UK Research and Innovation

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Future Flight Aircraft Capabilities

Exploring the requirements of next-generation aircraft

UK Civil Aviation Authority

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Foreword

Aviation is at the start of one of the biggest evolutions to the way people fly and goods are transported that we have seen for many decades. Hydrogen and electric powered aircraft, including those with vertical take-off and landing capability, are set to transform our skies.

This combination of new technologies, alongside the imperative to decarbonise aviation, is driving changes that come under the 'Advanced Air Mobility' (AAM) umbrella.

Recent years have seen significant numbers of proposals for these new types of aircraft, in many cases driven by large-scale investments and commercial partnerships. The UK has been playing a leading role in the sector, and making the UK an attractive proposition for aviation innovation is a UK Government priority.

Gaining regulatory approval for AAM operations is new territory: aviation regulations and approval mechanisms must adapt, and innovators must understand how to integrate within the national and international aviation framework. This will require the CAA to work in new ways and become more agile to engage with and regulate the AAM. In answer to this, the CAA stood up its 'AAM challenge' to accelerate the development of new policies and regulations that maintain appropriate public and consumer protection.

Technological developments are occurring at a rapid pace and, in many cases, are being led by organisations outside of the traditional aviation structure. Combined with the fact that new technologies are still being refined, this means we lack the richness of data that we have become accustomed to from current operations. Regulators and industry alike use data-driven methods to evaluate risks. Similarly, data is vital to determine proportionate and risk-based regulation that ensures the safety of the public and consumers while not stifling technology development and new business models.

The CAA is committed to working with all stakeholders to enhance our common understanding of the risks and facilitate appropriate mitigations. We therefore commissioned a study to gather publicly available performance data of the most significant future flight aircraft under development. We anticipate that the data provided in this report will be a significant addition to the overall intelligence on AAM, usable by stakeholders from aerodrome and vertiport developers, to ATM providers, airspace planners and many others.

We hope that this report increases the knowledge of this up-and-coming sector, and that all involved continue to openly share their data for the benefit of safety to deliver the sustainable aviation industry that we need for the future.

Sincerely,

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Contents

Appendices

Tables

Figures

Acronyms and Abbreviations

AAM	Advanced Air Mobility
CAA	Civil Aviation Authority
CFRP	Carbon Fibre Reinforced Polymers
CNS	Communications, Navigation and Surveillance
ConOps	Concept of Operations
CS	Certification Specification
CTOL	Conventional Take-Off and Landing
D	Controlling Dimension
dBA	"A-weighted" decibels
DEP	Distributed Electric Propulsion
EASA	European Union Aviation Safety Agency
EFCS	Electronic Flight Control System
eVTOL	Electric Vertical Take-Off and Landing
FAA	Federal Aviation Authority
FATO	Final Approach and Take-Off (area)
FbL	Fly-by-Light
FbW	Fly-by-Wire
FPP	Fixed-Pitch Propellers
HOGE	Hover Out of Ground Effect
HTPEM	High Temperature Proton Exchange Membrane
HVTOL	Hybrid Vertical Take-Off and Landing
ICAO	International Civil Aviation Organisation
ICE	Internal Combustion Engine
LE	Leading Edge
LTPEM	Low Temperature Proton Exchange Membrane
MTOM	Maximum Take-Off Mass
NASA	National Aeronautics and Space Administration
OEM	Original Equipment Manufacturer
PAX	Passengers
RAM	Regional Air Mobility
Redox	Reduction-Oxidation
RPAS	Remotely Piloted Aircraft System
RPM	Revolutions Per Minute
SC-VTOL	Special Condition Vertical Take-Off and Landing
TBO	Time Before Overhaul
TE	Trailing Edge
TLOF	Touchdown and Lift-Off (area)
TO/L	Take-Off / Landing
UAM	Urban Air Mobility
UAS	Uncrewed Aircraft Systems
UKRI	UK Research and Innovation
UTM	Unmanned Aerial Systems Traffic Management
VFS	Vertical Flight Society
VPP	Variable-Pitch Propellers
VRS	Vortex Ring State
VTOL	Vertical Take-Off and Landing

Executive Summary

The CAA has a crucial role to play in enabling the safe operations of Future Flight Aircraft (e.g., eVTOL, hydrogen-powered and eCTOL) designed for the Advanced Air Mobility market. To fulfil this role, it is vital that the novelty of these aircraft is well understood so that gaps and opportunities in the regulatory frameworks can be strategically targeted.

This study provides a comprehensive overview of the aircraft capabilities and requirements to strengthen the collective understanding across the CAA and other industry stakeholders. Public domain characteristics for 28 aircraft targeting operations before the end of the decade were reviewed to draw insights concerning technology novelty, compatibility with existing regulations, and implications for Take-Off and Landing infrastructure.

The success of these novel aircraft, and the wider market, is dependent on collaboration between the manufacturers and a broad stakeholder landscape including cities, airports, regulators, and planners. Yet, in a highly competitive race to market, specific details of the aircraft types are not universally shared and can often be misunderstood.

The first step in improving this understanding is to distinguish the different aircraft types, since the design configuration heavily influences the associated performance characteristics and capabilities. A taxonomy is proposed to align definitions from the FAA, EASA and VFS. With a consistent terminology, trends can be more easily communicated between the sub-classes of aircraft. The dataset used in this study includes aircraft from each classification, down-selected based on three key criteria: design maturity, points of novelty, and availability of published data. A total of 28 aircraft were selected, covering manufacturers from across the world. OEMs were provided the opportunity to comment on the dataset to ensure it accurately represents the latest aircraft characteristics in the public domain.

Adapting the approach applied by the FAA, three *Composite Aircraft* (a specification that aggregates characteristics of multiple aircraft concepts) have been proposed for stakeholders to consider, categorised as Wingless eVTOL, Winged eVTOL and Fixed Wing. The division of eVTOL aircraft is crucial to highlight the distinction in physical and performance characteristics. Wingless (Multicopters) are generally both lighter and smaller than winged counterparts but demonstrate significantly reduced range and payload capacity which is anticipated to influence stakeholder requirements.

Compatibility of infrastructure between various eVTOL aircraft types and conventional helicopters will vary depending on the design specification of the Vertiports. Regulatory approaches are evolving from ICAO Annex Vol II by considering the “Minimum Closing Circle” rather than the largest overall dimension of the aircraft. In the absence of data reported by the OEMs, this value must be conservatively estimated resulting in potentially inefficient infrastructure design.

Propulsor configurations with a high disc-loading will have significantly reduced hover performance compared to helicopters, requiring special consideration for Take-Off and Landing profiles, particularly in dense urban environments. These configurations may also impact the downwash profiles; however, little research exists to quantify this impact. For ground operations, further gaps are identified that will challenge Vertiport designers and operators responsible for deriving procedures.

The most important gaps in this sample are within the Performance category, where many values known for conventional aircraft are not available in the public domain. Further to this, given the maturity of most programmes, few of the reported values are likely to have been validated in flight. Unknown areas include reporting on battery specific energy and specific power which are key technology barriers. As development progresses, this is anticipated to improve – as evidenced by the commendable noise testing performed by Joby and NASA.

Overall, this report fulfils its purpose of aggregating aircraft characteristics and advancing the high level understanding of the novelty of Future Flight requirements. Whilst many gaps remain in the dataset, it is an evolving market with time to mature. With an appreciation of these requirements and gaps, industry stakeholders can be better prepared to consider the implications for their role in the ecosystem.

To maximise the impact of this study and further the UK's position as a leading region for AAM operations, it is anticipated that this study will promote industry feedback and discussions to address the findings. Most importantly, as Future Flight aircraft approach their targeted certification dates this decade, it is vital that the validated performance capabilities are communicated to industry stakeholders to ensure that the supporting infrastructure can be prepared to enable the required levels of safety.

At a Glance

Aircraft Classification

1. **Reference aircraft characteristics are required to improve stakeholder understanding.**
   The Future Flight aircraft fleet mix will consist of a range of aircraft of different configurations and power sources. A single composite aircraft specification is insufficient to capture this range of capabilities. Therefore, 3 composite aircraft have been proposed for stakeholders to review, categorised as Wingless eVTOL, Winged eVTOL and Fixed Wing.

2. **Not all eVTOL are the same – distinction in performance and dimensions must be considered.**
   The division of eVTOL aircraft into winged and wingless is not common but is crucial to appreciate the distinction in physical and performance characteristics. Wingless (Multicopters) are generally both lighter and smaller than winged counterparts but offer significantly reduced range and payload capacity which will influence stakeholder requirements.

Infrastructure and Regulatory Compatability

3. **Aircraft dimensions influence the creation of safe, effective infrastructure.**
   Compatibility of infrastructure between various eVTOL aircraft types and conventional helicopters will vary depending upon the design specification of the Vertiports. Conservative sizing for the largest expected dimensions will maximise futureproofing and safety but at the compromise of site area efficiency.

4. **The absence of verified information may lead to oversizing for safety.**
   Regulatory approaches are evolving from ICAO Annex Vol II by considering the "Minimum Closing Circle" rather than the largest overall dimension of the aircraft. In the absence of data reported by the OEMs, this value must be conservatively estimated resulting in inefficient infrastructure design.

Novel Technologies and Gaps

5. **Novel designs will create novel effects – further research will be required to understand this.**
   Propulsor configurations with high disc-loading will have significantly reduced hover performance compared to helicopters, requiring special consideration for take-off and landing profiles, particularly in dense urban areas. These configurations may also impact the downwash profiles, but little research exists to quantify this impact.

6. **Effective operations require knowledge sharing to define suitable procedures.**
   A large gap exists in the details of required ground operations which has notable implications for supporting stakeholders. Vertiport designers and operators will need to derive procedures for towing, re-energising, and maintenance, all of which will be based on the aircraft specific requirements. Adding to this complexity, clarity will be required on how each operation fits under the existing regulatory framework.

7. **Performance is key; more verified data is required to effectively enable industry**
   The most important gaps in this sample are within the Performance category, where many values expected from conventional aircraft are not available in the public domain. Further to this, given the maturity of most programmes, few of the reported values are likely to have been validated in flight.

1. Introduction

The Aviation landscape is changing. Emerging technologies that have already impacted the automotive sector – from hydrogen fuel cells to Li-Ion batteries – are being developed to transform the Future of Flight. This disruptive innovation challenges the existing aviation ecosystem to prepare for a technology revolution; yet the characteristics of the solutions that will dominate remain uncertain.

With over 700 concepts[1] at the time of writing for Electrical Vertical Take-off and Landing (eVTOL) aircraft alone, there are many factors to consider when analysing the Future Flight landscape. Despite the vast number of concepts, few full-sized prototypes have flown, and the availability of flight-validated performance data is limited. Understanding emerging aircraft types and their characteristics is valuable for both regulators and industry to inform reference characteristics for aerodrome operations and set enabling infrastructure requirements.

1.1. Context

The CAA has a crucial role to play in enabling the safe operations of Future Flight aircraft. As the aviation regulator for the UK, it is the CAA's duty to develop regulation for all aircraft. These aircraft operations are underpinned by appropriate and effective infrastructure which is managed under frameworks developed and overseen by the CAA and UK Government. To fulfil this role, it is vital that the novelty of these aircraft is well understood so that gaps and opportunities in the regulatory frameworks can be strategically targeted.

1.2. Scope

This study aims to strengthen the collective understanding of maturing novel "Future Flight Aircraft" for passenger services in the Advanced Air Mobility (AAM) sector which includes both Urban Air Mobility (UAM) and Regional Air Mobility (RAM), defined herein as[2]:

- **Urban Air Mobility:** Air transportation with aircraft with ranges of less than 100 km, mainly used in urban environments;
- **Regional Air Mobility:** Air transportation aircraft with ranges of 100-300km and a passenger capacity less than or equal to 19 passengers.

Notably excluded from the scope of this study are: Remotely Piloted Aircraft Systems; long-range commercial transport; certification requirements; airspace design and modernisation; and social / economic / political factors.

1.3. Purpose

This report aims to provide the CAA with a comprehensive overview of the capabilities and design trends of emerging Future Flight Aircraft - identifying novel aircraft features and gaps in the published data. By comparing to conventional rotary and fixed wing aircraft as a reference point, the study will further explore the implications on the compatibility with the existing aviation sector. This analysis will form a basis to help enable regulators, with industry input, to understand operational and infrastructure requirements that need to be put in place to meet the needs of new class of aircraft expected in UK skies in the next 3-5 years.

[1] VFS Electric VTOL Directory Hits 700 Concepts | VFS
[2] Regional Air Mobility: How to unlock a new era of aviation | Roland Berger

1.4. Document Structure

This document is structured as follows:

- Section 2 – Approach & Methodology: The approach applied to analyse the aircraft characteristics.
- Section 3 – Industry Assessment: Insight into current technologies being developed in the AAM market to contextualise the study.
- Section 4 – Aircraft Characteristics Analysis: Description of characteristics of Future Flight aircraft from the data set with comparison to conventional reference aircraft.
- Section 5 – Key Implications: Highlighted implications of the novel aircraft characteristics on the supporting ecosystem and future regulatory policy.
- Section 6 – Conclusions: Key findings summarised for the CAA.

2. Approach & Methodology

Untangling the uncertainty in the industry requires a systematic approach to firstly identify the challenges and to then build a robust analysis to guide industry stakeholders. Without this rigour, further confusion could be added to an already complex industry.

A three-phase detailed approach was developed by Atkins applying the Double Diamond design process model (Figure 2-1). This process focuses on first exploring ideas broadly and then homing in on specific pieces of information for further analysis; a method that is ideally suited to the rich aircraft landscape.

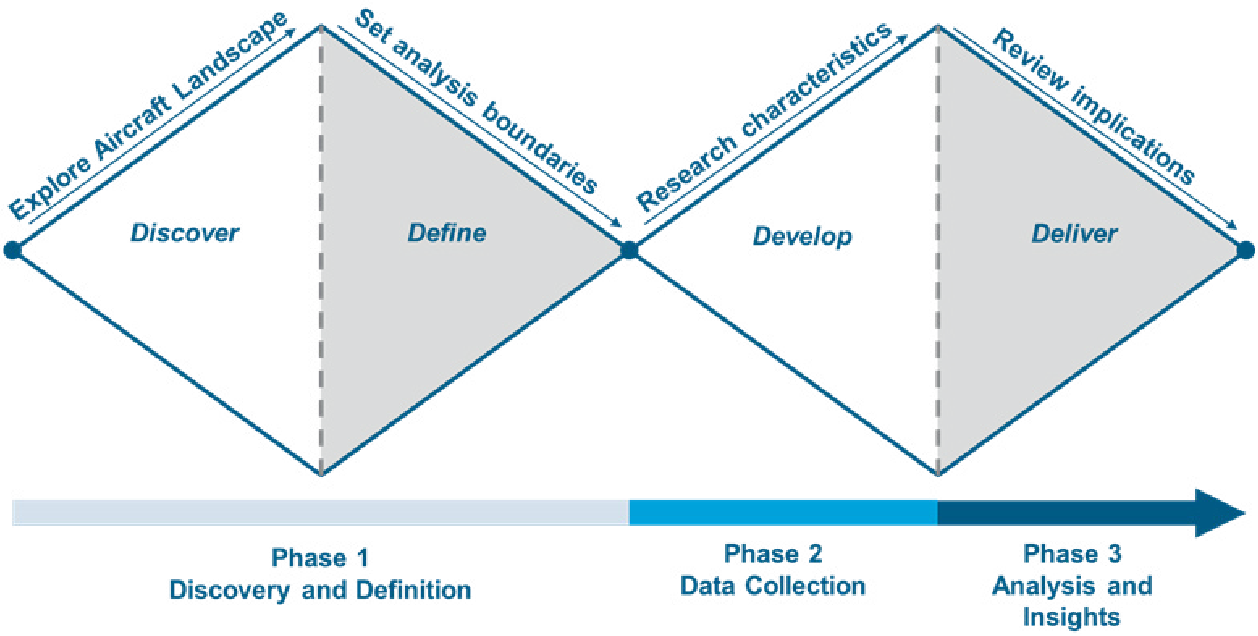


Figure 2-1 – Approach summary
Source: Derived from the Design Council[3]

[3] The Double Diamond: A universally accepted depiction of the design process | Design Council

2.1. Discovery and Definition

The first stage of the approach involved assembling preliminary data to set the boundaries of the study. The full landscape of manufacturers had to be explored at a high level to down-select to a shortlist. This helped develop the most appropriate data categorisations and critical characteristics that drive the subsequent analysis and insights. A logical taxonomy was developed arranging the aircraft based on their configuration and propulsor types in accordance with industry terminology and the latest regulatory best practice.

2.2. Data Collection

A comprehensive dataset of Future Flight aircraft characteristics was collected. To address shortfalls of similar databases online, data quality and traceability was considered a priority throughout by including referencing and indicating the source validity. Data was gathered from only public domain sources, focusing firstly on Original Equipment Manufacturer (OEM) publications, and then reviewing 3rd party sources such as news articles, academic papers, databases, and interviews to fill gaps. Importantly, all data in this study is approximate – based on the current stage of development of these aircraft and is therefore subject to change. It will not be used for CAA regulatory activities or oversight of individual companies.

2.3. Analysis and Insights

Applying expertise across aircraft, aerodrome and operational regulations, key insights and implications were created from the collected data. This included benchmarking against existing, conventional aircraft and a consideration of key regulations and industry standards where appropriate. Best practice identified in the US FAA Engineering Brief EB-105 ("Vertiport Design"), was applied to establish a theoretical "composite aircraft" to conclude the assessment. This composite aircraft represents an aircraft that integrates the performance and design characteristics of all the assessed aircraft to create a common reference point for the CAA and the wider industry stakeholders going forward.

