AEROSPACE TECHNOLOGY INSTITUTE

DESTINATION ZERO

THE TECHNOLOGY JOURNEY TO 2050

ABOUT THE ATI

The **Aerospace Technology Institute** is an independent organisation that works alongside government and industry to transform aerospace through technology and innovation.

The ATI is funded equally by the **Department for Business, Energy and Industrial Strategy** (BEIS) and by industrial recipients of project grants who pay a small levy. ATI projects are chosen and overseen through close collaboration with Innovate UK and BEIS.

Our role is to establish a challenging technology strategy for the sector, and to develop a portfolio of research and technology (R&T) activity to realise that strategy, exploiting the sector's strengths to the full and creating new capabilities for the future market. Government and industry have agreed to provide funding to the ATI Programme out to 2031, creating an ongoing commitment to the development of the UK sustainable aerospace sector.

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Cold weather test for the A350 (Airbus)

FOREWORD GARY ELLIOTT, CHIEF EXECUTIVE OFFICER - ATI

The aerospace sector is at a pivotal moment. Public concern about the environment has continued to increase in response to growing evidence about the impact of humankind's activities and the need to take more urgent action to mitigate climate change. In 2019 the UK became the first major economy to sign into legislation a target for Net Zero emissions by 2050. This set the ambition for our industry, which also committed to Net Zero in 2021, and we are now in a race to reach that target. Meanwhile, aerospace has been hit by the demand volatility resulting from the ongoing Covid-19 pandemic, which will have long-term implications for how people live, work and travel. The sector is also going through a period of disruptive innovation, with advances in engineering technologies and techniques enabling more efficient product development while opening the sector up to a new generation of start-ups.

This context sets the scene for the new Aerospace Technology Institute (ATI) technology strategy 2022, Destination Zero, which supersedes Accelerating Ambition published in 2019. Destination Zero sets out the UK's sector-wide Aerospace Technology Strategy and provides guidance on the challenges facing the aerospace industry if we are to meet our 2050 target; likely market technology evolution and adoption rates; and the ATI Programme investment priorities across our areas of focus. It sets our path towards achieving Net Zero carbon emissions for commercial aircraft by 2050 and supporting the competitiveness of the UK industry in sustainable design, manufacture, assembly and operations of future aircraft.

If we are to succeed, there are significant unknowns and challenges to overcome, and international competition will be intense. Speed is essential to achieving our goals and increasing our market share. With ambitious long-term cross-sector commitment, the UK can lead, inspire and change global aviation. Doing so will deliver substantial economic benefits to the UK, building back better and supporting levelling up the country through the industry's regional footprint.

Battery electric propulsion demonstrator (Rolls-Royce)

Electrically powered propulsor (Blue Bear Systems Research)

EXECUTIVE SUMMARY

Destination Zero sets out the UK Aerospace Technology Strategy. It focuses on UK aerospace achieving its Net Zero 2050 target and maintaining its global competitiveness. This can only be achieved by **collaborating across the aviation ecosystem** and through cross-sector partnerships.

Investment in aircraft technologies that enable the use of both Sustainable Aviation Fuels (SAF) and hydrogen fuels will be a vital part of achieving Net Zero by 2050. Both SAF and hydrogen require substantial investment to increase production, increased access to clean energy and investment from other parts of the aviation sector to be adopted at scale. SAF will be commercially available earlier than liquid hydrogen, but both need investment to be made now.

Investment needs to be increasingly geared towards zero-carbon emission technologies. However, maintaining progress on ultra-efficient aircraft technologies is vital to future zero-carbon emissions aircraft and this needs to be progressed in parallel. To succeed in the delivery of ultra-efficient and zero-carbon aircraft technologies, the UK aerospace sector also needs to be at the forefront of a broad range of crosscutting enabling technologies.

The aerospace sector is facing unprecedented challenge and needs to invest to stay globally competitive. To do this UK companies will need to be more ambitious and accept more risk within their technology portfolios. If successful, **UK industry can grow its market share to nearly 18%** of a potential global market for more energy efficient commercial aircraft worth **£4.3 trillion in 2050**.

Development and adoption of sustainable aircraft technologies could enable **global carbon emissions to be reduced by nearly 2 gigatons by 2050**. Widebody and narrowbody aircraft market segments have the largest impacts on sustainability and the UK economy and should be prioritised for investment.

Hydrogen fuel cell electric propulsion system (ZeroAvia)

"The aerospace sector is facing unprecedented challenge and needs to invest to stay globally competitive."

Laser Additive Manufacture (TWI)

Ultra-efficient widebody concept aircraft (ATI)

INTRODUCTION

The global aerospace sector is at a pivotal moment. Aerospace has been hit by the demand volatility resulting from the Covid-19 pandemic and is also entering the most disruptive era of innovation since the jet age. Within the UK, the Government and the aerospace industry are racing to meet their Net Zero 2050 ambitions, and decisions are being made now that will shape the future of the aerospace and aviation ecosystems for the years to come. Ambitious investments will be needed across the sector in the short term to secure the future of the UK's aerospace industry in an ever more competitive environment.

Destination Zero sets out the ATI's view on which commercial aircraft technologies have the greatest potential for development by the UK industry and how we believe they will mature out to 2050. The entire ecosystem will also need to transform over this period to enable adoption of these technologies and to realise their potential. Our technology strategy is a guide to how the UK aerospace sector can increase content on future fleets while achieving its Net Zero targets and maximising the return to the UK economy.

> **"...decisions are being made now that will shape the future of the aerospace and aviation ecosystems for the years to come."**

In producing Destination Zero, the ATI has drawn on its extensive advisory networks, engaging with over 150 professionals from more than 30 organisations representing industry, academia and Government. We have also been informed by the outputs of the independent FlyZero feasibility study, commissioned by the ATI in 2020, to determine the technical, commercial and economic potential of large commercial zero-carbon emission aircraft. The FlyZero project, delivered over 12 months by a team of more than 100 specialists, has transformed the ATI and industry's understanding of the potential for zero-carbon emission technologies.

AIMS & OBJECTIVES

The aim of this strategy is to provide guidance on -

- The ATI Programme investment priorities across the three technology areas of focus -
  - **Zero-carbon emission** aircraft technologies
  - **Ultra-efficient** aircraft technologies
  - **Cross-cutting** enabling technologies and infrastructure
- The technological developments required and the potential timeframes to bring aviation closer to Net Zero emissions by 2050

It is imperative that the UK pursues all three technology areas of focus as they are interdependent and mutually supportive. Maintaining progress on ultra-efficient aircraft technologies is vital to the UK's future zero-carbon emissions opportunities, as our leading strengths in wings, propulsion and systems technologies are the areas that will see the biggest change and therefore competitive threat. The UK aerospace sector needs to be at the forefront of cross-cutting enabling infrastructure and tools to support the delivery of these ultra-efficient and zero-carbon emission technologies, in a market where rate will need to double and compressing design cost and time is ever more important.

Within each technology area, we have identified priorities for investment into the UK aerospace industry. These priorities are defined on *page 16* and are summarised by three main objectives -

- Position the UK to lead the global aerospace sector on the path to Net Zero
- Accelerate the adoption of technologies aligned with a Net Zero ambition through capabilities for design, manufacture and through-life support
- Secure UK industrial competitiveness

Advanced Flight Deck (GE Aviation)

DRIVERS OF CHANGE

We have identified four pillars that will underpin the evolution of the aviation sector, enabling the Net Zero 2050 target and allowing UK industry to remain globally competitive. The UK needs to position itself at the forefront of this research, particularly in disruptive technologies, to ensure that it is not locked out of future market developments.

1 - Taking risks will underpin clean technology growth for aviation

The global aviation industry must address sustainability in the broadest sense and take risks in development as no solution is without challenges. Many sustainable technologies exist or are in development in the UK now, but there are disruptive technologies that will emerge as we determine the right solutions. Learning from adjacent sectors and looking for economies of scale will be increasingly important. To meet the UK Government's Net Zero targets, UK companies will need to be more ambitious and accept more risk within their technology portfolios to make the advances that will be needed.

2 - Aircraft efficiency will continue to drive sustainability

Maximising aerodynamics, thermal efficiency, and reducing weight are key to the success of any aircraft. These factors reduce in-flight energy usage and improve affordability for operators. They will remain important areas of focus for UK industry and the ATI will continue to invest in aircraft and propulsion systems that improve efficiency and reduce the climate impact of aviation. Aircraft powered by alternative energies will depend on energy generated on the ground and transferred to an energy carrier (SAF, hydrogen or batteries). Reducing the energy consumption in-flight will enable considerable savings on the ground energy supply system and reduce competition for renewable energy.

