Aviation and the environment

Clean, green and smart technologies for the future
Reducing the impact of aviation on the environment is a key challenge facing developed societies

Aviation has been of great benefit to society over the past century, facilitating economic growth and an understanding of cultures around the world. This growth has been built on outstanding developments in aircraft and engine design, design of the passenger experience, infrastructure in and around the airport and flight operations. However, the broader aviation and aeronautics community now faces two existential challenges:

1. The Covid-19 pandemic has had a serious economic impact on the aviation sector and will undoubtedly impact passenger confidence. Learning, and recovering, from the Covid-19 pandemic and rethinking aviation’s safety structures and procedures will be needed to make aviation more resilient to future shocks. The entire aviation ecosystem needs to be considered from ground transportation, airport power supplies, logistics and supply lines through to biosecurity for passenger management in the airport and in the aircraft, as well as the impact of varying border requirements on flight routes and schedules.

2. The need to reduce the environmental impact of aviation, and especially on climate change, is becoming ever more urgent. Aviation has made its first global step to limiting its CO₂ emissions by agreeing the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). While welcome, it is widely recognised that CORSIA is an interim measure and will not be enough to meet aviation’s societal obligations. New low carbon technologies will be required, as well as an understanding of the future patterns and growth in aviation as attitudes evolve and as organisations reduce their air travel as part of plans to reduce their carbon footprint. Again, the full aviation ecosystem needs to be evaluated to make it more resilient and sustainable.

Cranfield, which in 2020 has become a member university of the National Centre for Atmospheric Science (NCAS) and has hosted its FAAM Airborne Laboratory since 2007, has major expertise and capabilities relevant to tackling the challenges of aviation and the environment, spanning decarbonising travel, the green airport, environmental technologies and sustainable materials and manufacture. Demonstrated by the appointment of two academics, working jointly across the aviation and the environment sectors, and as the only University in Europe with its own fully-operational airport, aircraft and air navigation on campus, Cranfield offers a unique combination of infrastructure for research. The University site is a living laboratory, with the newly launched Urban Observatory a key component. This new approach is capable of supporting enhanced social, economic and environmental outcomes in urban, transport and infrastructure systems.

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Decarbonising travel

Covid-19 has significantly and rapidly affected and changed practices in the aviation industry, and in our lifestyles. The way this, and possible future pandemics and other shocks, will impact travel behaviour and how airlines and other transport modes respond, will be one of the key challenges for the sector in the foreseeable future.

Cranfield is developing interconnected approaches to address these challenges - from digital aviation, through manufacturing, fuels, flight operations to environmental monitoring and mitigation.

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Travel behaviour and airline fleet and network planning

Emissions produced by air transport activity are based on the traffic volume. This results from users’ decisions which are based on their perceptions of the flight attributes, including fares, travel duration, schedules and comfort. Our comprehensive analysis considers the entire air transport system, from user selection, through transport to and from the airport to operations and fleet management.

Carbon transport calculator

Cranfield has developed a tool to understand travellers and emissions produced. This internationally-recognised resource has been developed to help the industry to mitigate the climate change impact.

The calculator covers 76 types of aircraft, all civil aviation airports around the world with their International Air Transport Association (IATA) codes, together with location data. It enables accurate estimation of the total amount of fuel consumption and carbon dioxide emission. This calculator has already been used extensively for academic and industry consulting to aid in the understanding of travellers to improve airline and airport management. Outputs include demand forecasting, network and fleet planning, passenger experience studies and airport planning and operation.
Reducing the impact on the environment

Airports need to be increasingly self-sustainable across their entire operation - by reducing emissions, generating cleaner energy, recycling water and waste, minimising air pollution, controlling hazardous materials, reducing noise around the airport, capturing and storing carbon dioxide emissions.

Aspects such as human-centred air transport systems, the evaluation of airline networks and connectivity, fleet optimisation, travel behaviour, mode choice, willingness to pay, and airport surface access and logistics including air freight are all areas in which Cranfield has extensive expertise.