3. Industry Assessment

To understand the emerging aircraft, it is first important to appreciate the market they intend to address, including the key terminology and an assessment of which aircraft have the maturity for consideration in this decade. In the Discovery and Definition phase, the context surrounding the study was explored to articulate the challenges faced by the industry associated with preparing for aircraft introduction. Within this remit, a taxonomy for aircraft configurations is proposed to improve distinction between concepts that would be inappropriate to consider as alike.

3.1. Advanced Air Mobility

Driven by developments in battery energy density, advanced control systems and lightweight composite materials, a variety of electric aircraft are being developed across the aerospace industry to create means to transport people and goods – this sector has been named Advanced Air Mobility (AAM):

Advanced Air Mobility is an air transportation system that moves people and cargo between places previously not served or underserved by aviation – local, regional, intraregional, urban – using revolutionary new aircraft that are only just now becoming possible.

The industry vision of a successful AAM market will require operations that bypass congestion in dense urban landscapes, offer compelling time-savings for sub-regional travel and/or augment transportation networks in disconnected rural communities. Broadly speaking, these use cases can be categorised as[4]:

- **Intra-city:** ~20-50km routes in and around urban areas including suburbs and airports. Limited take-off/landing space requires VTOL capability.
- **Inter-city:** ~50-300km routes between cities or from cities to rural areas. Longer range requires improved cruise efficiency and speed associated with winged aircraft (VTOL or CTOL).
- **Regional:** ~300km+ routes connecting regions. Long range exceeds potential of eVTOL, requiring aircraft with greater energy capacity.

In the last 5 years, private investment and public listings have dedicated funding to the industry, progressing concepts through to detailed designs and more recently to flight-tested prototypes. Whilst still faced with challenges in maturing innovative technologies, electric aircraft are increasingly being taken seriously by governments, regulators, and the general public. Notwithstanding, introducing disruptive technology to established transportation networks is a complex challenge, requiring collaborative efforts to reflect the range of disciplines required.

Future Flight Challenge

The Future Flight Challenge is a UK government initiative – supported by UK Research and Innovation (UKRI) investment and matched by industry – to develop new forms of green distributed aviation. The challenge aims to bring together technologies in electrification, aviation systems and autonomy to create new modes of air travel and capability. It is largely based around 3 classes of novel aircraft:

1. Drones or remotely piloted aircraft systems (RPAS) [outside scope of this study]
2. eVTOL Aircraft
3. RAM Aircraft

The CAA plays a key role in enabling the challenge by supporting successful consortia through identifying regulatory pathways for demonstration and offering a route to maximise regulatory readiness of innovations via the Regulatory Sandbox[5].

[4] The Future of Vertical Mobility | Porsche Consulting
[5] Future Flight Challenge | Civil Aviation Authority

Challenging Convention

Through years of iteration and analysis with established design requirements, the aerospace industry has generally converged on a "conventional design" for small-scale passenger transport, with aircraft such as the Cessna 172 and Robinson R44 (Figure 3-1) recognised ubiquitously as reference aircraft for these applications.

Figure 3-1 – "Conventional" Aircraft: Cessna 172 (Left) and Robinson R44 (Right)
Sources: Textron Aviation, Robinson Helicopters

In this market, convention is being challenged by the OEMs, who are exploiting the design flexibility offered by Distributed Electrical Propulsion (DEP) to revive concepts that have historically been impractical. As a result, eVTOL aircraft have been proposed in over 700 configurations[1], many of which differ in both function and form.

The success of these aircraft, and the wider market, is dependent on collaboration between aircraft manufacturers and a broad stakeholder landscape including cities, airports, regulators, and planners. Yet, in a highly competitive race to market, specific details of the aircraft types are not universally shared and are often misunderstood – resulting in a limited understanding from those who are vital to the market's success. By exploring and analysing the data in the public domain, this study intends to demystify the aircraft types for the industry stakeholders, providing the high-level knowledge to foster the AAM market.

3.2. Aircraft Classification

Consistent aircraft classification nomenclature helps ensure that there is no confusion when describing aircraft configurations and understanding the characteristics associated with their designs, which in turns provides us with assumptions on capabilities, performance, risks and mitigations. Various efforts have been made across the industry from regulators (EASA, FAA), societies (VFS) and analysts (SMG Consulting). Across these bodies, some common trends have been identified to allow a unified classification to be proposed as in Figure 3-2.

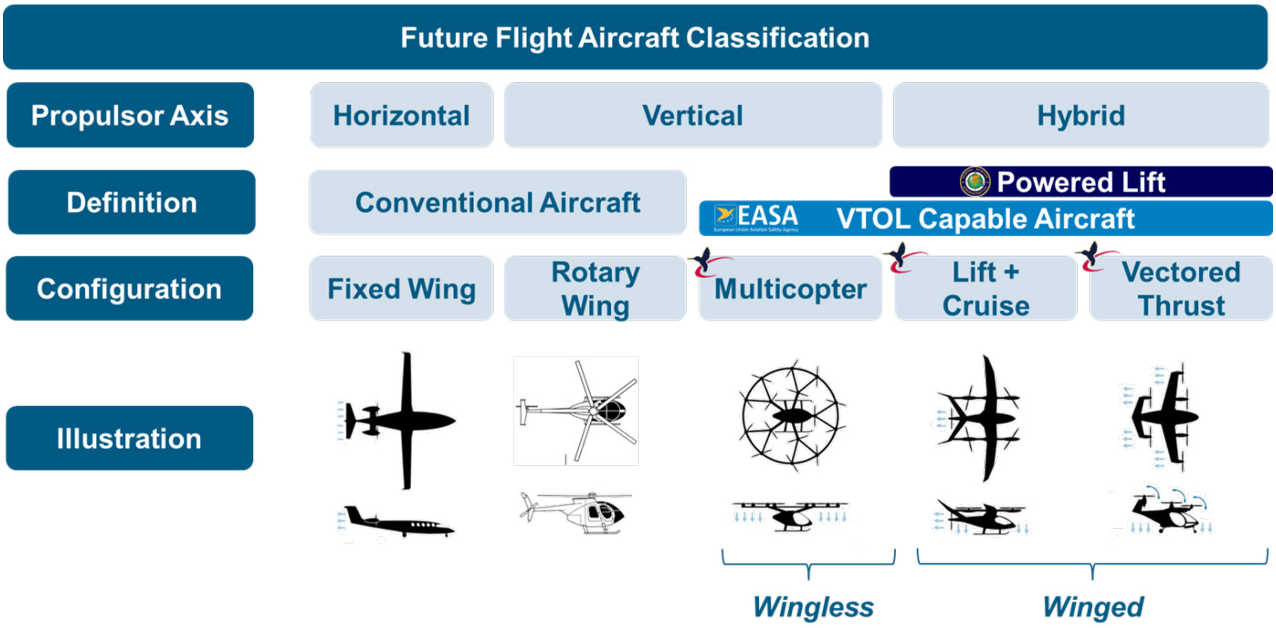


Figure 3-2 – Aircraft terminology
Source: Aircraft images from AAM Reality Index[6]

Differentiating between aircraft types is first achieved by considering the propulsion axis. Aircraft with a horizontal-axis thrust propulsor are the most common design for fixed-wing configurations and as such, can be considered as "conventional" – with existing regulations remaining applicable. Conventional Take-Off and Landing (CTOL) RAM aircraft will fit within this category with additional considerations required where novel propulsion systems are employed.

Similarly rotary wing aircraft are the conventional vertical propulsion aircraft, yet further distinction is required to categorise the vertically oriented propulsors to include the novel Vertical Take-Off and Landing (VTOL) aircraft explored in this study. For these aircraft, the EASA terminology of "VTOL Capable Aircraft" applies which includes aircraft within the scope of Special Condition VTOL (SC-VTOL) – the certification framework selected by the CAA. Within this sub-category, there are three key divisions from the VFS that are well-recognised across the industry, namely:

- Multicopter: VTOL capable aircraft with more than 2 lift-generating propellers with no fixed-wing surface for horizontal flight.
- Lift + Cruise: VTOL capable aircraft with a set of propulsors for generating lift for vertical flight and an additional set of propulsors combined with a fixed-wing surface for cruising in horizontal flight.
- Vectored Thrust: VTOL capable aircraft with propulsors which can change the direction of thrust during flight to transition from vertical flight to horizontal flight requiring the presence of a fixed-wing surface.

Aligned to the latest certification approach from the FAA, the "Powered-Lift" terminology should also be considered for the winged eVTOL aircraft (Lift + Cruise and Vectored Thrust) which feature a transitioning phase.

[6] Advanced Air Mobility Reality Index | SMG Consulting

The EASA "VTOL capable" denomination deliberately excludes reference to the propulsive system (e.g., eVTOL, HVTOL, etc.) to remain future proof for any combination of hydrogen, electric and hybrid powertrains. To fully define the aircraft, it is therefore essential to combine the airframe descriptor with a similarly devised powertrain terminology as per Figure 3-3.

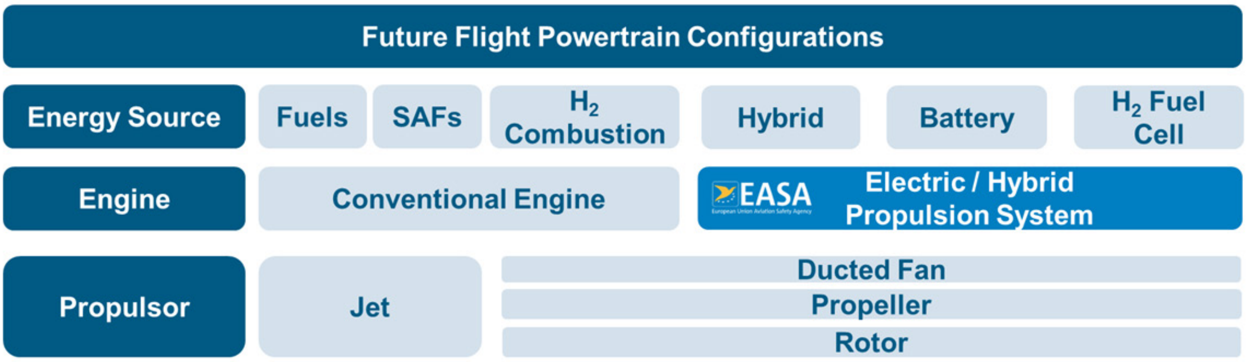


Figure 3-3 – Powertrain terminology

The first consideration for the powertrain is the energy source which helps differentiate traditional combustion fuels from batteries and fuel cells. The ability to function with a combustible fuel is considered a defining feature of a "conventional" engine, whereas electric and hybrid systems are added to deal with novel future flight aircraft.

When it comes to defining unducted propulsive thrust devices, the term "rotor" has been used liberally for many aircraft configurations historically. The VFS[8] argue the term "rotor" should not be applied so loosely. Paraphrasing this article:

"Conventional helicopter main rotors are used for vertical thrust, control and forward thrust. They use blade pitch-angle control to provide both collective blade variation and cyclic blade pitch variation. Meanwhile, propellers have historically provided horizontal thrust in axial-only flow along the aircraft longitudinal axis. As they are smaller and often directly driven by a power plant, they may use variable rpm for thrust control as an alternative to blade pitch. Propellers have no accommodations for flight perpendicular to the thrust axis. For these reasons, it can be concluded that the simple-in-design, variable-rpm and constant-rpm, pitch-controlled propulsors without any provisions for edgewise flight are mechanically the same as aeroplane propellers."

As such, unducted VTOL capable aircraft propulsors should be classed not as "rotors," but as "propellers" – regardless of their fixture. The term "rotor" should be used exclusively for propulsors that have cyclic blade control or flapping hinges – or both – for edgewise flight.

[8] Coming to Terms: Rotor | Vertical Flight Society

Ducted Fan propulsors are an additional subcategory as featured on the Lilium aircraft. With the combined terminology from Figure 3-2 and Figure 3-3, all future flight aircraft can be categorised, allowing requirements to be detailed and analysed for alike aircraft.

3.3. Aircraft Selection

Future Flight aircraft exhibit a wide range of configurations and characteristics. With a refined scope, inclusion in this activity has been evaluated based on 3 key criteria: design maturity, points of novelty, and availability of published data. A full list of analysed OEMs is included in Appendix A.

To best equip the UK airspace and infrastructure stakeholders for the arrival of AAM aircraft, it is imperative to analyse aircraft that have planned entry-into-service within the next 10 years with funding/resources to achieve this. It is these aircraft that could become the front-runners in the market, requiring enabling considerations in the UK to be readied as a priority. Notably, this review does not intend to offer insight on commercial viability, it is to measure technical maturity from published development milestones that indicate progress.

Aircraft that exhibit high levels of novelty must also be considered for futureproofing – ensuring a wide range of Concepts of Operation (ConOps), solution architectures and operating envelopes inform the regulatory landscape. This breadth allows the CAA to make more comprehensive strategic decisions, fully capturing the anticipated aircraft abilities and limits of operation.

Finally, this research activity is highly dependent on the availability of OEM data in the public domain. For this reason, aircraft which have insufficient data published will still be analysed, albeit in a more limited capacity. Prior to the publication of this report, OEMs were provided the opportunity to comment on the dataset to ensure it accurately represents the latest aircraft characteristics in the public domain.

4. Aircraft Characteristics Analysis

Aircraft design requires a complex balance of trade-offs to determine the physical characteristics. As such, accurate explanations of design choices can only truly be gathered by the engineers involved. Regardless, public domain information on the reported aircraft characteristics offers insight into the behaviour of emerging aircraft when combined with a high level, and first principle approach to explaining trends.

A comprehensive examination into the aircraft characteristics from the collected aircraft dataset is presented in this section with key plots and figures to identify trends and insights. By reviewing the aircraft characteristics in detail, the combined implications can then be brought together in Section 5.

4.1. Physical Characteristics

4.1.1. Overview

Physical characteristics include features of the aircraft, either qualitatively defined or quantitatively measured, that serve to identify and explain the aircraft structure and behaviour. These characteristics form the bedrock for designing Take-off and Landing (TO/L) infrastructure, since their design must complement and align to the various use cases in order to support passenger safety, both on the ground and in the air. Definitions of the collected parameters are presented in Table 6-2 within Appendix B.

4.1.2. Mass and Payload

Maximum Take Off Mass

The studied OEMs have generally reported their targeted Maximum Take-Off Masses well, ranging from Jetson ONE's 181kg to Eviation Alice's 7,484kg. Figure 4-1 shows the distribution of reported masses for each of the eVTOL aircraft configuration types with the Robinson R44 illustrated for comparison.

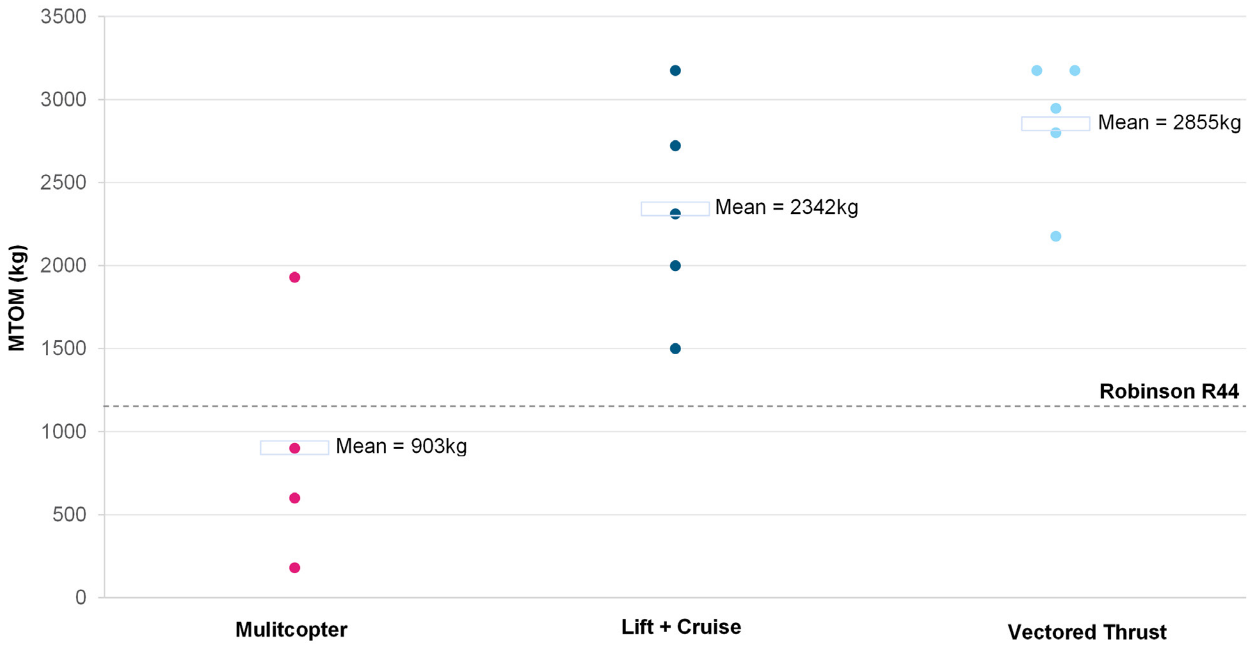


Figure 4-1 – MTOM comparison

Sources: OEM public domain data + approximate 3rd party articles

Multicopters have the lowest average MTOM because the fixed propulsion system must simultaneously generate both the vertical and forward thrust components and is therefore less efficient than an aircraft with a fixed wing. Whilst the mean mass of Multicopters is comparable to that of the R44, there are notable outliers observed with the maximum from the Hydrogen Fuel Cell powered concept from Urban Aeronautics and the minimum the single passenger Jetson. Whilst marketed as an eVTOL, the Jetson is classified as a private ultralight vehicle, which due to limited non-commercial use will require proportionate regulatory frameworks that fall to national / local requirements rather than Part 21 legislation. As such, it will not be permitted to fly in populated areas or use the TO/L infrastructure designed for the AAM market. These "Personal Aerial Vehicle" remain worthy of consideration however as they will still share the airspace with AAM aircraft and are engaged in the same developments in electric propulsion and other innovative technologies.