Prototype engine nacelle mounted on a stub wing for wind tunnel test (QinetiQ)

Gas turbine demonstrator with 100% Sustainable Aviation Fuels (Rolls-Royce)

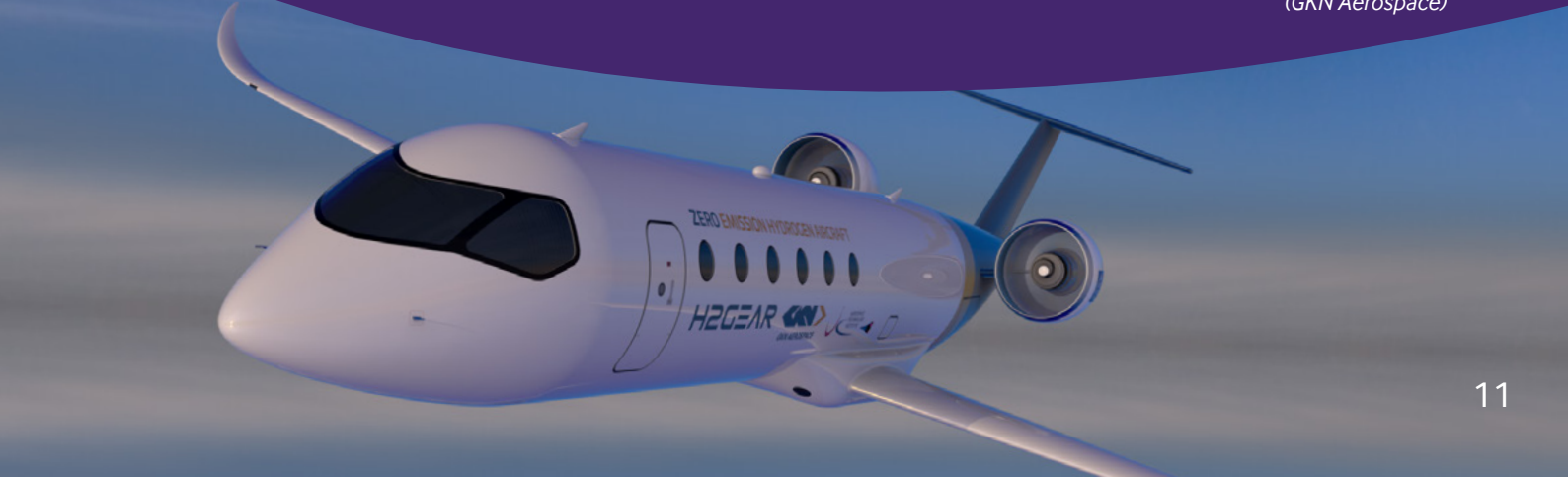
3 - Sustainable Aviation Fuels usage will expand rapidly

Bio-derived SAF will be a vital part of moving towards Net Zero 2050 in the short term, although production capacity will be a limiting factor. For this reason, new pathways for SAF which don't depend on bio-feedstocks will need to be developed and scaled-up. SAF can already be used in blended form to provide some carbon emissions mitigation over 100% kerosene. As low-cost green electricity production increases this could allow for large scale Power-to-Liquid SAF production, which could use atmospheric carbon as a feedstock, although uptake may be affected by a high market price. Development of any type of SAF to a large enough scale has challenges and is not an 'easy' solution to reducing carbon emissions. Future changes to aircraft fuel systems and infrastructure will be required to progress from blended SAF as used today to 100% SAF, this will further reduce but still not eliminate carbon emissions.

4 - Disruptive technologies will enable zero-carbon commercial flight

New technologies based on batteries and hydrogen energy sources will disrupt the aerospace market. Battery powered aircraft will enter the market for shorter range conventional and vertical take-off and landing (VTOL) applications, offering radically lower operational costs than conventional aircraft. The ATI's FlyZero project has shown that liquid hydrogen could be used to power midsize and narrowbody aircraft using a hydrogen gas turbine and regional aircraft can be powered using fuel cells with key development taking place in the UK. Overcoming the challenges for commercial use of liquid hydrogen in this way, will require substantial technology development, particularly to allow the storage and use of cryogenic hydrogen. Seizing these disruptive opportunities is crucial for the future of the UK aerospace industry and wider UK transport infrastructure.

Hydrogen fuel cell powered concept aircraft (GKN Aerospace)



MARKET POTENTIAL

Achieving Net Zero emissions by 2050 will require the global aviation market to develop aircraft that adopt new low or zero-carbon technologies, and create the infrastructure required to support them. There is a potential global market for more energy efficient commercial aircraft of £4.3 trillion from 2022 to 2050. This is based on a moderate scenario in which a new generation of ultra-efficient 100% SAF capable narrow body aircraft starts to enter service by the early 2030s, followed by new ultra-efficient wide body aircraft from 2040. It also anticipates that a zero-carbon hydrogen fuelled regional aircraft could enter the market around 2035, with a zero-carbon hydrogen fuelled single aisle aircraft in the early 2040s.

In this future market scenario (below), UK industry could grow its market share from 13% to nearly 18% by 2050, as entire fleets transition towards zero-carbon emission technologies. However, achieving this market growth relies on early and sustained investment into the development of zero-carbon, ultra-efficient and cross-cutting technologies.

Market Baseline

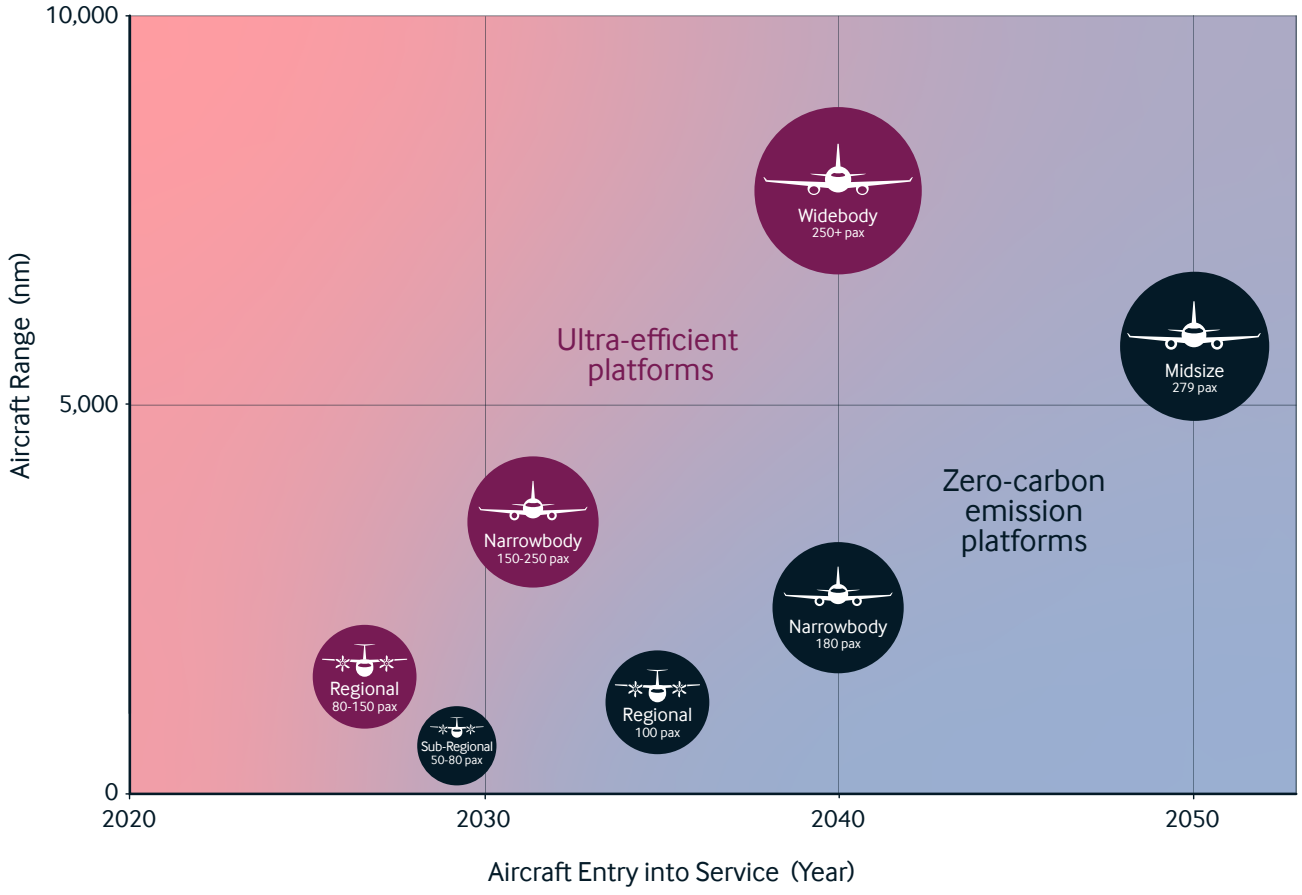
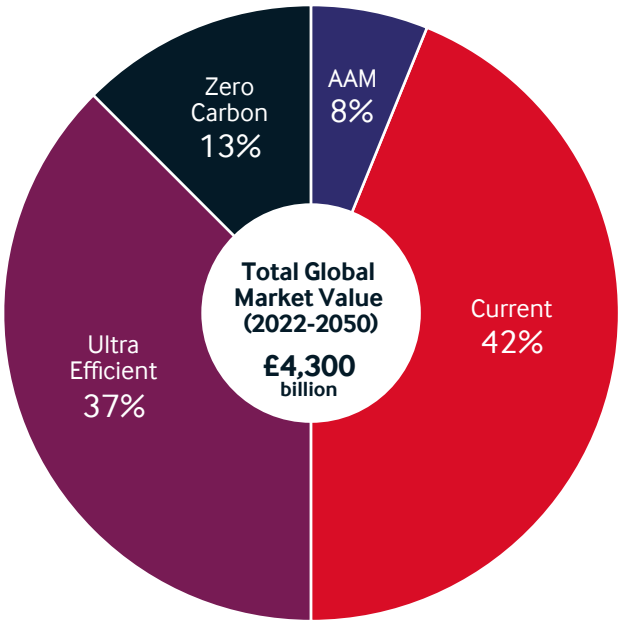


