Institution: Loughborough University

Unit of Assessment: B12 Engineering

Section 1. UNIT STRUCTURE, RESEARCH AND IMPACT STRATEGY

Loughborough has one of the largest engineering research activities of any UK University. In our analysis of a 'composite' engineering sub-panel (combining Units 12-15) from REF2014, Loughborough ranked 6th of 85 institutions by engineering research power (GPA x Volume). The enduring strategic importance of engineering to Loughborough is exemplified by £59m investment in STEM facilities (2019) and opening the National Centre for Combustion and Aerothermal Technology (2019, with partners ATI and Rolls-Royce). Our vitality is evident in the formation of our Institute for Digital Technologies (2015) on our new London Campus and in creating a new School (2015) to recognise increasing technological integration between mechanical and electrical devices and systems. From the latest HESA data for the mechanical, aeronautical and manufacturing engineering cost centre (to which half of this return maps), we are one of 65 active universities but supervise 1 in 20 of all postgraduate researchers and attract more than 4% of total research funding awarded.

1.1 Research Structure

The Unit comprises (headcount) 214 staff (209.95FTE, 12% like-for-like growth since REF2014) from the School of Aeronautical, Automotive, Chemical and Materials Engineering (AACME), the School of Mechanical, Electrical and Manufacturing Engineering (MEME) and the Institute for Digital Technologies (IDT).

The opening of Loughborough University London (LUL) on the Queen Elizabeth Olympic Park (QEOP), with the formation of IDT (2015), and creation of MEME shortly afterwards are key developments in the Unit's structure. As a research-intensive, postgraduate-only School with a directive to foster partnerships in the growing community of local start-up companies, LUL is Loughborough's largest strategic investment since gaining University status in 1966. IDT, one of LUL's seven Institutes, has a focus on data analytics and machine learning and was paired with the then School of Electronic, Electrical and Systems Engineering (EESE) on the Midlands Campus, sharing joint appointments during start-up.

Aligning strengths in mechanical and electrical systems to better serve growth in automation and robotics whilst extending the links between the two university campuses, the second strategic development of the Unit's structure was the merger (2015) of EESE with the School of Mechanical and Manufacturing Engineering to form the School of Mechanical, Electrical and Manufacturing Engineering. The strategic significance of these links is evident in Validated Digital Engineering (VDE), an area of growing importance in our research and impact strategy. The BEIS-funded Institute of Digital Engineering (IDE) is a joint project between LUL and AACME (£6.4m, 2015-22), bringing together industry input at the most senior level (e.g., Hoare, Chairman, Ford of Britain) and academic expertise to accelerate the uptake of VDE tools in developing future automotive products.

Within each School, research, enterprise and impact activities are led by Associate Deans for Research (ADR) and Enterprise (ADE) who are members of each School's Senior Management Team (SMT), chaired by the Dean. Associate Deans also sit on the University's Research and Enterprise Committees, chaired by the respective Pro Vice-Chancellors. In this way, Associate Deans hold critical roles in ensuring that School activity informs and is informed by institutional strategy, and that best practice is shared across Schools.

1.1.1 Priority Research Areas

As Chairs of School Research and Enterprise Committees, Associate Deans lead their School's research and impact strategy, developed and implemented with senior colleagues, especially those leading research centres, institutes and major research groups. This subsection provides a sense of activity in the Unit's priority research areas.

1. **Aerospace**. Centred around the long-established Rolls-Royce University Technology Centre (RR-UTC) in Combustion System Aerothermal Processes (Director Carrotte) and the EPSRC CDT in Gas Turbine Aerodynamics (CDT-GTA, £5.3m, 2014-22) we pioneer experimental and computational approaches to understanding gas turbine dynamics. The new National Centre for Combustion and Aerothermal Technology (NCCAT, 2019) will focus on future low emission aerospace combustion systems to reduce the environmental impact of aircraft.

2. **Automotive** research applies a unique range of experimental and modelling expertise to the analysis of automotive systems and whole vehicle integration. Focused on increasing efficiency and reducing vehicle emissions, we consider fuel cells, batteries, super-capacitors, tribology, tyre modelling, vehicle handling and aerodynamics. The Caterpillar Innovation and Research Centre (Cat-IRC**,** Director Spencer) is a longstanding industrial collaboration (since 2008). With a team of 20 academics and researchers, it has strengths in complex system optimisation and control, engine diagnostics, after-treatment and engine modelling.

3. **Energy**. The Centre for Renewable Energy Systems Technology (CREST, Director Eames) has been pioneering renewable energy generation, distribution, end use demand and storage for more than 25 years. Nationally leading laboratory facilities have been established to support research that spans materials characterisation, energy systems modelling and in-situ performance verification. As a pioneer of photovoltaic technologies, CREST is home to the UK's only ISO17025 accredited cell-efficiency lab and leads the Supergen Solar Network Plus (EPSRC-funded, £1m, 2018-22, Walls).

4. **Manufacturing** strengths lie in electronics, additive and multi-functional materials manufacturing, robotics, automation, and manufacturing processes including continuous pharmaceutical production. The EPSRC Innovative Electronics Manufacturing Research Centre (£9m, 2004-15, Director Conway) initiated our current foci on Validated Digital Engineering (VDE) and smart manufacturing. The Centre for Innovative Manufacturing in Intelligent Automation (CIM-IA, EPSRC £5.9m, 2011-17, Director Lohse) now leads work on collaborative robotics and integration of AI in manufacturing. The CIM in Continuous Manufacturing and Crystallisation (CIM-CMAC, EPSRC-funded, £6m, 2011-16, led Strathclyde, Co-Is Rielly and Nagy) accelerated industry transformation to continuous pharmaceutical processes through digital design.

5. **Biological engineering**. The Centre for Biological Engineering (CBE, Director Thomas) was established in 2005 (Director Williams) to address barriers to the cost-effective manufacture of advanced cell-based therapies and medical products. Our EPSRC Centre for Innovative Manufacturing in Regenerative Medicine (CIM-RM, £5.8m, 2010-16, Medcalf) established statistical and dynamic models of biomanufacturing process and initiated a portfolio of work that now includes medical devices for cardio/pulmonary therapy and novel sensing for rapid identification of in-process and clinical biological markers.

6. **Materials** research addresses highly demanding applications in the defence, aerospace and healthcare sectors including advanced ceramics, novel biomedical materials for regenerative medicine and drug delivery, and energy materials for renewable, conventional and battery technology. The Mechanics of Advanced Materials Group (MoAM, led Silberschmidt) is a prolific, internationally recognised group, renowned for its work on structural integrity, ultrasonic machining and composite components.

7. **Communications** covers theoretical analysis and practical realisation of electronic communications in applications ranging from wireless networks and defence systems to environmental and biomedical devices. We have unique expertise in antennas, artificial

intelligence (AI), signal processing, environmental sensor deployment, metamaterials and network security. Since its inception, IDT (Director Kondoz) has brought complementary expertise in data security and broadcast media. It participates in LORCA (London Office for Rapid Cybersecurity Advancement), funded by the Department for Digital, Culture, Media and Sport to solve digital challenges faced by enterprises, the economy and society, and delivered from the Plexal innovation centre on QEOP.

8. **Sports technology**. The Sports Technology Institute (STI) is positioned at the intersection of engineering and elite sports. From its beginnings, it has developed sensor and digital technologies to understand athlete performance at all ability levels e.g., EPSRC Platform: ESPRIT with Pervasive Sensing (£6.2m, 2009-15, led by ICL, Co-I Caine). STI works closely with National Federations (UK Sport, ECB) to support the competitive performance of national athletes and teams and maintains strong partnerships with leading international sports brands including adidas, PING and Head as well as governing bodies including FIFA, the International Olympic Committee, the International Cricket Council, and the International Hockey Federation.

9. **Autonomous systems and control** serves aerospace, automotive and railway sectors. Emphasising safety and energy efficiency, research includes unmanned aerial vehicles (UAVs), and personalised intelligent vehicles. The Centre for Autonomous Systems (Director Chen) is internationally recognised for pioneering research into goal-oriented control theory for robotics and autonomous systems, the interaction between artificial intelligence and sensor feedback to ensure safety in a future highly automated society.

1.1.2 Supporting Interdisciplinary Research

Interdisciplinary research has always been important to the Unit. For example, STI (Caine) and IDT (De Silva) demonstrated novel machine learning techniques as an analysis tool in elite sport (Chelsea Football Club and US National Basketball Association), now under further development in De Silva's EPSRC New Investigator Award: Multimodal Imitation Learning in Multi-Agent Environments (£260k, 2019-21).

At institutional level, the Beacons and Global Challenge (GC) programmes under Loughborough's CALIBRE research framework combine strengths across Schools and the Unit's leadership contribution to these strategic research initiatives is significant. Of CALIBRE's five Beacons, we lead the Transport Technologies (Passmore) and High Value Manufacturing (HVM) (Kinnell) Beacons and give theme leadership within the Sport and Exercise Beacon (Harland). Similarly, of the four GC programmes, Unit academics lead the Energy GC (Eames), and the Secure and Resilient Societies GC (Henshaw), with further leadership input to the Changing Environments and Infrastructures GC (Deputy Lead Das) and the Health and Wellbeing GC (Deputy Lead Coopman, Theme Lead Malik).

In these roles, Unit staff are driving interdisciplinary research. Under the HVM Beacon, for example, Networks on Artificial Intelligence, Plastics and Additive Manufacturing organise open seminars and sandpit events to focus attention on key issues and build competitive groups of like-minded academics from across disciplines. From the HVM Plastics Network, Woolley secured the £920k Perpetual Plastic for Food to Go (part of the £8m, UKRI/NERC Smart Sustainable Plastic Packaging Challenge), led by Wilson (Design, returning to D32) working with retailer Marks and Spencer and their supply chain to address a foremost challenge of the circular economy. The Transport Technologies Beacon (Passmore) provided interdisciplinary thought leadership to diverse publics on the Future of Transport through a PR campaign and YouTube Channel playlist.

1.2 Review of Objectives and Plans since REF 2014

With explicit emphasis on excellence, our REF2014 plans addressed major research questions raised by our industrial partners and significant challenges posed by wider society. We planned to focus on existing areas where we already had track record of internationally leading research

and impact but also to create space and support within our research infrastructure to allow curiosity-driven initiatives to identify emerging areas with high potential for academic, social or economic impact. The following examples are indicative of the many achievements, both in established and emerging areas, since 2014.

In **aerospace**, planned growth of our successful UTC partnership with Rolls-Royce targeted technological areas critical to the development of next generation gas turbines. New optical diagnostics have been developed to access previously unexplored regions of primary fuel break up in dense, two-phase fuel injector nozzles. High accuracy sensors for unsteady turbulent flows have been developed with temperature resolution of better than 0.15K and efficiency gains in advanced bypass fan design that represent more than £1m in annual savings for operators have been demonstrated. Building on this success, the EPSRC CDT-GTA was renewed in 2018, becoming the EPSRC CDT in Future Propulsion and Power (CDT-FPP, £7.4m, 2019-28, led by Cambridge, Co-I Carrotte) and, with the new NCCAT facility, we lead UK research into reacting flows with novel fuels to address the stringent emissions reductions required to meet the aviation industry international Flightpath 2050 goals.

The Unit has delivered significant innovation in **automotive** engineering from the award-winning ACCT exhaust after-treatment to completely new engine concepts – Cryogenic Engines for Mobile Zero Emission Power. Led by Clean Cold Power Ltd (£6m, APC/IUK, 2016-21, Zhao), we demonstrated an ultra-low emissions refrigeration truck concept, now commercialised, and our prominence in this emerging field has been further strengthened by a new Cryogenic Laboratory and new collaborations (e.g., National Cryogenics Group at University of Twente). The Programme for Simulation Innovation Themes 1 and 2 (EPSRC/JLR-funded, £3m, 2013-18, Dickerson and Passmore) demonstrated the potential of digital twinning and other digital engineering concepts in the automotive industry, providing a catalyst for formation of the Institute of Digital Engineering (IDE).

In CREST, we addressed **energy** challenges critical to the UK's legally binding target of transition to Net Zero by 2050. Within the Midlands Innovation (MI) Energy Research Accelerator (ERA, led Eames at Loughborough), we addressed ways to minimise and re-use waste heat in industrial settings and to develop compact high energy density thermal energy storage systems to help address the challenge of de-carbonising heating and cooling in a cost-effective way. Work in this area has demonstrated new storage technologies using highly efficient compact phase-change materials paving the way to greater deployment of heat pumps by avoiding peak electrical loads and delaying the need for grid strengthening.