With our own airport, solar power farm and range of large-scale innovation facilities, Cranfield University is a living laboratory which offers transformative technologies and new approaches to delivering enhanced social, economic and environmental outcomes in urban, transport and infrastructure systems.

The Cranfield Urban Observatory

The Cranfield Urban Observatory is a sensor network tracking the environment and infrastructure use such as movement, air and noise pollution, and water flows across the campus. Our semi-rural, peri-urban location at the centre of the Oxford-Milton Keynes-Cambridge Arc provides an unparalleled research and learning opportunity.

An example of current work is an investigation into how air quality throughout the Arc changes as the Covid-19 lockdown measures are eased. The Arc is a priority area of economic development for the UK Government, and one of its ambitions is for growth in the region to have a neutral or even positive gain on the environment. This study, funded by the Natural Environment Research Council (NERC) and the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC), will be key in understanding infrastructure requirements for better living. The Cranfield Urban Observatory is the cornerstone for these measurements.

Reducing the impact of de-icing on the environment

Cranfield is working on smart materials for the manufacture of aircraft to reduce the requirements for the de-icing sprays used by commercial airports to ensure the safe operation of aircraft during cold weather.

While this technology is progressing, tons of de-icing chemicals are used during the winter months, and despite controls on their discharge, undesirable biofilms are commonly found in waterbodies around airports. Cranfield has worked on a project with Heathrow and the results were used to inform de-icer management and pollution mitigation strategies.

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The impact of climate change on aircraft operations

Climate change is creating substantial changes in aviation’s operating environment. More severe weather, increasing localised rainfall, increasing surface temperatures, changing average winds, shifting bird populations are all having an impact on aviation. Remote and island communities that depend upon air transport for social and economic activities, and often have limited airport capability, will be particularly affected.

Cranfield-led research shows that these issues have become more significant over the past decades. Future climate change may accelerate these consequences. Air traffic management, monitoring weather patterns and contingency planning can all improve infrastructure resilience.

This research showed that for several critical airports in Greece, climate change has already either increased take-off distances, or reduced the average payload significantly. In the most significant instance, at Chios with an Airbus A320, this was equivalent to an average of 38 less passengers with their luggage, or fuel for 1300km, per departure since the A320 entered service in 1988.

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Reduced emissions
air traffic
management

Digital aviation has often been cited as being the next significant business transformation in the sector and one which can support the aerospace industry towards delivering greater customer satisfaction, while addressing efficiency, cost and capacity issues.

It offers a holistic approach in which aircraft, air transportation and air traffic management are integrated in our unique state-of-the-art ecosystem for transformational research towards the net-zero carbon aviation goal.

With the pace of air travel growth already causing strains across the sector, and UK passenger numbers expected to increase by more than 50% by 2050, greener solutions other than expansion of airport capacity and ground infrastructure need to be found.

The Digital Aviation Research and Technology Centre (DARTeC) is being built at Cranfield and will spearhead the UK’s research into digital aviation technology.

Cranfield’s airport is the first in the UK to have an operational digital air traffic control centre. Supplied by Saab Digital Air Traffic Solutions, the innovative technology replicates and enhances what can be seen through the windows of a traditional air traffic control tower. It enables smarter approaches to air traffic control by digitising and integrating airport functions and improves a controller’s situational awareness, enabling quick and informed decisions. The new system provides controllers with a 360-degree view of the airport and the ability to zoom in on aircraft, improving visibility.

As well as serving Cranfield Airport, the digital control tower further enhances our research capabilities, ensuring our place as the home of the leading aerospace research facilities in Europe.

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Aviation ecosystems and the production and distribution of electrical power

Our work in this area focuses on infrastructure and redesigning our airport network to allow for a range of electric vehicle re-charging while managing the electricity grid.