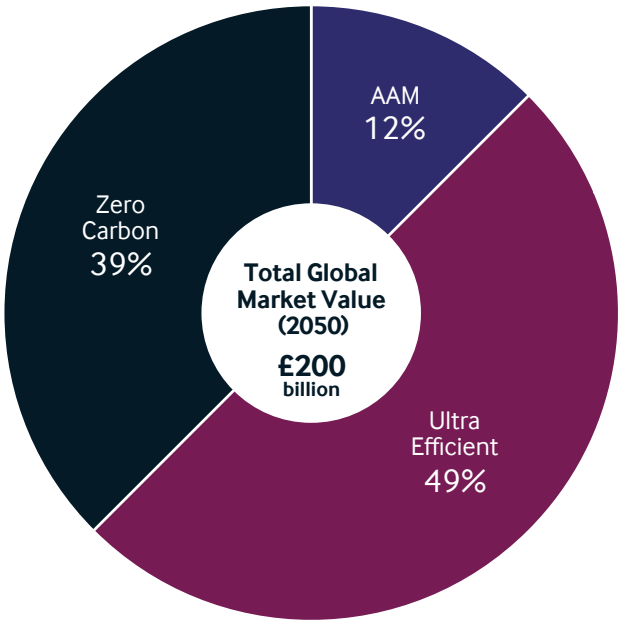
Figure 1 – Future Market Scenario

*Forming of the **Wing of Tomorrow** spar at the Global Technology Centre (GKN Aerospace)*

Global Market Revenue – Aircraft Deliveries



UK potential market share up to 15%



UK potential market share up to 18%

Figure 2 – ATI Global Market Modelling to 2050

Our modelling is based on assumptions aligned to our moderate market scenario. If industry were able to adopt zero-carbon technologies earlier, then economic and sustainability impacts would accelerate. FlyZero has explored the impact of investing in developing the midsize zero-carbon aircraft ahead of regional or narrowbody. Although this could be seen as a higher-risk development path, the entry into service of a midsize zero-carbon aircraft in the mid-2030s would address carbon emissions more aggressively. Although technology and infrastructure development would need to be accelerated, the infrastructure requirements would be lower than for a regional aircraft to enter service.

ACHIEVING NET ZERO 2050

In 2019, aviation contributed around 3.5% to global warming through carbon dioxide (CO_2), nitrogen oxides (NO_X) and contrails. Without adoption of lower carbon technologies, aviation will contribute to 38 gigatonnes (Gt) of CO_2 emissions to 2050, representing 9.5% of the total global carbon budget to limit global warming to 1.5°C. Development and adoption of sustainable aircraft technologies and improved operations as assumed in our future market scenario would enable global carbon emissions to be reduced by nearly 2.5 Gt by 2050. An extra 8.3 Gt could be abated beyond the tailpipe emissions through market-based measures and bio-SAF as shown in Figure 2. To reach Net Zero by 2050, the sector will need to rely further on carbon offsets and the development and scale-up of other pathways for drop-in synthetic fuels.

Impact of Future Market Scenario on Global Aviation CO_2 Emissions

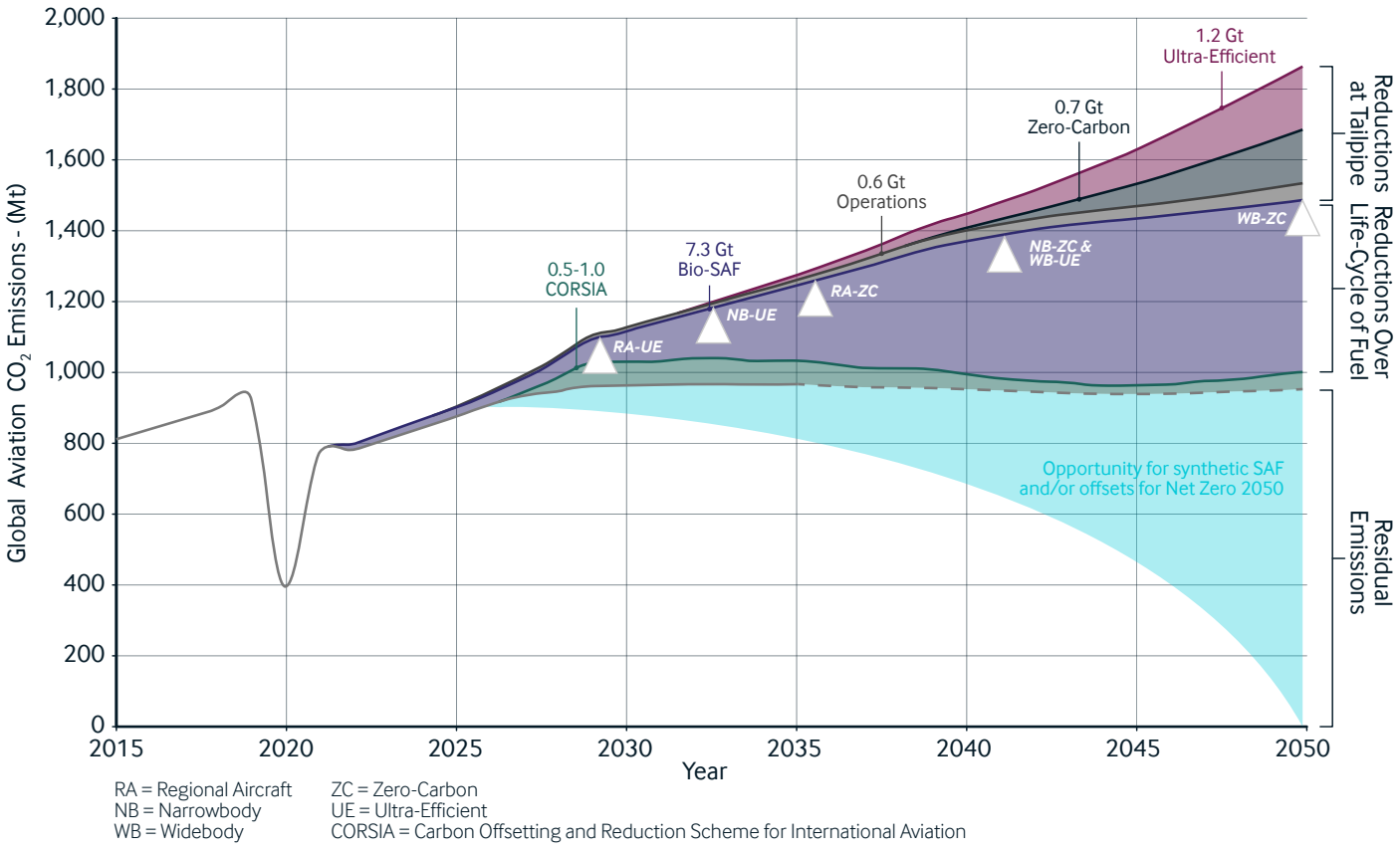


Figure 3 – Impact of future market scenario on Global Aviation CO_2 emissions

"The biggest research and technology challenges concern the safe storage and use of cryogenic hydrogen as a fuel on aircraft..."

