

Aircraft electrification

The future of aerospace starts with Cranfield

The relationship between aviation and the environment is one of the key challenges facing developed societies.

Major reductions in carbon emissions are required to meet environmental targets. Aviation emissions are increasing by around 5% a year and the EU's Flightpath 2050 programme calls for a 75% reduction in carbon emissions per passenger kilometre by 2050. Aircraft electrification is a necessary step towards achieving those goals and tackling climate change.

As the only university in Europe with its own airport, aircraft and air navigation service provider, Cranfield offers a unique spectrum of relevant capabilities, expertise and facilities for the development of aircraft electrification and the aviation ecosystem. This includes the relevant approvals to design, build and fly a whole new aircraft concept. This is integral to achieving urban air mobility.

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

for this transformative future technology.

Aircraft electrification will not succeed without parallel development in airport infrastructure, power supply and distribution, and assessment of the impact of aviation on the environment. With Cranfield's global research airport and airside solar power farm, our £67 million Digital Aviation Research and Technology Centre (DARTeC), and our fully instrumented autonomous vehicle test road

Professor Dame Helen Atkinson DBE CBE FREng

(MUEAVI) alongside the airport perimeter, we provide a testbed

Pro-Vice-Chancellor, Aerospace, Transport Systems and Manufacturing

> Above: Cross sectional drawing of a hybrid-electric aircraft. Cover: Turbo-electric airliner.

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Aircraft vehicle design

Our experience in whole electric aircraft design includes aircraft structures, systems, avionics and propulsion systems integration. We use state-of-the art, computer-aided design tools and in-house bespoke modelling and simulation software to facilitate development and certification. This enables us to model the whole aircraft in a synthetic environment at various design stages to achieve cost-effective

Expertise includes thermal and battery management, trajectory optimisation, aerodynamics, propulsion, structures, systems, avionics, and comparisons between conventional and more-electric aircraft.

We have completed multiple studies and high-fidelity models for different aircraft sizes and configurations including: • unmanned aerial vehicles, electric vertical take-off and landing,

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- single aisle,

A new concept in personal air mobility

The Volante Vision Concept (pictured left) is a near-future study that envisions a luxurious form of air travel in the form of an autonomous hybrid-electric vehicle with vertical take-off and landing (VTOL) capabilities. In partnership with Aston Martin, Cranfield Aerospace Solutions and Rolls-Royce, Cranfield is leading work on the autonomous flight controls, connectivity and security of the aircraft. Our digital aviation research at the University will also support how the aircraft fits into the wider transportation ecosystem.

sub-regional, regional and medium range,

· blended wing body configurations.



For further information, please contact

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Aircraft propulsion

Our capabilities span from 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 powerplant integration and diagnostics. This unique set of capabilities has been developed through sustained collaboration with industry including the Cranfield Rolls-Royce University Technology Centre, Siemens, Hitachi, Samsung, easyJet, NASA, DSTL, MoD, EU Clean Sky, EPSRC, ATI, 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, Vertical Take-Off and Landing (VTOL) and Vertical and/or Short Take-Off and Landing (VSTOL) and gas turbine propulsion) including models for propulsion system components, whole powerplant, 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 lifecycle analysis methods can form the basis of digital twins.
- The Centre for Propulsion and Thermal Power 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, combustion, thermal management, turbomachinery (including SCO2), instrumentation and measurement development, inlet and exhaust ducting etc.
- 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.

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 air frame performance, as well as achieving reductions in noise, emissions and energy consumption.

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Unmanned **Aerial Systems** (UAS) technology

Our research shows that artificial intelligence-based control strategies for UAS power management reduce fuel consumption for designed flight missions.

Electrification systems architectures have been developed that lead to optimal trade-off between fuel consumption and flight duration, from conceptual design which balances propulsion energy that each energy source can make to design validation using hardware-in-the-loop and flying tests.

The National Beyond Visual Line of Sight Experimentation Corridor (NBEC) provides industry and academia with a unique 16 km development facility to help solve the challenges that low-altitude unsegregated autonomous and electric flight presents.

Our specialisms include:

- minimisation strategies,
- systems integration,
- sizing of hybrid-electric propulsion systems,
- thermoelectric power generation for UAV applications.

Persistent green autonomous air vehicles

We have worked on various projects to provide high efficiency power plants for UAS to extend operational times and payloads, decreasing costs and increasing productivity. We have developed a hybrid-electric propulsion system that is recharged by an internal combustion engine, and other methods to sustain battery charge levels and improve safety by guaranteeing that aircraft can land using remaining electrical energy if the engine fails. We are also researching fuel cells to potentially bridge the transition between battery-powered and internal combustion engine-powered UAVs.

artificial intelligence-based equivalent consumption

• design of hybrid fuel cell and battery propulsion systems for long endurance small Unmanned Aerial Vehicles (UAVs),

Relevant technologies

Batteries, energy storage, electric motors and generators

Our research in this area centres on managing ultralight batteries and the characterisation of batteries and their associated duty cycles, including lithium-sulfur batteries. 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.

