University of Nottingham
Propulsion Futures

Revolutionising the way we travel

Propulsion Futures

Beacon of Excellence

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Contents

An exciting and productive year

PICTURED: Professor David Grant, Director of Propulsion Futures Beacon of Excellence, Professor of Materials Science and Head of Advanced Materials Research Group

Foreword

It has been an exciting and productive year for Propulsion Futures Beacon of Excellence. Our annual report highlights how the Beacon has taken its business case through to operational level, and put in place an efficient operating model that both promotes the Beacon and supports the existing faculty structures in Engineering and Science.

Recruitment

Our Research Software Engineer, David Rogers; Electrified Propulsion Centre Manager, Chris Varley; and Beacon Project Officer, Graham Harrison are in post, with the Devices Lab Technician and Research Development Manager posts to be recruited. Two Nottingham Research Fellows have joined us, one of whom, Lee Johnson (Chemistry) has also secured a five-year UKRI Innovation Fellowship. Anne McLaren Fellow Karen Robertson (Engineering) and Nottingham Research Fellow Jesum Alves Fernandes (Chemistry) join us in autumn 2018, with two Beacon-specific research areas advertised in the 2018/19 recruitment round. Xuanli Lou (Engineering) has commenced a Daphne Jackson Trust Fellowship.

Equipment

Unique equipment is a key part of the Beacon's investment strategy. The focus is on the Electrified Propulsion Centre, located in the new UK Research Partnership Investment Fund (UKRPIF) Power Electronics and Machine Centre; the Beacon Devices Laboratory, in the newly completed Research Acceleration and Demonstration Building; and the establishment of the Beacon Processing Laboratory on University Park Campus.

Collaborations

A critical strand of Beacon activity is the development and growth of collaborations, both within the University, and with academic and corporate partners. We have 91 academic members from the Faculty of Engineering and Schools of Chemistry, and Physics and Astronomy who are working together to tackle the Beacon challenges. An internal showcase event and two themed workshops, Computational Chemistry and Molecular Devices, have been run over the summer, with over 130 attendees. Four more workshops are planned for the autumn, focusing on Electrical Machines Material Challenges; Batteries; Disruptive Technologies and Non-Battery Energy Storage. These workshops are forming the basis of new collaborations and bids for research funding.

Partnerships

The Beacon is leveraging new research from existing relationships with key corporate partners, for example Rolls-Royce, Siemens, Cummins, GE Aviation, and we had an excellent presence at the Farnborough Air Show. In terms of academic collaborations, the establishment of the National Aerospace Research Consortium (10 partners) underpins the preparation of the £20m UKRPIF bid (September submission), with a further £40m industrial match. 'Future Propulsion in Aerospace' will fund unique large demonstrators to be located in the Power Electronics and Machines Centre, and will provide Nottingham with a significant comparative advantage as the collaborator of choice with our industrial partners.

Significant collaborations with national and international partners through agreements, synergies and proposed new centres are all under way and will be reported when formal agreements are finalised.

In summary, the Beacon has been fully operational since March 2018. Significant work was undertaken prior to March enabling an effective first year in which the Beacon Executive Board has approved 28 projects with a total value £3.6m, of which £1.29m has been spent/committed in year one (financial year 2017/18) against a projected year one spend of £1.31m. Investment has been on significant equipment, recruitment of staff and refurbishment of laboratory facilities.

Professor David Grant
Director of Propulsion Futures

Transport is at the most important crossroads for a century

The University's Beacons of Excellence build on our world-leading reputation in the fields of human rights, healthcare, agriculture and food, advanced materials and engineering, bio manufacturing, and smart industries. All are driven by the need for sustainable solutions to key global challenges, and all are characterised by our transdisciplinary ethos.

Introduction

The Propulsion Futures Beacon will deliver world-leading research enabling the University to be a key player in developing the propulsion system of the future.