Our work on thin film cadmium telluride photovoltaics resulted in world record conversion efficiencies (>20%). We resolved a previously unexplained observation that adding selenium as a CdSeTe alloy to the front of the solar cell dramatically improves device performance (published in Nature Energy, 2019). From an industry perspective, this work "…opens up new opportunities for device characterisation and design…" as stated in Nature Energy News and Views by Dmitry Krasilov of US-based First Solar, Inc., the world's dominant supplier of thin film photovoltaics.

Our achievements in **manufacturing** related to new processes, design tools and automation for future manufacturing ambitions. CIM-IA considered tasks best addressed through a combination of flexible robots and manual labour. In the €8.7m H2020 openMOS project (2016-19, Lohse), we created a new cyber-physical system standard for skill-based automation that was demonstrated at Automatica (Munich, 2018) the leading industrial exhibition in this field. Supporting growth in the high value pharmaceuticals manufacturing sector, a principal output from CIM-CMAC was the development of informatics and digital modelling tools to underpin a paradigm shift in crystalline pharmaceutical production. Evaluation by AstraZeneca (and others) has demonstrated improvements in product quality, reducing failed production runs to almost zero and shortening of process development and production times from months to less than a week.

The Centre for **Biological Engineering** (CBE) enabled new classes of advanced therapies involving cell, gene and combination products to be manufactured. The EPSRC Fellowship: Engineering Biological Science – Processes and Systems for Haematopoietic Stem Cell Based Therapy Manufacture (£1.3m, 2013-19, Thomas) demonstrated advanced modelling to identify process limiting factors; delivering a 3-fold increase in productivity for a human, clinical stage platelet product in the US, and novel process design for preclinical and animal safety/efficacy trials for mesenchymal stem cells (bone degeneration), immune cells (solid tumours), and micro-vesicles (gene delivery) in the UK. The EPSRC Centre for Doctoral Training Regenerative Medicine (CDT-RM, £7.2m, 2008-18, Williams) was renewed in 2014 (£3.6m, 2014-23, Coopman) integrating CBE's research with healthcare-related work at the Universities of Nottingham and Keele.

Materials research covered a range of applications from biomaterials for healthcare devices to bespoke materials for the power industries. Building on the Flexible and Efficient Power Plant: Flex-E-Plant project (EPSRC-funded, £2m, 2013-18, Thomson) we considered the manufacture (casting and welding) of a novel MarBN steel, demonstrating the optimal treatment of this material in high temperature power plant (EPSRC-funded, £264k, 2016-19, Jepson). Our work on advanced functional ceramics includes the first ever genuinely nanostructured bioceramic implants for dental, hip and knee prosthesis that are totally immune to hydrothermal-ageing and which surpassed many commercial implants on performance. This was identified as one of the best Materials of the Modern Age by the 2018 BBC documentary on most impactful future technologies.

We delivered significant advances in secure data **communications** for current and future generations of wireless and sensor networks. Building on DSTL/EPSRC grants, Signal Processing Solutions for the Networked Battlespace (£3.6m, 2013-15 and £2.1m, 2015-18, Chambers) we were able to solve the DSTL Challenge, Temporal Anomaly Detection, using innovative applications of unsupervised machine learning to large defence data sets. Pioneering work on network optimisation has been supported by further EPSRC funding leading to landmark publications including the first demonstration of optimal resource sharing in massive multiple-input and multiple-output (MIMO) wireless networks using Stackelberg Game Theory.

Sports technology research focussed on performance and safety. Research into collisions between deformable bodies featured in work funded by the International Cricket Council, International Hockey Federation (FIH), Football Association and England and Wales Cricket Board, that informed strategies for policy making and equipment specification. Our partnership with Tokyo Institute of Technology designed a sports-specific human surrogate head and neck (patented 2020) that offers substantially improved biofidelity, providing impact specific insights into baseball, cricket and martial arts injuries. Research on athlete/equipment interaction increased understanding of human performance and was notably applied to a batting performance programme with the England men's cricket team during 2017 and 2018 in preparation for their 2019 World Cup triumph. Research on equipment performance of surfaces, funded by FIFA, Labosport and FIH, developed new test devices and standards that have been used to certify pitches in the 2019 Rugby World Cup. Extensive aerodynamic work funded by adidas was applied to the footballs used in the 2014 and 2018 FIFA World Cups.

In **autonomous systems and control** we have successfully developed solutions in safety critical applications of control to road, rail and air transport. Addressing the problem of critical failure of aircraft systems, with support from BAE Systems, we demonstrated an advanced autonomous system capable of identifying and controlling the aircraft to a safe landing site. In 2018, Kalawsky was awarded a prestigious five-year Royal Academy of Engineering Research Chair sponsored by Airbus (£290k Airbus, £320k Royal Academy) to develop the digitalisation technologies – including advanced modelling, simulation and visual analytics – to accelerate aircraft design and production processes.

The success of our dual-focused plans to support emerging research areas whilst fostering excellence, can be seen in the evolving work of the Centre for Autonomous Systems (Director Chen). The Centre has strengthened over the REF period to develop autonomous functions to support the operation of large Unmanned Autonomous Vehicles (UAVs) in civil airspace, e.g., forced landing in the event of critical failures, with support from EPSRC and BAE Systems (Towards more Autonomy for Unmanned Vehicles, £1m, 2012-16, Chen). This has led to impact through the world's first field trial of an autonomous search system for chemical and other airborne pollution sources using both ground mobile robots and UAVs and an increase the UK defence capability by working with two SMEs (Swarm Systems and Createc Technology) and support from Dstl and the Home Office (Dstl/HO SceneSearch Programme £425k, 2017-2018; Dstl £275k 2019-2020). Chen has subsequently been awarded the only EPSRC Established Career Fellowship in control (£1.6m, 2020-25) to develop a new fundamental theory and design tools for Goal-Oriented Control Systems to underpin efficient and safe operation of highly automated systems from healthcare robots to driverless cars and UAVs.

1.3 Enabling and Facilitating the Achievement of Impact Arising from Research

The Unit has established a culture of enterprise with 3 core principles: the need to identify a clear pathway to impact from the earliest stages of research planning, the importance of partnerships (mainly industrial but also with policymakers), and the acceleration of impact through dedicated funding streams and specialist IP support.

Our **culture of enterprise** reflects a mission to apply knowledge for wider benefit. We want to promote the relevance of our work beyond academia and embed the support to ensure our research has maximum impact on society. This approach has been strongly influenced by long-standing connections with MIT (e.g., Prof. Hosoi's Bio-Inspired Design Group) where the integration of faculty staff, researchers and students has engrained an ambition and expectation of research-enabled, enterprise activity and where achievement is celebrated. The MIT collaboration has enabled the Unit to develop its own unique approach to supporting a culture of enterprise during the REF period. With funding from Santander and internal investment, a series of Visiting Academic appointments, periods of Study Leave, summer internships and reciprocal student exchanges have raised ambition and enhanced capability for translation of knowledge into viable business endeavours. The success of this approach can be seen in the fledgling companies recognised by our Innovation Awards: Outstanding Achievement Awards were presented in 2019 to Alex Nash (Alcuris) and Chris Ruddock (INCUS Performance) who (with Unit mentors) launched their successful businesses on Loughborough University Science and Enterprise Park (LUSEP) in 2016, having benefitted from the entrepreneurial ecosystem at MIT Exchange.

Dedicated funding from the Higher Education Innovation Fund (HEIF) and EPSRC Impact Acceleration Account (IAA) is available to all Unit staff to generate commercial value from intellectual property and to support entrepreneurial training (e.g., Medici). Allocated through Loughborough's Enterprise Projects Group (EPG), the Unit has 45 active enterprise projects supported in this way, the majority initiated as 'invention disclosures' that have been evaluated for their commercial viability, following allocation of proof-of-concept funding. For example:

- REPOINT, an innovative rail track switching technology with the potential to improve safety, reliability, and boost capacity on rail networks, has been taken from a patented concept to a full-size demonstration on a local heritage railway attracting significant interest from rail companies.
- Advanced Bioprocess Services Ltd (established 2016, Thomas) is a consultancy service offering expertise and modelling capability to address process engineering of cell therapies approaching clinical trial. Since 2016, the company has had significant economic impact with an annual turnover of £500k from UK and US based clients, supporting two CBE staff conducting commercial research.

Industrial partnerships, especially those associated with the Unit's industrially funded Centres (e.g., Cat-IRC and RR-UTC), remain principal drivers for our highly impactful research, leveraging strength and resources unavailable elsewhere. The Cat-IRC**,** for example, has a 5-year rolling agreement allowing unencumbered two-way flow of information without concern or ambiguity over IP, enabling understanding and delivering research that addresses root questions. Since 2014, 120 formal recordings of generated IP have been made, 20 leading to awarded patents, many of which now appear on over 0.5m heavy-duty engines worldwide.

SMEs are significant amongst our industrial partners. The Unit leads almost 40% of Loughborough's Knowledge Transfer Partnerships (KTPs) with significant successes e.g., Frame™ – a novel ceramic coating to suppress wind turbine radar interference has been developed in collaboration with Trelleborg Applied Technologies (Yarahmadi, Critchlow). With the potential to unlock many gigawatts of latent green power, Frame™ was launched in 2019 and predicted annual sales are estimated to be more than £10m.

1.3.1 How the Selected Impact Case Studies Relate to our Approach to Achieving Impact

Industrial partnerships. Through RR-UTC, ICS B12-01 (Carrotte) and ICS B12-02 (Walker) exemplify a clear pathway to impact supported by a structured approach to knowledge transfer in CDT-GTA projects, industrial training, and bi-directional secondments (e.g., Senior RR Engineer part-time PhD) and the RR/RAEng Chair in Aerothermal Technology (Carrotte). Similarly, ICS B12-10 (Novac) follows from a body of fundamental work commissioned by DSTL and the development of Radio Frequency Directed Energy concepts with major defence contractors (MBDA, BAE Systems and QinetiQ). In this case study, effective knowledge transfer was through multiple short-term consultancy projects and participation at high level events (e.g., as part of UK MOD delegation at major UK/US Defence Meetings).

Engagement with policy makers. In 5 ICSs (B12-03, -05, -06, -08, and -10) we have demonstrated impact through engagement with major governing bodies, international standards agencies or UK Government policy units. The growing importance of political engagement in developing high quality, impactful research is reflected in our future strategy (section 1.4).

Funding to support development. ICSs B12-04 (King), B12-06 (West), B12-08 (Hargrave) and B12-09 (Passmore) result from one or more major publicly funded research projects with a consortium of industrial partners and a clear and direct **pathway to impact** established within the research proposal. In these cases, funding was sought to realise concepts and add commercial value from a variety of sources including IUK, Energy Technologies Institute and APC. For example, B12-04 (King) stems from an EPSRC Programme Grant (Encyclopaedic, £2.6m, 2009-14, Rahnejat) with impact generated through Eco-Driveline project (JCB, IUK-funded, £501k, 2015-17, King) and 11 doctoral research projects funded principally through project partners (Aston Martin, Capricorn Automotive and Mercedes F1). A similar approach underpins impact developed in ICS B12-09 (Passmore) with further research and structured knowledge transfer programme delivered through the research of two cohorts of doctoral researchers (total 12) matched-funded by JLR.

Protection of intellectual property. In ICSs B12-07 (Caine) and B12-08 (Hargrave), IP was secured at an early stage (with HEIF funding) and ICS B12-10 (Novac) with a restricted UK MOD patent. In ICS B12-07 (Caine), protection of the High-Speed Sintering (HSS) process was critical. Following disclosure in 2003 (GB0317387D0), development funds (EPSRC-funded Follow On: Proving Commercial Liability of High-speed Sintering Through a Larger Build Area, £89k, 2006-07, Hopkinson) added value to the IP and Loughborough's first ever Enterprise Fellowship (EPSRC IAA-funded, 2008, Hopkinson) accelerated commercialisation, with the now proven commercial process protected by US8186414B2 (2012). Licence agreements secured with UK, German and US companies have enabled the significant economic and societal impact of this invention to be realised.

1.4 Research and Impact Objectives and Plans for the Next Five Years

Our plans are motivated by an ambition to shape and address the national agenda through proactive, two-way conversation with government, collaboration with existing and future partners and amplified cross-sector engagement to generate impact with significance and reach. Research across all our areas will centre on three priorities drawing upon the considerable expertise we have developed in Validated Digital Engineering (VDE) and focused on relevance to some of society's biggest cross-sector and interdisciplinary challenges:

- Integrated Transport and Mobility
- Energy and Commitment to Net Zero
- Smart Manufacturing and the Circular Economy

Integrated Transport and Mobility. The UK's strategy for mobility signals a transition from combustion engines and hybrid powertrains to zero emission private vehicles by 2035. It predicts traditional transport based on car ownership will decrease, replaced by Mobility-as-a-Service (MaaS) and more integrated transport networks. Close collaborations with the automotive, aerospace and rail sectors will help to deliver this ambition through next generation transport and mobility solutions.

