Advanced Aerial Mobility and eVTOL aircraft in Australia:

Promise and Challenges

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CSCL Centre for Supply Chain and Logistics

Authors

Professor Doug Creighton, Deputy Director Institute for Intelligent Systems Research and Innovation
Dr Hermione Parsons, Industry Professor, Director Centre for Supply Chain and Logistics
Ms Laura Marcela Usma Alvarez, Institute for Intelligent Systems Research and Innovation
Dr Bruce Gunn, Institute for Intelligent Systems Research and Innovation
Dr Roberto Perez-Franco, Centre for Supply Chain and Logistics
Associate Professor Michael Johnstone, Institute for Intelligent Systems Research and Innovation

Affiliation

Deakin University's Institute for Intelligent Systems Research and Innovation and Centre for Supply chain and Logistics.

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Reliance and disclaimer

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Contact Deakin University

Director, Research Sectoral Partnerships
Office of DVC (Research)
Genevieve Reid g.reid@deakin.edu.au

Deputy Director, Institute for Intelligent Systems Research and Innovation (IISRI)
Office of DVC (Research)
Douglas Creighton douglas.creighton@deakin.edu.au

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1. Foreword

It is my pleasure to introduce this Deakin Mobility Series Whitepaper exploring the challenges and opportunities of electric Vertical Take-Off and Landing (eVTOL) aircraft in the Australian passenger and freight context.

Concepts for vertical take-off and landing vehicles and the dream of personal flying craft have captured people's imagination for generations. Recent technology advancements mean Advanced Aerial Mobility (AAM) using eVTOL may soon become a reality.

As the world continues to urbanise, developing new and efficient systems will be critical, and AAM has the potential to augment and even transform our transportation systems. Far from science fiction, this technology could deliver tangible benefits to individuals and communities on a global scale, by reducing the congestion of urban areas and linking regional areas via safe, efficient and fast travel.

We are on the cusp of seeing a new mode of transport emerge. Several major cities have prioritised the exploration and development of eVTOL and are preparing for deployment. Australia is positioned to make a significant contribution to the sector and can leverage the technology in a diverse range of markets, such as air-taxis, emergency service operations, logistics, aerial surveying, and tourism.

This white paper provides the first comprehensive literature review and study of this nature, and analyses the regulatory challenges, operating potential and likely benefits of AAM and eVTOL. In undertaking this work, the authors seek to promote conversation in AAM and provide Australian policy makers and regulators, infrastructure owners, operators and transport users with a greater understanding of the barriers to overcome and the benefits that can be realised.

Deakin University recognises the importance of transport and supply chain systems for the Australian community in our cities and our regional and rural areas. In such a complex and shifting space, Deakin Mobility is leading the way by bringing together industries, communities and our researchers to look beyond the obvious convenience and cost savings to a host of other benefits that are beginning to reveal themselves in this world of new, inclusive mobility.

Deakin is uniquely placed to contribute to this emerging industry, with its expertise and proven outcomes in advanced materials, battery technology and manufacturing – areas of speciality that Advanced Aerial Mobility relies on. Research and academia play a central role in the field: in the development of enabling technologies, in exploring the implications, and in providing the evidence base to guide sound decision-making.

I congratulate the research team on this comprehensive, timely and exciting literature review and study, and look forward to seeing the many positive outcomes that will follow.

Professor Iain Martin
Vice-Chancellor, Deakin University

2. Glossary

AAM	Advanced Aerial Mobility
ANSP	Air Navigation Service Providers
ADS-B	Automatic Detection Surveillance – Broadcast
ATM	Air Traffic Management
BVLOS	Beyond Visual Line of Sight
CASA	Civil Aviation Safety Authority
CBD	Central Business District
ConOps	Concept of Operations
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEP	Distributed Electrical Propulsion
eVTOL	Electric Vertical Take-Off and Landing
FNA	Voluntary Fly Neighbourly Agreements
ICAO	International Civil Aviation Organization
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LCM	Lifecycle Management
MRO	Maintenance, Repair and Overhaul
NAAs	National Aviation Authorities
NAS	National Academy of Sciences
OEM	Original Equipment Manufacturer
PEM	Proton Exchange Membrane
ReOC	Remotely Piloted Aircraft Operator's Certificate
RePL	Remote Pilot Licence
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft Systems
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems (includes RPAS and AAS)
UAV	Unmanned Air Vehicles (obsolete term for Remotely Piloted Aircraft)
UTM	Unmanned Traffic Management
WLAN	Wireless Local Area Network
4G, LTE	Fourth generation technology standard for cellular networks, Long-term evolution
5G	Fifth generation technology standard for cellular networks

3. Executive Summary

This white paper aims to raise awareness of Advanced Aerial Mobility (AAM) utilising electric Vertical Take-Off and Landing (eVTOL) aircraft in the Australian passenger and freight context.

The opportunities and challenges for AAM and eVTOL in Australia are discussed, providing policy makers and regulators, infrastructure owners, operators and transport users with an understanding of the regulatory challenges, operating potential and likely benefit from safe AAM operations.

Through a review of publicly available literature and targeted interviews to investigate early adopter systems, this paper identifies:

- potential market segments for eVTOL aircraft and the opportunities to manage those markets
- insight into future infrastructure, airspace and land requirements and how to integrate into Australia's existing infrastructure and transport systems
- identification of gaps in infrastructure, regulations and planning requirements within Australia
- early understanding of requirements to meet Australian conditions to support regulation harmonisation and allow Australia to contribute into the development of international standards (rather than having to modify standards afterwards, which slows development and rapid adoption of technology innovation)
- directions for Australian research and development, and establishment of potential case studies for early trials and testing of the evolving eVTOL technology.

As with other high technology sectors, the aviation industry has been under a constant state of evolution since the beginning of human-assisted flight and has adapted to disruptions such as the introduction of jet engine and 9-11 and now continues to adapt to Covid19 hibernation.

We expect the sector to continually evolve to meet passenger and freight demands, albeit under different business and operating models. With many countries rethinking how they do localisation, manufacturing and import/export transport routes, the aviation sector will evolve further to meet the challenges. The movement of people and goods through urban and regional areas will be very different in 15 years-time compared to how it looks now.

Trends and drivers:

The current trends and drivers of new technology in the transport sector include:

- Growing aviation sector demand, both through population increase and an increase in tourist numbers, but currently paused due to Covid19
- A significant increase in transport infrastructure investment in Australia
- Increasing urban congestion, due to growing urban populations
- Skill shortages in airspace control, pilots, project management and infrastructure design
- Lighter materials leading to aircraft designs that were not possible even 10 years ago
- Rapidly evolving energy storage technologies that will enable electric powered aircraft
- Competing modes of transport – speed and variety i.e. high-speed rail
- Growing market segment of the aviation industry driven by start-ups and original equipment manufacturers (OEMs)
- Distributed Electrical Propulsion (DEP) has opened the door to a VTOL evolution
- Relatively soon, eVTOL may replace helicopters in several applications
- eVTOL has revived the old dream of AAM within congested urban areas and linking regional areas via safe, efficient and fast travel.

3.1 Conclusions

General conclusions in relation to AAM value outcomes

- Electric aviation is going to happen
- AAM does not specifically tackle congestion, but currently is thought to be a congestion avoidance technology
- Environmental friendliness should be assessed in comparison to future transport modes, not in the context of current transport
- AAM will generate time savings for some commutes and freight deliveries, as well as add value to other aerial transport services currently in operation
- AAM is a high-tech industry sector development opportunity for Australia, with potential for employment and export growth
- Various models of AAM could be enabled, such as air taxi's, shuttle services including regional services, package delivery and tourism applications

Advanced aerial mobility operations

- AAM still requires research into aircraft design and certification, airspace control, identified flight paths, regulation changes and a viable operating model
- AAM will happen, but not for everybody, and not door to door, in the short to medium term
- Regional to city flights may be viable with eVTOL technologies, but range restrictions will limit their scope of operations
- Aircraft will initially be piloted, but a transition is envisaged to autonomy
- Two critical challenges are reducing noise and tackling invasion of privacy concerns
- Potential for initial co-location of vertiports with or near transport hubs and regional hubs in urban, suburban and regional areas.

The range of market segments that AAM would service is dependent upon the aircraft capabilities and the relative operational costs. The main market segments being considered at present are air-metros (vertiport-to-vertiport travel), city to airport travel, regional links to airports and urban centres, small freight deliveries in populated areas and possibly parcel delivery to designated drop-offs. Potential operational concepts linking airports with concentrated urban areas, would need to develop a solution to enable eVTOL operations near controlled aerodromes.

Considering the key themes identified from the literature and through consultation, the following issues need clarification in order to develop the potential markets for aircraft manufacturers, flight service operators and regulators. The key themes are summarised below.

Regulation

The regulatory environment is currently innovation driven; the challenge is to develop a solid safety case in line with updated standards and certification requirements for the aircraft design and airspace system integration of the operational concepts and the missions proposed. Furthermore, education initiatives would need to target different user and stakeholder groups, including training for operators, pilots, aeronautics maintenance, support service providers and government employees.

Safety

Safety is of critical importance for the aircraft sector of the transport industry and particularly CASA. It is unlikely that unmanned flight operations will be enabled in the short to medium term, due to concerns over aircraft and operational safety. For air-taxi and air shuttle eVTOL missions to be approved, operations must provide comparable, or improved, safety standards to what currently exist. Automation and autonomy add additional complexity and require an evidence-based approach to demonstrate that they would result in operations as safe or safer than existing systems. The key areas of concern regarding safety through air traffic control support services include flight separation, traffic information and alerts on route.

Noise

One of the most critical challenges in the wide-spread development of UAM is the level of noise produced by current eVTOL designs. While significantly lower than helicopters, the levels of noise of current eVTOL concepts – especially during take-off and landing – are above what would be desirable for frequent operation in residential areas. Noise limits the locations that could be frequently accessed with eVTOL, ruling out flights taking off and landing in residential areas in the foreseeable future. This, in turn, has implications about how UAM can be deployed in our cities.

It is important to capture the lessons on noise from the work and experience of Airservices Australia, in aligning airlines and airports to adopt consistent actions on noise, based on a balanced ICAO approach to noise management. The current ICAO standards, however, "do not prescribe noise standards for RPAS and UAM aircraft types", meaning there is currently no regulatory oversight of noise for emerging AAM applications.[1]

Community acceptance

It is important to distinguish between different sizes of aircraft systems, and how they will operate based on their payload. If constraints related to safety and noise can be resolved, a likely viable scenario is where noise disturbances during take-off and landing are minimised, and eVTOLs are flown at mid-high altitudes, following fixed routes and where capacity is regulated to avoid noise and visual pollution. Regardless of how AAM is deployed, an agency should be responsible for actively addressing community concerns, rather than being the exclusive responsibility of the operator.

AAM could also deliver benefits in terms of reducing the necessary scale of future infrastructure investment requirements to grow capacity of rail and road infrastructure networks.

Locations

Vertiports are the key ground infrastructure required for the development of AAM. Given the moderate/high levels of noise from eVTOL take-off and landing, it is likely that vertiports and vertistops will not be in residential areas. They will instead be in areas with higher background noise levels, such as existing transportation hubs. This would allow for AAM applications that offer flights between transportation hubs, such as train stations and airports, but not for the more general door-to-door UAM model. There will be fewer restrictions with regional travel, but the lower levels of background noise will limit the potential locations of vertiports in regional towns and centres.

In the short term, the use of existing heliports in urban areas could be considered, but extra vertiports at transport hubs also makes sense, as the cost of establishing and operating these ports will be minimised. For freight operations in congested urban areas, the pick-up and drop-off locations will be varied and as such the pilot programs will use parcel hubs as the most likely location for pick-up and drop-off of small-to-medium weight (10 to 200kg) consignments.

Aircraft

There are over 200 models of eVTOL aircraft, [2] the selection of the best design will be highly dependent on the mission requirements and parameters. A list of aircraft concepts designers and manufacturers is provided by the Vertical Flight Society in the eVTOL aircraft directory. Many of the designs are still in the early design or prototype phase, but a significant number are close to flight readiness. The final choice of aircraft design will depend heavily on the application areas chosen for trials and commercial operation.

Communications

A coordinated effort between the operator, regulator and Air Navigation Service Providers (ANSP) is required to develop standard operating procedures and operations manuals that address how eVTOL aircraft will communicate and interact with other aircraft, crew and air traffic control systems, including:

- suitable contingency plans in the event of failure or risk
- procedures to minimise risk associated to software and flight path configuration
- how both automation and autonomy would be monitored and controlled.

Lessons from other industries

Based on previous studies completed by Australian transport research groups, the following are a list of key challenges for the AAM opportunities:

- lifecycle management of new assets and ageing infrastructure
- harmonisation between state regulatory and economic frameworks
- interoperability and harmonisation
- local content of aircraft, maintenance and infrastructure
- effective operations in terms of capacity, reliability, efficiency and sustainability
- effective customer experience including timely service, frequency, safety, information service, and on-time delivery.

3.2 Recommendations for Advanced Aerial Mobility deployment in Australia

Proof of concept programs

A proof of concept program to test and evaluate the AAM aircraft operation, facilities, maintenance, processes and procedures would enable learning opportunities for safe AAM operating paradigms. The evaluation would examine the different aspects related to enable a safe AAM environment that can satisfy CASA's certification and licensing requirements. Any AAM test cases must be designed to provide meaningful results for the operators and regulators.

