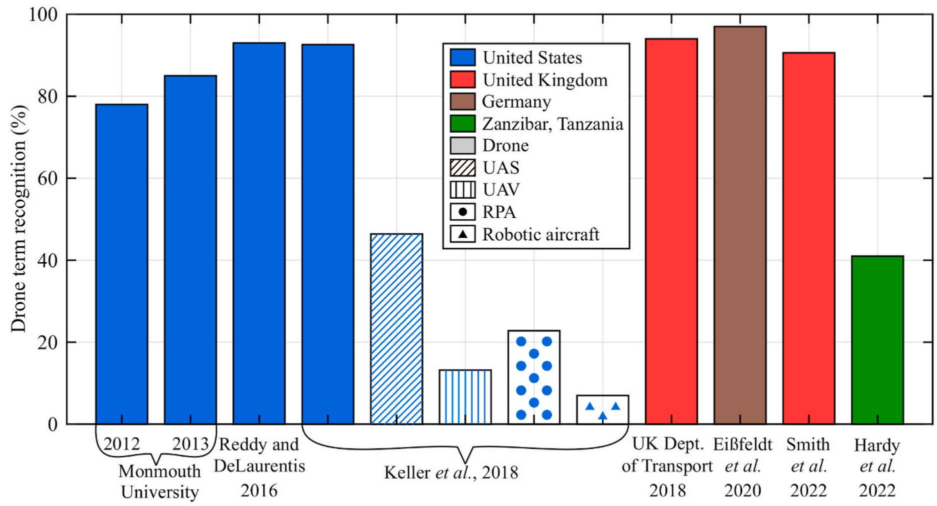

Fig. 8. *Awareness and recognition of drone-related terms in major studies. Data originating from* [9,105,109–114].

geographical population. In the case of the latter, the sample size is either too small, a convenience recruiting strategy is employed, or the demographics of people surveyed do not match those of the local population. Convenience recruiting often attracts specific segments of a population (whether it be that they are stakeholders with regards to the survey topic or they have some sort of privilege that gives them access to the researchers) and has been shown to underrepresent minorities in the United States [135]. It can be particularly problematic if results obtained with this method are extrapolated onto a larger segment of the population.

In a survey of 1040 American adults, Keller et al. identified knowledge as a key factor in determining technological adoption [111]. Knowledge of UAM concepts and operations is significantly less than that for RPAS due to the lack of present-day services. Shaheen et al. (USA) found only 23% of 1702 respondents were aware of UAM, with the highest proportion being from Los Angeles (32%) [136], one of the two initial launch cities for Uber Elevate (prior to being acquired by Joby Aviation in December 2020). Additionally, Eker et al. (USA) reported a limited awareness of flying cars among the public [137] and even used an information session prior to a subsequent survey to convey their features and operational characteristics [138].

4.2. Perception of RPAS

While awareness of the technology is vital to understanding its existence and how it works, an overall positive perception is required for widespread adoption. All surveys look at perception in some sense, whether it be a general impression or if the public is supportive of specific applications. Next, we present surveys chronologically, first looking at overall support, followed by support based on distinct use cases, such as for humanitarian missions or by law enforcement.

4.2.1. Overall perception

The major surveys looking at public perception of RPAS in a general sense are summarized in Table 2. Results are limited as most surveys tend to either divide perception questions based on the type of drone application or type of drone user. This was also found in the Reddy and DeLaurentis studies in which most respondents stated that their support or opposition for drone usage was conditional and based on the application, operating environment, costs, benefits, risks, or aircraft characteristics [9,139]. Regardless of these limitations, there are some key takeaways that can be discussed. First in the study reported by Cameron, drones were compared to traditionally piloted aircraft finding that support for conventional aircraft was nearly twice as high as that of RPAS [129]. A survey performed around the same time in Canada showed higher levels of support; however, support for UAVs always fell below the level of support for piloted aircraft [15]. The major difference between these two surveys is that Cameron polled participants on perceptions of both piloted aircraft and drones, whereas the results presented in Thompson and Bracken-Roche only polled either piloted aircraft or drones. As such, introducing piloted aircraft as an alternative could skew results.

Table 2
Acceptance comparison of RPAS/drones.

Author	Year	Country	Sample size/ distribution method	Findings
Cameron [129]	2014	USA	535/online (Craigslist and Facebook)	35–39% of participants supportive of drones compared to 74–80% supportive of traditionally piloted aircraft.
Reddy and DeLaurentis [9,139]	2016	USA	400/online panel (Qualtrics)	75% expressed conditional support to RPAS usage whereas 16% supported in all cases and 9% opposed in all cases. Additionally, 87% of stakeholders offered conditional support with 13% supporting in all cases and 1% opposed in all cases.
Eißfeldt et al. [114]	2020	Germany	832/telephone	Public was slightly more supporting (49% rather positive, 8% undecided, and 43% rather negative).
Tan et al. [115]	2021	Singapore	1050/online panel (Qualtrics)	All drone applications had at least 62.0% support.

In Reddy and DeLaurentis, the associated risks were identified as the most important consideration affecting level of support, followed by the application, benefits, and environmental factors, while vehicle characteristics and costs had little impact [9]. Their definition of possible risks included the potential for midair collisions, crash landings, and invasion of privacy. While the risks posed to other aircraft are low due to the low prevalence of drones at present, the potential for RPAS to invade one's privacy is a major concern and discussed further in Section 5.2. While the majority of respondents were open to the use of drones in this survey, another conducted by Eiβfeldt et al. in Germany found approximately half of the population had a positive attitude towards civil drones [114]. This German survey went further, identifying that perception was heavily linked to previous knowledge, as those who were somewhat or very well informed displayed at least a 59.7% favourability, while those with no knowledge had only a 35% favourability. Additionally, it was reported that male respondents are more positive about the use of civil drones than women and older individuals were less favourable than younger respondents [114]. Similar findings were reported in a number of studies with regards to gender and age [9,15,117,132].