VDE is central to achieving this, with advanced simulation tools including embedded knowledge (e.g., digital twins) crucial to expedite the design process. For example, the £17m (2019-22) APC-funded Virtual Vehicle Integration and Development (ViVID) collaboration with Ford Motor Company, IPG Automotive and McLaren Applied Technologies, will bring future generations of electrified vehicles to the market faster by replacing expensive engineering prototyping with VDE methods, ultimately enabling significant CO_2 reductions in commercial fleets.

The success of electric vehicles depends critically on their efficiency and research is needed to increase range and/or reduce energy storage requirements and thereby also cut costs. The Unit will build on successful research with F1 racing teams that reduced frictional losses in gears and bearings. Studies of tyre dynamics are planned, including aerodynamic and hydrodynamic losses and spray generation. This innovative work will improve performance and safety using predictive models from projects such as the recently awarded £1m Advanced Route to Market Project: PREPARE – Optimisation of Powertrain through Predictive Modelling and Machine Learning (APC/JLR-funded, 2020-2021).

The Unit's work in autonomous systems and control will be critical to advances in this area. Our fundamental work on situational awareness e.g., EPSRC Fellowship Goal-Oriented Control Systems: Disturbance, Uncertainty and Constraints (£1.6m, 2020-25, Chen) will provide a platform to integrate data from on-board sensors with information from other vehicles and a-priori knowledge of terrain, traffic and historic events.

Energy and Commitment to Net Zero. The UK's energy policy is developing as an integrated National Energy and Climate Plan (NECP) that calls for a holistic approach to prioritise de-carbonisation, greater use of renewables and alternative energy vectors (e.g., 'the hydrogen pathway').

CREST's strategy aligns to NECP, placing emphasis on decarbonisation of heating and cooling in domestic and industrial settings. High-capacity thermal storage concepts will be developed using thermo-mechanical and thermo-chemical media as cost-effective solutions to mitigate short- and medium-term peaks in demand. The new EPSRC Decarbonisation of Low Temperature Process Heat Industry (£2.2m, 2020-23, Eames) will address heating and cooling concepts in industrial processes and settings. Further integrating our work on photovoltaic integration e.g., The Integration of Photovoltaic Devices with Carbon-fibre Composites, (EPSRC-funded, £120k, 2019-21, Walls) we will advance active solar energy and thermal energy technologies e.g., Advanced Building Façade Design for Optimal Delivery of End Use Energy

Demand (EPSRC-funded, £1.6m, 2019-23, led by Nottingham, Co-I Eames) with the potential to generate energy in domestic and commercial settings (i.e., deliver negative load over an annual cycle).

The sector-by-sector analysis provided by the Committee for Climate Change Net Zero Technical Report shows how the UK might achieve net-zero greenhouse gases by 2050. Meeting these goals in the aerospace sector is perhaps the greatest challenge with gas turbine technologies forecast to remain in service for the foreseeable future and net emissions reduced through synthetic fuels, hydrogen and offset carbon sequestration. The National Centre for Combustion and Aerothermal Technology (NCCAT) is a unique facility with state-of-the-art instrumentation that will be exploited in National Programmes and Research Clusters e.g., £5.8m EPSRC Laser Imaging of Turbine Engine Combustion Species (LITECS) project (£5.8m, 2020-24, led Strathclyde, Co-I Carrotte) and is central to the Unit's work in reducing the environmental impact of aircraft. Integrating expertise in combustion, heating and cooling, we are uniquely placed to develop thermal technologies in other sectors including marine and power generation.

Smart Manufacturing and the Circular Economy. The European Commission's Circular Economy Action Plan (CEAP, 2020) predicts the application of circular economy principles across the EU to meet the relevant UN 2030 Sustainable Development Goals whilst also increasing GDP by 0.5% and creating approximately 700,000 new jobs. The UK Government's 2020 Circular Economy Package (CEP) makes a similar commitment to minimising waste. Up to 80% of products' environmental impact is locked in at the design phase and can be reduced through improved VDE. In the growing area of smart manufacturing, the EPSRC Programme Grant: Re-Imagining Engineering Design: Growing Radical Cyber-Physical-Socio Phenotypes (£7.4m, 2021-26, led Queen's Belfast, Co-I Conway) aims to create a new design methodology to generate product and manufacturing systems simultaneously, enabling a step change in UK manufacturing productivity for high value-added processes and sustainable supply chains. In the EPSRC Future Continuous Manufacturing and Advanced Crystallisation Research Hub (£10.5m, led by Strathclyde, 2017-23, Co-I Rielly), we will accelerate the use of quality by digital design, applied to the rapid development of new pharmaceutical products, making use of digital twins and micro-factories.

The Unit will play a pivotal role in supporting Government plans to improve the sustainability of the UK chemical and construction industries. As part of a recent £22.5m UKRI investment, the Unit will lead the £4.3m EPSRC Interdisciplinary Centre for Circular Chemical Economy (IC-CCE) (2021-24, Xuan) to reshape resource management in the UK's £32bn chemical industry to build a greener, more sustainable economy. Xuan leads IC-CCE bringing together 7 universities and more than 20 industrial and international partners, including ExxonMobil, Shell and Unilever alongside SMEs and national and local initiatives, including the Waste and Resources Action Programme (WRAP).

1.4.1 Stakeholder Engagement and Achieving Impact

Industrial partnerships inspire our research. Cross-sector stakeholder engagement with organisations ranging from global manufacturing through to pioneering start-ups will remain a priority. Major partnerships such as the RR-UTC and Cat-IRC will be further developed and nurtured.

Mobility at Plexal operates in partnership with Transport for London and connects some of the world's most innovative mobility companies including Ford Smart Mobility. Working with our established industrial partners, the Automotive Council, APC and the cluster of emerging technology companies within Mobility at Plexal, the Unit is ideally placed, especially through IDE and Smart Mobility Living Lab (TRL-led), to progress transport and mobility solutions through collaboration and direct exchange with those driving change.

Knowledge exchange and innovative technology transfer activities will be a primary focus. The Midlands Centre for Data-Driven Metrology (MCDDM, £2.9m, Research England Development Fund, 2020-25) is a multi-institutional centre (Nottingham, Loughborough and Coventry) developing metrological training and practice in industries such as aerospace, automotive, medical and optical instrumentation, and construction. Through this collaboration we introduce the concept of "industrial interventions" – providing rapid solutions to common problems that block progress across many organisations.

1.4.2 Engagement with Industrial Policy

The next 5 years will be transformative as the global recovery from the pandemic develops pace and research efforts refocus onto global issues such as climate change and sustainability. Tackling these issues together and 'building back better', as expressed by the Organisation for Economic Co-operation and Development (OECD) and others, has clear advantages and the Unit will support UK Government to address these priorities.

The Unit is actively engaging with local and regional initiatives to bring universities, industry and government closer to enhance the region's contribution to the national agenda. Our leadership through IDE of the Automotive Council's Advancing Digitalisation Mission exemplifies our strategic commitment to regional and national level recovery post-pandemic. We are leading on major developments such as a proposal for a UK National Centre for Zero Emissions (£600m, 10-year programme) based at the former Ratcliffe Power Station. ERA is currently seeking £250m government investment for phase 2 of its activities. On a local level, the Loughborough Area of Innovation is an initiative bringing together local stakeholders, including local government to address how the expertise and experience of the area can meet the needs of the national industrial policy.

The Unit's Industrial Policy Research Centre (IPRC) launched (2020) in partnership with the Manufacturing Technology Centre (MTC) is central to this ambition. As its inaugural Director, former Member of Parliament Prof. Chris White is developing the Centre as a focal point for discussions between researchers, industry and political decision makers to provide practical responses to the national priorities. Supporting the Midlands Manufacturing Resilience Commission (M2R), chaired by Dr Clive Hickman (Chief Executive, MTC) with evidence from over 200 participants from industry, academia, and government, including significant input from this Unit (Kinnell), the Commission's Manufacturing Confidence Report was launched at a virtual event in December 2020. A National Manufacturing Summit will be organised by the IPRC and hosted by the Manufacturing Technology Centre in March 2021.

1.4.3 International Collaboration

We will strengthen our existing partnerships and build new international collaborations to deliver research and impact in our priority areas. In energy, for example, we have built a strong partnership with the National Renewable Energy Laboratory (NREL), the premier laboratory dedicated to the development of renewable energy technologies in the United States. Working on photovoltaics, 3 postgraduate researchers from CREST have taken 3-month secondments and NREL Senior Scientist, Dr Tim Silverman, spent a year working at CREST (2018-19), resulting in milestone joint publications on thin film CdTe, perovskite photovoltaics and anti-reflection/anti-soiling coatings. CREST's recently submitted EPSRC International Centre-to-Centre Research Collaborations proposal will widen the technical scope of our existing collaboration with NREL to cover other important renewables technologies of mutual interest including last-mile grid architectures and new high-performance low-cost materials for high temperature thermal energy storage. Recognising the need to support ECRs in this area, a critical component of collaboration is a formalised bi-directional secondment programme available to ECRs and PGRs within CREST and NREL to undertake significant research projects and develop joint proposals to build further collaboration. EDI implications will be addressed through ringfenced funds to address barriers to participation for those who might otherwise feel

excluded. Recognising that many of the challenges we face have global reach and significance, our plans for the next 5 years include bringing greater substance to our international co-operation based on this model.

1.5 Open Research Environment

Loughborough has been a pioneer of the Open Agenda, actively supporting repositories for text-based outputs (since 2005) and data (since 2015) and working beyond funder (including REF2021) open access requirements. LU ranks 9th in the CWTS Leiden index for open access. Under our landmark Open Research Position Statement, from 2020 the Unit has deposited the full text of 100% of its primary research outputs (journal papers) in our now unified (2019) Research Repository (including on closed access where unavoidable).

Our approach to Open Research has been a key enabler in several areas. Supporting growth in the renewable energy sector, for example, work from CREST has generated an open access demand-model that allows consumers and commercial installers to make accurate estimates of solar photovoltaic generation and self-consumption. Validated by the Building Research Establishment, datasets have been incorporated into the new open standard published by the Microgeneration Certification Scheme (2019). This work was shortlisted for Loughborough's Open Research CALIBRE Award (2019). More generally, our repository content has attracted nearly 12m views since 2014 with more than 400k downloads. PhD theses alone have 186k views and 55k downloads.

1.6 Culture of Research Integrity

Our research spans a diverse range of disciplines from biological engineering to safety-critical aerospace/automotive applications and close adherence to ethical principles is vital. Ethics is overseen within Schools by a senior academic ensuring that that the rigorous principles and processes of the University's comprehensive Ethical Policy Framework and Code of Practice for Research, underpinned by the principles of UUK's Concordat to Support Research Integrity, are strictly applied. Researchers within the Unit play an active role in the University's Ethics Committees with representation on Ethics Approvals (Human Participants) Sub-Committee. Coopman is the University's Human Tissue Authority Licence Designate Individual and Chair of the HTA licence Sub-Committee.

Section 2. PEOPLE

2.1 Staffing and Recruitment Policy

This Unit has 204 (headcount) academic staff, all on open-ended contracts, who contribute to teaching, research and enterprise activities. They have a minimum protected workload (450hrs) for research and impact. Each year, the Unit recruits c.40 research staff for projects, usually on fixed-term contracts in line with sector norms. We are submitting 10 who met the independent researcher definition including 6 holding competitively-won fellowships.

Part-time working is supported, and 10 Unit staff work part-time (5M/5F). We accommodate requests for part-time working at any time, including recruitment, (e.g., Clarke, Segura-Velandia, Ozcan-Taskin) and our processes ensure part-time staff are promoted (e.g., Strickland to Chair in CREST, 0.7FTE).

In line with our strategy, our policy promotes excellence by attracting and retaining outstanding staff at all career stages, from postdoctoral and ECRs through mid-career and senior roles. Since REF2014, the University's approach to recruiting has radically changed, driven by the University Strategy and beginning with the Excellence100 Campaign, from which we recruited a 5-year **Vice-Chancellor's Research Fellow** (Martin-Fabiani), and five **Doctoral Prize Fellows** (Dharmasena, Parsa, Pering, Wilson and Xu), two-year posts for outstanding researchers less than two years post-PhD. Following the Excellence100 model, recruitment to established posts is now conducted through biannual recruitment rounds, managed centrally but with significant School input, rather than piecemeal replacement hires. With excellence as the primary criterion, these rounds deliver better international recruitment and improved diversity. Our campaigns promote positive role models, emphasise family friendly policies, welcome part-time/flexible working and use targeted adverts and social media to attract a diverse range of candidates.

