ELECTRICAL PROPULSION SYSTEMS

UK Capability and Overseas Landscape

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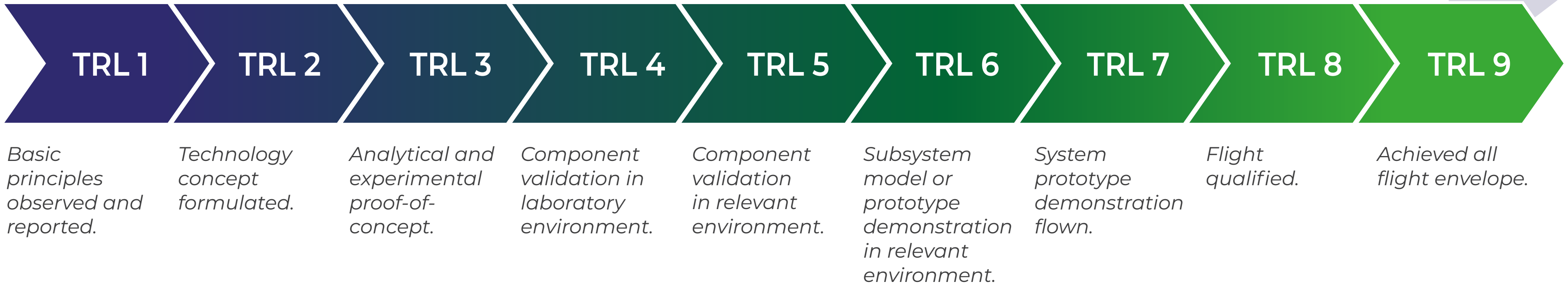
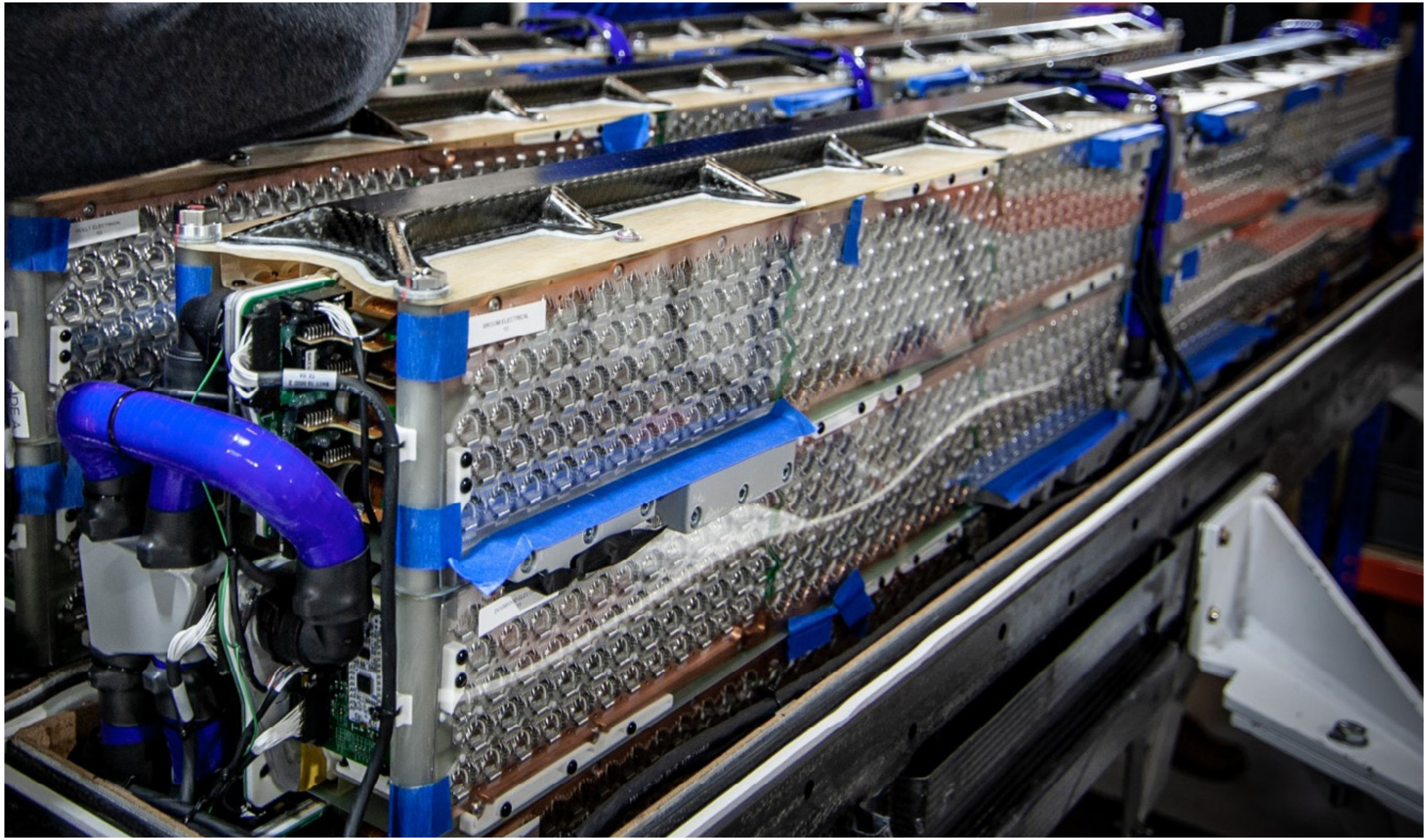