Synergies should be explored with Airservices Australia and their UAV integration and management services program. This initiative will provide insights on adaptability requirements to accommodate unmanned aircraft systems (UAS) and low-altitude entrants into Australian airspace. The program can be a valuable source of lessons around UTM capabilities interacting with ATM systems, data protocols and information formats, as well as, urban / regional complexity considerations for airspace design.[3]

The National Academy of Sciences (NAS) in the United States is recommending that test cases be developed for less complex cases such as regional or suburban AAM. This is due to the difficulty in testing the base-level systems in high density areas and the proof of concept may be better deployed within lower density areas.[4]

Research programs

A program of research is recommended, examining:

- different potential business scenario options under Australian conditions to:
    - develop a systematic understanding by modelling the aircraft designs and vertiport operations considering various types of operation concepts
    - define an integrated strategy that optimises the benefits for the community, customers, airline operators and infrastructure providers
- route and vertiports options, which will require comprehensive research on consumer behaviour to understand demand, price, comfort, security, journey time and other travel requirements
- materials, fuel cell/ battery and manufacturing research for light weight, high value components for eVTOL aircraft.

Collaboration

The expected advances in technology, climate change, and a greater focus in social and customer centric approaches will likely require an integrated transport system strategy, ensuring collaboration across the infrastructure sector, supply chains, funding and regulating bodies for the effective development and transition of AAM technologies in line with the relevant skills and competencies.

AAM will be less likely to succeed without cooperation across the different stakeholders. The task undertaking for AAM is complex, requiring a multidisciplinary approach by investors, regulators, entrepreneurs and governments. The task does not end with the aircraft flying their designated routes, but with AAM integrated with other transport systems. Integration with existing transport networks is also recommended to help build the idea of AAM into everyday travel and supply chains.

4. Introduction

Transport in cities globally is often constrained by the availability of suitable land-based transport for people as well as freight. Australia's highly urbanised population is being further concentrated into larger cities and regional towns through high population growth. This has led to increasing congestion and significant pressures on public transit systems and freight networks. Generally, it is becoming more difficult to transport people and goods around land-based transport networks, while extensive underground networks are expensive to build and maintain.

In addition to the difficulties with crowded cities and congestion, there is currently an energy transition taking place globally, moving away from fossil fuels to sustainably generated electricity, from renewable sources, and new energy storage technologies. These changes will have an evolutionary effect on transport options globally. Many ground-based transport systems will move from combustion-based engines, to distributed electric motors and battery/fuel cell storage systems. This evolution will have a significant impact on aircraft and associated infrastructure, thus improving the capability for short-medium hop aircraft in cities and regions over short, medium and longer ranges.

Air travel provides an option to improve overall transport networks within and between cities and regions in Australia. Put simply, the airways provide significant capacity for the transit of goods and people in an urban and regional environment, reducing the need to build inflexible, capital intensive land transport infrastructure. The rapid development of new types of aircraft has the potential to greatly add to the transport options for many people in large urban areas, as well as commutes between regional and city areas. In the short term, however, building the necessary infrastructure and aircraft, progressing regulations and allowing businesses to develop new business models will take time, money and human ingenuity.

4.1 What is Advanced Aerial Mobility and what is the vision?

There has been considerable research and commercial interest in the development of small aircraft for movement of people and small freight packages, leading to the development of new market concepts in the aircraft industries. These disruptive new technologies have been termed Advanced Aerial Mobility, which has been defined as "the emergence of transformative and disruptive new airborne technology supporting an ecosystem designed to transport people and things to locations not traditionally served by current modes of air transportation, including both rural and the more challenging and complex urban environments." [4] Advanced Aerial Mobility encompasses the development and operation of a range of new aircraft that allow for safe, clean, quiet and efficient operation for short to mid-range flights, for both freight and passengers.

The more commonly used terminology, Urban Air Mobility (UAM), refers to the "safe and efficient air traffic operations in a metropolitan area for manned aircraft and unmanned aircraft systems". [5] The aim of UAM is to provide a safe, clean and reliable mode of transport, powered by a network of aircraft servicing heavily congested cities and urban areas. As an alternative to ground-based transport, many of the challenges around mobility and traffic congestion and travel times can be significantly reduced by using airways effectively and efficiently; high priority freight and personal movements can be achieved, increasing productivity; and other benefits can be realised such as enabling new technical jobs and new sources of tax revenue.

As noted by the National Academy of Sciences, UAM is not broad enough in definition and is in fact a subset of AAM. The definition needs to be extended to include mid-range regional flights and options for freight transport in urban, suburban and regional settings. The NSA have acknowledged that large scale deployment of urban air transport is the most difficult of challenges for the transport industry and the capability of the sector may be best served by building a technology and operations base from less demanding transport sectors. For the purposes of this paper, therefore, we will refer to Advanced Aerial Mobility (AAM) rather than UAM in the following sections.

Under unconstrained technological development, the key enablers of AAM are:

- advanced control for aerodynamics and power distribution systems
- distributed electric propulsion and battery/fuel cell storage systems
- airspace traffic management and aerospace infrastructure systems
- the agility to support scalability of operations
- aeronautical experience from highly skilled technicians, engineers, pilots and operators.

As with most emerging technologies, developing the ecosystem for AAM makes it possible for businesses to flourish across a new and specialised supply chain. The AAM industrial environment will consist of the following sectors:

- transport operations carrying passengers and goods
- vertiport operations
- construction and infrastructure services dedicated to vertiports and asset monitoring
- equipment manufacturing and maintenance services linked to aeronautical products such as aircraft related hardware and software
- energy providers
- aerospace specialised recycling firms
- commercial and industrial real estate for vertiport, maintenance locations and decommissioning sites
- security services
- skills, training, research and development
- auxiliary activities such as insurance, finance and management.

While the increased investment and interest indicate areas where the new transport mode could deliver significant benefits; potential operational models will be constrained by legal, societal, environmental and economic aspects. These issues and challenges will be discussed in later sections of the paper.

4.2 What is eVTOL?

The electric Vertical Take-off and Landing (eVTOL) aircraft, which can be conventionally piloted, remotely piloted or autonomous, is the main technology enabler for the implementation of AAM. Vertical take-off and landing (VTOL) aircraft, propeller-driven aircraft, rotorcraft (helicopters) and tilt-rotor aircraft could all provide options for mobility by using the skyways for short/medium distance travel. But the problem, historically, has been that short/medium-hop air travel is expensive, noisy, relatively less safe than commercial airline travel, and difficult to manage in terms of air traffic control. Conversely, the proposed array of eVTOL aircraft designs and operational features anticipate an emissions friendly option that is safe, affordable, small, precise, fast, quiet, able for most weather conditions and easy to use and maintain.

Importantly, manufacturers are yet to address a variety of technological aspects and sensitivities linked to each prospective operation facilitated by eVTOL aircraft, particularly around designs that consider the safety, noise, lifecycle sustainability and economy. The eVTOL aircraft and associated operational concepts will be discussed in more detail in sections 7 and 8.

4.3 Current advances in Advanced Aerial Mobility and eVTOL

Given the increasing dynamics of the global transport sector around AAM and eVTOL aircraft technology,[6] various countries are assessing appropriate regulatory and standards frameworks to ensure that aircraft and supporting infrastructure technology can be incorporated effectively. Additionally, a series of public and private sector R&D programs have been instigated to investigate the relevant AAM technologies and their integration into the existing transport system and urban ecosystem.

Currently there are hundreds of companies of all sizes around the world working on the design, development and integration of the eVTOL aircraft, as well as their batteries, motors, navigation systems and related services. A range of demonstrators and city trials are starting to bring concepts to life and closer to commercialisation. According to the Vertical Flight Society's world eVTOL aircraft directory, there are over 200 eVTOL aircraft designs.[2] In June 2019 Uber elevate announced its plans to launch its UAM commercial fleet operations by 2023, providing air shared transportation services between suburbs and cities;[7] demonstrators were projected by 2020. In Australia, innovators like Alphabet's Wing, have established drone delivery services,[8] advancing the country's experience in relation to operations in low altitude airspace. South Korea is taking a different approach to the USA, with the rapid development and deployment of UAM with eVTOL aircraft.[9] This makes sense for Korea, as they are a highly urbanised country, with a small land area and high population density. They are aiming to have UAM operating within Korea in the next five years and become global leaders in the sector.

Many challenges lie ahead around realising the opportunities and mitigating the risks associated with AAM. This document provides insights into the challenges of operating a network of aircraft within Australia's urban and regional environment and establishing the relevant infrastructure and management systems. Early understanding of AAM in the Australian context will support stakeholders with an interest in realising potential economic opportunities; decision makers involved in the development of the regulatory frameworks and international standards; and the community in understanding the various AAM visions and their social, economic and environmental implications.

5. Market Profile

The anticipated forces that will drive demand in AAM include:

1. population growth
2. familiarity with domestic and international aviation services
3. familiarity with Remotely Piloted Aircraft Systems (RPAS) technology
4. the need for day to day travel and products

One advantage Australia has, in terms of uptake of AAM, is a highly concentrated population in urban and regional centres. In 2016, approximately 71% of Australians lived in major cities, while Sydney and Melbourne presented the most densely populated areas in 2018.[10] Sydney was the largest city, whereas Melbourne presented the highest growth by an average of 1,859 people per week between the 2011 and 2016[11] and it is projected to between 12.2 million and 8.6 million, surpassing Sydney by 2031.[12] There is also a recent trend for younger people to move to regional areas within easy travel distance of the cities. AAM presents has an opportunity to improve the travel time from regions to the cities. The deployment of AAM to regional centres could contribute to easing population pressures that exist within the major cities and enhance regional connectivity.

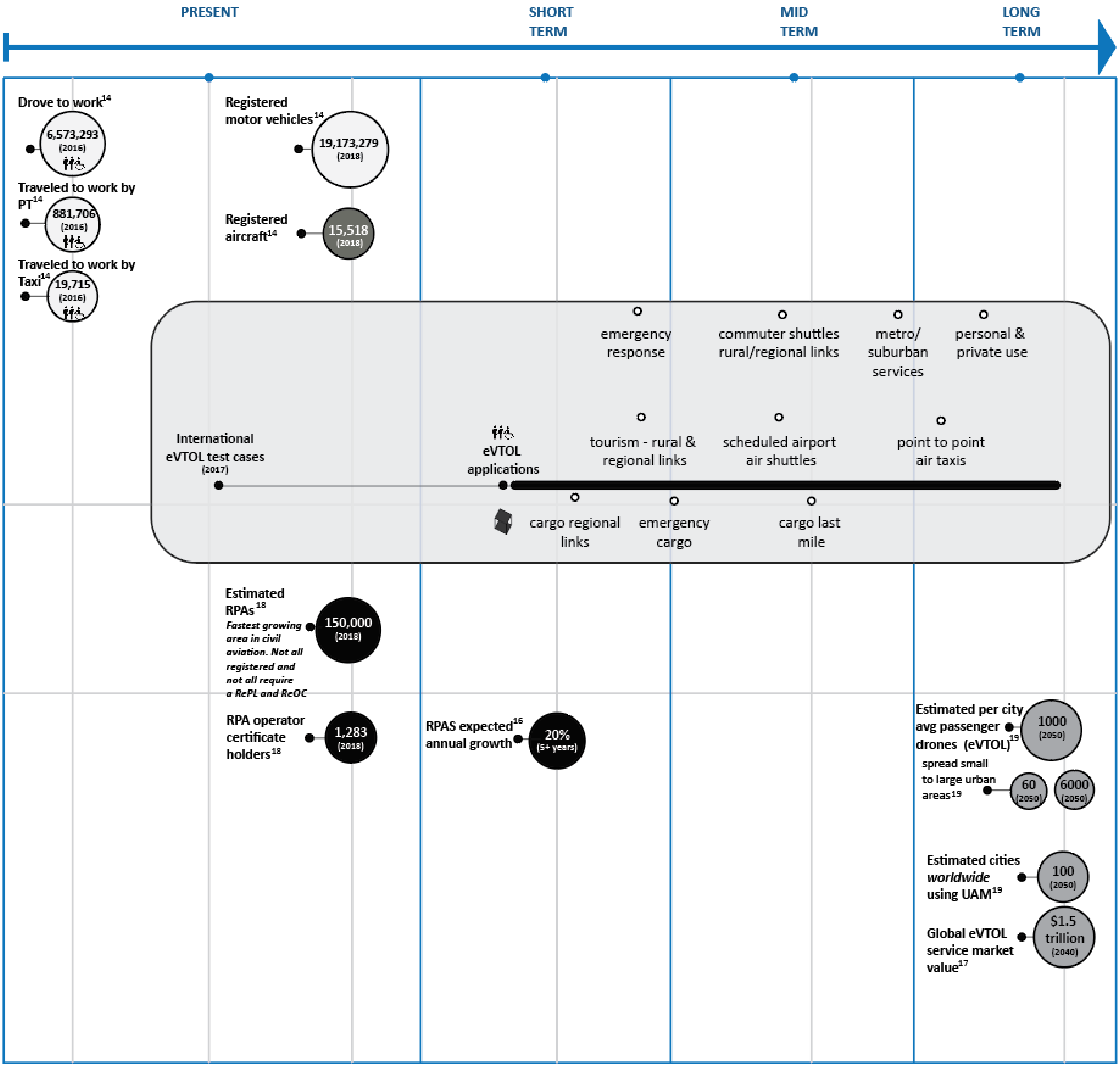
Since 2002, the use of commercial air transport has increased steadily in Australia, after a brief period of weakening due to 9/11 attacks.[13] In 2020, the pandemic Covid19 virus, was the cause of another large decline, however, a post-covid19 recovery is likely to occur if demand related factors return to a point of balance and growth. Future demand for both passenger and freight aviation services will reflect the new developments in travel requirements, consumption patterns and government policy in line with societal expectations and economic conditions.