Finally, Tan et al. evaluated the perception of drones in Singapore and found that all drone applications had at least 62.0% support from the public [115]. This particular survey also compared results with the United States and Switzerland, finding similarities in acceptance rates for environmental applications with the US and high support for research applications with Switzerland. Of all applications listed, the lowest level of support was for the transportation of people using drones, suggesting that risk also plays a role among a population that is more open to a wider adoption of RPAS technologies. One survey from Japan looking at public perception of different levels of risk places drones at a similar level as mountain climbing and alcoholic beverages, while autonomous vehicles are perceived to have a higher level of risk, but not quite at the same level as nuclear power or smoking [127].

4.2.2. Application specific perception

While risk tends to be one reason people shy away from an alternative, perceived benefit garners support. Some applications of drones are seen as more beneficial, especially in cases where all of society benefits from their use. Some of these applications include search and rescue, disaster response, and wildlife monitoring. On the other hand, the use of drones for food delivery or passenger transportation are seen as riskier and have lower levels of support. The results of public perception surveys looking at the use of drones for search and rescue, package delivery, and law enforcement are presented in Table 3 and studies reporting results as a favourability percentage are also pictured in Fig. 9 to depict the level of support over time. Each of these selected mission types represents a broader category of usage, for example search and rescue can be representative of use for the public interest, package delivery speaking to corporate use for individual gain, and use by law enforcement representing drone use for government oversight in some capacity.

Search and rescue saw the highest level of support, followed by law enforcement, and package delivery. Over time, support for search and rescue missions has increased, and this has aligned with the rising level of familiarization about RPAS from the public. Smith et al. showed the stark divide in level of support between those with awareness of drones and those without [113], suggesting that even in applications of societal benefit, education is the key to adoption.

In package delivery applications, results were mixed with support levels ranging from 18% in Switzerland to the low eighties in Singapore. Overall, the Tan et al. study done in Singapore showed very high levels of support for all applications [115], as did the Komasová et al. study performed in the Czech Republic [141] (although not to the same levels as Tan et al.). Other European countries had much lower levels of support for package delivery. In a survey performed by Aydin in the United States, drone use for transportation purposes was broken down into cargo which scored a favourability rating of 4.04 out of 5 and food delivery (3.58 out of 5) [107]. It is likely that the public sees the transportation of cargo by drones as a benefit to society with a lower level of risk (as the introduction of drones to transport cargo would not necessarily be noticed by the public) than drones regularly delivering food or packages to a person's home or business. In the latter case, vehicles would continuously perform flights close to humans and the potential for vehicle failure could change the behavioural patterns of individuals, such that they avoid areas of dense drone activity.

Finally for law enforcement applications, only surveys that presented law enforcement in a general sense were included in Table 3 to allow for consistent comparison. Use of RPAS by police can include applications such as border monitoring, surveillance, crowd control, issuing of speeding tickets, traffic collision reconstruction, and hostage situation monitoring [145]. Support for general police use of RPAS has increased over time with familiarity; however, applications such as traffic monitoring and identification receive lower levels of support [15]. Engberts and Gillissen make the distinction between drones for sensing applications and drones to be used as a tool [146]. When used as a tool, the public is able to clearly see the benefits of drones which they perceive outweigh the risks, whereas sensing applications lead to individual consequences such as the issuance of speeding tickets and these can be perceived to be an invasion of one's privacy.

Additionally, there are some surveys that look at singular cases of drone usage to address a particular issue. For example, Stokes et al. (Australia, 2020) surveyed 439 beach-users to determine attitudes towards drone usage for shark surveillance and found that 88% of the public was supportive of drone use for this application [23]. A survey such as this mirrors the characteristics of public interest missions where benefits to society are emphasized. On the other hand, surveys can focus on the negative aspects of RPAS such as the perceived invasion of privacy associated with drones [131,132] to assess the acceptable level of personal risk people may be willing to accept. Risk is most associated with commercial use of RPAS as the operator is profiting from the use of the vehicle, often with little regard for those not involved in the operation.

While only search and rescue, package delivery, and law enforcement missions are discussed here, levels of support for other applications can be inferred from these results. The favourability of the search and rescue application likely influences feelings towards RPAS usage for other public safety and scientific research applications such as firefighting and wildlife monitoring. The high benefit to society and relatively low frequency of vehicle interaction with the public makes these missions the most appealing. The public has a more complex view of commercial RPAS usage that can be described as supportive in cases where there is a low probability of public interaction (use on one's private property or infrequent use in public spaces) and less supportive when they perceive an elevated chance of interaction (personal transportation or for delivery of items). There is especially poor perception in scenarios where individuals expect some degree of privacy, such as in their home or on the private property of others [15,132]. In law enforcement applications, if drones are used sparingly and as a tool, they are only deployed for the most time sensitive and safety critical applications – such as for prevention of disturbances and potential threats, which provides a more comfortable environment for citizens than when used for sensing or data collection (for instance, radar guns or thermal imaging).

4.3. Perception of UAM

While drones offer a window into public feelings about automation and futuristic uses of technology, the adoption of UAM requires significantly more trust due to the larger scale and higher level of risk. There have been a number of studies to date addressing the interest in UAM from a market viability perspective [34,147–152] as well as consumer willingness to fly. The major findings from willingness to fly studies for autonomous aircraft are presented in Table 4. It should be noted that although authors Winter and Rice have published findings from several willingness to fly studies for autonomous aircraft [153], their work has been excluded from Table 4 as the findings do not make any reference to the original data and thus cannot be directly compared to other results.