Transport is responsible for almost a quarter of global carbon dioxide emissions. The industrial and scientific community is at the most important crossroads of change in transport to occur since the introduction of carbon-based fuels and engines over a century ago. This change will have greener, electric transport at its heart. The Propulsion Futures Beacon is proposing a pathway towards truly sustainable, responsible and carbon-neutral travel through electrification, based on new materials, novel technologies and seamless systems integration. It will help tackle the ever-increasing climate change and health issues linked to the growth of transport based on combustion of fossil fuels, while directly supporting economic growth by building a scientific and engineering basis for more sustainable and responsible travel technologies.

Through our seven Visions, investment in facilities and equipment, and its technology streams, the Beacon will deliver:

- significant scientific outcomes in green and sustainable new materials, electrification and propulsion
- new materials and propulsion systems for all forms of transport, reducing the destructive impact on the environment and benefiting societies across the world
- hybrid and electric demonstrators for air, land and marine transport, developed through unique investments in infrastructure, equipment and people

The Beacon will make a significant contribution to the goals of the University's Research Vision through:

- **research delivery:** maximise leverage from the University investment to drive a significant increase in research awards over the lifeline of the Beacon
- **research quality:** high-quality papers are delivered by high-quality individuals and teams, and the Beacon will expand current capability in two ways. Firstly, by recruiting eight Nottingham Research Fellows, 50 PhD students (funded through a variety of sources) and post-doctoral research associates. Secondly, by providing an environment in which fellows and existing established career academics are highly motivated to apply for funding, build new collaborations, tackle Propulsion Futures research challenges and to publish high-quality papers
- **research impact:** by delivering novel technologies, unique devices, new materials and new energy storage systems, and through our demonstrators, which will ensure industrial buy-in, partnerships and innovative research we will deliver world-leading impactful research. There will be significant opportunities to generate IP and commercialise technologies, and for those technologies to be adopted throughout the Beacon technology stream
- **research reputation:** will continue to be built through high-quality outputs, value of research grants and awards, building capacity, delivering impact to the economy and society, developing partnerships and collaborations and delivering research-led teaching

Snapshot of achievements

130 bids
£59m total value
submitted since March 2017

18 new awards
£8m total value
since March 2017

99 bids
£37m total value
with outcome pending

Cummins Innovation Centre
renewal of Royal Academy of Engineering funding for a further 5 years

£1.4m from Innovate UK
for Advanced Integrated and Cooled Electric Drive awarded to Yuying Yan

£858k from Innovate UK for ELITS: Efficient Light Integrated Traction Solution awarded to Chris Gerada

£637k from EPSRC for UKRI Innovation Fellowship Unlocking Na-ion systems through interphase design awarded to Lee Johnson

£4.6m from EPSRC CornerStone
awarded to Seamus Garvey

£600k from Clean Sky 2 for QUICK:
Quick Disconnect System awarded to Michael Galea

£490k from Clean Sky 2 for LIFT:
awarded to Chris Gerada

Snapshot of achievements

Accolades

Debbie Kays,
Royal Society of Chemistry
'Chemistry of Transition Metals' winner 2018

Amalia Patanè,
CAS (Chinese Academy of Sciences)
President's International Fellowship for Visiting Scientists 2018

Michael Galea
Appointed to Fellow of the Royal Aeronautical Society (FRAeS)

Pat Wheeler,
UK Aerospace Technology Institute Strategic Advisory Group
Member of Engineering 2030 Advisory Board

Al Cairns
Board member of the Institution of Mechanical Engineers Powertrain Systems and Fuels Group and IMechE Vehicle Thermal Management Systems committee

Serhiy Bozhko
Member of SAE-AE7 International Standards Committee members (Aircraft Electric Power Systems) and Chair of AE-7M subcommittee working on Model-Based Design for Aircraft Electric Power Systems

Papers

147 papers have been published by Beacon members in the first six months of 2018

Of these:

26% are in **fundamental materials research**

23% are in **higher TRL materials development and performance**

35% are in **power electronics and engineering**

16% are in **cross-cutting fundamental atomistic and device modelling**

28 of these papers already have a **Field Weighted Citation Impact of over 2.5**

Case study

Materials discovery

A key focus is the integration of research groups across the University to meet the challenges of fundamental materials discovery, to deliver enhanced properties and to develop more efficient devices.

