Institution:	**Loughborough University**
Unit of Assessment:	**B12 Aeronautical, Mechanical, Chemical & Manufacturing Engineering**

a. Overview

Research in this Unit of Assessment (UoA) is centred around the School of Aeronautical, Automotive, Chemical & Materials Engineering (AACME) and the Wolfson School of Mechanical & Manufacturing Engineering (Wolfson). Research is managed via 8 multidisciplinary Research Themes that span both Schools. Each Research Theme has a Theme Leader who Chairs the Theme Research Committee meetings and reports back to quarterly meetings of the Schools' Research Committees, which are Chaired by the Associate Deans for Research. This feeds into the meetings of School Senior Management Teams. Many academic staff make contributions to more than one Research Theme. There are also extensive interactions between the Themes, which are illustrated in the subsequent text. In alphabetical order, the Research Themes are *Advanced Materials*, *Applied Aerodynamics*, *Dynamics, Healthcare & Pharmaceuticals*, *Manufacturing*, *Optical Engineering*, *Process Engineering* and *Thermofluids*.

b. Research strategy

Our research spans Technology Readiness Levels (TRL) 1 – 7 through 6 EPSRC Centres for Innovative Manufacturing (e.g. IMRC in Regenerative Medicine, TRL 1 – 3), 4 industrially funded Centres (e.g. Rolls Royce University Technology Centre (UTC) TRL 2 – 4), the Manufacturing Technology Centre (MTC, TRL 4 – 6) and 10 spinout companies (e.g. Progressive Sports Technologies, Micropore Technologies, TRL 6 – 7). Indeed, the growing importance of linking Research with Enterprise has led to the creation, in the last 3 years, of 2 new Associate Deans for Enterprise, one for each School, operating at a senior management level to ensure from the outset that our research has impact. Some of the Research Themes map directly onto the research structure that existed in RAE2008 with only relatively minor changes in the magnitude or direction of the research undertaken; these include *Advanced Materials*, *Process Engineering*, *Thermofluids* and *Optical Engineering*. For these reasons our ***strategic aims*** for the REF period, following on from the RAE 2008 submission, were to ***i) carry out world class industrially-relevant research that would change and influence society at large, ii) focus on internationally leading work that has the potential for academic, social and/or economic impact, iii) disseminate our key findings through publication in the best journals and presentation at leading conference events and iv) grow not only our existing research strengths but also to develop and explore nascent areas.*** In pursuit of these strategic aims we have spent over £74M on research activities over the assessment period with an additional £13M cash from industry. The £6M pa QR income received across the UoA has been used strategically to grow areas of strength and to reshape the environment so that new areas of research emerge and are encouraged to develop. Consequently, the *Manufacturing* Theme has grown substantially indeed it won a **Queens Anniversary Prize for High Value Manufacturing (2012 – 2104)**, the *Dynamics* Group has combined with the *Structural Mechanics & Acoustics* and the *Control & Reliability* Groups to form a single Theme entitled *Dynamics,* and new avenues of research are also being explored within this Theme, e.g. autonomous vehicles. New Themes have also been developed, e.g. *Healthcare & Pharmaceuticals* with an emphasis on the new industry of regenerative medicine and drug delivery systems. We envisage further evolution as the University develops and moves to a new Research Strategy post-2014 where the aim will be *'to support curiosity-driven scholars alongside a strategy which sets out an innovative, cross-disciplinary and ambitious application-facing research agenda'*.

Assessment Period	Research Spend per annum	Publications			PhDs/EngDs awarded per annum	Staff Return (FTE)
		Journals	*Books*	*Conf.*		
RAE96	£3,091,388	853	26	854	13	63.70
RAE01	£4,372,995	1292	31	1198	23	60.06
RAE08	£8,785,994	1719	31	1572	59	143.43
REF14	£14,813,719	2415	30	1450	73	127.40

We have met all of our objectives since 2008. For example, amongst other developments key research by the UoA has developed and verified complex models for predicting the changes in the

microstructures and hence properties of materials used in conventional power plant, enabling their lifespans to be significantly extended (*Advanced Materials*); provided an enhanced understanding of industrially-relevant aeronautical and automotive flow problems (*Applied Aerodynamics*); developed metamaterials for noise and vibration control (*Dynamics*); demonstrated the first larger-scale cultivation and recovery of fully functional human mesenchymal stem cells in a conventional stirred tank bioreactor (*Healthcare and Pharmaceutical*); showcased new methods for surgical simulation and training (*Manufacturing Engineering*); developed a theoretical framework to characterise 3D microscopy and tomographic imaging systems (*Optical Engineering*); provided multi-dimensional population balance modelling, for systems ranging from microfluidic and droplet crystallization systems to large-scale industrial processes (*Process Engineering*) and developed new sub-models for turbulent mixed combustion (*Thermofluids*).

Overarching strategic aims moving forward are extending our research into the manufacture of nanostructured ceramic materials for a wider range of applications, e.g. bio-replacements, electronics and ballistic armour (*Advanced Materials*); developing combined aerodynamic/two-phase flow/aero-acoustic measurements (*Applied Aerodynamics*); exploring the acoustic black hole effect for sound absorption in air and for noise control in enclosures (*Dynamics*); developing innovative non-invasive imaging solutions and analytical tools for bioprocessing (*Healthcare and Pharmaceuticals*); developing novel electronics manufacturing processes and surface coatings to non-planar substrates and other complex product shapes (*Manufacturing Engineering*); using optical diagnostics to advance greener technology in the automotive and haulage industries (*Optical Engineering*); facilitating high-value manufacturing based on process engineering principles (*Process Engineering*) and understanding the science behind fuel cell degradation (*Thermofluids*). Given this submission's large size, further discussion on research infrastructure, evaluation post-2008 and future strategic plans are presented theme-by-theme.

Key Facts since 2008

- Membership of 23.2 FTE
- £12M external funding
- New Laboratories for Advanced Friction Materials and Materials Degradation
- £1.3M in new characterisation equipment