Other capabilities include:

- design of electric motors, from milliwatt to megawatt power range,
- high power density machines for hybrid/all-electric propulsion - including superconducting machines,
- modelling of motors, generators and electrical systems,
- · feedback control of motors, generators and electrical systems,
- wireless power transfer for stationary and dynamic charging of electric vehicles, including autonomous aerial vehicles.

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A lithium-sulfur cell ready for testing in Cranfield's advanced battery laboratory.

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Relevant technologies

Materials technology and additive manufacturing for aircraft electrification

The most common traditional materials used in electrical energy distribution systems are copper and copper alloys. Modern applications show an increasing demand for better heat and electric current carrying capacity at a level beyond the capability of copper base materials. Nanocarbon materials, such as carbon nanotubes and graphene have high electrical and thermal conductivity and exceptional mechanical properties.

Super lightweight multifunctional structures ideal for electric aeroplane development

We are combining copper as well as aluminium with nanocarbons to develop new grades of super strong conductors. Our concept composite structures are made using novel manufacturing techniques to produce structures with integrated electric conductors. This potentially serves the need for power and signal transmission within active load-bearing elements for the whole structure.

Wire + Arc Additive Manufacturing (WAAM) can create metallic, defectfree additive manufacture components in titanium and aluminium and core research has already been completed with aerospace components. The combination of WAAM with low energy plasma deposition processes could revolutionise new aircraft design by removing electrical and data cable assemblies in future aircraft. Conductive and insulating tracks used to carry electrical signals and data through aircraft can be embedded using WAAM, without the need to use separate conductors for this function.

Integrated vehicle health management Conscious aircraft

The Integrated Vehicle Health Management (IVHM) Centre, with its industrial partners, has a long-term aspiration to deliver a 'conscious aircraft' that is self-monitoring and self-learning.

This self-sensing/aware aircraft will be capable of monitoring its current health, reliably predicting remaining useful life and automatically reconfiguring to optimise and plan future maintenance, repair and overhaul to minimise cost. The conscious aircraft is likely to be hybrid-electric, with smaller new entrant aircraft being all-electric and autonomous.

Our projects in this area include:

- Prognostics Health Management (PHM)-based adaptive power management for hybrid-electric aircraft: a novel approach for adaptive power management considering prognostics health indicators for electrical power generation and distribution systems.
- Reliable power electronics for aircraft systems: with growth in the electrification of aircraft, power electronics will increasingly be placed in harsher environments for weight and cost savings. PHM algorithms have been developed to monitor and predict failures and calculate remaining useful life. This could be used for optimised maintenance planning and to provide high availability of new, more-electric aircraft systems.
- Health monitoring of motors and generators: we have developed health monitoring and prognostics capability for Integrated Drive Generators (IDG) in the European Union-funded RepAIR project. We have also developed 95 kilowatt electrical motors connected back-to-back to test and develop real-time health indicators for electrical motors and generators. These could be used to detect mechanical and electrical faults and evaluate new designs for reliability and performance.



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A step towards conscious aircraft – Cranfield's 737-400 ground-based demonstrator aircraft.



Rotorcraft technology

Electrification of future rotorcraft and electric vertical take-off and landing (eVTOL) platforms

At the forefront of rotorcraft research and technology evaluation for over ten years, we are now building on this track record with research into rotorcraft electrification. In addition to our membership of the Technology Evaluator of the EU Clean Sky joint technology initiative, which is responsible for rotorcraft, we have other ongoing research with key partners such as Rolls-Royce and Siemens on the electrification of current and future rotorcraft platforms. We are currently leading the organisation of a consortium of 14 partners to investigate future hybrid-electric, turbo-electric and superconducting rotorcraft applications.

Using fully integrated, multi-disciplinary technology evaluation tools, we offer.

- full rotorcraft aerodynamic modelling,
- full 3D rotor aero-elastic representation,
- 4D mission profile definition and performance analysis,
- conventional (turboshaft), hybrid-electric or turbo-electric power plant modelling,
- · systems modelling and thermal management,
- emissions, operability and certification assessment,
- source noise prediction on-the-fly,
- far-field ground noise impact,
- 4D mission-trajectory acoustic footprint,
- stochastic noise prediction under uncertainty,
- investment cost analysis,
- · a variety of modelling tools developed in-house.

More-electric rotorcraft applications

We are working with Siemens PLM Software to assess thermoelectric power plants for twin-engine medium helicopter applications in terms of performance and operability. We are considering hybrid-electric propulsion systems using simple gas turbine cycles, as well as recuperated ones. Preliminary results show that low degrees of hybridisation may offer both operational and performance benefits. Recuperated gas turbine configurations show larger benefits.

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- · aeroacoustic optimisation of novel rotorcraft configurations,

• mission, airport and air traffic systems performance assessment,



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Aviation ecosys production and of electrical por

Our work in this area focuses on in airport network to allow for a rang while managing the electricity gri systems and the energy and powe aircraft electrification that conside and net environmental gain.