Our expertise in transport systems and the energy and power sector allows an approach to aircraft electrification that considers the wider aviation ecosystem and net environmental gain. Our living laboratory is a testbed for transformative technologies. With our own airport, solar power farm and range of large-scale facilities, the Cranfield campus is a microcosm of a modern city. We can experiment with innovation at scale, including the use of our Urban Observatory with a campus-wide sensor network.

Other expertise includes:
- airline economics and route development,
- integration of electric aircraft into legacy systems and supply chains,
- passenger experience and acceptance,
- international and UK regulation,
- advanced vehicle engineering.

The production and distribution of electrical power is key to the successful integration of aircraft electrification into the aviation ecosystem. Both renewable and traditional power sources will be required along with reliable large-scale power storage systems.

We offer support in infrastructure-based disciplines including:
- renewable energy production and control systems,
- electrical distribution and grid systems,
- energy harvesting systems,
- power charging systems,
- electrical engineering – machines, motors and drives,
- monitoring and control systems,
- power storage – battery, thermal and chemical systems.

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Supplying future aircraft energy
The Aircraft to Grid (A2G) project is a conceptual design of a hybrid, self-generating and super-fast charging system for electric aircraft to improve airports’ use of clean energy. The research outcomes will have wider benefits to society, such as reduced carbon emissions to help mitigate global warming, and increased public awareness of green air travel.

The electrification of airports
Cranfield is working on The GRid flexibility by Electrifying Energy Networks (GREEN) for Airports project to improve the electricity network infrastructure for electric aircraft (EA) and electric vehicles (EVs) at airports.
Prior to the 2020 Covid-19 crisis, worldwide aviation emissions were increasing by about 3% per year. The UK has a zero net emissions target by 2050 and the EU’s Flightpath 2050 programme calls for a 75% reduction in carbon emissions per passenger kilometre by 2050. Aircraft electrification and hydrogen are key enablers towards achieving those goals and tackling climate change.

Challenges in electrification being addressed by experts at Cranfield include thermal management, systems design for integration into the airframe, battery management, power-to-weight ratios, testing, reliability and certification of new aircraft technology.

Cranfield has world leading expertise and facilities relevant to hydrogen propulsion for aircraft and is able to draw upon its strengths in aircraft structures, systems, avionics and propulsion systems to design revolutionary aircraft. With the support of specialists in battery management and electric motors, materials technology, integrated vehicle health management, rotorcraft, airworthiness and air transport management, hydrogen production, storage and utilisation we offer a capability that is second to none.

The £35 million Aerospace Integration Research Centre (AIRC) is one of Cranfield’s newest world-class facilities, working with industry to re-imagine aircraft and airspace concepts and shape the future of aerospace globally. The AIRC provides the capability to take aerospace concepts from theory to flight demonstration at technology readiness levels TRL 6/7.

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Aircraft propulsion

Our capabilities range from conventional gas turbines through hydrogen, hybrid electric and all-electric propulsion. We deliver performance evaluation, design space assessment and optimisation, component and prototype R&D, mission assessment and power plant integration and diagnostics. This unique set of capabilities has been developed through sustained collaboration with industry including the Cranfield Rolls-Royce University Technology Centre (UTC), Siemens, Hitachi, Samsung, easyJet, NASA, Dstl, Ministry of Defence (MOD), Clean Sky (EU), Engineering and Physical Sciences Research Council (EPSRC), the Aerospace Technology Institute (ATI) and Innovate UK.

Specific capabilities

• Fundamental research on key technologies: hybrid gas turbine design and performance including variable cycles, gas turbine re-sizing and the aerodynamic integration of electric propulsors.

• Bespoke multi-fidelity methods, tools and facilities to analyse and test a wide range of propulsion systems (hydrogen, hybrid, electric, VTOL and VSTOL and gas turbine propulsion) including models for propulsion system components, whole power plant, general arrangement and weight estimation, emissions, lifing, economics and integration. The whole capability can be used in an integrated way for a full Technoeconomic Environmental Risk Analysis (TERA). These capabilities, integrated with advanced diagnostic and life cycle analysis methods, can form the basis of digital twins.