Attracting a larger pool of applicants has enabled us to manage succession planning for existing areas of strength while investing in emerging areas. Over the assessment period we have recruited 76 academic staff (50 Lecturers, 19 Senior Lecturers and 7 Professors). To develop VDE across our automotive, communications and manufacturing priority areas, the Unit has made 20 academic appointments. To maintain leadership, these included professorial appointments in automotive engineering (Ebrahimi in AACME and Yorke-Biggs in IDE), and in communications (Kondoz in IDT). Additional leadership also comes through internal promotions: Whittow to Professor in communications and Lohse and Kinnell to Readerships in manufacturing. Yorke-Biggs' appointment is noteworthy; the newly introduced Professor of Practice position recognises those whose leadership is based on careers outside academia and whose role is to continue to engage with the end-user community.

In areas of existing strength, we have recruited in a targeted way: in materials, we recruited 10FTE to functional materials and biomaterials; in energy, 13FTE to photovoltaics, networks, thermal and low carbon economy; in manufacturing, 14FTE to additive, laser and chemical processing; in automotive engineering, 11FTE to dynamics and tribology; and in aerospace, 4FTE to aerothermal technologies in NCCAT and 4FTE in autonomous systems and control engineering.

Succession planning for leadership occurs through progression within our departmental, group and school research structures. CALIBRE roles provide opportunities for colleagues to gain leadership experience (e.g., Coopman is Deputy Lead of the Health and Wellbeing GC); Harland was Head of STI before ADE, and Rielly was HoD Chemical Engineering, then ADR before Dean.

2.2 Staff Development Strategy

Loughborough's Organisational Development team offer a wide spectrum of training opportunities and support for Unit staff at all career stages. Courses range from earliest stages (e.g., Welcome to Loughborough) through essential training (e.g., Information Security Training, Unconscious Bias) to training for staff becoming senior managers (e.g., Coaching Conversations for Managers, Recruitment and Selection).

All academics are expected to obtain Fellowship of the Higher Education Academy (HEA). For new lecturers, this is integral to their dedicated development programme. More experienced colleagues are supported through our Recognition of Experienced Practitioners Scheme which requires preparation of a dossier of evidence to support their application.

Loughborough was a founding signatory of the **Technician's Commitment** (2017), which acknowledges and aims to remedy the under-appreciated role of technicians working in higher education research with recognition and career development through a formal action plan. The Unit has offered technician apprentice roles since 2014 with a dedicated training scheme. Four are already in permanent positions in the Unit, others are in industry.

Following the principles of the Concordat to Support the Career Development of Researchers, the University provides structured support to **postdoctoral researchers** for career progression and development, including preparation of applications for funding. This was recognised by the European Commission's HR Excellence in Research Award (since 2010, renewed after external review every 4 years). This includes Recognition of Teaching for Researchers (ROTOR) and Associate Teaching Pathway programmes. Since 2016, 20 postdocs have gained AHEA via this route. Loughborough University Research Staff Association (LURSA) makes links across the university community and runs a mentoring programme.

Within the Unit, all postdoctoral researchers are associated with at least one research institute, centre or major research group and participate in research events (e.g., themed away days and annual research forum) with academic colleagues. While many postdocs seek lecturer posts or roles in industry, a small proportion, typically in applied research with a primary sponsor (e.g., Rolls-Royce, DSTL), are supported by sequential research contracts and transfer to open-ended contracts after 4 years according to institutional policy. Since 2014, the importance of these roles is now recognised by a process for redesignation as Research Fellow and post-holders can now follow a career pathway up to professorial status. In specific areas, we have operated schemes to accelerate careers e.g., recognising the need for trained professionals before the predicted benefits of cell-based therapies can be realised, the CBE led (with partners) an EPSRC-funded programme (£2.9m, 2012-18, Williams) training 12 Research Fellows. Of the 3 Fellows at Loughborough, 2 are in academia (UCL and Loughborough) and the third is employed at the Cell and Gene Therapy Catapult.

More generally, the career trajectories of our former postdoctoral researchers suggests that our support is effective; 34 gained lecturer posts within the Unit and many more took academic posts at other institutions within the assessment period.

On the **New Lecturers' Programme (NLP)**, ECRs are guided by an experienced and trained academic colleague who acts as Adviser. NLP (formerly academic probation) was substantially revised in 2017 and includes the full spectrum of research and impact activity (publication, funding applications, collaboration, public engagement, non-academic partnerships). New lecturers have a reduced workload in teaching and administration (33, 50 and 67% of School norms in consecutive years), which enables the establishment of a full academic profile in research, teaching and impact at a manageable pace. In addition to an extensive training programme leading to FHEA, new lecturers meet four times annually with their Advisers though many more informal meetings are the norm. New lecturers are allocated a University-funded PhD studentship within their first two years, for co-supervision with an experienced colleague.

Supervision is a requirement to pass the programme, alongside a minimum expectation on research output production and the submission of at least one substantial grant application. During the assessment period, 42 staff competed NLP and 21 staff are currently on the programme. Rapid subsequent promotions are typical; for example, after joining in 2016, Derakhshani won a Leverhulme Fellowship (Machine Learning) in 2020 and she was promoted to Senior Lecturer in 2021.

Mid-Career and Senior Staff. We expect and incentivise collegiality from the earliest career stages and, as careers develop, we expect broader leadership contributions across the Institution, supported by appropriate workload model allocations. For example, Eames, Passmore, Henshaw and Kinnell are Beacon and Global Challenge Leads with an allocation that still allows them to maintain substantial research portfolios. Since 2014, Unit academics have represented UCU at branch level (Kerr, Bonham), taken elected roles on University Senate (21 Staff), and joined Loughborough's Senior Management Team (PVCs Rothberg, Thomson). External leadership roles (section 4) are similarly supported. Additional support is available through Loughborough's innovative Coaching and Mentoring Scheme.

Research Fellowships are important to the development of the Unit's research leadership. During the assessment period, Unit staff have held EPSRC Fellowships (e.g., Chen, Kinnell, Thomas, Yuan), UKRI Innovation Fellowships (Lin, Zhao) Royal Society Industry Fellowships (Ruiz, Marimuthu), a Leverhulme Trust Research Fellowship (Derakhshani), ERC Fellowship (Nagy), Alexander Van Humboldt Fellowships (Vladisavljevic), Newton International Fellowships (Xuan, Nui) and UKRI FLF (Martin-Fabiani). Martin-Fabiani was an Excellence100 Vice-Chancellor's Research Fellow which positioned him as a strong candidate to win his prestigious Fellowship: A Platform Technology for the Next-generation of Functional Coatings, Applications in Clinical Settings and Photovoltaic Devices (2020).

All members of post-probationary staff in the Unit have an **annual Performance and Development Review (PDR)**. This University-wide scheme was revised and updated in 2017. A supportive one-to-one discussion between the reviewee and a trained reviewer reflects on achievements over the past year and agrees objectives across the full range of activities including CALIBRE-aligned goals for research and impact activity. The new PDR is a transparent way to recognise performance exceeding expectations (30% of Unit staff in recent years) with additional financial **reward**. The new scheme has particularly benefitted our research staff for whom a rigorous developmental discussion was previously sporadic and consideration for reward a rarity. Since the introduction of PDR, 166 Category A Staff have received a performance related award (16% self-identifying as female and 27% as BAME, in line with our staffing profile).

PDR also allows much fairer identification of candidates for promotion. The University has revised the criteria for **academic promotion** (Senior Lecturer and Reader/Professor), to ensure that the research components align with the University Strategy and CALIBRE. Evidence for cases can be based on research, teaching, enterprise (impact) or any combination to encourage balanced portfolios of work. We judge Excellence and International Reputation and Academic Leadership and Influence rather than traditional metrics based on quantity rather than quality. This focus allows panels to consider statements from promotion applicants describing how personal circumstances, such as caring responsibilities, may have affected their profile. 58 academic staff have been promoted to Senior Lecturer or Reader (13 female, 45 male) and 15 to Professor (2 female, 13 male) during the assessment period.

Research and impact leave is available in the form of School and University Fellowships of up to 12 months duration. Fellowships provide focused time outside regular workload to pursue an agreed programme of academic work. During the assessment period, 13 Unit staff held Fellowships, representing 132 months dedicated solely to research and impact. For example, Walker worked on the design and commissioning of NCCAT and Coopman established a new research area in fundamental cryobiology techniques to deliver process improvements in

manufacture of cell-based therapies. **Secondments and exchanges** with industry partners are encouraged and supported. Within RR-UTC, for example, 10 research staff have been seconded to Rolls-Royce (~1-year duration) matched by Rolls-Royce employees spending time at the University, including the Chief Project Engineer for Aerothermal Excellence who completed a part-time PhD.

2.3 Postgraduate Research (PGR) Students

PGR students are key to the research of the Unit. 656 PGRs (59% UK/EU, 41% International) have graduated during the REF period 37% (36%) female and 13% (12%) identifying as BAME, exceeding overall HESA cost centre figures shown in brackets. The Postgraduate Research Experience Survey (PRES 2019) commended "working space, computing resources and facilities" (90% positive), "supervisors' skills and knowledge" (89% positive) and "development of research skills" (93% positive), amongst others. Support for conference attendance and paper submission significantly exceeded national averages. The Institution's award-winning Doctoral College (DC) oversees all aspects of the PGR experience and has a strategy that promotes the value, vitality and visibility of the PGR community. Across this Unit, 15FTE support staff are dedicated to supporting the management of PGR programmes.

2.3.1 PGR Funding

The Unit attracts **funding** to maintain its PGR population (c. 380 students) via University scholarships, industry funding, UKRI funding including Centres for Doctoral Training (CDTs), and high-quality self-funded PGRs. The funding mix is approximately 50% internal funding, 30% from UKRI and 20% industry/self-funded.

The Unit awards approximately 35 DC studentships each year, supported by EPSRC DTP and central University funds. These studentships are strategically allocated to support new lecturers and to gear funding from larger scale research grants. Our EPSRC DTP researchers benefit from a 42-month enhanced programme and Research Training Support Grants, often with additional industrial sponsorship. For example, 2 cohorts of PGRs (12 in total) were matched-funded by JLR alongside the £3m EPSRC/JLR Programme for Simulation Innovation Themes 1 and 2 (Dickerson, Passmore, 2013-18). In energy research, 7 DTP studentships have been aligned with Midlands Innovation partners to form the ERA Doctoral Academy to address industry-led research challenges. Other significant PGR funding within the Unit has been gained through Marie Curie ITNs (e.g., €1.2m CLOUDSCREENS (Kondoz), €3.6m SOLAR-TRAIN (Walls), €2.8m AWESOME (Watson)) and Founder Partner Studentships sponsored by the Manufacturing Technology Centre.

Our engagements with EPSRC CDTs are extensive and longstanding. During the REF period, Unit academics have been PI or Co-I in 5 EPSRC CDTs. Our largest PGR cohorts have been funded through the EPSRC/MRC CDT in Regenerative Medicine (CDT-RM**,** £3.6m, PI Coopman, with Nottingham and Keele, 2014-23, originally DTC for Regenerative Medicine, 2008-2018) to develop the tools and skills needed to translate the potential of cell or tissue-based therapies from bench to bedside. The EPSRC CDT in Embedded Intelligence (£3.5m, 2014-23, PI Conway with Heriot Watt) is training students on the use of sensors, communications and processing embedded into products, processes or services to meet specific objectives. A substantial cohort of students (95 to date, 24 LU-based) are trained in the RR-UTC and funded by the EPSRC CDT in Gas Turbine Aerodynamics (CDT-GTA, Cambridge led, 2014-22, Co-Is Carrotte, Page, Walker). With the opening of NCCAT, this CDT was recently renewed as Future Propulsion and Power (CDT-FPP, 2019-28) ensuring the future vitality of this important area (c. 90 students growing to 108 depending on industry support). We have also trained PGR students through EPSRC CDTs in Additive Manufacturing and 3D Printing (Nottingham led, 2014-22), Carbon Capture and Storage and Cleaner Fossil Energy (Nottingham led, 2014-22), Continuous Manufacturing and Crystallisation (Strathclyde led, 2012-19) and New and Sustainable Photovoltaics (Liverpool led, 2014-23).

2.3.2 PGR Recruitment

We advertise via the University website, jobs.ac.uk, School and staff LinkedIn and Twitter accounts using imagery and inclusive language to reflect our diverse population. Rigorous selection prioritises academic achievement with decisions based on reviews, remote or in-person interviews by two academics and at least two references. Decisions are taken by two members of staff. We make efforts to attract and support part-time PhD candidates and have considerable success in attracting practising professionals as well as those with caring responsibilities. In the assessment period, 47 part-time PGRs graduated (33 UK/EU and 14 international). Applicants with disabilities are supported by the University's Counselling and Disability Service.

