INSIGHT

AEROSPACE TECHNOLOGY INSTITUTE

INTRODUCTION

The UK aerospace technology strategy *Engineering Growth* is a blueprint for sustainable growth in the sector, setting out future market opportunities and the technologies needed to secure them. By developing competitive, scalable technologies UK aerospace can achieve its goal of doubling its market value to US$18bn by 2035, supporting jobs and growth across the UK.

Engineering Growth identifies the next generation of ultra-efficient commercial aircraft as a key market opportunity for the UK. Batteries have the potential to play a crucial supporting role on these platforms, however securing market share will require the development and certification of necessary battery capabilities for specific airframe and propulsion system designs by the end of the decade.

Battery and electrification technologies also feature across the ATI's Zero-Carbon Emission Technologies Roadmap where they are already powering pioneering test flights on eVTOL and small electric aircraft, while also featuring in advanced fuel cell propulsion systems.

This paper defines the aerospace-specific requirements battery technologies must deliver to achieve our economic goals and sustainability commitments. Its purpose is to support alignment between the battery sector and the aerospace industry by providing a clear overview of future opportunities and performance requirements.

AEROSPACE BATTERY REQUIREMENTS

©ATI. Battery technologies have a key role to play in enabling a new generation of ultra-efficient single-aisle aircraft.

DEFINITIONS

CTOL

An aircraft with conventional take-off and landing.

eVTOL

A electric aircraft with vertical take-off and landing.

eAPU

Electrification of the Auxiliary Power Unit (APU) using batteries to provide ground support and emergency backup power, and start the main engines.

MEA

More electric aircraft. The battery in this system provides power for APU starting, supports the electrical network and provides back-up for essential electrical systems. This capability is expected to expand into the single-aisle market, and power demands are expected to increase beyond current levels in the next-generation widebody market.

Electric taxi

Electrification of aircraft taxiing at airports using electrically powered wheels instead of gas turbine thrust. Assumes up to 15 minutes of taxiing before take-off, and after landing, with recharge during flight.

Short-term opportunities

Defined as the next generation opportunities with likely market introduction in the mid to late 2030s. This would require Technology Readiness Level (TRL) 6 maturity by approximately 2030.

RAT replacement

Replacing the Ram Air Turbine (RAT) with batteries to provide emergency secondary power.

Hybridisation

Three categories of gas turbine hybridisation are defined with increasing degrees of electrical energy:

Gas turbine transient assist – Gas turbine hybrid system for short periods (<10 seconds) of electrical assist to provide shaft accelerations supporting operability. This system includes in-flight recharging.

Gas turbine targeted boost - Gas turbine hybrid system providing electrical input for one to two minutes to support performance and improve durability during challenging operational periods.

Gas turbine take-off and climb boost – A parallel hybrid system providing propulsive power for longer periods (>10mins) during the take-off and climb phases. This approach could allow greater gas turbine architectural changes and engine core downsizing to improve cruise efficiency.

Although three distinct hybrid categories are defined for simplicity, it should be recognised that the potential levels of hybridisation are not discrete. These three categories are intended to reflect the primary performance opportunities that gas turbine parallel hybridisation could offer.

BATTERY APPLICATIONS IN AEROSPACE

Future battery applications in aerospace are broad, ranging from backup power in more-electric aircraft to hybrid engines and short-range fully electric flight, each with their own unique requirements. While batteries hold the potential to improve fuel efficiency and reduce operating costs for large commercial aircraft, for eVTOLs, improved battery capability would increase payload and range.

Opportunities for the exploitation of battery technology exist across established and emerging markets, including regional and single-aisle aircraft, short-haul battery-electric concepts, eVTOL platforms and fuel-cell propulsion. No single battery type can meet these diverse aerospace needs, and this paper explores the unique demands of each application across specific energy, C-rate and cycle life, including where these are far beyond current capabilities.

The UK is well-positioned to address barriers to battery use in aerospace, leveraging strengths in propulsion, electrification, system integration, electromechanical research and advanced manufacturing. However, certification demands and the complexity of building a robust cell supply chain for aerospace's low-volume, high-grade environment present challenges to realising the sustainability and economic benefits of batteries. Collaboration between the battery sector and the aerospace industry is therefore essential to develop certifiable batteries that meet the required performance standards, thus achieving future gains in fuel efficiency and reduced operating costs.