Before the Covid19 virus, it was estimated that Australia's capital city airports could reach 235 million passengers a year by 2030, and international arrivals in the Oceania region were expected to grow from 17 million (2018) to 26 million (2028).[3] In terms of transport modes in Australia, the figure 1 below indicates that the transport of passengers and goods is dominated by road transport vehicles, with the number of motor vehicles more than 1,200 times greater than the number of registered aircraft, based on 2018 figures. For freight, there is little movement of urban and regional via current air transport technologies. The current role of air transport in freight is predominantly intercity transport. There has been, however, a significant increase in micro-freight deliveries to homes and business over the past ten years, which is largely serviced by small vans and light commercial vehicles[14] and adds considerably to city congestion. These types of goods delivery could be serviced with current and future eVTOL technologies.

The RPA market in Australia experienced growth at 120 per cent per annum during the period 2015 to 2018 and is expected to continue to annually at a rate of 20 per cent over the next five years.[15] Already there are over 1,200 certified UAS operators and that number is likely to grow rapidly, while the estimated number of RPA's is greater than the number of registered aircraft in 2018. Such growth in drone technology provides some optimism for future growth of the AAM industry.

Both internationally and domestically, much of the airline market is concentrated in conventional domestic and international services. For eVTOL aircraft manufacturers and operators that can first establish certified and viable commercial AAM airlines and public services, there is a strong prospect of achieving economies of scale through the global demand for passenger and freight AAM related aeronautical products, product upgrades and maintenance services required for compliance with the safety standards.

While current use of unmanned aircraft is for recreational and commercial use outside of transport, by 2040, the value of the eVTOL services and global UAM total addressable market is estimated to be 1.5 trillion dollars.[16] As eVTOL technologies mature, the market for Advanced Aerial Mobility services is expected to grow significantly. To what extend this estimate will be met, however, remains uncertain as it will depend on how technology matures across the AAM ecosystem.



Sources: from left to right BITRE,[13] CASA,[17] Roland Berger,[18] Morgan Stanley,[16] Australian Aviation[15]

Figure 1, Australian mobility context – relative market size and estimated changes over time

In terms of overall mobility, the number of people choosing to travel to work by taxi was very small compared to personal transport and public transport. While price may be important, other factors such as comfort, time and trust may influence the preference for a transport mode. From an aviation perspective, the current estimated number of RPAs already surpasses the number of aircraft, which under unconstrained conditions can perhaps be an indicator of future consumer preference to own eVTOL aircraft - like car ownership. Certain cases, like an airport shuttle where the consumer assesses the trade-off of shorter travel time, comfort and convenience against airport carparking, road time and other costs of travelling, may represent a viable option to consider in the mid- stages of AAM implementation and until the price points are more accessible, although is highly dependent on domestic and international airline performance.

5.1 Australian market characteristics

As discussed earlier, Australia has a highly concentrated urban/suburban population with eight main state and territory capital cities comprising over 70% of the population, several large regional centres and many large regional towns. This type of urban consolidation is one of the megatrends of the 20th and 21st centuries. Despite this, only Sydney and Melbourne have some areas of very high population density greater than 8,000 people per square km.[19] Much of the attention in the AAM international literature and business models has on focussed these very high population density areas, due to the high congestion rates and likely high demand levels for AAM. Australia will therefore require relevant business models to make AAM a reality.

Cities in Australia, particularly Sydney and Melbourne, are serviced by road transport, with rail corridors available to meet peak demand for passenger. Freight movements are also dominated by road transport, but the shortest distances covered generally add a significant percentage of the overall transport cost (30%). This opens a market for freight delivery based on last-mile delivery that is seen internationally as the most likely AAM market in goods movements.

In general, the higher the population density, the more difficult it is to move people and goods via road transport, while rail does not provide enough flexibility in travel options for many customers, particularly in peak times of travel. AAM has the advantage of high capacity levels in terms of sky-paths, but currently the land-based infrastructure is not suitable for proposed concepts like metro style services or air-taxis. In addition, higher than average background noise levels are already present in high density urban environments.

In Australia, there may be a possible market for regional services from satellite towns and large regional areas into congested capital city centres. The range of these aircraft will have to be significant, generally up to 200-250 kms. Rapid movement of people and freight from outside capital cities changes the dynamics of much population movements observed in Australia, with population pressures reduced from overcrowded cities to regional centres with minimal congestion.

5.2 Likely AAM development in the Australian market

It is likely that the nascent AAM market will develop initially with a series of test sites and case studies for evaluating the technology, thereby further developing the understanding of technology adaptation to and adoption under Australian conditions. One key difficulty at present is the lack of any information around likely AAM demand for any service prospect via eVTOL aircraft. As such, the market is being driven via technology push, rather than market pull, which is not unusual for technology disruption. A similar rapid change in the telecommunications market happened with the development of smart phones and internet connections through wireless telecommunications systems. It is quite possible that AAM and electric aircraft will be seen in the future as the technology that led to rapid evolution in the transport sector.

The scope of the paper does not extend to analysing the many different models that AAM operators may pursue. As an overview, however, the likely market development will include (as shown in Figure 1):

- Short term: change in existing markets like helicopter and charter flights
    - trials of different aircraft in different market segments
    - trial of likely demand for regional to city-based travel
    - evaluation of business markets with highest potential and demand
- Medium term: increased volume and demand leading to reduced costs
    - greater number of aircraft flying in a larger set of market sectors
    - need to increase levels of training across all sectors of the industry
    - advanced maintenance standards
- Long Term: let the informed market decide the best operators and business models.

It could be expected that the Australian market develops significantly over the next 10 years and fleets of eVTOL aircraft may be operational after 2030. The initial trials, using much of the existing heliport or transport infrastructure, could form the basis for evaluation, by comparing eVTOL with conventional helicopter charter flights and other transport modes, like taxi services and freight vans.

Figure 2 includes a series of potential eVTOL applications according to the required travel range and connections. The coloured circles in the figure, illustrate the possibility of a variety of service concepts within a 10 km radius and the lines represent the possibility for hubs and service options linking urban, sub-urban, regional and rural areas depending of selected aircraft and their fitness for purpose.

As Advanced Aerial Mobility supports the view of multiple possible operations, the cost for each operation will be the combination of aircraft manufacturing technologies and operating strategies for vertiports and aircraft. Operators will be concerned with finding the markets and volumes to make their service offer sustainable; manufacturers may need to consider how to achieve scale for the combination of multiple eVTOL applications; while vertiport operators will have to achieve the scale to support their real estate, infrastructure costs and level of support. Vertiport operators may need to compare the viability of allowing a single operation or multiple operation types. Further studies are required to understand the viability in synergies between AAM operations, manufacturing and vertiport operations considering various concepts.

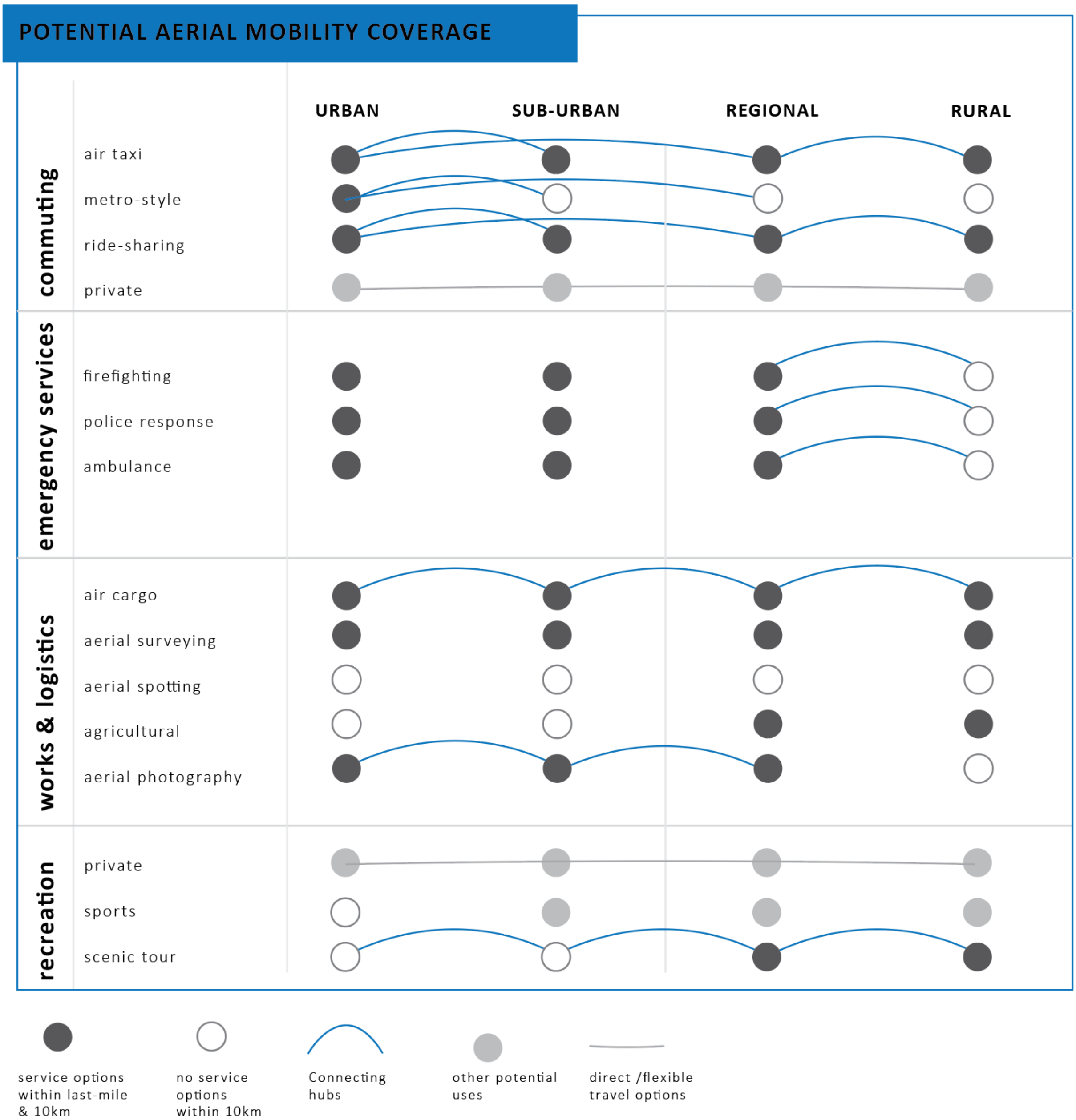


Figure 2, Potential applications for Advanced Aerial Mobility and eVTOL

The major challenge is that until there are customer price points, demand is difficult to forecast. Price points, however, are difficult to calculate without reasonable demand profiles for each market segment. This dilemma can only be resolved by assuming a demand level to establish estimated price points. Further trials and testing of the market and the eVTOL technologies would be required to assess the assumptions of the business cases. Furthermore, full autonomy, another factor driving affordability, cannot be envisaged in the short to medium term, as much of the technology requires significant levels of development, a comprehensive communications package and trust-building with communities and potential customers. These issues are addressed in sections 6, 7 and 8 of this paper.

Additionally, the costs of operating eVTOLs are expected to be high in the near and mid-term, due to low volumes of eVTOL manufacture, expensive batteries, pilot salaries and high barriers for new entrants across the sector limiting the ability to drive costs down from competition, i.e. heavily regulated sector. This means that for many years, absent heavy subsidies, the prices required by AAM providers to just recoup costs will put most flights beyond the reach of the middle-income earners in the case of passengers, although for freight it will depend on various factors like location, accessibility and payload.

It is probable that AAM will become a reality, but it will not be for all applications, at least not in the short to medium term. In the case of passengers, it will likely see initial adoption as a premium service transportation option, as the original Boeing 707 was. The high costs of an eVTOL air-taxi or air-Metro service do not correspond to accessibility for all, until the economies of scale work to reduce costs and increase service demand. For freight, however, the advent of small, agile eVTOL aircraft already has a small market share. This will provide greater flexibility to the delivery of small to medium sized products through various supply chains.

5.3 Potential applications for AAM and eVTOL

In the context of Advanced Aerial Mobility, the use of eVTOL for passenger and freight movement has been considered for multiple sets of origins and destinations, including air travel between city and airport, within a city, between regions and cities, as well as other regional and rural applications.

The range of market segments are suggested in Figure 2. The concise description for each market type is as follows:

- Commuting: which provides a passenger service for people commuting across a mixture of market types, such as air-taxi, metro-style services for fixed routes, ride-sharing and private operation.
- Public services: particularly providing services for emergency service operations such as police, ambulance and fire services
- Work and logistics: proving market opportunities for the work-related activities such as aerial surveying, spotting, photography, as well as agricultural services and logistics support for multi-sized package delivery.
- Recreation: use of AAM for private use, sports and scenic tours.

A brief overview of each type of operation is provided below:

- **As Private Aircraft:** eVTOL aircraft can serve as an alternative to helicopters, with lower noise levels and environmental impact, albeit with smaller range and payload capacity. A clear potential application of eVTOL is as a private or corporate aircraft, for movement of High Value personnel between sites, especially if these sites have landing pads within the premises. Privately owned aircraft can be used as needed for flights within a city, between cities, or to the airport. The critical question is economic viability, which must be answered in the context of the value attributed to the time saved by the personnel being flown.
- **Urban/Suburban Shuttle-Service:** the rapid transit of passengers in urban and suburban or regional settings is a vertiport to vertiport type operation. In this type of operation, a given eVTOL type will operate along a series of vertiports, which will enable the customers to hop on and off at their preferred vertiport. One example of this might be an airport shuttle, with vertiports at a central city location, an airport and selected other stops between them.