2.3.3 Monitoring and Support Mechanisms

The DC runs an **induction** event for new starters, complemented by School specific inductions. All students have at least two **supervisors** with formal meetings at least monthly and usually more frequently, with minutes recorded in the University's dedicated online Co-Tutor tool. Progress and evolving training needs are monitored via 6-monthly reviews by an allocated Independent Assessor and overseen by the Director of Doctoral Programmes (DDP) working with a formal panel to ensure fairness and consistency. A rigorous assessment is held at the end of each registration year, for which students produce significant written work and have an interview with an Independent Assessor. Records are maintained centrally, and re-registration requires a satisfactory review outcome. Those not making sufficient progress are given three months additional support, including signposting to specialist support services e.g., student counselling, to get back on track.

Quality assurance of research degree programmes is the responsibility of the School ADRs, each supported by a DDP. Schools hold quarterly Progress Review Boards to monitor cohort progression. Working closely with the Associate Pro Vice-Chancellor (A-PVC) for the DC, the DDPs sit on the Doctoral College Sub-Committee which in turn, reports to Research Committee. The A-PVC for the DC oversees quality assurance including admissions, examinations and appeals, ensuring equitable treatment.

PGRs actively contribute to the vitality and sustainability of their community. Elected PGR Representatives and a Lead PGR Representative report to each School's termly Staff and PGR Liaison Committee. At institutional level, a PGR President represents the views of PGR Reps, attending DC Sub-Committee and Research Committee.

2.3.4 Skills Development

Our PGRs benefit from comprehensive training provided via the DC, including induction and international orientation for new students, to transferable skills and employability training to meet the requirements of the Vitae Researcher Development Framework. The vitality of the research at Loughborough is celebrated through events such as the Annual Conference, Summer Showcase, Three Minute Thesis competition and Diversity in Research Workshops. All students have an opportunity to gain teaching experience by assisting in labs and tutorials on completion of the Essential Teaching Skills training. This is the gateway to the institutional Recognition of Teaching for Researchers (ROTOR) scheme. Since 2016, 7 PGRs have gained AHEA status via this route. Funding to support travel for research and external conferences is available through Santander Travel Awards and International PhD exchanges.

Our Schools run discipline specific training covering a wide range of activities, including Health and Safety Matters, Journal Clubs and presentations by Library and Career Development representatives. Monthly School seminars provide interaction with world-renowned academic researchers and industry leaders. Notable examples include; "Hydrodynamics of Fish Swimming" delivered by Prof Eloy from Ecole Centrale de Marseille (2019) and "Robotic

Solutions for Infrastructure Predictive Maintenance" delivered by Dr Michele Guarnieri, co-founder and executive director at HiBot Corporation of Japan (2018).

PGRs in CDTs benefit from enhanced provision, including a 46-month programme, cohort activities and individual Research Training Support Grants. For example, training in CDT-RM includes Insight into Clinical Practice (hospital based), Business Plan Development and a Translational Technology Review with the Cell and Gene Therapy Catapult. The CDT-EI programme includes our Transition Zone™ training package that is accredited by the Institute for Leadership and Management. CDT-GTA and CDT-FPP build on a training platform from the University of Cambridge leading to MRes qualification. CDT training boasts outstanding outcomes: for example, CDT-RM has graduated 57 students since 2014 with approximately 30% now in industry (e.g., Hitachi, GSK, Oxford AHSN) and 60% in academia (e.g., Bath, Imperial, UCL). In CDT-EI over 50 SMEs have sponsored 68 students with 13 graduated to date and 85% securing successful careers in manufacturing (e.g., Hitachi, Fraser-Nash, and Amazon).

2.4 Equality, Diversity and Inclusivity (ED&I)

ED&I is led from Schools, supported institutionally, and embedded in policies and working practices at all levels. All colleagues complete the Respecting Diversity mandatory course and must pass an online Unconscious Bias course. School SMTs receive bespoke Unconscious Bias training. Equality Impact Assessments (EIAs) are conducted annually and where concerns are identified, School Action Plans are drawn up. For example, a relatively poor gender balance in MEME in 2014 (particularly at Lecturer level) prompted introduction of targeted publicity (LinkedIn, Facebook), active encouragement of potential candidates and improved candidate packs emphasising local information and support networks. As a result, the proportion of female Lecturers increased from 7% to 22% and those recruited are now progressing through the grades. The Unit now exceeds sector averages on gender (from HESA) – 22% vs 20% Lecturer, 15% vs 14% Senior Lecturer, 21% vs 14% Reader and 13% vs 9% at Professorial level. We are now addressing gender imbalance in technical roles with good progress e.g., Grade 6 Technical Managers (Kavanagh, Fay, Spencer). AACME and MEME hold Athena SWAN Bronze Awards and have championed the Aurora and Stellar leadership programmes aimed at female and BAME staff, respectively. Since 2019, the Unit has sponsored Hubbard, Pacella and Derakhshani through these programmes.

Our EIAs on ethnicity currently compare well with HESA averages at all levels except Reader. The Race Equality Action Group (REAG) was established in October 2019 to lead on the Institution's work on advancing race equality and the Unit is actively engaged (Segura-Velandia). The Unit participates actively in University-led activities such as International Women's Day, Black History Month and LGBT+ History Month. In 2019, the Unit held celebrations to mark 100 years of women engineers at Loughborough.

Formal **flexible working** requests are submitted to and approved by HR with support from the School. Academic staff also can work flexibly or remotely on an informal basis so long as their responsibilities are fulfilled. Staff Survey responses have prompted adjustments, such as recognising part-time workers' needs when scheduling meetings, avoiding meetings at the start and end of the working day, adding comfort breaks into longer meetings and providing opportunities for social interaction (latterly online). For circumstances such as caring for a family member in poor health, staff can request compassionate leave for immediate issues or longer-term flexible working for ongoing responsibilities.

Remote working is facilitated via the VPN (with secure multifactor authentication) that provides access to all University online resources, with advice available to facilitate safe working practice at home. Such policies and supporting infrastructure have eased the transition to effective home working during the COVID-19 pandemic from March 2020.

It is University policy to fund cover for **parental leave** and support returning staff. When a member of staff reports that she is expecting a child, a risk assessment is made, laboratory work is limited or adapted accordingly, and support put in place where necessary. During parental leave, we use Keeping in Touch days to maintain contact with postgraduate researchers, mentors and funded projects. We allow gradual return to full-time or phased return via temporary fractional appointments and reduced responsibilities.

We ensure that **staff with protected characteristics** can research productively. We have an excellent record of supporting staff and PGRs with health challenges and disabilities, for example, providing dyslexia software, providing viva questions in advance, scheduling viva rest breaks and having a scribe to take notes. We have supported colleagues with severe eyesight conditions with specialist computer equipment and display screens. Colleagues with physical needs are accommodated in workspaces that include full wheelchair access, including showers and T-hearing loop. All new buildings have non-gender specific toilets, baby-change and feeding facilities and Braille signage.

Wellbeing support. The Unit has several Mental Health First Aiders with externally accredited training, who provide immediate support to staff and research students. The **Wellbeing Advisor** provides support to staff and research students. The **University Counselling Service** is available for emergency meetings and long-term treatment. The University also subscribes to the **Employee Assistance Programme** providing 24-hour telephone counselling and repeated sessions for staff with complex issues.

2.5 Equality and Diversity Issues in the Construction of the REF Submission

All preparations for this submission were conducted in accordance with the University's Code of Practice and subject to Equality Impact Assessments (EIA). In line with our Responsible Metrics Policy, output scoring for originality, significance and rigour was conducted through blind review by panels of trained reviewers drawn from a cohort of 60 reviewers representing all research areas and covering different career stages, gender and ethnicity (20% female, 30% BAME). Selection was based solely on excellence and did not set out to ensure even distribution across individuals or areas. The ICSs were reviewed periodically both within the Unit and by outside assessors on 3 occasions. All members of the submission team (2 female, 6 male) attended REF-specific ED&I training and all peer reviewers received unconscious bias and responsible use of metrics training. Extensive EIA revealed no indicators of bias in selection analysed by gender, parental leave, ethnicity and ECR status with attention to overall selection, allocation of co-authored outputs and characteristics of threshold-spanning outputs. We note that the ultimate gender/ethnicity of the staff submitting their chosen outputs 17% (17%) female, 25% (26%) BAME corresponding closely to the underlying staff population, shown in brackets.

Section 3. INCOME, INFRASTRUCTURE AND FACILITIES

3.1 Research Funding and Strategies

The delivery of our strategic research objectives could not be achieved without significant research funding. The Unit has built upon earlier successes to increase its total grant income to over £165m. Our funding comes from UKRI £85m, UK Central Government £32m, EU Government £11m, Industry £27m, Charities £3.4m and other funding agencies £7.2m.

Funding strategy in each School is driven by Deans and ADRs, signposting funding opportunities and ensuring that grant applications are peer reviewed internally by colleagues with relevant expertise. The Unit has established new theme-based activities, for example, biannual team building away days, and an annual research forum of all research-related staff. Our research centres, institutes and major research groups are fundamental to our strategy, acting as focal points for attracting research and impact funding.

With a strong track record of winning UKRI funding (52% of our research income) we aimed to diversify our income streams to tackle new challenges in several strategically important areas. Specific targets were:

- **Industry Partnerships**. Applying equally to our UKRI funded research centres (e.g., CIM-CIA) or our established industry funded centres (RR-UTC and Cat-IRC), we aimed to increase the proportion of research sponsored directly by industry or as part of collaborative, UK Central Government funded programs.
- **Research Consortia**. Addressing interdisciplinary research in areas of national and international importance, we aimed to increase our work with academic research consortia, including UKRI funded consortia (i.e., EPSRC Network Plus and Future Manufacturing Hubs) and those funded by EU Government.

Evidence of Success: In like-for-like comparison (B12 + B13) with REF 2014, our average annual income has increased by 23%. Research funded directly by industry has increased by 8% and income through collaborative programmes funded by UK Government (principally Innovate UK) by over 160%. Together these sources account for over 36% of our total income. Our strategy to develop new partnerships in Europe has resulted in a 14% increase in funding from EU Government and notably an 82% increase in direct funding from EU Industry, evidencing the increased reach of our research and impact activities.

3.1.1 Industry Partnerships

Our increased engagement with industrial partners is most clearly evidenced in automotive engineering, working through Cat-IRC or through new consortia and partnerships linked through the Advanced Propulsion Centre (APC). Examples include:

- **ASCEND**: Accurate Simulation and Casting for Efficient Design (£640k, Caterpillar/IUK-funded, 2015-18) combined as-cast material property prediction, cycle dependent property evolution and advanced Computer Aided Engineering (CAE) to optimise engine component design and production processes.
- **DeClutch**: Engine based Driveline Disconnects for Downsizing Design (£600k, Caterpillar/IUK-funded, 2015-17) successfully demonstrated a flywheel-based device to disconnect the engine from the machine transmission to enable downsizing and removal of machine parasitic loads.
- **ASCENT**: Low CO_2 Technologies for Accelerated Next Generation Caterpillar 4-7L Engines (£13m, APC/IUK-funded, 2015-18, Caterpillar led) delivered new technology to enable a major upgrade of heavy-duty diesel engines with significant CO_2 reduction and increased power density (now a high-volume global export).

- **VIRBIUS**: Design of Hybrid Electric Powertrain (£10.4m, APC/IUK-funded, 2018-21, led JLR) has significantly improve the vehicle system efficiency through utilisation of innovative electronic systems and componentry.
- **DYNAMO**: Dynamic Analysis Modelling and Optimisation of GDI Engines (£22m, APC/IUK-funded, 2017-21, led Ford) has led to significant improvements in the fuel efficiency of two high volume passenger vehicle powertrains through advanced computational modelling using High Performance Computing (HPC).

3.1.2 Research Consortia

Interdisciplinary work as part of research consortia has been extensive and includes work coordinated through EPSRC Network Plus, EPSRC Future Manufacturing and MRC Hubs, and work as part of large European Consortia. Examples include:

EPSRC Network Plus

- Building on the consortia established in EPSRC SuperSolar Hub (£4.8m, 2012-18, led Walls with 7 partners) CREST now leads the EPSRC Supergen Solar Network Plus (2018-22, £1m, led Walls with 9 partners) coordinating efforts to take the UK's early-stage solar technologies into production.
- We are co-investigators in the EPSRC Supergen Storage Network Plus (£1m, 2019-23, led by Birmingham with 11 partners, CoI Eames) bringing together academics working on thermal, mechanical, chemical and non-Li-ion based energy storage.
- A growing portfolio of work in underwater acoustics is recognised by participation in the EPSRC Acoustics Network Plus (£1.4m, 2020-24, led Sheffield with 8 partners, CoI Lepper) which unites over 870 members organised in 15 Special Interest Groups with a significant international dimension.