PICTURED: A new nanostructured oxide material for energy storage.

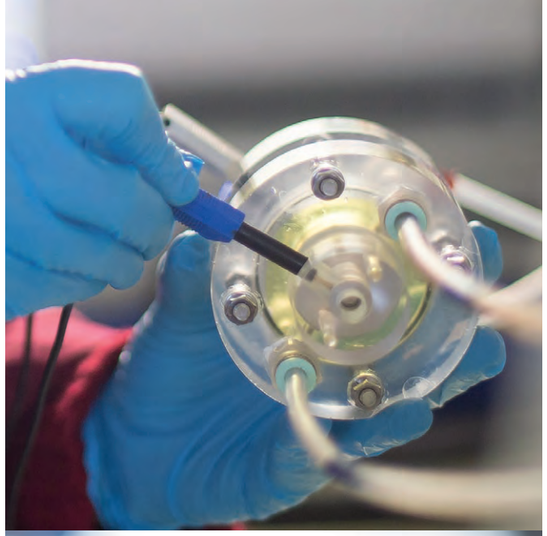
To secure a revolution in greener transport, electric machines must become more compact and operate at higher temperatures. Our Molecular Beam Epitaxy project is applying group III-nitrides for light and low volume, protective thermal and electrical insulating coatings. We will target hexagonal boron-nitride (hBN) which is a wide band gap (~6eV) semiconductor and is used in electronic devices and 2D technology. The team will study applications of hBN as a protective thermal, electrically insulating and wear resistant coating for metals, allowing electric machines be more compact and operate at higher temperatures. The project is exploring increasing flux to practical levels, which will be a major technological breakthrough and will be the only MBE system worldwide with such unique capabilities.

Modelling new materials and capability

Another challenge is the simulation capability and quantitative analysis of the materials and systems. One project aims to provide full-time scientific computing support for developing new modelling tools and enabling access to, and optimisation of, essential software. This will develop scientific techniques for calculating force fields and optical properties of new materials, including materials used in batteries, fuel cells and hydrogen storage devices. In silico modelling of complete components from atomic to macroscale will drive and support new design strategies in the Beacon. The appointment of our Research Software Engineer, David Rogers, in May 2018 has been crucial in influencing projects and future bids.

Accelerating thermal/insulation research

Our research will help meet the need for materials to deliver the step change in performance required by industry, by combining properties such as high thermal conductivity and high electrical insulation. The Thermal Coating Nanocomposites project aims to achieve a high thermal conducting and high electrical insulation coating with operational temperatures up to 325 °C. Furthermore, current materials are very hydroscopic (sensitive to water) and this is not ideal for operation. Effective thermal characterisation is therefore key in this area, and existing facilities are limited.



PICTURED (Top): Electrolyser cell, used to split water into hydrogen and oxygen –part of research into catalysts used to generate carbon at the Hydrogen Laboratory, Energy Technology building, Jubilee Campus. (Bottom picture): Permanent magnet dual element electric motor for helicopter swash plate control system.

We have therefore supported a Thermal Analysis Equipment project which provides high specification thermal analysis equipment which will firstly provide fast, versatile and precise measurements over a much wider range of thermal conductivity, thermal diffusivity, temperature and atmosphere in different material forms; and secondly, will accelerate research into new thermal conducting/insulation materials, and anti-icing/de-icing coatings enabling new national and international collaborations.