- **Urban/Suburban/Regional Air Taxi.** A frequently examined application is the use of eVTOL for an on-demand air taxi service within a given city, with links to regional areas. The feasibility of this application depends on several factors, including regulatory approval for flying over densely populated areas, and the availability of infrastructure such as vertiports at the origin and destination sites. Even if feasible, the attractiveness of this offering will depend on factors such as the general levels of road congestion in that city, the level of disposable income available to the target demographic, and the closeness of the vertiports to the actual origin and destinations of the passengers.
- **Emergency services.** An additional application of eVTOL that has been proposed is as emergency service vehicles, particularly the police, ambulance and firefighting. These applications have the advantage of being clearly time-critical and of vital importance, which may facilitate its community acceptance. It could also leverage existing infrastructure, especially with major hospitals already having helipads on their premises, which can easily be adapted to serve as vertiports. A factor against the technical feasibility of these applications is that some evaluations suggest that the additional weight of the service equipment and personnel required on board would exceed the payload capacity of current eVTOLs.
- **Scenic Tour Aircraft.** An interesting application of eVTOL is as a scenic tour aircraft. Wherever there are helicopters currently being used to provide tourists with aerial tours, we believe there is an opportunity to introduce the quieter, environmentally friendly alternative of eVTOLs. At popular tourist attractions, the large volume of visitors would enable a high utilisation of the equipment but would require the use of multiple battery packs (where a few are in use while several others are being charged). The premium prices commanded by aerial tours, combined with the large number of tours that can be conducted in a day, should make the use of eVTOL financially feasible.
- **Freight and Work-related Aircraft.** Last mile delivery systems and heavier than lightweight drone payload freight services have a significant potential eVTOL market. Currently, the freight delivery market is divided into weight ranges of the freight items, the timeliness of the delivery and the distance for the payload travel. There are several different eVTOL aircraft for autonomous or piloted freight delivery and these will be discussed further in section 7. Further to supply chain delivery enablers, many eVTOL vehicles also have application in aerial surveying for building and infrastructure development or agricultural applications in the visual inspection of crops and stock. Some of the freight applications for eVTOL are discussed in the next section.

For initial deployment, the development of eVTOL for missions such as airport, regional links, rural services and emergency response will greatly increase the attractiveness of AAM for other uses such as intracity aerial taxis, air freight delivery and personal use.

One potential commercial operation in the short term would be the development of short hop charter type flights, flying between designated vertiports. But to be sustainable, the vertiports would have to be a significant distance apart (15-20km) and probably located near major transport hubs.

5.4 Transport environment for eVTOL integration

The current range of passenger transport options will change significantly over the next 15-20 years, as electric and autonomous vehicles become more common. These vehicles also promise to reduce congestion, and improve travel times, the amenity and safety of city and regional road trips.

For passenger services, the potential alternatives for eVTOL transport are centred around the current public and private transport systems, including:

- Public transit – rail, light rail, buses
- Passenger vehicles, including ride sharing
- Uber or taxi's, including ride sharing
- Helicopters (for fast transit)
- Motorcycles, Bicycles and walking.

From the perspective of freight, the likely alternatives to eVTOL for the delivery of goods in urban and regional areas may depend on the possibilities in terms of payload, distance between origin and destination, and the time pressure of the delivery. These factors will influence the selection of the aircraft and ground transport options. The competing options for eVTOL include: Lightweight Drones, Synchropters, Hybrid VTOL, which will all be part of AAM, while Autonomous e-Vans will be a ground-based option.

Figure 3, shows the competing eVTOL concepts in terms of freight capability, those inside the dashed box fall between lightweight drones and synchropters. In this space, only other VTOL alternatives (such as synchropters and traditional helicopters) can compete with eVTOL in terms of speed, but at a higher noise level and – depending on utilisation – probably at a higher price point as well. The autonomous e-Vans are seen as a ground-based competitor to eVTOL aircraft.

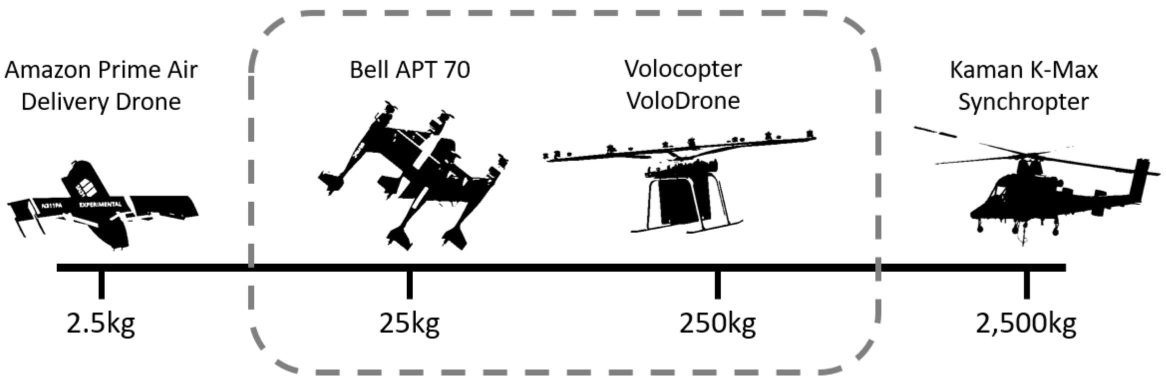


FIGURE 3, EVTOL FREIGHT COVERAGE CAPABILITY

A brief overview of competing options is provided below:

- **Lightweight Drones:** In recent years, several smaller, lighter delivery drones have been developed for last-mile delivery of small parcels. A few of these are today at a more mature stage of development than eVTOL, including the delivery drones developed by Amazon for their Prime Air service, the one developed by Alphabet Inc's subsidiary Wing, and the one developed by start-up Matternet for UPS. These drones typically aim at delivering payloads smaller than 2.5 kg over a range of less than 25 km, and within this weight and distance range should be able to delivery at a lower cost than eVTOL.

- **Synchropters:** At the other end of the spectrum, an order of magnitude above eVTOL in terms of payload, the K-MAX (or K-1200) by Kaman Aircraft is a helicopter with intermeshing rotors (called a *synchropter*), designed and certified for repetitive lifting of external freight. In the two decades since its inception, this “aerial truck” has been tried-and-tested as a workhorse for airborne freight movement in commercial, rescue and military settings, and has operated for years in an unmanned configuration[20] in support of critical missions. It can also be flown as a remotely controlled aircraft.

  The K-MAX can serve a segment of the market that requires heavier payloads, in excess of a tonne, which are well beyond the capacity of eVTOL currently in development. For payload within its range, eVTOL has a relative advantage over synchropters, namely their lower level of noise and emissions.

- **Hybrid VTOL:** The use of a fuel-powered turbine onboard to generate electricity during flight allows aircraft with distributed electric propulsion to cover greater distances. These are known as *hybrid* or hybrid-electric VTOL. There is a hybrid version of ASX’s MOBi-One, with a delivery range that is triple that of its purely electric counterpart. Other hybrid VTOL have no purely electric counterparts: these include Pipistrel’s freight drone, expected to carry up to 300 kg over 300 km, and SabreWing’s Rhaegal RG-1, designed to carry up to 454 kg over an impressive 1850 km at 330 km/h. Despite their higher level of noise, these hybrid offerings should be able to serve better than eVTOL the segment of the market that requires delivery over longer distances, such as regional freight movement.

- **Autonomous e-Vans:** When delivery within a very short window of time is not required, land-based alternatives – such as vans and utility vehicles – may compete with eVTOL for the same freight business.

5.5 Australian ecosystem to support AAM

Australia has series advantages across various sectors in the context of experience, links to the global supply chain, infrastructure and resources, as well as culture that favours innovation. Yet, from transport infrastructure to telecommunications to energy supply, enabling AAM will require major investment in a complex infrastructure ecosystem that is flexible to support various AAM operational concepts. Moreover, assurance of safety, sustainability, security and resiliency linked to assets and materials are increasingly becoming basic requirements in the development and provision of mobility services. Careful planning of procurement and contracts will likely require the lifetime evaluation of the new assets and materials involved building, maintenance, operations.

Energy and mineral resources

The development of affordable renewable electricity generation and portable energy storage technologies has begun to transform the whole transport sector. The economies of scale and research resulting from the transition of cars from combustion engines to electric motors will be an enabler to the integration of these technologies in the aviation sector.

Australia has an advantage in relation to both renewable and non-renewable energy, with a surplus in relation to domestic production and consumption of electricity, except during peak summer periods. Although 81% of electricity is generated from fossil fuels (including coal, gas and oil),[21] there is a good potential to harness abundant natural resources such as solar radiation and wind power.[14]

These same natural resources can further support the production of hydrogen, which is increasingly been recognised as a safe and clean power fuel, if produced using renewable sources. The Australian governments have developed a National Hydrogen Strategy with goals to be a global leader in the production of clean hydrogen by 2030.[22]

Renewable resources are thought to be crucial in meeting the lower emissions targets, however, transition will require significant investment in energy infrastructure as current capacity is insufficient to generate the clean energy supply required for the range and scale of future applications including electric cars and eVTOL aircraft. In addition, considerations are needed in terms of network reliability and backup arrangements to mitigate energy fluctuations that can cause disruptions.

Future mobility products are being designed to incorporate energy storage technology such as batteries or fuel cell. The mass production of new storage technologies will provide significant efficiencies in terms of cost and further attract research and development efforts to optimise weight, power and recharging times of eVTOL aircraft. Minerals used in batteries like Cobalt and Lithium, No. 2 and 3 respectively in world rankings for major mineral and energy resources,[23] are also abundant in Australia which can represent a significant opportunity for domestic use and to meet the global demand, however, there is still significant research and planning needed in terms of recycling of waste, safe disposing and responsible resourcing of materials in batteries, as well as considerations in terms of the emissions produced during their production and recycling. Research of impacts related to large scale energy solutions to support mobility will be a significant area of consideration for regulators, operators and manufacturers.

The current demand for sustainable industrial practice and clean energy presents opportunities to leverage Australian energy resources combined with its research and development capability to help position Australia as a global leader.[14] Safer battery components and materials are current fields of research in Australia, that could potentially have global effects. There is also a need to research batteries and fuel cells with materials that are more abundant and easier to recycle.

Manufacturing and maintenance base

Australia is home to many manufacturing firms supporting the global aviation supply. Boeing, Airbus and BAE systems are amongst the largest aircraft and aircraft components manufacturers with a presence in Australia and globally. Moreover, Australia participates in significant international trade with countries like USA, Singapore, UK, NZ, Italy and France. Most exports consist of product parts, which are well regarded in the aviation sector for their quality, while imports consist of complete aircraft - a market dominated by the USA.[24] It is also known that Airbus and Boeing, amongst many other companies, have been exploring the options around AAM.

Australia has advantages in terms of manufacturing expertise in advanced manufacturing of carbon fibre and other composite materials. Composite materials are light, strong but not cheap. The manufacturing process for carbon fibre and other lightweight materials is often difficult to manufacture, have stringent quality requirements and require a highly skilled workforce and development teams. The application of light weight composites will be on a case-by-case basis but is suited to aircraft, and Australian manufacturing is generally adaptable, flexible and competent in low volume components. Australia also has experience and knowledge of manufacture for Aluminium and other light metals for electric vehicles.

Skills and competencies

At present, the shortage in workforce skills and competencies across infrastructure and transport service operations, including aviation, has been acknowledged in various industry reports. [14, 25, 26] These industries are also likely to compete for skills in the areas of digital, telecommunications and automation technologies. With the potential growth in the aviation sector, shortages are anticipated in terms of pilots, aeronautical engineers, trainers, avionics/software engineers. With competition for these skills on a global scale. While the anticipated future of AAM is that of pilotless aircraft, with pilots required only in the early stages, aircraft manufacturing is a mature industry sector that relies heavily on highly skilled and high cost labour for design, production and maintenance.

Many aspects of the manufacturing operations today involve human tasks with little viability for production automation, which requires continuous updates due to technological advances.[24] Furthermore, despite the fact that other countries can provide relative lower labour cost in maintenance, repair and overhaul (MRO) services, these have been increasingly subcontracted domestically.[24] This provides an opportunity for leveraging an experience base that can be transferred and nurtured toward AAM requirements, for which aircraft are likely to be maintained and repaired locally due to the range specifications. In addition, raising passenger movements and aircraft kilometres flown can provide more opportunities for repair and maintenance service in AAM aircraft and parts.

Innovation culture and R&D

It is well known that innovation is a driver of economic performance. Australia produces research outputs that are rated as "well above world standard" in various engineering and information and computer sciences fields of research.[27] Counting with highly regarded research and academic organisations in the field of aerospace engineering.

In 2017, the Gross Expenditure on R&D (GERD) was estimated at $33,062 million, with a very active business sector in R&D investment.[28] Moreover, in the last ten years many SME’s and start-ups are now globally competitive, producing technology that is world leading and often growing out of the universities and CSIRO. However, Australia falls behind other advanced economies when looking at business R&D as a share of GDP, particularly in the areas manufacturing and ICT,[29] which are crucial in the development of AAM technology.