COMMON CONSIDERATIONS

Safety

Safety is always the first priority in aerospace. Future battery systems must comply with strict safety standards specified in RTCA DO-311A and DO-160G. The relevance and content of these standards are briefly summarised below:

- DO-311A specifies the minimum operational performance standards for rechargeable lithium-based batteries and battery systems. The document provides guidance on the design, testing, and installation of battery systems. Notably, the document defines the containment requirements when multiple cells are subject to thermal runaway.
- DO-160G specifies the environmental conditions and test procedures for airborne equipment, including batteries. This document covers the relevant requirements and tests for temperature, altitude, vibration, and shock.

Additional relevant documentation includes the EASA SC-VTOL and EASA SC-E19, which outline the conditions for vertical take-off and landing aircraft and electric and hybrid propulsion systems respectively.

Costs

Across all applications, battery lifecycle requirements will be driven by economic considerations. If a lower battery cost can be achieved (including cell and replacement costs), lower cycle-life requirements can be accepted. However, replacement intervals are likely to align with the existing scheduled maintenance checks (A, B, C, and D checks) to minimise operational disruption.

Maintenance and end of life

The location, accessibility, module size and mass of the battery or batteries need to be selected to facilitate quick and easy replacements and maintenance. The battery must be sized and designed to account for deterioration to ensure it can meet performance requirements at end of life.

Safran's ATI Programme-funded ENGINeUS™ 100 electric motor ©Safran Electrical & Power

AEROSPACE BATTERY REQUIREMENTS

More-electric aircraft systems and hybrid propulsion present opportunities to achieve improved performance in new and existing aviation markets. These include incremental applications as well as more ambitious hybrid enhancement options. Each route can lead to reduced fuel consumption and lower operating costs if successfully implemented.

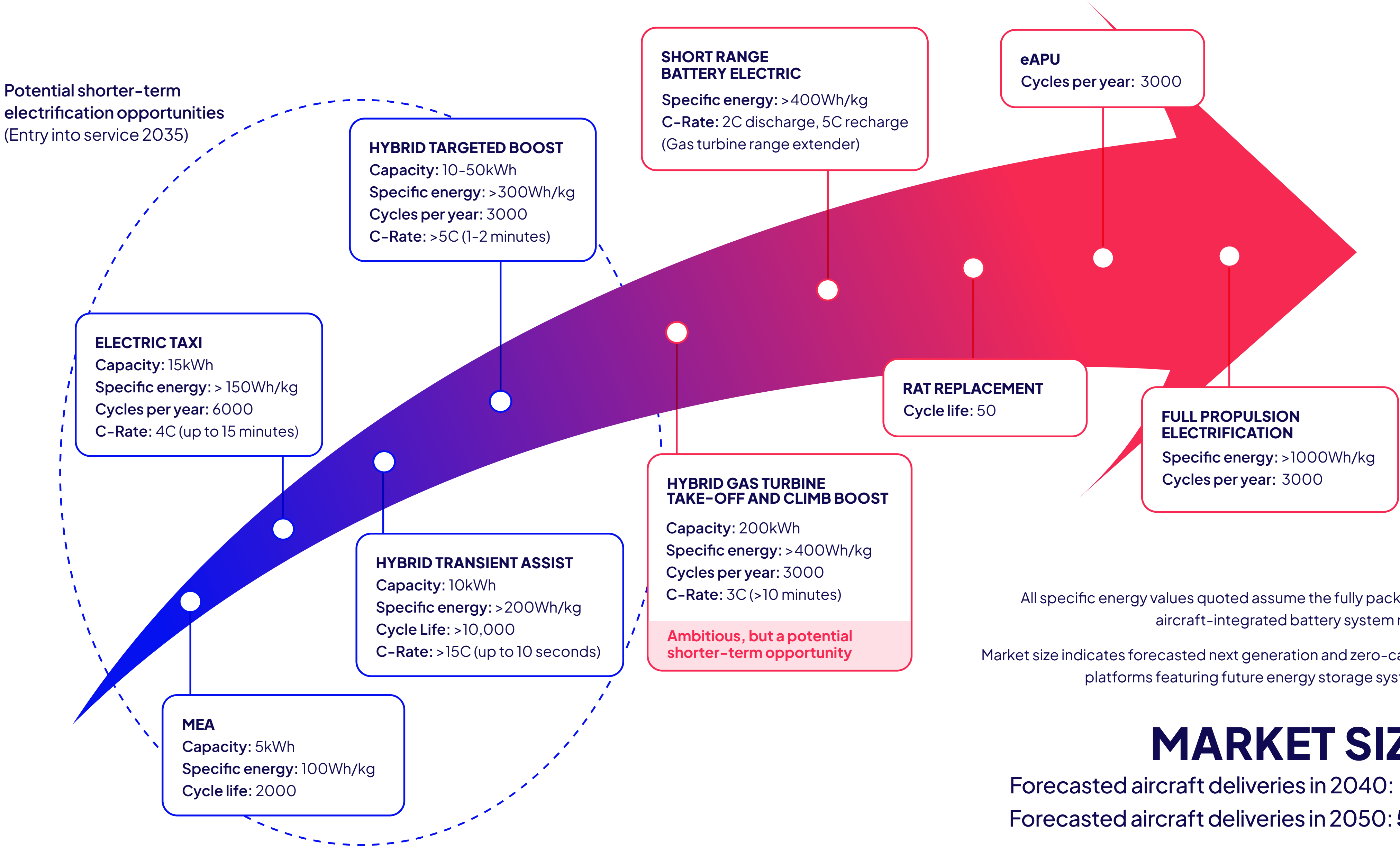
The requirements charts in this section provide requirements for regional and single-aisle commercial aircraft. The application requirements included in the charts remain highly uncertain, subject to future platform definitions and propulsion architectures. The values provided are model-based estimates, designed to illustrate the scope and variety of potential opportunities rather than to define precise standards.