Advanced Materials: Since 2008 work has focused on five key areas; *Advanced Ceramics, Energy Materials, Advanced Polymers, Surface Engineering* and *Mechanics of Materials*. We adopt an interdisciplinary approach to our research enhanced by very significant interactions with other Schools within LU; the university's virtual Materials Research School has around 110 members from across the University. The work also involves collaborations with other world-class Universities (e.g. Imperial College, Lyon, Oxford, Maryland), industry (e.g. Alstom, EPRI, Bentley Motors, Ford, Pepsico, Rolls-Royce plc) and research bodies (e.g. The Royal Society, DSTL, Japanese National Institute for Materials Science, Max Plank Institute for Polymer Science, US Air Force Research Labs). Research has centred on the engineering design, processing and use of a very wide range of new and existing materials and includes multi-scale analysis of many processes including damage, fracture and the effect of impact loading on applications ranging from adhesive joints for aerospace to bone tissue, sports equipment to armour and degradation in all classes of materials. We have state-of-the art, world-class facilities for use in materials synthesis, processing and characterisation, which support our research. The Loughborough Materials Characterisation Centre, LMCC (http://www.lboro.ac.uk/research/lmcc/) has a wide range of analytical techniques, e.g. electron microscopy and surface science, some of which have capabilities unique within the UK, e.g. the 3D EDS/EBSD. This uses a combined focused ion beam (FIB) and scanning electron microscope (SEM) to produce a 3 dimensional map of a material's microstructure; unlike other UK facilities, our instrument can simultaneously acquire chemical and crystallographic information. Since 2008 we have invested ~£1.3M in capital funds in advanced electron microscopy and analytical techniques within LMCC, including in the last 12 months alone, a new X-ray photoelectron spectroscopy instrument, X-ray diffraction facilities across the campus and a field emission gun transmission electron microscope system with extensive analytical capabilities. We have also been leading in the national equipment sharing agenda through the development of our award winning software, Kit-Catalogue™ which is now being used in >20 Universities worldwide.

We have also targeted growing areas of research, including creating a Materials Degradation Centre and a dedicated laboratory for Advanced Friction Materials and a new Furnace Room; refurbishment of our laboratories for polymer research (completion autumn 2013) is to be followed

by those used for our advanced ceramics research (completion spring 2014). The acquisition of major grants has underpinned the research in our major areas of interest with very significant funding for ultra high-temperature ceramic materials (£1.8M, *Advanced Ceramics*), disentangled UHMWPE (£1.5M, *Advanced Polymers*), friction materials and mitigating tin whiskers (£331k, *Surface Engineering*), developing materials for future power plant technologies (£6M, *Energy Materials*) and the macro, micro and nano aspects of machining (£448k, *Mechanics of Materials*). A relatively new addition to the portfolio has been a focus on biomaterials with a view to using multi-scale combined Smoothed Particle Hydrodynamics – Finite Elements (SPH-FE) numerical tools to study the effect of tool-bone interaction in surgery and the development of nanostructured dental ceramics.

Future Strategic aims include: (i) extending our research into the manufacture of nanostructured ceramic materials to a wider range of applications, e.g. from bio-replacements through electronics to ballistic armour (*Advanced Ceramics*); (ii) expanding the development and implementation of materials for power-generation applications and so helping to maintain a secure, sustainable and affordable energy supply (*Energy Materials*); (iii) enhancing our multi-disciplinary collaboration with specialists in healthcare engineering and biophysics on artificial soft tissues to underpin research into smart prosthetics (*Mechanics of Materials*).

Key facts since 2008

- Membership of 9 FTE
- 2.5 m^2 test section low-speed wind tunnel
- 700 m^2 UTC aero, acoustic, 2-phase flow and heat-transfer test facilities
- Specialist PIV, PDA, acoustic and liquid crystal instrumentation
- 140 m^2 UTC workshops
- 12 patents granted or pending (EP/US)
- £5M external funding

Applied Aerodynamics: Since 2008 work has focused on experimental and computational research that has led to an enhanced understanding of industrially relevant aeronautical and automotive flow problems. The largest single activity is the Rolls-Royce UTC in Combustion System Aero-thermal Processes. Established in 1991, this has continued to grow and now has an annual income in excess of £1.5M, roughly evenly distributed between EPSRC, EU, TSB and Rolls-Royce. In 2008 the UTC opened a state-of-the-art £3M Unsteady Fluid Mechanics laboratory. Notable achievements include experimental and numerical research into combustor and installation aerodynamics, combustor/compressor and combustor/turbine interface optimisation, and combustor and fuel injector aero-acoustics. There has also been a major expansion into two-phase flows and heat transfer/cooling applications. The work has produced 12 (European and US) patent applications. Academic collaborators include Cambridge, Oxford and Southampton and, in the EU, Karlsruhe, Darmstadt, Chalmers, TU Munich and Graz. In addition, the UTC regularly collaborates with European research organisations such as DLR and CNRS. The UTC has access to world-class computational, experimental and instrumentation capabilities, with 14 test cells including a unique electro-pneumatic driven 165 dB aero-acoustic rig, 3 fully annular combustion rigs, and a unique refractive index matching facility. Computational research is primarily focused on the development of Large Eddy Simulation (LES) CFD, both numerical algorithms and physical modelling (e.g. LES application to primary breakup of liquid jets via air-blast atomisation) and their validation in high-fidelity/large-scale applications, for example, jet aero-acoustics, low observable supersonic jet plume development relevant to military applications, and transition control on swept wings. Computational research is very well supported by the LU 1956-core high-performance computing (HPC) cluster and the recent addition of the 3000-core EPSRC-funded HPC-Midlands facility. The low-speed experimental aerodynamics activity has continued to expand with investment in a 3-component planar PIV system for the large 2.5 m^2 working section wind tunnel; this is supporting EPSRC/JLR-funded automotive research into base pressure recovery, cross-wind stability and passive and active methods of flow control.

Future strategic aims include: Expansion of the Rolls-Royce UTC laboratories over the next five years, in conjunction with the awarding of a Rolls-Royce/Royal Academy of Engineering Chair in May 2013, to extend capabilities into: (i) solid/fluid heat transfer/cooling, (ii) instrumentation calibration, (iii) combined aerodynamic/two-phase flow/aero-acoustic measurements, (iv) high-pressure fuel spray studies. The recently awarded £1.8M Programme for Simulation Innovation funded by EPSRC in a strategic partnership with Jaguar Land Rover builds on existing modelling and experimental capabilities.

Dynamics: Following on from the success of our long-established fundamental science base in multi-body system dynamics, control, vibration of structures and acoustic emission (RAE 2008), the 3 original Groups; *Dynamics*, *Structural Mechanics & Acoustics* and *Control & Reliability* are now integrated under the core discipline of *Dynamics*, creating a unique environment that has attracted 4 "new-blood" academic staff. Working with a range of industrial collaborators, including BP, BAE Systems, Ford, JLR, Aston Martin, AstraZeneca, 3M, the research is aimed at addressing key global and national imperatives, comprising: (i) *Energy conservation and environmental protection*: with the exemplar of mitigation of parasitic frictional and errant dynamic losses (thus improving fuel efficiency and reducing emissions) in IC engines with an EPSRC-funded Program Grant, in collaboration with Universities of Sheffield and Cranfield, and industrial partners BP, Aston Martin, ProDrive, Capricorn, Ricardo and ES Technology (£3.2M). Improved specific fuel consumption of the order of 2-3% has been achieved and the project has also resulted in state-of-the-art laser-textured surfaces for cylinder liners using advanced coating technology such as DLC or Ni-SiC as well as *in situ* direct in-cylinder friction-evaluation technology, applied to engines for the prestigious Le Mans race. (ii) *Environmental noise and vibration protection:* in addition to the *Encyclopaedic* Program Grant, also addressing engine cylinder-induced noise pollution, other exemplars of environmental vibration and acoustic protection include international and national collaborations (Universite du Maine, France and Open and Salford Universities) on the important topic of acoustic black-hole and its application to structural vibration damping (as a part of a recent EPSRC project), and to tyre cavity noise in collaboration with Jaguar-Land Rover, further expanding the tyre traction research, also sponsored by the EPSRC. Another major industrial noise and vibration issue is transmission rattle, the subject of a EPSRC-funded project in collaboration with Getrag, AVL and GKN that is seeking to limit the effect of engine torsional vibration upon torsional impact and acoustic emission from idling gear pairs, attracting further funding from Ford USA. A semi-anechoic chamber, a reverberation chamber and a full range of power and drivetrain instrumented rigs, including laser vibrometry and free-field microphones are created and support a diverse growing range of RC funded research in collaboration with industry.