To reduce the reliance of the sector on carbon offsets and other SAF pathways which don't currently exist at scale, there is an urgency to -

- Invest in new technologies so that more sustainable aircraft enter the market from 2028
- Develop policies and incentives to encourage adoption of more sustainable aircraft
- Develop industrial and airport infrastructure for SAF and hydrogen production and distribution at scale
- Create appropriate regulations and standards for testing and use of the new technologies and aircraft

The use of SAF to replace kerosene will increase from 2021 and will substantially contribute towards CO_2 abatement out to 2050. The UK Government's recent decision to invest £180m to support commercialisation of SAF is a good step in this direction. Global production of SAF (whether bio-derived or synthetic) will need to dramatically increase to meet expected demand. Later in the period, liquid hydrogen could become increasingly desirable as a fuel source if the challenges, costs and demands of research & technology, development, certification, production, logistics and infrastructure can be overcome. The biggest research and technology challenges concern the safe storage and use of cryogenic hydrogen as a fuel on aircraft, but the prize is zero-carbon emissions. Seizing this disruptive opportunity now is crucial for the future of the UK aerospace industry and wider UK transport infrastructure and will have significant impact on CO_2 abatement in the years beyond 2050.

Electric motor for all-electric and hybrid propulsion (Safran)

SCOPE AND PRIORITIES FOR INVESTMENT

The ATI will prioritise technology developments for commercial aircraft and associated manufacturing industry with the potential to deliver the greatest sustainability and economic benefits.

Our analysis has demonstrated that widebody and narrowbody aircraft market segments have the largest impacts on sustainability and the UK economy, therefore these are the priority areas for ATI technology investment under this strategy. Outside of these segments funding will be considered for projects that can demonstrate scalable technology solutions or substantial economic, sustainability and technological advantage for the UK. The ATI will continue to actively influence the partners involved in collaborative projects such that a broad UK supply chain is represented, including SME's, the whole of the UK, academia and broader ecosystem.

Figure 4 below, outlines the scope of the ATI's funding programme. We actively bring together other UK and internationally funded initiatives across the ecosystem to bring new capabilities and technologies into aerospace. We will also work collaboratively with other organisations whose focus is on the broader aviation landscape, providing advice and guidance on future aircraft technology developments, although we will not fund broader aviation technologies directly.

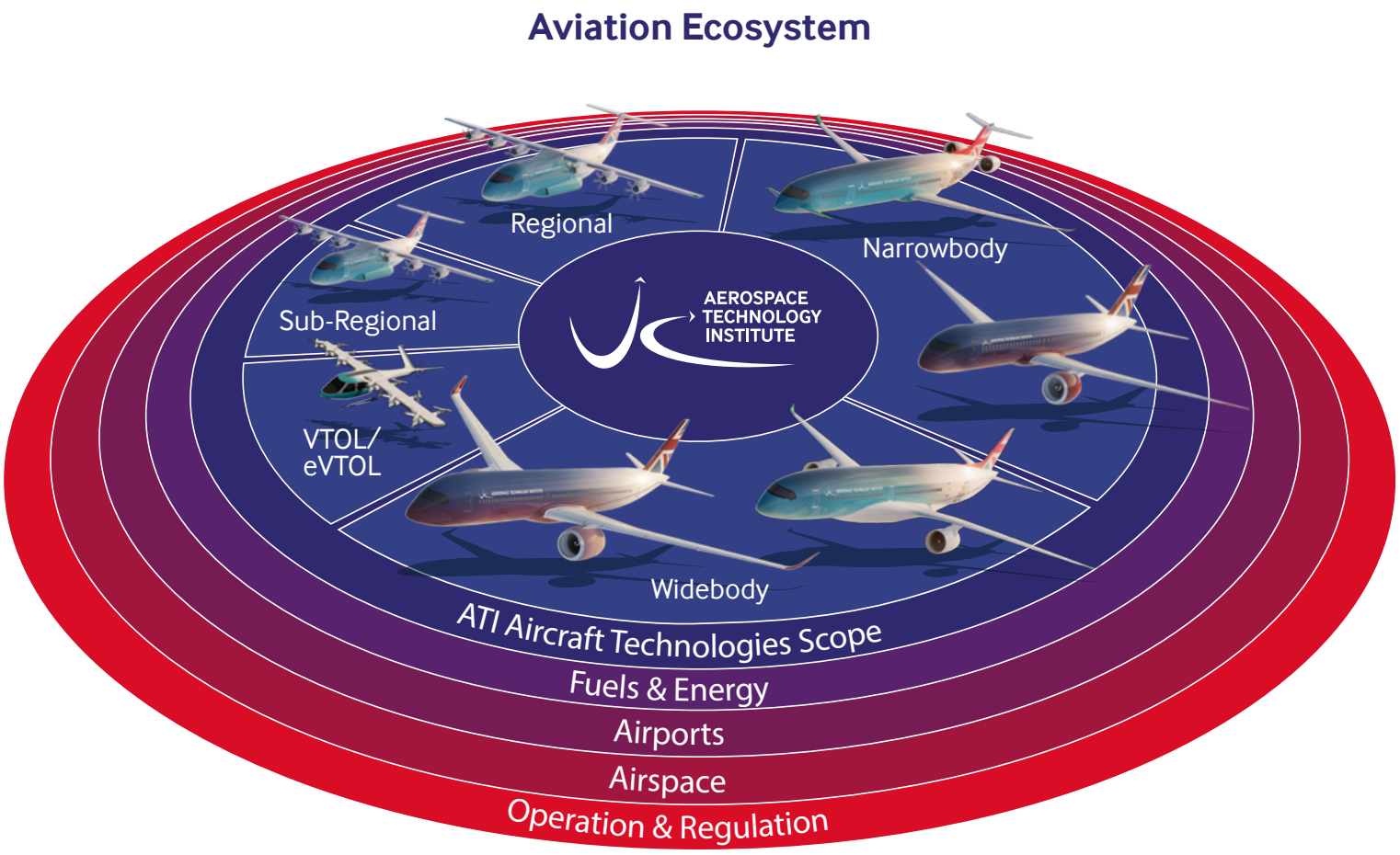


Figure 4 – UK technology funding routes

Sustainability has always been a core element of the ATI's technology prioritisation, with most of our £3.2 billion portfolio technology projects to date addressing the broader aspects of sustainability and over 50% of this investment directly focused on reducing emissions. The ATI has developed a sustainability model that can give a programme-level estimate of potential CO_2 savings globally by 2050. The sustainability model produces a profile of whole lifecycle emissions savings over time associated with the expected reduction in tailpipe emissions due to ATI-sponsored technology being successfully exploited on the future global aircraft fleet. We will use this approach to assess the CO_2 impact of different technologies as an input into technology investment priorities. We are also working to develop the model to incorporate non-CO_2 emissions including NO_x and contrails.

The ATI's milestones for success are outlined in the three roadmaps that form the core of this technology strategy -