Figure 1 – Technology has been assessed against the NASA Technology Readiness Level (TRL) scale

UK CAPABILITY

Battery electric powertrains were considered in the initial phase of the project. It was determined that batteries would need to achieve an energy density greater than 1kWh/kg to be a viable primary power source and that this is highly unlikely to be achievable within the next decade or more. Therefore, batteries will not provide a viable solution for the market segments targeted by FlyZero



UK CAPABILITY

In this assessment the electric motor scope is purely the motor body (and excludes the gearbox) and is powered by a fuel cell. Electric motors are becoming popular due to their power density. There is an opportunity for the UK to focus on development of increasing the achievable power densities. There is no established industrial base for volume manufacture of aerospace-standard main propulsion motors in the UK. Safran Electrical and Power is developing a UK footprint. The FlyZero team anticipates an investment in the range £50-100m would be required to build an aerospace-certified facility for manufacturing main propulsion motors at full industrial production rates.

While the UK supply chain is developing significant capability in high power electrical machines, none of these programmes have yet transitioned to full production rate. Examples include Aeristech developing power-dense motors in the H2GEAR programme and YASA, who are working with Rolls-Royce to develop the world's fastest electric plane in ACCEL. Rolls-Royce is developing an electrical propulsion system capability; this is being applied into Vertical Aerospace VA-X4 and the Tecnam P-Volt. Safran's Electrical and Power division in Buckinghamshire and their ENGINeUS motor was selected by Bye Aerospace for its eFlyer 800 aircraft.

The UK has a strong base of industry, consultants and research organisations developing solutions for automotive including Magtec, Ricardo, ProDrive, AVL, Newcastle University, University of Nottingham, Oxford University and WMG. The UK is also investing in electrical propulsion systems through the £80m Industrial Strategy Challenge Fund Driving the Electric Revolution. Large-scale commercial aviation is out of scope, but it is addressing applications in agriculture, maritime and rail.

Application of proven technologies from other sectors, opportunity to understand manufacturing rate capability considerations from automotive sector.

Figure 2 – Global TRL levels for aerospace electric motor

UK CAPABILITY

In the UK, power electronics development is being led by the ground-based transportation sector with Formula E driving technology advances. Developments focus on using gallium nitride as an alternative to silicon carbide for switching and packaging technology. The capability roadmap for power electronics is highly dependent on the voltage range selected. Within a 1-3kV range current silicon carbide switching devices provide the level of capability. Using gallium nitride technology may potentially generate much higher power densities and lower losses for applications than established silicon carbide technology. This switching technology is currently assessed at TRL 3 globally. The opportunity to cool the electronics within the thermal management of the system improves switching efficiency levels by as much as 30%. This has been incorporated in automotive applications and assessed at TRL 9, but is untested in aerospace applications.

Incorporating power electronics within the motor casing provides an opportunity for weight reduction of the overall electrical propulsion system. Further weight reductions can be achieved if the voltage range is increased beyond 3 kV, or superconducting technologies are incorporated in the system. UK capability for the higher voltage power electronics and superconducting is below TRL 2 for aerospace applications. The development of power electronics in the UK is highly dispersed across industry and academia. The universities of Cambridge, Nottingham and Warwick have programmes pursuing switching technology. Industrial developments are spread across several companies, including ATL Transformers, Clas-SiC, Dynex and Nexperia.