The Lift + Cruise and Vectored Thrust categories show a significant jump in the average MTOMs owed to the gain in lift efficiency in forward flight from the fixed wing surface allowing greater masses to be carried over greater distances. Once again, these masses show a large spread that results from aircraft specific design decisions. Notably, the mean mass for both winged eVTOL types is over 1,000kg greater than the reference R44.

The maximum eVTOL MTOM of 3,175kg is targeted by Beta, Lilium, and Overair. This mass is the maximum mass limit under the SC-VTOL certification basis. Certifying to this maximum could be a sensible choice to take advantage of as much battery and payload as possible for a given airframe. The maximum MTOM is an important characteristic that allows infrastructure developers to establish the TO/L infrastructure loading requirements. Regulations for this infrastructure will need to account for these maximum weights to ensure that the operation of high MTOM configurations is not limited by Vertiport capability. Vehicle-agnostic vertiports are important for optimising user experience of the Vertiport network for future passengers but may be avoided by some developers who will find it simpler, and more cost-effective, to design around a single aircraft.

For even further futureproofing, it may be necessary to look beyond the initial time horizon of this study. Lilium has communicated a roadmap to scale up their technology in the future for a 16-person configuration and GKN Aerospace has proposed a 30-seater eVTOL Skybus[9]. As technology matures, other manufacturers may also look to create larger, longer-range designs that take advantage of technology developments. Future infrastructure requirements may therefore need to evolve as the technology enters a second generation or if technology simply matures differently to expectations.

Excluding Eviation Alice, the analysed Fixed Wing aircraft use existing airframes retrofitted with electric propulsion systems. The regulations surrounding such aircraft are traced to the UK/EASA CS-23 and FAA Part 23 categories which allow a MTOM of up to 8,618kg. These aircraft will not utilise purpose-built Vertiports but will instead make use of existing aerodrome infrastructure that is appropriate for aircraft of this type.

Payload

Payload and passenger numbers directly impact commercial viability, can dictate safety driven regulatory requirements, and influence Vertiport terminal and airfield capacity sizing. The OEMs demonstrate maximum payload masses ranging from 95kg for Jetson ONE's single occupant aircraft, up to Dufour Aerospace Aero3's 750kg capacity for 7 passengers or cargo.

Figure 4-2 shows how the passenger capacity is distributed for each of the aircraft types.

[9] GKN-led project concludes eVTOL bus is viable concept | Aerospace Testing International

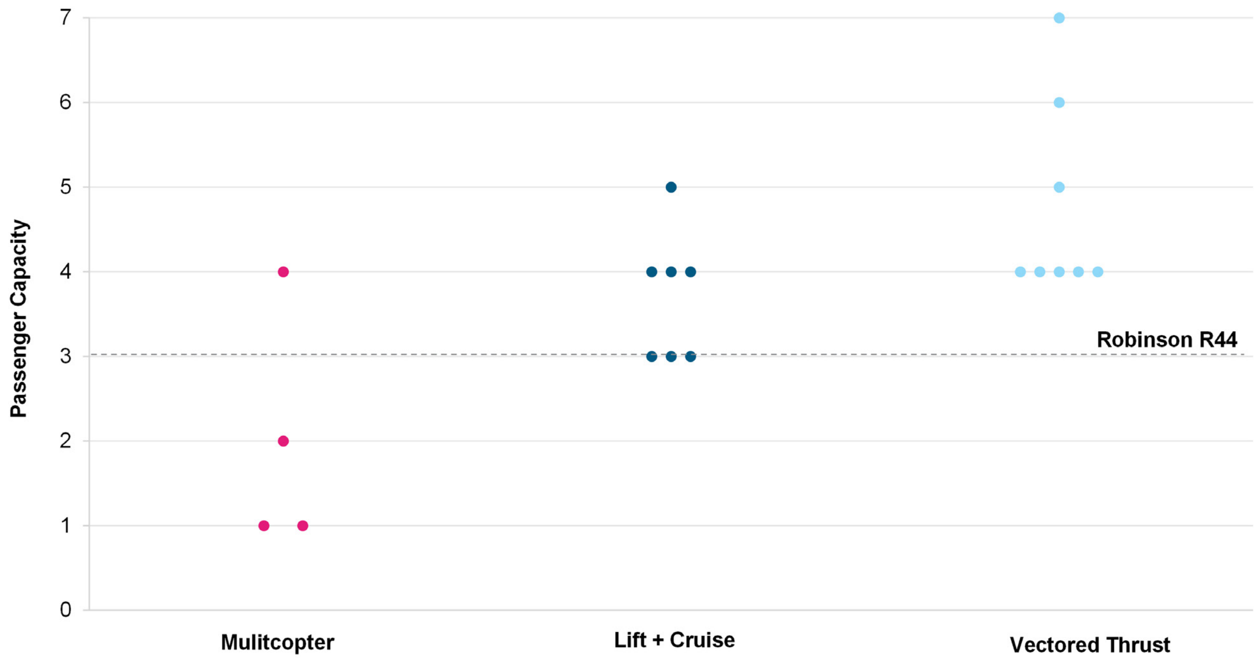


Figure 4-2 – Variation of passenger capacity
Sources: OEM public domain data + approximate 3rd party articles

The trend shows passenger capacity increasing from the Multicopter configuration to Fixed-Wing. Vectored Thrust have the highest modal eVTOL passenger capacity of 4, with a maximum of 7 from Dufour. This range in passenger capacity will be important for infrastructure stakeholders when sizing the facilities. A higher customer throughput associated with higher passenger capacity will inform the peak demand requirements for Vertiport staffing and terminal sizing. Vertiport developers will crucially need to determine whether they design around the maximum capacity, mean or a weighted average of the anticipated fleet mix.

Fixed Wing aircraft have a mode of 9 passengers, with the Ampaire Electric EEL appearing as an outlier with only 3. The maximum capacity of ~20 from the ZeroAvia retrofitted Dornier 228 sits at the limit of the definition for the RAM market. Whilst this aircraft could service short regional mobility routes within the scope of this study, for ZeroAvia it is a step on the roadmap to the larger regional transport market with 50-90 seat aircraft[10].

Figure 4-3 plots the relation between MTOM and payload for each aircraft type with trend lines to illustrate the average payload fraction of both AAM and conventional aircraft.

[10] Zero Emission Flight Infrastructure Grants | ZeroAvia

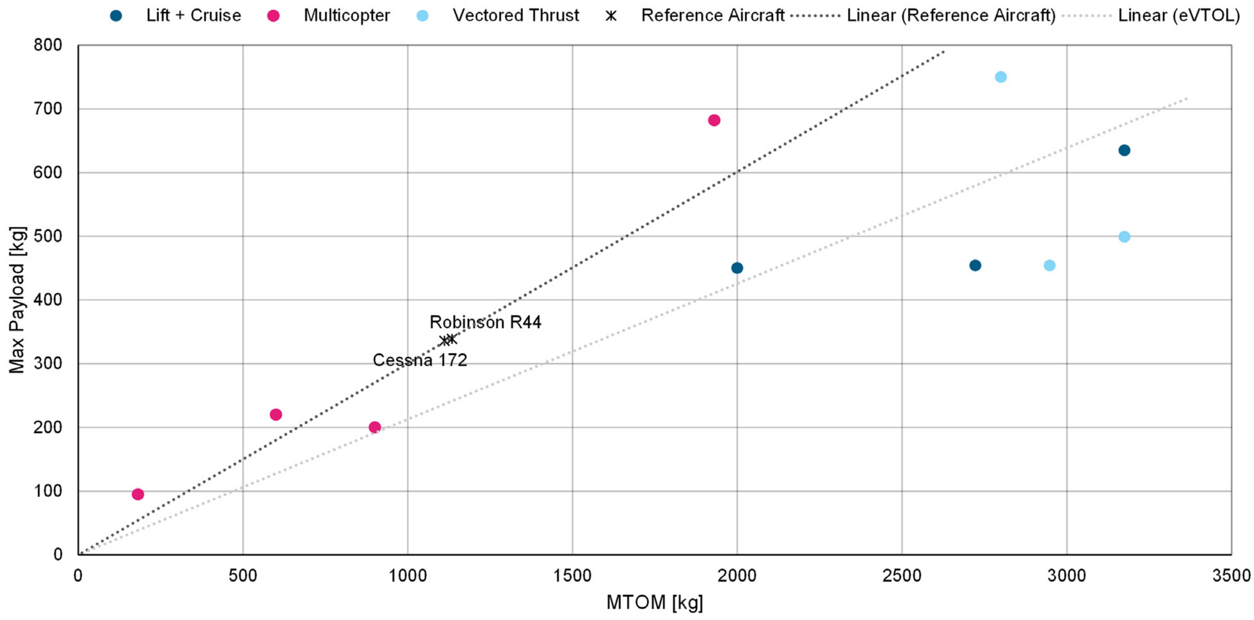


Figure 4-3 – Relation of maximum payload mass and MTOM
Sources: OEM public domain data + approximate 3rd party articles

Aircraft are generally clustered based on configuration type with the winged eVTOLs capable of carrying greater payloads with larger total masses. Urban Aeronautics is an outlier as the heaviest Multicopter, explained by the novelty of the concept – Hydrogen Fuel Cells impose distinctive design requirements at the concept stage.

Payload fraction can be used as a high-level measure of efficiency, by showing how much of the payload comes out of the overall mass budget. If an aircraft can carry greater payload for a smaller MTOM, it suggests the airframe must be efficient at withstanding loads for a lower structural mass. Alternatively, the OEMs could sacrifice energy source mass – and therefore range – to fit within the set mass budget. For further insights on the mass breakdown, the battery mass fraction is required also. Overall, each aircraft design will have varying mass constraints driven by the intricacies of its configuration (e.g., actuation systems for Vectored Thrust) and the selection of components.

The trend lines show that on average, the eVTOL aircraft will have lower, and therefore less efficient, payload fractions compared to the reference aircraft. This is to be expected given the reduced specific energy (Section 4.3.2) of the energy sources compared to traditional fuels. Furthermore, unlike conventional aircraft where the fuel mass decreases through flight, electric aircraft must carry around the full weight of the battery throughout flight, requiring the aircraft to land at its maximum weight. This requires a change in convention when considering how an anticipated breakdown of mass appears within the aircraft as well altering the load cases under which onboard systems will be tested for safety.

4.1.3. Configuration and Dimensioning

Wing and Tail Configuration

The observed wing and tail configurations of the aircraft help to identify novel features and understand emerging trends. Figure 4-4 compares the wing and tail configurations to illustrate the emergence of dominant designs within AAM.

	Wingless	Low Wing	High Wing
Tailless	4	1	-
Conventional	-	-	5
V-Tail	-	-	7
T-Tail	-	1	2
H-Tail	-	-	2

Figure 4-4 – Wing and tail configurations

Lift + Cruise and Vectored Thrust types utilise a main wing to provide lift generation in horizontal flight and the yawing and pitching control is provided by the tailplane (rudder for yaw and elevators for pitch). Multicopters (i.e., wingless, and tailless) are more closely related to rotorcraft and rely on differential thrust for directional control and stability rather than aerodynamic surfaces. The CityAirbus is a novel example that challenges convention by featuring a wing for aerodynamic support only, with no control surfaces.

The most popular configuration exhibited by 7 of the OEMs in this analysis is the high-wing, V-tail design. The high-wing configurations provide inherent lateral stability due to the pendulum effect produced by the aircraft Centre of Gravity sitting below the lifting surface. They also reduce likelihood of harm to passengers and/or the airframe via loss-of-blade in flight since the spinning propellers sit above the plane of the passengers. In addition, the elevated mounting of the propulsion units increases ground clearance to mitigate the risk of blade strike with the ground in low-level manoeuvring and to improve passenger clearance during ingress/egress[11].

Only Lilium Jet and Eviation Alice choose a low-wing design, defined within this analysis to capture a design where the wing does not sit above the main fuselage section, for example Lilium Jet's wing sits approximately half-way across the fuselage section and is referred to as "low-wing" designs. Such designs are typically suited to more high-speed, agile aircraft but may have been chosen for these aircraft for reasons known only to those in the engineering team.

Aircraft Dimensions

The wingspan and aircraft lengths are vitally important to calculate the critical dimensions for sizing TO/L infrastructure. The eVTOL "Minimum Closing Circle" or "Controlling Dimension" (D) is a new parameter defined to standardise the approach to sizing Vertiports on the basis that the "largest overall dimension" will not necessarily encompass the entire defined area of the aircraft as shown in Figure 4-5.

[11] VTOL Urban Air Mobility Concept Vehicles for Technology Development | NASA

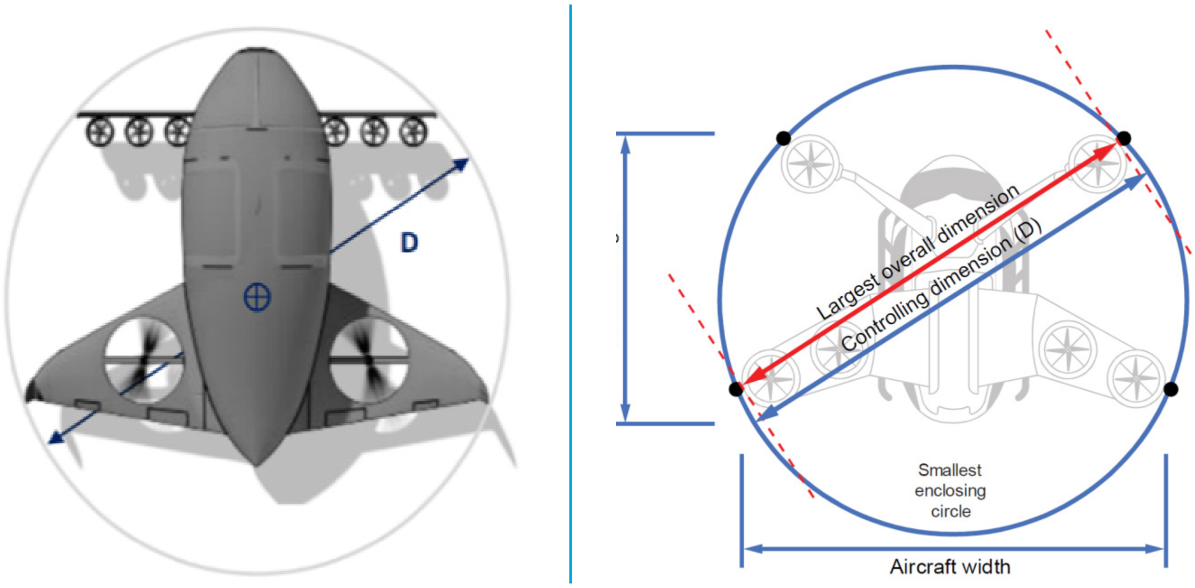


Figure 4-5 – EASA smallest enclosing circle (left) and FAA controlling dimension (right)
Sources: EASA[12], FAA[13]

EASA provide a conservative method to calculate D in the absence of reported data - a factor of $2/\sqrt{3}$ multiplies the largest overall dimension (assumed to be the larger of wingspan and aircraft length). Applying this approach, the Minimum Closing Circle values were calculated for each of the aircraft configurations and tabulated in Table 4-1 in comparison to the controlling dimension (i.e., largest overall dimension in accordance with ICAO Annex 14 Vol II) of the Robinson R44 and wingspan of the Cessna 172.

Aircraft	Wingspan [m]	Aircraft Length [m]	Controlling Dimension, D
Multicopter	N/A	2.5 - 11.3	2.9 - 13.1
Lift + Cruise	12.8 - 15.2	6.4 - 12.0	14.8 - 17.6
Vectored Thrust	11.6 - 15.2	6.4 - 13.0	13.4 - 17.3
Fixed-Wing	11.6 - 19.8	9.1 - 17.5	N/A
Robinson R44	N/A	11.7	11.7
Cessna 172	11.0	8.2	N/A

Table 4-1 – Aircraft dimension comparison
Sources: OEM public domain data + approximate 3rd party articles

[12] Prototype Technical Specifications for the Design of VFR Vertiports (PTS-VPT-DSN) | EASA
[13] FAA Engineering Brief No. 105, Vertiport Design | FAA

The largest Minimum Closing Circle values is found to be 17.6m for the Beta Alia aircraft, whereas the smallest one was for Jetson ONE at 2.5m. In keeping with mass comparisons, Multicopters again are found to be smaller than the winged eVTOL. This dimension is an important value for Vertiport designers to consider ensuring all first-generation eVTOL configurations can be accommodated for. Most Minimum Closing Circle values for eVTOL are higher than the Robinson R44, highlighting the importance of reviewing existing helipad sizing against eVTOL requirements for compatibility. The impact of these differences is explored in more detail in Section 5.