Increasing understanding at molecular level

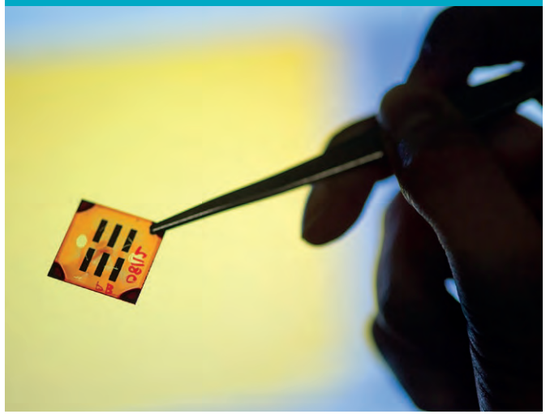
New products and devices for advanced applications cannot be developed without knowledge of the relationships between the structure and properties of their component materials. Molecular-level characterisation is key to the rational design of new materials for technological applications with improved properties. The Electron Paramagnetic Resonance project will deliver an EPR spectrometer with improved sensitivity. It will probe materials for photovoltaics, energy storage and thermo-electrochemical cells and provide data that is crucial for the success of projects within the Beacon.

The Dynamic Nuclear Polarization (DNP) project focuses on the characterisation of multi-functional materials and sustainable molecular systems by DNP enhanced solid-state nuclear magnetic resonance. This allows the power of solid-state NMR to be brought to bear on novel materials and their surfaces for the first time, informing progress in their characterisation and development by Beacon researchers.

UK-leading near-ambient pressure XPS

Another project provides effective access to our sustainable near-ambient pressure XPS facility which is unique to the UK. While normal XPS enables us to look at the chemical and electronic structure of the atoms and molecules at the surfaces of energy materials, NAP-XPS allows us to do this at pressures up to tens of millibars - bridging the pressure gap between surface science and real systems. Both the DNP and NAP-XPS illustrate how the Beacon is exploiting existing unique infrastructure to increase excellence in materials research.

Molecular-level characterization is key to the rational design of new materials for technological applications with improved properties. The Electron Paramagnetic Resonance project will deliver an EPR spectrometer with improved sensitivity.



PICTURED: making dyes for organic solar cells.

Thin Film Analysis

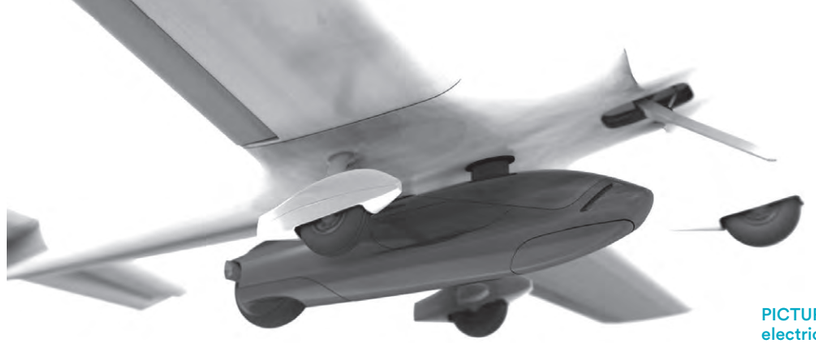
Thin Film Analysis equipment allows access to the first reliable commercial kit that simultaneously determines for a thin film sample: electrical conductivity (σ), Seebeck coefficient (α), thermal conductivity (κ) and specific heat capacity (Cp) (by both indirect heating and 3ω-methods), hall effect constant (Ah), carrier mobility (μ), carrier concentration (n) and sample emissivity (ε) from -196 °C to +200 °C. Measurement of these eight parameters explicitly indicate a material's optimal final device use rapidly allowing high-throughput screening for applications needed to accelerate materials performance in the Beacon.

PICTURED: back to back motor test rig in the Tower Building, Engineering, University Park.

Case study

Electric machines and disruptive technologies

PICTURED: The E-bike team, managed by Miquel Gimeno-Fabra, has enjoyed continuing success, including second place at the Isle of Man TT-Zero.



PICTURED: RexMoto hybrid land/air electric transport prototype.

One of the high-impact projects of the Beacon is the Multi Megawatt Propulsion Facility. We will design and create these facilities, which over five years will become a sustainable asset for the University and ensure the success of the Beacon.