The market size figures are sourced from the ATI's market models to provide insight into the annual battery energy needs for each application.

In all cases, the C-rate displayed is the discharge C-rate unless otherwise specified. Any application that requires ground charging will need a minimum of 2C charging capability to ensure that aircraft turnaround times are maintained. To support this, charging will likely need to be carried out while other turnaround tasks are in progress.

All specific energy values quoted assume the fully packaged aircraft-integrated battery system mass.

REGIONAL



All specific energy values quoted assume the fully packaged aircraft-integrated battery system mass.

Market size indicates forecasted next generation and zero-carbon platforms featuring future energy storage systems.

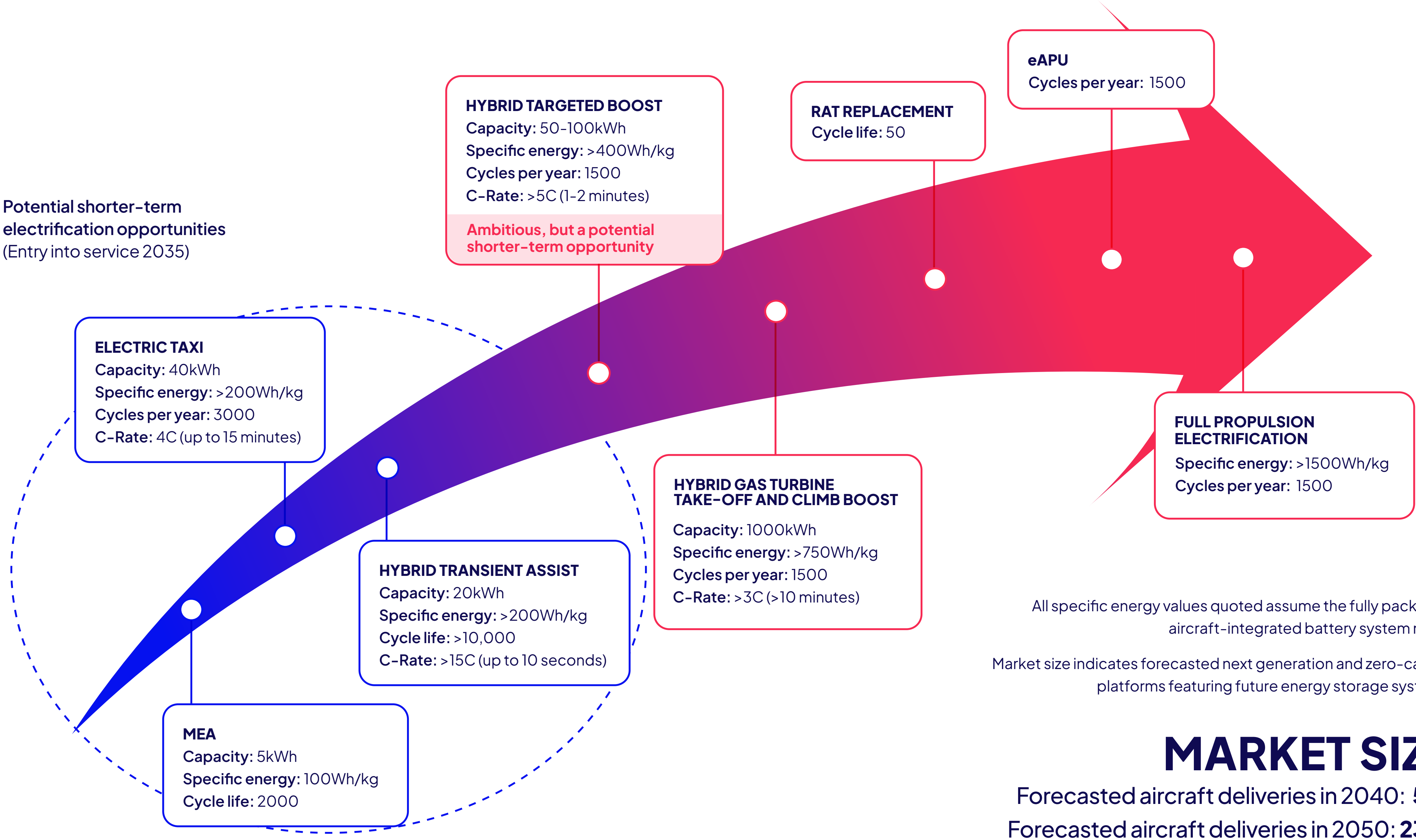
MARKET SIZE

Forecasted aircraft deliveries in 2040: **150**

Forecasted aircraft deliveries in 2050: **530**

SINGLE-AISLE

Potential shorter-term electrification opportunities
(Entry into service 2035)



All specific energy values quoted assume the fully packaged aircraft-integrated battery system mass.

Market size indicates forecasted next generation and zero-carbon platforms featuring future energy storage systems.

MARKET SIZE

Forecasted aircraft deliveries in 2040: **560**

Forecasted aircraft deliveries in 2050: **2360**

ASSUMPTIONS AND CLARIFICATIONS

Regional

- Shorter-range missions may result in improved fuel burn with take-off and climb boost despite increased mass. The aircraft must remain competitive in terms of upfront cost, maintenance and turnaround time. High C-rate charging (>2C) will be required to match current aircraft utilisation.
- Electric taxi assumes eight flights per day and two cycles per flight.
- For several applications, cycles per year are defined rather than a cycle life, which assumes eight flights per day. This is because the total life requirement will depend on the battery unit cost and the costs associated with replacing the battery. If battery cell and replacement costs are high, greater cycle life will be required to achieve an acceptable operational cost.
- Work completed by several organisations has identified opportunities to address lower-range missions in this sector with battery-electric solutions. Pure battery-electric missions are expected to have limited range, but the inclusion of a gas turbine for diversion and range extension could provide range flexibility.

