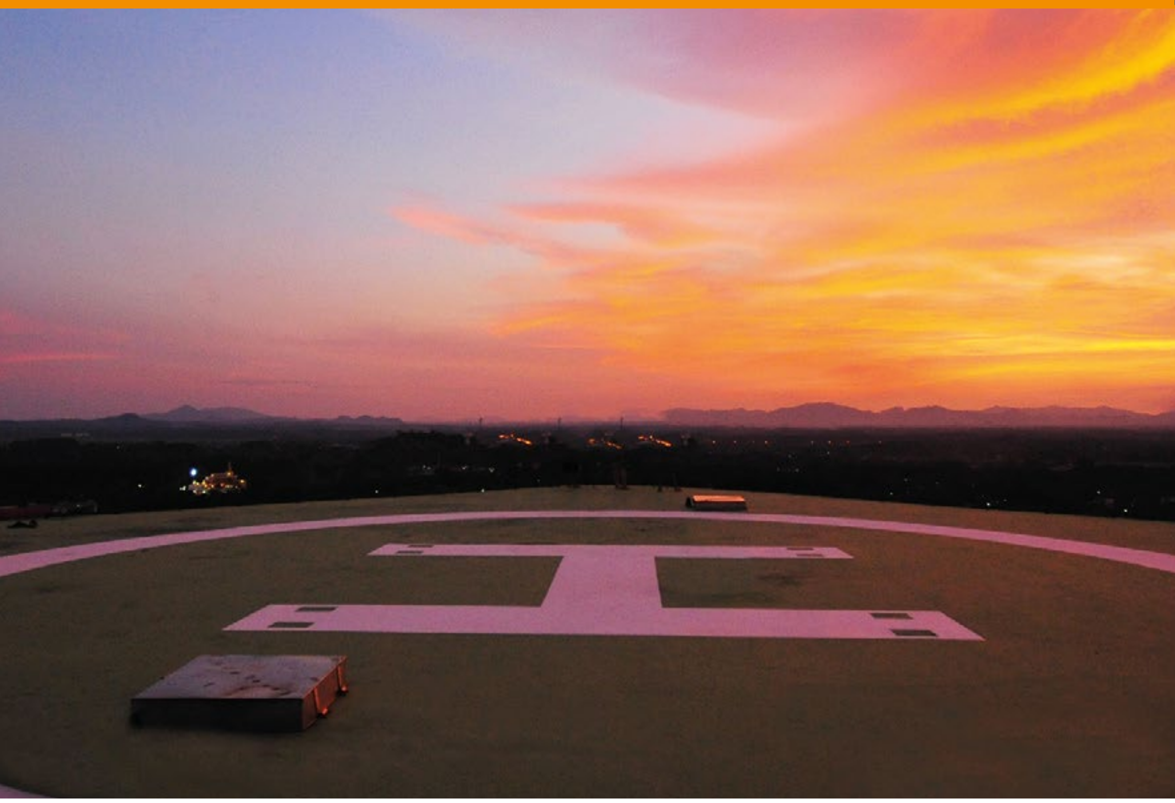
Advanced Air Mobility

UK Economic Impact Study

July 2023



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Advanced Air Mobility UK Economic Impact Study

Executive summary

It is an exciting time for Advanced Air Mobility (AAM). A concept that has been around for more than a century[1] is now closer than ever to being realised and has the potential to transform travel in the UK by offering a faster, greener way to connect communities, ease congestion and improve quality of life.

The AAM market is buoyant with global investment reaching $7Bn in 2021[2]. However, it is not clear whether this level of market momentum will translate into viable transport alternatives in the UK.

We assessed the viability of AAM in the UK based on a comparative analysis of six AAM use cases against current travel and freight options. We found that the AAM use cases with longer distances and higher occupancy are attractive compared to existing options. If we scale the attractive use cases out to 2040[3], their *annual* impact could be:

£2.1bn

in socioeconomic benefit (including time, carbon and avoided accidents)

£297m

in fare values; and

222m tons

of CO2e reduction, the equivalent of taking c.120,000 diesel cars off the road for a year.

In contrast to the longer distance use cases, we found that the short hop (less than 30km) AAM use cases that currently pervade the market are not attractive compared to existing travel options. This is despite our methodology assigning financial values to time, carbon and accident rates which usually favour AAM compared to existing travel. We did not scale these use cases and they are not part of the 2040 figures stated above. Many of the current short hop use cases in the market feature higher passenger occupancy than the 1 passenger (25% occupancy in a 4-seat aircraft) we assumed in our modelling. Short hop fares become attractive by 2035 if we increase our occupancy assumption to 75%, a level that we consider unlikely and only achievable through rideshare.

Our analysis suggests that, to realise AAM's considerable potential, the focus should be on use cases where AAM solutions are competitive with existing alternatives and their evolution. This means specifically identifying the higher occupancy, longer distance use cases that are most compelling. A viable rideshare model is also required for such use cases and, were this developed successfully, it may influence the viability of shorter hop use cases. It is important to note that our analysis relies on averages and will therefore not reflect the whole spectrum of demand. For example, first adopters that are willing to pay more to experience this new technology. Beyond more standard journeys there may also be niche use cases which provide community or social benefits that outweigh cost disadvantages. These should also be identified and pursued.

There are multiple challenges that must be addressed to enable AAM to flourish. These include perception, infrastructure, technology, safety and security, regulation, business models and skills. Multiple initiatives are underway to address these challenges including those from the FFC (Future Flight Challenge), DfT (Department for Transport), CAA (Civil Aviation Authority) and CPC (Connected Places Catapult). Actions to address AAM challenges will be most effective if focussed on compelling use cases.

This report discusses our approach to Determining UK AAM Potential, maps the AAM Ecosystem, discusses the Challenges associated with AAM adoption and follows this with a detailed breakdown of our Economic Modelling Approach and Key Findings. We would like to thank the FFC for their support in producing this paper and the DfT for their suggestions.

For the purposes of this report, AAM comprises eVTOL aircraft for passenger and freight transport. It excludes middle mile and last mile drones which we covered in our drone economic impact report Skies Without Limits v2.0.[4] Note that any references to the range of government initiatives to address AAM challenges are illustrative rather than exhaustive.

[1] "Glenn Curtiss Sees a Vision of Aviation's Future", Popular Science, July 1927. Curtiss unveiled the Curtiss Autoplane in 1917, widely considered the first of its kind.
[2] https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/future-air-mobility-blog/a-milestone-year-for-future-air-mobility
[3] This only considers journeys where individuals substitute away from 'traditional' modes of transport and freight, and does not include alternative use cases not analysed for this report
[4] https://www.pwc.co.uk/intelligent-digital/drones/skies-without-limits-2022.pdf

> "Our analysis suggests that, to realise AAM's considerable potential, the focus should be on use cases where AAM solutions are competitive with existing alternatives and their evolution."

1

Determining UK AAM potential

To determine the potential for AAM in the UK, we defined six use cases and calculated whether AAM was attractive compared to other transport options. We used a similar approach to our 2021 socioeconomic report for the FFC[5] and assigned monetary values to time, accident rates and carbon emissions and added these to fares to arrive at a "socioeconomic" cost for a given journey. We considered an AAM use case viable if its socioeconomic cost was less than the alternative. We then scaled the viable use cases to give a UK-wide economic impact out to 2040, applying an S-Curve adoption profile and adjusting for factors such as the degree of automation assumed over time.

Use Cases

Table 1 shows that AAM is socioeconomically attractive for three of our six use cases: rural rideshare, sub-regional shuttle and air ambulance. The most attractive use case is the sub-regional shuttle which assumes a larger capacity eVTOL which, unfortunately, is more conceptual than close to realisation at present. The two attractive passenger use cases highlight a fundamental point – for an AAM option to be socioeconomically viable, it needs to have a relatively high occupancy and be over a longer distance.

Table 1

AAM Use Case

Description	Distance	Profile (initial)	Counterfactual comparison	Socioeconomic cost delta	Scaled?
Urban Private Hire	10km	1 pilot, 1 passenger	Taxi (1 passenger)	+99%	No
Rural Private	28km	1 pilot, 1 passenger	Personal car (1 driver)	+151%	No
Rural Rideshare	60km	1 pilot, 3 passengers	3x individual car journeys	-33%	Yes
Sub-regional Shuttle	85km	1 pilot, 5 passengers	5x individual train journeys	-39%	Yes
Air Ambulance	80km		Helicopter	-38%	Yes
Cargo	75km	350kg	Van	+112%	No

"Current transport and freight options remain more attractive than the urban private hire and rural private throughout the 2025-2040 modelling period, and the cargo use case is not attractive."

[5] https://www.ukri.org/publications/future-flight-challenge-socio-economic-study/

We find that AAM is not socioeconomically attractive for three use cases – urban private hire, rural private and cargo. This is despite short distance use cases being the most frequently referenced, mass market applications in the AAM market, usually featuring high passenger occupancy such as 75% for a 4-5 seat capacity. In our modelling we have applied what we consider a more realistic occupancy assumption (25%, see table) based on the average occupancy of current comparable journeys[6]. In other modelling areas, we have made assumptions which could be considered favourable to AAM:

- conservative assumptions for key AAM cost elements such as eVTOL and vertiport capital costs and optimistic assumptions for operating windows, refer to Appendix 1 – Assumptions
- assignment of monetary values to time saved, reduction in accident rates and carbon emissions, that all usually favour the AAM use case
- assumption that current AAM implementation challenges do not inhibit adoption. Challenges include perception, infrastructure, technology, safety and security, regulation, skills and business models, refer to the Challenges section below.

Despite this approach, current transport and freight options remain more attractive than the urban private hire and rural private throughout the 2025-2040 modelling period, and the cargo use case is not attractive. It should be noted that these are based on average values and there will be organisations, individuals, and situations where certain considerations – such as time or safety – are valued more highly.

Scaling

We scale the three viable use cases from 2025-2040 using an S-curve for adoption that caps at a counterfactual substitution rate of 5% in 2040. This could result in an annual impact of up to:

£2.1bn
in socioeconomic benefit (including time, carbon and avoided accidents);

£297m
in fare values; and

222m tons
of CO2e reduction, the equivalent of taking c.120,000 diesel cars off the road for a year.

To deliver this level of annual socioeconomic benefit in 2040 we would require:

2,136
4-5 capacity eVTOLs and
121 11-12 capacity eVTOLs;

565
pilots, noting that this figure peaks at 3,105 in 2035 prior to eVTOLs becoming predominantly autonomous; and

376
Vertiports (take-off and landing locations).

It is important to note that the scope of these figures includes only substituted journeys, and therefore does not reflect that there may be some entirely new journeys (and use cases) that arise a result of AAM technology.

[6] NTS0905 https://www.gov.uk/government/statistical-data-sets/nts09-vehicle-mileage-and-occupancy

Model Implications

Given the prevalence of short hop (less than 30km), high occupancy (50-75% in 4-5 seat eVTOLs) use cases in the AAM market, we have used sensitivity analysis to determine whether changes in model assumptions could make such use cases socioeconomically attractive. We tested changes in rideshare and eVTOL capital cost assumptions.

If we assume that short hop rideshare is reasonable and results in 3 out of 4 available eVTOL seats being occupied (and three individual taxi journeys being replaced), then the urban private hire scenario is viable in all time periods from marginally more attractive in 2025 to 31% more attractive in 2040. Applying the same approach to the rural private scenario only results in it being similarly attractive in 2030 and 18% more attractive in 2035. As mentioned above, we consider it unlikely that this level of rideshare and occupancy will apply to high volume travel over short distances given existing car occupancy rates. This means that the key question for short hop AAM journeys is the extent to which a ridesharing model could be made attractive to consumers.

eVTOL capital costs are usually in the £3-5M range and they typically seat 4 or 5 passengers. These aircraft appear over-specified for the two short hop scenarios we are testing. If we dramatically reduce the capital cost from our assumption of £3M to c.£0.2M to reflect eVTOLs capable of carrying a small number of passengers for short distances, we find that this could make the urban hire scenario attractive if the eVTOL were autonomous. This change does not make the rural private use case attractive.

These sensitivities suggest that it will be difficult to make the case for short hop AAM using realistic average occupancy and rideshare assumptions. This finding is shared by the FFC supported Skybus[7] project. Skybus is based on 30-50 seat battery-electric and zero-emissions eVTOLs which takes the “Park and Ride” concept into the air for mass transit over extremely congested routes eliminating the 2D constraints of current surface transport.

The Skybus concept could address transport congestion, pollution, and sustainability issues through a widely accessible, affordable, scalable and interconnected multi-modal network. Skybus cost modelling found that 30 seat eVTOLs were economically compelling and were 20%-33% of the cost per passenger mile of high occupancy 4-5 seat eVTOLs. Refer to Appendix 2 and note that this cost modelling does not factor in time, accident rates or carbon.

These findings are consistent with our modelling where longer distance, higher occupancy viable use cases deliver notable socioeconomic savings, including carbon reductions. AAM has the potential to deliver further benefits to society in other niche use cases such as passenger travel to UK Islands from the mainland where the socioeconomic cost penalty is offset by other societal benefits. Competitively priced AAM solutions could help to integrate communities currently cut-off from traditional transportation and help them to level-up. Increasing the distance and ease of travel could allow an expansion of the commuter belt which could reduce congestion, overcrowding and increase quality of life. As the UK population grows, AAMs could be part of a suite of measures designed to ease congestion and pollution.

This implies that the UK AAM market should focus on identifying the longer distance, higher occupancy and niche use cases which deliver compelling societal and/or connectivity benefits (including establishing new routes) and deliver these in the first instance. Actions to address the multiple challenges associated with AAM implementation should be focussed on the compelling use cases. We note the possibility that, should a rideshare model be successfully deployed for longer distance routes, this may pave the way for short hop rideshare (which we consider unlikely otherwise, see Use Cases above).

[7] https://cp.catapult.org.uk/report/skybus-the-public-transport-revolution/

While it is conceivable that a premium market could develop for short flights with low occupancy, we question whether the required infrastructure could be funded without mass market demand. If enough Vertiports are deployed to meet the demand for longer distance, higher occupancy use cases, it is possible that these could be used for premium-priced, short hop low occupancy transport in the medium term.

As with any new technology, there are a number of challenges that must be addressed before AAM solutions can take to the skies in volume. Challenges include eVTOL and vertiport realisation going at two very different paces, finding enough eVTOL pilots, unprecedented change in airspace management and the rise of competing clean transport tech such as EVs (Electric Vehicles). We expand on these and other potential growth challenges including perception, infrastructure, technology, safety and security, regulation, business models and skills in the Challenges section below. We also noted above that there are several UK initiatives underway to address AAM challenges including those from FFC, DfT, CAA and CPC.

Infrastructure is perhaps the largest market challenge and a lack of Vertiports may stifle UK AAM potential. If we continue to take an optimistic view and consider that all other challenges are addressed, we still need hundreds of Vertiports to deliver the socioeconomically attractive AAM services. These Vertiports are unlikely to be in the same location as the UK's 45 certified Aerodromes[8] and c.400 GA (General Aviation) airfields[9]. Even if we assume all Vertiports can be used by all eVTOLs and that technical and regulatory challenges are solved, this means finding vast quantities of real estate, often in built up areas, and obtaining planning permission from local councils. Local councils are likely to have to change their approach and capacity to keep up with the vertiport planning permission requests. The process itself may be lengthy and not have a positive outcome, especially where cultural heritage and wildlife are involved[10]. We note that this could be a different story in a greenfield development, such as NEOM in Saudi Arabia[11]. The FFC have recognised this potential challenge and are about to launch a Community Integration Working Group which will include local council initiatives which aim to streamline this process. We consider that the identification of specific and compelling socioeconomic use cases may assist such discussions, refer also to the Perception challenge discussion below.

As you can see in Figure 1 in the AAM Ecosystem section below, the majority of AAM solutions start off piloted. At the volumes suggested by the market and our modelling, there will initially be a skills gap/pilot shortage, followed by pilot oversupply, based on our assumption that autonomy is prevalent from 2035, refer to the eVTOL and pilot forecasts section (page 58). This leads to a practical challenge of attracting pilots when their role may be replaced by autonomous solutions in the medium term, refer also to the Skills section below.

The UK's busy airspace will become even busier over the next decades and, in addition to the thousands of AAMs modelled in this paper, we estimate there could be more than 900,000 commercial drones in the UK by 2030, most of which will be flying BVLOS (Beyond Visual Line of Sight) and autonomously[12]. There will also be an increase in the volume of traditional commercial aviation and its green evolution. This unprecedented increase in scale and complexity will predominantly manifest at low altitudes and in built up areas. Existing ATM (Air Traffic Management, manned) has to adapt and evolve to include automation (including AI) and seamlessly integrate with UTM (Unmanned Traffic Management), presenting significant challenges in areas such as those discussed in the Technology, Regulation and Skills sections below. The CAA's Airspace Modernisation Strategy (AMS)[13] aims to address this challenge, amongst other things. We note the success of the FFC and other contributors in broadening the focus of the AMS, for example, from no mention of AAM in CAP 1711 to "integration of diverse users" (which include AAM) forming a core part of the new AMS vision.

AAM solutions will also face stiff competition from existing transport options and other new(er) solutions including EVs, High Speed 2 and clean regional aviation. Like AAMs, EVs are also clean but they will usually take travellers point to point. AAM travellers have to get themselves to and from Vertiports and, while they may save time overall, our modelling indicates that private urban and rural eVTOL journeys will be more expensive on a fares basis, refer to the Key Findings section below. This is not to say that EVs solve congestion issues and we expect that compelling AAM solutions will be a key part of a portfolio of measures to address congestion issues.

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[8] https://www.caa.co.uk/commercial-industry/airports/aerodrome-licences/certificates/uk-certificated-aerodromes/
[9] https://www.gov.uk/government/publications/general-aviation-sector-and-airfields-studies
[10] https://www.easa.europa.eu/sites/default/files/dfu/uam-full-report.pdf
[11] https://www.neom.com/en-us/newsroom/neom-invests-in-volocopter
[12] https://www.pwc.co.uk/intelligent-digital/drones/skies-without-limits-2022.pdf
[13] https://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=11069

2
AAM ecosystem

The AAM ecosystem is complex and we have attempted to distil it into "5 As": Aircraft, Ancillary, Airline, Airport and Airspace. While there are limitations to this approach, we believe these are outweighed by the clarity it offers.

As mentioned above, for the purposes of this report, AAM comprises electrically-powered Vertical Take Off and Landing (eVTOL) aircraft primarily for passenger transport, noting that there are also freight applications. It excludes middle mile and last mile cargo drones and other drone applications.

1 Aircraft	2 Ancillary	3 Airline	4 Airport	5 Airspace
Entities which design and manufacture eVTOLs and are responsible for design, production and type certification, refer also to the Regulation section.	Entities which carry out MRO (Maintenance, Repair & Overhaul) servicing and associated activities on behalf of the Airline. In the AAM industry MRO may predominantly be carried out by OEMs (Original Equipment Manufacturers), see below and refer also to the Technology section.	Entity that owns and operates a fleet of Aircraft to serve passengers from ticket sales through to disembarkation and/ or delivers freight. Also responsible for passenger compensation for delayed or cancelled flights, baggage issues, etc.	"Vertiport" take-off and landing locations for Aircraft which include passenger processing/ security and charging facilities. We expect several tiers of vertiport, from basic take-off and landing facilities in rural locations to full-service hubs, likely to be located in cities.	Provider of airspace management solutions.

The figure below shows which of the 5As the listed Aircraft manufacturers intend to participate in.

Figure 1: indicating the extent to which selected Aircraft entities intend to participate in the AAM ecosystem. Icons also indicate if Aircraft entities have aviation/ aerospace or automotive backers, as well as which will be autonomous/ pilotless at launch and which have opted for multiple use cases from their single eVTOL. Note that Figure 1 is indicative only, based on our interpretation of publicly available information, and does not necessarily represent the current strategy of the entities listed.