As such, Australia is likely to keep pace with the new technologies rather than becoming a global leader in AAM. Leveraging on strong international and local collaborations to ensure the country is well position to advance with the global trends in transport mobility. Furthermore, a favourable regulatory environment can eventually support trials and evaluation stages of enabling AAM. Evidence of this is that commercial RPAS operations were first regulated and approved in Australia.[30]

6. Regulatory and Legislative Environment

The growth of the aviation industry and non-traditional aircraft comes with new challenges and lessons for all the stakeholders, including those involved in the development of the rules. The Australian government seems to be open to exploring a range of solutions to improve mobility and reduce congestion, considering also those options arising from new technology. However, regulations and rulemaking will require flexibility and cross-agency coordination to accommodate for growth in air traffic volumes across current and emerging aviation sectors - including commercial, general aviation and recreational operation types of various sizes.

In Australia, as shown in Figure 4, key federal agencies involved civil aviation, civil aviation is an area of commonwealth authority involving a series of government agencies responsible for aviation policy, regulation and service provision.[31] The Department of Infrastructure, Transport, Regional Development and Communications (the Department) advises the Government on the development of the policy and regulatory framework for Australian airports and the aviation industry, provides advice to the minister on management of airspace and aircraft noise, oversees the management of privatised airports and administers arrangements under the Chicago Convention. Australian aviation is largely aligned with the International Civil Aviation Organization (ICAO) standards, which have traditionally informed the regulations. The Department retains all powers that are not specifically delegated to other government bodies.[32, 33] The federal legislation and regulations for airspace management are administered by two statutory authorities: The Civil Aviation Safety Authority (CASA), which regulates civil aviation, prioritising safety, and has responsibilities to foster the efficient use and equitable access to Australian administered airspace; and Airservices Australia (Airservices), which is the independent Air Navigation Service Provider (ANSP). These three entities represent key functions in civil aviation.

The state and local government levels are responsible for land use planning controls in proximity to airports and under flight paths, along with policy development and approvals in relation to landing sites.[34, 35] According to the *Australian Constitution*, states retain legislative power over matters that are not controlled by the Commonwealth law, under *section 51*. However, where there is a conflict between laws, the commonwealth law has precedence.[36]

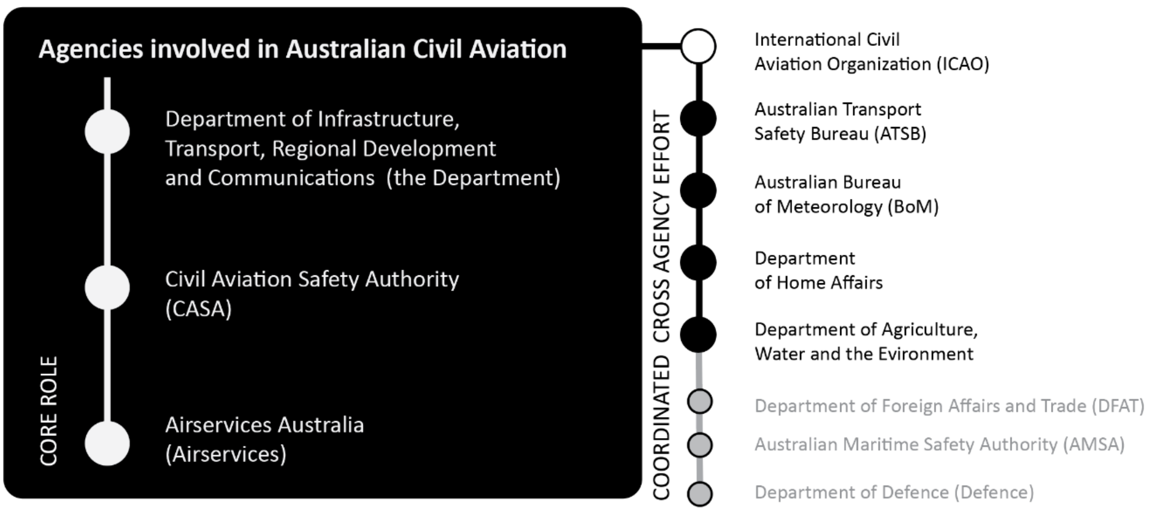


FIGURE 4, KEY FEDERAL AGENCIES INVOLVED CIVIL AVIATION

The initial deployment of AAM aircraft would likely require a pilot in command supported by ground/satellite communications and vertiport infrastructure. The future progression, however, is thought to be that of a transport network enabled by autonomous aircraft and unmanned traffic management systems. As previously shown in Figure 1, as technology matures and markets emerge, various commercial models could potentially be permitted to operate. But optimum solutions, would need to address a series of requirements likely to develop at every stage.

Introducing eVTOL transportation, whether manned or unmanned, to fly at varying altitudes, over metropolitan and regional areas, seems advantageous in the short-term to replace noisy helicopter operations at their current levels of frequency. However, supporting industry expectations for high volume operations could present several challenges in the medium and long term in relation to guaranteeing relevant safety systems, while ensuring a socially viable option that can efficiently address concerns around security, privacy, liability for damages, environmental protection and noise mitigation.

Part of the regulatory task would involve assessing the requirements within the existing set of rules, which at the same time would involve implementing the appropriate level of training and competency for all stakeholders involved. The sub-sections below discuss the regulatory challenge in detail.

6.1 Targeting the requirements within existing rules and test case resources

Aviation safety is prioritised and protected using mechanisms including standards, air route and airway facilities and civil aviation authorisations for pilots, operators and aircraft. As such, the biggest challenge for operators and eVTOL aircraft manufacturers is proving that both aircraft and operations are safe to other airspace users, crew, and people and property on the ground.

Expanding or modifying regulation to enable disruptive technology can be difficult in the short-term, due to the uncertainty linked to the lack of detailed business concepts and practical evidence of how operations could unfold in the local urban environments. Realistic estimation of the scope and breadth for advancing regulations is dependent on developing an understanding of how potential air mobility concepts could integrate into the Australian air and ground transport systems and their potential impacts. Although, while this knowledge is still reliant on further research and trials, for both piloted and no-pilot versions, much of the base work has already been established and remains under constant development.

From a pilotless perspective, since 1998 the Commonwealth has been consulting and advancing the rules governing all unmanned aircraft activities through the development of *Part 101 - Unmanned aircraft and rockets* of the *Civil Aviation Safety Regulations 1998 (CASR),* and guidance materials.[37] In addition, trials for commercial drone delivery services over residential areas were approved in North Canberra (ACT), where an *inquiry report*[32] was also released in July 2019. The same service provider has commenced highly automated operations in Logan (QLD) and currently holds a range of operational exceptions from CASA,[38, 39] including the ability to operate beyond visual line of sight (BVLOS) over populous areas.[15] Moreover, assessments of some aspects of the potential integration of eVTOL concepts have commenced; in September 2019, an issues paper was published by the Department, as part of a review of the *Air Navigation (Aircraft Noise) Regulations 2018,* requesting feedback in relation to remotely piloted aircraft (RPA or drones) and urban air mobility (UAM) aircraft.[7]

From a conventional aircraft viewpoint, the closest concept to eVTOL aircraft permitted to operate in and around urban areas are helicopters. Voluntary Fly Neighbourly Agreements (FNA),[35] defined between helicopter operators and communities, are the existing mechanism to reduce disturbances caused by aircraft and guide operators on methods to circumvent noise sensitive areas. Such agreements lead to the use of preferred route options such as freeways, highways, waterways, commercial and industrial areas. FNAs may also determine limits on flight frequency, areas of operations and heights.

International programs like the NASA grand challenge and test cases underway,[40] could provide essential knowledge to accelerate civil aviation certification and lessons in relation to operational issues. Further test case data and analytical models in the Australian context, could provide opportunities to address the key areas of regulatory concern for both piloted and unmanned aircraft accessing low altitude airspace, although this will require significant resources in flight test capability. Understanding of various operation concepts can aid in understanding safety hazards to and from eVTOLs; accessibility across airspace classes; system requirements and interoperability; community disturbance, security and privacy; and environmental impacts from both product lifecycle and operational perspectives.

Naturally, both the drone delivery systems and helicopter operations, as well as the appropriate level of research, could help identify the number of gaps to be addressed by future regulation. For instance, one concern raised in a senate enquiry highlighted the need for research data on the consequences of collision between RPAs under 2kg and aeroplanes or helicopters.[41] This is an important point because without the appropriate controls, drones, even more than bird-strikes, could interfere with eVTOL aircraft and vertiport operations. Moreover, some smaller size RPA can operate in Australia without requiring remote pilot licence (RePL) and a remotely piloted aircraft operator's certificate (ReOC). Potential lesson from test case research could then inform the principles guiding eVTOL operations; navigation rules; best approach to autonomy transition; and best approach to community and environmental protection.

6.2 Civil aviation approvals and certification

CASA will likely require a range of approvals associated with eVTOL operations and pilot licenses; aircraft design, manufacturing, maintenance; and vertiport operations. Such approvals are all dependent on the product type certification, which is challenged by the fact that eVTOL concepts can combine category elements and new technologies relevant to both traditional airplanes and rotorcrafts, which are covered under different certification streams.

CASA must ensure that operators demonstrate a clear level of capability, competency and experience around the proposed operation.[42] This would include counting with qualified and licensed employees that can fulfil the level of experience required during flight and for maintenance protocols (of the certified eVTOL aircraft and aeronautical products); access to suitable facilities; and procedures and practices in place that can enable safe operations. Certified designs should provide the continuing airworthiness requirements to enable operators to generate a maintenance schedule and procedure manuals accordingly. Currently in Australia, aircraft (including large and specialised RPA), aircraft engine and propeller, must obtain a certificate of airworthiness.[7] In addition, before the aircraft can operate legally, it may need to comply separately with noise, emissions and other applicable legislation.[43]

For such an ’aircraft’ and ‘potential operation’ a commercial pilot license will be required. One view from an aircraft manufacturer is that the eVTOL aircraft models can provide opportunities to simplify the requirements for aeronautical experience after fly school to become a pilot in command, making it attractive for new pilots. License for eVTOL aircraft may not be comparable to that of a helicopter pilot license in terms of the aeronautical experience required - a commercial passenger helicopter to fly Instrument flight rules (IFR) is the most advanced that you can see in terms of requirements. It typically it takes several flight hours just as co-pilots before becoming the pilot in command. The new aircraft simplifies the interface and requirements for the pilot, using software that can steer the engine. Pilots can initially collect aeronautical experience using eVTOL aircraft and then progress their career path toward commercial airline experience.

In Australia, 'special classes of aircraft' are enabled for those instances where airworthiness standards have not been prescribed. Defined under sub regulation 21.017, the airworthiness standards are the portions mentioned in Parts 22, 23, 25, 27, 29, 31, 32, 33 and 35 and those in Part 21 Manual Of Standards (MOS) that CASA deems to be appropriate as a basis for certification, or an equivalent criteria that demonstrates level of safety to those airworthiness standards.[43] Unmanned aircraft require additional consideration around standards related to systems for command and control, detect and avoid, ground control, flight termination and automated recovery.[44] Currently, large RPA in Australia, can only be operated under a special certificate of airworthiness (restricted category) or an experimental certificate,[43, 44] and complex beyond visual line of sight (BVLOS) operations, can be approved under a robust safety case. [15, 44]

Australian regulation is consistent with the FAA, in the United States, and the European Union Aviation Safety Agency (EASA). The large aviation regulators have already taken steps to assess the issues around standards to enable eVTOL aircraft certification. Australia manages a significant portion of the global airspace and is likely to keep pace - and influence these to some extent - with new standards and certification developments. In addition, Australia has been an active contributor in approximately 55 ICAO technical committees, panels and study groups,[10, 45] and CASA participates as a member of the Joint Authorities for Rulemaking on Unmanned Systems (JARUS). JARUS brings together experts from the National Aviation Authorities (NAAs) and regional aviation safety organisations to produce technical guiding materials, including recommendations around certification standards, unmanned traffic management systems and risk management, which are leveraged by CASA.[17]

In the United States, the FAA announced a policy statement for Multirotor Electric VTOL aircraft. FAR Part 21 could allow for establishment of the certification standards for eVTOL aircraft using two paths: the first is to use standards that are already established for the aircraft type, and second is to develop the standards where no applicable standards are available for the new product.[46]

On July 2019, EASA presented a special condition to enable certification of hybrid and electrical VTOL aircraft applicable to person-carrying VTOL aircraft in the small category. The enhanced certification category of the special condition requires that eVTOL aircraft designed for commercial air transport operations meets the safety objectives for CS25 (fixed wing) and CS 27/29 (rotary wing) aircraft, covering the corresponding highest operational risks to passengers and third parties.[47]

In enabling the overall environment, UAM has attracted special focus although it is the most complex AAM concept. In June 2020, the FAA published the first Concept of Operations for UAM which considers the stage of maturity for passenger and freight service operations within urban and suburban environments. This Concept of Operations considers scale, enabling UAM corridors, traffic management system allocation within different airspace classes, separation methodologies, automation and autonomy for traffic management and aircraft.[48] The Korean government provides a different example, as it has undertaken a more involved approach partnering with industry, developing a profit-sharing system, and working on a special law to speed up commercialisation of UAM within five years to capitalise on first mover leadership advantages. Korea sees the progression from freight services to later passenger services, enabling drones by 2025 and autonomous aircraft by 2035.[49]

6.3 Navigation and interaction rules toward high scale operations

Discussion with eVTOL manufacturers has highlighted a diversity in their approach to planned flight altitude and preferred locations for vertiports. Therefore, large scale urban airspace entrants may be sharing low-altitude airspace with drones and high-altitude airspace with conventional aircraft. This raises questions around:

- how air routes across different classes of airspace will be regulated?
- what level of service will be needed from ANSP?
- how will equitable access to airspace be defined? and
- who will be monitoring potential impacts caused by operators?