Zero-carbon priorities

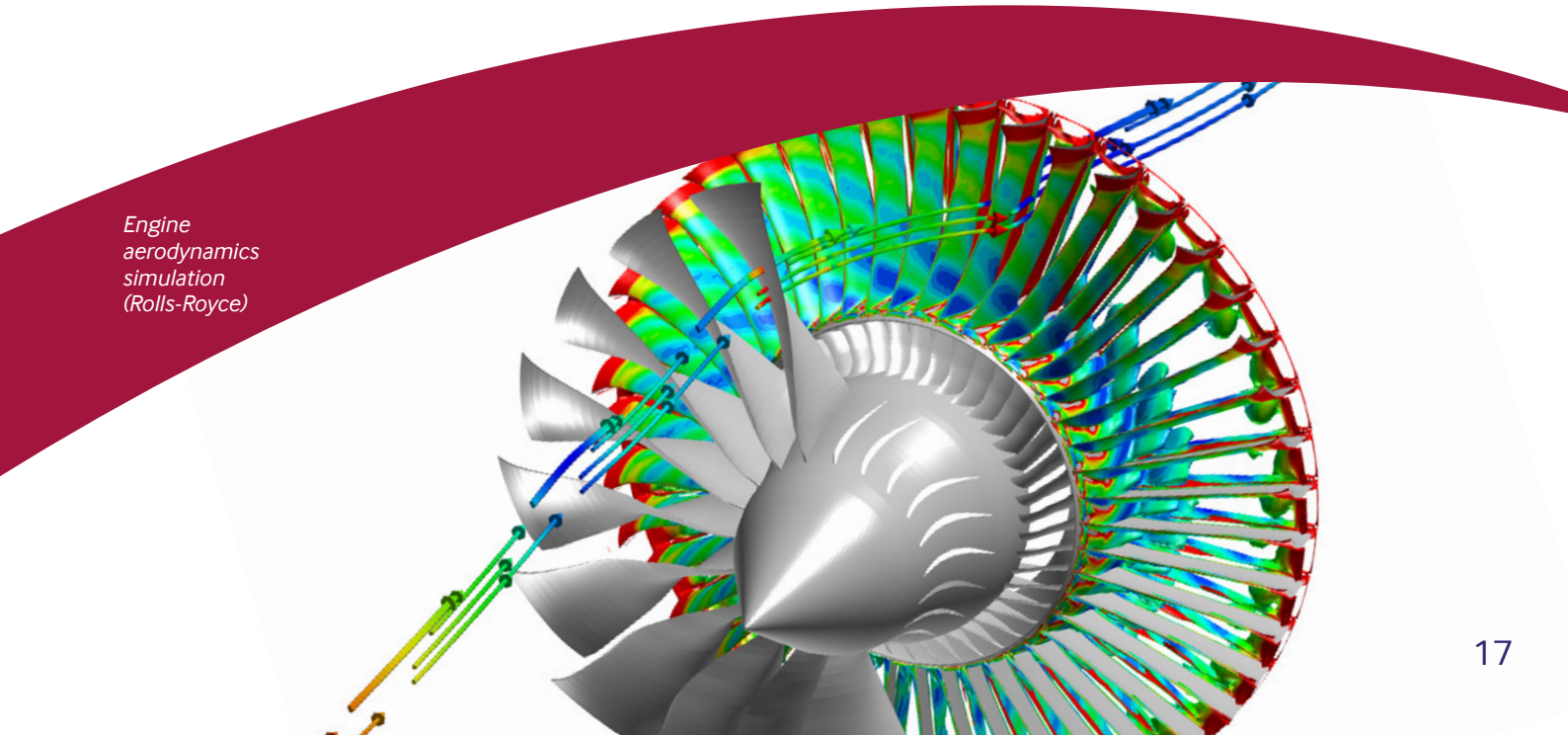
- Mature UK strategic zero-carbon systems, hydrogen gas turbine, cryogenic and heat management fuel systems and dry wing, to TRL 6 ground demonstration by 2025
- Develop, with international partners, a route to flying test of the UK strategic zero-carbon systems ahead of 2030
- Continue support to fuel cell regional demonstration, enabling UK technology supported vehicle with EIS by 2030

Ultra-efficient priorities

- Mature ultra-high bypass ratio turbofan engines to TRL6, ensuring readiness for new commercial aircraft opportunities with entries into service from 2030 onwards
- Exploit new aerodynamic technologies and high-rate manufacturing and assembly of composite wings for the next generation of single aisle aircraft from 2030 and the next generation widebody aircraft from 2035

Cross-cutting enabling technologies

As an enabling function, success for the cross-cutting technologies within the ATI Programme will be judged by our ability to meet the ultra-efficient and zero-carbon milestones. We do this by developing technologies that dramatically improve the speed and cost to design, develop, manufacture and support aircraft, ensuring the UK is a leader in the development and delivery of more sustainable aircraft, and growing the UK's market share.



Engine aerodynamics simulation (Rolls-Royce)

ZERO-CARBON EMISSION AIRCRAFT TECHNOLOGIES

Zero-carbon emission technologies are focused on propulsion and infrastructure development to enable zero-carbon tailpipe emissions. This encompasses battery, hydrogen, and fuel cell technologies, much of which are in early stages of development. More work is required to confirm the viability of future hydrogen fuelled aircraft, particularly the need for high upfront infrastructure costs to scale up green hydrogen production, transport and storage and handling at airports. Whilst propulsion systems where hydrogen is burned in a gas turbine eliminate carbon emissions (assuming green hydrogen is used), emissions of water vapour and NO_x will be remaining issues for climate change, requiring further research and mitigation. The understanding of contrail formation from hydrogen powered aircraft and the associated climate impact will also become an enabler to these concepts. More detail on the work needed in this area is available in the FlyZero output. Maintaining progress on the ultra-efficient aircraft technologies is vital to the UK's future zero-carbon emissions opportunities, as our leading strengths in wings, propulsion and systems technologies are the areas that will see the biggest change and therefore competitive threat.

The ATI FlyZero project developed a range of aircraft concepts, identifying the potential for hydrogen to be one of the fuels of the future. The work indicates that cryogenic hydrogen fuelled, ultra-high bypass ratio turbofan powered airliners could be capable of ranges up to 5750 nm, making hydrogen powered commercial transatlantic flights possible and enabling a global network of zero-carbon, hydrogen powered commercial flights.

The three FlyZero zero-carbon emissions aircraft concepts (ATI)

The zero-carbon roadmap shows the milestones for technology development out to 2050. The zero-carbon aircraft technologies which are priorities for the ATI Programme are -

- **Hydrogen in fuel cells and gas turbines** – Fuel cell powered propulsion systems are already being demonstrated, with the potential to eliminate both tailpipe CO_2 and NO_x. More research in increasing the operating temperature of fuel cells to reduce weight, as well as on heat management will be required. Low NO_x hydrogen combustors and their associated systems will need to be developed and tested through ground and flight demonstrators before 2025.
- **Hydrogen storage** – Cryogenic hydrogen tanks and the associated distribution and safety systems on board the aircraft will have to be developed and tested for both, fuel cell and gas turbine applications.
- **Battery powered aircraft** – Continued technology development for battery power and energy density is required in eVTOL and sub-regional applications. Further development to larger commercial aircraft is not foreseen due to limitations in ultimate battery performance.

Battery module for electric propulsion (Electroflight)

The key ATI programme milestones for zero-carbon emissions aircraft technologies are -

- **Mature UK strategic zero-carbon systems, hydrogen gas turbine, cryogenic and heat management fuel systems and dry wing, to TRL 6 ground demonstration by 2025.**
- **Develop a route to flying test of the UK strategic zero-carbon systems, with international partners, ahead of 2030.**
- **Continue support to fuel cell regional aircraft demonstration, enabling UK technology supported vehicle with EIS by 2030.**

ZERO-CARBON EMISSION AIRCRAFT TECHNOLOGIES ROADMAP

2020 2025 2030 2040 2050

AIRCRAFT CONCEPTS

- Sub-Regional/eVTOL (Battery) — 2025
- Fuel Cell Aircraft (GH_2) — 2030
- Fuel Cell Aircraft (LH_2) — 2040
- Gas Turbine Aircraft (LH_2) — 2050

PROPULSION & POWER

LH_2 GT

- H_2 combustion sector rig test
- Full annular low NOx combustion rig test
- Engine control systems ground test
- Propulsion systems ground demonstration
- LH_2 engine ground demo
- Gas turbine flying test bed
- Generation 2 technology TRL 6 target reached
- Flight control systems for highly flexible wing ground test
- Energy harvesting and reuse systems and sensors

H_2 FC

- Low temperature fuel cell system
- Fuel cell power train full scale test rig
- GH_2 fuel cell flying test bed
- High temperature fuel cell rig test
- LH_2 fuel cell flying test bed

BATTERY

- High power density aero battery development centre
- Distributed propulsion motor systems rig test
- High power motors & drive systems for electric propulsion
- Sub-regional battery powered aircraft demonstrator
- Systems to enable reduced crew operation

ADVANCED SYSTEMS

H_2

- Sensing and prevention systems for health management, fire protection and leaks
- LH_2 cryogenic generation 1 fuel storage rig test
- Systems ground test demo
- Integrated energy management systems
- LH_2 cryogenic generation 2 fuel system storage and distribution
- H_2 APU/secondary power engine ground test
- Next-gen low weight and cost sustainable landing systems

CROSS CUTTING

- Next-gen cabin systems, passenger connectivity & environmental control system
- LH_2 cryogenic generation 1 fuel system rig test
- Novel heat exchanger development for fuel cell and gas turbine applications
- Next-gen low power, ice and rain protection technologies
- Large aircraft demonstrator including dry wing
- More electric non-propulsive electrical power systems
- Integrated antenna with structures
- Next-gen cyber secure avionics technologies including enablers for autonomy
- Regional aircraft demonstrator including dry wing