Collaborating with China

An important Beacon objective is to integrate activity and ensure knowledge transfer with our campuses in China and Malaysia. A University of Nottingham China based project on Power Hardware in the Loop (PHIL) and emulation capabilities aims to analyse and develop high performance electro-mechanical power systems and components for enclosed, smart power systems including power amplifiers, DC-AC converters, flying probe testing equipment and other technologies all related to the concept. The facilities will also serve as a research and development testing station for the reliability and life-time consumption of such systems.

> It is important that the Beacon is exploring the potential of disruptive technologies and challenging accepted thinking.

Driving partnerships with industry

The EFAN+ project will directly support the research and demonstration activities of electric fan motors and will enable a platform for supporting research and development of new insulation systems and the understanding of their characteristics under representative operating conditions. It is an important example of large hardware and partnerships with industry. In its first phase EFAN+ will be able to test electrical fan motor drives in terms of their steady state and transient loading performance especially during load and power supply transients. It will also be able to assess insulation and impregnation goodness on the motor itself, as well as separate test sections in representative environmental conditions of high dv/dt (proposed motors will be HV (1kV+) and fed by fast switching (SiC) devices. EFAN+ is integral to the National Aerospace Research Consortium (NARC) which we lead.

It is important that the Beacon is exploring the potential of disruptive technologies and challenging accepted thinking. The recruitment of Frank Kirkland as our Synergy Lead will give a cross-sectorial view of Beacon technology elements and innovation stream spearheading. Frank is the chair of the Academy of Senior Technical Fellows within Rolls-Royce and holds the Royal Aeronautical Society Gold Medal for services to aerospace.

Beacon Executive Board

David Grant
Propulsion Futures Director, Professor of Materials Science and Head of Advanced Materials Research

Michael Galea
Co-Director Propulsion Futures Beacon, Director of the Institute of Aerospace Technology China and Vision Lead for Advanced Propulsors

Amalia Patane
Professor of Physics and Vision Lead for Onboard Energy

Elena Besley
Professor of Computational and Theoretical Chemistry and Vision Lead for Energy Carrying Systems

David Amabilino
Professor of Sustainable Chemistry and Vision Lead for Sustainable and Greener Materials for Propulsion Systems

Chris Gerada
Professor of Electrical Machines and Vision Lead for Fully Integrated Generation Systems

Seamus Garvey
Professor of Dynamics and Vision Lead for Disruptive Technologies

Our experts

(Listed in alphabetical order)

Ifty Ahmed
Andrey Akimov
David Amabilino
Jesum Alves Fernandes
Emma Barney
Chris Bennett
Elena Besely
Nick Besely
Peter Beton
Boyan Bonev
Giampaolo Buticchi
Alasdair Cairns
Richard Campion
Neil Champness
George Chen
Jon Clare
Alex Conradie
Michele Degano
Davide De Focatiis
Carol Eastwick
Laurence Eaves
Tom Foxon
Mark Fromhold
Michael Galea
Jaun Garrahan
Seamus Garvey
Mike George
Christopher Gerada
Paolo Giangrande
Miquel Gimeno-Fabra
Richard Glassock
David Grant
Chris Hill
Jonathan Hirst
Xianghui Hou
Steve Howdle
Tanvir Hussain
Chris Hyde
Derek Irvine
Richard Jefferson-Loveday
Lee Johnson
Mark Johnson
Rob Jones
Debbie Kays
Anthony Kent
Andrei Khlobystov
Walter Kockenberger
Antonio La Rocca
Ed Lester
Ming Li
Pete Licence
Sanliang Ling
Xuanli Luo
Roderick MacKenzie
Vincenzo Madonna
Hanafy Mahmoud
Claire McIlroy
Oleg Makarovskiy
Jon Mckechnie
Jonathan McMaster
Christopher Mellor
Robert Mokaya
Graham Newton
Sergei Novikov
James O'Shea
Amalia Patane
Stephen Pickering
Karen Robinson
David Rogers
Giacomo Sala
Victor Sans Sangorrin
Phil Shipway
Kathy Simmons
Mark Sumner
Andy Teale
Rob Temperton
Jeremy Titman
Begum Tokay
Gaurang Vakil
Christopher Varley
Katy Voisey
Gavin Walker
Darren Walsh
Richard Wheatley
Pat Wheeler
Simon Woodward
Fang Xu
Yuying Yan
He Zhang
Wen Zhu
Serhiy Bozhko