Whilst the controlling dimension is vital for sizing take-off and landing elements of the Vertiport, further details will be required from the OEMs to define the undercarriage width in line with the ICAO definition in Annex 14. This width is required as the sizing dimension for the taxiways which will be a key feature of high throughput Vertiports with multiple stands connected to the Touchdown and Lift-Off areas (TLOFs).

4.1.4. Propulsion

Propulsion Configurations

The propulsion systems used by the OEMs vary based on operational performance requirements, with several options classified in Section 3.2. Each configuration brings with it both advantages and complexities, many of which will be summarised in this section. The propulsion configurations are:

- **Multicopter:** consists of multiple statically fixed lifting-propellers which provide lift and horizontal thrust upon changing the aircraft attitude.
- **Lift + Cruise**: a system with a set of statically fixed lifting-propellers which provide lift thrust and cruising-propellers that provide horizontal thrust.
- **Vectored Thrust:** made up of propulsors which can augment the direction of their thrust by tilting the propulsors from vertical to horizontal positions.
- **Fixed Wing (RAM):** the aircraft in this category use hybrid-electric / hydrogen fuel cell technology which have tractor / pusher propellers found on conventional normal/ commuter category aircraft.

Common to each configuration, the majority of the eVTOL aircraft in this study make the use of a DEP system whereby the propulsion system is closely integrated with the airframe with multiple motors distributed across the wing to increase efficiency, lower operating costs, and increase safety[14].

Propulsor Types

The propulsion configurations can be defined by the different types of propulsors used, namely:

- **Open propellers:** unshrouded propellers in a tractor or pusher configuration
- **Co-axial propellers**: a pair of propellers sharing a common shaft but rotating in opposite directions
- **Rotors:** lifting / cruising propulsor with a flapping hinge as seen on helicopters
- **Ducted fan**: propellers which are enclosed within a shrouded structure that streamlines airflow

[14] Electric Propulsion Technologies | NASA

Open propeller designs are by far the most common across all configurations. They are simple in design, well-understood and straight-forward to maintain with few total components. They perform well aerodynamically to provide thrust in the chosen direction; however fluid interactions can affect their function when closely spaced together with a potential 8.4% reduction in thrust[15].

The open propeller category can be further refined to distinguish between Fixed-Pitch Propellers (FPP) and Variable-Pitch Propellers (VPP). FPP, as the name suggests, have a fixed propeller blade angle that has been optimised for a particular flight condition. VPP can adjust the propeller blade angle allowing optimised thrust control across the flight envelope. Vectored Thrust aircraft have two key flight modes performed by the same propulsors which will require different power / speed requirements. Lessons from the design of military tiltrotors shows that there is no single blade design solution which is optimum for both flight regimes[16]. VPP are therefore almost certainly necessary if maximum efficiency is required. This will require an actuation system on each propulsor to rotate the pitch angle, adding weight and complexity to the system. Lift + Cruise OEMs on the other hand can optimise each set of propulsors for the flight conditions under which they operate, at the compromise of a drag penalty in cruise from the unused set of propulsors. A popular subset of Vectored Thrust aircraft, including Vertical Aerospace and Archer, will also experience this compromise as they feature some non-tilting propellers for VTOL flight which are unused in cruise.

Ducted fan designs used by Lilium Jet and Urban Aeronautics CityHawk use a “duct” to reduce the vortices produced by the air flowing around the ends of the blades. This reduces blade tip losses and swirl losses, thus increasing the overall efficiency of the system for a given disc-load[17]. Lilium can additionally vary the cross-section of the duct to alter the airflow which improves thrust across the mission profile like a VPP system.

One distinctly novel propulsion system is the slow-moving rotor of the Jaunt Journey. Derived from a patent acquired from CarterCopter, the main purpose of this system is to support the aircraft weight at low speeds whilst rotating at only 100RPM in cruise. This low rotational speed is linked to noise, drag and vibration reduction[18]. Importantly, the ability to autorotate is maintained which is key factor for helicopter safety.

Propulsion Safety

Aircraft certification via SC-VTOL requires the eVTOL aircraft to perform continued safe flight and landing at a Vertiport under failure conditions. Whilst helicopters would achieve this requirement through autorotation, and fixed wing through gliding, eVTOL rely upon the redundancy of the many distributed propulsors to continue flight in the event of a loss of power. This is a crucial safety consideration as the use of smaller propellers removes the potential to autorotate safely like a helicopter.

As part of the development process, the OEMs will perform several safety assessment techniques to define the potential failure cases and the probability of their occurrence. Particularly relevant failure modes are those that have the potential to propagate or “cascade” to other failures. For instance, when considering the loss of propeller blades due to a bird strike, the potential downstream impact on other systems must be considered. Such considerations will have a significant impact on design decisions that may often override performance requirements in priority.

[15] A Systematic CFD-Based Examination of Rotor-Rotor Separation Effects | Rensselaer Polytechnic Institute
[16] Improvements to Tilt Rotor Performance Through Passive Blade Twist Control | NASA
[17] Technology Behind the Lilium Jet - Lilium
[18] For Jaunt’s eVTOL Design, Slow Rotor Compound Technology Is the Secret Sauce | FutureFlight

One major safety consideration for eVTOL aircraft, based on early failures modes of the V-22 Osprey, is the impact of Vortex Ring State (VRS). VRS is a potentially hazardous regime of operation that can occur during the descent and landing phases where the velocity up through one or more of the propulsors becomes comparable in strength to the downward velocity that is induced by the propulsor[19], cancelling each other out thus resulting in a loss of thrust. The referenced paper suggests that through a combination of higher disc loading and propeller design, VRS-related behaviour could be different in character compared to conventional rotorcraft. This necessitates further research to understand impact VRS could have on different aircraft types.

Disc Loading

The performance of the propulsion system can be better understood by considering the disc loading – a ratio of the aircraft weight and its thrust area. Figure 4-6 shows a widely used correlation between disc loading and hover lift efficiency for various categories of VTOL aircraft with Lilium and Propeller aircraft (e.g. Joby) superimposed.

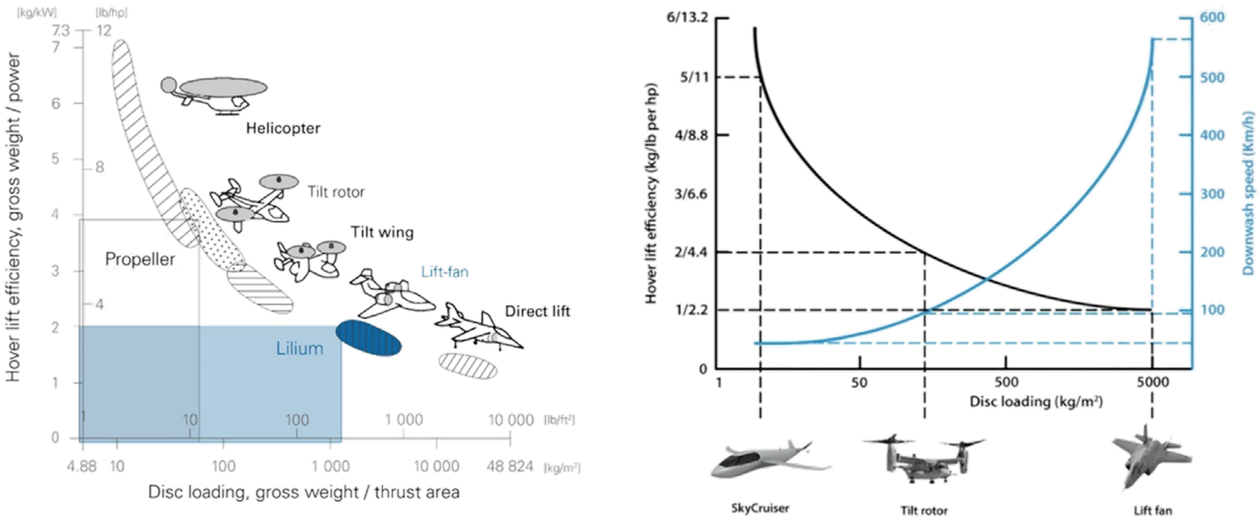


Figure 4-6 – Disc loading variation impacts
Sources: Lilium[17], Krossblade Aerospace[20]

There is a general trend that as aircraft disc loading increases, hover efficiency decreases, i.e., the larger the propulsive area is relative to the weight, the less energy is consumed in hover. With a low reporting of data associated with propeller dimensions, meaningful data points could not be plotted on this relation, but this could be an area for future work to define further eVTOL aircraft types on this illustration.

Disc-loading can be used as a high-level indicator of propulsion performance from which several implications can be derived. For example, the secondary plot illustrates the variation in downwash speed with disc-loading. High disc loading corresponds to high velocity downwash which could have implications on the clearance zones imposed at Vertiports. The potential impact of this effect is a topic that requires further research and experimental validation, which will inform safety risk mitigations in future regulations for commercial operations.

[19] Are eVTOL aircraft inherently more susceptible to the Vortex Ring State than conventional helicopters? | Sophrodyne Aerospace
[20] Disc Loading and Hover Efficiency | Krossblade Aerospace

4.2. Systems

4.2.1. Overview

The *systems* category includes a selection of the components onboard the aircraft which work together to allow it to perform its operations. The systems category includes a selection of the components onboard the aircraft which work together to allow it to perform its operations; the design of which will dictate the performance and capabilities of the aircraft. Definitions of the collected parameters are presented in Table 6-3 within Appendix B and represent only a small sample from a vast array of systems expected on Future Flight aircraft. The subset of systems chosen for review was based upon the implications for the CAA and other industry stakeholders as follows:

- The data gathered surrounding EFCS will demonstrate the certification obstacles that OEMs will need to face to implement a novel control architecture.
- High-lift systems used will inform procedures surrounding low-altitude, low-speed flight as well as landing performance.
- Airframe materials information will highlight the importance of considerations for damage + inspection procedures and non-destructive testing in maintenance operations. These materials will also inform the through life sustainability which will become a critical indicator for the market success.
- Chosen landing gear systems will define the ground operation capabilities (ground/air taxi, turnaround profile, towing vehicles) which Vertiports will need to accommodate for.
- The type of power sources used by the OEMs will inform the infrastructure decisions surrounding fuel storage, refuelling, and charging.

Other systems characteristics initially considered in this study but not included because of a lack of public information are as follows:

- Communications System.
- Navigation System.
- Electric Flight Actuation.
- Electronic Flight Instrumentation System Architecture.
- Flight Management System Architecture.
- Electrical Power Architecture.
- Hydraulic Architecture.

As aircraft mature and public supply chain agreements are in place, additional insights could be gathered by reviewing novelty in the characteristics of these systems.

4.2.2. EFCS

Many of the OEMs in this study intend to use a Fly-by-Wire (FbW) flight control system. The FbW system replaces the cables, pulleys and gears found in older mechanical controls with copper wires which carry electrical signals from the flightdeck to the control surfaces. FbW eliminates the need to maintain the mechanical elements that often suffer from increased wear over time. This also offers a significant weight-saving as the new FbW components are not as heavy as the steel elements of a mechanical system and provides greater design efficiency since the placement of wiring is more flexible than mechanical linkages and cabling. One of the main advantages of implementing FbW systems is that it allows for augmentation of the aircraft flight dynamics/control to facilitate easier attainment of carefree handling qualities, envelope protection, and reconfiguration during aircraft failure scenarios all of which are much more difficult with conventional controls.

Although FbW is considered the preferred option for the OEMs, it still poses limitations. It is common for aircraft to have bundles of copper wires which introduces strenuous maintenance delays during fault isolation. Whilst FbW systems are far lighter than mechanical systems, they are still considered to be heavy due to the amount of copper cabling involved alongside caging from Electromagnetic Interference (EMI). The redundancy in the power system also must be improved, meaning more power generation redundancy along with wire weight could add further mass penalties.

Volocopter is an outlier within the dataset as the only OEM planning to take advantage of a Fly-by-Light (FbL) system. FbL has opened the doors to a theoretically more robust EFCS, using light to transfer information through fibre-optic cables as opposed to electric signals via copper wires, offering the following advantages:

- High bandwidth: Fibre optics offer potentially higher bandwidth than copper wires for faster data rates
- Noise Immunity: Information transfer over long distances without signal degradation via EMI[21].

The main drawback of this system has been the material properties of the cables itself. Fibre optics cables are very small glass fibres, which when subjected to high-vibration environments, are susceptible to breaking. For this reason, major regulatory authorities have been traditionally conservative in approving the use of this technology despite the fact it has been in existence for over 40 years.

In general, the EFCS design will face new challenges in the AAM market due to the increased number of propulsors and complex transitioning phase. Honeywell's system, supplying both Lilium and Vertical Aerospace, will consist of triplex architecture, lockstep processing and other features similar to those found in existing fixed-wing fly-by-wire systems, all packaged into a volume smaller than a hard-cover book[22]. Certification will also be a major hurdle to overcome due to the high criticality of the functionality coupled with highly complex electronics. This is particularly challenging with complex commercial off the shelf hardware such as multi-core processors and large array programmable devices.

4.2.3. High-lift devices

High-Lift (HL) devices are split into two categories based on location: Leading Edge (LE) and Trailing Edge (TE). The primary purpose of LE devices is to increase wing camber and critical stall angle of attack, this allows the aircraft to pitch to greater attitudes as flow attachment is retained; thus, improving low speed flight handling qualities. TE devices, on the other hand, work to increase surface area as well as camber.

Multicopters do not use any high-lift devices since the configuration allows the aircraft to slow to hovering flight with the propellers producing all the lifting thrust. Meanwhile, a small proportion of the Lift + Cruise, Vectored Thrust and Fixed-Wing aircraft are observed to use

[21] Connecting The Future of Flight | TE Connectivity
[22] Autonomy and Avionics for Urban Air Mobility | Honeywell

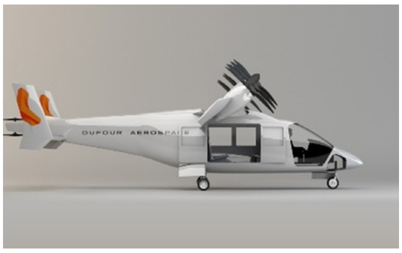
TE flaps in flight test images. These winged eVTOLs have a "transitioning" phase in their flight profile where the aircraft changes from vertical to horizontal flight and vice versa. In both instances, the aircraft flies at low speeds and can risk stalling; flaps enable the wings to generate lift at the lower airspeeds, improving the efficiency and safety of the manoeuvre. The ability to perform this transition phase safely will be dependent on the obstacle environment in the approach path to the Vertiports.

Fixed-Wing RAM aircraft will conventionally land on runways and so will utilise similar landing profiles and high-lift devices used by their conventional counterparts. In these instances, high-lift devices will inform field performance which could impact which airfields are compatible with the aircraft.

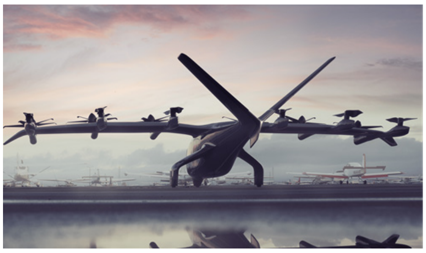
4.2.4. Landing gear

The aircraft in this study use a wide variety of different landing gear configurations as shown in Figure 4-7. This introduces many considerations for both the ground operations and the TO/L infrastructure.

Volocopter Volocity – Skids



Dufour – Tricycle retractable



Archer Midnight – Tricycle fixed

CityAirbus NextGen – Struts

Jetson ONE – Airframe base

REGENT Viceroy – Hydrofoils

Figure 4-7 – Landing gear configurations

Sources: Volocopter, Dufour, Archer, CityAirbus, Jetson, Regent

All the analysed Multicopters and some Lift + Cruise designs have no wheel attachments on the landing gear. This configuration limits the ability to ground taxi, implying the need to land directly onto a TLOF area close to a terminal, use a towing vehicle or move around Vertiports via air taxiing close to ground level. This will similarly pose constraints when positioning the aircraft for routine inspections and maintenance.

Multicopters also all feature fixed landing gear which are mechanically simple in design – reducing weight and saving space onboard. There is a performance trade-off however due to the drag penalty from exposure to the airstream which becomes more relevant as cruise speed increases. Most Lift + Cruise aircraft also use fixed landing gear, whereas Vectored Thrust are more varied with some OEMs opting for retractable. Considering the cruise speed data, Multicopter and Lift + Cruise aircraft fly at similarly low speeds during cruise. In contrast, the Vectored Thrust and Fixed-Wing aircraft fly on average over 100km/h faster.

At higher speeds, retractable landing gear are increasingly attractive as drag increases with the square of velocity (Equation 4-1).

Equation 4-1

$$D_0 = C_{D_0} \frac{1}{2} \rho V^2 S_{wet}$$

Where D_0 = total zero-lift drag, C_{D_0} = zero-lift drag coefficient, ρ = air density, V = aircraft speed and S_{wet} = surface area of the aircraft exposed to the airstream.

To offset the drag increase at a given altitude, the drag coefficient and/or surface area need to be reduced to counter the increase in speed. One means of achieving this is to use retractable landing gears, as stowing removes exposure to the airstream during cruise flight.

4.2.5. Airframe

In the last century, airframe materials have progressed from wood and fabric to high-strength sheet metal that can withstand the greater loads of high-speed flight. Most recently, the use of composites – mainly Carbon Fibre Reinforced Polymers (CFRP) – has increased in popularity due to their low-density, high-strength properties. Following this industry evolution, the analysed OEMs are primarily planning to use composites (Figure 4-8).