EPSRC Future Manufacturing and MRC Hubs. Our work in the EPSRC CIMs has translated into further collaboration through EPSRC Future Manufacturing Hubs.

- Research generated by CIM-CMAC has led to a body of work concerning machine learning approaches to provide insight and control of medicines manufacturing (e.g., EPSRC-funded, ARTICULAR: Artificial Intelligence for Integrated ICT-enabled Pharmaceutical Manufacturing, £2m, 2018-22, led by Strathclyde, CoI Rielly). The Unit leads simulation and control (including digital twins) within the EPSRC Continuous Manufacturing and Advanced Crystallisation Research Hub (£10.5m, 2017-23, led by Strathclyde with 7 partners, CoI Rielly).
- Building on successful projects (e.g., EPSRC-funded The Light Controlled Factory, £2.5m, 2013-19, led by Bath, CoI Huntley and In Jet Interferometry for Ultra Precise Electrolyte Jet Machining, £291k, 2015-18, Kinnell) we have demonstrated unique instrumentation capable of 3D digitisation at the factory scale and control of precision manufacturing processes at the microscale. Recognising the increasing importance of metrology in manufacturing, the Unit leads work on optical measurement within the EPSRC Future Advanced Metrology Hub (£10.5m, 2017-24, led by Huddersfield with 4 partners, CoI Huntley).
- In biological engineering, the Unit is responsible for the creation of new decision-support tools to accelerate the development and optimisation of manufacturing processes in the EPSRC Future Targeted Healthcare Manufacturing Hub (£10.5m, 2017-23, led UCL with 8 partners, CoI Thomas) and we lead the manufacturing research programme within the MRC Pluripotent Stem Cells and Engineered Cell Hub (£4m, 2018-23, led Cambridge with 4 partners, CoI Thomas) concerning blood clotting components generated from human pluripotent stem cell derived megakaryocytes and dopaminergic cells for Parkinson's disease.

European Consortia. We have increased our collaboration with universities and industries across Europe. Examples include:

- **PERFORM**: Production Harmonized Reconfiguration of Flexible Robots and Machinery (€9.2m, 2015-18, led by Siemens, CoI Lohse) targeted the need for increasing flexibility and reconfigurability in the manufacturing domain with a hybrid agent-based scheduling approach to optimise production.
- **HEMACURE**: Application of combined gene and cell therapy within an implantable therapeutic device for the treatment of severe haemophilia A (€5.6m, 2015-18, led by Wurzburg, CoI Stolzing), addressed technologies for a cell-based treatment of haemophilia and developed pre-clinical models.
- **SOPRANO**: Soot Processes and Radiation in Aeronautical Innovative Combustors (€6.8m, 2016-21, led by SAFRAN SA, CoI Carrotte) is providing more accurate experimental and numerical methodologies for predicting the soot emissions in alternative combustion systems for future aircraft.

3.1.3 Major and Prestigious Grant Awards

Forward-looking research has led to several prestigious grant awards, all under Unit leadership:

- In communications, the EPSRC Grand Challenge Project, SYMETA: Synthesizing 3D Metamaterials for RF, Microwave and THz Applications (£4m, 2016-21, Vardaxoglou) is a consortium of 5 universities bringing together world-renowned experts including Prof. Sir Roy Sambles FRS and Prof. Ian Reaney FRMS. SYMETA has developed novel ultra-low loss ceramics that are temperature stable and can be 3D-printed to create graded structures with multiple materials. To date, SYMETA has created more than 50 high impact journal publications, more than 50 keynote presentations international talks and more than £10m of follow-on funding from grants and industrial projects.
- ELEVATE: Electrochemical Vehicle Advanced Technology (EPSRC-funded, £3.3m, 2015-19, Thring) brought together 6 universities to investigate new materials and processes to optimise fuel cells, supercapacitors and batteries for use in hybrid vehicles. Novel diagnostic techniques for on-board monitoring, control and validation of these technologies were demonstrated in a test vehicle. Work in this area is continuing through, for example the UKRI Innovation Fellowship: Towards Energy Efficient Autonomous Vehicles via Cloud-Aided Learning (£527k, 2018-22, Zhao).
- In biological engineering, the EPSRC/NIHR Healthcare Technology Co-operative (HTC) Partnership Awards – UNIFY and UNIFY Plus (£159k, 2014-17, and £364k, 2016-18, Williams) addressed the repair and rehabilitation of non-union fractures for long-bone and cranio-facial trauma. Novel enabling technologies were demonstrated including for example, bone growth monitoring using radio frequency location of metallic fixturing (Whittow, Panagamuwa) – a technology featured in Physics World (IoP).
- The EPSRC funded project: Tackling Antimicrobial Resistance: An Interdisciplinary Approach (£546m, 2015-18, Malik) built a body of university-wide interdisciplinary research with around £1m of additional UKRI and industry funding and strategic support (DTP-funded) for a cohort of PGRs working in this area.
- Synthetic Aperture Interferometry: High-resolution Optical Measurement over an Exceptionally Large Field of View, (EPSRC-funded, £693k, 2015-18, Coupland). This project demonstrated that an array of miniature digital-holographic cameras based on mobile phone technology can combine to output large-area, surface data with a fidelity comparable to an interference microscope.
- The EPSRC Platform Grant, Embedded Integrated Intelligent Systems for Manufacturing (2015-22, £1.6m, West) leads work on the design and development of products and processes that can demonstrate adaptation and learning. The work combines expertise within MEME, AACME and the School of Business and Economics with strategic direction supported by project partners through the MTC and IDE in London.

3.2 Organisational Infrastructure supporting Research and Impact

Supporting funding applications. Within Schools, Research Administrators support staff with project administration, finance and events management. Since 2014, Research Development Managers (RDMs), an additional senior resource with specialist knowledge of funding areas, have assisted academics to develop their research strategies, win funding and build collaborations. Fellowship applications, including those available to ECRs, are supported by a dedicated RDM providing mock review panels, coaching and detailed feedback. For example, Dr Martin-Fabiani's UKRI Future Leaders Fellowship was actively supported through scrutiny of the initial call at the outline stage, analysis of draft proposals and reviewers' comments and a mock review panel (chaired by the PVCR) – all contributing to his successful bid.

Interdisciplinary projects are supported with RDMs aligned both to Schools and to interdisciplinary elements of the CALIBRE strategy (Beacons and Global Challenges). The University's Research Support Teams provide costings, contracts support and post-award financial management. A Research Data Manager leads a team to support the development of data management plans and to develop and share good practice. A Research Governance Officer can advise on issues of ethics and research integrity. Rigorous peer review is conducted in Schools by experienced colleagues followed by review stage and approval by senior staff (Operations Managers, ADRs and Deans).

Supporting research outputs. We have strengthened our efforts to increase publication quality; to increase the number of outputs published in leading journals and to ensure open access to our publications and research data. Librarians dedicated to each School, provide training and advice on visibility and open access requirements. Journal selection and publication self-assessment guides have been made available in the Schools. Where appropriate, Advisors and Mentors support the drafting of papers and internal peer review of drafts is encouraged. The Library and Research Data Manager supports academics to make their research open access through the Research Repository. We have increased the proportion of our papers published in leading journals (top 10% by SJR) from 27% in 2014 to 36% and the proportion of those made available in the Institution's Research Repository has risen from 40% to 100% in 2020.

Supporting impact. Enterprise and impact generating activities are coordinated by School ADEs working closely with University Marketing, and Research and Enterprise Offices to support communications and interactions with our industrial partners. Partnership Development Managers (PDMs) are a new (2016) senior resource assisting ADEs to develop non-academic networks (training, scoping partner requirements, brokering relationships, sourcing funding opportunities). For example, in the recently awarded project, Robots as a Service (EPSRC-funded £1.5m, 2021-24, PI Lohse), PDM support translated the research vision into an accessible flyer ensuring that the project was focused on the needs of the 20 companies (including Toyota, Airbus and AiVision Robotics) supporting the bid.

PDMs assist academics to build business cases to attract additional resources to develop impact e.g., Knowledge Transfer Partnerships (KTPs) and funding through the University's Enterprise Projects Group who review, select and awarded financial support for knowledge transfer and impact activities from HEIF and EPSRC IAA. PDMs offer advice on consultancy through Loughborough University Enterprises Ltd (LUEL). Specialists in the Commercialisation Team provide expertise on the identification, protection and commercialisation of intellectual property.

3.3 Operational Infrastructure and Facilities

The Unit has benefitted considerably from the University's West Park redevelopment (£59m, 2019), enabling us to refurbish and reconfigure approximately 60% of our research facilities. Through this investment:

- Our facilities in **automotive** engineering have been enhanced with new laboratories in tribo-dynamics, power electronics and electrochemical propulsion complementing existing IC engine test cells and a medium-scale wind-tunnel. The Cryogenic Laboratory is an exciting new facility addressing energy systems for waste heat recovery in applications such as truck refrigeration and supporting an area of emerging research.
- Our **manufacturing** facilities have been renewed with laboratories in process engineering, crystallisation, intelligent automation and robotics, optical measurement, and a new Microbiology Laboratory has been added to our extensive Category 1 and 2, HTA compliant laboratories in **biological engineering**.
- In **communications** we have created new acoustic laboratories (air and underwater) and new anechoic, electromagnetic test facilities that have allowed us to characterise new antennae concepts based on meta-materials. Our Pulsed Power Laboratories have been refurbished and have gained MOD "List X" security status.
- A new 100m^2 high-bay laboratory underpins our work on **autonomous systems**. This space has been equipped with Vicon Vision Systems allowing the in-flight position of UAVs or robotic vehicles to be tracked and control algorithms to be optimised.

Supporting current and future research in aerothermal processes, NCCAT is the Unit's single biggest investment within the REF period. The £19m facility includes 850m^2 of purpose-built laboratory space incorporating 8 test cells. Specialist plant and equipment which provides the infrastructure to support single-phase and two-phase, non-reacting and reacting flow experiments over a unique range of conditions from sub-atmospheric to elevated temperatures and pressures (up to 900K, 11 bara). Test cells are instrumented with both high-specification traditional measurement techniques and advanced laser diagnostics. The Chief Technology Officer of the Aerospace Technology Initiative describes it as "the best facility of its kind in the world".

Our **energy** related work in CREST has received significant investment (ERA and EPSRC-funded, £5m total) over the REF period. New capability in thermal energy management and storage includes a guarded hot box calorimeter and Passy-type test cells for accurate characterisation and testing of advanced building facade systems, and an extensive suite of thermal characterisation equipment for accurate measurement of phase-change and thermochemical storage material properties. In solar photovoltaics, we have created a new fabrication and coating facility and enhanced environmental testing capabilities with thermal imaging and panel tracking equipment (EPSRC-funded, £1m).

LMCC is a core facility for **materials** characterisation with £7.5m of state-of-the-art analytical instruments for surface analysis, spectroscopy, electron and optical microscopy and thermal analysis. Seven specialist staff have supported nearly 300 internal researchers over the REF period with over 21,000 hrs of machine-time. The Centre has established a national reputation in focussed ion beam microscopy (FIB) and is one of the leading UK centres in 3D analysis of materials, Over the last five years the Centre has worked with over 125 companies including Rolls-Royce, Aston Martin, McLaren, General Electric (GE), and Electric Power Research Institute (EPRI)

Supporting the work of UKRI FLF (Martin-Fabiani), the EPSRC Strategic Equipment Award Integrated Atomic Force and Confocal Fluorescence Lifetime Imaging Microscope (£817k, 2019-22, Martin-Fabiani) provides a unique facility to understand the relationship between surface and bulk chemical properties in a variety of applications from photovoltaic semi-conductors to tissue engineering.

3.3.1 Collaborative Research Infrastructure

The HPC Midlands+ is the Loughborough-led Tier-2 High Performance Computing Centre (EPSRC, £3.2m, 2016-21, Director Kenny). Serving the Midlands Innovation (MI) group of universities and Queen Mary University of London, the facility underpins our work in

computational fluid dynamics (e.g., EPSRC-funded, UK Turbulence Consortium, £573k, 2013-18, led by Southampton, CoI Page) and materials (e.g., EPSRC Platform for Ensemble Computing, £3m, 2020-25, led Warwick, CoI Kenny). The HPC supports funded research, doctoral projects and provides researchers with up to 20,000 hours of 'seed time' to explore capabilities or to obtain pilot data to underpin research proposals.

As part of the €8m European Projects ESCAPE 1 and ESCAPE 2: Energy-efficient Scalable Algorithms for Weather and Climate Prediction at Exascale (2018-21, Szmelter) the Unit uses the Tier 1 Supercomputing Facilities at the European Centre for Medium-Range Weather Forecasting (ECMWF) in Reading. ESCAPE 2 is developing extreme-scale computing capabilities for European operational numerical weather and climate prediction, to provide the key components for weather and climate domain benchmarks to be deployed on extreme-scale demonstrators and beyond.