Many early studies used the terms *autonomous* and *airliner* to describe a flight onboard one of these aircraft; however, terminology evolved to include *UAM*, *pilotless aircraft*, and *air taxi*. The first six studies listed were completed in the United States and show (with the exclusion of the results from the convenience survey developed by Wollert) that there was an increase over time of the favourability towards flying on an

Table 3
Acceptance comparison of drones by application.

	Author	Year	Country	Sample size/distribution method	Findings
Search and Rescue	Monmouth University [105]	2012	USA	1708/telephone	80% supportive of search and rescue missions
	Monmouth University [100]	2013	USA	1012/telephone	83% supportive of search and rescue missions
	Miethe et al. [101]	2014	USA	636/online via 3 survey websites	93% supportive of search and rescue operations in remote areas
	Angus Reid Global [135]	2014	Canada	3045/online panel	51.6% of respondents supportive of search and rescue with 33.4% unsure and 15.0% opposed
	Markowitz et al. [136]	2017[a]	USA	1904/online panel	In a survey of 1904 adults, 90.9% expressed some degree of support, with another 6.5% remaining neutral
	United Kingdom Department of Transport [107]	2018	United Kingdom	3500/panel	Of 3538 respondents, 84% are supportive of drone use for emergency response in applications such as search and rescue, with another 9% selecting neither support nor oppose
	Aydin [102]	2019	USA	153/email faculty and interested groups	On a 1 (strongly oppose) – 5 (strongly support) Likert scale, search and rescue averaged 4.74, an absolute percentage of 94.8%
	Komasová et al. [137]	2020	Czech Republic	123 drone users, 103 non-users/ screened online panel	98% of drone users and 90% of non-users support drone usage in search and rescue operations
	Del-Real and Diaz-Fernández [138]	2021	Spain	3363/in-person interview at beach	A sample of beach visitors found that 52.3% would continue to use the beach if rescue drones were used, compared with 47.8% who would not return
	Tan et al. [110]	2021	Singapore	1050/online panel (Qualtrics)	92.1% of participants support government drone use for search and rescue applications
	Smith et al. [108]	2022	United Kingdom	10,615 (collected between 12/ 2017 and 8/2020)/online	88% of participants who had previously heard of drones either strongly or somewhat support the use of drones for search and rescue applications with another 8% answering neither support nor oppose while for those who had not heard of drones, 39% supported use in search and rescue, whereas 55% answered they neither support nor oppose or were unsure
Package delivery	Miethe et al. [101]	2014	USA	636/online via 3 survey websites	42% supportive of delivery services for small items to private residences
	United States Postal Service [25]	2016	USA	1207/online via panel invitation	44% of respondents like the idea of drone delivery while 23% state they neither like nor dislike the idea
	Klauser and Pedrozo [139]	2017	Switzerland	604/mailed questionnaire	18% had a favourable view of commercial drones for package delivery, with 67% holding an unfavourable view
	United Kingdom Department of Transport [107]	2018	United Kingdom	3500/panel	36% of 3538 participants are supportive of drone use for retail such as package delivery, with another 29% selecting neither support nor oppose
	Aydin [102]	2019	USA	153/email faculty and interested groups	On a 1 (strongly oppose) – 5 (strongly support) Likert scale, transportation and delivery of cargo averaged approximately 4.04 while food delivery averaged 3.58.
	Komasová et al. [137]	2020	Czech Republic	123 drone users, 103 non-users/ screened online panel	61% of drone users and 52% of non-users support drone usage for commercial purposes such as the delivery of goods
	Eißfeldt et al. [109]	2020	Germany	832/telephone	Parcel delivery was the 2nd least supported application out of the 10 listed, receiving a mean agreement score of 2.73 (1 = strongly agree, 4 = strongly disagree)
	Tan et al. [110]	2021	Singapore	1050/online panel (Qualtrics)	82.9% of participants support corporate use for delivery and pickup
	Smith et al. [108]	2022	United Kingdom	10,615 (collected between 12/ 2017 and 8/2020)/online	37% of participants who had previously heard of drones support the use of drones for package delivery with another 30% answering neither support nor oppose or were unsure while for individuals who had not heard of drones, just 16% supported package delivery by drone, whereas 65% answered they neither support nor oppose or were unsure
Law enforcement	Angus Reid Global [135]	2014	Canada	3045/online panel	41.0% of sample supportive of UAV use by law enforcement with 38.6% unsure and 20.4% opposed
	Markowitz et al. [136]	2017[a]	USA	1904/online panel	On a 7-point Likert scale, 54.7% indicated some degree of support for police use of drones, with 18.2% expressing neutrality
	Klauser and Pedrozo [139]	2017	Switzerland	604/mailed questionnaire	72% of 604 respondents were supportive of police drones, with 10% indifferent and 18% having an unfavourable view
	United Kingdom Department of Transport [107]	2018	United Kingdom	3500/panel	78% of 3538 respondents are supportive of drone use by the police for border monitoring and surveillance, with another 13% selecting neither support nor oppose
	Smith et al. [108]	2022	United Kingdom	10,615 (collected between 12/ 2017 and 8/2020)/online	81% of participants previously aware of drones support their use for law enforcement applications with another 13% answering neither support nor oppose or were unsure while for individuals who had not heard of drones, 36% supported use by police, whereas 57% answered they neither support nor oppose or were unsure

[a] Survey was conducted in January 2015.