Figure 5 shows the current height navigation context using helicopters and drones as a basis and including some CASA exemptions.

In helicopter terms the minimum permitted altitude would generally be 1000 ft or 500 ft above ground level (AGL). Inversely, in low altitude airspace, unmanned aircraft may fly under standard operating conditions (SOC) to a maximum height of 400ft. However, CASA may authorise exemptions.[50] For RPA these can include:

- flying above 400ft AGL in controlled and uncontrolled airspace;
- closer than 30 metres from people;
- operating near aerodromes, over movement areas and approach and departure paths; and
- the use of extended visual line-of-sight (EVLOS) and beyond visual line-of-sight (BVLOS).

At this point, some eVTOL aircraft are being designed to cruise at the minimum allowed altitudes to maximise efficiency, while others are being planned to cruise at altitudes of around 10,000ft AGL.

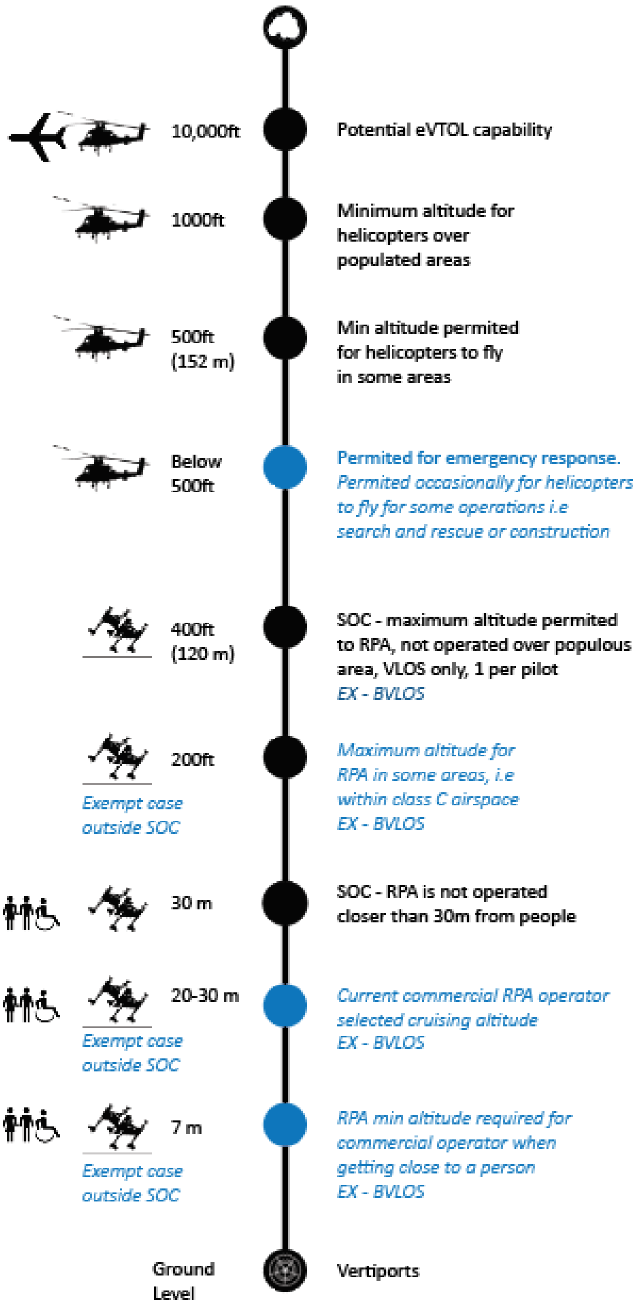


FIGURE 5, CURRENT HEIGHT AUTHORISATIONS FOR HELICOPTERS AND RPA (*INCLUDING SOME EXEMPTIONS)*

Also, commercial drone operators are cruising at altitudes of 20-30 metres AGL, to optimise the operational efficiency,[15] as opposed to the allowed maximum of 400ft, or 200ft under class C airspace.[38] It is found, however, that optimising for the minimum altitude may not be in the best interest for the community, and many concerns could arise.[32]

Additional to the discussion around figure 5, controlling aircraft operations is the responsibility of the Air Navigation Service Providers (ANSP) and the aircraft operators.[51] In uncontrolled airspace, however, some pilots may not be visible to air traffic controllers,[52] which leaves much of the responsibility at the request of the operator. Moreover, Airservices does not hold regulatory authority to approve access and set conditions in uncontrolled airspace.[32] Assessment of unmanned aircraft applications by Airservices is only conducted when operations are proposed within 5.5 km of an aerodrome, with a control tower, and above 400 ft AGL in controlled airspace. Nevertheless, there is recognition of the growing need for integration of controlled and uncontrolled airspace to ensure safety, security and resilience of the growing air traffic control task and the need for collaboration between ANSP and regulatory bodies toward policies and regulation that reflect the anticipated civil aviation future, as stated in the *Airservices Corporate Plan 2019-20.*[3]

From an infrastructure view point, an area that will require exploration involving the state and local governments, is the new layer of complexity around land use planning along flight paths and in proximity to aerodromes, zoning in line with noise exposure, and management of new take-off and landing facilities.[34] Within the urban area, various ground infrastructure configurations are possible, and expected to match the type and scale of operations.[18] For example, landing pads could be located over existing building rooftops (such as working hubs, carparks, train stations), heliports and airports or greenfield developments at a practical distance but away from built-up areas. Part of the assessment would need to consider the systematic implications of enabling operations of aircraft capable for short versus longer flight ranges, i.e. if flight ranges are short, more vertiports would need to be enabled depending on operation. Furthermore, possible variability of legal requirements for eVTOL transportation across different jurisdictions may hinder economies of scale.[53]

Whether the operations are manned or unmanned, there will be a need to establish the operating principles for eVTOL transportation, as part of the broader aviation context, and move away from the likely individualised approvals of potential test cases and trials to a harmonised formal approach. A clear set of principles could facilitate the interaction protocols with urban and natural objects on the ground, as well as in the airspace. Such principles would also incorporate an advanced understanding on the safety aspects related to the combination of technologies to address the service-related communication aspects such as data related to navigation, aircraft systems status, command and control and weather. Current radio communication system requirements are based on the Australian airspace architecture combined with the operation types.[54] These requirements will likely evolve in line with increasing airspace traffic, changing customer expectations and the transition towards autonomy, for which flexibility and agility should be embedded in an integrated and staged certification strategy that ensures interoperability.

Further research and evidence is needed to understand how new traffic management concepts, and relevant technology i.e. data sharing network of aircraft,[4] could ensure safety for navigation of AAM aircraft across all classes of airspace, and increase efficiency for operators while minimising community disruption. This research will help inform the options for airspace class accessibility and flexibility within each class.

6.4 Transition to autonomy

There is a potential that each category of aircraft[55] will have a level of automation and/or autonomy,[55] with autonomous operations as a goal toward safety and economy. However, at this point, a recent advisory circular produced by CASA addressing Unmanned Aircraft Systems (UAS) states that "only RPA will be able to integrate into the civil aviation system in the foreseeable future as the remote pilot's functions and responsibilities are, at this stage, considered essential to the safe and predictable operation of the aircraft as it interacts with other aircraft and the air traffic management system."[44]

It is not yet clear how the progressions to autonomy on a large scale will take place and this is partly dependent on monitoring of technological advances and risk assessment. It could be reasoned that large-scale autonomous eVTOL transportation is not likely to occur in the short-term, since neither urban air transportation nor autonomy in ground passenger or freight systems have been extensively realised or tested. Furthermore, assessing the risk around each operating environment to enable BVLOS operations as required to achieve autonomy will take time and there are still many challenges including those related to community acceptance, liability insurance and ethics.

This uncertainty in the transition is reflected in how some manufacturers think that a gradual process to autonomy will involve a remote pilot who can control more than one aircraft, while others see that remote pilots are not viable due to limitations in real time control for high speed flights, and rather they consider that detect and avoid technology should be utilised from the start.

Unmanned Traffic Management (UTM) to support BVLOS operations, seems to be a good solution to manage conflicts from ground and air obstacles, integrate wind conditions and minimise separation while considering safety and regulatory margins. However, at present if operators use different versions of UTM systems, an aircraft and its planned flight path may not be identifiable across different providers, causing a potential risk to other airspace users.[15] This issue is likely to be resolved by using the ADS-B capability to automatically broadcast the precise location of an aircraft, enhancing communication with other aircraft and air traffic control via a digital data link.[56]

An additional consideration is that if the function of both pilots and remote pilots, who require a license and extensive training, becomes a step in between manned aircraft and autonomous aircraft. Transition procedures should also be considered for attracting pilots and remote pilots and then migrating them into other functions.

Nevertheless, commercial autonomous operations of any scale would be expected to demonstrate a safety level similar to that achieved with conventional piloted aircraft for commercial operations, which is being addressed from various angles. On one side, some eVTOL manufacturers are equipping the early piloted and highly automated eVTOL aircraft models with hardware and sensors to provide the data to understand and develop the autonomy requirements for the medium and long-term. From the other perspective, initial authorisations using exemptions, like the commercial drones which are nearly autonomous,[15] can provide important real-life lessons to understand risk and address the community concerns around different aircraft sizes cruising at low altitudes.

Likewise, Airservices' program to understand adaptability requirements to accommodate unmanned aircraft systems (UAS), and others like the NASA's UTM initiative, can provide lessons around UTM capabilities, data and connectivity requirements, boundary management between ATM and UTM systems and urban complexity considerations.[3] Such lessons can inform the requirements around airspace design, flight rules and high-volume air traffic management.

6.5 Environmental and biodiversity impacts

Adverse environmental impact can be caused by energy management, material components, noise and wildlife disturbance, particularly if large Advanced Aerial Mobility operations are authorised. In Australia, airspace and aircraft operations need to be consistent with *the Environment Protection and Biodiversity Conservation (EPBC) Act 1999*, *Air Navigation (Aircraft Noise) Regulations 2018*, and the *Air Navigation (Aircraft Engine Emissions) Regulations.*

From a state and local area perspective, a key component in developing the rules for AAM is identifying the sensitive locations and assessing existing mechanisms to minimise disturbance and their adequacy for high-volume operations in the medium to long term. Initially, instances like visual pollution and managing community concerns generated from emergent airspace technology may have a less clear governmental oversight outside the traditional aviation. However, as operators propose new models, the regulators will need to anticipate the parameters to manage emergent issues around community acceptance.

Noise is a complex domain and a sensitive issue both technically and from a community perspective. Emitted both from the aircraft and the scale/frequency of the operation, noise may be a significant contributor to the evolution of operations and aircraft design. The noise profile of an aircraft depends on its design and build, including the type of engine, airframe, landing gear and size, and may be affected by meteorological conditions and how the aircraft is flown. At scale AAM will represent an additional source of noise within already noisy urban environments. within communities, some residents will be more disturbed than others, according to their location in relation to the flight path and the proximity to the aerodromes.

Because aircraft can be easily moved, there could be a potential opportunity for testing the same concepts in various locations to evaluate different social contexts and understand the psychological factors associated with the new transportation option. Testing could also extend to the use of new technologies to manage noise and visual pollution, some of the currently proposed applications include participatory noise sensing and utility of city noise maps.[57]

High volume operations will also increase the use of natural materials for the manufacturing of aircraft and associated infrastructure. Part of the challenge is understanding of the impacts of operation in relation to the broader environment, transport sector and the safety risks. Climate change and the risk of increasing extreme weather events which are likely to impact aircraft operations in the long-term.[24]

7. Aircraft Design

Currently there are over 200 eVTOL aircraft programs, covering a wide range of designs and operational capabilities.[2] The number of companies and organisations designing and researching within this space is diverse and dynamic, from start-ups to established collaboration between large companies, government agencies and academia. Such a significant level of R&D investment suggests industry operatives see a big future for the sector.

The aircraft vary in design, which is dependent upon the operation as determined by target market. While passenger and freight requirements vary, there are key design specification areas of importance to all designers and manufacturers, which are listed below. The list must be aligned to the market application, as the specifications of the aircraft will have to match the use case. Differences in aircraft design features will be translated in each of these areas.

Key design specification areas

- Payload
- Range
- Cruising speed
- Safety and precision
- Weather resilience
- Environmental footprint and eco-manufacturing
- Noise
- Altitude
- Gross weight
- Cost per kilowatt-hour
- Dimensions
- Charge times
- Infrastructure requirements
- Communications
- Autonomy
- Maintenance

A full assessment of all aircraft designs is not within the scope of this paper, these would need to be evaluated against each use case and operation type. Instead following figures present a series of selected key eVTOL designs that provide an overview of most developed or highest potential eVTOL aircraft for passenger and freight transport. The subsections below discuss various considerations challenging the decision-making on the selection of an aircraft model while addressing the key specification areas. The subsections also highlight the need for operators and manufacturers to consider a transition roadmap to prepare for the anticipated updates and upgrades aircraft and infrastructure technology supporting large scale fleets and operations.