Figure 4-8 – OEM airframe material selections
Sources: OEM public domain data + approximate 3rd party articles

There are many reasons why composites could be considered more favourable than aluminium:

- **Weight-reduction:** carbon-fibre composites used in a component which has the same dimensions as an aluminium alternative can offer weight-savings of 42%[23].
- **Ease of manufacturing:** composite structures can be moulded into complex shapes. This allows sections of aircraft to be produced in various locations with lower manufacturing costs, instead of aluminium sheets needing to be assembled in one main location together.
- **Increased fatigue-life:** carbon-fibre composites are more resistant to fatigue.

The weight-saving gained by using CFRP is highly important for eVTOL aircraft, with OEMs aiming to minimise airframe weight to maximise both the battery and payload fractions. With current battery technology offering limited range, maximising the structural efficiency is key to achieve the commercial performance objectives. Composites however are not without

[23] Aluminium vs carbon fiber – comparison of materials
[24] Composite Vs Aluminum – Which Fuselage Is Best?

disadvantages; OEMs will have to consider the following limitations[24]:

- **Cost:** CFRP components are more expensive and take longer to produce. The manufacturing process requires expensive tooling and takes a long time to layer the carbon-fibre laminates before it can be cured to its final shape. Material qualification also takes longer which can become a long and expensive process, especially when including damage tolerance properties.
- **Damage detection:** Impact damage may not be as easy to detect by operators and maintainers due to the layering of the carbon fibre laminates or takes longer to inspect in comparison to metallics.
- **Waste/recyclability**: There is significant waste material produced from the layering process, which importantly cannot be reused. In pursuit of sustainable aviation for a net-zero future; end-of-life processing should also be considered. Currently, there is little technology available to recycle CFRP parts, whereas aluminium components can be melted down for secondary applications.

Whilst most composites will use thermoset polymers as the matrix, Jaunt are planning to use thermoplastics for most primary structure components. Thermoplastics potentially increase the efficiency of automated manufacturing processes and could improve crashworthiness, but the fabrication processes are currently at a lower level of maturity with regulators[25]. Of the fixed-wing RAM aircraft studied, only three are choosing to use CFRP airframes. Five are still reportedly using the aluminium airframes which their retrofitted aircraft were originally constructed with, and one has not disclosed the airframe material at this stage.

4.2.6. Power Source

Electric aircraft work on the principle of converting electrical energy supplied by a source into useful mechanical energy in the propellers. The benefits of electric propulsion units can be achieved with several power sources; this study identifies the following key contenders for the AAM market:

- **Batteries:** a collection of one or more cells, in which stored chemical energy is converted into electrical energy and used as a source of power.
- **Hybrid electric:** a source which combines a conventional internal combustion engine (ICE) system with an electric propulsion system (e.g. battery power or hydrogen fuel cell).
- **Hydrogen Fuel Cell (HFC):** an electrochemical cell which converts the chemical energy of hydrogen and an oxidizing agent (usually oxygen) into electricity through a pair of reduction-oxidation (redox) reactions.

Hydrogen combustion and Sustainable Aviation Fuels (SAFs) are two further potential Future Flight power sources that are considered outside of the scope of this study as they will be more relevant to longer range applications beyond the AAM market. Figure 4-9 shows the power sources used by the aircraft types. The most popular choice being batteries, which 22 out of the 20 aircraft analysed have selected.

[25] Stamping Out Air Taxis | evtol.news

	Batteries	Hydrogen FC	Hybrid Electric
Multicopter	3	2	-
Lift + Cruise	7	-	1
Vectored Thrust	8	-	1
Fixed Wing	4	2	3

Figure 4-9 – Power sources comparison
Sources: OEM public domain data + approximate 3rd party articles

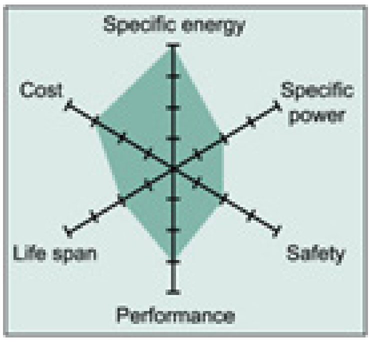
The eVTOL aircraft require a power source that can store enough energy to reach the range requirements but also deliver high power (see Section 4.3.3) – all whilst minimising mass. Further to these performance demands, the power source also influences the level of supporting infrastructure required for the operation.

Due to the growth in maturity of both battery and charging technology driven by the automotive market, and anticipated cost deflation, batteries have proven to be an attractive option for eVTOL aircraft. Where higher range is required however, batteries remain limited, shifting OEMs to consider higher specific energy solutions.

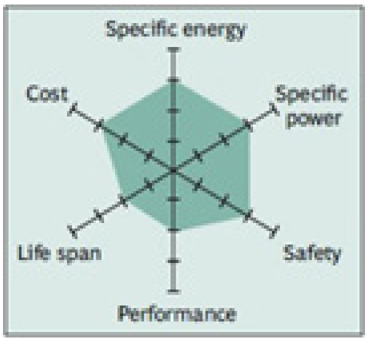
Batteries

Electric aircraft will primarily use a variety of the Lithium-ion battery however most OEMs have decided not to disclose the specific cell chemistries in the public domain. This decision may be for commercial sensitivity or simply because specific suppliers have not yet been selected.

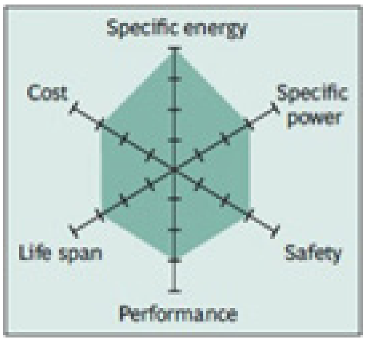
A summary of the various chemistries of Li-ion batteries is shown below in Figure 4-10, describing the key properties which inform battery supply selection. These factors include *specific energy* (how much energy per unit mass); *capacity* (total energy stored); *specific power* (the ability to deliver high current); *safety; performance* at hot and cold temperatures; *life span*; and *cost.*



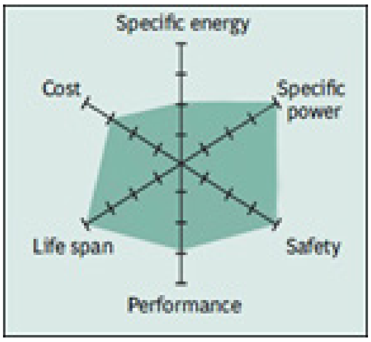
Lithium Cobalt Oxide – LCO



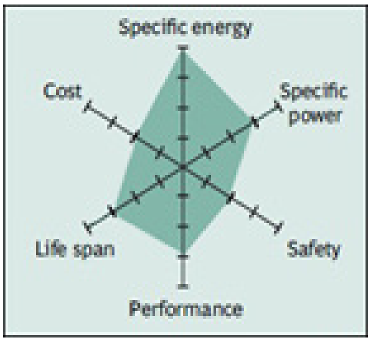
Lithium Manganese Oxide – LMO



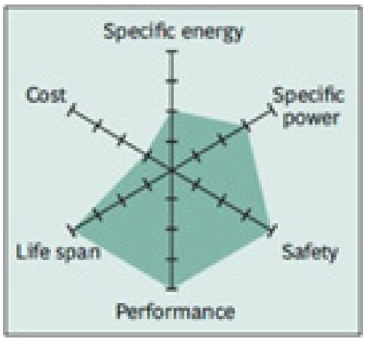
Lithium Nickel Manganese Cobalt Oxide – NMC



Lithium Iron Phosphate – LFP



Lithium Nickel Cobalt Aluminium Oxide – NCA



Lithium Titanate – LTO

Figure 4-10 – Property trade-off for Li-ion cell chemistries

Source: Battery University[26]

With a strong balance of each parameter, the Li-NMC is a popular cell chemistry.

With a strong balance of each parameter, the Li-NMC is a popular cell chemistry. Beyond these factors, OEMs will also need to consider other properties of interest such as fast-charge capabilities, self-discharge, and shelf life. In pursuit of increasing range, the OEMs will look to exploit revolutionary new chemistries that offer higher specific energy. Battery types which may emerge in future generations of aircraft include:

› **Solid-state Li-ion:** High specific energy but poor loading (specific power) and safety.
› **Lithium-sulphur:** High specific energy but poor cycle life and poor loading
› **Lithium-air:** High specific energy but poor loading, needs clean air to breath and has short life[27].

The types of batteries onboard the aircraft could influence requirements at the Vertiport such as emergency response in the event of a fire.

Hybrid Electric

Hybrid electric power sources can be operated in **parallel** to provide power from both the electric and fossil-fuel-based source simultaneously or in **series** with one source exclusively providing the power and the second providing electricity.

[26] Types of Lithium-ion | Battery University
[27] BU-205: Types of Lithium-ion

Hybrid systems have the advantage of offering power source redundancy, however the two systems are typically designed to provide the total power required together. This means there may be a significant reduction in power available should one system fail, potentially limiting the viability of continued safe flight and landing.

Compared to all-electric battery powered aircraft, the hybrid-electric variants have much higher ranges owed to the higher specific energy of conventional fuels. However, disadvantages include increased maintenance costs from the additional Internal Combustion Engine (ICE) system that wears more than the electrical motor system resulting in a reduced Time Before Overhaul (TBO). Moreover, out of all the different power sources, hybrid systems directly emit the greatest quantity of greenhouse gases via the ICE system. Whilst this could be offset with Sustainable Aviation Fuels (SAFs), hybrid remains a less prevalent configuration for the AAM market for these cost and sustainability considerations.

Hydrogen Fuel Cell

Hydrogen Fuel Cells (HFCs) offer one of the most potentially environmentally friendly systems to produce electricity, which is important to all the OEMs whose business are centred around sustainable transportation. They produce electricity through redox reactions using only hydrogen and oxygen molecules. The exothermic reactions produce heat and electricity, with the only by-product of the reaction being water vapour. The water vapour could still have an impact on climate with studies on-going to determine if the vapour produced by HFC at altitude will present an issue. Current research suggests that despite the high frequency of contrail formation from fuel cells, their climate impact is lower than that of contrails from jet engines[28].

Few of the eVTOL OEMs have chosen HFCs as a power source for first generation aircraft. Whilst it may provide high specific energy, current HFC technology does not deliver the high specific power required for VTOL flight without being supplemented by batteries. This is vitally important for winged eVTOL, that could require powers up to 2,000kW. Current Low Temperature Proton Exchange Membrane (LTPEM) technology can deliver around 1kW/kg[29] when including the supporting systems to make the fuel cell function. For a 2,000kW power demand, this would require over 2,000kg of power source on an aircraft of less than 3,175kg – over twice the weight of battery options. Urban Aeronautics have partnered with HyPoint (recently acquired by ZeroAvia) who are developing High Temperature Proton Exchange Membrane (HTPEM) fuel cells which aim for a specific power in excess of 3kW/kg.

Hydrogen fuel cells are more prevalent for the RAM market with UK organisations ZeroAvia and Fresson analysed in this study. Without a VTOL flight phase, maximum power demands are reduced allowing the benefits of the increased specific energy to offer vastly improved range compared to batteries.

With 3 key power sources being explored, industry stakeholders will need to keep abreast of several ecosystem considerations. Compatibility with existing heliports, and planned Vertiports, will require a combination of charging and refuelling infrastructure to remain fully aircraft agnostic. These systems will impose novel safety requirements on the storage and handling of the energy sources – requiring additional standardisation and regulatory oversight.

[28] Theory of Contrail Formation for Fuel Cells | K. Gierens
[29] Technical White Paper | Hypoint

4.3. Performance

4.3.1. Overview

Performance characteristics are defined as a measure of the ability of the aircraft to fulfil its intended applications. Performance is important for this study to quantify the impact of the physical features and understand how novel aircraft behave relative to their conventional counterparts. Definitions of the collected parameters are presented in Table 6-4 within Appendix B.

4.3.2. Specific Energy

Specific energy is an important measure of Future Flight aircraft performance that is often identified as a key technical barrier to entry. Fundamentally, batteries have significantly less energy per kilogram than conventional fuels, resulting in reduced range for a given aircraft mass. Current batteries have an assumed state of the art value of ~260Wh/kg[30]; for comparison, aviation fuels have a specific energy of around 12,000Wh/kg (~43MJ/kg)[31].

Many of the most mature OEMs have now signed agreements to develop and supply their battery systems. Lilium have a supply agreement for Zenlabs' high-silicon anode Li-Ion cells which aims for a high specific energy over 300Wh/kg. Supernal recently partnered with EP Systems, targeting a later EIS of 2028 to allow time for battery technology to mature. Both Archer and Vertical Aerospace have selected Tawainese battery producer Molicel to provide their high performance cells.

Outside of the eVTOL sector, battery manufacturer Amprius (backed by Airbus investment) have achieved breakthrough demonstrations of 450Wh/kg cell densities which could offer the performance required to service longer range routes. The evolution from cell-level to battery-level perfomance must not be forgotten though – additonal systems and structures can reduce this by a factor of ~0.55-0.75 once scaled to pack level .

The comparison to automotive technology should also consider aerospace-specific challenges due to the higher power demands and stringent regulatory requirements. As a result, the usable battery capacity is reduced as the battery should not discharge below a 10% State of Charge (SOC) due to voltage drops, and energy reserves are required for balked landing and diversion32. Furthermore, degradation through life reduces the usuable capacity which must also be considered in the battery sizing and for maintenance, longevity, and sustainability.

Noting that only 4 of the manufacturers openly report their targeted specific energy, this is a key gap that should be addressed in coming years to help the stakeholders plan for realistic ranges and understand the safety implications. Additional battery metrics are publicised even less, with Power Density and Cycle Life being similarly important for operational considerations. Research at Carnegie Mellin University (shown in Figure 4-11) modelled the battery requirements for various designs, indicating the trade-off required between peak power and energy.

[30] EV battery technologies: From the state of the art to the future energy stores | Battery Power Tips

[31] Characteristics of Petroleum Products Stored and Dispensed | Petroleum Products Division GN

[32] Challenges and key requirements of batteries for electric vertical takeoff and landing aircraft | X. Yang et al.

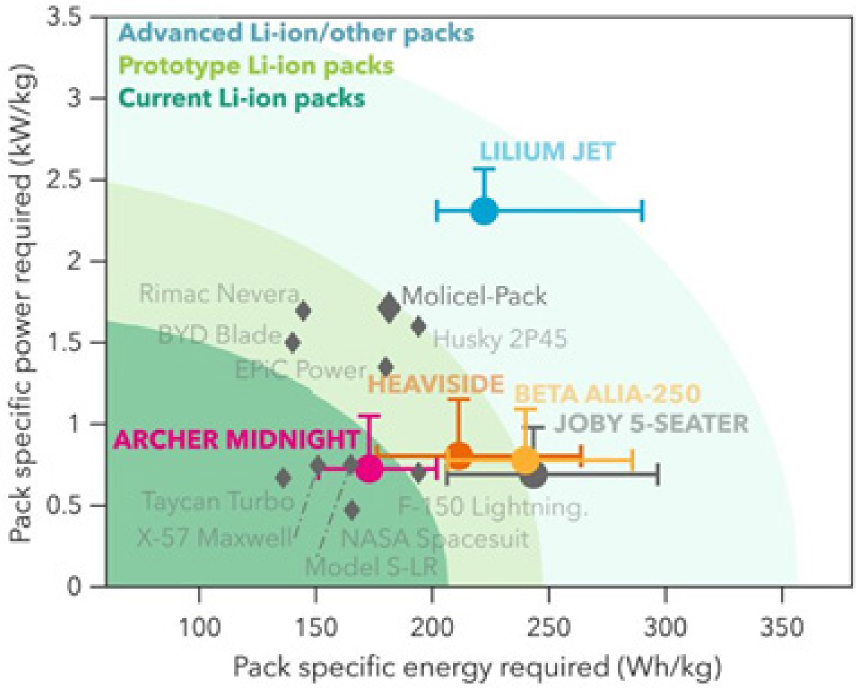


Figure 4-11 – Battery specific energy and specific power requirements
Source: Proceedings of the National Academy of Sciences of the United States of America[33]

This research estimates that the performance requirements targeted may rely on advanced prototype battery performance. Increased transparency on how these performance objectives are to be achieved could improve the readiness of the supporting industry stakeholders so that appropriate flight plans for the current technology capability can be selected. Of course, this level of collaboration may be seen as counterproductive for business strategy which may favour protecting key innovations that offer a competitive advantage.

4.3.3. Power

Power requirements are not well-reported by the manufacturers, with limited data available in the public domain. Of the available data, it is noted that hover power demands are extremely high compared to cruise requirements due to the VTOL mission profile. This imposes a challenging performance optimisation for the designers that will influence the propulsion system and battery as discussed in the previous sections. With momentum theory it is possible to calculate an estimate of power to weight ratio in hover as shown in Equation 4-2.

Equation 4-2

$$\frac{P}{W} = \sqrt{\frac{T/A}{2\rho}}$$

Where P/W = Power to weight ratio, T/A = disc loading, ρ = air density.