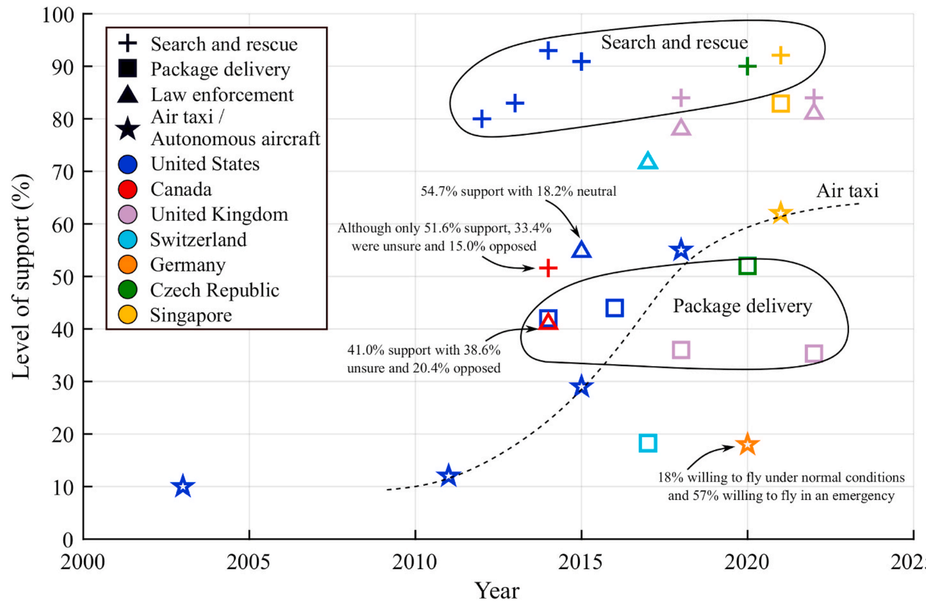

Fig. 9. Graphical presentation of public acceptance of drone use for search and rescue, package delivery, law enforcement, and air-taxi services. Data compiled from sources [29,30,105,106,110,112,113,115,130,136,140–144].

autonomous aircraft (also pictured in Fig. 9). This is likely tied to an increase in familiarity with similar technologies such as RPAS and autonomous vehicles and a rise in the perceived risk to benefit ratio. Furthermore, Rice et al. found that willingness to fly is most associated with individuals who are familiar with the technology, feel happiness toward the concepts, believe them to be fun, and have higher levels of education [154].

Knowledge of UAM and autonomous aircraft is still quite limited with only 23% of those surveyed by Shaheen et al. (USA) reporting UAM awareness [136], while 19 and 20% responded similarly in the Aydin [107] and United Kingdom Department of Transport surveys [112], respectively. On the other hand, drones have a much higher level of awareness for practically all applications [15,107], likely correlating to their higher level of acceptance.

An interesting finding from the Dannenberger et al. survey was that the proportion of the population willing to use an air taxi increased by a factor of three in the event of an emergency [30]. Keller et al. identified the perceived safety-risk benefit as the most important factor when attempting to market the use of RPAS to the public [111]. In the event of an emergency, time is of the utmost importance and thus, one may select a transportation alternative that minimizes time, even though it may be perceived to be riskier than others. As UAM concepts come to market, public trust will increase as the technology is demonstrated to be safe and reliable. Keller et al. reported that following the safety-risk benefit, trust in the technology was the second most important factor determining if one would be willing to fly and identified that flight crew members were more willing to fly on UAS than others, suggesting a link between flight frequency and trust [111]. However, trust can be very fragile, and a singular trust-decreasing event can have a larger impact on public feelings than numerous trust-increasing events [155].

Several studies investigated the potential decrease in the number of pilots onboard commercial aircraft and found a strong preference for maintaining the typical flight deck layout with two pilots. A multinational study from India and the United States performed by Winter et al. found that although Indians are less willing to fly on a piloted commercial aircraft, they are significantly more willing to fly on a remotely piloted aircraft than Americans [156]. For the most part, Indians were willing to fly on a commercial aircraft with one pilot on board and one remote pilot on the ground, while Americans were rather neutral.

Finally, looking at the geographical location of each of the surveys, the highest rate of acceptance was reported in the Tan et al. study done in Singapore [115]. Surveys performed in the United States from 2015 onward showed the second highest regional area levels of support for UAM, while the three surveys done in Germany had the lowest levels of support. These findings seem to offer an insight into the present-day UAM market demand in different regions of the world with Asia leading the way in public acceptance, followed by the United States, and lastly Europe. When overlayed on a global map showing passenger UAM companies (Fig. 10), the results seem to correlate as these three regions are home to most organizations in the industry. With further research and development in other geographical areas, public perception will rise in these areas as well.

5. Discussion

The previous section summarized the notable past studies that quantified public perception towards RPAS and UAM aircraft concepts. The following sections will relate these results to other technologies and identify commonalities. It will then discuss some of the remaining challenges to technological adoption and present a roadmap of the necessary steps to achieve this goal.

5.1. Similarities in the adoption process of other novel technologies

In the late 1990s and early 2000s, there was a negative perception associated with mobile phones amongst a large percentage of the population due to the link made between microwave radiation and brain cancer. Although there was lots of conflicting evidence [158–160], many people did not immediately adopt the technology. Over time, the perceived usefulness of mobile phones increased (due to the introduction of the smartphone and the associated advancements in features) which adjusted the risk-benefit ratio in the minds of many and led to increased adoption. When looking at public perception and the risk of brain cancer from radiation, Karger noted that public perception may be distorted by not all scientific evidence being immediately available, the public not knowing how to weigh each piece of evidence, and the presence of false information [160]. Each of these points is pertinent for RPAS and UAM.

Table 4
Reported willingness to fly on autonomous aircraft.