Our living laboratory is a testbed for transform deliver enhanced social, economic and enviror infrastructure systems. With our own airport, s facilities, the Cranfield campus is a microcosm innovation at scale, using all of the infrastructure Observatory with a campus-wide sensor netwo

Other expertise includes:

- airline economics and route development,
- integration of electric aircraft into legacy system
- passenger experience and acceptance,
- international and UK regulation.

The production and distribution of electrical p aircraft electrification into the aviation ecosys sources will be required along with reliable lar

- We offer support in infrastructure-based disc
- renewable energy production and control sy
- electrical distribution and grid systems,
- energy harvesting systems,
- power charging systems,
- electrical engineering machines, motors ar
- monitoring and control systems,
- power storage battery, thermal and chemi

Pollutant monitoring at Heathrow

The value of identifying various emission sources Airport involving Cranfield scientists. Low-cost se measures taken to improve pollutant levels. This of and co-ordinated with existing air quality network

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Cranfield Aerospace Solutions is at the centre of a number of market-leading electric and hybrid-electric aircraft projects.

A unique UK aerospace SME with the capability to design, build and fly a whole new aircraft concept, it holds CAA/EASA Design Organisation (DOA) and Production Organisation (POA) Approvals.

Cranfield.

Cranfield Aerospace **Solutions Ltd**

A partner company located at the heart of Cranfield University's campus, Cranfield Aerospace Solutions Ltd, aims to accelerate the world's transition to innovative, electric and autonomous air vehicles. It is the aircraft DOA and POA for the Volante Vision eVTOL aircraft concept, launched at Farnborough 2018 with partners Cranfield University, Aston Martin and Rolls-Royce.

Project Fresson – Scottish islands electric aircraft service

Project Fresson is the first phase in a long-term strategy to exploit the sub-regional global aviation market that is now ripe for disruption by means of electric and hybrid-electric propulsion. The project aims to develop the world's first passenger-carrying commercial electric aircraft by modifying an existing aircraft design - the nine-seat, twin-turboprop Britten-Norman Islander – with an electric propulsion system. The project hopes to have the aircraft EASA-approved by 2023/24, ready to launch the world's first commercial electric air transport routes. Routes operated by Scottish regional airline Loganair in the Orkney Islands are targeted for the initial service launch.

The final phase of the strategy will be to design, flight-test and manufacture a new EASA-certified 19-seat aircraft at

Cranfield's global research airport

Multi-User Environment for Autonomous Vehicle Innovation (MUEAVI)

This instrumented transport corridor runs through the middle of the campus and is used for the development of intelligent and autonomous vehicles. Sensors include lidar (laser scanners that can measure distance), radar that can detect pedestrians and cyclists at up to 200 metres, and thermal imaging cameras.

Digital air traffic control centre

Housing the UK's first operational remote air traffic control tower, the centre provides air traffic services for the airport. **Operational December 2018**

Boeing 737

Donated by British Airways, the aircraft is used for research and teaching and is an important part of DARTeC.

Holographic radar

State-of-the-art Aveillant drone detection radar for research as part of DARTeC

Digital Aviation Research and Technology Centre (DARTeC)

A unique centre addressing the global challenges of digital systems integration across aviation.

Gas turbine power and propulsion laboratories



Living laboratory

HyPER Hydrogen

Production

Sensors around the airport monitor air guality, soil moisture, temperature and noise levels, including sound from wildlife. Other sensors monitor water quality and levels, and runway and ground movements.

> Aviation Innovation and Technology Entrepreneurship cluster (AVIATE+)

Hydrogen refuel poin

'Smart' car park

connected to MUEAVI

Aerospace Integration Research Centre (AIRC)

Major research facility with Airbus and Rolls-Royce dedicated to future aerospace integration challenges.



National Facility for Beyond Visual Line of Sight (BVLOS) Research (NFBR)

Designed to enable drones and unmanned aircraft to fly in the same airspace as manned aircraft, NFBR will open in phases as surveillance systems are approved. The first NBEC test flights were undertaken in February 2019 in collaboration with the CAA innovation team and Blue Bear Systems.

Data from MUEAVI is relayed into the Intelligent Mobility Engineering Centre (IMEC)

control room. Within IMEC there are vehicle workshops, vehicle electrification and autonomous vehicle research capabilities.

Fire station \vee

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A national asset for the UK

National Flying Laboratory Centre (NFLC) including the SAAB 340B Flying Test Bed

The NFLC's 'flying laboratory' provides a viable alternative to flight test and research work using simulators, wind tunnels, or more expensive turbine aircraft, often testing new parts and equipment for industry partners. The NFLC also has other light aircraft used for research.



Cranfield Aerospace Solutions Ltd

A partner company specialising in aircraft prototyping, modifications and approvals located at the heart of the Cranfield campus.

Solar power farm

Clean, renewable energy for the airport flows from a solar power farm located on the other side of the airfield.

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