Our experts — current projects

Molecular Beam Epitaxy of group III-nitrides for light and low volume, protective thermal and electrical insulating coatings project

Sergei Novikov, Chris Mellor, Andrei Khlobystov, Laurence Eaves, Peter Beton, David Grant, Michael Galea

Computing support for developing new modelling tools

Richard Wheatley Elena Besley, Nick Besley, Mark Fromhold, Jonathan Hirst, Amalia Patane, Andy Teale, David Rogers

Thermal Coating Nanocomposites project

Xianghui Hou, Michael George, Fang Xu, David Grant, Chris Gerada, Paolo Giangrande

Thermal Analysis Equipment project

Xianghui Hou, Fang Xu, Michael George, Tanvir Hussain, David Grant, Ming Li, Davide De Focatiis, Miquel Gimeno-Fabra, Carol Eastwick, Katy Voisey, Ifty Ahmed, Emma Barney, Chris Gerada, Paolo Giangrande

Electron Paramagnetic Resonance project

Jon McMaster, Graham Newton, David Amabilino, Neil Champness, Mike George, Deborah Kays, Andrei Khlobystov, Lee Johnson, Victor Sans, Darren Walsh

Dynamic Nuclear Polarization (DNP) project

Jeremy Titman, Walter Köckenberger, Boyan Bonev, David Amaballino, Lee Johnson

Sustainable near-ambient pressure XPS facility

James O'Shea, Ming Li, Robert Temperton, Darren Walsh, Lee Johnson, Rob Jones, Amalia Patane

Thin Film Analysis equipment

Simon Woodward, Oleg Makarovskiy, David Amabilino, Peter Beton, David Grant Xianghui Hou, Tanvir Hussain, Ming Li, Roderick MacKenzie, Darren Walsh,Lee Johnson, Graham Newton

Multi-megawatt Propulsion Facility

Chris Gerada, Michael Galea, David Grant, Seamus Garvey

Power Hardware in the Loop (PHIL) and emulation capabilities

Michael Galea, Giampaolo Buticchi, Paolo Giangrande, Pat Wheeler, He Zhang, Chris Gerada

EFAN+ project

Paolo Giangrande, Vincenzo Madonna, Giacomo Sala, David Gerada, Michele Degano, Michael Galea, Chris Gerada, David Grant

Energy Storage Devices project

Lee Johnson, Darren Walsh, Graham Newton, Ming Li, Pete Licence, Robert Mokaya, David Amabilino, Steve Howdle, Rob Jones, Neil Champness, David Grant, Alistair Cairns, Victor Sans, Andrei Khlobystov, Tanvir Hussein, Begum Tokay, Debbie Kays, Elena Besley, Nick Besley, Jonathan Hirst, Jon McMaster, Rob Temperton, Miquel Gimeno-Fabra

Spark Plasma Sintering project

Ming Li, Fang Xu, Michele Degano, David Grant, Chris Gerada, Michael Galea, Ed Lester

Materials Processing

Ming Li, Fang Xu, Xianghui Hou, Gavin Walker, Tanvir Hussain

Hybrid Electric VTOL capable UAV

Richard Glassock, Chris Gerada, Michael Galea, Pat Wheeler

RExMoto_Phase1 project

Richard Glassock, Chris Gerada, Michael Galea, Pat Wheeler

Validation of low weight, high energy density power train

Miquel Gimeno-Fabra, Chris Gerada, Pat Wheeler, Jon Clare

Case study

World-leading facilities and equipment

PICTURED: XPS (X-ray Photoelectron Spectroscopy) machine, which is used to analyse samples at molecular level including the energy emitted by electrons.