The Unit collaborates with other leading universities to build infrastructure where necessary. The EPSRC National Thin-Film Cluster Facility for Advanced Functional Materials (£461k, 2015-21, CoI Walls) is a world-leading resource for thin-film deposition located at University of Oxford. This unique facility places the UK at the centre of the development of next-generation materials and devices for applications in energy, photonics and electronics.

Section 4. COLLABORATION AND CONTRIBUTION TO THE RESEARCH BASE, ECONOMY AND SOCIETY

4.1 Support for Research Collaborations, Networks and Partnerships

Our commitment to delivering excellence in research and impact is evidenced through the collaborations that we have created with industry and leading research institutions on a regional, national and international scale. To support these partnerships, we have appointed RDMs and PDMs with additional specialist support from the University's International Office, Research and Enterprise Office, Library, and Doctoral College.

International collaborations are routine for individual academics, and section 3.1 showed the importance of consortia to our funding portfolio, especially EPSRC-funded research hubs and networks. In this subsection, we concentrate on collaborations at the Unit level.

In the Midlands region, Loughborough is a member of Midlands Innovation (MI), the strategic partnership of the Midlands' 8 research-intensive universities (with Aston, Birmingham, Cranfield, Keele, Leicester, Nottingham and Warwick). The Unit contributes at the most senior level to MI; Rothberg was inaugural chair of the (PVC-level) Executive Management Group and remains a member. MI supports the aims of the Midlands Engine and presents formidable research strength in energy, transport and health, in all of which the Unit is active.

Taking energy as an example, MI secured £60m government funding for capital, matched by £110m from industry, for the Energy Research Accelerator (ERA). Rothberg is the ERA Management Group Chair, and Eames and Garner are Research Committee members. The Unit is part of the Thermal-ERA Programme (T-ERA), creating new laboratories for pioneering new technologies from heating and cooling in domestic settings to large-scale energy storage for small modular reactors. With RDM support, we run strategic workshops (e.g., Nuclear Cogeneration: Workshop Royal Society 2019, Eames) and engage with policy makers (e.g., BEIS Mission Innovation Workshop, Abu Dhabi, 2017, Eames). The ERA partnership is active in securing research funding necessary to extract full value from ERA capital investment:

- Multi-scale Analysis for Facilities for Energy Storage (Manifest) (EPSRC-funded, £4m, 2016-21, 5 universities, led Birmingham, CoI Eames) – defining the future role of energy storage technologies to balance the supply and demand of energy in UK.
- Low Temperature Heat Recovery and Distribution Network Technologies (LoT-NET) (EPSRC-funded, £5.4m, 2019-23, 4 universities led Warwick. CoI Eames) – showing how waste heat streams can combine with optimal heat pump and thermal storage technologies to meet the heating and cooling needs of UK buildings and industrial processes.

The Unit leverages off ERA's regional focus to engage in large scale national collaborations such as EPSRC's Active Building Centre (£36m, 2018-20) and Active Building Centre Research Project (£9.3m, 2020-22) – a consortium of 10 universities led by Swansea with CoIs Eames, Walls – working to revolutionise the way the UK designs, manufactures, constructs and operates buildings.

Loughborough's Institute of Advanced Studies (IAS) is a focal point for established and emergent international collaboration, hosting 214 Fellows from 35 countries since launch in 2017 under its annual themes and its open programme for smaller-scale initiatives. Under the Motion Theme, for example, IAS Fellows Ozguner (Ohio State University) and Murray (California Institute of Technology) joined the Unit's Centre for Autonomous Systems, supporting our work on goal-oriented control that catalysed Chen's successful EPSRC Established Career Fellowship proposal.

Our international collaborations are also facilitated by exchanges, especially for PGRs supported by the Doctoral College. Our exchange programme in photovoltaics with Colorado State

University (CSU), the US leader in solar cell research, has allowed 6 PGRs (both institutions) to take 3-month secondments building the partnership between academics many of which have also made visits in the course of jointly authoring more than 40 journal papers. The scope of this collaboration widened with Prof. James (Head of Mechanical Engineering, CSU) spending her sabbatical year at Loughborough working on ceramic prosthetic devices with our materials group.

4.1.1 Key Research Users, Beneficiaries or Audiences to Develop Impact

Collaborating with research users is deeply embedded in the Unit philosophy and routine for individual academics. In this subsection, we provide examples of those partnerships in which we have significant Unit participation and active engagement at the most senior level (PVC/VC and Main Board membership).

Our formal partnership with **Rolls-Royce** dates back to 1991 but the opening of the **National Centre for Combustion and Aerothermal Technology (NCCAT)** in 2019 has taken even this most substantial of partnerships to another level**,** supporting the immediate objectives of CDT-FPP and sustaining the long-term plans of RR-UTC. As a national facility, NCCAT widens the scope for impact beyond aerospace and into automotive, defence, power generation and energy sectors; 75 engineers from industry can be accommodated on-site. Extensive test programmes are underway with Rolls-Royce but also with companies such as Bladon Jets, pioneer of micro-turbine generator sets.

In the Unit's **Caterpillar Innovation and Research Centre (Cat-IRC)**, academics work closely with Caterpillar staff on fundamental aspects of engine technology, including electronics and control methods. The relationship is managed directly form Caterpillar US headquarters, working with Perkins Engines in the UK and other company sites in UK and US. In addition to funded research, the relationship includes annual short courses, PGR sponsorship, recruitment (72 LU graduates and former research staff have been hired by Caterpillar since 2014) and support for initiatives such as Women in Engineering and Formula Student.

The Unit is a founder (with the Universities of Birmingham and Nottingham) of the **Manufacturing Technology Centre** (MTC), part of the High Value Manufacturing Catapult. The Unit provides Main Board leadership (Rothberg) and academic leadership in Intelligent Automation (Lohse). MTC has partnered on 7 significant EPSRC-funded research projects during the assessment period, while our joint PGR Scholarship Scheme (3/year) and staff exchanges (Webb, Morris) have enhanced knowledge exchange between the institutions. Notable successes include mechatronic tooling for Rolls-Royce (a Tier 1 MTC Partner) developed by CIM-IA that is estimated to reduce assembly costs of the current Trent Engine family by £2m and make next generation engines (e.g., UltraFan) possible (Jackson, Lohse).

The **Advanced Propulsion Centre (APC**) was formed in 2013 as a partnership between UK Government and the Automotive Council to position the UK as a global leader for low carbon powertrain. The Unit secured BEIS-funding (£6.4m, 2015-22, Rothberg) to establish the Institute of Digital Engineering (IDE) which leads the Automotive Council's Advancing Digitalisation Mission (one of three alongside Transition to Zero, and Mobility) and is the Digital Engineering spoke in the APC network (led Passmore). Garner is a non-executive director of APC (2014-). The success of our partnership is evident in the Unit's 6 substantial APC projects (total value £79m). The Virtual Vehicle Integration and Development project (with Ford, McLaren, IPG), for example, was recently showcased in an IDE event attracting over 250 delegates from industry, academia and UK Government as an exemplar of Validated Digital Engineering tools. With Unit leadership (West) and collaboration through IDE with the High Speed Sustainable Manufacturing Institute, a Digital Readiness Level Tool was developed to enable companies of all sizes to improve their digital maturity. Nationwide workshops have been delivered by the Digital and HVM Catapults, and Knowledge Transfer Network to maximise impact of the Tool.

4.1.2 Wider Contributions to the Economy and Society

The Unit engages with government and its initiatives in a wide variety of ways to deliver societal impact. We describe 3 diverse examples here:

- **Secondment to BEIS.** At the invitation of the former Minister of State for Universities, Science, Research and Innovation, Caine was Head of Innovation Ecosystems (2019-20). His pilot study (£350k), delivered by Loughborough and MIT, supported 10 LEP regions across England to accelerate the deployment of their Local Industrial Strategies. BEIS have invited a multi-million-pound scale-up proposal to roll out this intervention nationwide.
- **Major regional interventions**. The Midlands Industrial Ceramics Group (MICG) combines the research strengths of Loughborough, Leicester and Birmingham universities and 22 companies, and is predicted to contribute 4,200 jobs to the region by 2030. Focussed on advanced ceramic materials and high value products, including functional ceramics developed by the Unit (Vaidhyanathan), the MICG has been successful in winning seed-corn funding to prepare a full bid to the UKRI Strength in Places Fund.
- **Nationally significant projects**. Detonation of unexploded ordnance poses a hazard to offshore windfarms and marine wildlife. Our work with the National Physical Laboratory has demonstrated a new method with significantly reduced peak pressure waves compared to conventional detonation. The Minister of State for Business, Energy and Clean Growth is aware and its significance for marine wildlife has been championed by actor and campaigner Joanna Lumley (https://www.bbc.co.uk/news/av/uk-politics-55996538).

4.1.3 Engaging with Diverse Communities and Publics

The Unit has an active outreach programme targeting a range of audiences from potential STEM students, through to groups who are underrepresented in STEM. Sponsored by the Ford Fund since 2017, Girls into STEM welcomes more than 50 Year 10 students to the Loughborough campus each year for a free 4-day residential event with a series of academic workshops and talks covering topics including energy, solar cars, fuel cells and a team project to raise interest in STEM subjects. The Unit also contributes to the National British Science Week (annually in March) through our STEM Community Day aimed at school children and their families (attendance in 2019 exceeded 1500). ‘Hands on’ activities include a laser-cut human-scale spirograph.

Outreach activities are extensively supported by ECRs. PGR Lewis Wright won the outreach competition ‘I’m a Scientist, Get me out of here!’ (2017), using his prize money to commission a video to promote solar panels and renewables. Senior Unit staff are equally engaged; since 2014, Prof. Whittow has given more than 100 talks promoting equality in Engineering including invited talks at the 3M Young Innovators Challenge Awards and the Girls Day School Trust. Whittow has built up > 40,000 Twitter followers for his content on engineering education and he was the inaugural winner of the Women’s Engineering Society (WES), Men as Allies Award (2017), and a Finalist in the Everywoman Male Agent of Change Award (2018). In 2020, WES made him their first Associate Fellow and invited him to speak at the 2020 WES Student Conference.

4.2 Contribution to the Sustainability of the Discipline

Unit academics are encouraged to take leading roles in the development of the discipline such as the **organisation of topical conferences and workshops**.

- The Loughborough Antennas and Propagation Conference (Chair Vardaxoglou, 2005-18) has pioneered a range of topics from mobile phone antennas to future metamaterial concepts, attracting more than 250 delegates each year (now the IET Antennas and Propagation Conference, Birmingham, 2019, online in 2020).

- In control engineering, the Unit hosted Control 2014 the bi-annual UK conference of the International Federation of Automatic Control (Chair Dixon, Co-Chair Ward) with over 150 delegates and Mechatronics 2016 bringing together two international conferences to the UK (7th IFAC Symposium on Mechatronic Systems and 15th Mechatronics Forum (IMechE)) (Chairs: Dixon, Goodall).
- In automotive engineering we hosted Powertrain Modelling and Control (PMC2016, Chair: Ebrahimi, Co-Chairs Chen, Hargrave, Stobart) leading to 2 Special Issues: IMechE Part K, 2017, 231(3), and International Journal of Powertrains, 2018, 7(1-3). We have also hosted TriboUK (2015) – an international conference on tribology for ECRs, attracting over 60 PGR speakers with delegates from academia and industry (Mohammad-Pour).

Working with the European Structural Integrity Society (ESIS), Silberschmidt's group has **progressed the field of biomaterials**. The ESIS TC 14 - Integrity of Biomedical and Biological Materials (Chair Silberschmidt) focuses on characterisation and testing protocols for biomedical materials within the ESIS' flagship European Conference on Fracture. Related work was presented at the Unit's inaugural International Conference on Stents Materials, Mechanics and Manufacturing ICS3M that was delivered on the London Campus (ESIS/EPSRC-sponsored, 2019, Zhou).

The Unit encourages participation in national and international **standards committees**:

- Tyrer chairs IEC WG7 TC76 High Power Lasers and BS EN 60825-4. Safety of laser products. Part 4. Laser guards
- Strickland is Vice-Chair of the IEEE working groups for standard P1459 Power System Instrumentation and Measurements & P120 Electrical Measurements in Power Circuits

Membership of other standards committees include:

- ISO WG10 TC213 Dimensional and geometrical product specifications and verification (Kinnell)
- ISO TC43 SC3 Underwater acoustics and IEC WG11 TC114 Marine energy – Wave, tidal and other water current converters (Lepper)
- BSI IST/15 Software and systems engineering (Henshaw)
- BSI PH/006/06/03 Revision of BS 7928 cricket helmets (Harland)

4.2.1 Response to National and International Priorities and Initiatives

Working closely with national programmes (e.g., Catapults, APC) and through our industrial partnerships in **aerospace** (e.g. Rolls-Royce, Airbus), **automotive** (e.g., JLR, Caterpillar) and **manufacturing** industry (e.g., Ford, AstraZeneca) we have established work programmes that closely align to the UK Industrial Strategy.