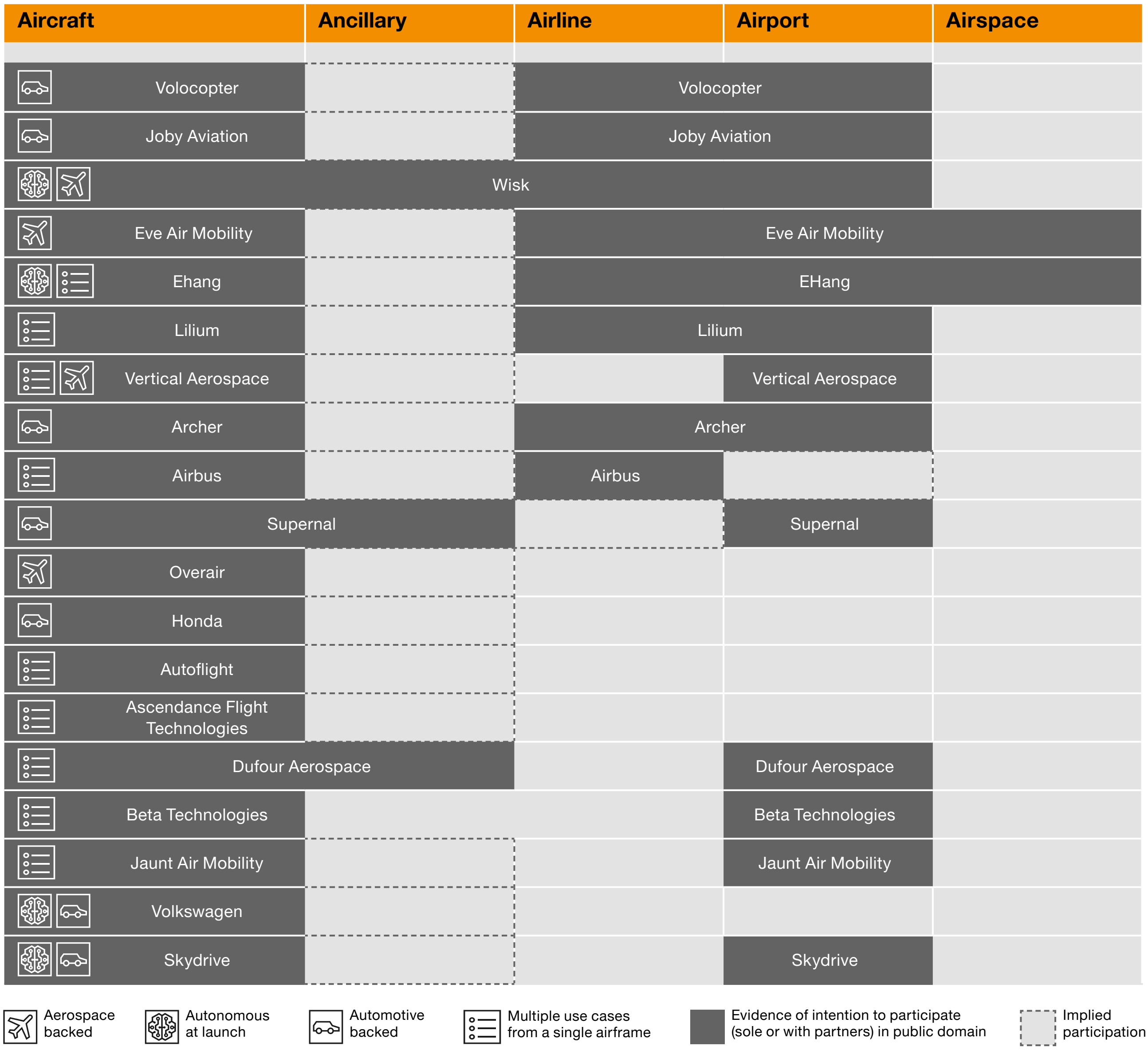


Figure 1 indicates that many eVTOL players are focussed in the Aircraft space and planning to operate in the "OEM Model" which is analogous to traditional aerospace manufacturers, e.g. Vertical Aerospace (noting their intent to participate in vertiports which is not part of the traditional OEM model). For the purposes of this paper, we have not covered Aircraft leasing companies which are active in this space, such as Avolon. A smaller number of entities are focussed on an integrated model where they are also the Airline and construct and operate Airports, e.g. Volocopter. We expect that AAM companies that plan to offer a vertically integrated solution will also offer integration with ground transport modes (multimodal) to give the passenger a one stop experience. Multimodal transport is not an area we have covered in this paper, save for assumptions on journey time to Vertiports, see Appendix 1 – Assumptions.

3
Challenges

The AAM market will not realise its exciting potential unless multiple challenges are addressed. These include perception, infrastructure, technology, safety and security, regulation, business models and skills. There are also associated future aviation technology developments that may impact AAM adoption such as drones and regional aviation.

Drones

We expect drones to be the vanguard for much of future aviation technology. For example, ubiquitous commercial drones could pave the way for AAM to become socially desirable and other pivotal future aviation technologies such as UTM. If BVLOS drone solutions and the associated UTM developments for, say, last mile delivery drones do not progress at pace, this will have an adverse impact on AAM timelines.

The FFC's scope includes drones, eVTOLs and regional (see below) to encourage this flow of technology. It is one of few such integrated government programmes globally, see also ENAC (L'Ente Nazionale per l'Aviazione Civile, Italian CAA)[14].

Regional

Commercial air travel between UK airports

We note that clean regional aviation will be analogous to existing regional flights and expect that many AAM challenges such as air traffic solutions, infrastructure and becoming socially desirable will have minimal impact on this market. The AAM passenger use cases which are attractive tend to feature higher occupancy and longer distances, i.e. they tend towards regional aviation. If regional solutions are available before AAM and offer similar connectivity, they may have an impact on AAM implementation timing and market share.

There is considerable evidence that the UK government is aware of these challenges and is actively addressing them through multiple initiatives, in addition to the FFC[15]. These include the DfT's Flightpath to the Future[16], the CAA's programme of regulatory enablement such as the Airspace Modernisation Strategy[17] and various CPC initiatives including the Future of Air Mobility Accelerator[18].

Perception

Sounds great but not in my backyard

In the early years, AAM was usually referred to as UAM (Urban Air Mobility) and this still refers to a subset of AAM. When we think about perception, there is certainly a clue in the UAM acronym. Is it realistic to expect people who live in built up urban areas to welcome 18 hours (or more) per day of noise, visual blight and the architectural disruption that would be associated with AAM solutions? Perhaps if they offer greener, more efficient and affordable services than the alternatives.

The challenge is particularly stark when set against the rise of EVs which are not only powered by "clean" energy but require minimal infrastructural disruption, compared to AAM. EVs, whether personally owned, taxi operated or taken via a rideshare usually go directly from the starting point of the journey to the end destination, rather than requiring a journey to and from a vertiport. Our models also indicate that, for urban and rural private hire, AAM solutions are more expensive to buy than the alternatives. EVs, however, do not address congestion issues.

There are many perception studies and we will consider three here. The first is the 2021 study from EASA[19] which found that respondents were keen on the principle and viewed AAM as a new, attractive solution which they were ready to try. They were, however, less keen when they stopped and considered the implications and sought to limit their personal exposure to risks such as safety, noise, security and environmental impact. Concerns about cybersecurity and cultural heritage were also noted.

The second is the DfT Attitudes Tracker (Wave 7, 2021)[20] which indicates that, in the UK, there is a very low awareness of "air taxis" with a total of 80% of respondents who had either "heard of, know nothing about them" (19%) or "never heard of them" (61%). The comparable total figure for drones is 12%.

[14] https://www.enac.gov.it/sites/default/files/allegati/2022-Mar/01_Piano%20Strategico%20Nazionale%20AAM_ENAC_web%20en-GB.pdf
[15] https://www.ukri.org/what-we-offer/browse-our-areas-of-investment-and-support/future-flight/
[16] https://www.gov.uk/government/publications/flightpath-to-the-future-a-strategic-framework-for-the-aviation-sector
[17] https://www.caa.co.uk/commercial-industry/airspace/airspace-modernisation/airspace-modernisation-strategy/about-the-strategy/
[18] https://cp.catapult.org.uk/news/future-of-air-mobility-accelerator-2022-cohort-announced/
[19] https://www.easa.europa.eu/sites/default/files/dfu/uam-full-report.pdf
[20] https://www.gov.uk/government/publications/transport-and-transport-technology-public-attitudes-tracker (wave 7)

Finally, we will consider our own data from a study of the UK industry's perception of drones, conducted in 2022 with BEIS (Department for Business, Energy and Industrial Strategy)[21]. This study was consistent with our 2019 survey[22] in finding that out of 15 use cases (13 drone, 2 AAM using our definitions), the two least supported were AAM, but we noted an increase in the level of support between 2019 and 2022. The least supported use case remains "flying taxis" but support has increased 9% to 45% in 2022. Similarly, drones as patient transport "air-ambulance" is second bottom of the table but has increased by 6% to 59%. This broadly aligns with the EASA study referenced above where use cases that were of benefit to the community such as air ambulances were better supported than those designed to meet individual needs.

There is certainly work to do to make the public aware of AAM and persuade them that the benefits of AAM outweigh the costs. As previously mentioned, progress within the commercial drone industry could help here. For instance, it is possible that thousands of delivery drones flying back and forth will normalise future aviation tech and pave the way for acceptance of AAM.

We note that FFC projects such as "Aviation Innovation in the South West – Development of an operational environment in a representative urban region" (Phase 2), include provision for further public perception research on AAM.

The importance of social licence for new forms of aviation is recognised by FFC whose approach is to work with the public in the very early stages (via a £1.6m social science research programme). The FFC's intent is to engage the public to influence overall ecosystem design.

Infrastructure

Build it and they will come

One of the key assumptions in our modelling is that AAMs take off and land at Vertiports and that Vertiports are not a constraint. Vertiports are as critical to AAM adoption as they are fraught with practical challenges. We touch on the complexities and potential time delays associated with finding real estate and obtaining planning permission above (Model Implications) and operating Vertiports for extended periods (Perception) above. Other challenges include design and compliance standards (Regulation section) and the amount of power that will be required from the grid, assuming there are no issues with other utilities. We have, of course, just skimmed the surface, refer to Advanced Air Mobility Vertiport Considerations: A List and Overview for a more comprehensive, US-centric discussion which distils 450 vertiport considerations[23].

In addition to Vertiports, communications which are low latency, high bandwidth and have comprehensive coverage and redundancy will also be critical to AAMs safely navigating the skies. The communications must enable a traffic management system which seamlessly combines manned and unmanned traffic management and enables AAM to safely operate at low levels in a sky busy with drones and other air traffic. Refer to the Technology and Regulation sections below for further discussion of UTM (Unmanned Traffic Management) and its critical role in unlocking future aviation technologies such as AAM and BVLOS (Beyond Visual Line of Sight) autonomous drones.

There is also the "chicken and egg" challenge which some AAM Infrastructure players are keenly aware of. For example we came across this quote from Skyportz from January 2022 **"Forget the hype, concept plans, and fancy designs, the reality is that there is no existing industry in vertiport infrastructure anywhere in the world as there aren't any aircraft commercially certified to use them… Until we have the aircraft approved, there is no point in building anything as we don't yet know what the requirements will be."[24]**

[21] Building Trust in Commercial Drones (report will be published in H1 2023)
[22] https://www.pwc.co.uk/issues/emerging-technologies/drones/drones-and-trust.html
[23] https://ntrs.nasa.gov/api/citations/20220007100/downloads/Vertiport%20Considerations%20Paper%20Final%20v2.pdf
[24] https://www.futureflight.aero/news-article/2021-12-20/ground-infrastructure-experts-wrestle-vertiport-challenges

None of the vertiport challenges are insurmountable and in April 2022 there was an interesting example of a "pop up" vertiport in Coventry. The Air One Vertiport was designed and deployed by UK-based Urban-Air Port[25] and was supported by the FFC and Coventry City Council. It took only 11 weeks to erect the 17,000 square feet site and it features a passenger lounge, a café, a cargo logistics hub, an electric and hydrogen air vehicle hangar, a security screening area, and a command centre. There are also multiple other FFC initiatives to develop vertiport and AAM solutions, including the Advanced Mobility Ecosystem Consortium[26] which includes Skyports building and operating a "Living Lab" vertiport to test ground, passenger and air elements. The CPC's second Future of Air Mobility Accelerator (in partnership with the FFC) includes a stream for Future Airport & Vertiport Operations (along with Aviation Sustainability, Future Air & Space Traffic Management and Enabling End-to-End Mobility).[27]

> "It took only 11 weeks to erect the 17,000 square feet site and it features a passenger lounge, a café, a cargo logistics hub, an electric and hydrogen air vehicle hangar, a security screening area, and a command centre."

[25] https://www.urbanairport.com/airone
[26] https://skyports.net/uk-government-awards-9-5m-to-british-consortium-to-build-world-first-advanced-electric-flight-ecosystem/
[27] https://cp.catapult.org.uk/news/future-of-air-mobility-accelerator-2022-cohort-announced

Safety and Security

Current aviation has set a high bar and the tech landscape is changing

When we think of new technology, our initial excitement may be tempered when we start to consider the risk involved. In our modelling, we have used commercial aviation accident rates as a proxy for AAM. The logic for this is that AAMs will essentially go through the same rigorous certification process as current commercial aviation, see Regulation below. If one accepts this premise, AAM travel will be safer than, say, road travel.

Continuing with the commercial aviation theme, we find it difficult to imagine that AAM flights will have less rigorous security and passenger/ baggage screening than is currently in place for domestic air travel in the UK. To achieve the 10 mins boarding (arrival at vertiport to take off, see Appendix 1 – Assumptions) time we have modelled in the majority of passenger use cases, a different approach is required. Less stringent security may not be an option and new solutions will be required to automate and streamline vertiport processing, refer to the Technology/ Airport section below. That said, we note that the shortest flight in the world has no security screening which implies that different levels of screening may be possible depending on capacity and distance[28].

"Both AAM and Airspace automation imply a deep reliance on AI which will have to make many decisions per second that impact passenger safety. Accordingly, effective and holistic AI testing and certification and cybersecurity will be paramount."

There are other considerations associated with an increasingly digital and automated solution such as AAM. The piloted AAM phase will feature high levels of automation which will, of course, increase when the pilot is removed and we have fully autonomous AAM. The Airspace (ATM/ UTM) automation will also be at an unprecedented level. Both AAM and Airspace automation imply a deep reliance on AI which will have to make many decisions per second that impact passenger safety. Accordingly, effective and holistic AI testing and certification and cybersecurity will be paramount. Such cybersecurity must cover the entire digital ecosystem, from the AAMs themselves to passenger processing and Airspace management. Distributed ledger technologies (DLT) such as blockchain could play a key role here, refer to the Technology/ Airspace section. Other elements of physical security will also be important, consider, for example, the "hostile vehicle mitigation" concrete bollards outside most airports.

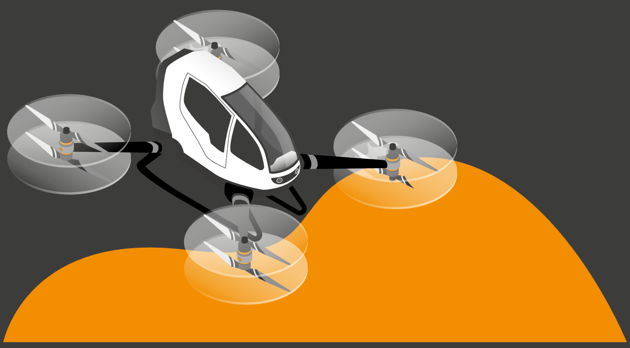
Following the drone incidents at Gatwick in 2018[29], the counter-drone market is certainly buoyant. The counter-AAM segment is less well defined but no less required in a world where it seems that any vehicle can be used for nefarious purposes[30]. In the 2021 EASA perception study, respondents showed a limited trust in the security and cybersecurity of AAM and noted a requirement for threat prevention steps[31]. There is also a potential blurring of lines between AAM and drones, for example, an eVTOL carrying cargo vs a cargo drone. All risk scenarios must be defined and mitigated.

[28] https://frequentmiler.com/flying-on-the-worlds-shortest-flight-papa-westray-to-westray-less-than-2-minutes/
[29] https://www.bbc.co.uk/news/uk-england-sussex-46623754
[30] https://www.bbc.co.uk/news/uk-40146916
[31] https://www.easa.europa.eu/sites/default/files/dfu/uam-full-report.pdf

Technology

We will discuss technology through the lens of the 5As model from the AAM Ecosystem section above – Aircraft, Ancillary, Airline, Airspace and Airport.

Aircraft



These exciting new eVTOL aircraft require a change in approach to design, maintenance and repair including failure modes, redundancies, and contingency procedures. The high-volume production required to meet global demand will also test manufacturers and their supply chains.

The propulsion systems associated with eVTOLs have a level of ambition not seen before for electrically powered vehicles and there are many associated challenges. We could also argue that the sheer number of different eVTOLs being designed (347 entities involved in eVTOL design concepts[32]) represent a missed opportunity for collaboration which would result in fewer designs but faster iteration and lower overall industry risk. The batteries required to power the eVTOLs are, perhaps, in a different place with the rise of EVs. Although aviation safety requirements may drive overall battery design in a different direction, the EV market is driving innovation and high-volume production of batteries. The AAM market will be able to leverage this, significantly reducing design and supply chain risk and cost compared to tech developed from scratch[33]. Related, eVTOL flight endurance (compared to conventional propulsion) is cited as a concern[34] for scenarios where holding patterns or rerouting is required due to weather and other disruptions in traffic flow and this potential issue must also be addressed.

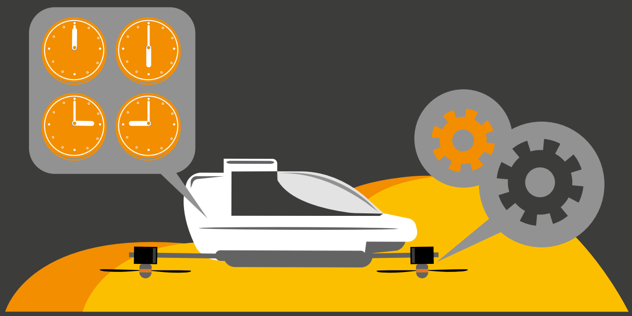
When we think of the economics of AAM, technology that removes or reduces piloting levels is key to increasing the viability of certain use cases. There are many avionics challenges to resolve including autonomy, DAA (Detect and Avoid) and BVLOS (Beyond Visual Line of Sight). Consider, for example, the interlinked challenge of Airspace and Technology/ Avionics – the AI and automated systems in the eVTOL will have to combine seamlessly with AI and automation in the UTM/ ATM to deliver a safe and efficient solution that can deal with an unprecedented level of air traffic. Increased air traffic will also require an unprecedented level of data transmission. Accordingly, communications backbone which is low latency, high bandwidth, high reliability and has redundancy will also be key.

If we go back to the eVTOL itself and consider the component level, eVTOL manufacturers have broadly followed an insource model (majority of components designed in house, vertical integration e.g. Joby) or an outsource model (majority of components purchased from third parties, e.g. Vertical Aerospace). In both cases, many of the components are single-sourced and have not been produced in volume. This represents a significant technical challenge and supply chain risk.

To produce the number of eVTOLs forecast, a high-volume manufacturing model is required, at a scale which is unprecedented in traditional aerospace. The required manufacturing model is more akin to the volume production of cars and we note with interest the investments of, for example, Toyota (Joby), Hyundai (Supernal), Daimler (Volocopter), Fiat Chyrsler (Archer), and Suzuki (Skydrive), refer also to the AAM Ecosystem section. The volume manufacturing model must be addressed not only to deliver the quantity and quality of units required but also to achieve an eVTOL unit cost that will make the AAM unit economics work. You will note that, in the Model Implications section above, we mention our use of a relatively low initial capital cost (initially £3M per eVTOL) and that we consider this an optimistic assumption. The degree to which eVTOLs embrace Design for Manufacture (DfM) principles to hit volume and cost targets will be a key success criterion.

[32] https://vtol.org/news/press-release-vfs-electric-vtol-directory-hits-700-concepts
[33] https://www.umlaut.com/uploads/documents/umlaut_Whitepaper_eVTOL.pdf
[34] http://publicapps.caa.co.uk/docs/33/CAP2272%20%20with%20dates%20Key%20Considerations%20for%20Airspace%20Integration%20within%20an%20Urban%20Air%20Mobility%20Landscape%20(1).pdf

Ancillary



When we think about MRO (Maintenance, Repair and Overhaul) for AAMs it is clear that the technology and approach required to work on AAMs will differ from existing commercial aviation.

There are, perhaps, three main factors at play, over and above cost pressure. These are the profile of AAM design (lower cost and lower maintenance components compared to existing commercial aviation, fewer moving parts), relatively small AAM MRO market size and OEM desire to keep IP (Intellectual Property). This is likely to result in MRO initially being carried out by OEMs and the rise of AI-powered predictive maintenance.[35]

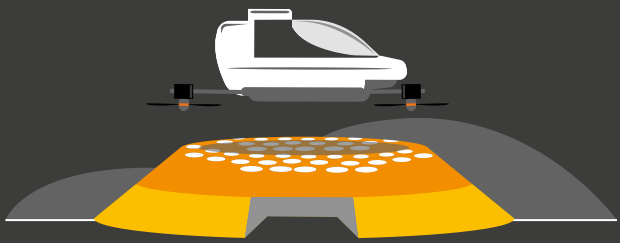
Airline

In addition to the implementation of new passenger and baggage processing tech, Airlines will face many other challenges.

These include an increased level of interconnectivity with other modes of transport (mobility as a service). For example a passenger may use the Airline's app to buy point to point transport which includes an AAM leg and certain airlines will wish to coordinate, say, EV taxi travel at either end in a seamless manner. Airlines will also increasingly have robotic and other automated technologies for check in, boarding, inflight service, etc.