In the absence of reported data, this relation could be a used as a quick estimate if power requirements were required. Power will have wide-reaching safety implications driven by the high voltages necessary to deliver the power through the aircraft. Effects such as

[33] The promise of energy-efficient battery-powered urban aircraft | S. Sripad et al. (Revised: LinkedIn)

electromagnetic compatibility and fire protection will need to be considered by the OEMs carefully to ensure safe interactions with the environment.

4.3.4. Speed, Range and Endurance

Speed, range, and endurance are perhaps the most important measures of performance for the eVTOL aircraft as the balanced combination of the three is key to both commercial success and safety. Range and speed are widely reported by the manufacturers allowing interesting insights to be gathered on the impact of the different configurations as shown in Figure 4-12.

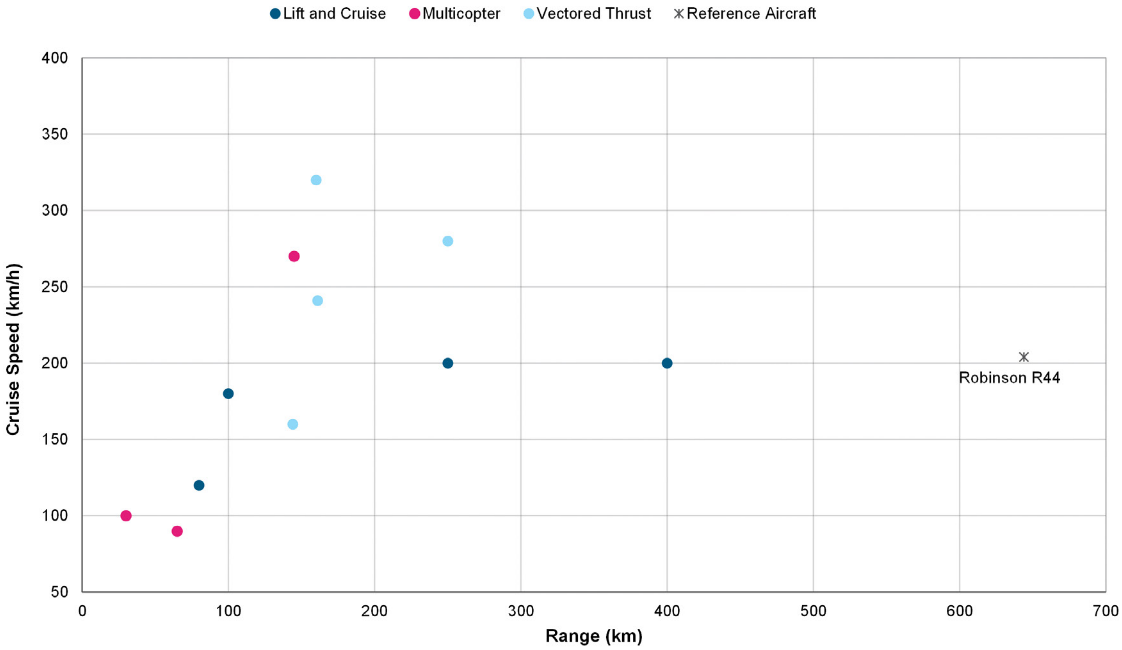


Figure 4-12 – Speed and range comparison
Sources: OEM public domain data + approximate 3rd party articles

To understand these trends, it is useful to reference the Breguet range equation simplified for the cruise portion of battery-electric flight as per Equation 4-3. For each aircraft, the design will have a major influence on the properties of the power source and the lift to drag ratio.

Equation 4-3

$$R = E \cdot \eta \cdot \frac{1}{g} \cdot (L/D) \cdot \frac{m_{bat}}{m}$$

Where R = range, E = battery energy, η = drivetrain effiency, g = acceleration due to gravity, (L/D) = lift to drag ratio and m_{bat}/m = battery mass fraction.

Similar variations of this fundamental equation can be derived for the different power sources, with the lift to drag ratio remaining a key influencing factor. Multicopter aircraft have a low lift to drag ratio associated with the lack of a wing and therefore demonstrate a reduced range for battery designs. Urban Aeronautics exceed the battery counterparts due to the planned use of hydrogen fuel cells as a power source.

Lift and Cruise aircraft on average have an improved range compared to Multicopters due to the addition of a wing, but generally demonstrate a lower range than the Vectored Thrust aircraft. Lift + Cruise are more likely to have a lower lift to drag ratio because of the lifting propulsors not being used in cruise. The outlier of the Ascendance ATEA does not meet this trend due to its hybrid propulsion system. Vectored Thrust aircraft also target greater speeds which could be beneficial for offering competitive time-savings to customers.

All eVTOL aircraft have signficantly reduced range compared to the Robinson R44 reference aircraft. Flight plans will have to be optimised around this reduced range, with particular attention to the safety of reserves for diversion as flight endurance will be limited. Understanding these parameters is particularly important as operations scale up – increasing congestion at Vertiports. The in-flight characteristics will influence factors such as a separation distance and holding patterns that may be required at destination Vertiports. This will contribute to a new set of requirements to be integrated into air traffic control practices, particularly under emergency scenarios where procedures will have to differ from conventional aviation.

4.3.5. Noise

Noise is a highly relevant factor for Future Flight aircraft performance given the planned scale of operations in high population density areas. Reducing noise will be crucial for both the viability of building approvals for TO/L infrastructure in urban locations and the public acceptance of aircraft flying overhead. Whilst many OEMs claim noise levels far quieter than helicopters, the availability of independently verified noise data is minimal at present.

There are many metrics to quantify noise, appreciating that it is not just amplitude but also pitch and tonality that will impact community acceptance. The focus of this study is level of sound measured in 'A-weighted decibels' (dBA) which adjusts decibel values to take account of the frequencies that the human ear is most sensitive to.

Conventional helicopters are logically the benchmark for comparison to eVTOL noise due to similarity in operations, and as such, predicted noise levels are often described as fractions of helicopter noise.

Noise emissions from eVTOLs are highly dependent on the aircraft design including their size and configuration. In general, however, the increased number of distributed propulsion units reduces the propeller diameter, thus decreasing the tip speeds and impacting the noise characteristics. Thickness noise (generated by the displacement of air by the blade) is strongly dependent on tip speed, with Loading noise (generated by the lift and drag forces on the blade) impacted to a lesser degree[34]. In particular, Unsteady Loading Noise is anticipated to be the primary concern. This simply infers that aircraft propellers will have to be optimised around design and performance constraints that balances these noise sources.

Much like helicopters, additional noise will be generated through complex aerodynamic interactions that are highly dependent on the configuration of the propulsive system. Design decisions such as the position of the propellers relative to each other and airframe components will impact the acoustic behaviour.

Noise is a poorly reported characteristic. Whilst some OEMs report a noise value, few describe the conditions under which this noise would be recorded – i.e. distance and flight mode. Take-off and landing noise is the most important value given the need to demonstrate to cities that the Vertiports will meet requirements to avoid disruption. Figure 4-13 shows the reported cruise and take-off/landing noise of a small sample of eVTOL aircraft. In comparison, the Robinson R44 has an overflight noise of approximately 80dBA[35].

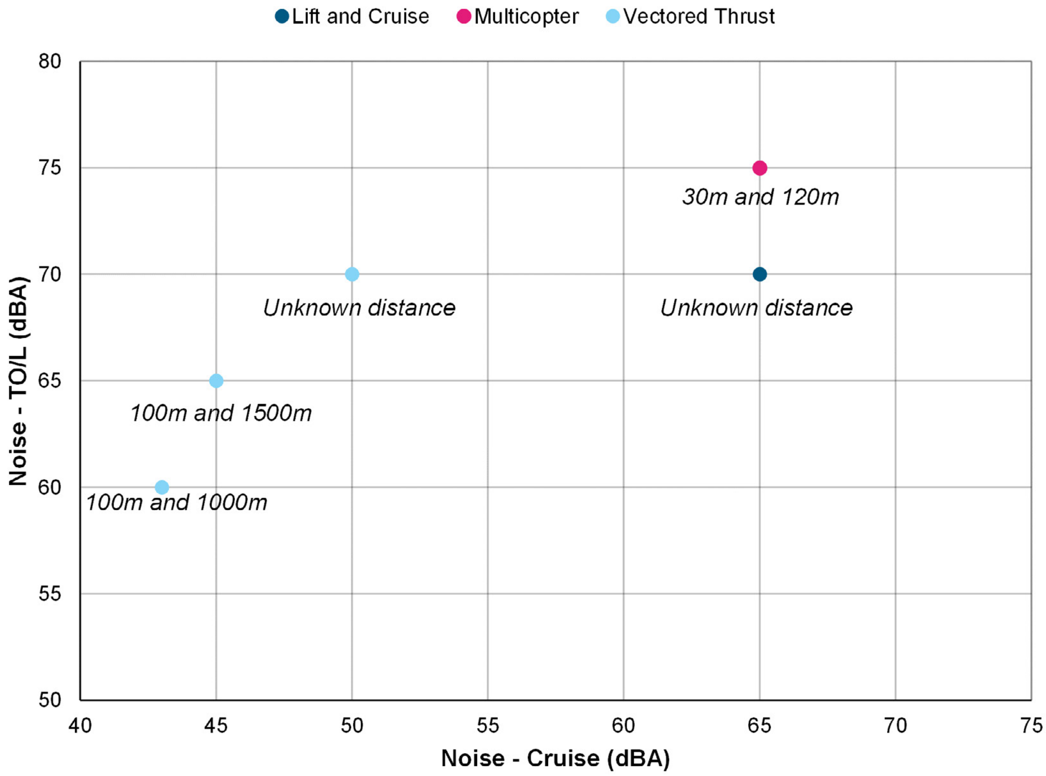


Figure 4-13 – eVTOL Noise comparison
Sources: OEM public domain data

The quality of the correlations that can be observed from this data are limited at this time due to this inconsistency in the reporting method. For instance, Volocopter quote their landing noise from 30m whereas Joby use 100m. Standardisation of these metrics is vital to allow valid comparisons. Draft guidance has been released by EASA for <600kg RPAS[36] but no guidance yet exists specifically for eVTOLs.

In the absence of reliable data, it is more useful to consider the theoretical implications for the different aircraft types. For winged eVTOL aircraft, the propellers are aligned with the oncoming air flow in cruise, rather than perpendicular to the flow, creating noise levels more aligned to conventional fixed wing aircraft. Additionally, cruising is likely to be performed at sufficiently high altitudes to minimise the noise at ground-level. However, in take-off and landing, the higher disc-loading of these configurations (see Section 4.1.4) could correlate to increased noise.

The strongest evidence of eVTOL noise performance comes from collaboration between Joby and NASA. In this research[37], NASA used a field array of 50+ microphones to record noise at numerous flight speeds and altitudes. In cruise at 500m overhead, the research confirmed a noise of 45dBA with take-off and landing noise calculated as 65dBA from 100m. This is around 15dBA quieter than the reference aircraft which is a significant difference given that decibels are a logarithmic scale.

[34] Challenges and opportunities for low noise electric aircraft | E. Greenwood et al.
[35] Type Certificate Data Sheet for Noise - EASA.IM.R.121 | EASA
[36] Guidelines on Noise Measurement of Unmanned Aircraft Systems Lighter than 600 kg Operating in the Specific Category (Low and Medium Risk) | EASA

4.4. Operations

4.4.1. Overview

Operations describes the capabilities of the aircraft relating to their intended flights, piloting, and ground handling requirements. Operational characteristics are notably important for informing the design and development of Future Flight aerodromes, with many unique requirements that differ from conventional aviation. Definitions of the collected parameters are presented in Table 6-5 within Appendix B.

4.4.2. Use Case(s)

From the analysed dataset, 6 key use case categories were identified and analysed in Figure 4-14:

- **Passenger Transport:** Passenger carrying missions for a range of applications such as airport shuttles, private flights, intra-city air taxis and regional connectivity.
- **Emergency Response:** Supporting public emergency services including medical transport, air ambulance and firefighting.
- **Logistics:** Transportation of cargo.
- **Defence:** Broad range of military applications.
- **Tourism:** A-A flights for sightseeing tours.
- **Surveillance:** Aerial reconnaissance to support law enforcement agencies.

Whilst all Future Flight aircraft are targeting passenger operations of some form, alternative applications must also be considered in the future; closely aligned to the capabilities of the aircraft types.

Multicopters and Lift + Cruise aircraft, with improved hover capability, are well-suited to traditional VTOL applications such as emergency response, tourism, and surveillance. Fixed Wing designs with superior speed and range are better suited to logistics operations, potentially as this aligns with the aircraft they are looking to substitute in the market.

[37] Joby Confirms Revolutionary Low Noise Footprint Following NASA Testing | Joby

	Passenger Transport	Emergency Response	Logistics	Defence	Tourism	Surveillance
Multicopter	5	4	2	-	1	-
Lift + Cruise	8	3	2	1	3	2
Vectored Thrust	8	3	2	-	-	-
Fixed Wing	9	1	7	1	-	-

Figure 4-14 – Aircraft use case distribution
Sources: OEM public domain data + approximate 3rd party articles

4.4.3. Autonomy

Autonomous operations are naturally targeted for the AAM market given the impact of a low pilot-passenger ratio on the operating economics. Removing a pilot from the aircraft creates the possibility for one or two extra seats, increasing passenger load factor and thus improving profitability and/or decreasing ticket prices. Furthermore, analogous to the automotive world, automation has the potential to reduce the impact of pilot error in large-scale operations. Whilst the route to full automation will be challenged by technology limitations, regulatory maturity, and public support, it remains an important milestone that the industry strives towards.

Autonomous operations are likely to mature through a phased approach, decreasing the level of pilot oversight at each step – proposed by McKinsey[38] as follows:

- **Phase 1:** No automation of human assistance;
- **Phase 2**: Partial or conditional automation;
- **Phase 3:** High automation with remotely supervised aircraft;
- **Phase 4:** Full automation.

Regulators are considering this phased approach seriously, with EASA publishing a roadmap for the use of Artificial Intelligence (AI) in aviation[39]. Figure 4-15 illustrates the timeline each of the OEMs targeting autonomy are working to:

[38] Flying cab drivers wanted for urban air mobility | McKinsey

Figure 4-15 – Timeline to autonomous operations
Sources: OEM public domain data + approximate 3rd party articles

From the aircraft dataset, Ehang are following the fastest timeline – targeting unpiloted operations by entry into service in the early 2020s. This objective will be challenged by the maturity of the global regulations surrounding the aircraft certification and operations.

Importantly, the impact of autonomy affects not only the regulation of the aircraft themselves and the criticality of the onboard software but also the supporting infrastructure. As Wisk notes[40], the introduction of autonomous aircraft will pose unique areas (e.g. automation systems for effective data exchange) to address to maintain the safety levels achieved by piloted aircraft. Adding autonomous aircraft to the future fleet mix will further challenge the enabling stakeholders to prepare suitable infrastructure, procedures, regulations and standards.

4.4.4. Re-energising Time

Of all the ground operations required for aircraft turnaround at the Vertiport, re-energising time is the mostly widely publicised, yet is not widely available in the public domain. Figure 4-16 shows how reported re-energising time varies. There is no standard definition for how recharging time should be reported so there could be variation between OEMs over whether they consider this to be a full charge, or to ~80% which might be sufficient for many uses.

[39] Artificial Intelligence Roadmap | EASA
[40] Concept of Operations: Autonomous AAM Aircraft Operations and Vertiport Integration | Wisk, Skyports

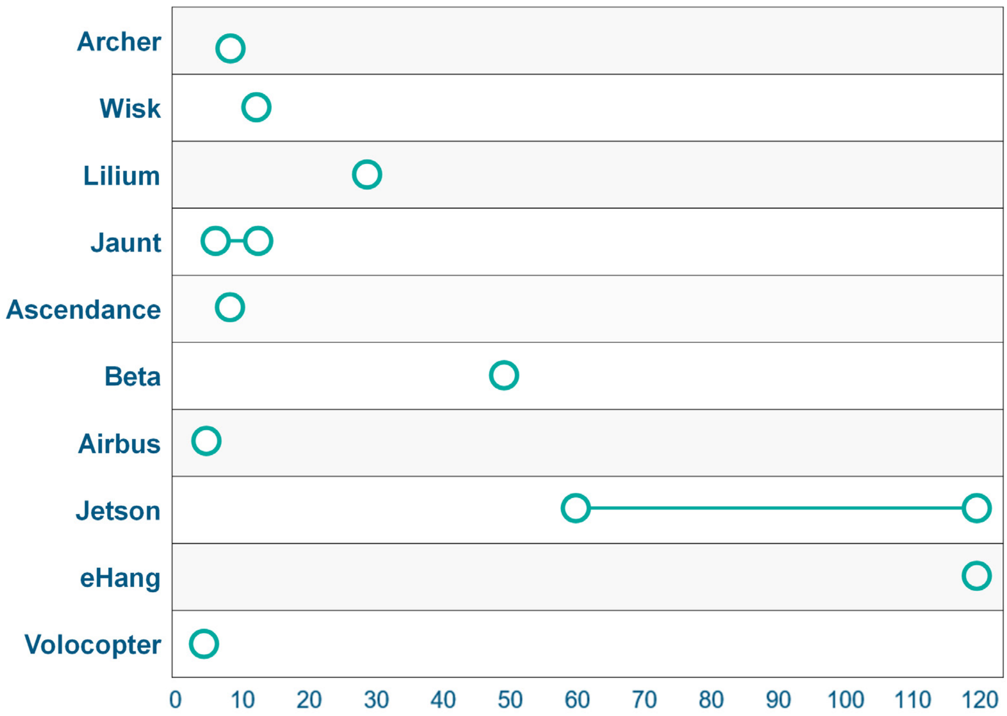


Figure 4-16 – Re-energising times
Sources: OEM public domain data + approximate 3rd party articles

Of the analysed aircraft, only Volocopter aim to use battery swap to re-energise, and hence present the lowest theoretical time. For a given route, the reduced range Multicopter configuration will reach a reduced state-of-charge more quickly compared to winged competitors, associated with lengthy recharging times and a significant impact on aircraft utilisation which impacts viability[41]. Battery swapping could therefore be essential to maximise their throughput at Vertiports. The consequence of this however is the reliance on the infrastructure to provision for battery swapping support equipment and associated skilled staff at each Vertiport with procedures in place that could slow the process down further.