Key Facts since 2008
- Membership of 26 FTE
- 250 m^2 fully instrumented drive train laboratory
- State-of-the-art engine testing facility with precise tribo-dynamic evaluation
- Autonomous Systems Laboratory for ground and aerial vehicle tracking system
- Anechoic chamber, rolling road and transient engine testing dynamometry
- Extensive industrial collaborative research
- £5M external funding

Future strategic aims include: (i) increasing capability of the research in all areas of dynamics with more emphasis on energy efficiency and harvesting, as well as NVH refinement for engine and powertrain systems; (ii) development of new meta-materials for noise and vibration control and exploring the new methods for sound absorption in air and for noise control in enclosures (acoustic black-hole effect); (iii) creating research activities in unmanned/autonomous/semi-autonomous vehicles for aeronautical and automotive applications.

Healthcare and Pharmaceuticals: Work post-2008 has been focused in the new, fully integrated 'innovation-to-product' Centre for Biological Engineering (CBE). The vision is to enable Loughborough's engineering strength to be developed at a direct interface with biology and medicine. Activities within the CBE are positioned in the translational space between scientific discovery and the production of cell-based biological products, techniques and therapies. We believe that it has now earned the reputation of being the major UK National Centre for late-stage process-oriented research in Regenerative Medicine; indeed, the CBE is one of only four such groups in the world (the others being Toronto, Georgia Tech and Singapore). Within the reporting period a strong multi-disciplinary research team with skills ranging from clinical and pharmaceutical, through biochemistry, biotechnology and tissue engineering to

Key Facts since 2008
- Membership of 17 FTE
- 650 m^2 of Class 2 laboratories and a dedicated cGMP suite
- £20M external funding
- EPSRC CDT in Regen Medicine
- EPSRC CIM in Regen Medicine

mechanical, chemical and polymer engineering has been created. Facilities include a suite of Class 2 laboratories for human cell growth, with a state-of-the-art analytical suite to service all laboratories. A second self-contained laboratory suite is dedicated to cGMP operation. Equipment available includes a range of cell-culture vessels, automated cell-culture platforms (e.g. AMBR and CompacTSelect), fluorescence-activated cell sorting, fluorescent and confocal microscopy as well as other imaging and analytical techniques. Key achievements since 2008 include: (i) the creation of technology platforms for the cGMP bioprocessing of a wide range of important human cell types. Industrial interaction with e.g. Lonza, Fujifilm and AstraZeneca has led to notable breakthroughs, including the first automated cell culture of human embryonic and mesenchymal stem cells and innovative larger-scale cultivation and recovery of fully functional human mesenchymal stem cells in a (5L) conventional stirred tank bioreactor; (ii) understanding the electrophysiology of neural cells; (iii) understanding flow control in metered dose inhalers and aerosolisation of solutions for gene therapy. The CBE is home to the £7.5M EPSRC Centre for Doctoral Training (CDT) in Regenerative Medicine, £5M EPSRC Centre for Innovative Manufacturing in Regenerative Medicine and the £3.3M EPSRC Landscape programme 'Engineering Tissue Engineering and Regenerative Medicine'. Core partners actively involved with the management, evolution and delivery of the CBE have been carefully chosen as representatives of key industrial and agency stakeholders and include, but are not limited to, Fujifilm Diosynth (CMO), GSK (Pharma), Pfizer (Pharma), GSK (Pharma), Future Health (SME), Pall (Equipment Manufacturer), TAP Biosystems (Equipment Manufacturer), Smith and Nephew (Medical Technologies), National Institute for Biological Standards and Control (Regulatory) and the Cell Therapy Catapult (UK Government-funded Technology and Innovation Centre of Excellence, with whom we have signed an MOU). Importantly, we have also entered into fully reciprocal arrangements with two international partner Universities; the Technical University of Lisbon, Portugal (Prof. Joaquim Cabral) and Georgia Institute of Technology, USA (Prof. Robert Nerem and Dr Todd Mcdevitt). The partners will actively participate in research exchange programmes, co-supervise PhD projects and will support secondments to all of our research teams.

Future strategic aims include: (i) increasing capability in biological sensing and closed-loop control of bioprocesses; (ii) exploring larger-scale bioprocessing issues in regenerative medicine and synthetic biology that align with our capability; (iii) developing imaging solutions and analytical tools for bioprocessing; (iv) providing cryopreservation platforms for emerging industrial and commercial cell types.

Key Facts since 2008

- Membership of 21 FTE
- Queens Anniversary Prize (2012-2014)
- EPSRC CIM in Intelligent Automation (£5.6M)
- EPSRC IeMRC (£9.8M)
- EPSRC CIM in Food Manufacture
- EPSRC CIM in Additive Manufacturing
- EPSRC CIM in Sustainable Manufacturing
- £30M external funding
- £2M capital investment

Manufacturing: Since 2008 work has focused on five key areas: *Additive Manufacturing*, *Intelligent Automation*, *Electronics Manufacturing*, *Sports Technology* and *Sustainable Manufacture*. Loughborough's is now one of the main manufacturing research centres in the UK, manifested by the UK's largest Innovative Manufacturing Research Centre (2001-2011). Researchers in this theme are now leading one Centre for Innovative Manufacturing (CIM) and taking an active part in three other CIMs, enhancing significantly its national standing and visibility. The broad remit of this research presupposes an interdisciplinary approach. The work on *Additive Manufacturing* since RAE 2008 has re-focused from the development of manufacturing processes to specialisation in their medical applications and smart-materials structures. This has allowed development of new methods for surgical simulation and training, increasing collaboration with *Healthcare and Pharmaceuticals* and *Advanced Materials*. Among the key achievements are new routines for scaffold design for biomedical applications, resulting in a multi-national €11M project and application of ultrasonic consolidation for creation of nano-structures that received the prestigious IMechE PE Publishing award 2011. The research in the area of automation, control and mechatronics after 2008 concentrated more and more on problems of *Intelligent Automation,* advancing understanding and developing automated processes for high-value, difficult-to-automate processes and improving supervisory and production functionality. In recognition of the Group's

expertise and experience of working with industrial partners, it was selected as the lead institution in the EPSRC CIM in Intelligent Automation in partnership with Cranfield University. Its work has focused on deployment of virtual engineering tools for simulation and reconfiguration of assembly lines, working in close collaboration with the Manufacturing Technology Centre (a part of the High Value Manufacturing Catapult, funded by TSB) and with Rolls Royce, Airbus and Aero Engine Controls for industrial exploitation of research outputs.