• System architecture: modelling, sizing and analysis of fully integrated systems at system, aircraft and mission levels, including the ability to size and match electrical, energy storage, thermal management and propulsion modules.

• Advanced energy management strategies to minimise fuel, energy and maintenance costs, emissions and environmental impact. Schedules are customised for aircraft size and mission as well as technology level.

• Design concepts for cryogenic cooling systems for all-electric or combustion-based gas turbine propulsion systems.

Centre for Propulsion Engineering facilities

The Centre for Propulsion Engineering operates a large suite of facilities occupying a 3,000 square metre site that comprises 12 test houses and ancillary facilities including a workshop. The team can conceive, design, build, commission and operate large-scale, one-off prototype rigs for bespoke research and development requirements up to TRL 6. The Centre has 11 gas turbines (of up to 1 MW) at its disposal to support its education and research activities. Facilities comprise icing tunnels, combustion, thermal management, turbomachinery (including supercritical CO₂), instrumentation and measurement development, inlet and exhaust ducting etc.

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Alternative fuel options for aviation

Reducing reliance on fossil fuels is critical and major technological advances are required in a number of areas including biofuels, synthetic fuels, hydrogen and electrification.

Technology development will be central to this initiative, but it will also be important to develop methodologies which can assess the overall system impact, including economic and environmental factors, as well as how quickly such technologies can be introduced. The web of connections between aviation and society is complex and a systems approach is required to ensure a cost- and environment-effective transition to sustainable growth in the aviation sector.

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The pebble bed heater. With its 1800K, 15 bar and 4kg/s capability, it is already pushing the boundaries of ultra-low NOx combustion systems within the EU H2020 ENABLEH2 project and is spearheading Cranfield’s activities in hydrogen propulsion for civil aircraft.

NASA research grant

In 2013, NASA awarded Cranfield a three-year grant for research into future distributed propulsion systems, including turbo-electric. The award to a non-US institution was a first and provided for wide-ranging research to improve both propulsive efficiency and airframe performance, as well as achieving reductions in noise, emissions and energy consumption.

Life cycle assessment of hydrogen fuel cell-powered aircraft

This project, sponsored by Cranfield-based ZeroAvia, analysed the environmental benefits of hydrogen fuel cells for powering small commercial aircraft. It compared the energy flow chain from electricity production through hydrogen production to electricity generation and the resulting thrust. This was compared with conventional alternative propulsion technologies using a cradle-to-grave life cycle assessment (LCA), analysing not only the main target environmental impact of greenhouse gas (GHG) emissions, but also indicators of air quality, non-renewable resource use and toxicity.
**Sustainable fuels**

Advances in sustainable aviation fuel production are key to the aviation sector, to reduce emissions and increase carbon offsetting towards net-zero aviation.

Cranfield has expertise in the relevant areas of precision agriculture; applied remote sensing; crop models; food security; informatics and statistics; experimental design; and glasshouse phenotyping.

### Optimising mixed food-fuel cropping for sustainable aviation fuel

Cranfield is investigating mixed food-fuel cropping for production of sustainable aviation fuel by applying multi-cropping techniques. When optimised and scaled to large operations for select food-fuel crop combinations, they have the potential to deliver a yield uplift of 30% and reduced impact to the environment by 40%. This allows an increase in biofuel production (needed for sustainable aviation fuel) without impacting or displacing existing food production.

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Batteries, energy storage and electric machines

Batteries and energy storage

Our research in this area centres on managing batteries and the characterisation of cells with real application duty cycles. We work with conventional lithium-ion batteries and novel ultralight technologies such as lithium-sulfur. We have expertise in state-of-the-art estimation techniques and AI.

We focus on the practicalities of using batteries in the real world. This extends from the design of algorithms to estimate the internal state of charge and health of batteries to facilities to subject cells and small modules or packs to realistic electrical and thermal duty cycles. We have led the development of critical battery management algorithms for lithium-sulfur batteries, which combine light weight with strong safety, low production-scale costs and good environmental credentials.