Charging is the more prevalent solution for the electric aircraft, with charging times a delicate balance of maximising throughput and efficiency. The fastest charging time of 6 minutes is claimed by Amprius[42], a battery manufacturer backed by Airbus and assumed to be a potential supplier for the CityAirbus aircraft. Achieving these times however will be reliant on high voltage fast charging equipment at the Vertiports. With high-capacity batteries, this will impose significant load on the electrical supply, particularly where multiple aircraft are charging simultaneously. This comes with both safety and cost implications on the Vertiport operator.

RAM aircraft – which are more likely to be hybrid or hydrogen powered – benefit from faster re-energising times compared to electric aircraft. The challenges raised by hydrogen are more likely to be associated with the safe storage, transport and refuelling with either pressurised gaseous hydrogen or cooled liquid hydrogen. Airports will need to build future fuel farms and associated refuelling systems for compatibility with the range of technologies.

[41] The Economics of Vertical Mobility | Porsche Consulting
[42] Breakthrough Extreme Fast Charge Capability Of 80% Charge In Six Minutes | Amprius

4.4.5. Operating Profile

The operating profiles of Future Flight Aircraft, both airborne and on the ground, will present many new requirements for stakeholders. As illustrated by Eve Air Mobility in Figure 4-17, winged eVTOL aircraft will follow a mission profile involving a vertical take-off, transition to wing-borne flight, cruise, re-transition, and vertical landing. Whilst the take-off and cruise portions of flight are comparable to rotary and fixed-wing aircraft respectively, the transition imposes novel requirements unparalleled in civil aviation. The transition behaviour will vary dependent on aircraft configuration, for instance, the high disc loading design of the Lilium jet necessitates a short VTOL period (15s take-off, 45s landing)[43] to avoid excessive battery drain. The intended aircraft compatibility will therefore play a key role in Vertiport site selection to ensure the obstacle environment is fit-for-purpose. Furthermore, this operating profile could influence the orientation of the Vertiport site and the placement of TLOFs/stands to ensure the transition can safely be performed with consideration of the prevailing wind direction.

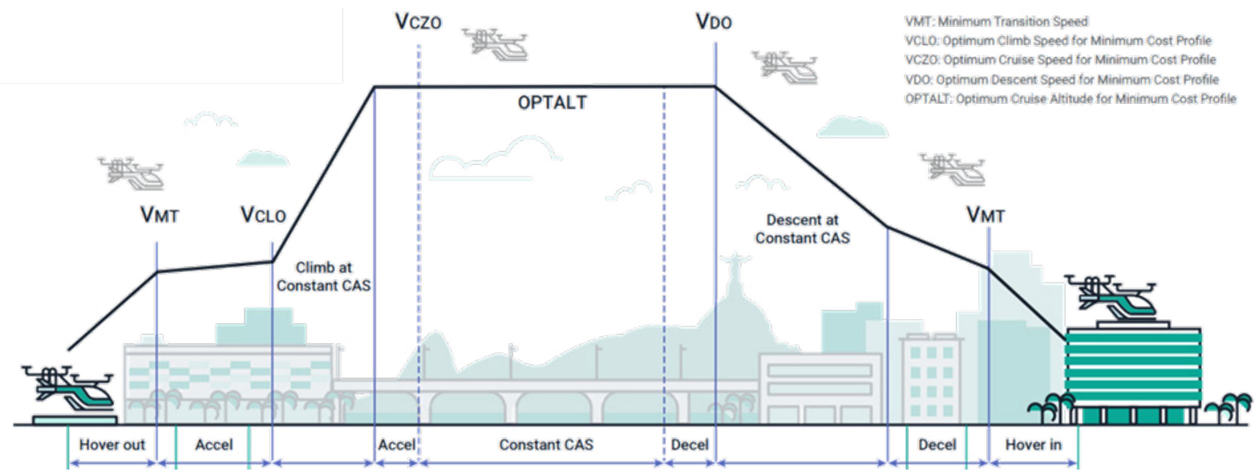


Figure 4-17 – eVTOL Flight Profile

Source: Eve Air Mobility[44]

On the ground, further requirements will be imposed by the landing gear selection/capability. eVTOL aircraft may ground taxi under their own power, be towed by a vehicle or even air taxi. These requirements are not well published or often discussed, yet have a major influence on the size, configuration, and capability of the Vertiport infrastructure.

5. Key Implications

To prepare for the future of Advanced Air Mobility, the aircraft must not only be flight-ready but also supported by a complex surrounding ecosystem. The novel features of these aircraft explored in the previous section will at times challenge industry stakeholders to evolve to successfully introduce the aircraft into the sector.

[43] Architectural performance assessment of an e-VTOL aircraft | Lilium
[44] Eve Rio de Janeiro Concept of Operations | Eve Air Mobility

This section integrates insights on the individual aircraft characteristics from the previous analysis to derive key implications influencing compatibility with the regulatory frameworks, gaps in the data collection and the impact on the future of the industry.

5.1. Regulatory

Whilst RAM aircraft will take full advantage of existing airfields across the country for conventional take-off and landing, eVTOL aircraft will eventually require dedicated Vertiports to enable complex, high throughput operations at scale. Overseeing these Vertiports will require expansion upon the standards written for heliports to account for the novel aircraft characteristics and requirements.

Considerable progress in the Vertiport world has been made in the regulatory space in 2022 with two key publications from the FAA and EASA – namely:

- **EASA PTS-VPT-DSN**[12] – Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category; and
- **FAA Engineering Brief 105**[13] – Vertiport Design.

At a high level, the contents can be aligned with ICAO Annex 14 Vol II (as shown in Table 5-1), which provides guidance on Heliport Aerodromes. The CAA is globally recognised for its expertise in heliport design through the publication of CAP 437 (Standards for Offshore Landing Areas) and CAP 1264 (Standards for Helicopter Landing Areas at Hospitals) but has not yet provided specific guidance on the approach to Vertiport standardisation.

ICAO ANNEX 14 VOL II	EASA PTS-VPT-DSN	FAA EB-105
CHAPTER 2: Heliport Data	**CHAPTER B:** VERTIPORT DATA	–
CHAPTER 3: Physical Characteristics	**CHAPTER C:** Physical Characteristics	**CHAPTER 2.0:** Vertiport Design and Geometry
CHAPTER 4: Obstacle Restriction and Removal	**CHAPTER D:** Obstacle Environment	–
CHAPTER 5: Visual Aids	**CHAPTER E:** Visual Aids	**CHAPTER 3.0:** Marking, Lighting and Visual Aids
CHAPTER 6: Heliport Services	**CHAPTER G:** Emergency Procedures and RFFS	**CHAPTER 6.0:** Site Safety Elements
–	–	**CHAPTER 4.0:** Charging and Electric Infrastructure
–	–	**CHAPTER 5.0:** On Aiports Vertiports

Table 5-1 – Vertiport guidance comparison

As explored in Section 4, eVTOL aircraft can differ from traditional helicopters with novel propulsion configurations, new power sources and unconventional operational requirements; as such, new requirements must be considered for the ground infrastructure to maximise both safety and viability.

To address this challenge, EASA collaborated with eVTOL manufacturers to gather aircraft data – however this was performed under confidentiality agreements limiting the value for wider industry stakeholders. With significant investment at risk, the sensitivity of this data is understandable, but the lack of transparency imposes a hurdle for Vertiport planners and designers who do not have reliable performance specifications to work from.

The FAA approach instead defines a "composite" aircraft specification that integrates the performance and design features of nine key VTOL aircraft under development. Utilising an imagined aircraft, with a representative set of conservative characteristics to envelope multiple solutions, enables analysis and insights to be generated in lieu of complete and reliable data. The specification of the passenger eVTOL composite aircraft is shown in Table 5-2.

Characteristics	Specification
General	
Propulsion	Electric battery driven with distributed electric propulsion
Propulsive units	2+
Battery packs	2+
Maximum Take-Off Weight (MTOW)	<5 640kg
Aircraft Length	<15.2m
Aircraft Width	<15.2m
Operating	
Operation location	Land-based (ground or elevated) – no amphibious or float operations.
Pilot	On board
Flight conditions	VFR
Performance	
Hover	Hover Out of Ground Effect (HOGE) in normal operations
Take-off	Vertical
Landing	Vertical
Downwash/Outwash	To be considered in TLOF/FATO sizing and ingress/egress areas to ensure no endangerment and impact on safety.

Table 5-2 – Passenger transport composite aircraft specification (FAA EB-105)

This approach is particularly useful as it allows stakeholders to understand requirements in an aircraft-agnostic manner whilst still protecting the sensitivity of the OEM data. The downside of this technique however is that with so many gaps in understanding, the FAA is forced to be overly prescriptive and conservative on Vertiport requirements. Review of characteristics in this study draws similar conclusions that the performance characteristics are not yet published in sufficient completeness, or with suitable independent validation, to accurately define requirements. With the greater sample size and breadth of characteristics explored in this study, alternative composite aircraft for the CAA's consideration are proposed in Table 5-3 overleaf.

With an increased scope to review both UAM and RAM aircraft in this study, a single composite aircraft does not capture the distinction between aircraft types. Section 4 repeatedly highlights the distinction between Multicopters (e.g., Volocopter) and the Winged eVTOLs of both Vectored Thrust (e.g., Joby) and Lift + Cruise (e.g., Eve) variants. This pattern is reported across physical dimensions as well as operational capabilities. As such, separate composite aircraft are proposed to distinguish the three prominent classes of Wingless eVTOL, Winged eVTOL and Fixed Wing Future Flight Aircraft. Within these groups, further distinction is required to separate performance estimates of HFC and hybrid aircraft which differ from battery powered designs.

Recalling the launch dates from Table 6-1, Volocopter is on a timeline to launch operations in 2023/24. The appreciation that these Multicopter aircraft sit in a separate sub-class compared to their winged counterparts could result in better optimised infrastructure planning that suits the aircraft requirements and limitations. Similar attention is required for the Winged eVTOLs, which may have improved range and speed but as a trade-off for hover performance altering the mission profiles. Overseeing suitable flight plans and proposed Vertiports sites will require a strong level of familiarity with the technology characteristics and associated requirements.

Importantly, these values will evolve as the industry matures and feedback from OEMs validates and improves the findings. As gaps in the dataset are filled, the conservative composite aircraft method could be adapted in favour of a performance-based approach to tailor requirements more appropriately to individual aircraft types.

Chracteristic	Wingless VTOL	Winged VTOL	Fixed Wing
Physical			
MTOM	<900kg (battery), <1,930kg (HFC)	<3,175kg	<7,484kg
PAX Capacity	<2 (battery), <4 (HFC)	<6	<20
Payload Capacity	<220kg (battery), <760kg (HFC)	<760kg	<5,000kg
Aircraft Length	<11.3m	<13m	<17.5m
Wingspan	N/A	<15.2m	<19.2m
Minimum Closing Circle	<13.03m	<17.6m	N/A
Systems			
EFCS	Fly-by-Wire or Fly-by-Light	Fly-by-Wire	Fly-by-Wire or mechanical
High Lift Systems	N/A	Trailing-edge flaps	Trailing-edge Flaps
Airframe	Composite or Aluminium	Composite	Composite or Aluminium
Landing Gear	Wheels (fixed) or skid	Wheels (fixed or retractable) or skid	Wheels
Power Source	Batteries or hydrogen fuel cell.	Batteries or hybrid.	Batteries, hydrogen fuel cell or hybrid.
Performance			
Battery Specific Energy	<400Wh/kg	220 – 350Wh/kg	*Insufficient Data*
Max Speed	<234km/h	<330km/h	463km/h
Max Range	<65km (battery), <241km (HFC)	<463km (battery), <1,020km (hybrid)	1851km
Cruise Altitude	<5,500m	<4,572m	<7,260m
Max Power	<1,400kW	<2,570kW	<1,280kW
Noise	<75dBA (Methods vary per Section 4.3.5)	<70dBA (Methods vary per Section 4.3.5)	*Insufficient Data*
Operations			
Re-Energising time (mins)	5mins (swapping only), 120mins (charging)	6 – 50mins	*Insufficient Data*
Autonomy	Piloted and Autonomous (2023+)	Piloted (<2030), Autonomous (~2030+)	Piloted
Use Cases	Passenger Transport, Tourism, Logistics, Emergency Response	Passenger Transport, Emergency Response, Logistics, Defence, Tourism, Surveillance.	Passenger Transport, Logistics, Emergency Response, Defence

Table 5-3 – Future Flight Composite Aircraft

5.2. Infrastructure and Operations

The design of Vertiport infrastructure will be heavily driven by the physical characteristics of the aircraft. Firstly, the maximum mass must be considered by civil engineers for the loading requirements of the TLOF surface. These surfaces must be able to withstand not only the static loads associated with the aircraft mass, but also dynamic loading and downwash from the propulsive system.

By designing around the Winged eVTOL Composite Aircraft (Table 5-3), a MTOM of 3,175kg must be considered. For the sake of loading, this value will envelope the smaller Multicopter aircraft also. This compatibility does not go both ways, however. As a result, some elevated intra-city Vertiports – favoured for the Multicopter design – could be designed to be incompatible with competitor aircraft. To maintain a competitive free market, stakeholders should explore whether infrastructure designs will be aircraft-agnostic or tied to individual aircraft in this manner. This has implications on both commercial viability and safety, as agnostic infrastructure could also act as an emergency landing site in abnormal scenarios. Importantly, the above maximum mass is over 2,000kg greater than the reference Robinson R44 helicopter. In many instances, existing heliports will be identified as viable launch locations for eVTOL routes, requiring suitability for heavier eVTOL to be reviewed to ensure compatibility. For larger sites such as London Heliport this is unlikely to be an issue as current passenger charter routes are flown by much larger Airbus H155 helicopters with a MTOM of 4950kg.

Compatibility with heliports is not just a matter of loading; the sizing of TLOFs, Final Approach and Take-Off areas (FATOs) and taxiways is equally important. In fact, this will be the greatest difference considered due to the novel configuration and dimensioning of the aircraft. As noted in Section 4.1.3, best practice in ICAO Annex 14 Vol II to use the largest overall dimension to size infrastructure requires modification. The "Minimum Closing Circle" is proposed instead to fully encompass the shape of eVTOL aircraft and avoid obstacles. In this study, a worst-case estimate was derived with a scaling factor from EASA. Improving this accuracy with actual dimensions, including undercarriage width, from the OEMs will be essential to maximise efficiency in the infrastructure footprint. With this dimension, the Vertiport elements can be sized following precedent set by the heliport documentation as per Figure 5-1.

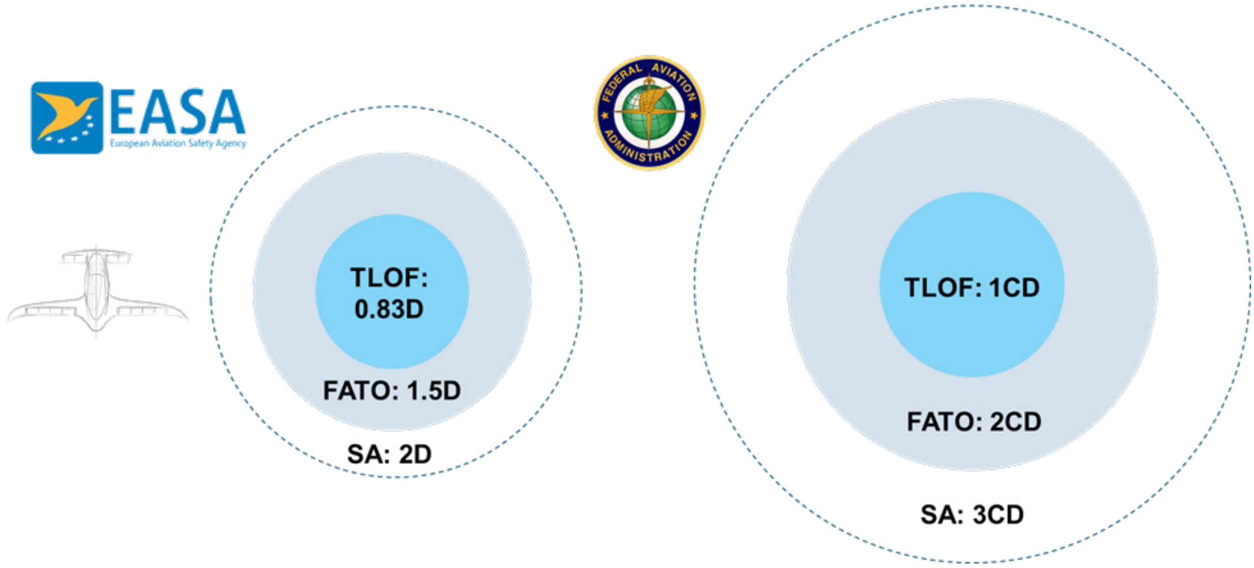
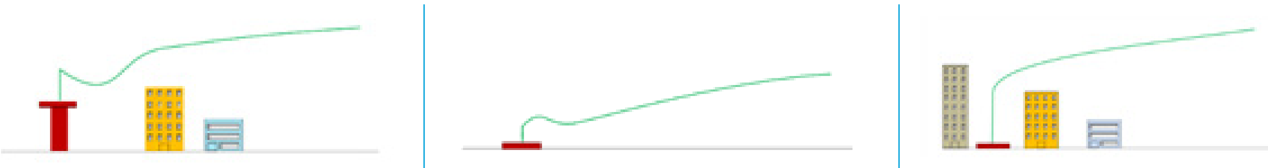


Figure 5-1 – Regulator sizing requirements

Vertiports are not just tarmac for landing, industry reports suggest they will play a key role in monitoring the surrounding airspace to enable safe approach and departure much like existing aerodromes. These processes will be supported by Communication, Navigation and Surveillance (CNS) technologies, the exact details of which are not extensively reported by the OEMs. In line with conventional aviation, ADS-B is still expected to be used widely for position reporting and tracking. Further to this, advances in the development of Uncrewed Aircraft System (UAS) Traffic Management (UTM) systems could require novel technologies that are not currently in use to be able to share the airspace with these smaller UAS.