Author	Year	Country	Sample size/ distribution method	Findings
MacSween-George [125]	2003	USA	100/paper questionnaire at a conference	Low support for passenger flights abord unmanned aircraft (10–15% support) for both business and recreational purposes.
Tam [140]	2011	USA	158/email faculty and interested groups	12% indicating they would fly on an autonomous airliner.
Vance and Malik [141]	2015	USA	1478/ distributed online	A vignette survey found that 29% of respondents were willing to fly on an autonomous passenger airliner at the start of the survey. Following the survey, this number rose to 44%.
Wollert [128]	2018	USA	157/distributed by social media	Most were uncomfortable if a commercial flight used one pilot instead of two and most were very uncomfortable with fully autonomous aircraft.
Shaheen et al. [131]	2018	USA	1722/online panel (Qualtrics)	55% of respondents were willing to fly on an UAM aircraft.
Aydin [102]	2019	USA	153/email faculty and interested groups	On a 1 (unfavourable) – 5 (favourable) Likert scale, passenger transportation scored 3.34 (the third least favourable application of drones).
Wild et al. [112]	2019	Australia	83/paper questionnaire in downtown Melbourne	Similar to the Wollert study, most were uncomfortable with single pilot commercial aircraft and were even more uncomfortable with pilotless aircraft.
Fu et al. [151]	2019	Germany	248/distributed by email and social media	In a stated choice survey, autonomous flying taxi was selected in 13% of all choices. Additionally, it is notable that an autonomous (ground) taxi was selected in an additional 12% of observed choices.
Al Haddad et al. [77]	2020	Germany[a]	221/distributed online, by email and social media	22% stated they would adopt UAM immediately, followed by 37% adopting service in either the second or third year of service.
Dannenberger et al. [26]	2020	Germany	1000/telephone survey	18% said they would use air taxis, while 57% indicated they would use air taxis for emergencies only.
Tan et al. [110]	2021	Singapore	1050/online panel (Qualtrics)	62.0% of respondents were in support of drone usage for transporting people.

[a] Responses collected from all over the world with approximately 60% of responses from Germany and 97/221 responses from the Munich area.

- As is the case with any novel technology, the communication of information to the public lags behind the technological readiness. Safety data for the likelihood of drone mid-air collisions or UAM accident rates are not available until testing and implementation phases are completed. Premature public judgements on the perceived level of safety, without any evidence can be detrimental to long-term public trust. Results presented in the Vance and Malik autonomous airliner survey identified a 15% increase in willingness to fly after providing information such as the track record of the service provider with autonomous aircraft or a description of the level of sophistication of the autopilot [143], suggesting that the inclusion of such information is vital to gaining public trust.
- Weighing differing pieces of information in determining favourability of RPAS or UAM is highly subjective and depends on the individual's background, experiences, and opinions. While researchers identify statistically significant factors that are associated with elevated or lowered rates of acceptance (such as gender, age, ethnicity, or level of awareness), they do not have the ability to control their participants without sacrificing the integrity of their results. Aside from this, an individual may view a technology unfavourably for no specific reason, as is their right.
- The presence of false information can also play a role in influencing one's perception of RPAS and UAM. In the early days of development, not much is known about a new technology so the information in circulation plays a larger role in shaping opinion. Some surveys have used an aptitude test containing true-or-false questions to assess the prior level of knowledge of survey respondents. Reddy and DeLaurentis found that the general public answered either 2 or 3 of the questions correctly (out of 5), while those identified as RPAS stakeholders scored on average between 4 and 5 [9] and this stakeholder group had a higher rate of support, underscoring the value of accurate information in informing opinion.

Originally, early smartphones were geared towards business clients as they resembled a personal digital assistant and could be used for communication and had features such as task scheduling and email access. They also had slow data speeds, limited connectivity to Wi-Fi networks, and only offered pre-installed functionality, making them unattractive to the average person. In the mid to late 2000s, these issues were addressed by the inclusion of touchscreens, digital cameras, and third-party software, leading to the smartphone revolution [161]. Smartphone sales increased exponentially between 2007 and 2014 [162] before eventually plateauing around 1.5 billion units per year. The early period between 2007 and 2008 saw investment by the early adopters, while the early majority joined in up until approximately 2013 (Fig. 11(a)). Although not everyone owns a smartphone today, virtually everyone knows about them and the capabilities they have.

The authors believe RPAS adoption has closely followed the stages seen for smartphones. Early RPAS usage was among those coming from the hobby industry who enjoyed building and flying model aircraft.

Fig. 10. *An overview of passenger UAM vehicle companies (Status June 2020, public data only). Reproduced from Ref.* [157] *with author permission.*