Electric machines

We adopt innovative design methodologies and exploit the latest devices and materials in electric machine technology to achieve more efficient and reliable power conversion and control in applications ranging from renewable energy systems, transportation, and Mobility-as-a-Service (MaaS).

Specific capabilities include:

• Bio-inspired micro electromagnetic actuator for novel conjugate battery cooling.
• Modelling of multi-MW superconducting machines for electric distributed propulsion aircraft.
• High frequency converter for wireless power transfer for static and dynamic charging of electric vehicles, including autonomous aerial vehicles.
• Modular electric vehicle platform as Mobility-as-a-Service for electric-taxiing, zero-emission airport ground transportation, and the like.

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Smart, clean and green manufacturing

Sustainable materials and manufacturing are integral to the aerospace industry. Cranfield has been developing a roadmap for a sustainable manufacturing sector by applying fundamental science and thought leadership for manufacturing solutions across all sectors to support the aspiration of net zero carbon emissions.

National facilities such as our materials characterisation suite and the National High Temperature Surface Engineering Centre in Surface Engineering and Precision, which is now an associate member of the Henry Royce Institute, build on the strong synergies between manufacturing, materials, design and management. We are supporting the transition from product service systems (PSS) to through-life engineering services as a contributor to high value manufacturing; and enhance our commitment to manufacturing technology (composites, welding and laser technology, advanced materials) in the context of sustainable, resource-efficient manufacturing.

To meet these objectives, the main research strategies are:

• Smart: operations efficiency across topics such as business model innovation, resilient supply chains and reverse logistics, cloud manufacturing, sustainability as part of manufacturing company key performance indicators (KPI), circular economy and decentralised manufacturing.
• Clean: process efficiency using sensors and big data for factory management, product service systems, factory modelling and artificial intelligence for eco-efficiency, internet of things for traceability and authenticity, intelligent micro-factories and autonomous manufacturing systems.
• Green: resource efficiency such as energy efficient manufacturing, development of materials production with low carbon footprint, closed loop materials and circular economy, real-time life cycle analysis and advanced materials.

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Sustainability in the aviation sector will be based upon the principles of the circular economy and it is important to assess the overall impact of technological solutions rigorously. For example, the development of more efficient materials such as lightweight cabling which will reduce the use of energy, water and materials across the entire life cycle.

The enhancement of eco-efficiency straddles the improvement and development of new materials, more efficient manufacturing processes and the reduction of, and better use of, waste materials. New expectations in component safety, recyclability and zero carbon operations are key factors in future planning and life cycle assessment covers every aspect from the energy usage in the factories in which aircraft and components are built to the length of time they are in use. Advancements such as anti-microbial materials will be key for post-Covid-19 passenger safety.

Cranfield’s multidisciplinary expertise tackling industry issues and the impact of the aviation sector enable significant progress. One such area is the creation of new materials to build aircraft so that de-icing can be reduced or eradicated altogether. However, until these clever materials are used on all aircraft, the need for de-icing continues, and Cranfield researchers are helping airport operators reduce the impact on the surrounding environment.

Comparing the environmental impact of different transport modes

This project investigated the potential environmental benefit of mode shift from air and road transportation by the introduction of a high-speed train between London and Manchester, focusing on life cycle carbon dioxide emissions.
Cranfield is home to an extensive fleet of research aircraft, either owned by the University or by our partners including UK Research and Innovation (UKRI) and BAE Systems. These can be used for environmental measurements, science training, equipment testing, prototype development, procedural explorations, and other research uses.

This provides us with the ability to conduct experimental trials and test flights to enable certification with research payloads from grammes to tonnes. Cranfield Airport is experienced in supporting third-party research aircraft.

The FAAM Airborne Laboratory is a world-leading research facility aircraft dedicated to the advancement of atmospheric science. It is used for a wide range of atmospheric studies including the 2010 eruption of the Eyjafjallajökull volcano which caused great disruption to air travel across Europe.

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