To enable operations in dense urban environments, there could be some difficulty in designing Vertiports with existing helicopter flight take-off profiles, and associated obstacle limitation surfaces. Whilst elevated sites may function suitably with traditional surfaces, ground-level sites are likely to struggle to become viable in the city landscape. To provide an alternate solution to this problem, EASA have proposed a new "Vertical take-off" profile that allows for a longer vertical climb as per Figure 5-2. This method allows the aircraft to operate in denser environments and requires a new obstacle definition for the Vertiport designer.



Elevated conventional take-off | Conventional take-off | Vertical take-off

Figure 5-2 – EASA VTOL take-off profiles

The viability of these manoeuvres will depend on the aircraft configuration and design as per Section 4.4.5. For instance, aircraft with a high disc-loading and poor hover efficiency will not be able perform an extended VTOL flight phase without draining battery reserves; this manoeuvre instead favours the Multicopter configuration. This could impose operational limitations on some aircraft determining whether they are permitted to use certain urban Vertiports.

Ground operations, provided by the Vertiport Operator, will have to consider the broad range of landing gear types, power sources and re-energising times. Firstly, landing gear will dictate how the aircraft are moved around the Vertiport between stands, TLOFs and maintenance areas. If towing vehicles are required, this will be an important consideration for the organisations who will need to design and operate compatible vehicles. The novel power sources will introduce greater turnaround times associated with battery charging. Optimising operations to maintain profitability will be a novel challenge. In instances where multiple aircraft intend to fast-charge, high power demands will be required from the charging infrastructure which could challenge the power supply of the site. If facilities are designed to be fully aircraft agnostic, they may need to prepare not only for different charging times but also different charging adaptors, swapping capabilities or even alternative fuels such as hydrogen on supply. For these areas, industry standardisation will be vital to reduce inefficiencies. Such requirements may influence the applicable standards for ensuring safety of the facility. Gaps in the data associated with operations will become particularly problematic for infrastructure developers who will soon have to put in place major investments to prepare for the planned Entry Into Service dates mid-decade. By mitigating these gaps, well-planned, futureproof infrastructure could become a differentiating factor for the future of AAM in the UK.

5.3. Data Availability

The lack of collated and corroborated data is one of the primary industry challenges that this study set out to investigate. Building upon previous industry efforts to catalogue Future Flight aircraft, the dataset also includes sources for each data point and assesses the validity of each source, with over 43% of the sources directly from the OEMs. By consolidating data into the 4 key categories explored in Section 4, the number of gaps in the dataset are illustrated in Figure 5-3.

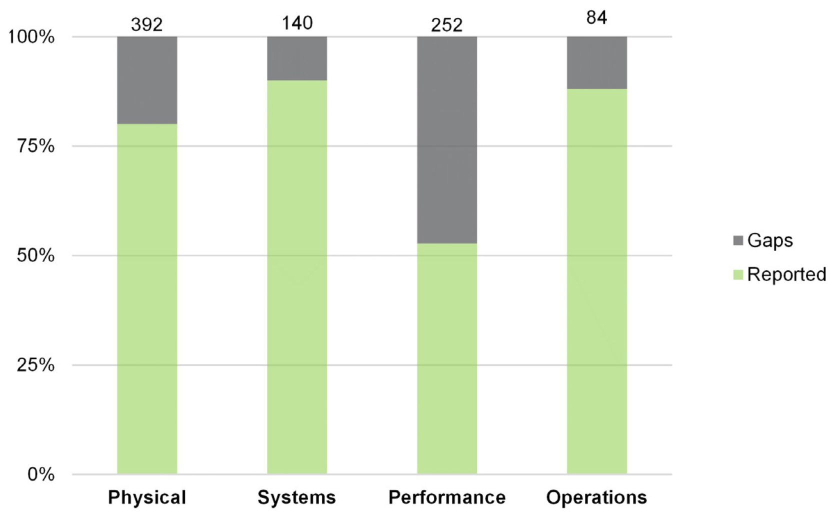


Figure 5-3 – Data Availability Summary

Firstly, it should be noted that a sample size of only 28 aircraft is too few to gather meaningful statistical analysis; however, general trends can still be observed. Physical Characteristics, Systems and Operations are well reported, offering valuable insight to infrastructure developers. The Systems and Operations categories focused on a refined scope of functions, if this net had been cast wider then it is likely that further gaps would have been identified.

The lack of Performance data meets expectations that OEMs are guarded around data which is potentially sensitive to their business cases. Understandably, we cannot expect to see proprietary information that could impact the competitive dynamics of the market. However, as aircraft mature, it is vital that validated, flight-tested performance achievements are shared with industry stakeholders to improve the readiness of the ecosystem.

At this early stage of development, a lack of complete data is inevitable, yet work can still be done to improve the quality of knowledge-sharing. This study is anticipated to fulfil the first step of resolving these gaps, i.e., identifying the challenge and encouraging increased engagement. Through publication of the findings and targeted feedback from stakeholders, the data can be iterated to improve reliability – targeting characteristics that will influence safety first. Beyond this, further simulation and flight testing will be key to validate the aircraft capabilities as they continue to develop.

5.4. Conventional Comparison

Throughout this study, comparisons have been made to conventional Fixed Wing and Rotary Wing aircraft, namely the Cessna 172 and Robinson R44, respectively. The differences of Future Flight aircraft will become a key theme for the evolution of the sector. Table 5-4 summarises key distinctions between the aircraft by taking the Winged eVTOL Composite as a worst-case comparator.

eVTOL Composite Aircraft	Robinson R44	Cessna 172
		
Mass: <3,175kg	**Mass:** 1,134kg	**Mass:** 1,111kg
Passengers: <7	**Passengers:** <3	**Passengers:** <3
Dimensions: 15.2m (W), 13m (L)	**Dimensions**: 10m (D), 12m (L)	**Dimensions:** 11m (W), 8m (L)
Range: <463km (battery)	**Range:** <644km	**Range:** <1,289km
Speed: <322km/h	**Speed:** <204km/h	**Speed:** <302km/h

Table 5-4 – Conventional aircraft comparison

Physically, eVTOL aircraft are both heavier and larger than the conventional aircraft of comparable capacity. For example, the 4-seat 172 and R44 are 1,000-2,000kg lighter than most eVTOL aircraft. Similarly, the largest overall dimensions can be over 3m larger than the reference aircraft. These features imply that safely designed Vertiports may exceed the size of heliports and helipads designed for similar capacity rotorcraft. This is particularly relevant when determining the approach to regulating Vertiports, as conservatively sized safety areas will drive up the footprint of ground infrastructure rapidly – potentially limiting the viability of some proposed locations.

In terms of performance, even with state-of-the-art battery technology, range will remain far less than conventional aircraft due to the fundamental specific energy limitations. Crucially, whilst the ranges may be reduced, this does not discredit the market potential which relies instead on additional factors such as noise reduction and low operating costs to service new routes and customers. To increase the total addressable market, the potential to evolve to alternative power sources such as hydrogen fuel cells may be explored; this technology will be particularly crucial for RAM use cases.

To ensure safety, eVTOL aircraft are being designed in accordance with SC-VTOL and/or FAA Part 21.17(b), and Fixed Wing aircraft are targeting certification in line with requirements traced from existing regulations for normal category aircraft except for the powertrain. For eVTOL aircraft, SC-VTOL has more stringent safety objectives than the regulations for similarly sized aircraft. For instance, the requirement for continued safe flight and landing to an operating site will challenge infrastructure planners to strategically place Vertiports across the route network to provide suitable landing locations. The performance capabilities of these aircraft, particularly under failure conditions, will heavily influence the placement of these sites which must be considered in the planning phase.

6. Conclusions

This study provides a comprehensive overview of the capabilities and requirements of emerging Future Flight Aircraft for the Advanced Air Mobility market. This report analyses the gathered data to draw insights for the CAA and wider industry stakeholders concerning technology novelty, compatibility with existing regulations and implications for operating infrastructure. The following key conclusions have been determined:

1. **Reference aircraft characteristics are required to improve stakeholder understanding.**
   The Future Flight aircraft fleet mix will consist of a range of aircraft of different configurations and power sources. A single composite aircraft specification is insufficient to capture this range of capabilities. Therefore, 3 composite aircraft have been proposed for stakeholders to review, categorised as Wingless eVTOL, Winged eVTOL and Fixed Wing.
2. **Not all eVTOL are the same – distinction in performance and dimensions must be considered.**
   The division of eVTOL aircraft into winged and wingless is not common but is crucial to appreciate the distinction in physical and performance characteristics. Wingless (Multicopters) are generally both lighter and smaller than winged counterparts but offer significantly reduced range and payload capacity which will influence stakeholder requirements.
3. **Aircraft dimensions influence the creation of safe, effective infrastructure.**
   Compatibility of infrastructure between various eVTOL aircraft types and conventional helicopters will vary depending upon the design specification of the Vertiports. Conservative sizing for the largest expected dimensions will maximise futureproofing and safety but at the compromise of site area efficiency.
4. **The absence of verified information may lead to oversizing for safety.**
   Regulatory approaches are evolving from ICAO Annex Vol II by considering the "Minimum Closing Circle" rather than the largest overall dimension of the aircraft. In the absence of data reported by the OEMs, this value must be conservatively estimated resulting in inefficient infrastructure design.
5. **Novel designs will create novel effects – further research will be required to understand this.**
   Propulsor configurations with high disc-loading will have significantly reduced hover performance compared to helicopters, requiring special consideration for take-off and landing profiles, particularly in dense urban areas. These configurations may also impact the downwash profiles, but little research exists to quantify this impact.
6. **Effective operations require knowledge sharing to define suitable procedures.**
   A large gap exists in the details of required ground operations which has notable implications for supporting stakeholders. Vertiport designers and operators will need to derive procedures for towing, re-energising, and maintenance, all of which will be based on the aircraft specific requirements. Adding to this complexity, clarity will be required on how each operation fits under the existing regulatory framework.

7. **Performance is key; more verified data is required to enable the industry effectively.** The most important gaps in this sample are within the Performance category, where many values expected from conventional aircraft are not available in the public domain. Further to this, given the maturity of most programmes, few of the reported values are likely to have been validated in flight.

To maximise the impact of this study and further the UK's position as a leading region for AAM operations, it is anticipated that this study will promote industry feedback and discussions to address the findings. Most importantly, as *Future Flight* aircraft approach their targeted certification dates this decade, it is vital that the validated performance capabilities are communicated to industry stakeholders to ensure that the supporting infrastructure can be prepared to enable the required levels of safety.

Appendices

Appendix A. Aircraft Selection

	OEM List	Target EIS	Analysis Justification
Multicopter	Volocopter VoloCity	2023-2024	**Maturity:** Flight tested and <2030 time frame
	eHang E216	*Undisclosed*	**Maturity:** Flight tested and <2030 time frame
	Jetson ONE	2022-2023	**Novelty:** Personal Air Vehicle
	Urban Aeronautics CityHawk	2029	**Novelty:** Hydrogen Fuel Cell eVTOL
Lift + Cruise	Embraer Eve	2025-26	**Maturity:** Flight tested and <2030 time frame
	Volocopter VoloConnect	2026-27	**Maturity:** Flight tested and <2030 time frame
	Airbus CityAirbus NextGen	2025-26	**Maturity:** Flight tested and <2030 time frame
	Beta Alia-250	2024-25	**Maturity:** Flight tested and <2030 time frame
	Ascendance Flight Technologies	2025	**Novelty:** Hybrid eVTOL
	Jaunt Journey	2026	**Novelty:** Rotor Configuration
	Autoflight Prosperity	2025-26	**Maturity:** Flight tested and <2030 time frame
	Wisk Cora	2028-2030 (Assumed)	**Maturity:** Flight tested and <2030 time frame
Vectored Thrust	Joby	2025	**Maturity:** Flight tested and <2030 time frame
	Vertical Aerospace VX4	2025	**Maturity:** Flight tested and <2030 time frame
	Archer Midnight	2025	**Maturity:** Flight tested and <2030 time frame
	Lilium Jet	2025	**Maturity:** Flight tested and <2030 time frame
	Supernal	2028	**Maturity:** Strong funding support (Hyundai)
	Dufour Aerospace Aero3	*Undisclosed*	**Maturity:** Flight tested and <2030 time frame
	Overair Butterfly	2024-2026 (Assumed)	**Maturity:** Ground tested and <2030 time frame
Fixed-Wing	Electra	2026-27	**Maturity:** Ground tested and <2030 time frame
	ZeroAvia	2024-25	**Maturity:** Flight tested and <2030 time frame
	Cranfield Fresson	2026	**Maturity:** <2030 time frame
	Ampaire Electric EEL	*Undisclosed*	**Maturity:** Flight tested and <2030 time frame
	Ampaire Eco Caravan	2024	**Maturity:** Flight tested and <2030 time frame
	Eviation Alice	2024	**Maturity:** Flight tested and <2030 time frame
	Tecnam P-VOLT	2026	**Maturity:** Flight tested and <2030 time frame
	Faradair BEHA M1H	2027-28	**Novelty:** UK-based hybrid electric
	REGENT Viceroy	2025	**Novelty:** Electric seaplane

Table 6-1 – Aircraft OEM Selection

Appendix B. Data Definitions

Characteristic	Definition
Maximum Take-off Mass (MTOM)	The Maximum Take-Off Mass of the aircraft (kg).
Passenger Capacity (PAX)	The number of passengers the aircraft will carry.
Maximum Payload	The amount of mass that can be transported by the aircraft (kg).
Passenger allowance	The maximum payload divided by passenger capacity, determining allowance for passenger + luggage (kg).
Payload fraction	The percentage of MTOM made up by the Maximum Payload (%)
Wing/tail configuration	The arrangement in which the wing and tail are laid out, e.g., high-wing, low wing and T-tail or H-tail.
Wingspan	The overall distance from one wingtip to the other wingtip (m).
Aircraft length	The distance from the front-most point of the aircraft to the aft-most point (m).
Minimum Closing Circle	The diameter of the smallest circle enclosing the VTOL aircraft planform projection while the aircraft is in the take-off or landing configuration, with propellers / rotor(s) turning, if applicable (m).
Propulsor type	The means through which the aircraft generates thrust in a desired direction.
Number of propulsors	Total number of propulsors on the aircraft in the lift and/or cruise orientation.
Lifting Propulsor Diameter	The diameter of the propellers/rotors which produce the vertical lift of the aircraft (m).
Disc Loading	The average pressure change across the lifting propeller/rotor disc area, given by the ratio of aircraft gross weight to thrust area of lifting propeller/rotor (kg/m2)

Table 6-2 – Physical Characteristics definitions

Characteristic	Definition
Electronic Flight Control Systems (EFCS)	A system comprised of multiple computers which uses electronic inputs from the pilot via the control column / Flight Management System which communicate with the various control surfaces onboard an aircraft.
High-lift systems	A system consisting of multiple secondary control surfaces such as leading-edge slats and trailing-edge flaps which work to augment lift during flight.
Landing Gear	The undercarriage of an aircraft that supports the aircraft weight when on the ground.
Airframe	The body of an aircraft as distinct from its engine, consisting of the fuselage, wings, and empennage.
Power Source	The chemical source of potential energy that is used to generate energy to drive the propulsive system.

Table 6-3 – Systems definitions

Characteristic	Definition
Specific Energy	The energy capacity of the battery per unit mass (Wh/kg).
Maximum Speed	The maximum speed of the aircraft in cruise (km/h).
Maximum Range	The maximum range (km).
Maximum Endurance	The maximum time of flight (mins).
Cruise Speed	Speed of the aircraft in cruise (km/h).
Cruise Altitude	Cruising altitude (m).
Maximum Power – Cruise	Maximum power in cruise flight mode (kW).
Maximum Power – Hover	Maximum power in hover flight mode (kW).
Noise	Noise generated in cruise and hover flight modes (dBA).

Table 6-4 – Performance characteristics definitions

Characteristic	Definition
Use Case(s)	The specific missions for which the aircraft are intended to be operated.
Autonomy	The aircraft's ability to operate with/without a pilot onboard.
Re-energising time	The time to replenish the energy of the aircraft, whether through conventional fuel, charging or hydrogen re-supply.

Table 6-5 – Operations characteristics definitions

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