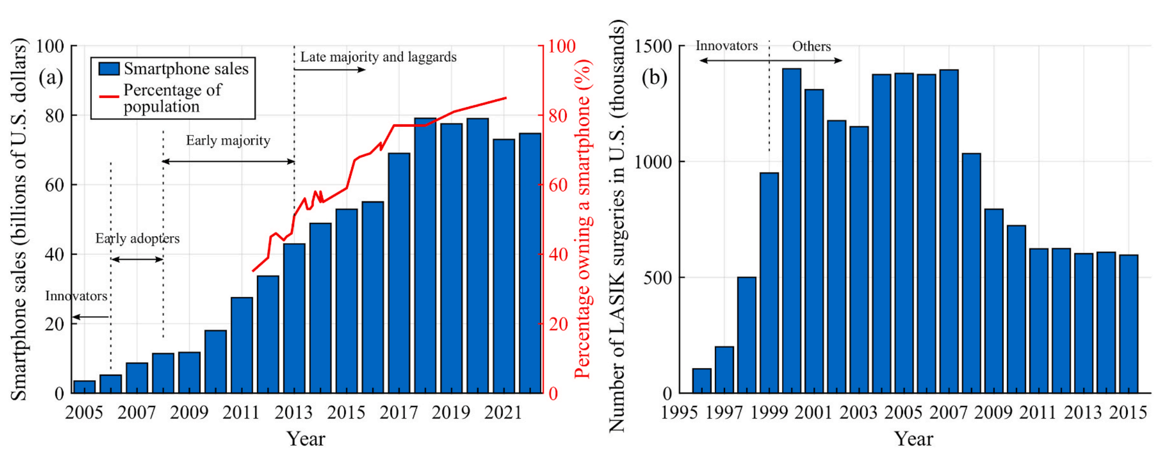

Fig. 11. *(a) Smartphone sales forecast and percentage of individuals owning a smartphone in the U.S. and (b) number of LASIK surgeries performed in the U.S. between 1996 and 2015. Data originating from Statista (smartphones sales)* [163]*, Pew Research (smartphone ownership)* [164]*, and Joffe (LASIK surgeries)* [165].

These users often had a limited budget and would not incorporate any specialized payloads beyond a camera. The client base then shifted to those who would employ RPAS for work or research purposes as they could make use of the aerial aspect of these systems to accomplish specialized missions. Commercialization then made the technology accessible to the early majority as decreases in cost and the simplified nature of off-the-shelf platforms makes them appealing to the average person. This has translated into usage as some surveys report up to 30% of a population having previously used drones [131] and greater than 90% of people approving of the use of drones in specific applications [106,115,141]. Additionally, the adoption of RPAS may look different than typical consumer products in the sense that not all people will own a RPAS platform, but they will not necessarily be opposed to their use. Due to their limited general usefulness, people may not be able to justify owning a drone when considering all of their other daily expenses. With this in mind, acceptance can be presented as a lack of fear, in which one would be willing to pilot a drone if presented the opportunity or they would not be afraid of the operation of drones if certain assurances are presented. These assurances are discussed in more detail in Section 5.2.

However, UAM acceptance falls into a different category as risk perception plays a much larger role in shaping opinion when a person's safety is directly tied to successful mission execution. Rather than equating adoption of UAM to consumer products, better comparables are perceived "risky" experiences such as medical procedures or roller coasters. For example, laser vision correction surgery offers an alternative to conventional means of vision improvement such as wearing glasses or contact lenses. Since its introduction in 1995, the estimated number of procedures in the United States increased substantially to the year 2000, before beginning to decline in 2008 and stabilizing around 600,000 procedures per year for the last decade (Fig. 11(b)) [165]. Joffe also notes that the number of procedures is closely tied to the economy at the time the procedure is performed, and fear of the technology is no longer the largest deterrent, but rather the cost. The number of procedures likely spiked early on due to pent-up demand, and once those clients had been addressed, a steady state was achieved. UAM may follow a model similar to this with some innovators purchasing their own vehicle, while the remainder and some early adopters will be able to afford the initially high prices of a UAM transportation service. Once prices relax, a larger percentage of the population will incorporate an air taxi service into their travel itinerary. Even today, the number of people wearing glasses is far greater than the total number of vision correction surgeries performed, meaning that although the technology has matured, it is not the primary method to improve one's vision. The same can be forecast for UAM as it aims to supplement existing transportation methods rather than replacing them all together.

In addition to cost, fear also plays a role in overall willingness to fly. An estimated 90% of the global population does not fly in a given year [166], and although lower, this number is still above 50% in developed countries such as the United States. While the estimated prevalence of a specific phobia of flying is approximately 2.5%, there is evidence to suggest that a much greater percentage of people, estimated between 10 and 35%, exhibit a level of anxiety such that they avoid flying [167]. This sets an upper threshold on the proportion of the population that would be willing to adopt UAM transportation. Much like that for vision correction surgery, fears are relaxed over time due to word of mouth referrals and positive results [165]. With this adoption structure in place, willingness to fly in UAM aircraft should not deviate much from conventional commercial aircraft.

5.2. Remaining integration challenges

While Fig. 9 indicates that the public has become more accepting of RPAS and UAM technologies over time, there are still major challenges that need to be addressed. On the technology side, each of the enabling technologies will continue to be developed, but there are other major issues such as reliability and cyber security. From the perspective of aviation regulators, certification of UAM aircraft will pose a major obstacle as there will be potentially hundreds of different vehicle prototypes, each requiring careful consideration and analysis. The conventional airspace model will also need to be adapted to account for the increased low level traffic density, and flight into urban areas. As for concerns of interest to the everyday person, privacy is the number one barrier to the acceptance of RPAS, while noise is a major issue for the integration of UAM into densely populated areas. This section will focus on issues of high interest to the general public as that is the major consumer demographic operating RPAS or traveling on an UAM aircraft.

5.2.1. Privacy considerations

The capabilities of RPAS often allow for data to be collected by the user. The type, quantity, and quality of the data is governed by the category of user, type of vehicle and specific payloads employed. Opinions can vary significantly from people that express no privacy concerns to those who feel that the presence of a drone in a public space can be seen as an invasion of their privacy. Klauser and Pedrozo found that the Swiss population was most concerned with commercial and hobby drones, reporting that 60 and 62% of individuals found these to be intrusive, compared to military and police drones at 28 and 36%, respectively [144].

The issue around privacy is further complicated by privacy laws which can vary significantly by jurisdiction. In a general sense, one's privacy rights are limited in public spaces; however, there is often significantly more privacy protections on one's private property. Privacy discussions should be centred around reasonable expectations and violations could be addressed under trespassing laws or by creating privacy laws specific to drone usage [168]. There are often approvals required for police, government, and military usage of RPAS which take into consideration the privacy rights of individuals of interest to the operation and potential bystanders. There is less regulation surrounding the use of RPAS by individuals and corporations and as a result, can create a situation where the privacy of individuals can be compromised. Several mitigation strategies can be employed such as prohibiting flight over private property, creating local fly or no-fly zones, and informing drone operators about how their platform could infringe on the privacy of others.