[35] https://altonaviation.com/alton_insights/the-rise-of-advanced-air-mobility-implications-on-mro/

Airport



There are multiple technology challenges to solve when it comes to Vertiports. One of the main challenges is the ability to cope with multiple eVTOL shapes and sizes, with more than 300 types logged. Sophisticated, AI-powered planning and scheduling tech will be required to safely get the maximum vertiport utilisation, as will robotic/ automated eVTOL movement and charging and baggage handling.

As mentioned in the Safety and Security section above, to achieve the 10 minute boarding time we state in Appendix 1 – Assumptions, new security technology will be required. This could include use of baggage handling and security robots. These security robots may include facial recognition cameras and the ability to remotely measure pulse rate and detect explosives without interrupting passenger flow[36]. Another example of using technology to speed up vertiport processing is biometric, DL processing prior to passengers arriving at the airport. It is worth noting that much of this is likely to be the responsibility of the Airline, above.

As touched in the Safety and Security section above, there is also the matter of counter drone and counter AAM; the technology required to ensure that nefarious drone or AAM use can be detected and neutralised. In the counter drone market, this often comprises RF, optical and radar based detection systems, along with AI aircraft identification. Refer to the Infrastructure section above for the range of government and industry initiatives that aim to address vertiport challenges.

[36] https://www.mordorintelligence.com/industry-reports/airport-robots-market

Airspace

There are a significant number of technology challenges when it comes to airspace. As mentioned in the Model Implications section, we estimate there could be more than 900,000 commercial drones in the UK by 2030, many of which will be flying BVLOS and autonomously.[37] Add this to the thousands of AAMs and anticipated increases in helicopters and General Aviation (GA) traffic (whether clean or not) and we have a step change in the volume of aviation traffic. This increased scale and activity will be predominantly at lower altitudes in built up areas (whether urban or rural) and, again, these are unprecedented challenges.

This increase in scale and complexity requires effective UTM and a paradigm shift in ATM. ATM must adapt and evolve to include automation (including AI) and seamless integration with UTM which, with less of the technical baggage associated with ATM, will have a smoother path to automation. Automation is key not only for safety due to the required speed of decision making but also to address the air traffic skills shortage we mention in the Skills section below.

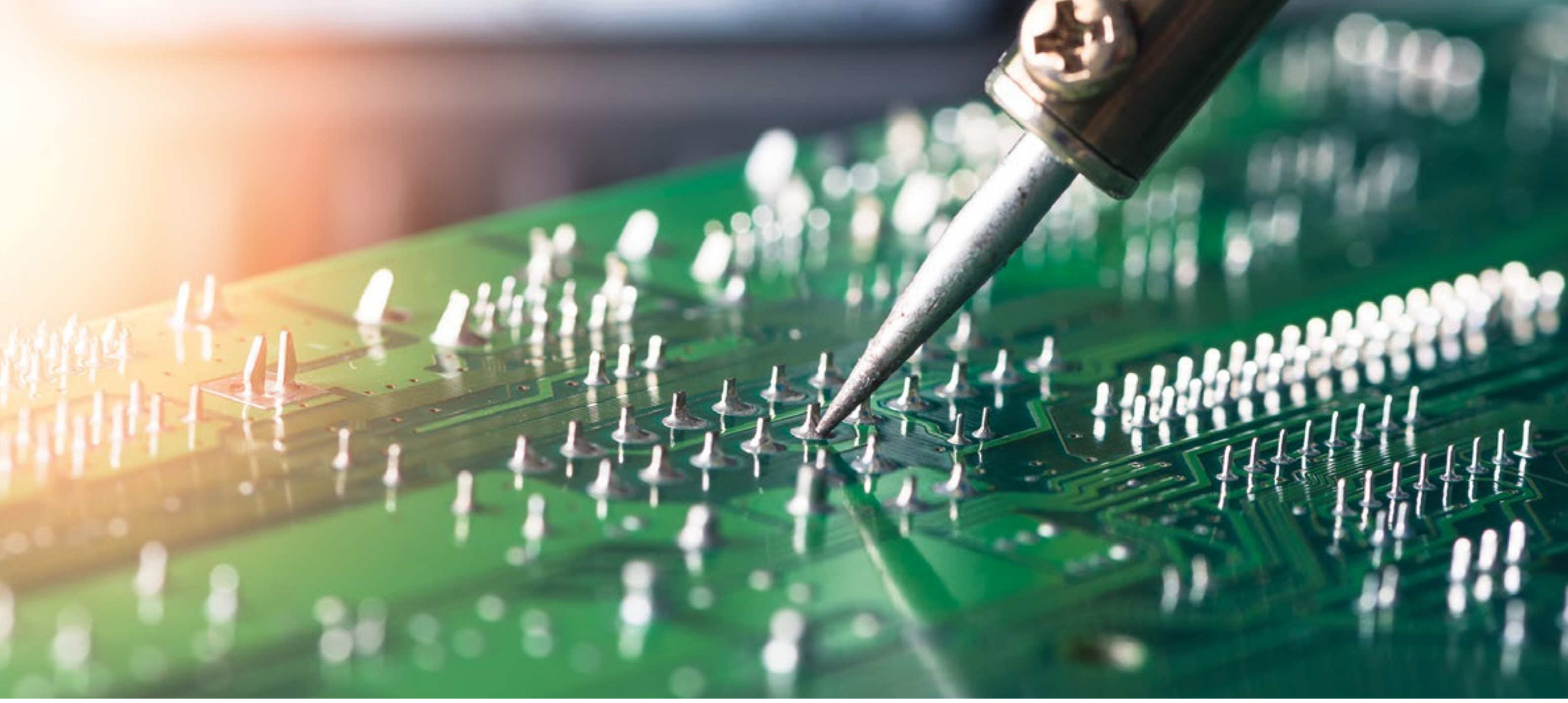
For UTM/ATM technology to succeed, seamless integration of all data feeds and digital infrastructure capable of managing the sheer volume of data (with redundancy) will be key. As mentioned in the Aircraft section above, a communications backbone which is low latency, high bandwidth, resilient and has redundancy will also have a key part to play in DAA and cybersecurity.

The CAA's Airspace Modernisation Strategy (AMS) recognises and aims to address these challenges. The current AMS draft[38] notes that the current ATM approach is not scalable. It also considers that AAM and drones will speed up the transition to an environment rich in digital information which will require a fully harmonised global air navigation system built on agreed performance-based standards with interoperable and scalable systems able to react in real-time.

As touched on in the Safety and Security section above, it is also critical that any data exchanged, not least between UTM and ATM systems, is reliable and trusted. DLTs and AI are likely to combine to play a key role here. Refer to the Fly2plan[39] initiative, part of FFC phase 2 and to the associated paper from Cranfield[40]. Other relevant initiatives include the CPC/ FFC's Future of Air Mobility Accelerator (refer to the Infrastructure section above) and the FFC (phase 3) AgiLe Integrated Airspace System (ALIAS) project.

> “This increase in scale and complexity requires effective UTM and a paradigm shift in ATM.”

[37] https://www.pwc.co.uk/issues/intelligent-digital/the-impact-of-drones-on-the-uk-economy.html
[38] https://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=11069
[39] https://www.heathrow.com/company/about-heathrow/future-flight-challenge/fly2plan
[40] https://www.cranfield.ac.uk/-/media/files/FutureFlightswhitepaper



Regulation

Innovation and adaptation

The safety-first, conservative approach and rigorous regulation that has kept air travel relatively safe for decades will apply to this exciting new technology. AAM is also springing up at a time when there are broader technical and operational changes that regulation must address for all commercial aviation. This includes the rise of AI and DLs across the board and the busier airspace associated with new drone use cases such as delivery and security.

Brexit and the push to level up the UK could drive us to adopt different regulations in the UK than in Europe but this seems unlikely at the time of writing. For example, the CAA confirmed in June 2022 that it will use the Special Conditions (SC)-VTOL certification standards[41] developed by EASA (European Aviation Safety Agency)[42]. The most likely scenario is that we will continue to be led by EASA's regulatory approach (although we note the CAA collaboration with the FAA (Federal Aviation Administration))[43] and feed into the ICAO (International Civil Aviation Organisation). We expect that the UK will also make use of recently announced NAA (National Aviation Authority) network (UK, Australia, Canada, New Zealand, USA)[44].

There are a plethora of regulatory innovations and adaptations required for AAMs to take to the skies safely and these are at an early stage.

Examples of regulatory innovations (regulations likely to be based on new approaches for a new class of vehicle) include

- eVTOL Type Certification
- Operational authorisations
- Pilot licensing, noting the anticipated evolution from piloted to autonomous flight (which some eVTOL manufacturers aim to start with)
- AI-powered autonomous flight including DAA and UTM integration
- AI-powered autonomous UTM and ATM (noting that the interaction between humans and machines will need to be monitored and regulated and that this includes staff training and licensing), use of DLT
- Vertiports (harmonisation of technical specifications for vertiports with the existing national and legal framework on urban, landscape and mobility planning)
- Communication networks (e.g. 5G)
- "Counter AAM" and cybersecurity

These new approaches are at early stages, for example EASA – (SC)-VTOL (eVTOL certification)[45], PTS-VPT-DSN (Vertiports)[46] and an intent to introduce a comprehensive regulatory framework for drones and AAM[47].

[41] https://www.easa.europa.eu/sites/default/files/dfu/SC-VTOL-01.pdf, see also CAP2537 (May 2023)
[42] https://www.caa.co.uk/news/uk-determines-certification-standards-for-new-electric-vertical-take-off-and-landing-aircraft/
[43] https://www.caa.co.uk/news/caa-and-faa-joint-statement-on-supporting-the-future-of-evtol
[44] https://www.gov.uk/government/news/uk-joins-up-with-closest-allies-to-create-new-forum-to-work-together-to-tackle-aviations-biggest-challenges
[45] https://www.easa.europa.eu/sites/default/files/dfu/SC-VTOL-01.pdf
[46] https://www.easa.europa.eu/en/downloads/136259/en, see also CAP2538 from the CAA (May 2023)
[47] https://www.easa.europa.eu/en/downloads/136705/en

Examples of regulatory adaptations (areas which are likely to more closely mirror existing approaches) include

- Design Organisation Authorisation (DOA, required to design aircraft of a given type)
- Production Organisation Authorisation (POA, required for producing aircraft of a given type in volume)
- Air Operator Certificate (AOC, required to operate an airline)
- Various safety, security and environmental (including noise) regulations
- Passenger rights, including compensation for delayed, diverted or cancelled flights, refer also to CAP2539 from the CAA (May 2023) which covers the application of their consumer principles to AAM[48]

In Europe, DOA and POA are being awarded based on existing regulation, for example EASA have awarded eVTOL certification pioneer Volocopter a DOA under EASA Part21J (2019) and POA under EASA Part 21G (2021) with the balance, including Type Certification, still required.

This approach is not supported by all stakeholders. For example, in SC-VTOL[49], EASA mandates the same safety standards as are applied to commercial aviation for eVTOLs which are in the "enhanced" category and some consider this to be overkill. We note that, in the EASA perception study referenced above, AAM safety standards were assumed to be equivalent to those for current manned aviation.

We have elected not to drill down further into airspace regulation (which is touched on above), given that it is covered in depth in many publications. The CAA is very (pro)active here with examples including the Airspace Modernisation Strategy (see above and note draft refreshed strategy includes "Integration of diverse users" as one of its 4 key objectives and that this objective names AAM).

Other examples are CAP2122[50] (AAM Taking a Use Case Approach), CAP2272[51] (Key Considerations for Airspace Integration within an Urban Air Mobility Landscape) and even a Conops (Concept of Operations) for AAM in London, in collaboration with the Eve and CAA's Sandbox project[52] which leverages an earlier Conops project in Australia[53]. However, if we look at the global picture, it is fragmented and "over 12 UTM standardisation and advisory organisations exist today in the United States, Europe and the Asia-Pacific region" resulting in "spaghetti development increasing risks at all levels"[54].

[48] http://publicapps.caa.co.uk/modalapplication.aspx?catid=1&pagetype=65&appid=11&mode=detail&id=12099
[49] https://www.easa.europa.eu/sites/default/files/dfu/SC-VTOL-01.pdf
[50] http://publicapps.caa.co.uk/docs/33/Advanced%20Air%20Mobility%20Taking%20a%20Use%20Case%20Approach.pdf
[51] https://publicapps.caa.co.uk/docs/33/CAP2272%20%20with%20dates%20Key%20Considerations%20for%20Airspace%20Integration%20within%20an%20Urban%20Air%20Mobility%20Landscape%20(1).pdf
[52] https://eveairmobility.com/uk-consortium-completes-urban-air-mobility-concept-of-operations-for-the-civil-aviation-authority
[53] https://engage.airservicesaustralia.com/urban-air-traffic-management-concept-of-operations
[54] https://www.icao.tv/videos/how-aam-is-to-be-managed-and-are-atm-or-utm-a-solution

Skills

A lot has been written about the current and future skills gap in STEM and Aerospace, including our recent report on drones and the UK economy[55], and we do not cover this in detail here. Instead, we will focus on the insight our modelling provides into the AAM pilot resourcing challenge. In our model there are three main phases to piloting, with a peak requirement of 3,105 pilots to meet the demands of the 3 use cases we have scaled:

- 2025-2030 eVTOLs are expected to require highly qualified pilots similar to commercial airlines now
- 2030-2035 eVTOLs have become more sophisticated and do not require fully qualified pilots: a pilot with basic training will operate the eVTOL with the support of a remote highly qualified pilot if required
- 2035-2040 we assume that eVTOLs are fully autonomous only requiring a remote pilot for emergencies. We assume that one remote pilot will be responsible for managing 4 eVTOLs

This presents a sequence of practical challenges. Initially there will be a skills shortage (pilots and pilot trainers) which will level out and then, when autonomy kicks in, there will be a glut of pilots who will have to retrain or find alternative employment, refer to eVTOL and pilot forecasts (page 58). Attracting new candidates to train as pilots is likely to prove challenging, especially with a potentially short career on offer due to the anticipated eVTOL automation. The challenge is amplified if we set it against a projected global shortage of 80,000 pilots by 2032[56] and note that our modelling only covers 54% of potentially substitutable journeys and no new journeys, see AAM market coverage (page 61).

There are, of course, many roles other than pilots. Integrating human performance into the system and paving the way to autonomy will be key. Other requirements include training standards for cabin crew (in light of increased levels of autonomy and robotics) and air traffic control (who will need to manage significantly increased traffic volume and prevalence of AI), not to mention engineers, ground site staff and security personnel etc.[57] There is also the wider supply chain to consider, refer to the Technology/ Aircraft section above, for example.

We note that the FFC has recognised the skills issue, refer to the challenge "Future flight: closing the skills gaps"[58].

Business Models

New business models are also required for AAM to flourish. While these will not necessarily be a barrier at the same level as, say, Vertiports or pilot numbers, business models will need to evolve to accommodate AAM. These range from the terms and conditions / contractual framework for this new form of travel (including multimodal integration) to insurance and the UTM commercial model. The responsibilities and liabilities borne by the different parties involved will have to be understood and integrated into the ecosystem. Some of these will be regulated, for example passenger compensation and standard level of insurance, others will be driven by market forces. The legal framework for autonomous flight is currently being reviewed by the law commission. They are evaluating existing legislation to identify any "blocks, gaps or uncertainties" with a view to law reforms that enable the UK to reap the benefit of advances in automation[59].

> "Initially there will be a skills shortage (pilots and pilot trainers) which will level out and then, when autonomy kicks in, there will be a glut of pilots who will have to retrain or find alternative employment."

[55] https://www.pwc.co.uk/intelligent-digital/drones/skies-without-limits-2022.pdf
[56] https://www.oliverwyman.com/our-expertise/insights/2022/jul/airline-pilot-shortage-will-get-worse.html?bsrc=oliverwyman
[57] http://publicapps.caa.co.uk/docs/33/CAP1923FutureAirMobilityRegulatoryChallenge.pdf
[58] https://apply-for-innovation-funding.service.gov.uk/competition/1363/overview/623bc6ff-4f6b-4e38-b077-4adb8fed6636#summary
[59] https://www.lawcom.gov.uk/new-project-to-examine-the-legal-implications-of-increased-autonomy-in-aviation/

4
Economic modelling approach

This section outlines our approach to modelling individual use cases and scaling up benefits of these to obtain aggregate socioeconomic impacts, including methodology, data and assumptions. There are three broad phases to our methodology:

Phase 1 defines and models the cost, time, accident risk and environmental impacts of use cases. This involves disaggregating the different journey segments of each of our use cases and alternative counterfactuals before developing a bottom-up model that compares key journey factors to estimate the net impact of substituting from traditional transport modes to eVTOLs.

Phase 2 scales up individual use case impacts by an expected total number of journey switches, which is used to estimate the number **of eVTOLS, pilots and vertiports required to service our scaled individual use cases.** We assume an S-curve for adoption rates.

Phase 3 estimates the total marginal impact of a switch to AAM journeys for our use cases to the UK economy between 2025-2040. The scaling methodology only accounts for the included use cases and impacts, estimating the substitution effect rather than the impact of new journeys. These results therefore do not represent the impact of the AAM market as a whole.

Figure 2: Economic modelling approach

Identify use cases

Define use cases:

- Urban private hire
- Rural private hire
- Rural rideshare
- Sub-regional public shuttle (minibus)
- Cargo
- Air-ambulance
- Define counterfactual for each case
- Specify key differences

Map & model impact pathways

Define the passenger journey and identify key benefits. Categories including:

- Approximate fares
- Time savings
- Carbon emissions
- Accident rates
- Develop model to quantify benefits

Develop scaling methodology

Define approach, identify key data sources and shape adoption curve.

- Develop model outline to scale-up benefits identified in the use cases with positive net benefits across years (2025-2040) and the UK population

Calulate AAM figures

Use case and scaling methodology to produce indicative figures of the number of eVTOL's, pilots and vertiport required to service the scaled use cases.

Estimate impact to UK economy

The total of all scaled-up benefits gives an estimate of the direct economic benefits, number of eVTOL's and pilots for our given use cases.

It does not include GDP benefits but represent the total cost, time and environmental benefits that we have captured.

Phase 1: Develop individual use cases

The first step in estimating the impact of AAMs is to understand the journeys people will use them for, and the impact that replacing current journeys with the AAM alternative has on those individuals and broader society. We have used best practice WebTAG[60] and Green Book[61] guidance to inform our assumptions and analysis alongside information from DfT's National Travel Survey.[62]

PwC's recent Socioeconomic Study[63] of future aviation technology forms the basis for our modelling of individual use cases: we identify and estimate the key impacts of each use case, capturing private costs and benefits as well as resulting externalities (i.e. the impacts on wider society) as follows:

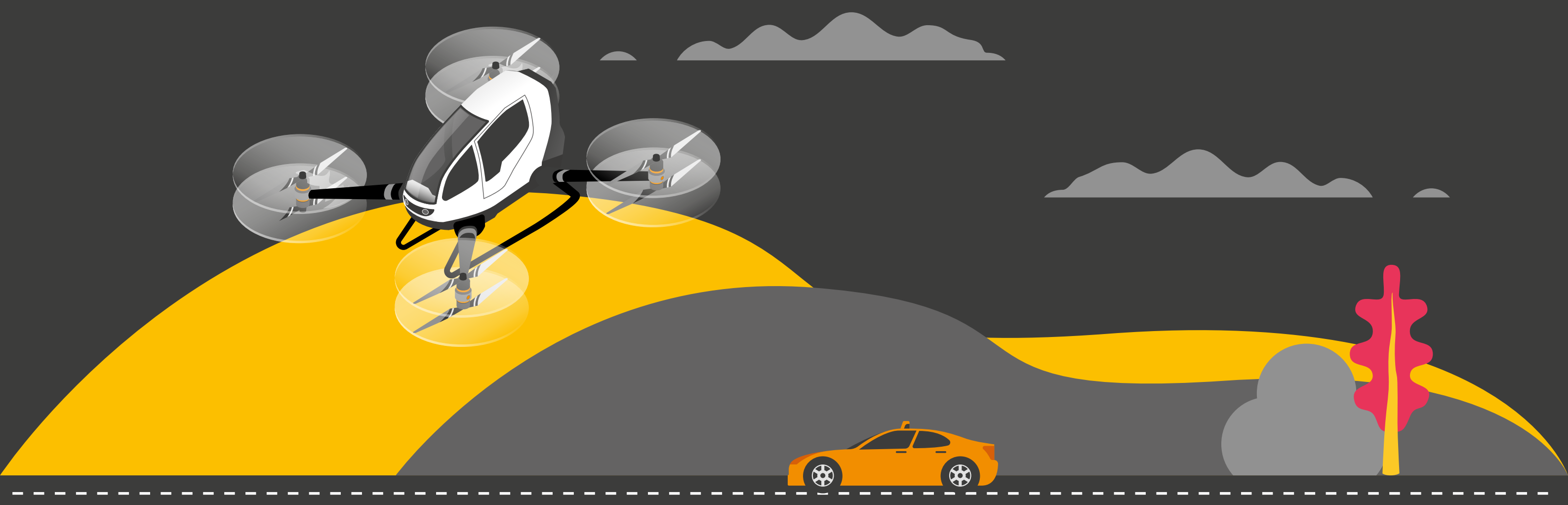
1. **Define the use cases and counterfactuals** to capture a selection of potential journeys that AAM technology could replace, including the different journey segments required (e.g. travelling to a vertiport). These have been selected to represent a range of different applications and types of journey that illustrate the versatility of AAM technology. A summary of our use cases are provided in Table 2.
2. **Estimate annual journeys and total journeys completed per vehicle lifetime** based on assumptions around capacity, operating hours and cruising/charging speed. This allows us to estimate the capital and operational costs per journey.
3. **Estimate capital and operational costs** using market research and expert input to develop a bottom-up approach to calculate the total costs. Based upon our capacity and utilisation assumptions, we have calculated the associated cost of operating an eVTOL per journey. As outlined above, we use this with estimated journey numbers to estimate the cost attributed to each journey i.e. the fare cost.
4. **Identify and quantify associated externalities of journeys**, that is the wider social implications of mode choice beyond the private fare and time costs to individuals. This includes the costs of accidents, CO2 emissions and references to noise pollution.
5. **Undertake sensitivity analysis** by varying key assumptions to test the robustness of our results to different scenarios, which illustrate the uncertainty and wide range of potential outcomes relating to AAM technology adoption.