A new group in Manufacturing, *Sustainable Manufacture*, was formed in 2009, but has already created impact as a major international centre in this important research area. Work has focused on developing strategies, methodologies and enabling technologies that safeguard long-term economic sustainability through added value and improved production capability, as well as supporting environmental sustainability through a decrease in the consumption of natural resources. Its main research goal is to provide industry with the opportunity to achieve a progressive transition from traditional manufacturing approaches to high value-added green manufacturing methods. The Group has a wide range of expertise and projects in life-cycle analysis, sustainable design, resource-efficient manufacturing processes, sustainable business models and servitisation, and end-of-life processing and recycling technologies. The group's remit has been extended recently into the growing area of 'security and sustainable manufacturing of food', one of the latest EPSRC CIMs to be awarded.

The established area of *Electronics Manufacturing*, exemplified by the UK's largest IMRC in electronics, enhanced its dominant position in the UK. Its work spans the complete electronics supply chain, from design through manufacture and into recycling and reclamation. The group has successfully addressed and reflected the substantial changes in electronics manufacturing, evolving a core capability in multiple sectors. Post-2008 research has focused on (i) links between product function/performance and manufacturing, employing multiple simulation engines with implementation in the aerospace electronics supply chain; (ii) novel processes for flexible "digital" manufacture of electronic products based on ink-jet printing and surface coatings, which delivered award-winning tool-less PCB production techniques, such as waveguide direct printing and patterned surface modification; (iii) embedded intelligence capabilities.

Loughborough's world-leading role in *Sports Technology* research was additionally strengthened by creation of the Sports Technology Institute in 2008; it was facilitated through a £5.4M grant from the East Midlands Development Agency and £6.5M of University investment. The main focus since 2008 has been on (i) analysis of personalised, sport-specific human kinetics, kinematics and body deformations for the design and development of apparel in close collaboration with R&D and innovation teams of leading manufacturers (Adidas, Nike, Mizuno, Head); (ii) human-equipment interface, combining applied biomechanics, human perception and robotic emulation for such institutions as the World Taekwondo Federation, International Cricket Council, British Standards Institute, International Tennis Federation, FIFA; (iii) enhancing competitive advantage of world-class athletes (in rowing, cycling, swimming, sailing and wheelchair basketball), with research driven by the pursuit of success in major competition, such as the London 2012 Olympics. Based on its research reputation, the Sports Technology group (with others across the University) was invited to partner Nanyang Technological University in 2010 and formed the Institute of Sports Research, funded with S$10M from the Economic Development Board of Singapore.

Future strategic aims include: working with other Research Themes within the UoA, including (i) exploring the combination and integration of Additive Manufacturing with other emerging fields of science and technology to realise radically new products and applications; (ii) design for automation and intelligent automation of tasks with a high manual labour content; (iii) developing novel electronics manufacturing processes and surface coatings to non-planar substrates and complex product shapes as well as enabling more intelligent manufacturing, product data embedded in product and end-of-life remanufacturing; (iv) sustainable design, resource-efficient manufacturing, and product recycling in enhanced strategic alliances with industrial leaders to strengthen the impact on national policies and industrial practices, setting a global agenda in sustainable manufacturing.

Optical Engineering: As an enabling technology optical engineering is inherently multi-disciplinary in nature and spans EPSRC themes in energy, manufacturing and healthcare technologies. High-power lasers and industrial-scale optical diagnostics for combustion studies are housed in the Optical Engineering Annex – a 300 m^2 suite of purpose-built laboratories. Optical metrology, including holography, tomography, flow measurement and medical diagnostics is undertaken in a further 180 m^2 of laboratories. Equipment available includes high-power lasers for material processing and a unique high-power, short-pulse holographic laser facility (£455k EPSRC). The group operates 5 "glass" research engines instrumented with Particle Image Velocimetry and Laser Induced Fluorescence and has extensive spray diagnostics including "glass" fuel injectors and particle sizing using Phase Doppler Anemometry. The Group is well connected with leading groups nationally, e.g. Bath, UCL, Oxford, City and Southampton, and internationally, e.g. Erlangen, Stuttgart and Naples, Kyoto University. Optical metrology is a key feature of the £2.4M India/UK Collaborative Research Initiative in Solar Energy (EPSRC) and plays a central role in work under way in the £1.2M Institute of Cavitation Research (collaboration with City University and TU Delft funded by Lloyd's Register Educational Trust). The Group works closely with National Standards Institutes, NPL in the UK and PTB in Germany, as part of the £3.2M EU EMRP Project "Microparts". In addition to Research Council funding, since 2008 the Group has received over £2M direct cash funding from industry (e.g. Caterpillar, JLR, Hardstaff and SME's such as Campbell Scientific and Scitek Consultants). Since 2008 work has focused on (i) developing new methods to measure high-aspect-ratio structured surfaces and (ii) characterisation of dense fuel sprays. Notable firsts include the development of a theoretical framework to characterise 3D microscopy and tomographic imaging systems in terms of their point-spread and transfer characteristics. 3D phase-sensitive tomographic imaging for internal strain measurement was devised and single-shot technology for high-speed areal surface characterisation patented. An optical fuel-injector test rig and optical diagnostics to characterise internal flow structure at realistic, 2000 bar operating pressures was developed and patented. New laser-based instrumentation for explosives detection was pioneered; it became a category winner at the National Counter Terrorism and Specialist Security Awards 2012.

Key facts since 2008
- Membership of 7 FTE
- 480 m^2 laboratory space
- £5M external funding
- £1M cash from industry

Future strategic aims include: (i) using optical diagnostics in close collaboration with key industrial partners to advance greener technology in the automotive and haulage industries through more efficient combustion and catalytic technologies; (ii) together with the National Standards Institutes (NPL and PTB), developing new tomographic techniques to make traceable measurements of 3D structure and surface profile; (iii) continuing a successful programme of collaborative projects with instrumentation companies (particularly SMEs) to develop bespoke products and manufacturing processes, e.g. vibration sensors in turbo-machinery and cold laser materials processing technologies.