Another aspect of privacy is that an individual should have the opportunity to visually detect a drone if the platform is within observational range of the person. Most RPAS are equipped with some sort of visual sensing capability and if the platform can make out the identity of an individual on the ground, the drone should also be able to be seen. Allowing civilian access to the nano aerial vehicle category would introduce the possibility of individuals being able to misuse the technology to spy on others. To prevent this, drones at a minimum should be large enough to be visible during flight and operations that require beyond visual line of sight should require permission and training. Some regulations, such as those of the FAA also require that the drone be identifiable with a serial number linked to the operator. This ensures that the platform can be traced in the event of vehicle misuse or operator negligence.

5.2.2. Noise and vehicle routing

As discussed in Section 3.2.4, noise is an important factor in the integration of UAM into society. Developing and enforcing noise mitigation standards and procedures will take cooperation between both vehicle manufacturers and governments. On the manufacturer side, design steps can be taken such as employing a DEP strategy, increasing efficiencies to reduce blade tip speed, and reducing vehicle weight by employing composite materials and AM. At the local level, locations for vertiports should be carefully considered such that they do not interfere with regular city operation or traffic flow. Common flight routes and takeoff/landing paths should consider the noise signature of the area and ensure that vehicle noise blends into the existing background sound profile. Together, this hybrid design strategy between OEMs and cities will provide the framework for ensuring community acceptance of the additional noise introduced by the integration of UAM.

5.3. Roadmap for adoption

In order to make UAM and RPAS a viable business case, it is important to understand the development pathway for their introduction and possible solutions for increasing adoption and acceptance.

5.3.1. Building blocks for successful service uptake

Public acceptance and user adoption are key components for the successful introduction of RPAS and UAM [169]. Yet, in addition to that, requirements in other building blocks have to be met as well [170]. These building blocks are regulation and certification, vehicle and technology, advanced drone intelligent navigation system, ground infrastructure, integration with other modes of transport, market structure & ecosystem, and use-cases & CONOPS. Straubinger et al. distinguish between three different phases: demonstrator flights, first commercial services, and regular operation (Fig. 12) [170]. Each of these phases has different requirements. While demonstrator flights (Phase 1) only require first navigation systems and vehicle technology in place, large-scale role-out (Phase 3), requires the integration of each of these building blocks. Public acceptance and user adoption only start playing a role once commercial operation takes place (from Phase 2) but then play an essential role, meaning that the mechanisms must be in place earlier to ensure success.

5.3.2. Increasing adoption and acceptance

As described above, public acceptance and user adoption are expected to be one of the main hurdles for the large-scale introduction of RPAS and UAM [171]. One major challenge for adoption is the potential for severe accidents to occur in an early phase, which would likely have a strong negative impact on the public's perception, similar to what happened with helicopter shuttle services to the airport in the US during the 1960s [172].

Literature has suggested different approaches to increase the willingness to adopt novel services [170]. One possible approach is participatory design that includes the public and potential users early on. Understanding the needs and concerns is key to building a user-centred and beneficial service. Besides that, information campaigns help to

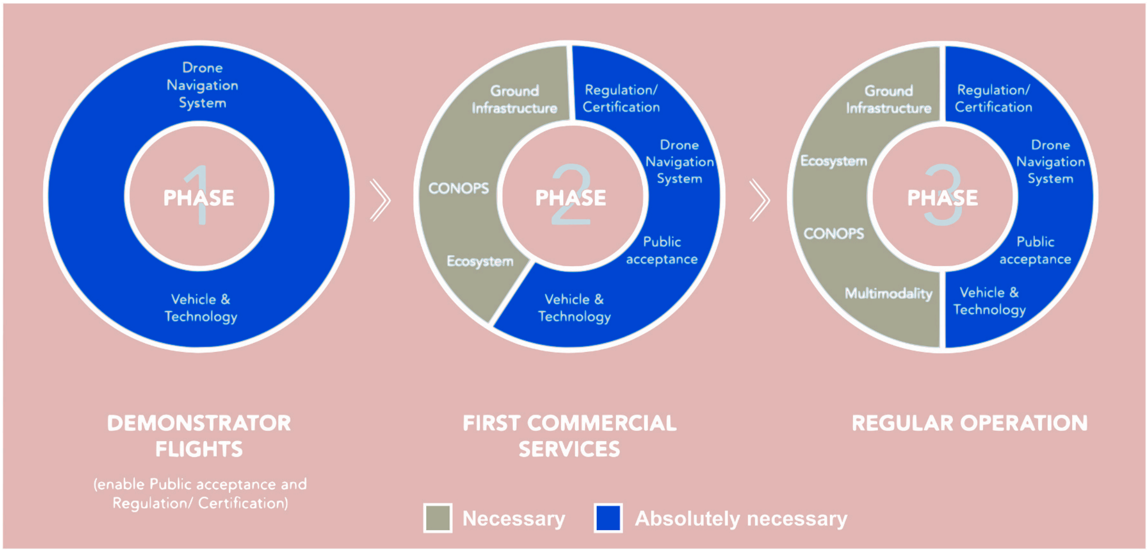

Fig. 12. *Prerequisites for the three development phases of UAM. Reproduced from* Ref. [170] *with author permission.*

familiarize the public with the new technology and allows an opportunity for interaction to provide transparent information about potential risks, gathered data, and other concerns the public might have.

In addition to companies and private actors, regulators and public entities also have the opportunity to positively affect adoption. Currently regulatory agencies are often behind the curve, especially for RPAS applications. Clear regulatory standards, safety standards, and communication can help to build trust in the novel services. Proposing no-fly zones, curfew hours, or obligatory public remote identification could increase public acceptance [173].