Our analysis covers the fifteen years from 2025 to 2040 and many factors are unlikely to remain fixed over this period. We vary assumptions (e.g. around capital and direct operating costs) over time in five year intervals: 2025-2029, 2030-2034, and 2034-2040.

[60] Transport Analysis Guidance, DfT, November 2022, link
[61] The Green Book (2022), HM Treasury, November 2022, link
[62] National Travel Survey (2019), DfT, August 2020, link.
[63] UKRI, Future Flight Challenge Socio-economic study, January 2021, link

Table 2: Use Case summary

Route		Description	eVTOL Capacity	Setting	Distance
Urban Private Hire		Replace a taxi journey with an eVTOL 'taxi' service. Use case replaces a single taxi journey for one person with a single eVTOL journey for one person.	4-5	Intra city	8km – 16km
Rural Hire	Individual	Replace a private car journey with an eVTOL 'taxi' service. Use case replaces a single private car journey of only the driver with a single eVTOL journey for the one person.	4-5	Rural	16km – 40km
	Rideshare	Replace 3 private car journeys with an eVTOL 'taxi' service (similar to Uber "pool" mode). Use case replaces 3 individual car journeys with a single eVTOL journey with 3 occupants.	4-5	Rural	40km – 80km
Sub-Regional Shuttle		Replace rail travel with an eVTOL 'shuttle' service. Use case replaces 5 passengers on a train journey with a single eVTOL journey with 5 passengers. The eVTOL route is fixed between 2 set vertiport locations.	11-12	Regional	100km – 160km
Cargo Delivery		Replace road transportation with an eVTOL goods service. Use case replaces a van transporting a payload of 350kg with an eVTOL carrying the same payload, representing middle mile transportation (e.g. warehouse to warehouse).	4-5	Urban	50km – 100km
Air Ambulance		Replace emergency air ambulance with an eVTOL service. Use case replaces traditional Air Ambulance helicopters with eVTOLs. Use cases represent rapid response journeys to emergency situations, particularly applicable in hard-to-reach rural locations.	4-5	Rural	60km – 100km



Core sensitivities

Our research and engagement has identified that some of the assumptions made for the core case calculations are particularly uncertain. We address this by including key sensitivities for each case study. In some instances we vary the sensitivity by use case. Table 3 shows our mapping of sensitivities to use cases.

Table 3: Use case sensitivity testing

	Urban Private Hire	Rural Private Hire	Rural Rideshare	Sub-regional Shuttle	Cargo Delivery	Air Ambulance
Higher eVTOL costs	✓	✓	✓	✓	✓	✓
Lower eVTOL costs	✓	✓	✗	✗	✗	✗
Reduced flying window	✓	✓	✓	✓	✓	✗
Increased time to vertiports	✓	✓	✓	✓	✗	✗
Decreased eVTOL lifetime	✓	✓	✓	✓	✓	✓
Earlier autonomous capability	✓	✓	✓	✓	✓	✓
Alternative counterfactual	✗	✗	✗	✗	✓	✗
Rideshare use cases	✓	✓	✗	✗	✗	✗

Higher eVTOL costs

Our core analysis assumes that 4-5 seat eVTOLs cost approximately £3.0m. This aligns to the lower end of industry figures, eVTOL capital costs are usually in the £3-5m range and they typically seat 4 or 5 passengers. We therefore test the economic viability of eVTOLs if they cost £5.0m, towards the upper end of market estimates.

Lower eVTOL costs

Our core analysis assumes that 4-5 seat eVTOLs cost approximately £3.0m. Evidence suggests that eVTOLs such as the EHang,[64] may have significantly lower capital costs because they are tailored to shorter journeys with a lower capacity of two passenger seats. We therefore test the economic viability of eVTOLs if they cost £182k, aligned with the cheapest potential market supplier. There may be other impacts of using this type of eVTOL, for example in terms of comfort that we have not considered in the analysis.

Reduced flying window

Our assumptions around operating hours, utilised hours, and flight ready hours equate to a flying window of over 12 hours for all use cases. This may be optimistic in the short-term, and so we test the impact of reducing the flying window by 20%.

Increased time to vertiports

We have assumed that a vertiport is located within close proximity at the start and end of the passenger journey, meaning that passengers only need to take a short walk from their starting point and to their destination. As AAM technology is at the beginning stages of entering the commercial market, with few vertiports available initially, we test the impact of increasing the travel to vertiport time by a factor of four.

Decreased eVTOL lifetime

We have assumed that eVTOLs have a lifetime of 10 years based on market information and the anticipated level of technological evolution. Depending on the rate of technological development, the lifetime may be shorter. In our sensitivity analysis we explore the impact of reducing the eVTOL lifetime to five years to illustrate the impact this would have on the use case.

Earlier autonomous capability

Our model assumes that eVTOLs become autonomous by 2035, at which point there is no longer a need for a physical pilot to sit in the cockpit and that there will be remote pilots responsible for managing multiple eVTOLs. There is much debate in the AAM industry on when autonomous capabilities will be developed and approved by regulatory authorities, although some are already entering international markets (e.g. EHang). We therefore test the economic implications of eVTOLs becoming autonomous in 2030.

Alternative counterfactual

Our core Cargo Delivery scenario has a road transport counterfactual because it is the most common mode of transport for middle-mile delivery. We have selected a small vehicle as the maximum payload is comparable to that of an eVTOL. There are an array of existing alternative modes of transport which eVTOLs could be compared against. We test the economic viability of eVTOLs against cargo planes transporting 2.1 tonnes of cargo as they have more similarities as a mode of travel whilst representing a larger market than helicopters. Transporting this quantity of cargo will require multiple eVTOL trips so we calculate the average cost per eVTOL trip for consistency when comparing against our core case.

Rideshare use cases

The AAM industry often references shorter, high occupancy journeys when showcasing eVTOL applications. We test the economic viability of shorter rideshare journeys by applying the same principles of the Rural Rideshare use case to the Urban Private Hire and Rural Private Hire use cases. In this sensitivity we replace three counterfactual journeys, from the same starting point to the same destination, with a single eVTOL journey.

[64] EHang AAV: The Era of Urban Air Mobility is Coming, Ehang, 2022, link

Phase 2: Scaling methodology and AAM estimates

Estimating the overall impact of journey substitutions requires scaling up the benefits of a single journey to the aggregate number of trips over time. For this study we have assumed that no new journeys happen as a result of eVTOL deployment, and so these aggregate benefits are only for substituted journeys and exist because they have replaced a less desirable journey (in terms of time, cost, environmental or accident risk factors). This means that entirely new journeys or alternative use cases stimulated by the availability of AAM technology are excluded – these will likely have at best a neutral impact in terms of CO2 emissions[65].

Negative impacts may be offset by positive effects such as increased connectivity or tourism for hard-to-reach areas. Where our use case analysis shows that using an eVTOL is less desirable than the existing mode of transport, we assume individuals would not substitute their journey and so the net impact is zero. To estimate eVTOL journeys to 2040 we:

1. **Identify the number of current counterfactual journeys that are relevant to each of our use cases**, giving a baseline for the total journeys individuals could substitute away from. We use the 2019 National Travel Survey,[66] which provides information about the number of trips per person by year, distance travelled, and mode of transport.
2. **Estimate the change in number of journeys per year for the relevant period (2025-2040)** by assuming that the number of journeys will increase in line with urban and rural population growth[67] (as some journeys will only happen in urban areas, and some in rural areas).
3. **Assume an S-curve of adoption to estimate the proportion of journeys that could be replaced by eVTOLs**, using our Skies Without Limits v2.0 adoption curve for drones as a starting point given uncertainty about the market. To illustrate how the potential magnitude of impact can differ between uptake scenarios we create two S-curves, one which caps at a substitution rate of 5.0% in 2040 and the other at 2.5%.

We tailor the S-curve across the use cases to reflect their differing characteristics. For example, the Sub-Regional Shuttle adoption curve does not begin until 2030 because we assume the later 12 person eVTOL will not enter the market as early as mature 4-5 capacity vehicles. Table 4 lists the start point of each use case, which are also illustrated in Figure 3.

Table 4: AAM use case scaling year Table 2

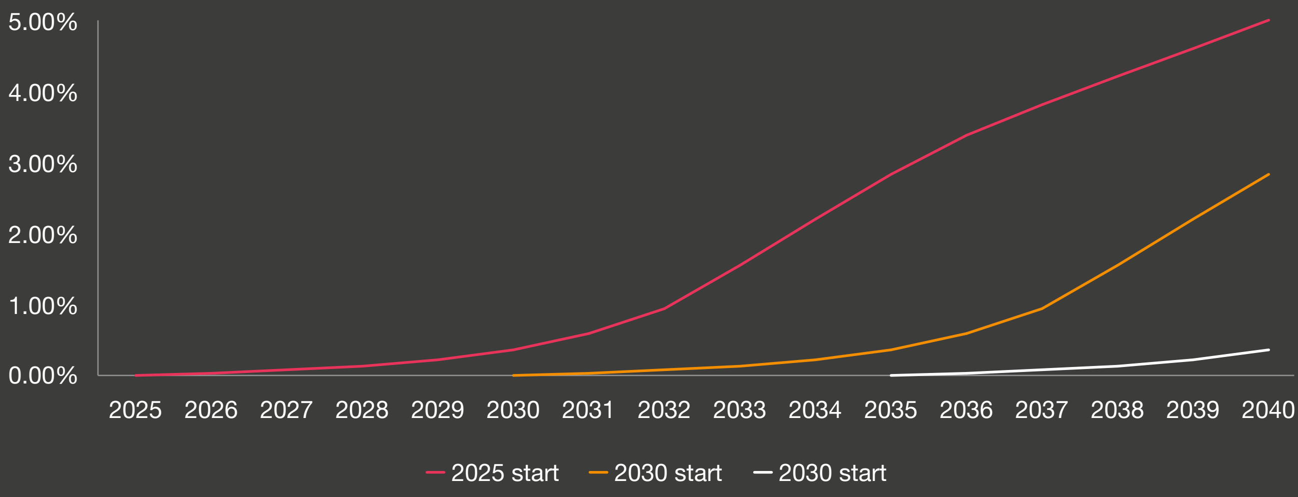
Use case	Scaling start year
Urban Private Hire	Not scaled
Rural Private Hire	Not scaled
Rural Rideshare	2025
Sub-Regional Shuttle	2030
Cargo Delivery	Not scaled
Air Ambulance	2025

The scaled number of AAM journeys provides a basis for calculating the number of eVTOLs, pilots and vertiports required to service this portion of the market. To do this we:

1. **Combine estimates of the number of annual journeys substituted by eVTOLs and annual journeys completed by an individual eVTOL to** understand how many eVTOLs would be required to meet demand at an annual and cumulative level.
2. **Estimating the number of pilots as a function of eVTOLs in the market** – our assumptions around operating hours allow us to estimate the number of FTE pilots required. In 2035 we assume that the autonomous technology will be deployed across all eVTOLS, meaning that only remote pilots are required and will be responsible for operating 4 vehicles each.
3. **Estimate the number of vertiports required using a ratio of eVTOLs to vertiports** – we assume that eVTOLs will be stored at vertiports outside of operating hours (i.e. overnight) and an average ratio of 6 eVTOLs per vertiport.

[65] There will also be broader negative effects such as noise that are not quantified in this study.
[66] National Travel Survey, DfT, Table NTS0308a, link
[67] Annual Population Survey, NOMIS, Jan 2023, link

Figure 3: AAM S-curves of adoption, capped at 5%



Phase 3: Net impact to the UK economy

Combining the individual use case estimates with our estimates for the total scaled number of AAM journeys by use case enables us to make indicative estimates of the net UK-wide impact of substituting counterfactual journeys with AAM technology:

1. **We discount the impacts of each individual use case journey** throughout our appraisal period using the recommended Green Book discount rates.[68] This bases the costs and benefits in 2022 prices.
2. **We aggregate total annual benefits from each scaled use case** to estimate the real and cumulative benefits associated with substituting from one journey type to another.

We present results in ranges to reflect the uncertainty around the launch timeline and pace of uptake of eVTOLs in the UK, particularly the regulatory requirements and passenger willingness to substitute away from existing transport modes. The interpretation of these results is that they represent the private and social benefits that could arise from individuals switching their modes of transport and should not be considered additive to national account figures such as GDP (or as financial impacts, given the use of non-market valuation techniques).

[68] We have used the core Green Book discount rate of 3.5% to discount the value of time, fares and accidents. We have used the intergenerational discount rate of 1.5% to discount CO2 emissions.

5
Key findings

This section presents the results of analysis on an individual use case and aggregate level. Our use cases have been selected to demonstrate the range of journeys eVTOLs could service, and how different factors will influence their relative desirability. Our analysis is based on averages, and will therefore not reflect the full spectrum of responses – for example, there will be individuals who are happier to spend more on fares or value time more highly which will not be reflected in central results (and vice versa).

We define a counterfactual for each use case based on the most directly comparable and common mode of transport that is currently used to make those trips – for example, Urban Private Hire journeys are more likely to take place in a ride-hailing car than on a scooter.

As different journeys have different associated costs, we only model those relevant to that mode of transport. For example, privately hired vehicles include passenger fare costs where cargo and emergency service trips do not. These are set out in each case study section.

Common themes are summarised below, followed by detailed use case analysis. We present results over the entire appraisal period, and at every 5-year interval to illustrate how a changing market environment impacts the benefits of each use case. Sensitivity analysis tests the robustness of these findings to different scenarios and assumptions.

Summary and common themes across all use cases

The benefits of eVTOLs are expected to increase over time. At the start of our appraisal period, when eVTOLs enter the market, journeys are consistently expected to cost comparatively more than in the future. We expect costs to fall over time as the market matures, leading to benefits including economies of scale in manufacturing and operation, greater technological capabilities.

We can differentiate between private impacts and externalities. Private impacts are the effects directly felt by the individual or firm using eVTOLs for journeys or services. In our analysis, the private effects consist of time savings and fare prices. Externalities are impacts felt by third parties not participating in the transaction and are not captured in the prices charged for the good or service producing them.

eVTOL journey distances differ from the counterfactual because they represent a modal shift. eVTOLs are able to take a more direct route by air compared to existing land-based travel as illustrated by the Urban Private Hire case study where the taxi is 12km compared to 8km for the eVTOL. This does not apply to the Air Ambulance as both use air travel.

Shorter passenger journeys face a trade-off between time savings and the cost of a higher fare, as demonstrated in the Urban Hire and Rural Private Hire use cases. This means consumer preferences and the value placed on time will be a key determinant of uptake. This implies that AAM adoption will predominantly be for individuals that place a high value on their time (e.g. in business settings) and are more willing to pay the additional cost incurred by using eVTOLs.

CO2 emissions are high for shorter journeys. The energy intensity of take-off and landing is significantly higher than cruising meaning that the energy consumption per kilometre of shorter journeys is significantly higher than long distances.[69] This means that eVTOL emissions are higher than internal combustion engine (ICE) car and taxi journeys in our Urban Private Hire and Rural Private Hire use cases when accounting for upstream emissions in energy generation. Emissions per kilometre are estimated to decrease over longer journeys and over time as the transition towards renewable energy generation means that electricity generation relies less on fossil fuels.

Longer journeys are more economically viable for eVTOLs as they are expected to be significantly faster than trains or cars meaning that they will be able to deliver greater time savings over longer distances. Energy efficiency will also increase over distance due to a greater proportion of time spent cruising rather than conducting energy intensive activities like taking-off and landing. The average fare cost per passenger per kilometre decreases as the use case distance increases because a greater proportion of time is spent completing revenue generating travel compared to the fixed time costs of activities such as boarding passengers.

Early substitution towards AAM is more likely in cases that are economically viable, and our results suggest that even when using favourable assumptions, AAM technology is only viable for a limited number of use cases. It is likely AAM services will primarily be focused on profitable applications when they enter the market or where the current transport provision is poor or expensive.

There are a suite of impacts that cannot be robustly quantified but should be considered as part of a holistic appraisal. Our use case analysis captures the main impacts but is not exhaustive; there are a range of other economic, social and environmental effects – such as the impacts of noise and visual pollution, or improved innovation and access to services – that we do not capture. In particular, AAM noise impacts have the potential to deliver significant benefits but are heavily reliant on place-based characteristics and difficult to quantify robustly.

> "It is likely AAM services will primarily be focused on profitable applications when they enter the market or where the current transport provision is poor or expensive."

[69] Sirpad S, Viswanathan V, The promise of energy-efficient battery-powered urban aircraft, June 2021, link.

Urban Private Hire

This use case is based in an urban environment where the counterfactual, a taxi or Uber journey, is replaced by an eVTOL journey for the same distance. The counterfactual journey is an Uber for one passenger that travels a total distance of 12km, the corresponding journey is assumed to be shorter for AAM because eVTOLs are able to take a more direct route via air travel.

The journey could be supplied by an Uber or taxi, however we will refer to Ubers as the modelling is based on the Uber pricing structure. For this use case, we model the costs associated with:

- Fare price
- Time cost
- Accidents
- CO_2 emissions

Counterfactual

Taxi

1	2	3
Passenger books an Uber and waits for it to arrive	Passenger is picked up by the Uber and travels from their starting point to the destination	The Uber arrives at the drop-off point and the passenger disembarks

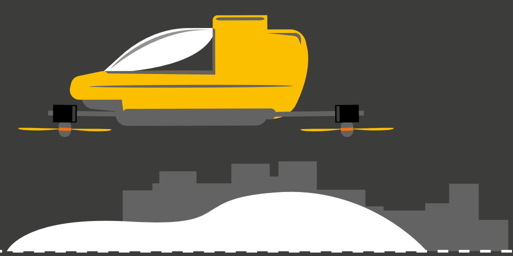
Location A → **Location B**

A → B: **12 km**

Use Case

eVTOL

1	2	3	4
Passenger books an eVTOL and walks from their starting point to a nearby vertiport	Passenger enters the vertiport and boards the waiting eVTOL	The eVTOL takes-off and travels from Vertiport B to Vertiport C	Passenger disembarks and travels to final destination



Start A → **Vertiport B** B → **Vertiport C** C → **End** D

B → C: **8 km**

Figure 4: Change in Urban Private Hire use case and counterfactual costs

Results

eVTOLs are significantly more expensive than the Uber counterfactual throughout our appraisal period, meaning AAM technology is not economically viable, unless consumers value marginal time savings above higher fare costs.

Figure 4 shows that use case costs are expected to be approximately double the counterfactual in 2025. The use case fare is 224% higher than the counterfactual and is 80% of the net cost. It is primarily driven by high eVTOL prices and opex estimations, the majority of which can be attributed to pilot costs.

As the eVTOL market grows and becomes more efficient, we expect use case costs to fall but fail to close the price gap compared to the counterfactual.

Our use case is expected to be approximately 8 minutes quicker than the counterfactual given congestion and travel assumptions, leading to a monetised benefit of £4.72 per journey.

The estimated cost of accidents per journey is negligible compared to the other benefits, equivalent to less than £0.01 and £0.24 in the use case and counterfactual respectively. We assume that eVTOLs will have the same accident rate as domestic passenger air travel, meaning that the accident rate is much lower than that of cars.

CO2 emissions are higher for an eVTOL journey than the counterfactual: landing and take-off consume much more energy than cruising, meaning that shorter eVTOL journeys are energy intensive. This results in an additional 2.6kg of CO2 emissions, with a value of £0.68.