AERO STRUCTURES

- Materials & process development for AM, composites, cryogenic and high temp. applications
- Multi-functional structures for thermal management
- Cryogenic assembly systems rigs and test
- Advanced large dry wing demo
- Sealing systems and joint integrity
- Cryogenic component/ sub-system rig and test
- Advanced dry wing wind tunnel and functional test
- Passive dry wing wind tunnel & functional testing
- eVTOL production wing demonstrator

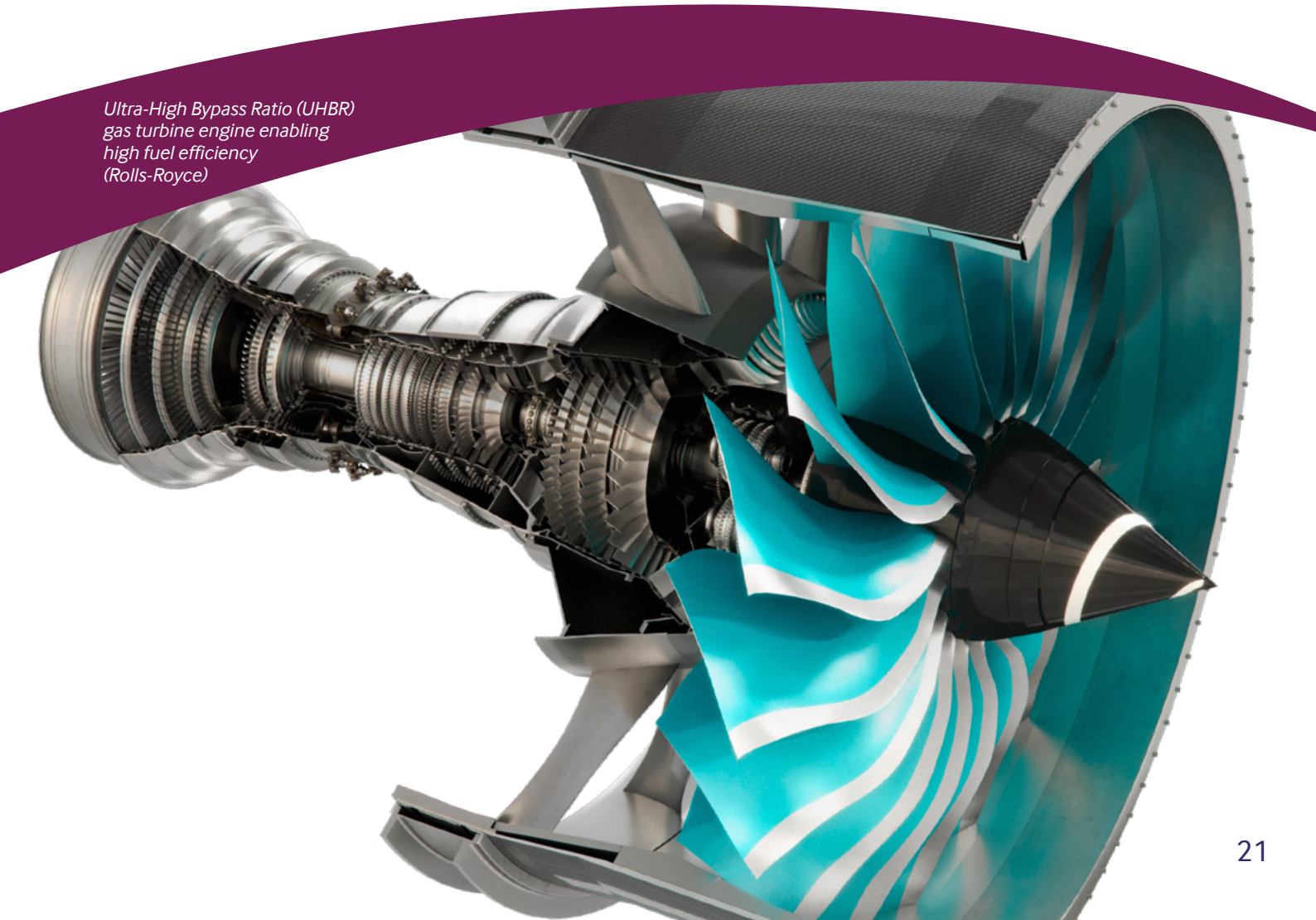
TARGETS

- 0.7 Gt of additional CO_2 saved through zero-carbon emissions aircraft (2021-2050)
- 8% of annual aviation CO_2 avoided by zero-carbon emissions aircraft in 2050
- 90% NO_x reduction & 65% reduced perceived noise per aircraft by 2050 vs 2000 platforms
- £0.6 trillion global market opportunity for zero-carbon emissions aircraft to 2050.
- The UK could potentially have up to 19% share of future global zero-carbon emissions aircraft market, securing a position for future generations of aircraft
- 60,000 aerospace jobs on zero-carbon emissions aircraft by 2050

ULTRA-EFFICIENT AIRCRAFT TECHNOLOGIES

Ultra-efficient technologies are focused on improving energy efficiency and hence impact CO_2 emissions, NO_x and noise. Continued development of crucial high value, sustainable, high productivity manufacturing technologies will position the UK to be a first-choice location for the industry. These technologies are translatable to all market sectors and are directly deployable into later zero-carbon emissions aircraft. They will also benefit large scale aircraft that are unable to use a zero-carbon fuel source. The ATI has modelled future ultra-efficient widebody and single aisle aircraft, predicting that efficiency improvements of 16% and 20% respectively can be achieved by the next generation.

The ATI is supporting the strategic development of next generation ultra-high bypass turbofan engines to disrupt the market with reduced fuel burn for applications spanning the narrowbody to widebody market segments. Critical architectural components include the lightweight composite fan system, power gearbox (developed in Germany), high speed IP core, and lightweight low speed turbine. In addition, the ATI is supporting development of a generational change in wing technology to introduce lightweight, high performance composite wing structures and integrated systems. This strategic programme introduces the latest composite materials, advanced in aerodynamics and wing architecture and critically develops a path to support future wing manufacturing and industrialisation.



Ultra-High Bypass Ratio (UHBR) gas turbine engine enabling high fuel efficiency (Rolls-Royce)

The ultra-efficient roadmap shows the milestones for technology development out to 2050. The ultra-efficient aircraft technologies which are priorities for the ATI Programme are -