Single-aisle

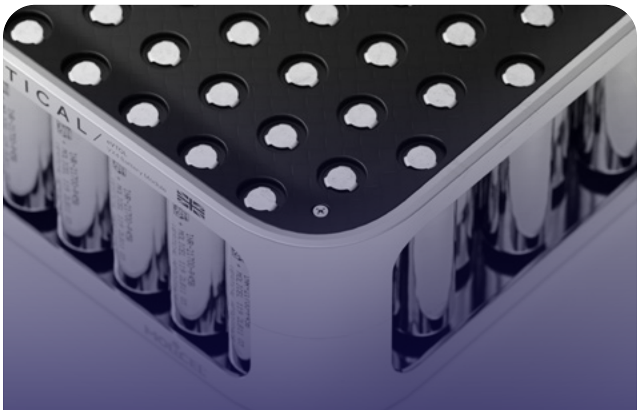
- The benefit of electric taxi will depend on the mission length and airport traffic management. The benefit will be more pronounced on shorter-range missions where taxi fuel usage is a higher percentage of the overall mission. Electric taxi assumes four flights per day and two cycles per flight.
- For several applications, cycles per year are defined rather than a cycle life, which assumes four flights per day. This is because the total life requirement will depend on the battery unit cost and the costs associated with replacing the battery. If battery cell and replacement costs are high, greater cycle life will be required to achieve an acceptable operational cost. The battery depth of discharge will also significantly affect life. This must be managed to balance aircraft utilisation, system mass and life.

Widebody

Widebody platforms are not included as the additional battery mass in these applications has a disproportionate impact on fuel burn, driving the need for exceptionally high energy-density solutions. Widebody delivery volumes are also comparatively low. In the near term, realistic battery opportunities are limited to upgrades of existing MEA systems (e.g. Boeing 787 and Airbus A350) and transient-assist hybridisation. The performance requirements for widebody transient assist are similar to those of single-aisle aircraft (>200Wh/kg, >15C for up to 10seconds, 10,000-cycle life).

eAPU and RAT replacement

eAPU and RAT replacement are included as potential opportunities in the requirements charts. However, ATI analysis has found the performance requirements for directly electrifying these systems to be challenging. eAPUs and RATs must supply continuous power for up to 120 minutes in regional applications and 180 minutes in single-aisle configurations. These endurance requirements impose high performance demands if targeting direct replacement with batteries. Consequently, electrifying these systems may only be viable as part of the aircraft's broader electrification strategy, where higher levels of electrification and energy storage already integrated in the aircraft can be used to provide redundancy.