High power electrical systems are under constant development; competitive fields like Formula E motor racing are continually pushing boundaries of bulk power extraction and efficiency. In Formula E, these systems are rated at 250 kW, operating at 800 V with silicon carbide switching. This niche application represents the leading edge of high-power automotive technology. Suppliers for mass market applications such as for Tesla power switching are based in Italy and Japan. In the UK, Delphi Technologies holds a robust market share in a specific sub-set of the e-automotive sector, with three out of the four premium automotive manufacturers using their systems.

Application of proven technologies from other sectors, transition of technology and manufacturing for aerospace applications considered low risk.

Figure 3 – Global TRL levels for aerospace power electronics

OVERSEAS LANDSCAPE

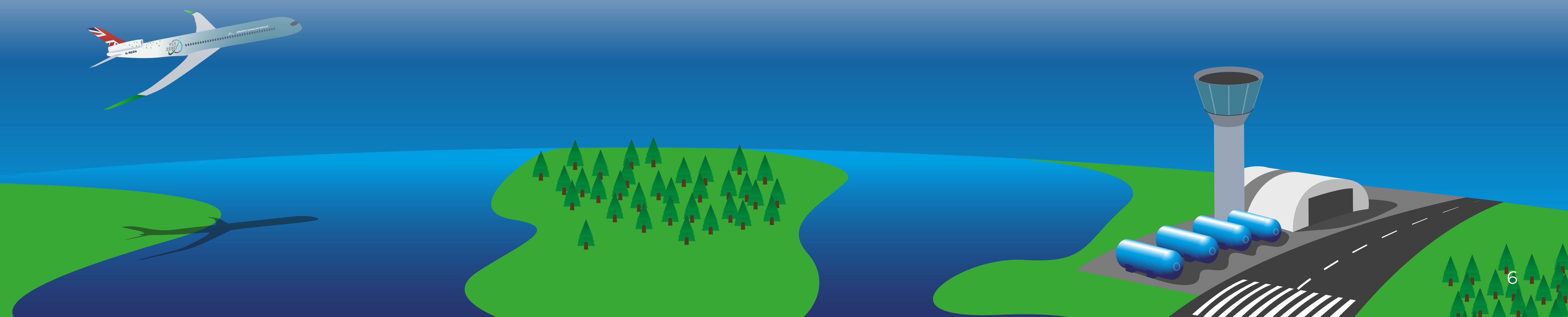
The leading countries for motors, power electronics and batteries are Japan, South Korea, USA, and EU member states collaborating on international technology programmes.

US-based firm Magnix is one of the leading developers of high-power electrical machines for aviation applications. Its drivetrain is used in, amongst others, Eviation's Alice aircraft, Aerotec's eCaravan, and the Harbour Air e-plane. Honeywell and Denso have partnered to deliver powertrains for electric aircraft, initially targeting the urban air mobility market.

For power electronics, Japan is home to companies with strong superconductor manufacturing capabilities such as Fujikura, Japan Superconductor Technology, and Furukuma Electric Co.

Power density constraints limit the application of battery technology. However Japan and the USA are leading the development of batteries for electric vehicles - for example manufacturing large volumes of batteries for Tesla at their Nevada gigafactory. US-based firm Cuberg supplies batteries for battery-electric aircraft manufacturers BETA technologies and Ampaire (also has a small UK representation), and hybrid-electric aircraft manufacturer VoltAero. South Korean battery manufacturer Kokam is the selected battery supplier for electric aircraft produced by Pipistrel and Eviation.

In the USA, there is Cryomagnetics Inc, Hyper Tech Research Inc, and Superconductor Technologies Inc. Additionally, Magnix manufactures world-leading electric drivetrains for aerospace. H3X based out of Denver, Colorado is developing technologies around silicon carbide switching devices at high power densities with a high-speed operation.



KEY MESSAGES

In the UK there are good emerging capabilities in electric aerospace motor design in the UK built from the strong foundations in academia and industrial start-ups. This platform presents an opportunity to scale up and capture market share. The developments in motor technology can be combined with the incorporation of other motor topology advances, e.g. coil and magnet. There is a lack of industrial test capacity for these larger machines in the UK. Current test capacity is orientated around academic facilities and there is little capacity for full environmental testing operating a continuous duty cycle. Similarly, there is little evidence of any production rate capable facilities for an aerospace electricalpropulsion system at these higher power levels. This presents an opportunity for the UK to establish itself as a global supplier of high-power electrical propulsion system. Currently, there is no global expertise for high-voltage power electronics capable of operating in an aerospace environment and this presents an opportunity for the UK to take the lead in developing this technology.