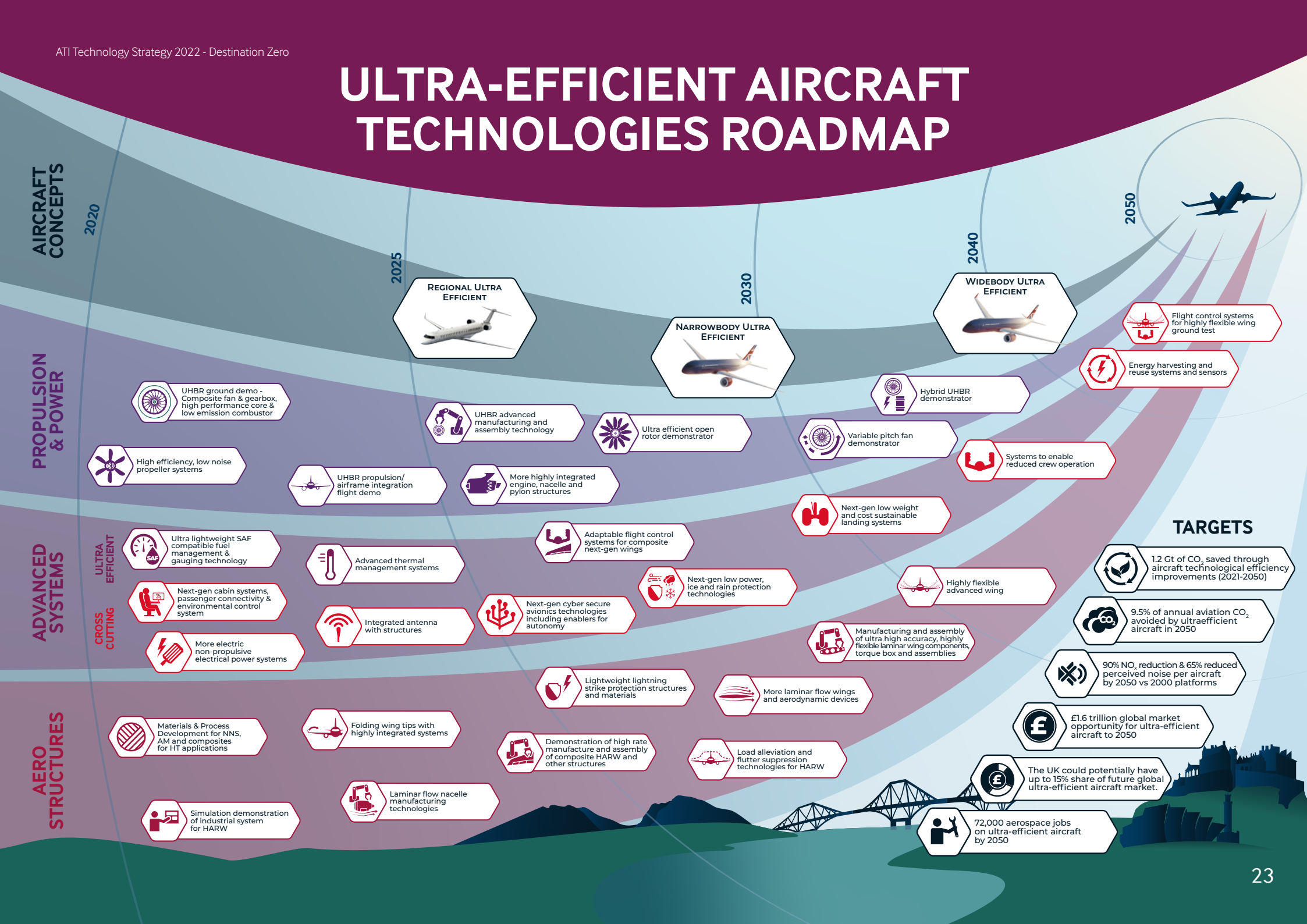
- **Ultra-high bypass ratio turbofans** – with composite, gear driven fan systems for high propulsive and aerodynamic efficiencies and low noise, ultra-efficient high pressure high temperature cores, intelligent control and monitoring systems. We aim to achieve over 10% efficiency and CO_2 emissions improvements by 2030, with further benefits from electrical hybridisation and variable pitch fan from 2030 onwards.
- **Lightweight, high aspect ratio, high production rate composite wings** – high aspect ratio wings, optimised for aerodynamic efficiency and rapid assembly, fully automated high-rate composite wing structure components manufacture and wing assembly. We aim to achieve at least 10% efficiency improvement with over 15% weight reduction and over 10% aerodynamic improvement for the next generation of aircraft.
- **Energy efficient, lightweight more-electric aircraft systems** – including electrical power systems, landing systems, ice & rain protection systems, fuel systems, thermal management, flight control systems, communication systems, flight deck displays and control systems, environmental control systems and cabin systems. We aim to achieve an overall efficiency improvement of up to 5% including energy consumption and weight reduction.

Ultra-efficient narrowbody concept aircraft (ATI)

The key ATI programme milestones for ultra-efficient aircraft technologies are -

- **Mature ultra-high bypass ratio turbofan engines to TRL6, ensuring readiness for new commercial aircraft opportunities with entries into service from 2030 onwards.**
- **Exploit new aerodynamics technologies and high-rate manufacturing and assembly of composite wings for the next generation of single aisle aircraft from 2030 and the next generation widebody aircraft from 2035.**

ULTRA-EFFICIENT AIRCRAFT TECHNOLOGIES ROADMAP



CROSS-CUTTING ENABLING TECHNOLOGIES

To enable both the zero-carbon and ultra-efficient opportunities, the UK must develop cross-cutting enabling technologies and capabilities for whole aircraft design and analysis. These capabilities should extend to the aircraft lifecycle from design, through manufacture & assembly, operation, and end of life. For ultra-efficient aircraft technologies, there are challenges with finding further improvements beyond the optimised designs of today so that emissions and block energy can be reduced as much as possible. For zero-carbon aircraft, there is a particular challenge in rapidly identifying the technologies and systems which can be transferred from existing and ultra-efficient aircraft, and how to integrate these successfully and safely into new platforms. As tailpipe emissions are reduced or eliminated, the embodied emissions in the life cycle of aircraft will become more dominant, so quantifying and reducing these will be more important than ever.

Recent years have seen significant advances in areas including computing power, connectivity, sensing, AI/machine learning, simulation, augmented and virtual reality (AR/VR), robotics and other technologies associated with Industry 4.0. These advances, coupled with innovations in engineering and programme management tools and techniques, are enabling dramatic improvements in the speed and cost to design, develop, manufacture and support aircraft maintenance and operations.

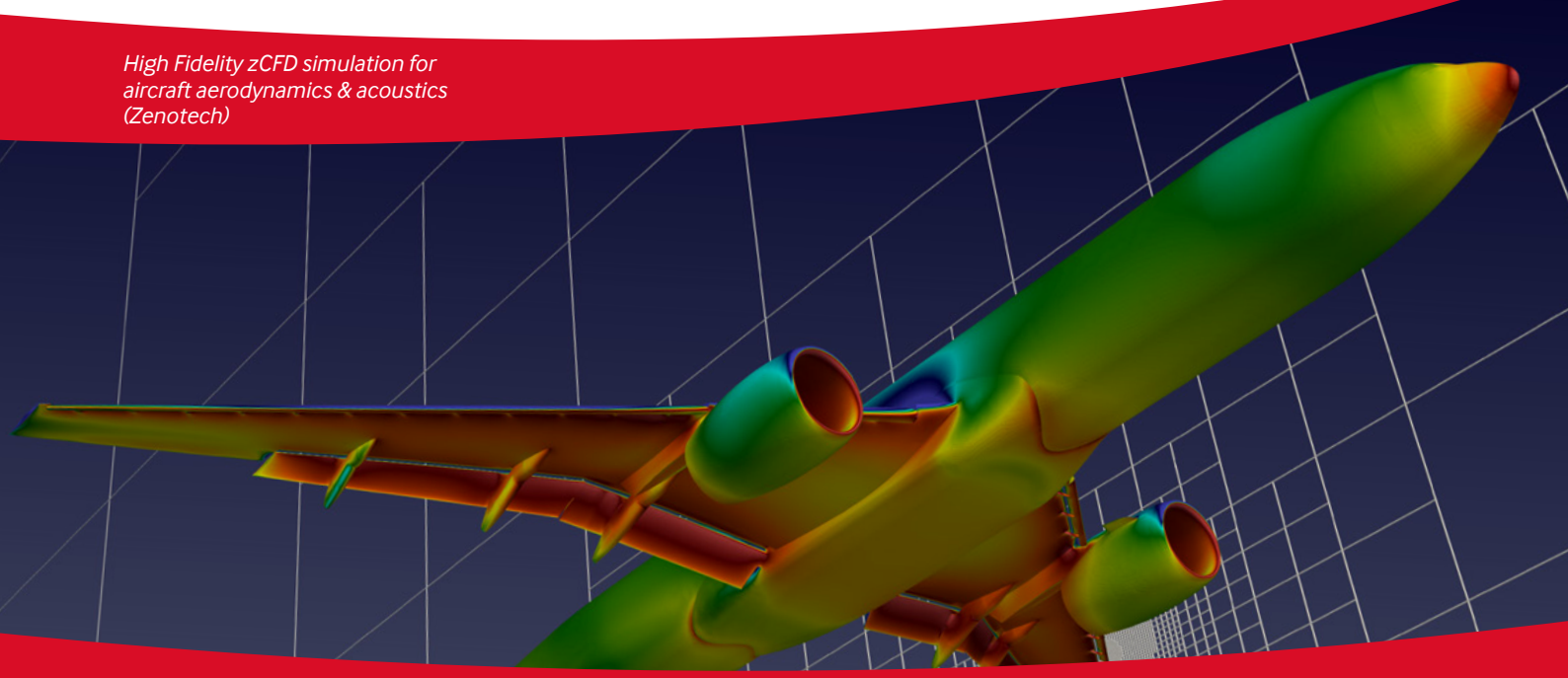
The High Value Manufacturing Catapult (HVMC) network of centres provide world-class infrastructure and experts to support industry with research supporting the three priorities in the crosscutting area. An example of this is the Advanced Manufacturing Research Centre (AMRC) capital equipment project to establish a Product and Process Verification Centre of Excellence as the core of the AMRC Cymru site at Broughton. This enables a digitally connected supply chain and smart factory for the Airbus Wing of Tomorrow. Innovations include capture of manufacturing data with no time or cost penalty, industrialisation of frequency scanning interferometry, model-based certification, automated hole inspection with robotic co-worker, embedded process and product monitoring, human-robot collaboration and the development of a hyper-flexible workforce.