Public perception and willingness to use RPAS and UAM strongly differ across different geographical regions [171]. This will significantly impact the market entry strategies of companies, that are likely to start their business in areas where RPAS and UAM operation is more accepted. In this case, the population will be more familiar with the technology and changes in attitudes would be based on one's perceived level of success of the demonstrator flights or early commercial services.

5.4. *Recommendation for future surveys*

5.4.1. *Survey framework and standardization*

As shown in this review, there are many different researchers monitoring the public acceptance of both drones and UAM aircraft; however, each researcher has their own priorities as to which research questions to address. This can make it difficult to compare surveys between authors to establish a composite estimate of public acceptance for a specific region. Our proposed method to address this discrepancy is to include some level of overlap with past studies to better establish the present study within the field. This approach requires authors to perform a review of past work to identify key overlapping questions before introducing their own to the survey. This approach has been used before in polls of drone use conducted by Monmouth University [105,110] in which questions pertaining to the use of drones for border patrol and search and rescue were repeated prior to asking questions about drones armed with weapons in the second survey. At a minimum, the survey should ask about the participant's level of familiarity with drones (whether it be by a yes or no question or a Likert scale) and either the overall perception of the individual towards drones or specific applications of drones (such as search and rescue, package delivery, and law enforcement). This way, surveys will be able to be directly compared and a meta-analysis could be performed if the corresponding data is made public.

There should also be some agreement as to how participants are recruited. It was shown that participants were recruited to studies using a variety of platforms and methods. Unless the survey has a specific focus (e.g., geographical area, career type, etc.), those recruited to participate should be recruited randomly and the overall sample should match the demographics of the target area. Some surveys such as the one conducted by Cameron [129] use websites such as Facebook and Craigslist for recruiting and this generates a sample in which one gender can be dominant and as a result, does not capture the true feelings of the population. Where possible, recruiting should be conducted by a contracted polling firm such as Qualtrics or CloudResearch via an online panel. Companies such as these have a large participant pool and can scrub results, delivering a satisfactory data set to the researchers. Other lower cost alternatives such as Amazon's Mechanical Turk (MTurk), are also acceptable; however, there is less assistance with data filtering.

5.4.2. *Remaining research questions*

As demonstrated by Fig. 9, there has been a significant amount of work conducted to assess the public acceptance of RPAS and UAM aircraft. However, there are some remaining research questions that have not yet been addressed. As far as the authors are aware, no surveys to date have tracked an individual's change in perception of the discussed technologies over time. As discussed in Section 4.1, awareness and knowledge about a technology is key to adoption, thus it can be assumed that as people learn more about RPAS and urban air services, their perception will shift. The Vance and Malik study found an increased willingness to fly after the administration of the survey [143]; however, longer term monitoring is also of interest. There has also been no work on the public perception of advanced aviation technologies among children and adolescents. This age group is more difficult to target due to the additional ethical considerations needed for working with minors; however, the data would be valuable as the commercial market for UAM is over ten years away so this age group would be among the youngest clients when the market is realized.

6. Concluding remarks

The technological advancements of the past few decades have enabled a world where highly automated aircraft will play a significant role in the skies above us. In particular, RPAS can be used for dozens of different applications of which the mission objective and operational requirements dictate the configuration, size, and design parameters of the system. Drones can be used by individuals, corporations, and governments; however, jurisdictions place restrictions on vehicle capabilities, often limiting the type of system available to the public. Studies show an increasing level of awareness of drones by the general public, likely associated with their increasing availability as a consumer product.

As for public perception of RPAS, trends show a slow increase in the level of support over time. Applications perceived to be in the public benefit such as search and rescue and disaster monitoring have more support than commercial applications including package delivery and photography. Law enforcement missions show a higher degree of support when the vehicle is being used as a tool (e.g., accident forensics or hostage negotiation) rather than as a sensor (e.g., surveillance or issuing speeding tickets). Many factors influence level of support including gender, age, geographical location, level of drone knowledge, and political beliefs.

One application of remotely piloted aircraft that has seen a significant rise in the level of support in recent years is passenger transport. Surveys mostly from the United States show a stark rise in air taxi favourability after about 2010, with current levels sitting above 50%. Not all countries have seen this rise as a survey performed in Germany in 2020 reported 18% of the respondents were willing to fly with that number rising to 57% in an emergency scenario. Factors affecting technological adoption were similar to those for drones with the addition of projected time savings, trip cost, and household income. With further increases in the level of automation employed by society and familiarity with UAM, adoption will one day be realized.

Technological adoption may also look different for RPAS and UAM services. The perceived usefulness and relatively low risk of RPAS in comparison to UAM aircraft means that the public will be more supportive of the use of RPAS (with the potential exception of applications that infringe on the privacy of individuals). RPAS adoption may entail that although one does not use a drone for their own purposes, they will not necessarily be opposed to their use by others. On the other hand, for UAM adoption to be successful, it will require adopters to use the aircraft as part of a transportation service. The cost will be higher than other alternatives at first; however, with increasing availability, reliability, and a larger client base, trip cost will decrease over time. Adoption will also depend on scale of operations. During early commercial services, ensuring that there is sufficient demand to financially support the operation will be the objective, whereas with regular operations adoption will follow the adoption model for disruptive transportation technologies in which decision making will shift away from trust in the technology to focusing on social behaviours, the perceived value of time, and associated costs. Overall, with the progress made towards quantifying public perception and social acceptance of advanced aviation technologies in the past few years and the projections made by market research firms such as Morgan Stanley and Gartner Inc., the state of the field is promising and looks poised to grow in the coming years.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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