The capabilities developed for specialist battery applications, for example technologies in Formula E could be developed and applied in the aerospace sector; the two applications share common requirements such as, for example, lightweighting and high discharge demand.

RELATED FLYZERO FURTHER READING

The ATI FlyZero project developed its technology roadmaps through a combination of broad industry consultation and assessment of technologies by experts. Technology assessment was carried out both by the FlyZero team and by approximately 50 industrial and academic organisations that partnered with FlyZero to support delivery. During the project, FlyZero developed three concept aircraft and used this exercise to gain a deep understanding of requirements and challenges for systems and technologies, which have been reflected in the roadmaps. Further detail of these technologies and developments can be found in the following reports, available to download from **ati.org.uk**

FlyZero

Zero-Carbon Emission Aircraft Concepts
Report
Ref. FZO-AIN-REP-0007

Technology Roadmaps
Report
Ref. FZO-IST-MAP-0012

Workforce to Deliver Liquid Hydrogen Powered Aircraft
Report
Ref. FZO-IST-PPL-0053

Hydrogen Aircraft

Aerodynamic Structures
Technical Report
Ref. FZO-AIR-REP-014
Roadmap
Ref. FZO-AIR-MAP-0015
Roadmap Report
Ref. FZO-AIR-COM-0016
Capability Report
Ref. FZO-AIR-CAP-0066

Electrical Propulsion System
Technical Report
Ref. FZO-PPN-REP-0028
Roadmap
Ref. FZO-PPN-MAP-0029
Roadmap Report
Ref. FZO-PPN-COM-0030
Capability Report
Ref. FZO-PPN-CAP-0070

Thermal Management
Technical Report
Ref. FZO-PPN-REP-017
Roadmap
Ref. FZO-PPN-MAP-0018
Roadmap Report
Ref. FZO-PPN-COM-0019
Capability Report
Ref. FZO-PPN-CAP-0067

Fuel Cells
Technical Report
Ref. FZO-PPN-REP-0031
Roadmap
Ref. FZO-PPN-MAP-0032
Roadmap Report
Ref. FZO-PPN-COM-0033
Capability Report
Ref. FZO-PPN-CAP-0071

Hydrogen Gas Turbines & Thrust Generation
Gas Turbine Technical Report
Ref. FZO-PPN-REP-020
Thrust Devices Technical Report
Ref. FZO-PPN-REP-021
Roadmap
Ref. FZO-PPN-MAP-0022
Roadmap Report
Ref. FZO-PPN-COM-0023
Capability Report
Ref. FZO-PPN-CAP-0068

Cryogenic Hydrogen Fuel System & Storage
Fuel System Technical Report
Ref. FZO-PPN-REP-024
Fuel Storage Technical Report
Ref. FZO-PPN-REP-025
Roadmap
Ref. FZO-PPN-MAP-0026
Roadmap Report
Ref. FZO-PPN-COM-0027
Capability Report
Ref. FZO-PPN-CAP-0069

Cross-Cutting

Aircraft Systems
Ref. FZO-AIR-POS-0013

Airports, Airlines, Airspace - Operations & Hydrogen Infrastructure
Ref. FZO-CST-POS-0035

Advanced Materials
Ref. FZO-IST-POS-0036

Lifecycle Impact
Ref. FZO-STY-POS-0034

Sustainable Cabin Design
Ref. FZO-AIR-POS-0039

Compressed Design and Validation - Culture and Digital Tools
Ref. FZO-IST-POS-0038

Advanced Manufacturing
Ref. FZO-IST-POS-0037

ABOUT FLYZERO

Led by the Aerospace Technology Institute and backed by the UK government, FlyZero began in early 2021 as an intensive research project investigating zero-carbon emission commercial flight. This independent study has brought together experts from across the UK to assess the design challenges, manufacturing demands, operational requirements and market opportunity of potential zero-carbon emission aircraft concepts.

FlyZero has concluded that green liquid hydrogen is the most viable zero-carbon emission fuel with the potential to scale to larger aircraft utilising fuel cell, gas turbine and hybrid systems. This has guided the focus, conclusions and recommendations of the project.

This report forms part of a suite of FlyZero outputs which will help shape the future of global aviation with the intention of gearing up the UK to stand at the forefront of sustainable flight in design, manufacture, technology and skills for years to come. To discover more and download the FlyZero reports, visit **ati.org.uk**

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These roadmaps have been developed with a view to accelerate zero-carbon technology development and maximise the potential future value for the UK. They are unconstrained by the availability of funding.

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FLY ZERO

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