Friction stir welding (TWI)

The cross-cutting technologies roadmap shows the milestones for technology development out to 2050. The cross-cutting technologies which are priorities for the ATI Programme are -

- **High Value Design and Validation** – higher levels of integration and optimisation across ever more complex systems, shall require accurate prediction of how aircraft will perform throughout their lives, evolving through validation to enable certification via analysis. Digital design and modelling tools need to become ever more automated, integrated, capable and accurate across the product lifecycle.
- **Manufacturing and Assembly** – implement affordable, adaptable and intelligent automated manufacturing systems and connected factories across the supply chain to align with customer needs for data at high-rate production, and readily accommodate product changes with competitive costs. Improve material sustainability through optimising material utilisation through Near Net Shape and joining processes alongside developing the next generation of materials. Aerospace manufacturing requires high levels of precision and strict quality standards throughout manufacture, from components up to assembly of large complex systems driving demands for in-process monitoring and control, advanced metrology and non-destructive evaluation technologies.
- **Through-life Support** – maximise aircraft operational availability at the lowest possible through-life cost, to anticipate and adapt to future requirements. The required technologies for enhanced through-life engineering include inspection & repair processes, health monitoring for both structures and systems, predictive maintenance and enhanced digital vehicle support. Finally, anticipating end of life with systems for automated disassembly and materials recycling.

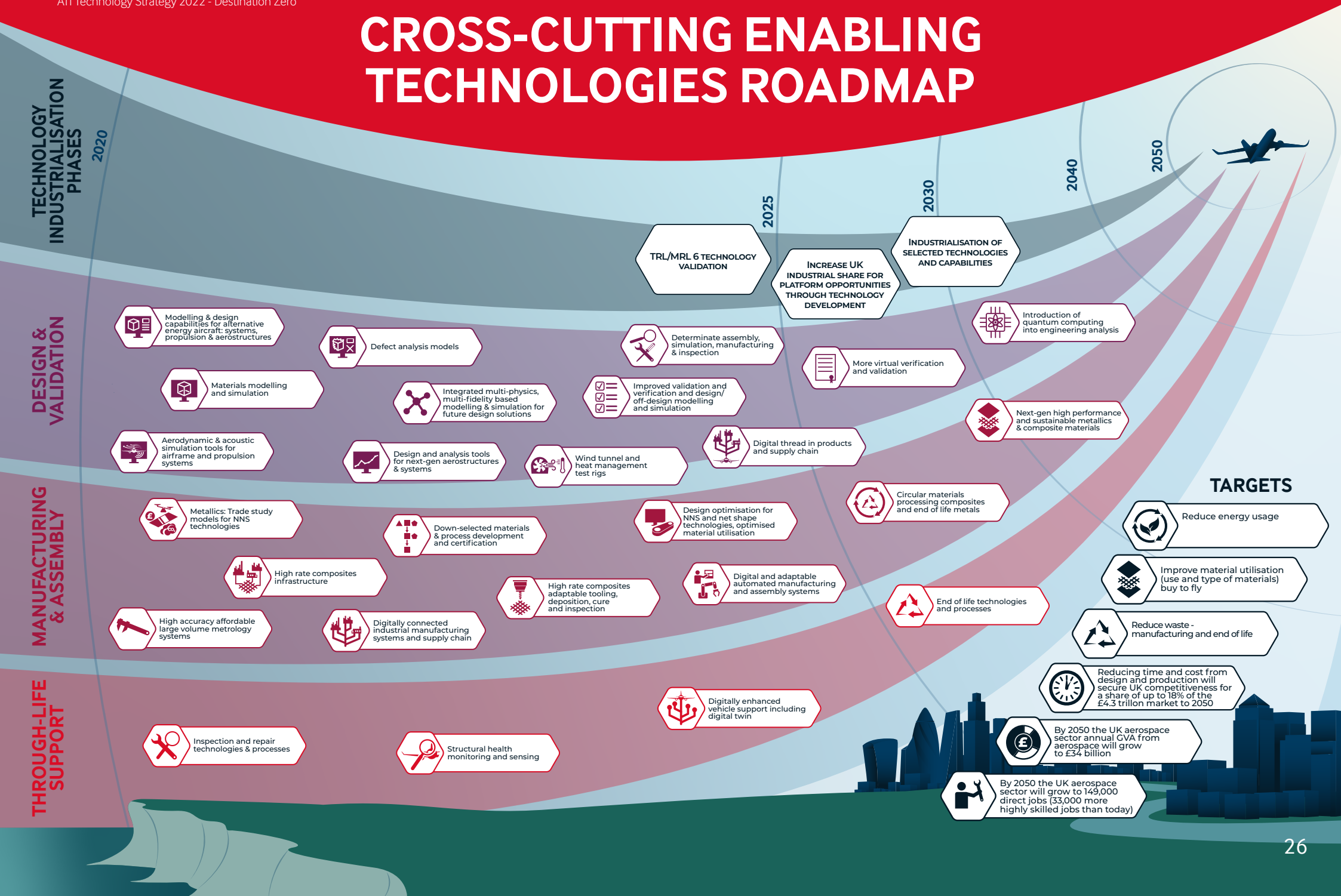
High Fidelity zCFD simulation for aircraft aerodynamics & acoustics (Zenotech)



As an enabling function, success for the cross-cutting technologies within the ATI Programme will be judged by our ability to meet the ultra-efficient and zero-carbon milestones. We do this by -

- **As an enabling function, success for the cross-cutting technologies within the ATI Programme will be judged by our ability to meet the ultra-efficient and zero-carbon milestones. We do this by developing technologies that dramatically improve the speed and cost to design, develop, manufacture and support aircraft, ensuring the UK is a leader in the development and delivery of more sustainable aircraft, and growing the UK's market share.**

CROSS-CUTTING ENABLING TECHNOLOGIES ROADMAP



Automation of complex geometry composite pipes manufacture (Collins Aerospace)

CONCLUSIONS

The UK government and the aviation industry have both committed to reaching Net Zero emissions by 2050 covering all domestic and international aviation operations in the UK. Destination Zero sets out potential technology roadmaps towards that objective, while ensuring the UK commercial market share grows and the UK increases its global competitiveness in the sector.

We have highlighted the priority areas that need investment to achieve this goal and identified the following overarching conclusions -

- **Zero-carbon emission aircraft technologies have the largest potential for reducing carbon emissions at the tailpipe for the future.** It should remain a top priority to accelerate the adoption of zero-carbon aircraft to have the greatest impact by 2050 and ensure the UK is a leader in their development for a greater economic benefit.
- **Ultra-efficient aircraft technologies considerably reduce the in-flight energy consumption of aircraft.** Many will also enable energy savings on zero-carbon platforms.
- **Sustainable Aviation Fuels have a vital part to play in net CO_2 reductions to 2050.** Current and ultra-efficient technology require SAF for net-zero. To have the required impact SAF scale-up needs to happen now, along with mechanisms which close the price gap between these fuels and kerosene.
- **Cross-cutting technologies could accelerate the introduction of novel aircraft platforms and establish the UK as the global leader for future sustainable aircraft.** They will enable zero-carbon, and ultra-efficient technology development, validation, manufacture and adoption.

The UK is well positioned to grow its presence in the civil aviation market and to become a global leader of aviation CO_2 emissions reductions. Existing industrial, research, and higher education organisations can be leveraged to accelerate the developments needed across the entire aviation ecosystem including energy transition, infrastructure development and regulation. Destination Zero provides a view on how we might achieve that from a technology perspective and, as technologies progress, this strategy will also need to evolve.

One thing is clear though, and that is that the time to act is now for our sector. Good progress has already been made including those areas that the ATI has been supporting since 2014, but the challenges outlined in this strategy show that, as a sector, we need to step up our efforts to meet the targets we have set out. The research, investment and technology development required is unprecedented and is reminiscent of the revolution into the jet age.

While changes must be made to accelerate towards Net Zero, the scale of the challenge also reflects the size of the opportunity. We must work together across the wider ecosystem to seize the opportunities presented and establish the UK aerospace sector as the global leader for future sustainable aircraft. How successful we are will depend on how fast and how aggressively we respond.

// We must work together across the wider ecosystem to seize the opportunities presented and establish the UK aerospace sector as the global leader for future sustainable aircraft. //

FlyZero Zero-carbon emission aircraft concepts (ATI)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