Process Engineering: Work since 2008 has been focused on understanding the formation of crystalline products, emulsions and particles mainly for pharmaceutical purposes, as well as the modelling and control of these manufacturing processes. This has resulted in a university spin-out company, Micropore Technologies Ltd, making emulsions and particles and the funding in 2012 for participation in an EPSRC Centre for Innovative Manufacturing (CIM) and a Centre for Doctoral Training (CDT) in Continuous Manufacturing and Crystallisation. A notable first is in the area of Crystallization Systems Engineering, with an ERC Fellowship developing CryPRINS, an informatics system to monitor and control the size and shape distribution, polymorphic form and purity of crystals. It is applied using a variety of state-of-the-art process analytical technologies (PAT) and multi-dimensional population-balance modelling, and was developed for systems ranging from microfluidic and droplet crystallization systems to large-scale industrial processes. Industrial interaction with BASF, GSK and AstraZeneca has resulted in pilot scale applications of

Key facts since 2008
- Membership of 13 FTE
- 640 m^2 of dedicated labs
- £5M external funding
- £500k investment in equipment
- EPSRC CDT in Continuous Manufacturing and Crystallisation
- EPSRC CIM in Continuous Manufacturing & Crystallisation

this system, which will be exploited further in an EPSRC ICT project on intelligent decision support and control for continuous manufacture and crystallisation. Further particle production research is based on emulsion generation, followed by polymerisation or other forms of solidification, using microfluidic systems and membrane emulsification. Downstream process engineering operations including filtration and drying are also a major part of the integrated research of the group; with both software and web applications provided by staff members for the selection and design of these unit operations (with over 380,000 unique visits to the dedicated web site). The aim of these developments is to provide significant economic benefits by reducing time-to-market and increasing product quality, leading to improved quality of life.

Future strategic aims include: (i) further work on combining formulation science with engineering operations to assist in the understanding and control of processes and product quality; (ii) increasing cross-discipline collaboration on environmental challenges and resource efficiency; (iii) facilitating High Value Manufacturing based on process engineering principles; (iv) strengthening our industrial biotechnology provision.

Key facts since 2008

- Membership of 11 FTE
- £5M external funding
- The largest IC engines research team in the UK
- 8 state-of-the-art fully instrumented engine research cells
- Five optical engines with full flow diagnostic capability
- Optical diagnostics laboratories for advanced fluid flow and combustion
- High-performance computing cluster for combustion modelling

Thermofluids: Since 2008 work has focused primarily on internal combustion (IC) engine and whole-vehicle fuel efficiency and emissions reduction (including CO_2) as well as on fluid flow and combustion modelling. Under these primary headings come successes in combustion of sustainable fuels, exhaust after-treatment systems, ultra-low emission combustion systems, fuel cells, battery technology and super-capacitor research. There have been key achievements in advanced fluid and combustion modelling using Large Eddy Simulation (LES), the development of new sub-models for turbulent combustion and experimental validation. Within the fuel cells area, success has been in gas diffusion layer material simulation. Electrical impedance spectroscopy results have been compared with fundamental theory to reveal the operative mechanisms during degradation and normal operation. Achievements in vehicle work include gaining a detailed understanding of battery electric vehicle operation, control of fuel cell vehicles and research on system thermal and water balance in evaporatively cooled fuel cell vehicles. In addition, work with Civil and Building Engineering has provided unique understanding of the barriers to people accepting ultra-low carbon technology vehicles. Fundamentally new streams of research have been initiated during this period. Loughborough is, for example, the only group internationally with experimental, simulation and design capability in Turbo-Discharging (a new technology path and cost-effective approach to IC engine efficiency improvement), which has attracted investment from research councils (EPSRC and TSB), industry (AltEnergis) and the Higher Education Innovation Fund (HEIF). State-of-the-art optical engine facilities have experimentally quantified the impact of turbulence sources and eddy structures on combustion stability and cycle-to-cycle variation enabling high-efficiency combustion systems in next generation engines (with, for example, Jaguar Land Rover). Research into dual-fuel diesel and natural gas systems for reduced CO_2 emissions (>15% reduction) and conversion of truck fleets to cleaner fuels has resulted directly in technologies now implemented in the transport industry. Emission-reduction research has led to new technology concepts (pulsed electric discharge diesel particulate filter regeneration) and advanced design tools, for example, to manage hydrocarbon-rich crankcase gases. Engineering tools developed by us are now in regular use within industry (e.g. Caterpillar). Focused efforts on developing new modelling techniques for fluid flow and combustion have enabled improved simulation of sustainable fuel combustion, emission formation and atmospheric flows with methods now in-use within the European Centre for Atmospheric Research. The group has four fully equipped laboratories, including a state-of-the-art engine laboratory comprising 8 test cells with steady state, transient, single and multi-cylinder capability for 12 engines up to 300 kW each. Our laser and optical diagnostic labs contain five fully optical engines and both high- and low-pressure spray facilities together other fluid flow and combustion rigs. Eleven academics complement each other with expertise in subjects including computation

methods, fluid flow, thermodynamics, combustion and heat transfer. The UKCTRF high performance computing cluster (funded by EPSRC) provides outstanding support for modelling turbulent reacting flows at Loughborough. The group's extensive facilities have continued to expand with the award of an Energy Technologies Institute (ETI) Grant of £4.7M in collaboration with Caterpillar and Johnson Matthey. This has funded the establishment of two large-scale Class 3 full exhaust flow optical rigs for analysing and optimising new heavy duty exhaust emission systems.

Future strategic aims include: (i) expanding research contributing to total IC engine and real-world vehicle CO_2 reduction and fuel economy, emission reduction, fuel cell durability and computational methods; (ii) to deliver research generating tools and solutions that are well positioned to translate to technology areas such as large-scale power generation, energy storage and power electronics.

c. People, including:

i. Staffing strategy and staff development

Staffing Strategy

At every opportunity, we seek to promote early career researchers of exceptional promise from within and to appoint experienced senior researchers with international reputations from elsewhere (from academe and industry). This allows us not only to grow existing Research Themes but also to develop and explore new areas. In order for them to define their niche and grow their research area, newly appointed junior staff have a protected reduced teaching load, preferential access to PhD students and are actively mentored by senior academics throughout their 3-year probationary period. Extensive growth since 2008 includes 4 professorial and 44 'new blood' appointments. Transparent, rigorously applied promotion criteria assist staff in their career development. The aim is to ensure that every colleague achieves their aspirations and develops into the best academic that they can be. Emphasising this commitment to career progression, since 2008 21 members of staff have been promoted from Lecturer to Senior Lecturer or Reader and 15 to full Professor, having demonstrated the appropriate level of research excellence and leadership and international recognition through external peer review.

Personal Research fellowships – Since 2008 we have had three Personal Research Fellowships awarded: (i) Dr Robert Thomas (*Healthcare and Pharmaceuticals*) was awarded an early career manufacturing fellowship to develop methodologies to develop technologies for human cells for regenerative medicine purposes; (ii) Professor Nick Medcalfe (*Healthcare and Pharmaceuticals*) was awarded an 'established career' manufacturing fellowship to apply engineering research to overcome regulatory challenges in the commercialisation of regenerative medicine; (iii) Dr Aya Suzuki-Shin (*Advanced Materials*) worked at Loughborough for 2 years on a prestigious personal Fellowship from the Japanese Society for the Promotion of Science.