©Vertical Aerospace, battery capability developed through ATI Programme project CEBD.

ZERO-CARBON EMISSION AIRCRAFT APPLICATIONS

There are additional opportunities for aerospace batteries within the eVTOL market and for supporting fuel cell propulsion systems. The potential scale of these opportunities depends on the performance of the energy storage systems, and ongoing advancements will promote future growth. Because platform designs in these markets are still uncertain, the requirements should be regarded as provisional.

APPLICATION

eVTOL

BATTERY REQUIREMENTS

Capacity: ~150kWh (5 seat eVTOL)
Specific Energy: >200Wh/kg
Peak C-Rate: >5C
Continuous C-Rate: 1-2C

COMMENTS

The battery lifecycle requirement will be strongly linked to the battery replacement cost to manage overall operating cost.

Energy density developments are a key enabler for increased range.

The battery requirements will vary significantly depending on the airframe design and target use case.

The expected size of this market is currently unclear.

©Vertical Aerospace - ATI Programme funded technologies take to the skies as Vertical achieves two-way piloted transition under civil aviation Design Organisation Approval regulatory oversight.

APPLICATION

FUEL CELL PROPULSION

BATTERY REQUIREMENTS

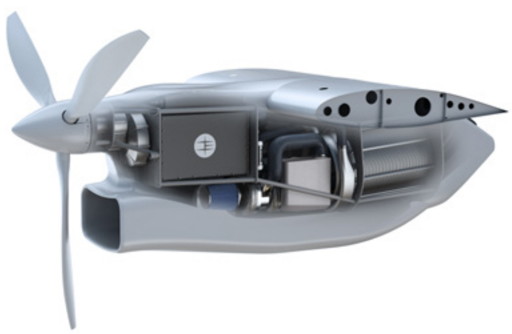
Capacity (regional aircraft): 50kWh
Specific Energy: 200Wh/kg
Peak C-Rate: >5C

COMMENTS

Expected use for start-up power requirements and transient operation (electric compressor etc.)

The scalability, and hence market opportunity, for fuel cell propulsion is still unclear.

Potential opportunities for fuel cell - battery hybridisation which would require much larger battery capacities.



©Intelligent Energy's IE FLIGHT fuel cell systems combine lightweight design with high power density and fast transient response.

CONCLUSION

Across the range of applications covered in this paper, the battery performance requirements vary considerably. To cater to the range of opportunities, different cell chemistries, pack designs and manufacturing approaches will be required.

The challenges to aerospace batteries achieving these requirements in the necessary timeframes remain considerable. Delivering the required levels of energy density, cycle life, and C-rate, while complying with strict certification standards, is resource and cost intensive. Additionally, creating a supply chain capable of delivering aerospace-grade cells that meet high-performance standards at small volumes is particularly challenging, especially when compared to sectors like automotive. Focused efforts are therefore needed to overcome these hurdles and align requirements with other industries demanding similar high-performance batteries. The ATI is working alongside the Faraday Institution to shape the development of new energy storage solutions for aerospace and identify key market opportunities for the UK. With an understanding of the requirements, the UK should leverage strengths in propulsion, system integration, advanced manufacturing, electrochemical research and battery pack design to collaborate with parallel sectors. This will unlock more electric and hybrid aircraft applications with the potential to reduce fuel consumption, aircraft emissions and operating costs, and enhance UK competitiveness to increase content on next generation aircraft.

©Evolito. Through ATI Programme project SONATA, led by Airbus, Evolito is developing compact and lightweight motors for an on-aircraft, electric taxi system powered by batteries, and Denchi is developing the advanced battery system for TRL maturity testing.

ABOUT THE ATI

The Aerospace Technology Institute (ATI) is an independent not-for-profit organisation working in partnership with the UK government and industry to enhance the competitiveness of the UK aerospace sector through technology leadership and funding. Since 2014, the ATI Programme has invested over £4.2 billion of joint government-industry funding in a balanced portfolio of research and technology projects. The ATI Programme is delivered in partnership with the Department for Business, Innovation, Science and Trade and Innovate UK.

The figures in this document are preliminary estimates aimed at highlighting opportunities for batteries in aerospace and they do not represent detailed specifications. Substantial uncertainty remains around the requirements and the technologies that will be selected in future particularly for long-term propulsion electrification, as novel battery technologies may open new use cases.