We assume that eVTOL capital and operating costs will decrease over time as the market matures and benefits from economies of scale, and such that **by 2030, eVTOL journey costs are 74% higher than the counterfactual,** a significant decrease from the 2025 estimate. The reduction in eVTOL costs are set against an increase in counterfactual costs driven by increased congestion in urban areas which is not offset by increased Electric Vehicle uptake. Nevertheless, fare costs to individuals are still higher for eVTOLs for this time period.

In 2035, Figure 4 shows that use case costs are expected to be 22% higher than the counterfactual, despite use case costs falling significantly as eVTOLs are assumed to become autonomous. This reduces the need for pilots that are a key driver of fare prices. Despite the associated reductions in fares, they remain 86% above the counterfactual and so uptake is less likely for individuals who place a lower value on their time.

Sensitivity analysis

We use sensitivity analysis to explore how changes to key inputs and assumptions for our use case impact results. The sensitivities shown below were selected based upon their materiality, associated level of uncertainty and/or likelihood of occurring.

Commentary

Sensitivity analysis suggests that mass market take-up is unlikely in the Urban Private Hire use case – the sensitivities and core scenario consistently estimate eVTOL fares will remain higher than taxi fares. This implies the takeup demographic is more likely to be individuals who place a higher value on time and a lower value on monetary cost/fares (e.g. business and/or affluent travellers as opposed to the general population.

"Sensitivity analysis suggests that mass market take-up is unlikely in the Urban Private Hire use case – the sensitivities and core scenario consistently estimate eVTOL fares will remain higher than taxi fares."

Table 5: Sensitivity analysis, AAM cost per journey and percentage change in cost per journey

Core scenario		2025-2029	2030-2034	2035-2040
Base use case cost		**£75.15**	**£68.93**	**£50.89**
Counterfactual cost		**£37.68**	**£39.68**	**£41.78**
Sensitivity	Test	**2025-2029**	**2030-2034**	**2035-2040**
Higher eVTOL costs	+ £2.0m cost	**£90.14** (+20%)	**£79.61** (+15%)	**£59.55** (+17%)
Lower eVTOL costs	– £2.8m cost	**£54.03** (-28%)	**£49.80** (-28%)	**£34.21** (-33%)
Reduced flying window	– 20% flying window	**£90.8017** (+21%)	**£82.84** (+19%)	**£59.67** (+17%)
Increased time to vertiports	4x longer travel time	**£95.76** (+27%)	**£91.49** (+32%)	**£74.42** (+46%)
Decreased eVTOL lifetime	-5 year lifetime	**£97.63** (+30%)	**£90.19** (+30%)	**£68.54** (+35%)
Earlier autonomous capability	+5 years faster autonomy	**£75.15** (+0%)	**£53.90** (-22%)	**£50.89** (+0%)

Rural Private Hire

This use case considers a journey where an individual travels 28km from their start to end destination via private car in a rural setting, and the impact of shifting mode of transport to an eVTOL for the same journey.

We model the costs associated with:

- Fare price
- Time cost
- Accidents
- CO2 emissions

Counterfactual

Private Car

1 Individual gets into their car

2 Individual drives from point A to B

3 Individual parks car at B

4 Individual travels to final destination C

Start — Location A (A) → 28 km → Location B (B) → End (C)

Use Case

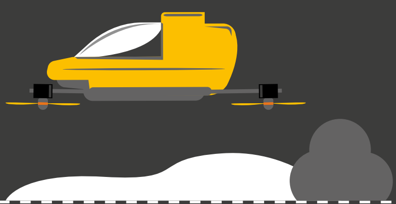
eVTOL

1 Passenger books an eVTOL and walks from their starting point to a nearby vertiport

2 Passenger enters the vertiport and boards the waiting eVTOL

3 The eVTOL takes-off and travels from Vertiport B to Vertiport C[70]

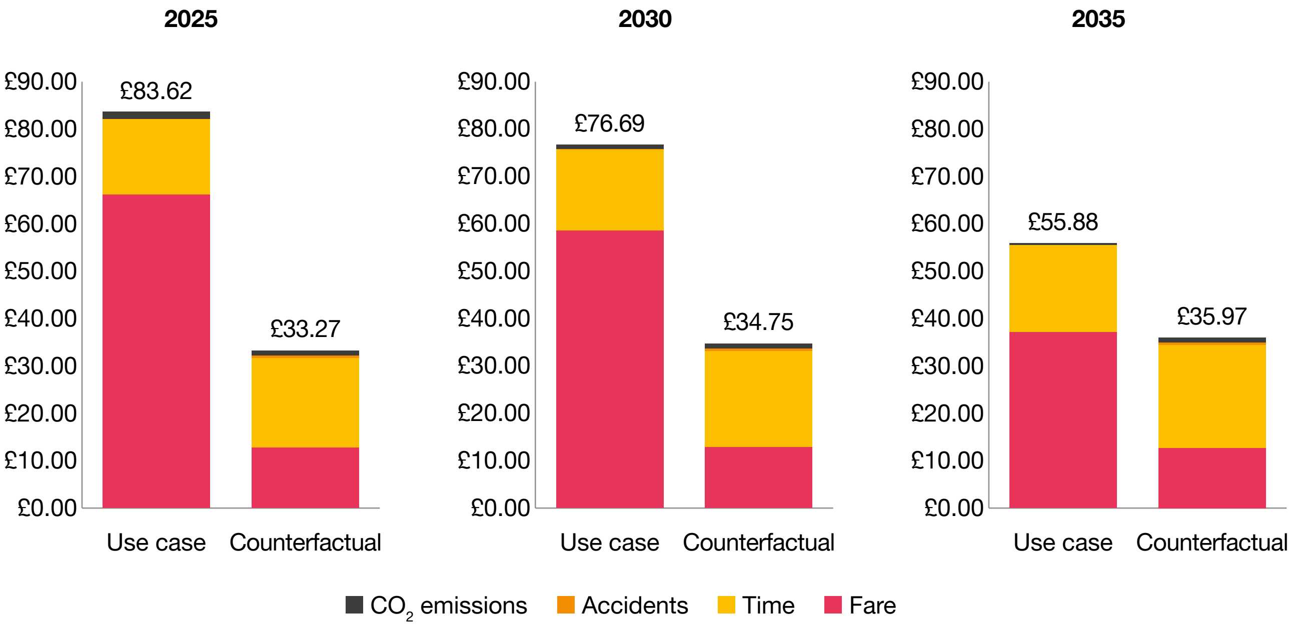
4 Passenger disembarks and travels to final destination D



Start (A) → Vertiport B (B) → 20 km → Vertiport C (C) → End (D)

[70] The journey length is slightly longer due to the deadhead distance i.e. non-revenue generating travel.

Figure 5: Change in Rural Private Hire use case and counterfactual costs



Results

We anticipate that AAM journeys remain significantly higher than counterfactual costs from 2025-2040 due to high fare costs. Figure 5 visualises the cost breakdown of the Rural Private Hire during our appraisal period.

In 2025, use case costs are expected to be 153% higher than the counterfactual. High fare costs are almost entirely responsible for the relatively higher eVTOL costs along with lower costs of owning and driving a car. Operating costs are a core driver of fare costs due the high cost associated with piloting eVTOLs. Capital costs, primarily driven by eVTOL prices, play an equally important role in driving fare costs.

Results show that eVTOL journeys are marginally quicker in the Rural Private Hire use case, with a time savings of approximately 7 minutes and monetary value of £2.99. Although the journey itself is quicker, the time associated with travelling to a vertiport and boarding an eVTOL almost completely offset the time savings from the faster travel speed.

Forecasted accident costs per journey are expected to be significantly lower in the use case equivalent to £0.02 compared to £0.55 in the counterfactual.

We estimate that CO2 emissions will be 1.5kg higher in the use case, equating to £0.38. The high energy intensity of take-off and landing mean that the eVTOL journey produces more emissions[71] compared to the counterfactual despite the majority of car travel using hydrocarbon fuel.

In 2030, use case costs are expected to be 121% higher than the counterfactual, becoming somewhat more competitive as capex and direct opex costs are expected to reduce due to economies of scale (i.e because of manufacturing volume and network effects).

In 2035, use case costs are expected to be 55% higher than the counterfactual. The switch to autonomous eVTOLs in the 2035 use case improves competitiveness through reduced fare costs. Despite the fall in operating costs, high vehicle eVTOL costs mean that the fare is still significantly higher than the counterfactual, offsetting benefits from time savings, reduced accidents and emissions.

[71] Emissions are produced from upstream electricity generation rather than energy consumption.

Sensitivity analysis

We use sensitivity analysis to explore how changes to key inputs and assumptions for our use case may change the results.

Commentary

The cost of an eVTOL journey is significantly higher than the counterfactual in all settings, with even the smallest differential equivalent to more than 19% of the core scenario journey cost. Although earlier autonomous capability does improve the differential this is not sufficient to offset the higher costs and in the scenario where it takes longer to go to a vertiport the costs are nearly tripled for an eVTOL journey. It is unlikely that this use case would see much uptake.

> "The cost of an eVTOL journey is significantly higher than the counterfactual in all settings, with even the smallest differential equivalent to more than 19% of the core scenario journey cost."

Table 6: Sensitivity analysis, AAM cost per journey and percentage change in cost per journey

Core scenario		**2025-2029**	**2030-2034**	**2035-2040**
AMM base use case cost		**£83.62**	**£76.69**	**£55.88**
Counterfactual cost		**£33.27**	**£34.75**	**£35.97**
Sensitivity	Test	**2025-2029**	**2030-2034**	**2035-2040**
Higher eVTOL costs	+ £2.0m cost	**£100.06** (+20%)	**£88.41** (+14%)	**£65.07** (+16%)
Lower eVTOL costs	– £2.8m cost	**£60.46** (-28%)	**£55.80** (-28%)	**£38.19** (-32%)
Reduced flying window	– 20% flying window	**£99.51** (+19%)	**£93.70** (+21%)	**£65.91** (+18%)
Increased time to vertiports	4x longer travel time	**£111.39** (+33%)	**£106.90** (+38%)	**£87.25** (+56%)
Decreased eVTOL lifetime	-5 year lifetime	**£108.28** (+29%)	**£99.97** (+29%)	**£74.60** (+33%)
Earlier autonomous capability	+5 years faster autonomy	**£83.62** (+00%)	**£60.28** (-22%)	**£55.88** (+00%)

Rural Rideshare

We explore the impact of consolidating three individual trips into a single eVTOL journey. In the counterfactual, three individuals start their own separate journeys from nearby locations (for instance within the same village) and travel to the same destination, where the average journey length is 60km. The journey distance is reduced for the use case because eVTOLs are assumed to take a more direct route compared to cars. Refer to the visual representation below.

The use case estimates the potential impacts of an eVTOL completing the same journey, however the three individual counterfactual journeys are consolidated into a single eVTOL journey with passengers needing to complete a short trip at each end of their trips to travel to and from the vertiports. We model the costs associated with:

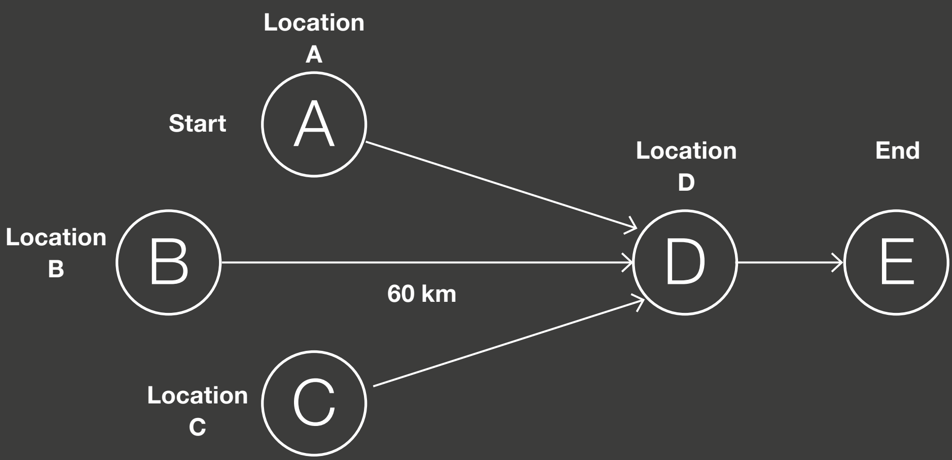
- Fare price
- Time cost
- Accidents
- CO_2 emissions

1 Each individual gets into their car

2 Each individual drives from their respective starting point to the same destination, location D

3 Individuals park their car

4 Individuals travel to final destination



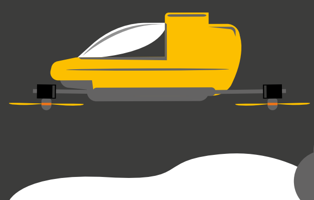
eVTOL

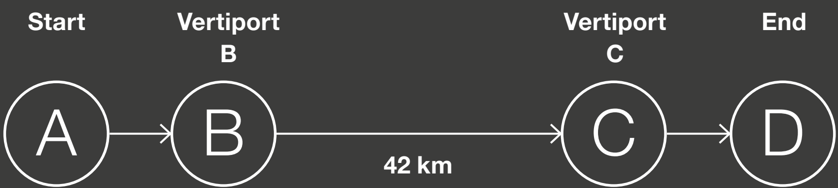
1 Each passenger books an eVTOL and walks from their starting point to a nearby vertiport[72]

2 Passengers enter the vertiport and boards the waiting eVTOL

3 The eVTOL takes-off and travels from Vertiport B to Vertiport C

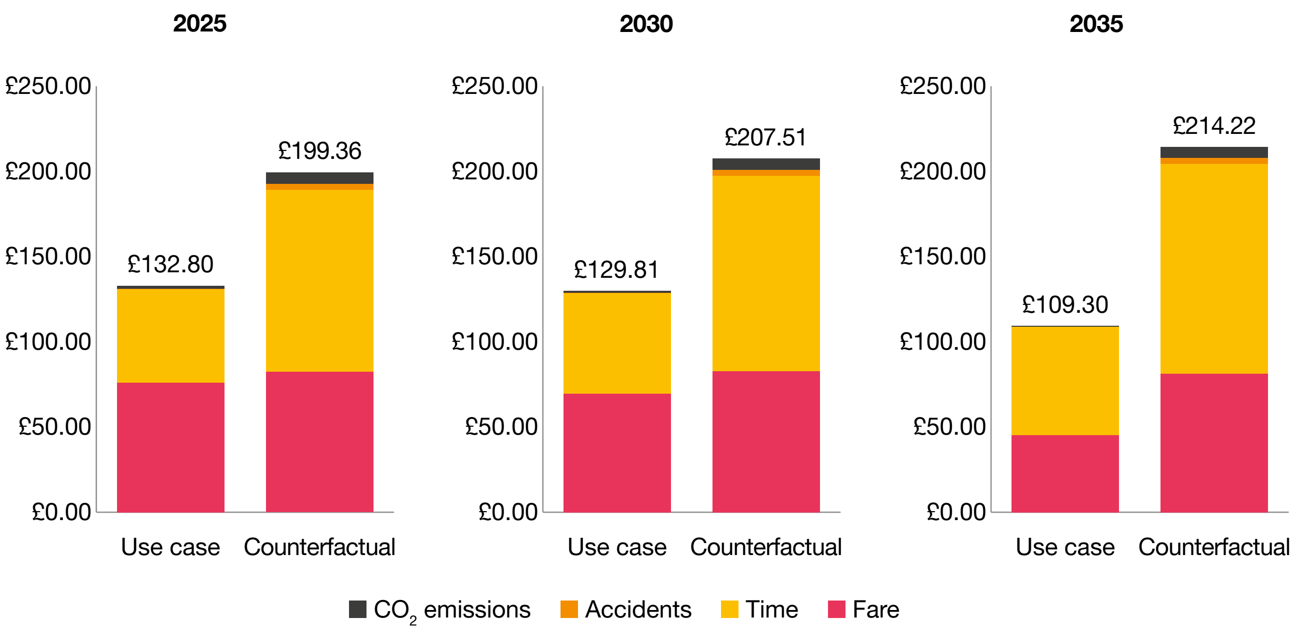
4 Passenger disembarks and travels to final destination





[72] Each passenger books their own individual journey, however the eVTOL app coordinates similar rides much like current Uber rideshare technology.

Figure 6: Change in Urban Private Hire use case and counterfactual costs



Results

Our results suggest that the use case will deliver significant savings across all considered timeframes and impacts, with the greatest benefit delivered through fare costs and time savings. We expect the relative benefits to increase over time, primarily due efficiency gains from a larger eVTOL market, but also because of changes to inputs such as falling CO2 emissions attributed with electricity generation.

In 2025, use case costs are expected to be 34% lower than the counterfactual. The eVTOL fare is 8% lower than the counterfactual because the use case replaces three individual car journeys with a single eVTOL journey, meaning that even though it has a higher cost per km, the reduction in net distance travelled delivers major savings.

Time savings represent the greatest individual benefit area in this use case. Increased travel distance means that the time associated with travelling to a vertiport and boarding an eVTOL is offset by higher eVTOL travel speeds. We estimate that the eVTOLs could provide time savings of approximately 40 minutes per passenger, providing a net time savings of 120 minutes per journey with an equivalent monetary value of £51.71.

The assumed lower accident rate of eVTOL travel, benchmarked against commercial aviation, means that average cost of accidents per journey is very small compared to the counterfactual as with other use cases.

We have estimated that the use case produces about 20.5kg less CO2 compared to the counterfactual, with a monetary value of £5.33. In this use case, there would be CO2 savings even if just one car journey were replaced with a single eVTOL journey, unlike the urban and rural private hire examples first: the longer journey length means that the net CO2 emissions per km from an eVTOL are lower than the counterfactual, a car journey.

In 2030, use case costs are expected to be 37% lower than the counterfactual. Decreases in eVTOL costs paired with increases in the cost of driving a car mean that the relative price of an eVTOL fare is 15% lower than the counterfactual.

In 2035, use case costs are expected to be 49% lower than the counterfactual. Higher time values and lower eVTOL operating costs, driven by a switch from manned flights to autonomous, mean that the fare price of the use case is expected to fall to almost half of the counterfactual.

Sensitivity analysis

We use sensitivity analysis to explore how changes to key inputs and assumptions for our use case may change the results.

Commentary

The Rural Rideshare use case is economically viable against all sensitivities by 2035 and under most sensitivities from 2025. Our core scenario achieves a strong benefit margin meaning that the net impact still achieves benefits in most cases.

Travel time to and from vertiports is a key determinant of net benefit because the majority of benefit derives from time savings. If vertiports locations are inconvenient then this will significantly reduce the potential benefit of AAM travel, although the switching value suggested by our modelling (with a factor 4 increase still being sufficiently offset overall in 2035-2040) is relatively high.

Rideshare sensitivity testing

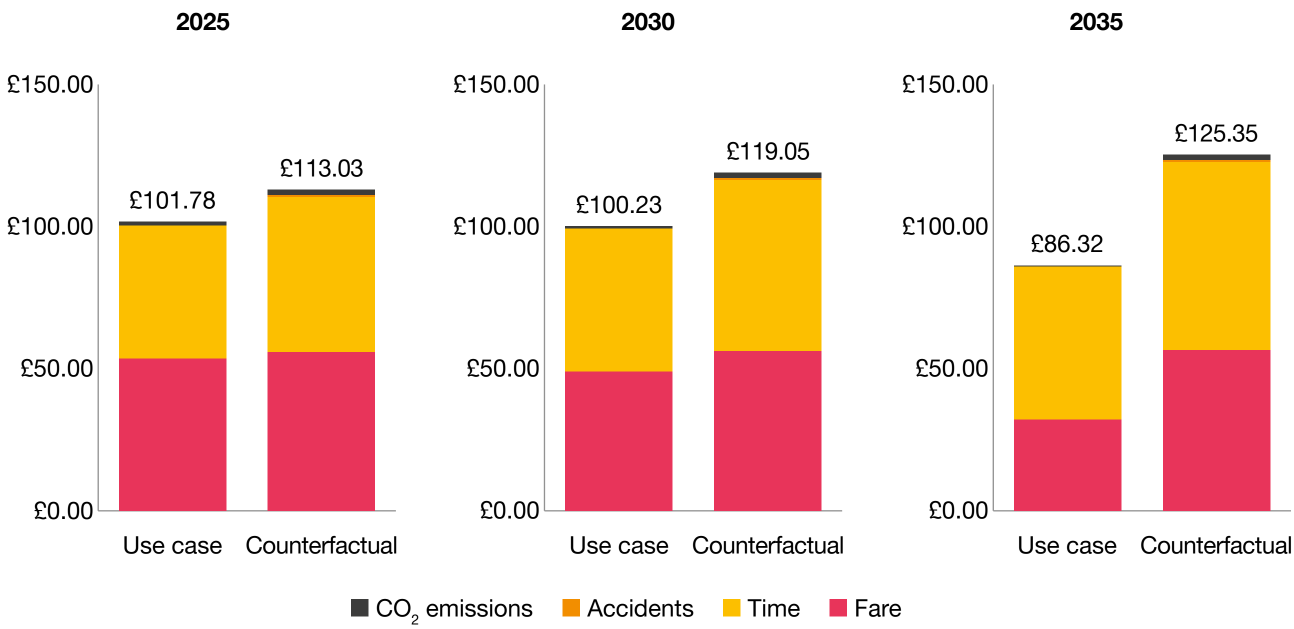
We test the economic viability of rideshare style journeys against the different distances set out in our Urban Private Hire and Rural Private Hire use cases as the market commonly references these types of journeys with short distances and high occupancy. For these sensitivities we maintain the assumption that an individual eVTOL journey replaces three counterfactual journeys where one person is travelling alone. In the Urban Private Hire we substitute three 10km taxi journeys whilst we substitute three 28km car journeys in the Rural Private Hire.