Succession Planning – We appoint staff to a range of managerial positions, including Research Theme Leader, Head of Department, Associate Dean and Dean. In each case, appointments are for periods of 3 years. To ensure that there is always a supply of new blood and ideas, competition is strongly encouraged whenever posts are advertised. This gives us the opportunity to follow new research directions and further develop areas of strength. Over a 6-year horizon, therefore, it is probable that individual members of the UoA leadership team and related initiatives will change at least once; it is therefore critical that the necessary steps are taken to plan and implement succession management principles. To this end, all academics are deliberately exposed to the full range of issues that affect the running of the Schools, the management of which is made as transparent as possible. This approach means that neither the UoA nor the Schools are over-dependent on any one individual. LU has also used institutional funding from the EPSRC to run two Staff Development courses focused on Leadership, one aimed at more senior staff (Senior Lecturers and above) and one at more junior staff (recently appointed Senior Lecturers and below). This ensured that staff at all stages of their careers were confronted with the important issues of the time and, via activities such as role playing, were given the opportunity to debate them and draw their own conclusions.

Staff Development – LU undertook a comprehensive analysis of its alignment with the Concordat to support the Career Development of Researchers in 2009/10, and published an implementation

plan in 2010, for which it received the EC's HR Excellence in Research Award. The plan was updated in 2012, as part of an internal review for the HR Excellence award. Specific outcomes from the plan include a continuing commitment to a University-wide Research Staff mentoring scheme, a revised Code of Practice for the Employment of Researchers, and establishment of the Loughborough University Research Staff Association. Monitoring takes place through participation in the Careers in Research Online Survey, and through university-wide Staff Surveys, held every 2 – 3 years, for which the Research Job family had the highest number of 'green' categorised responses (10% more positive than the institutional average). Collaboration between Themes and across Schools is commonplace and actively encouraged by pan-institution virtual Research Schools. Continuous improvement of research performance across the UoA is a key priority and all academic staff complete an annual Personal Research Plan and undergo a Performance & Development Review with their immediate line manager, which facilitates discussion and highlights areas for development for individuals and within Schools. This process embeds research in performance monitoring and reward systems and is monitored by the University's Research Performance Monitoring Committee, chaired by the Pro-Vice Chancellor for Research. To ensure workload equity, workload models include all academic activities and are reported annually to the Deputy VC. Professional Development programmes cover every aspect of academic life, including research. Programmes accredited by the Institute of Leadership and Management are available to all staff. Research staff can also attend courses run by the Graduate School, Careers and Employability Centre, and Staff Development courses. Mentoring is mandatory for all Early Career Researchers and academic staff are encouraged to participate as mentors. In 2011/12 research staff and early career Lecturers were eligible to apply to participate in the Developing Future Research Leaders programme, an EPSRC funded-initiative that saw research staff and early career Lecturers receive a leadership-development grant, dedicated coaching, participation in Action Learning and 360° Feedback. Staff are encouraged to focus exclusively on research for up to a year through flexible study-leave arrangements, with the Dean's approval.

Equality and Diversity – The University is committed to providing "a fair, supportive and cohesive environment that promotes equality of opportunity for staff and students and values diversity". The University recognises that the promotion of equality of opportunity and diversity is crucial in influencing the economic and social development of individuals, businesses, professions and communities. In its Strategic Plan 'Towards 2016', the University commits to undertaking this promotion in all of its activities.

ii. Research students

Culture and Structure – Since 2008, 365 research students have graduated from the UoA, with many more yet to complete their studies and as such research students form an active part of the Schools' research life and much of their output contributes to our international reputation. Research funding for MPhil, PhD and EngD students comes principally from the UK Research Councils (mainly EPSRC and BBSRC), TSB, EC Frameworks, together with industrial sponsorship and a significant contribution from within the University. Funding also comes from overseas Governments. In all cases each research student is associated with at least one of the Research Themes described above.

Graduate School – The Graduate School (which provides generic PGR training) works alongside other University services (e.g. Careers and Employability, Library) to enhance the postgraduate experience and encourage a vibrant graduate community at LU. The Graduate School offers a comprehensive training programme that is mapped to the Researcher Development Framework, comprising face-to-face workshops, an annual research conference including poster competition (also open to academic and research staff) and the 'Café Academique', which is a forum where PhD students can debate the latest ideas from all areas of research. The Careers and Employability Centre have a dedicated Careers Advisor for Researchers, to support research staff and research students.

EPSRC Centres for Doctoral Training (CDT) – The UoA hosts 1 EPSRC CDT in *Regenerative Medicine* and is a significant partner in 4 others *Hydrogen Fuel Cells & Their Applications* (with Birmingham renewed November 2013)*, Continuous Manufacturing and* Crystallisation (led by Strathclyde with 6 others) and the recently announced (November 2013) *Gas Turbine Aerodynamics* (with Cambridge and Oxford) and *Additive Manufacturing* (with Nottingham). These

provide training to students in addition to that coming from the Schools and University. Students associated with a CDT benefit from the increased scale of operation. Within each cohort (~10 students/year) there is a wide breadth of expertise and students learn from and interact with one another from an early stage. Our CDTs build upon the strong teaching and research track records of a number of partner universities, exposing students to a diverse network of experts, resulting in a unique learning and research environment and cohort experience not available to the conventional PhD student.

Recruitment, Selection and Interview – Across the UoA, research applications are processed by a team comprising the research coordinator, research administrator and, if necessary, the Theme Leaders. In all cases PhD applications undergo rigorous assessment and interviews are mandatory. The aim is to recruit students with at least a high 2:1 and preferably a first class degree. In all cases the turnaround time is expected to be no more than 4 weeks in total.

Induction – Across the UoA, induction is seen as an important part of a successful recruitment process. All students take part in one of the quarterly 'Induction Meetings' where 'What a PhD is all about' is discussed and meet with important contacts within the School and wider university environment (Safety Reps, Librarian, etc.). Importantly, all students must complete a thorough 'Day One' safety induction and must read and sign a copy of the Safety Policy before being allowed to start work. They also sign the student handbook declaration confirming acceptance of its rules and procedures. This is then filed in the Student Support Office.

Joint Supervision – Across the UoA, joint supervision is manditory with second supervisors being fully involved with, and contributing intellectually to, the project. Supervision teams are often chosen from different themes or Schools to optimise support.

Role of Supervisor, Research Co-ordinators and Directors of Research Programmes – Across the School, supervision is undertaken by supervisors who meet the students on a bi-weekly basis. Students take minutes of the meeting, which are recorded (using our online web based software 'Co-tutor') and there is a formal process of feedback in the form of written annual reports from supervisors to students. Supervisors provide both research guidance as well as pastoral care for their students. They also assess the student's short- and long-term training needs and provide regular guidance and feedback to the student.