		CORA	VoloCity	Lilium Jet
CONCEPT INFO	company	**Wisk**	**Volocopter**	**Lilium**
	operation	autonomous air taxi	autonomous air taxi piloted air taxi	autonomous air taxi piloted air taxi
SPECIFICATIONS	payload	2 passengers	2 passengers or 1 pilot & 1 passenger	5 passengers or 1 pilot & 4 passengers
	range	40 km (plus reserves)	35 km	300 km
	altitude	450 m		10,000 ft approx.
	speed	160 km/h	110 km/h	300 km/h
	charging			
DESIGN FEATURES	features	12 fixed rotors for vertical lift fixed wings and a rear propeller for forward thrust		vectored thrust 36 electric jet engines
PROGRESS	stage	prototype 1000 fligths experimental airworthiness certificates from FAA and NZ's CAA		
		PASSENGER intracity	**PASSENGER** intracity	**PASSENGER** intracity & intercity

		S4	EHang 216	Seraph
CONCEPT INFO	company	**Joby Aviation**	**EHang**	**Vertical Aerospace**
	operation	piloted air taxi	autonomous air taxi	passenger air taxi piloted air taxi
SPECIFICATIONS	payload	4 passengers 1 pilot	2 passengers	1 pilot & 2 passengers 250kg
	range	240 km	35 km	
	altitude			
	speed	320 km/h	130 km/h	80 k/h
	charging		1h	
DESIGN FEATURES	features	vectored thrust with six tilting propellers	multicopter with 16 propellers	multicopter 6 pairs of propellers. Highly customisable, with options for wheels or floats (to facilitate water landings) .
PROGRESS	stage	in 2020 US$590 in funding led by Toyota Motor Co.		full-sized prototype
		PASSENGER intracity & intercity	**PASSENGER** intracity *tourism sightseeing, logistics and medical aid*	**PASSENGER** unknown

FIGURE 7, SELECTED PASSENGER EVTOL MODELS BY SPECIFICATIONS, DESIGN FEATURES AND PROGRESS MADE

VoloDrone

CONCEPT INFO	company	**Volocopter**
	operation	air cargo
SPECIFICATIONS	payload	200kg
	range	40 km (plus reserves)
	altitude	
	speed	80 km/h
	charging	
DESIGN FEATURES	features	
PROGRESS	stage	conducted demonstration flights
	FREIGHT	intracity *logistics, relief, agriculture & infrastructure*

CAV

CONCEPT INFO	company	**Boeing**
	operation	air cargo
SPECIFICATIONS	payload	230kg
	range	15 - 30 km
	altitude	
	speed	unknown
	charging	
DESIGN FEATURES	features	
PROGRESS	stage	conducted demonstration flights
	FREIGHT	intracity

MOBi-One

CONCEPT INFO	company	**ASX**
	operation	passenger and air cargo
SPECIFICATIONS	payload	500kg
	range	104 km
	altitude	
	speed	240 km/h
	charging	
DESIGN FEATURES	features	
PROGRESS	stage	scale models have been flown a full-size not yet demonstrated estimated cost below US$1 millions
	FREIGHT & PASSENGER	intracity & intercity *alternative to helicopter operations*

APT

CONCEPT INFO	company	**Bell**
	operation	autonomous transport
SPECIFICATIONS	payload	25 kg
	range	29 km
	altitude	
	speed	121 km/h
	charging	
DESIGN FEATURES	features	
PROGRESS	stage	
	FREIGHT	intracity

FIGURE 8B, SELECTED FREIGHT EVTOL MODELS BY SPECIFICATIONS, DESIGN FEATURES AND PROGRESS MADE

7.1 Aircraft concepts

A review of VTOL technologies identified six aircraft configurations:[58]

1. compound aircraft
2. tilting thrust producer
3. tilt-wing
4. tail-sitter
5. lift fans
6. vectored thrust

Each of the categories exhibits strengths and weaknesses in relation to requirements around speed, payload and range. For instance, the lift fans configuration can reach speed levels of 1,930 km/h, which are also linked to high cost and therefore the enabling technology is mostly relevant for military use. In civil aviation, where high speed levels are not required,[58] the electric VTOL aircraft concepts being developed in preparation for air mobility, propose speeds ranging from 80km/h to 300 km/h.

The VTOL definitions help with the identification of the key types of eVTOL aircraft possible in the AAM market. A Roland Berger study[18] identified five basic architectures of eVTOL aircraft:

1. highly distributed propulsion concepts - with many rotors for distributed lift capabilities;
2. quadcopters – for power lifting of mid-range payloads (people and goods);
3. tilt-wing aircraft – to allow from vertical lift to forward power for longer ranges;
4. winged eVTOL craft – added wings to allow better aerodynamics during flight;
5. new hybrid concepts – a mixture of design concepts for different applications.

Requirements on aircraft range and maximum payload, influence the need (or not) for large wings and rotors, which in turn determines the dimensions and need for space in terms of infrastructure. Consequently, for longer flight paths, and/or high payloads, a combination of rotors and wings are required to develop the required aerodynamic lift at cruising altitudes.[18] The small, more agile aircraft designs of quadcopters or multi-copters are preferable for short hop due to their low-medium range required for intracity flights. There is therefore an important connection between, the size of the aircraft and the likely operating conditions.

7.2 Energy sources and management

Distributed Electrical Propulsion (DEP), is an important technology enabling different aircraft designs, including several VTOL configurations.[18] Full electric propulsion is a key desired feature to achieve lower aircraft noise and emissions. However, battery size, weight and operating life, as well as power and charging times, are inadequate today limiting VTOL performance in terms of range and cost.[59] In the short term, or until a fully electric concept is available, hybrid electric propulsion presents a potential solution.

As storage technologies, some disadvantages of batteries are found around sustainable manufacture due to material components, and can pose a fire risk due to some common electrochemical components like Lithium Ions.[60] Solid polymer material can replace volatile liquid electrolyte used in batteries.

Further research is also needed to be undertaken into the lifecycle management of batteries in general, and the use of Li-ion batteries in future transport options. The recycling of Lithium and other relatively rare materials will be crucial to maintain low prices for these key commodities. [61]

There are questions on the need to use batteries at all when considering the potential of hydrogen fuel cells, which, due to higher energy densities, solves energy storage issues related to power over long distances. If hydrogen and oxygen are provided, Proton Exchange Membrane (PEM) fuel cells can convert chemical energy, from these two elements, into electrical energy, without any additional processes or external energy required. PEM fuel cell replenishment process is fast and represents a significant advantage over batteries. If the difficulties with hydrogen storage can be solved for aircraft, then fuel cells can become a viable alternative to rechargeable batteries. The current research and development of hydrogen fuels for commercial transport use will spur further development and cost reduction into this technology.

7.3 Navigation, detection and manoeuvrability

AAM users should be able to travel short and medium distances and access low and medium altitudes. Highly automated eVTOLs will navigate maps, detect people, property, other airspace objects and surroundings and communicate with static and mobile objects.[17]

The future of air travel will be largely an automatic function of navigation, flight path and landing, with the pilots only on-board to provide supervisory functions and piloting ability in case of an emergency or severe weather events. In the medium term it is anticipated that aircraft will have advanced capabilities in detection of other aircraft and algorithms for collision avoidance in emergency situations. The evolution over the past 50 years in aircraft control means that advanced and automated collision detection and avoidance will become standard in the future. The aerospace industry has long pioneered the development and implementation of equipment and software to help pilots manage the task of flying aircraft from one location to another. Autopilot and autoland are two examples of automation technology that assist the pilot during operations and landing. Automatic Detection Surveillance – Broadcast (ADS-B) is another technology to allow automatic detection of aircraft operating in the same vicinity. This technology is currently applied to high altitude aircraft in Australia, thus implementation for low altitude aircraft such as eVTOL will require significant testing, along with automatic collision avoidance algorithms in high-density areas. Other technologies that need to be developed and deployed for eVTOL include path following and altitude control. [62]

7.4 Intelligent systems integration and the operating environment

Full autonomy is projected to ensure efficiency and safety over the built environment. Currently other areas of transport are moving towards semi-autonomous navigation and operations, particularly road and rail transport vehicles. The implementation of modern sensors, improved cognitive systems, and AI are currently advancing in the area of autonomous vehicles. Developing the systems that facilitate autonomy to navigate paths within the built environment which has buildings, cables, towers will require time and resources. Obviously, operating in a 3D aerial environment means the level of decision making and cognitive systems is greater for aircraft than land-based transport, but many of the key principles and technology will be applicable for eVTOL vehicles in the near future.

As the vehicles have greater levels of semi-autonomous or autonomous operation, cybersecurity and physical security both become key concerns for the aircraft operators, pilots and the public in general. As observed in other transport sectors and more generally in industry, the greater interconnectivity of devices the greater the potential for cyber-attacks on critical infrastructure and operations. A great deal of research is being undertaken to isolate the critical flight operations systems from the highly connected devices available elsewhere.

7.5 Aircraft lifecycle management

Lifecycle Management (LCM) involves the design and manufacture, service and disposal of goods used within society. The aim of LCM is to develop products and services that reduce as much as possible the environmental footprint. As a product comes to the end of its useful life, the product designers need to consider how the product components will be reused, recycled or disposed of in a sustainable way. The analysis can be performed by Lifecycle Assessment (ISO 14040 series), looking at raw materials through to disposal of components at the end of life.

For many electric components, and lightweight materials this is a significant challenge. Current battery and fuel cell technologies are difficult to recycle and reuse, whilst lightweight materials such as carbon fibre composites are difficult to either recycle or dispose of. A full Lifecycle Assessment and management plan of the current and future UAM aircraft and facilities should inform the relevant operational functions as well as help identify and mitigate potential environmental impacts caused by transport sector.

The service and maintenance of aircraft will likely be simpler for many eVTOL, due to the replacements of motors and transmission components to batteries/fuel cells and electric motors on the powered fans and thrust delivery mechanisms. The overall reduction in moving parts within the "drivetrain" means a safer and easier service task. [4]

Given that aircraft typically have 10-15 years of operational life, the design aspects of how aircraft will be decommissioned and recycled should be considered during the design phase. Currently the frame and body components will be light metals (Aluminium, Titanium or Magnesium alloys) or composite materials (Carbon fibre and resin or similar fabric and resin combinations). The composite materials are difficult to recycle at present, whilst the metals have the advantage of ease of recycling and reuse. Battery technology has considerable difficulties with recycling and reuse, but current research is likely to provide some improvements in reuse of components. With the current rate of expansion in battery and fuel cell uptake, without significant improvements in recycling and reuse of key components and elements, there will be significant increases in material costs, due to limitations on supply, particularly for Lithium and Cobalt.[61] Research is also being undertaken to develop improved batteries with different chemical compositions, which may alleviate some of the challenges for the future.

8. Operational Concepts and Challenges

Generally, the public are not so concerned with the technology of a product, rather they require simplified solutions that will benefit their lives and increasingly, that are environmentally and socially sustainable.[63] Thus, the operation for vertiports and AAM airlines will need to be developed around identified target markets and a series of customer value outcomes configured accordingly, while balancing the operator business goals. These include:

TABLE 1, CUSTOMER VALUE OUTCOMES VERSUS OPERATOR BUSINESS GOALS

CUSTOMER VALUE OUTCOMES	OPERATOR BUSINESS GOALS
• safety • reliability • timeliness • convenience • affordability • environmentally friendly	• profitability and efficiency • community acceptance • attractiveness of workplace environment • compliance

From a business perspective, the aerial transport of people and freight presents an opportunity for economic benefit, where the value outcomes are effectively delivered. Understanding the measure of the economic benefit is important as a return on the investment (ROI) on AAM systems needs to be achievable. However, these benefits also need to be balanced against the potential negative consequences of the new technologies, the magnitude of which will also need to be assessed.

If a 'high scale' operation for this transport alternative needs to be established to realise the business benefits, then this expectation also needs to be communicated and socialised with stakeholders early from the design phase of the operational concept. This should include the operational strategy at full scale, the relevant stages, potential impacts, mitigation strategies and the weighted benefits. Acceptance of AAM operations by the existing aviation sector and communities will need the operation concept design to disclose considerations in relation to safety, privacy, noise and visual pollution.

8.1 Exploring potential concept of operations (ConOps)

In an ideal/unbounded business case, for the fastest delivery, the passengers or freight would move directly from the point of origin to the point of destination. This requires that eVTOL vehicles may be able – both in terms of infrastructure and of regulation – to take off and land from these points. There would have to be a certified vertiport, either designed for the specific needs of passenger and freight services, at both origin and destination. The likely reality, however, is that to protect communities and customers Advanced Aerial Mobility will be limited by air corridors and approvals in the selected locations. Some of the viable initial Concepts of Operations (ConOps), dependant on locations where high-volume operations can be achieved, may include:

- **Between Site A and Site B.** A human (2-5 pax) or freight (25 – 500kg) payload is prepared at a commercial or industrial Site A and taken to a vertiport located within the premises. There it is loaded/boarded into a capable eVTOL and flown directly to its destination: the vertiport of a different commercial or industrial Site B (within a radius of 15 km to 100 km). After the passenger/freight is unloaded, the eVTOL can recharge its batteries at Site B or return immediately to Site A. An airport could be either Site A or B, but there will be restrictions on the vertiport location at an airport, due to restricted airspace. The reverse is also possible: an eVTOL can be loaded/boarded at the commercial or industrial Site B with the human/freight payload to be flown to the airport, where the payload/passengers are quickly loaded/boarded into a plane to go elsewhere; the eVTOL returns to Site B.

A sufficiently large projected demand for eVTOL freight or passenger services at a given site may justify the investment in a vertiport, in terms of infrastructure, equipment and certification. A large enough open-sky area, free of obstacles and passers-by, would be required for the vertiport: informed by current regulation, we anticipate that a dedicated surface with a radius of at least 30-40 m clear of any obstacles around the landing site would be necessary. Some commercial or industrial sites may fit this profile of high demand and vast open space, including:

- large production sites (including agricultural, mining and manufacturing)
- large logistics sites (including warehouses, distribution centres and consolidation centres)
- large retail sites (including malls, shopping centres and very large stores)
- large service sites (including hospitals, office and educational campuses)
- the rooftops of sufficiently wide and tall buildings (in and near CBD)
- open spaces with cordoned off areas (retail carparks, parks, open field sites).