Devices Lab

The Beacon Devices Lab is a comprehensive suite of facilities for building and testing prototype electrochemical devices based on materials and fundamental research. Specifically, the Beacon Devices Lab will bridge the gap between fundamental researchers with strengths at Technology Readiness Level (TRL) 1-3 and those at TRL 5-7. The Energy Storage Devices project has begun with equipment being moved into the Research Acceleration and Demonstration building in July 2018. Two outcomes are expected; firstly, transition of basic science and materials discovery into first stage prototype devices targeted at electrification of transport; secondly, enabling the development of devices based on the fundamental research performed at the University. A comprehensive suite of facilities for building and testing prototype electrochemical devices based on materials and fundamental research is being established. The facility will include dedicated electrochemical test stations specifically designed for low current, small-scale prototypes that are needed for low TRL materials development, handling facilities for the reactive air-sensitive materials that underpin emerging advance energy storage devices, and facilities for fabricating new device components such as separators and membranes.

Processing Lab

The Beacon Processing Lab will provide equipment that will make a significant difference to material performance. This includes Spark Plasma Sintering (SPS) which offers many advantages over conventional sintering systems including greatly reduced sintering temperature by 100-300 °C, and much shorter sintering period, 3-5 minutes instead of 6-20 hours required by conventional sintering. SPS offers entirely new possibilities to manufacture a wide range of materials with extraordinary characteristics; it will open up a variety of new research areas and significantly enhance the manufacturing capability of the Beacon for devices. Other materials processing equipment includes a cold isostatic press, an arc melter and a high-energy ball mill which are needed to enable advanced processing of energy materials developed at Nottingham and to build devices required by the Beacon.

High-impact demonstrators

Demonstrators are key to our strategy of delivering research with industrial and societal impact. Our Aerospace Demonstrator Lead, Richard Glassock, has been employed to deliver the Beacon a suite of activities designed to ensure the development of a flying technology demonstrator that will showcase cutting-edge Beacon research. The work builds on already established projects and prospects which have high visibility and merit for leading industrial, research and educational agendas principally within the propulsion domain, but including materials, structures, human factors and operations. Current projects include Hybrid Electric VTOL capable UAV. This project will deliver a flying technology demonstrator to showcase cutting edge research on hybrid, turbo-electric and distributed propulsion applied to a Vertical Take-Off and Landing (VTOL) capable Unmanned Aerial Vehicle (UAV). The aircraft can be fitted with several types of propulsion systems which will demonstrate all the main topics of interest in modern hybrid and electric propulsion research. The RExMoto Phase1 project takes the concept of transport inter-modality into the more electric aircraft domain by incorporating a hybrid electric motorcycle, with an electric aircraft into one package. The ultimate aim of this project is to develop the RExMoto prototype leading to a spinout company to market the commercial product. Department of Transport funding which was awarded in August 2018 will be used to progress this project.

Additionally, the Beacon has supported the validation of a low weight, high energy density power train project. The demonstrator project supported the completion and validation of the first University of Nottingham prototype low weight, high energy density AC motor. This is a project to demonstrate doubling the power density of the electric motor of an electric motorbike. The University eBike achieved an impressive second place at the Isle of Man TT Zero averaging close to 120mph, the second highest average speed for an electric bike ever. The eBike also won at Pikes Peak in the USA.

University of Nottingham
Propulsion Futures

Discover more about our world-class research

nottingham.ac.uk/propulsion-futures

Professor David Grant
Director
David.Grant@nottingham.ac.uk

Michael Galea
Co-Director
Michael.Galea@nottingham.ac.uk

Romina Davoudi
Head of Operations
Romina.Davoudi@nottingham.ac.uk

@UoN_Propulsion

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+44 (0)115 951 5559