Students make use of the internal training offered by the University; courses are selected in conjunction with supervisors and are dependent on the student's needs. Attendance is recorded in the Supervisor's annual progress report, and the relevant Director of Research Programmes (see below) ensures that RCUK's training requirements are met and preferaby exceeded. The Schools also run separate equipment and research technique training sessions on all its facilities. The LMCC also runs theory & practice seminars for a number of the materials characterisation techniques; these are compulsory for students in the *Advanced Materials* Research Theme and optional for all other research students across the University. Students also receive risk assessment training for the Schools' Health, Safety & Environment procedures. All students complete risk assessment forms prior to commencement of any research activity, with input from supervisors and the Safety Officers.

Progression – The students have very clear goals to achieve in each of their three (standard PhD) or four (Centres for Doctoral Training or EngD programmes) years. All students must write a major report towards the end of their first year and pass a rigorous viva voce; either write a shorter report or a research paper towards the end of their second year and write a thesis towards the end of their research. They are also required to make presentations, both in oral or poster form, at different stages of their degree; this includes giving at least one seminar presentation or taking part in the annual PGR Conferences where all researchers, including postdocs, present their work to a very large audience that includes invited industrialists. PhD students are expected to publish their results in top international academic journals and to attend appropriate conferences whenever possible. Whilst most funding for the latter comes from individual research grants, the UoA also makes additional funding available for research student travel. It is a University requirement that each School has Directors of Research Programmes that look after PhD progression and advise on remedial action where necessary. They also take the first steps to sort out any issues that very occasionally arise between students and their research supervisors. They review each student's

progress on an annual basis and present a summary at the progress Review Boards, which report to the School Research Committee meeting. Students are expected to submit their final thesis for examination within 3.5 years and extensions to this are only granted by the ADRs under exceptional circumstances.

PhD students nominate a representative who attends the staff-student committees, which meet every term. PGR matters are brought to the attention of the relevant School committees for discussion. Minutes of the meeting are made available to academic staff and PGR students.

Facilities and Resources – Research students have their own study spaces within the Schools with access to computing, printing and photocopying facilities. Research students have access to all research facilities in the Schools, which are pooled for common use. Students are also able to access university-wide facilities and, where funding permits, off-site specialist facilities. The UoA has workshops where experimental rigs are built and there is a clearly defined procedure for the design and construction of rigs with full support from technical staff. Many PhD students gain supervisory experience by helping their supervisor to supervise final-year undergraduate and MSc research projects. Research students are also encouraged to undertake extra-curricular activities that are relevant to their work.

Seminar programme – PGR students are made aware that research cultures are created by understanding and taking an interest in the work of colleagues. A monthly seminar series is organised with external guest speakers where industrial and academic experts are invited to present research focusing on topical issues affecting the scientific and engineering disciplines concerned. All PhD students are expected to attend the external seminar series and checks are carried out to ensure that this occurs.

Research Open Days – The UoA organises themed annual Research Open Days that introduce research to both LU final-year undergraduate and MSc students and are also advertised locally and nationally to attract potential research students from other universities.

PGR Conferences –Annual PGR Conferences are organised for the different disciplines involved. The academics, postdocs and PhD / EngD students across the UoA are invited to the different events where the researchers present their results, in either oral or poster form depending on transparent criteria. This also provides an opportunity to promote communication between staff and students and, with industrial delegates also invited, enhance the Schools' reputation and increase industrial support and interaction. Prizes are typically offered at the end of the day to the students who have made the best contributions.

d. Income, infrastructure and facilities
Income

The Unit has built upon its success in RAE2008 to further grow its grant income over the REF period. This funding comes from RCUK (£62M), European Union (£7M), industry (£13M), charities (£800k) and other funding agencies (£16.5M). Total spend over the REF period is in excess of £99M. Examples of major grants and platforms include:

EPSRC IMRCs and CDT (Loughborough-led):

- £10.8M EPSRC Centre for Innovative Manufacturing Research Centre (IMRC) for Intelligent Automation (PI: Prof. Mike Jackson with Cranfield University) with industrial partners including Rolls-Royce and Airbus. The Centre aims to improve synergy between humans and their automated counterparts by researching advanced automation for high-value manufacturing.
- £9.2M EPSRC IMRC in Electronics (PI: Prof. Paul Conway) is focused on growing high-value electronics manufacturing in the UK, delivering innovative and exploitable new technologies in partnership with the electronics industry.
- £8.3M EPSRC IMRC in Regenerative Medicine (PI: Prof. David Williams with Nottingham and Keele Universities) The Centre's aim is to create next-generation platforms for manufacturing regenerative medicines and to inform business models, policy and public debate.
- £7.5M EPSRC Doctoral Training Centre for Regenerative Medicine (PI: Prof. Chris Hewitt with Nottingham and Keele Universities) where students are trained in the core skills needed to work at the life science/engineering interface in the emerging field of Regenerative Medicine.

EPSRC CIMs and DTC (Loughborough non-lead):

- £6M EPSRC CIM for Additive Manufacturing (CoI: Prof. Russ Harris). The Centre aims to research into next generation additive manufacturing production technologies and design systems, with a focus on multi-functional parts.
- £6M EPSRC Doctoral Training Centre in Hydrogen, Fuel Cells and their Applications (CoI: Prof. Richard Stobart with Birmingham and Nottingham Universities). The aim is to produce Hydrogen and Fuel Cell scientists, engineers and economists who are equipped to play leading roles in a professional capacity in both industry and academia.
- £5M EPSRC CIM for Continuous Manufacturing and Crystallisation (CoI: Prof. Chris Rielly with Strathclyde, Bath, Glasgow, Heriot-Watt, Edinburgh and Cambridge Universities). The Centre aims to improve products and processes through continuous manufacturing technology in the chemical process industries.
- £4.75M EPSRC CIM in Industrial Sustainability (CoI: Prof. Shahin Rahimifard with Cambridge and Cranfield Universities and Imperial College). The Centre aims to reduce the resource and energy-intensity of the production of existing goods, and to redesign industrial systems.
- £4.5M EPSRC CIM in Food (CoI: Prof. Rahimifard with Nottingham and Birmingham Universities) that involves such companies as AB Sugar (British Sugar Group), Cargill R&D Centre Europe, Mars UK Ltd, McCain Foods Ltd, Nestle SA, PepsiCo etc.
- £6.8M Research Council UK EngD Centre in Efficient Fossil Energy Technologies (CoI: Prof Rachel Thomson with Nottingham and Birmingham Universities).