However, other potential origins or destinations for eVTOL passengers/freight may lack a high enough demand for the service to justify a dedicated vertiport, and/or they may lack in their premises an open-sky area large enough to accommodate a vertiport. For example, residential customers may – every now and then – require the fast delivery of freight above 25 kg. But even if many residential customers are willing to pay the price for an eVTOL delivery, very few of them will have within the boundaries of their property an open-sky area large enough to serve as a vertiport where eVTOL can land. This scenario is also true of passenger services.

For these less-than-ideal cases, when the origin and/or destination lack a vertiport, it may still be possible to take advantage of the faster transit/delivery times of eVTOL by means of a network of commercial vertiports and vertistops in convenient locations spread throughout populated areas. The main difference between a vertiport and vertistop would be the services provided. A vertistop could potentially be an open area location, without any charging facilities or dedicated boarding or loading facilities. An advantage of eVTOL services is that have flexibility of a large network of improvised vertistops in conjunction with fully serviced vertiports. Using an eVTOL service through only the commercial vertiports would require first and/or last mile trips, which would detract somewhat from the speed of the delivery or travel and would add to the overall transportation costs.

8.2 Operational challenges

Ground infrastructure will need to accommodate a variety of operational conditions. From an aircraft perspective, approaches and departures, landing and take-offs, charging, maintenance and storage. Aircraft management should consider how to reduce noise and visual pollution community concerns. For vertiport management of passengers and freight, safe access to the facility, accessibility, security processing, access to parking, waiting areas and integration and transfer to other modes of transport.

Operational concepts will require significant research to understand how to integrate AAM operations into current aerial and ground transport systems, which essential for safety and journey planning. Several operational barriers, beyond the aircraft design challenges, will need to be addressed. This is highlighted best by an example with contrasting operational goals.

> *Example:*
> *As UAM flights increase in frequency, safety regarding separation from other aircraft while ensuring efficient use of shared infrastructure such as vertiports will require a unique operational solution. Such as solution will require interoperability between all airspace actors and should consider technical aspects such as communication, navigation and data exchange. While increasing the utilisation of a vertiport improves efficiency, noise and visual pollution will be restricted through regulation.*

The difficulty, with AAM particularly, from an operational perspective is that ten eVTOL aircraft flying in urban areas is manageable, but thousands of aircraft becomes a large operational burden. The burden on the ground infrastructure, communications and control networks, as well as being challenging to the public in the vicinity of the vertiports and flight paths. The subsections below expand on these challenges.

Vertiports

Ensuring vertiports, servicing AAM airlines, will likely require enough passenger and freight traffic volumes to offset the relative fixed costs of real estate (premium locations drive higher cost and regional location may be more favourable) and control tower and communication equipment to support operations. Usually, larger airport operations are more profitable due to scale, and growth is achieved through increasing capacity in runways and terminals.[64] However, the differences between airports and vertiports are significant.

Since the nature of AAM, is to service near or within built up areas, once the maximum capacity is reached, increasing the scale of operations in each vertiport will be a function of what is possible within the selected location (i.e. innovation to reduce aircraft separation) and surrounding urban environment (i.e. curfews). Restricted traffic volumes, due to restricted capacity in urban areas, versus increased demand may cause a price increase reducing travel affordability. Securing land within industrial, commercial and urban servicing zones for vertiports will be a significant challenge. Additional vertiports will dependent on favourable land-use regulations where cities will exhibit many restrictions in comparison to regional areas. Although, having a position within such environment and the potential use of current infrastructure could help relieve some of the pressure on roads, Vertiport within cities could add to the noise and clutter problem, including during construction phase. Conversely, regional links can benefit current smaller airports with significant capacity.

A range of baseline activities will need to be defined for vertiport services. For instance the role of security, usually activities conducted at airports such as passenger scanning and items allowed on flight;[64] the requirements for air traffic management services, considering the likely evolution into Unmanned Traffic Management (UTM); the level of support needed for check-in and baggage handling, considering the increased automation; the aeronautics services related to landing, aircraft parking and recharging. Automation in both traffic management and supporting operations such as check-in and baggage handling, provide opportunities to run vertiports at profitable levels, since these areas tend to have a high cost in wages.[64]

Location for Services

Integration with existing transport systems will dictate some decisions around location of services, providing ease of use to consumers and increasing transportation efficiency. Reducing congestion should also play a role in decision making.

Given the level of noise emitted by eVTOL during take-off and landing, it is likely that vertiports and vertistops may be developed in areas where relative levels of noise are permitted, such as current transportation hubs (airports, train stations, etc.). This would allow for a limited form of AAM, that offers flights between transportation hubs, such as train stations and airports, but not for the more general AAM model of a door to door offer.

Technology improvements around operational procedures and noise source generation may bring aircraft noise levels within what could be acceptable to operate in already noisy areas, such as around train stations during the daytime. However, operating at night in residential areas would be even more challenging as aircraft operational noise levels are not sufficiently low.

Telecommunications and interoperability

Operators should be able provide an integrated transport solution that communicates effectively with customers. High volume AAM will require efficient scheduling of vertiport resources and aircraft. Research into the combination of satellite, WLAN, LTE and 5G technologies is required to address the service-related communication such as vehicle and prognostics data, navigation data, command and control and weather data.[5, 18, 65] Through AAM aircraft integration with other systems, such as ATM and communication systems, there will be the need to ensure cybersecurity of data exchange relating to weather, vehicle telemetry, navigation and passenger data.

Customer expectations will reinforce the need for safety in the communications space, for example multiple redundant communication links. Additionally, customer expectations will likely push the bandwidth requirements as eVTOLs operate in an on-demand manner, integrated into journey planning systems and provide IP services inflight.

Weather

Weather factors influence many aspects of AAM, including operations, passenger comfort, community acceptance, infrastructure and traffic management.[53] Seasonal and diurnal conditions additionally influence weather patterns of Australian major cities. Weather events can impact UAM operations in different magnitudes depending on the specific configurations shaped by missions, vehicle technology and market size.[53]

Reported historical weather events in Melbourne and Sydney, include: smoke haze, fog, low cloud and rain, which my impede visibility; windshear, strong winds, thunderstorms and lightning, which can cause changes in speed (and exhaust fuel level if causing the aircraft to slow down), delays and even costly damage to the aircraft. Wind shear (sudden change of wind direction or speed, which can be both vertical and horizontal) in particular, is a significant condition challenging aircraft control during take-off and landing.[66]

Bad weather can impact how comfortable and positive passengers feel about flying, and bystanders about aircraft flying above urban areas. Furthermore, different geographic areas demand different approaches in terms of infrastructure and asset health.[53]

Substantial statistics on historical weather, currently available from BOM, can support the characterisation of favourable and unfavourable weather conditions in terms of frequency of occurrence, time of the day, season, magnitude and variability in selected urban areas to estimate the average number of weather impacted hours per season and model their effects on operations in terms of potential scheduling, cost and timeliness. [53]

Asset management

The development of AAM infrastructure will require several updates, upgrades and changes overtime to ensure resiliency and efficiency as new capabilities are realised. In addition to the aircraft manufacturing lifecycle requirements mentioned in section 7, aircraft and vertiports operators will require planning approaches and technologies that consider the assets whole of lifecycle safety risk and communication requirements to support better management and maintenance.

Community Acceptance

Community acceptance and concerns relating to AAM will evolve in parallel with the technology, operations and enabling regulation. Previous studies[67] identified five typical categories of concern:

- Safety – distrust due to the lack of familiarity with autonomous systems and level of proximity to humans and objects on the ground. Safety is linked to accountability where clarity is needed in relation to responsibility and risk allocation, liability for accident damages and contractual arrangements with customers.
- Noise and visual disruption – changes to the natural and built environment and associated psychological factors.
- Privacy – particularly around cameras on airborne vehicles.
- Environment – how to manage the lifecycle of vehicles materials, emissions and impacts to wildlife.
- Jobs – lost jobs due to autonomy

9. Potential Future Program Areas

Given the need to address Air Mobility as an integrated system consisting of aircraft, operation and transport infrastructure while understanding the related social and regulatory implications, a combined effort between government, industry, research and academia is recommended to develop research and testing mechanisms to accelerate the study of the multidisciplinary aspects of AAM in Australian cities and regions.

Better understanding of AAM technical and social challenges in the Australian context can inform the regulatory task, support efficient innovation and develop the skill set required for effective deployment and transition of AAM technologies. As a baseline, it will be necessary to achieve agreement on approaches for communication and information exchange.

It is proposed to advance research in the following areas:

Program Priority #1: Financial feasibility study of operation models

In terms of the market, there is a clear product or service that can be offered by eVTOL that cannot be matched by land-based alternatives: a faster transportation service (i.e. delivery in less than an hour) carrying a payload between 25 kg and 250 kg that can both connect and travel within urban, suburban, regional and rural areas.

The largest uncertainty concerning the movement of freight or passengers via eVTOL is not on the technology side, but rather the regulation and demand side uncertainties. For instance:

- is there a real need in the market for what freight or passenger dedicated eVTOL have to offer?
- would regulators and communities support the AAM services?
- how do vehicles compare to eVTOL for specific selected corridors?

It is recommended, as a next step, exploring the feasibility of eVTOL service cases according different market segments and their proposed value for customers. We recommend the following research:

- Demand being a function of price point and vice-versa, calculating price ranges for passenger and commercial freight services using eVTOL, for different demand profiles, different utilisation rate profiles, different payload profiles, and different operational models. Using price ranges, can then help explore both potential passenger and freight customers' willingness to pay for such a service, and passenger and freight service providers' willingness to offer such a service.
- Explore the opportunities for regional and rural logistic models and how AAM can enhance the regions and decentralisation efforts. Understanding of how eVTOL could increase liveability and economic growth outside urban areas.

Program Priority #2: Community acceptance

In defining community acceptance for AAM and eVTOL in Australia, the various Concept of Operations and potential business cases would need to be evaluated to understand the attitudes toward eVTOL in urban, suburban, regional and rural areas. Studies can helps address questions such as: will the level of noise from eVTOL operation exceed that which Australian communities consider acceptable in terms of amenity? Will overflying aircraft be considered by communities as a threat to their safety or their privacy? Consideration should be given to AAM independently and also community perception in regard to aggregated number of aircraft options, including smaller drones.

Research in this area should prioritise the following themes:

- Urban, suburban, regional and rural attitudes toward (1) AAM and (2) eVTOL
- Approaches to minimising community disturbance. Such as Technologies that capture real time community perception for noise and visual pollution, to inform operation management.

Program Priority #3: Systemic analysis and integrated AAM planning

We recommend conducting a research project to identify, in a manner similar to Vascik, Hansman [68] but specific to cities and surrounding regions, the constraints and challenges to the deployment of AAM from a systems perspective, including weather, market, social, technological, regulatory and other considerations. It can be conducted on its own, or jointly with the previous study. Further areas of collaboration might include:

- Development of a common geospatial framework for AAM to ensure interoperability over time, enabling coordinated updates for data content and formats.
- Qualification methodologies for suitable locations of vertiports and networks. Integration of vertiports into existing transport network. Including understanding in which situations could AAM help relieve ground congestion.
- Aircraft selection according to operation requirements. Trade-off analysis to find best aircraft fit to operation.
- Approaches to lifecycle management of aircraft components and infrastructure

Program Priority #4: Communications capability

With the prospect of autonomous aircraft and UTM, a it is important to enable staged and coordinated approaches for exploring and introducing aircraft networking technology to manage air traffic control, separation and flight paths, ensuring interoperability and standards.[4] Research in this area should prioritise the following themes:

- Characterisation of Advanced Aerial Mobility data – diversity, size and requirements
- Protocols, data formats and data exchange standards
- Realtime data processing to inform flight plan, detect and avoid, interaction
- Detect and avoid applications
- System contingency management and cyber-resilience
- Modelling of system architecture and requirements towards increasing capability and scale of AAM system to enable various aircraft operations
- Realtime data process to develop and manage schedules

Program Priority #5: Energy storage systems and high value manufacturing

Given the potential range of aircraft in the Australian context, especially for regional travel and supply, a program of research is recommended to investigate the following technologies. Of most interest is where Australian R&D, innovation and high value manufacturing can add economic value for the regions and country. The key technologies include:

- Battery technology – weight and capacity
- Hydrogen fuel cells – Storage of H_2 on board aircraft
- Recycling of key airframe and battery/fuel cell materials
- Materials and manufacturing research for light weight, high value components for eVTOL aircraft

Program Priority #6: Software and aircraft systems

- Data for user interface, what if analysis
- System complexity
- Improved safety analysis tools for software systems
- Approaches to hazard and safety analysis for complex systems[4]

Program Priority #7: Natural environment factors

With the expectation that eVTOL can fly in all weather conditions, it will be important to test how performance of an eVTOL aircraft would be affected by extreme weather conditions experienced in Australia, including dust storms, hailstorms, strong winds, smoke and heat waves. In addition, climate change is likely to increase the frequency of extreme weather events. As such the following research areas are suggested:

- Technical performance of eVTOL under a range of weather conditions
- Estimating the average number of weather-impacted hours per season for Australian cities or regions and the influence on operations scheduling, cost and timeliness
- Environmental footprint of aircraft components, infrastructure and operation. Impacts on built and natural environment, including wildlife.

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