Table 7: Sensitivity analysis, AAM cost per journey and percentage change in cost per journey

Core scenario		**2025-2029**	**2030-2034**	**2035-2040**
AAM base use case cost		**£132.80**	**£129.81**	**£109.30**
Counterfactual cost		**£199.36**	**£207.51**	**£214.22**
Sensitivity	Test	**2025-2029**	**2030-2034**	**2035-2040**
Higher eVTOL costs	+ £2.0m cost	**£151.67** (+14%)	**£143.65** (+10%)	**£120.53** (+10%)
Reduced flying window	– 20% flying window	**£150.08** (+13%)	**£146.25** (+12%)	**£119.65** (+9%)
Increased time to vertiports	4x longer travel time	**£212.91** (+60%)	**£216.59** (+66%)	**£201.57** (+84%)
Decreased eVTOL lifetime	-5 year lifetime	**£161.11** (+21%)	**£157.35** (+21%)	**£132.18** (+21%)
Earlier autonomous capability	+5 years faster autonomy	**£132.80** (+0%)	**£110.32** (-15%)	**£109.30** (+0%)

Table 8: Rideshare sensitivity analysis for Urban Private Hire use case

Core scenario	2025-2029	2030-2034	2035-2040
Urban Private Hire – Rideshare	**£101.78**	**£100.23**	**£86.32**
Counterfactual cost	**£113.03**	**£119.05**	**£125.35**



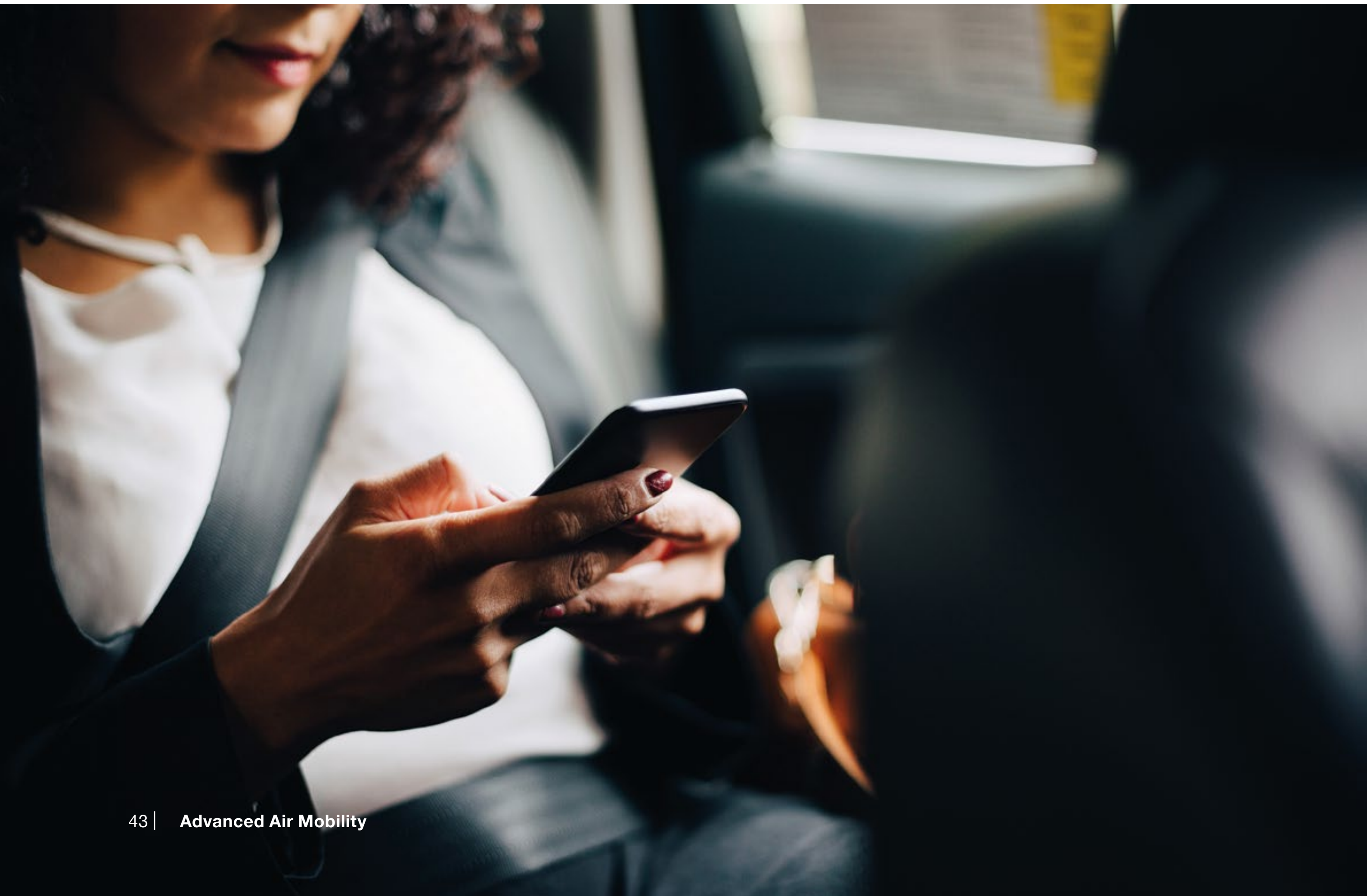
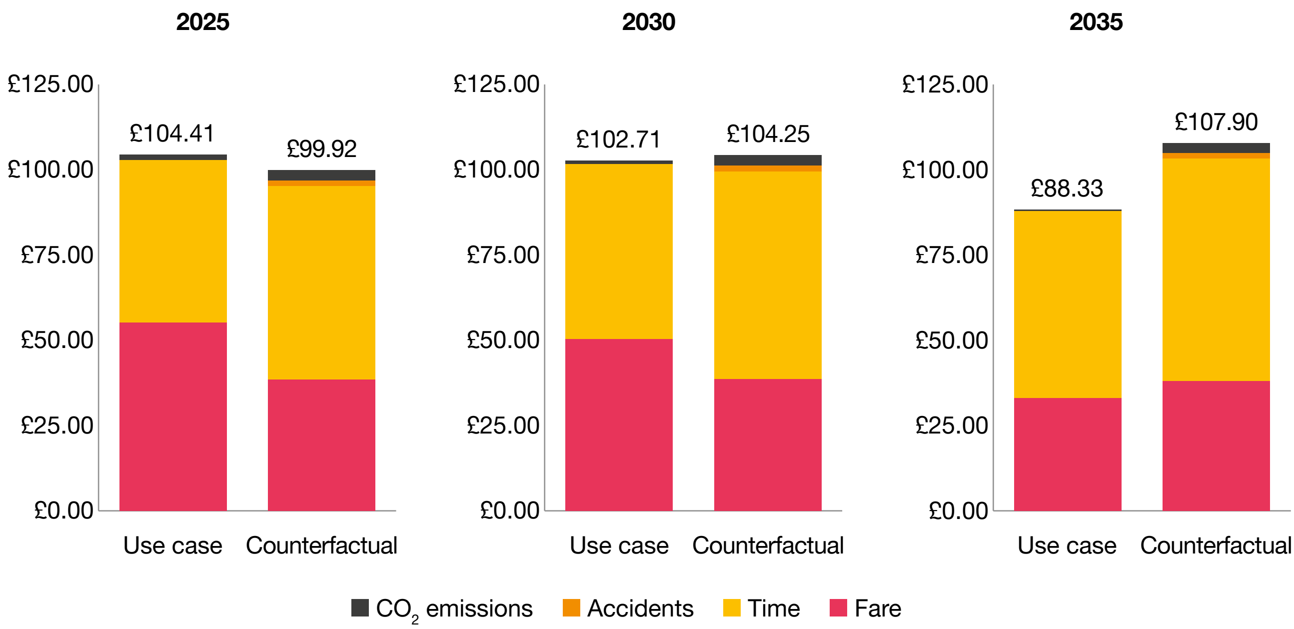


Table 9: Rideshare sensitivity analysis for Rural Private Hire use case

Core scenario	2025-2029	2030-2034	2035-2040
Rural Private Hire – Rideshare	**£104.41**	**£102.71**	**£88.33**
Counterfactual cost	**£99.92**	£104.25	**£107.90**



Rideshares are shown to be economically viable in both the use cases by 2035 once autonomous technology has significantly reduced fare costs. Urban Private Hire rideshares are 10% cheaper than the counterfactual in 2025, and deliver greater marginal benefits throughout our appraisal period, although the likelihood of an eVTOL journey replacing three separate taxi journeys from the same starting point to the same destination is a strong assumption.

The Rural Private Hire rideshare is not viable in the near-term, with eVTOL costs 4% higher than the counterfactual. As the AAM market matures and eVTOL costs fall, eVTOLs become viable. In 2035, we estimate that eVTOLs are 18% cheaper than the counterfactual of three car journeys.

> “The Rural Private Hire rideshare is not viable in the near-term, with eVTOL costs 4% higher than the counterfactual. As the AAM market matures and eVTOL costs fall, eVTOLs become viable.”

Sub-regional Shuttle

In this use case we estimate the impacts associated with a modal shift from rail travel to an eVTOL journey. The counterfactual represents five individuals travelling on the same train journey of 120km. In the use case, these same passengers switch to a single eVTOL journey which has a lower distance due to more direct air travel. We assume that the AAM journey is shorter, due to a more direct flight path and that a larger eVTOL that is designed for longer journeys with a capacity of 12 is used.

For this use case, we model the costs associated with:

- Fare price
- Time cost
- Accidents
- CO_2 emissions

Counterfactual

Rail

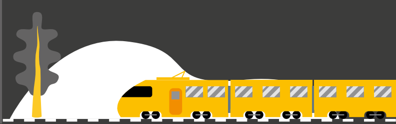
1 Passengers travels from their respective starting locations to train station B

2 Passengers purchase train ticket (or have booked in advance) and wait for train to arrive then board

3 Train travels from point B to C

4 Passengers disembarks train and leaves the station

5 Passengers travel to final destination D



Start A → **Train station B** B → (120 km) → **Train station C** C → **End** D

Use Case

eVTOL

1 Passengers travel from their respective starting locations to the vertiport

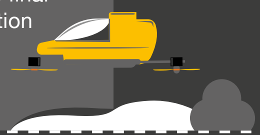
2 Passengers purchase eVTOL ticket (or have booked in advance) and wait for train to arrive

3 Passengers enter the vertiport and boards the waiting eVTOL

4 The eVTOL travels from Vertiport A to Vertiport B

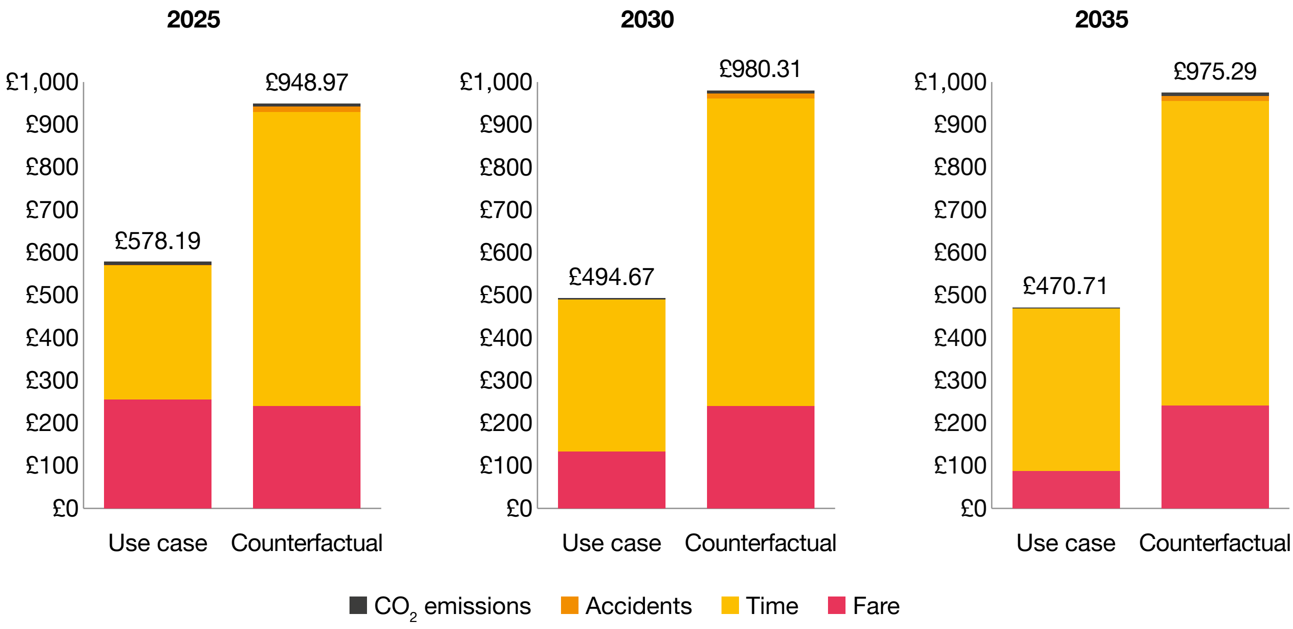
5 Passengers disembark

6 Passengers travel to final destination



Start A → **Vertiport B** B → (85 km) → **Vertiport C** C → **End** D

Figure 7: Change in Sub-regional Shuttle use case and counterfactual costs



Results

Our results in figure 7 show that the use case is significantly cheaper than the counterfactual, driven primarily by time savings. It is likely that the time savings will decrease slightly over time as rail travel becomes faster through investment such as HS2, although this may be offset by advances in AAM technology.

In 2025, use case costs are expected to be 39% lower than the counterfactual. Despite net benefits, the use case fare is estimated to be approximately 6% higher than the counterfactual. The eVTOL fare is modelled using the same bottom up approach as other use cases, which is primarily driven by piloting costs and eVTOL prices. The counterfactual fare cost is based on the price of an anytime day single from York to Preston, at £48.20 per person.[73]

We estimate that the door-to-door eVTOL journey is around 111 minutes quicker than the corresponding rail journey. This has an attributable monetary value of £78.77 per passenger, with a net use case value of £393.85. It is important to note, whilst eVTOLs are quicker than trains, the train also stops at multiple points throughout its journey which significantly slows it down, whereas the eVTOL will only travel between two points of a fixed route.

We have used rail data to estimate the accident cost per km of travel and compared this to the corresponding value for commercial passenger air travel. Using these values gives an average cost of accidents is £0.24 per journey in our use case and £11.82 in the counterfactual, delivering a net benefit of £11.58.

CO2 emissions are estimated to be 12% higher in the use case, equating to 3.1kg more CO2 produced as rail travel is a relatively efficient mode of transport and so more efficient in the short to medium term.

In 2030, use case costs are expected to be 49% lower than the counterfactual, with eVTOL fare prices falling below rail. This stems from reductions in eVTOL prices and operating costs over time, and a fall in average pilot salaries driven by increased automation reducing their capability requirements and so lowering the skills barriers to qualification.

In 2035, use case costs are expected to be 52% lower than the counterfactual due to continued eVTOL cost reductions. Notably, we assume that eVTOLs are fully autonomous by 2035 meaning that piloting costs are almost completely eliminated, with a small allowance for a 'bunker' pilot to remotely manage a number of eVTOLs.

[73] We recognise that it is possible to buy a cheaper ticket (e.g. using a railcard), however we chose to use this as our base case because we have not attributed any discounts for different types of fare or travel times in our use case.

Sensitivity analysis

We use sensitivity analysis to explore how changes to key inputs and assumptions for our use case may change the results.

Commentary

eVTOL journeys deliver benefits across all sensitivities with the exception of increased travel time to and from vertiports. Longer connection times between vertiports erode the time savings from faster eVTOL travel, emphasising the importance that infrastructure accessibility plays in determining the scalability of AAM technology as time savings deliver the majority of benefit.

By 2030 fares are lower than counterfactual train tickets, which strengthens the likelihood of mass market uptake as passengers will be inclined to use eVTOLs even if they place no value on time savings. Benefits from lower accident and CO2 emissions also imply greater social benefits of switching.

Table 10: Sensitivity analysis, AAM cost per journey and percentage change in cost per journey

Core scenario		2025-2029	2030-2034	2035-2040
AAM base use case cost		**£578.19**	**£494.67**	**£470.71**
Counterfactual cost		**£948.97**	**£980.31**	**£975.29**
Sensitivity	Test	**2025-2029**	**2030-2034**	**2035-2040**
Higher eVTOL costs	+ £2.0m cost	**£687.40** (+19%)	**£677.57** (+36%)	**£623.86** (+33%)
Reduced flying window	– 20% flying window	**£647.97** (+12%)	**£533.96** (+7%)	**£494.64** (+5%)
Increased time to vertiports	4x longer travel time	**£1,118.14** (+93%)	**£1,078.08** (+117%)	**£1,092.61** (+132%)
Decreased eVTOL lifetime	-5 year lifetime	**£742.01** (+28%)	**£549.28** (+10%)	**£514.82** (+9%)
Earlier autonomous capability	+5 years faster autonomy	**£578.19** (+0%)	**£458.57** (-8%)	**£470.71** (+0%)

Cargo Delivery

We explore the impacts of a modal shift for cargo delivery. In the counterfactual, a 2.1-tonne GVW is used to transport a payload of 350kg with a journey distance of 75km. The use case replaces the same journey with an eVTOL, however the journey distance is reduced because it is able to take a more direct route. For this use case, we model the costs associated with:

- Fare price
- CO2 emissions

Counterfactual

Van

1. Cargo is loaded from into the van at depot A
2. Van drives from depot A to depot B
3. Cargo is unloaded

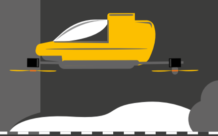
Depot A — **Depot B**

Start A → B (75 km)

Use Case

eVTOL

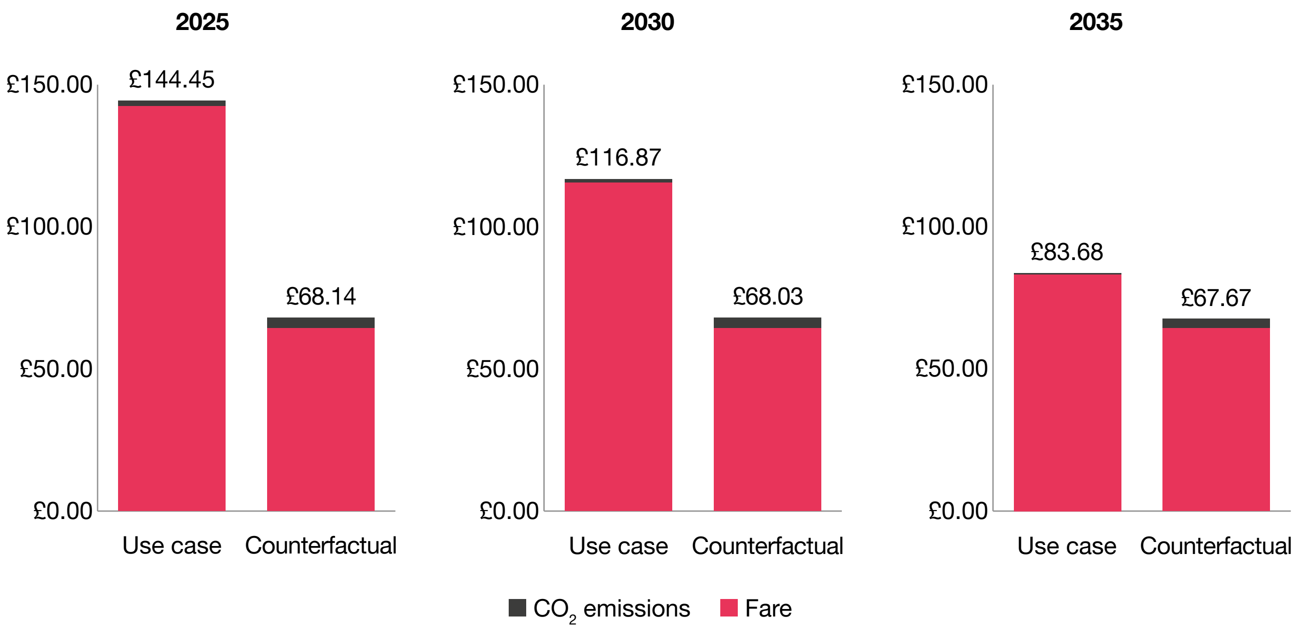
1. Cargo is loaded into van at depot A and transported to vertiport B
2. Cargo is moved from van to eVTOL
3. Cargo is transported from vertiport B to vertiport C
4. Cargo is unloaded from eVTOL into van
5. Cargo is driven from vertiport C to depot D
6. Cargo is unloaded from van at depot D



Depot A — **Vertiport B** — **Vertiport C** — **Depot D**

Start A → B → C → D End (53 km)

Figure 8: Change in Cargo Delivery use case and counterfactual cost



Results

Our model suggests that eVTOLs are not economically viable compared to the counterfactual in all scenarios. A particular limitation is if the payload increased, the counterfactual becomes more efficient per kilogram of cargo because a larger van can be used, whilst the eVTOL would need to complete multiple trips due to payload constraints.