Since 2014, we have also responded to international priorities with funding from the Global Challenges Research Fund (GCRF), Science and Technologies Facilities Council (STFC) and Newton Fund. Major examples (>£1m) include:

- Our work in autonomous systems and control included Enabling Wide Area Persistent Remote Sensing for Agriculture Applications through Developing and Coordinating Heterogenous Platforms (STFC Newton Agri-Tech Fund, £1.5m, 2016-19, Chen) – a successful collaboration with North West A&F University (China) and China Agricultural University. The project developed UAV technologies that were subsequently deployed in crop health monitoring and targeted intervention/treatment.
- The Loughborough-led JUICE: Joint UK-India Clean Energy Centre (EPSRC Newton-Bhabha Fund, £5m, 2016-21, Thomson) has brought together internationally leading experts in photovoltaic technology, electricity networks and energy storage from 9 UK and 9 Indian universities (led by IITs). With project partners including E.On, Tata Steel and the National

Grid, modelling chains have been created allowing forecasting, control and optimisation of clean energy supply in power systems as well as microgrids. JUICE has trained engineers and practitioners in the clean energy industry, through industry facing workshops, direct training of staff involved in the research and associated PGR projects within the partner universities.

- In communications, Flood Prediction Using Real Time Sensing Emergency Water Information Networks over mobile phone networks and WiFi (GCRF, £1.5m, 2017-21, Edwards) is a partnership with the National Autonomous University of Mexico supported by small companies with expertise in the fields of water engineering and embedded electronics. The project has delivered an advanced radio propagation model allowing scientists to design reliable radio communications between flood sensing stations in the dense Mexican tropical jungles of Colima. Analysis is enabling the water engineers to design water retention schemes to reduce flooding.

Our largest scale project is the biggest the University has ever led at £38m. The 5-year research programme on Modern Energy Cooking Services aims to transform the way people cook in low-income countries by focusing on the use of clean electricity and other modern fuels. This Foreign, Commonwealth and Development Office funded project is a partnership with the World Bank led by Brown (Geography, returning to C14) and Unit member Blanchard, trialling practical, sustainable solutions to bridge the gap between rhetoric and action.

4.3 Indicators of Wider Influence

Our strategy during the assessment period has included a commitment to excellence in research and the delivery of impact through industrial partnerships. Our success can be seen by the influence we have had within engineering, evidenced by recognition in professional institutions and learned societies, advisory roles, editorial roles, keynote addresses and the prizes awarded to our distinguished colleagues.

4.3.1 Professional Institutions and Learned Societies

Unit staff are active within the **Professional Institutions** (IMechE, IChemE, IMMM, RSC, IET, IEEE). 112 staff are recognised as Members/Senior Members of at least one Professional Institution and 51 staff hold Fellowships (including 2 recently conferred as Fellows of IEEE, Chen 2019 and Zheng 2020). Of note is a doubling of the number of **Fellows of the Royal Academy of Engineering** from 4 (Williams, Goodall, Vardaxoglou and McGuirk) in 2014. The distinguished contributions recognised by Academy Fellowships in the assessment period are:

- Garner (2015) for technologies adopted by the international automotive and engine industry.
- Novac (2016) for pulsed power technology and its applications.
- Thomson (2018) for her work on lifetime and environmental performance of power generation components.
- Carrotte (2020) for contributions to gas-turbine combustor aerothermal technology.

All four careers are characterised by significant influence with industry partners, evidenced further by Carrotte's Rolls-Royce/RAEng Chair in Aerothermal Technology. Kalawsky was also recognised with an Airbus/RAEng Chair in Digital and Engineering Information Systems.

4.3.2 Advisory Roles

Participation in **special interest groups and advisory boards** at all career stages is encouraged, to contribute to the vitality of the discipline. Membership examples include:

- EPSRC Early Career Forum (Justham 2014-16, Woolley 2016-18, Midgely 2018-21)
- UKRI H2FC Supergen Science Board (Members: Chen, Jackson, Malalasekera, 2013-)

- BioProNET Steering Group (Member: Coopman, 2016-19)
- IMechE Mechatronic, Informatics and Control Division Board (Members: Ebrahimi 2002-, Ward 2018-)
- IMechE Process Industries Division Board (Member: Xuan 2018-)
- JISC Research Strategy Forum (Member: Rothberg 2018-)

Memberships often progress to **positions of responsibility** on influential committees such as: IChemE Fluid Mixing Processes (Chairs: Rielly 2008-14, Ozcan-Taskin 2014-); EPSRC UK Fluids Network Fluid Mechanics of Nanostructured Materials (Chair: Vladisavljevic 2017-) EPSRC UK Fluids Network Ground Vehicle Aerodynamics Group (Chair: Passmore, 2016-20) Object Management Group Mathematical Formalisms Working Group (Chair: Dickerson, 2013-); Solar Energy Industrial Special Interest Group (BEIS) (Co-Chair: Walls, 2012-16); EPC Consortium of UK University Manufacturing and Engineering (Chair/Vice-Chair: Case, 2013-18); IMechE East Midlands Automotive Division (Chair: King 2001-); National Centre for Universities and Business (NCUB) Advisory Group for the 'Research to Recovery' Report (Co-Chair: Caine, 2020).

Important examples of more senior and **strategic advisory roles** include Garner's membership of the Automotive Council R&D Committee (2009-), Henshaw's membership of the International Council on Systems Engineering (2008-), and **UKRI strategic advisory** roles including:

- Manufacturing the Future Strategic Advisory Team (SAT) (Member Coopman 2014-17, Member: 2014-16, Chair Conway 2017-19)
- Research Infrastructure SAT (Chair Thomson 2017-19)
- Energy Strategic Advisory Committee (SAC) (Member Eames 2017-)

We encourage all staff to participate in the grant review process and join prioritisation panels when possible. The Unit includes 36 Full and 21 Associate Members of the **EPSRC Peer Review College** with, for example, Unit staff sitting on 14 EPSRC Prioritisation Panels (2 Chairs) in the 12 months to 31st July 2020.

Senior colleagues are often invited to **international review panels** e.g., Panel Chair for the funding of the Energy programme in the topic Energy Efficiency, Materials and Resources, Helmholtz Association in Germany (Eames, 2014). Member of the Review Panel National Sciences and Engineering Research Council of Canada (NSERC) for the award of 3 significant academic research prizes (Thomson, 2019, 2020); Finnish Academy of Science Flagship Panel (Eames, 2018); Irish Science Foundation Panel (Case); and Royal Academy of Engineering (RAEng) New Fellows Panel (Transport and Mechanical) 2016-18 (Garner). In 2015 Prof. Garner was an Engineering Panel Member in the Hong Kong University Grants Committee Research Assessment Exercise (RAE). Profs Conway and Garner are serving on REF2021 B12 Engineering Assessment Panel.

4.3.3 Editorial Roles

During the REF period, 79 academic staff served on the Editorial Boards of prestigious journals, 24 as editors/associate editors. As Editor-in-Chief of IMechE: Part D **Journal of Automobile Engineering** (2005-19) Garner took the Journal's impact factor from 0.25 to >1.2 with an increase in number of high-quality, international submissions (>500) and 12-14 substantial issues each year. Similarly, leadership of IMechE: Part E, **Journal of Process Mechanical Engineering** (2009-19, Backhouse) and Part K, **Journal of Multi-Body Dynamics** (Rahnejat, Associate Editors: Ebrahimi, Dolatabadi) has established these titles internationally. Silberschmidt was founder and Editor-in-Chief of **Mechanics of Advanced Materials and Modern Processes** (Springer, 2014-20). Li Puma is Editor of **Journal of Hazardous Materials**.

Other Editorial Board memberships include Biotechnology Letters (Coopman), ASME Journal of Autonomous Vehicles and Systems (Chen), ASME Journal of Electronics Packaging (Conway), Journal of Production and Manufacturing Research (Case), International Journal of Powertrains (Ebrahimi), Journal of Applied Biomechanics (Forrester), IMechE Part O, Journal of Risk and Reliability Modelling (Jackson), IEEE Transactions on Signal Processing (Lambotharan), IET Journal of Power Electronics (Strickland), Energies (Walls), IEEE Transactions on Intelligent vehicles, IEEE Robotics and Automation Society (Zecca), and Journal of Production and Manufacturing Research (Goh).

4.3.4 Keynote Addresses

Since 2014, 78 colleagues have delivered keynote presentations at major conferences.

In **materials**, Vaidhyanathan has delivered keynote plenary lectures addressing ceramic manufacturing and processing to the 16th and 17th International Conferences on Microwave and High Frequency Heating (AMPERE) (Delft, 2017 and València, 2019). Silberschmidt delivered a keynote lecture at the World Congress on Computational Mechanics for 3 consecutive events (2014, 2016, 2018). Zhao has been a keynote speaker at the 7th International Conference on Computational Methods (Berkeley) and the 5th Annual World Congress of Advanced Materials (Chongqing) (both 2016). Wang gave a plenary lecture at the 14th International Conference on Fracture 2017 (the world's leading conference on fracture held every 4 years) and organised a special symposium on “mechanics of interface fracture”.

In **energy,** Strickland was a keynote speaker at the 13th IET International Conference on AC and DC Power Transmission (Manchester, 2017). Yu was a keynote speaker at an International Water Association (IWA) Scientific Summit: Urban Water in Beijing and a plenary speaker at British Council UK-Vietnam Workshop on Green Electrochemical and Materials Processing for Environment and Energy Challenges (2018). Lin gave a keynote lecture at the 3rd World Congress on New Technologies (Rome, Italy, 2017) on Direct Alcohol Fuel Cells.

In **automotive** engineering Page delivered the opening lecture at the 1st Workshop on Automotive CFD Prediction (Oxford 2019), Szmelter has delivered keynote lectures on unstructured meshes at consecutive European Conferences on Computational Fluid Dynamics (2016-2018).

In **manufacturing** and process engineering, Conway gave a keynote presentation at the 20th World Micro Machines Conference, Sao Paulo, Brazil (2014). Li Puma has delivered 9 keynote lectures at IWA conferences and symposiums (2014 to 2019).

In **sports technology,** Zecca gave a keynote talk to the 3rd Annual Sports Medicine Conference, Abu Dhabi (2018) and Harland gave a keynote lecture – An Engineering Led Approach to Reducing Head Injuries in Cricket – at the 4th International Congress on Sport Sciences Research and Technology Support, Porto (2016).

In **autonomous systems and Control**, Chen gave an invited keynote on Electrochemical Impedance Spectroscopic Analysis of PEFC Stacks to the 5th Asia-Pacific Forum on Renewable Energy (2015), Korea. Henshaw has delivered keynote talks to IEEE Conferences in Systems of Systems Engineering (Adelaide, Australia, 2014) and Computer, Communication and Control (Indore, India, 2015) covering the challenges in Systems of Systems Engineering and the risks and opportunities in the Internet of Things.

4.3.5 Prizes and Awards

During the assessment period, 61 academics received prizes and awards for their work including 10 ECRs who have received prizes for publications and presentations (e.g., Baxevanakis: Best

paper award for 2018 in ASME Journal of Nondestructive Evaluation, Diagnostics and Prognostics of Engineering Systems). Notable awards include:

- Novac is the first scientist outside of Russia or the USA to be awarded the **Pavlovsky Prize** (2016) by the Russian Academy of Sciences; the IEEE **Sol Schneider Award** (2016) recognised his contributions to compact and repetitive pulsed power technologies.
- Eames was awarded the 2018 **Harry Leck Memorial Medal** for invention of low-temperature vacuum insulated glazings for buildings, electrochromic vacuum insulated glazings and the development of advanced vacuum flat-plate solar thermal collectors.
- Vaidhyanathan was awarded the 2015 **Verulam Medal** for distinguished contributions to ceramic materials.
- Higginson received the 2018 **Stokowiec Medal and Prize** in recognition of her distinguished work related to the technical, manufacturing, processing or engineering application of alloy steels, including stainless steels.
- Xuan received the 2020 **Beilby Medal and Prize** awarded by the Society of the Chemical Industry for his work on reaction and thermofluids engineering, the aim being to achieve clean growth, sustainable development and industrial decarbonisation.
- Williams, founder of the Centre for Biological Engineering, was awarded his OBE in 2014 for services to Science and Engineering and in 2016, the **Donald Medal** (IChemE) for his lifetime contribution to the regenerative medicine sector.