In 2025 Figure 8 shows that use case costs are expected to be 112% higher than the counterfactual. Piloting and loading labour costs drive over half of use case operating costs, making eVTOLs uncompetitive compared to the counterfactual. In particular, our use case journey assumes that the cargo will need to be transported to and from vertiports, meaning that there is double the loading and unloading requirements compared to a simple van journey from start to end. This contributes to eVTOL fare prices costing 62% more.

We estimate that eVTOLs will produce approximately 6.8kg less CO2 than the van, with a monetary value of £1.77. Vans typically use diesel which produces a significant amount of greenhouse case emissions, particularly compared to electricity.

By 2030 the net cost gap is expected to reduce to 72% because eVTOL costs fall while we assume the counterfactual costs of van travel remain relatively static – the fare price falls by 19% , primarily attributed to reduced operating costs based on our assumptions around increased eVTOL efficiency.

In 2035 we estimate that eVTOLs remain 24% more expensive than the counterfactual despite significant cost reductions associated with the uptake of autonomous eVTOLs and lower vehicle prices as production is assumed to increase and benefit from economies of scale.

Sensitivity analysis

We use sensitivity analysis to explore how changes to key inputs and assumptions for our use case may change the results.

Commentary

eVTOL journeys are significantly more expensive than the counterfactual in our core analysis and all sensitivities, suggesting that mass market uptake is highly unlikely as there is no case for substitution based purely on the cost of transporting goods.

There may be a case for AAM substitution for extremely time sensitive cargo as VTOLs will be able to transport goods quicker than via road for medium to long distances (within their operational range). If users – which could range from manufacturers to private hospitals – value time around £109 an hour then there could be a case for using eVTOLs in the 2025 scenario.

Transporting a larger payload will make eVTOLs less attractive. Our current scenario considers a payload that an eVTOL can complete in a single trip. However, if the weight exceeds its capacity then it would need to complete multiple return trips – while a van journey may require a larger vehicle, it would otherwise remain relatively unchanged.

If we change the counterfactual to a cargo plane the eVTOL option is more attractive and is 31% cheaper in 2025, despite multiple eVTOL journeys being required to move the same 2.1 tons of freight as the cargo plane moves in one trip.

Table 11: Sensitivity analysis, AAM cost per journey and percentage change in cost per journey

Core scenario		**2025-2029**	**2030-2034**	**2035-2040**
AAM base use case cost		**£144.45**	**£116.87**	**£83.68**
Counterfactual cost		**£69.61**	**£68.03**	**£67.67**
Sensitivity	Test	**2025-2029**	**2030-2034**	**2035-2040**
Alternative counterfactual	Cargo plane	**£209.12** (+200%)	**£209.56** (+208%)	**£210.23** (+211%)
Higher eVTOL costs	+ £2.0m cost	**£174.46** (+21%)	**£135.39** (+15%)	**£98.83** (+18%)
Reduced flying window	– 20% flying window	**£184.89** (+28%)	**£143.69** (+22%)	**£101.68** (+22%)
Decreased eVTOL lifetime	-5 year lifetime	**£189.45** (+31%)	**£153.89** (+31%)	**£114.56** (+37%)
Earlier autonomous capability	+5 years faster autonomy	**£144.48** (+0%)	**£90.39** (-23%)	**£83.68** (+0%)

Air Ambulance

We explore the impacts generated by replacing existing air ambulance services provided by an EC135 helicopter with an eVTOL, assuming that the journey is a round trip of 80km. The use case and counterfactual are more similar than other examples as the journey segments remain the same, the change is solely based upon the costs and externalities associated with each journey.

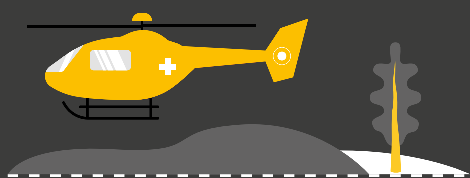
We model differences in:

- Fare price
- CO2 emissions

Counterfactual

Helicopter

1	2	3	4
Distress call is received and emergency response team boards helicopter	Helicopter travels from the helipad A to emergency location B	Paramedics treat patient and board them onto the helicopter	Helicopter flies from emergency location B to a nearby hospital, which could be the same as the starting point.

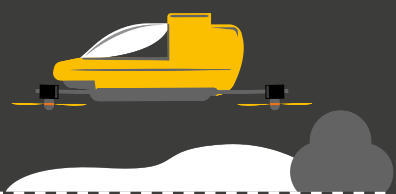


Start	Helipad A		Emergency location		Helipad C	End
	A	→ 40 km	B	→ 40 km	C	

Use Case

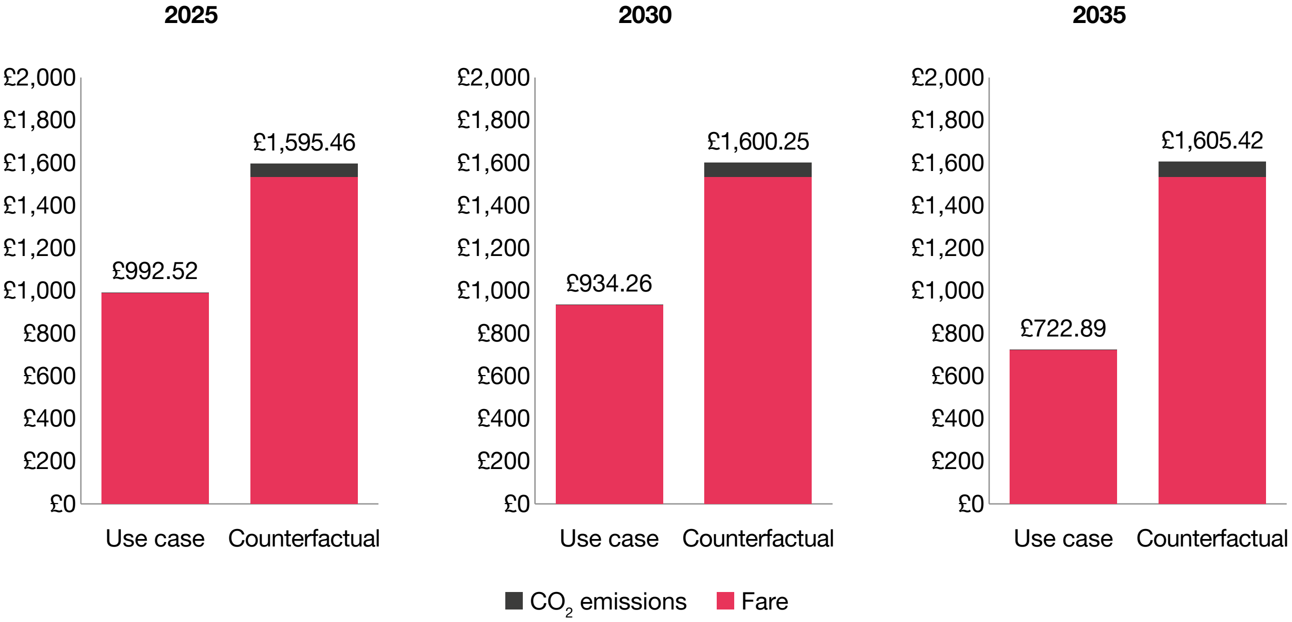
eVTOL

1	2	3	4
Distress call is received and emergency response team boards eVTOL	eVTOL travels from the vertiport A to emergency location B	Paramedics treat patient and board them onto the eVTOL	Helicopter flies from emergency location B to a nearby hospital, which could be the same as the starting point.



Start	Vertiport A		Emergency location		Vertiport B	End
	A	→ 40 km	B	→ 40 km	C	

Figure 9: Change in Air Ambulance use case and counterfactual cost



Results

eVTOLs deliver significant economic benefits that grow over time throughout the appraisal period – the use case and counterfactual have the same journey but eVTOLs are able to complete it at lower costs whilst producing less emissions.

Use case costs are 38% lower than the counterfactual in 2025. Operating costs are high for both journeys as we assume two paramedics need to be on standby to quickly respond to distress calls. Cost savings arise from eVTOLs only requiring one pilot against two for an EC135.

Both vehicles are energy intensive modes of transport meaning that the key emissions difference stems from fuel type. An EC135 uses jet fuel which produces 226.3kg more CO2 per journey than an eVTOL, which has a monetary value of £58.72.

AAM costs are expected to reduce by 6% in 2035 so that they are 42% lower than the counterfactual. eVTOLs are assumed to benefit from technological advancements that reduce operating expenses and vehicle costs, while the counterfactual marginally increases in price due to higher monetary values attributed to CO2 emissions.

Use case costs fall dramatically in 2035 as eVTOLs become autonomous, such that the price of a journey is 55% lower than an EC135: autonomy benefits are compounded by broader efficiency and technological gains that reduce stock eVTOL costs such as vehicle prices.

Sensitivity analysis

We use sensitivity analysis to explore how changes to key inputs and assumptions for our use case may change the results.

Commentary

eVTOLs offer an attractive alternative to helicopters as they have a similar functionality with lower capital and operating costs. Our sensitivity analysis shows that even if we assume eVTOLs have a lifetime of five years, fare costs and net benefits remain significantly lower than the counterfactual.

Table 12: Sensitivity analysis, AAM cost per journey and percentage change in cost per journey

Core scenario		2025-2029	2030-2034	2035-2040
AAM base use case cost		**£992.52**	**£934.26**	**£723.00**
Counterfactual cost		**£1,595.46**	**£1,600.25**	**£1,605.42**
Sensitivity	Test	**2025-2029**	**2030-2034**	**2035-2040**
Higher eVTOL costs	+ £2.0m cost	**£1,184.30** (+19%)	**£1,069.29** (+14%)	**£837.02** (+16%)
Decreased eVTOL lifetime	-5 year lifetime	**£1,280.19** (+29%)	**£1,208.52** (+29%)	**£955.37** (+32%)
Earlier autonomous capability	+5 years faster autonomy	**£992.52** (+0%)	**£774.82** (-17%)	**£723.00** (+0%)

6
Scaling up journeys and total socio-economic impact

We aggregate the findings of our use cases by the expected number of journeys substituted to estimate the UK-wide impacts. These results do not represent the whole AAM market but illustrate the potential impact of switching to eVTOLs for our chosen use cases under different adoption scenarios.

The estimated annual range of economic impact is only considered for use cases that deliver net economic benefits – for example, we do not scale the Urban Private Hire use case because it does not deliver net benefits throughout our appraisal period. For more information on our scaling approach refer to Appendix 1.

Annual impact

Figures 10 and 11 show the annual marginal impact of AAM journeys (right Y-axis) based upon the substitution of counterfactual journeys (left Y-axis). Figure 10 shows the scale of impact and substitution if adoption follows the S-curve capped at 5.0% whilst Figure 11 shows the effect if substitution was capped at 2.5%.

Lower fares and reduced travel time are responsible for more than 95% of benefit during the appraisal period so that the private incentive is much greater than benefit to wider society. Nevertheless a societal case for eVTOL uptake remains as accidents and emissions are reduced compared to conventional modes of transport – though the benefit will diminish as conventional travel becomes more efficient. Our scaling approach estimates that the annual benefit from reduced emissions and accidents could equate to more than £150m by 2040.

Passengers are the primary beneficiaries of AAM technology. Time savings initially drive the majority of benefits though the fare becomes an increasingly important benefit, so that they deliver over 40% of the benefits by 2035 in our 5% S-curve scenario. This time period shows a significant increase in benefits as eVTOLs become autonomous, reducing fare significantly.

Figure 10: Annual AAM economic impact and counterfactual substituted journeys, using 5.0% S-curve

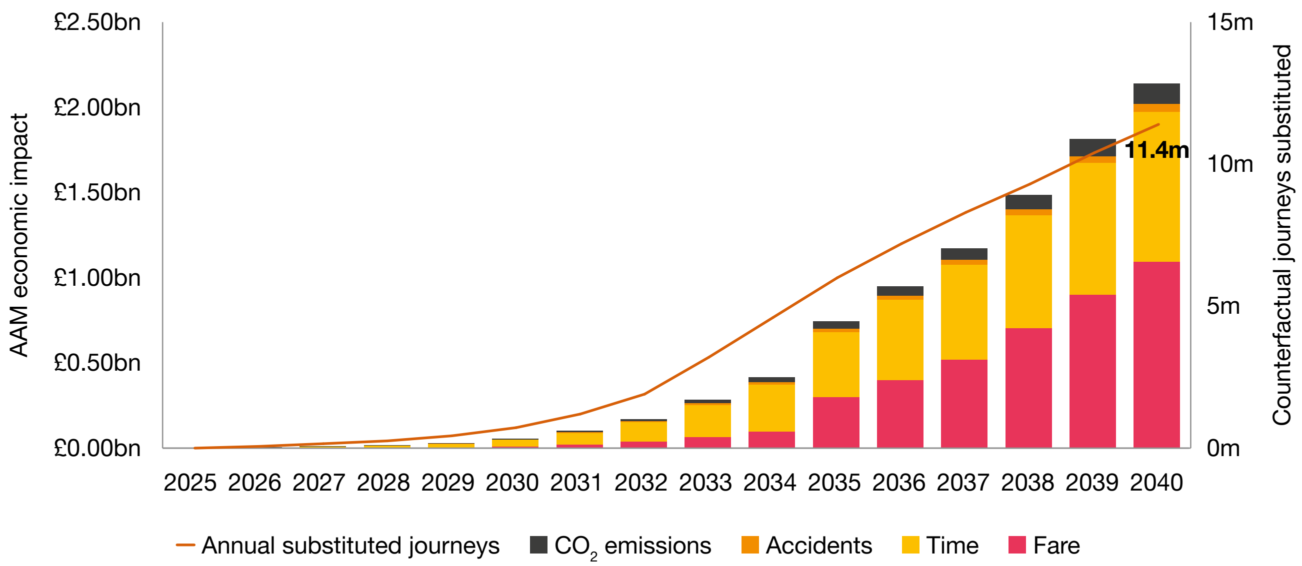
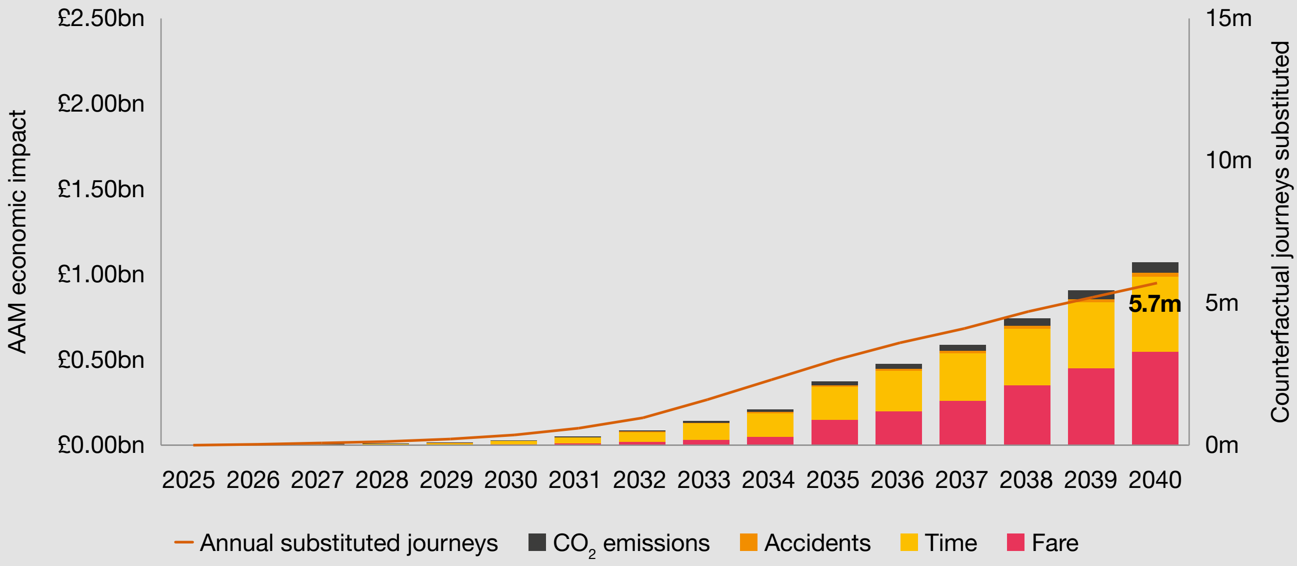


Figure 11: Annual AAM economic impact and counterfactual substituted journeys, using 2.5% S-curve



Our scaling approach estimates that between 5.7m and 11.4m counterfactual journeys will be substituted by eVTOLs in 2040 depending on the S-curve we use, resulting in an annual economic benefit between £1.1bn and £2.1bn.

Aggregate impact

Our scaling approach indicates that the cumulative benefits could be between £4.7bn and £9.4bn depending on the S-curve used. Results for each use case are differentiated across:

- **Number of counterfactual journeys** as these determine the pool of journeys that AAM technology could replace. We do not flex our S-curve by use case, meaning that the current number of counterfactual journeys play a pivotal role in determining net economic impact.
- **Year at which the use case is economically viable** as this is the point that the S-curve begins. Where use cases are only viable in 2035, only the initial – and flattest – part of the S-curve is applied to the counterfactual journeys substituted.
- **The scale of economic benefit compared to the counterfactual** as total benefits are calculated as a function of journeys substituted and marginal economic benefit per individual journey.

Benefits are primarily driven by the Rural Rideshare use case which delivers £3.1bn to £6.2bn driven by a combination of a high quantity of counterfactual journeys to replace, a viable use case from 2025, and significant marginal benefits compared to the counterfactual.

Journeys replaced by the Sub-Regional Shuttle use case achieve net benefits in the range of £577m to £1.2bn. They provide lower total benefits because the number of substitutable journeys is much smaller compared to the Rural Rideshare use case and substitution does not begin until 2030 when we assume the larger eVTOL enters the market.

The Air Ambulance use case delivers significant cumulative benefits between £998m and £2.0bn by 2040. It delivers a large marginal benefit per journey and adoption is assumed to start from 2025, however there are a relatively small number of journeys the eVTOL can replace. This means that the cumulative benefit is still significantly lower than the Rural Rideshare use case.

Figure 12: Cumulative economic impact by use case, using 5.0% S-curve

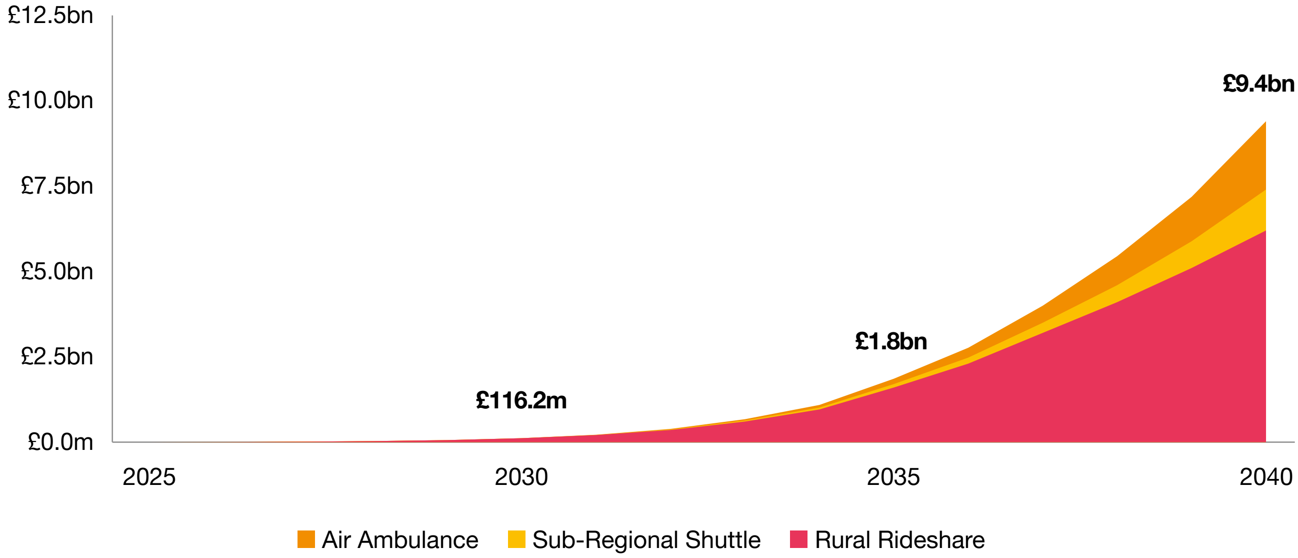
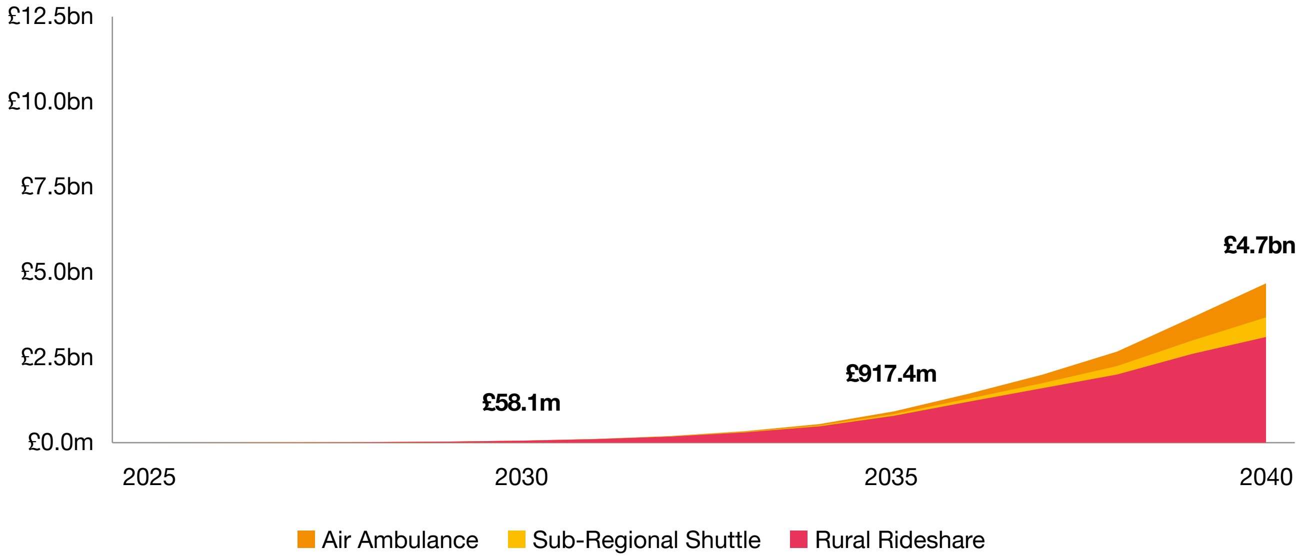


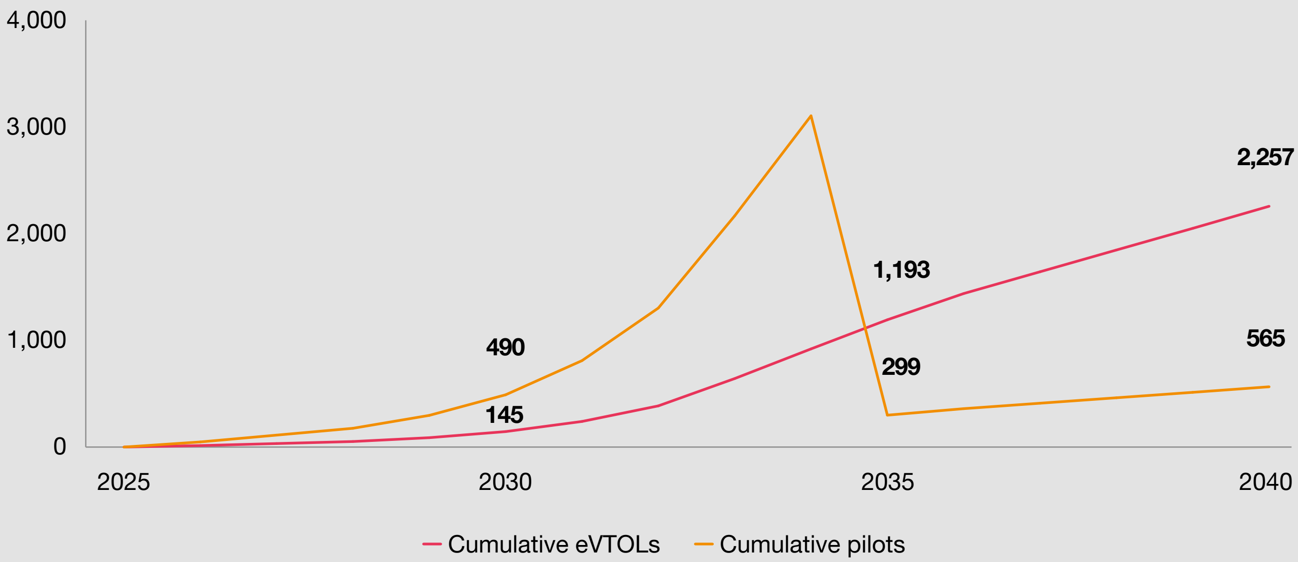
Figure 13: Cumulative economic impact by use case, using 2.5% S-curve



eVTOL and pilot forecasts

We estimate that our case cases will require 1,130 to 2,257 eVTOLs in the market by 2040 depending on the S-curve assumed. Our results show the number of additional annual eVTOLs required to service market demand will peak at 278 units in 2034 in the 5% S-curve scenario, when additional take up slows.

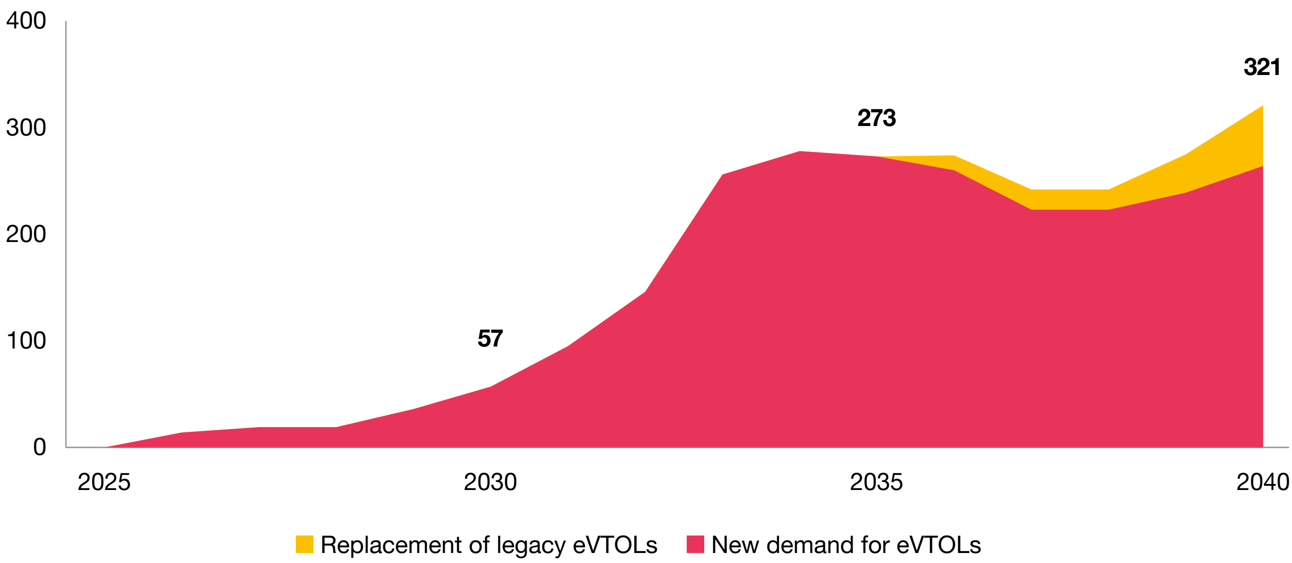
Figure 14: Cumulative eVTOLs and pilots, using 5.0% S-curve



NB results are calculated at five year intervals that do not reflect that changes will be more gradual and therefore smooth over time.

The number of new eVTOLs required to replace old technology will be greater than the number of additional eVTOLs required to meet demand by 2035. We have assumed a vehicle lifetime of 10 years, so that eVTOLS that enter the market in 2025 will need to be replaced by 2035. This means that suppliers will need to manufacture at a scale that replaces legacy units as well as growing demand. Over time, the replacement of legacy units are expected to form a greater proportion of demand for additional eVTOL units. Figure 15 shows the beginning of this process.

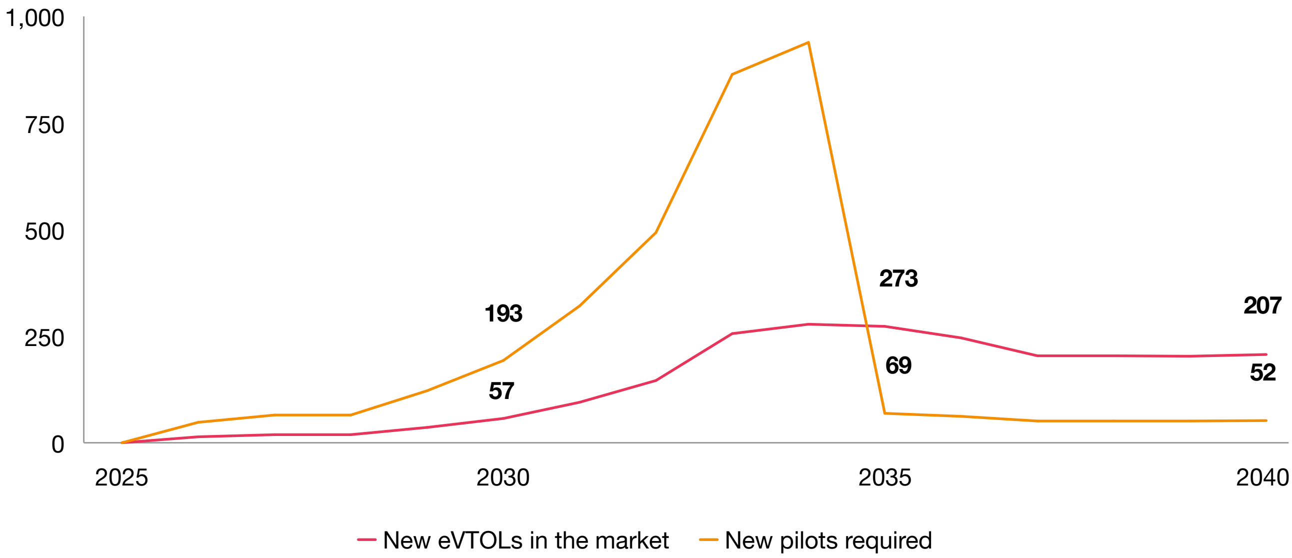
Figure 15: Total annual eVTOL demand, using 5.0% S-curve



Pilot demand and skill level is expected to change over time: in the first time block (2025-2029) eVTOLs are expected to require highly qualified pilots similar to commercial airlines now. By the second block (2030-2034) eVTOLs have become more sophisticated and do not require fully qualified pilots: a pilot with basic training will operate the eVTOL with the support of a remote highly qualified pilot if required. For our final appraisal block (2035-2040) we assume that eVTOLs are fully autonomous only requiring a remote pilot for emergencies.

The remote pilot will be responsible for managing around 4 eVTOLs, which leads to a significant reduction in costs. This poses a challenge for the AAM market if there is difficulty attracting the quantity and quality of pilots required if industry anticipates that their skills will only be needed for 10-15 years – although these changes will be much less rapid than what is reflected in our modelling due to the time-block approach.

Figure 16: Annual eVTOLs and pilots, using 5.0% S-curve



NB results are calculated at five year intervals that do not reflect that changes will be more gradual and therefore smooth over time.

Vertiports forecast

Our indicative estimates suggest that around 376 vertiports will be required to service our use cases in 2040.

We have taken a simplified approach based upon the size of eVTOLs and vertiports. This is not meant to provide an exact figure, rather it is a high level estimate, using a ratio of 6 eVTOLs to 1 vertiport, to indicate the potential infrastructure requirements. It is assumed that these vertiports are in the required locations for the scaled use cases.

AAM market coverage

The direct economic impact of AAM technology is likely to be much larger than our range of £4.7bn to £9.4bn: our appraisal period only covers the emergence of the AAM market, substituting a subset of current journeys and potential applications rather than creating new trips.

As the market matures it is likely to substitute an increasing number of journeys, different journey types and create new routes.[74]

We have mapped our use cases to DfT's National Travel Survey in order to estimate the proportion of passenger journeys covered by our analysis. Table 13 shows the trips per person per year by mode of transport and distance. We have identified journeys covered by our use cases (orange boxes) and those that eVTOLs may be able to service (grey boxes). The journeys covered by our use cases represent 54% of potential journeys and 36% of miles[75] serviceable by eVTOLs as identified in the National Travel Survey. This is not an estimate of the potential total AAM market size but provides an illustrative example showing that there are significant further opportunities and applications beyond our analysis.

Table 13: National Travel Survey 2019, Mode of Travel[76]

	Trips per person per year									
Main mode	**Under 1 mile**	**1 to under 2 miles**	**2 to under 5 miles**	**5 to under 10 miles**	**10 to under 25 miles**	**25 to under 50 mile**	**50 to under 100 miles**	**100 miles and over**	**All lengths**	**Unweighted sample size (trips '000s)**
Private:										
Walk	185	55	10	-	-	0	0	0	250	66
Bicycle	2	5	6	2	1	-	0	0	16	4
Car / van driver	26	66	125	78	62	16	5	3	380	101
Car / van passenger	15	39	66	39	28	7	4	2	200	53
Motorcycle	-	-	1	1	-	-	-	0	2	1
Other private transport	1	1	2	1	1	1	-	-	7	2
Public:										
Bus in London	1	4	8	4	1	0	0	0	18	4
Other local bus	1	4	16	7	3	-	-	0	32	8
Non-local bus	0	-	0	-	-	-	-	-	-	-
London Underground	-	-	2	6	4	-	0	0	12	2
Surface Rail	0	-	2	4	8	4	2	1	21	5
Taxi / minicab	-	2	5	2	1	-	-	-	11	3
Other public transport	-	-	1	1	1	-	-	-	3	1
All modes	**231**	**177**	**242**	**144**	**109**	**29**	**12**	**7**	**953**	**250**

[74] As outlined earlier in our report, we do not attempt to estimate the number of new routes or quantify the corresponding impact.
[75] Assuming that the average journey is the midpoint of the corresponding distance category and '100 miles and over' journeys are 100 miles.
[76] DfT, National Travel Survey Table NTS0308, 2019, link.

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Appendix 1: Assumptions

In order to estimate the economic impact of AAM technology we are required to make a range of assumptions given the commercial market has not entered the public domain yet. We have made an array of simplifying assumptions based upon market research and stakeholder engagement, with the most critical assumptions outlined below.

Journeys

We have made assumptions around the level of operation and utilisation to inform our estimates on the number of journeys eVTOLs are able to complete in a given timeframe.

Table 14: Journey assumptions

Operational days a year are 358 (7 days maintenance)
Operating hours are assumed to be 18 hours a day (from 5am-11pm)
Flight ready hours are 84% of hours (accounting for weather)
Utilised hours are assumed to be 85% of remaining hours
Landing and take-off are assumed to take 1 minute each
Boarding time is assumed to be 10 minutes (20 minutes for Sub-Regional Shuttle) and **disembarking time** is assumed to be 5 minutes (10 minutes for Sub-Regional Shuttle), with no security

Capital Costs

eVTOL and infrastructure costs depend heavily on the supplier figures and corresponding specs. We have based our assumptions around the midpoint of market values.

Table 15: Capital Cost assumptions

eVTOL prices are estimated to be approximately £3.0m (£9.0m for the Sub-Regional Shuttle and £3.6m for the Air Ambulance)
eVTOLs lifetimes are 10 years
eVTOLs have a residual value of 20%
Capacity is assumed to be 5 seats (with 1 seat taken by a pilot), Sub-Regional Shuttle capacity is 12
Vertiports are assumed to cost approximately £81k per eVTOL per year

Operational Costs

Operating costs are highly uncertain given the lack of market data. We have made simplifying assumptions based on information and estimates available.

Table 16: Operational Cost assumptions

Pilots per eVTOL are assumed to be 3.4 FTEs before they become autonomous
Occupancy rate is assumed to be 1 for the Urban Hire and Rural Hire use cases, 3 for the Rural Rideshare, and 5 for the Sub-regional
A profit margin of 6.3% has been applied to fare prices

Externalities

We have used conservative energy consumption estimations from industry in our use cases and used ONS and DfT data to inform our other assumptions around CO2 emissions.

Table 17: Externalities assumptions

Take-off & landing require 500 kW of power
Cruising requires 71 kW of power
CO2 emissions per kWh provided by TAG data book and assumed to decrease over time
CO2 emissions cost provided by TAG data book and assumed to increase over time

Scaling

In order to update our use cases to 2040 we have made some simplifying assumptions around how costs are likely to change over time. These were grounded in AAM industry figures or, where this was not possible, comparable markets.

Table 18: Scaling assumptions

eVTOLs become autonomous in 2035
eVTOL prices decrease by 15% in each 5 year block
Deadhead ratio assumed to fall in each 5 year block
Direct opex is assumed to fall by 10% in each 5 year block

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Appendix 2: Skybus

The following was shared by GKN Aerospace for inclusion in this report, we thank them for the contribution.

Skybus, based on 30-50 seat battery-electric and zero-emissions eVTOLs, takes the “Park and Ride” concept into the air for mass transit over extremely congested routes eliminating the 2-D constraints of current surface transport. Skybus will ultimately address transport congestion, pollution, and sustainability issues through a widely accessible, affordable, scalable and interconnected multi-modal network.

Through Future Flight Challenge funding, GKN have carried out cost modelling demonstrating <$1/passenger-mile total operating costs on 30 seat eVTOL aircraft (at ~75% load factors) compared the ~$3-5/passenger-mile costs typically forecasted for 4-5 seat eVTOLs. These bus sized eVTOLs are expected to primarily operate on airport shuttle routes with $20-30 ticket prices where:

- High passenger volumes sustain high load factors and utilisation rates
- Passenger time sensitivity is greater to avoid missing conventional flights
- Passenger willingness to pay is greater and road taxi at similar pricing is already significant
- Trip times from downtown areas can often take ~1h or greater by surface transport, with significant congestion challenges, especially where direct high speed rail connections don’t exist
- Driving is not always a favourable option due to airport parking costs
- Existing airport infrastructure and procedures can be adapted for eVTOL operations
- Constructing new ground infrastructure (e.g new railways) is extremely difficult in urban areas (especially in highly populated cities) due to limited land availability. It can also take several years, cost in the billions of dollars and result in significant greenhouse gas emissions.

Furthermore, the following benefits have been identified for using large eVTOLs compared to lower capacity air taxis on these dense routes:

- Reduced energy consumption per passenger mile
- Reduced vertiport footprint per passenger-landing
- Reduced airspace congestion and thus increased safety due to lower volumes of operations
- Fewer pilots required due to lower volumes of operations
- Increased storage space available for passenger luggage

Whilst numerous benefits have been identified, the operations are expected to be limited to high density routes instead of on-demand point to point intra-city trips commonly associated with UAM.

Specifications for a 30 seat Skybus are provided in the table below, following a two year conceptual design activity.

Table 19: Preliminary specifications for Skybus

Parameter	Value
MTOW (kg)	**14000**
Useful range with reserves on current battery technology (miles)	**~100**
Cruise speed (mph)	**200**
Passenger capacity	**30**
Crew	**2**
Direct operating costs per flight hour ($)	**~1300**
Expected aircraft unit cost ($m)	**~14**

Assumptions

An aircraft is capable 4 flights of ~35 miles per flight hour (note: a flight hour is not equivalent to an operational hour)

1. $0.23 (£0.19)/kWh used – UK 2021 average electricity costs
2. DOCs only include aircraft maintenance (scheduled and unscheduled) and energy costs (including battery replacement costs). Landing fees, insurance and crew costs etc. vary depending on the operator and area of operation and are considered indirect.
    - The <$1/passenger-mile total operating costs were based on a London use case and included indirect costs based on an additional set of assumptions.

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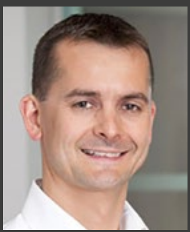

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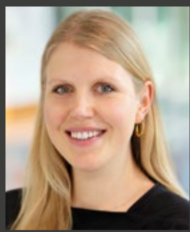

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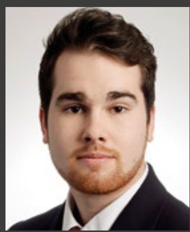

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