Other

- £5.76M EPSRC Grand Challenge Regenerative Medicine, A New Industry with Birmingham, Cambridge, Liverpool, Nottingham and Ulster universities.
- £4.2M EPSRC Programme Grant, Material Systems for Extreme Environments, XMat, with Imperial College and Queen Mary universities.
- £3.65M EPSRC/Dstl project Signal Processing Solutions for Networked Battlespace with Cardiff, Surrey and Strathclydeuniversities.
- £4M EPSRC project SUPERGEN 2 - Conventional Power Plant Lifetime Extension Consortium – CORE.
- £2.7M EPSRC Engineering - Tissue Engineering and Regenerative Medicine Landscape Fellowship Programme with Nottingham, Keele, York, Leeds and Sheffield universities.
- £2M EPSRC project Flexible and Efficient Power Plant: Flex-E-Plant.
- £2M EPSRC Adaptive Informatics for Intelligent Manufacturing, AI2M.
- £1.6M BBSRC Bioprocessing Research Industries Club in collaboration with Birmingham, Cambridge, Nottingham and Oxford universities.
- £1M EPSRC Autonomous and Intelligent Systems with Oxford and Bath universities and BAE systems.

Funding Strategy: The Unit's strategy for winning grant income is founded on our approach of building upon our track record in delivering high-quality, industrially-relevant research. To achieve this we put together fluid multi-disciplinary teams to respond to funding calls in order to build unique capabilities, which align with major funding programmes. Often these demand input from and collaboration with industrial or other agency partners and colleagues in other Schools/disciplines This enables us to develop the novel, integrated and multidisciplinary programmes evident in our submission. LU has a structured set of mechanisms for facilitating this collaboration and demand-managed calls are led by the LU Research Office (RO). The RO assists in identifying research funding opportunities by matching multi-disciplinary calls to Unit expertise and across multiple Units where appropriate. Each Research Theme is led by a senior academic from within the Unit who sits on the Schools' Research Committees, chaired by the Associate Deans (Research). The AD(R)s provide a link to the University Research Committee, which shapes university strategy, co-ordinates responses to calls and initiatives, and promotes collaborative research with other academics and research schools. All staff contribute to shaping research bids through meetings, away days and strategic research reviews. Collectively, this approach generates coherence and integrity of our bidding strategies and ensures that we maximise our collective effort towards successful grant outcomes.

Infrastructure: Enhancements to the research infrastructure since 2008 have been significant.

The University funded £20M just prior to 2008, provided >£10M investment over the reporting period, and ~£60M will be spent during 2014-15. Selected examples (> £1M only) of new and upgraded infrastructure that occurred during the REF period include:

- New £3M facilities of the Rolls Royce University Technology Centre – comprising four purpose-built test cells for isothermal measurements on complex combustion chamber geometries and other gas-turbine engine components. Instrumentation comprises a range of advanced probe, hot wire and optical instrumentation used for flow-field surveys. A second £1M phase of development is now underway.
- New £5M Centre for Biological Engineering (CBE) – Opened in 2009 by Sir Robert Winston, the CBE is made-up of a suite of Class 2 laboratories for human cell growth.
- £1M upgrade to Loughborough Materials Characterisation Centre (LMCC) – Recent enhancements include a new X-ray photoelectron spectroscopy instrument, X-ray diffraction facilities, and a field emission gun transmission electron microscope system.
- £5M (£1M pa on a 5 year rolling cycle) investment in The Caterpillar Innovation and Research Centre (I&RC) – Funded by Caterpillar as well as the EPSRC, TSB and ETI, since 2008 the I&RC conducts fundamental research into internal combustion engines and their sub-systems.

Planned – Discussions are at an advanced stage for an extensive £60M redevelopment of the buildings, space and facilities at Loughborough in the areas of *Advanced Materials*, *Process Engineering*, *Manufacturing,* parts of *Applied Aerodynamics*, as well as some other areas outside of this UoA. To occur during 2014 and 2015, the proposed redevelopment will significantly enhance the research-working environment for research students and staff, and will create suites of state-of-the-art research laboratories for all. This will provide an opportunity to further promote multi-disciplinary collaboration and equipment sharing, and further enhance our equipment base.

e. Collaboration or contribution to the discipline or research base

Research collaborations: To ensure that our research continues to make key theoretical and practical contributions to knowledge while delivering maximum impact and utility, all members of the UoA engage in on-going productive collaborations with academic and industrial partners both nationally and internationally. We currently have >100 significant collaborative research engagements with Universities and research institutions in >50 countries worldwide and numerous domestic links. Strong examples include Prof Rachel Thomson (*Advanced Materials*) who has extensive collaboration with the National Institute for Materials Science in Japan with whom she jointly organised and hosted a UK-Japan conference in 2012. The International Centre of Vibro-Impact Systems' (ICoVIS) President, Prof Vladimir Babitsky (*Dynamics*), and Director, Prof Vadim Silberschmidt (*Advanced Materials*), co-ordinate the research activities of scientists from more than 20 countries (including USA, Japan, Russia, Germany, China, UK). Prof James McGuirk (*Applied Aerodynamics*) is the Chair of the Rolls-Royce Propulsion and Power Systems Advisory Board, guiding the global research and development activities of Rolls-Royce. Profs Homer Rahnejat (*Dynamics*) and Colin Garner (*Thermofluids*) collaborate with Delft University of Technology (The Netherlands) and City University, forming the International Institute for Cavitation in 2012. Prof David Williams (*Healthcare and Pharmaceuticals*) has significantly contributed to the definition of European research strategy via the 'EU Manufuture technology platform'. This is demonstrated by his co-authorship of the most visible outputs of the activity including The Manufuture Road (Springer, 2009) with Profs Englebert Westkamper (IPA, Stuttgart, Germany) and Francesco Jovane (Politecnico di Milano, Italy). Prof Changqing Liu (*Manufacturing*) leads an EC-funded project, "M6 Micro- Multi-Material Manufacture to Enable Multifunctional Miniaturised Devices" (M6), in partnership with the National Institute of Advanced Industrial Science and Technology (Tsukuba, Japan), Kaiserslautern University of Applied Sciences (Germany), Huazhong University of Science and Technology (Wuhan, China). Professor Jeremy Coupland and Dr Jon Petzing (*Optical Engineering*) work in collaboration with two leading National Standards Institutes - National Physical Laboratory (UK) and the Physikalisch-Technische Bundesanstalt (Germany), as part of the £3.2m EU EMRP Project "Microparts". Prof Victor Starov (*Process Engineering*) sits on the Council of the International Association of Colloid and Interface Scientists contributing to the European agenda in Colloid Science and Multiscale Complex Flows.

The individual and collective international reputations and esteem of our staff is evidenced by the number and diversity of their externally facing activities. To provide a detailed commentary on each

one of these activities from such a large pool is well beyond the scope of this submission. Therefore, the table provides a summary of our current position, with the most notable activities highlighted and discussed further below.

Fellows of Professional Societies or Institutions	Members of Professional Societies or Institutions	Members of Advisory Boards	Members of Editorial Boards	Prizes and Awards	Visiting or Honorary Appointments	Keynote or Plenary Lectures	Conference Chairs	Industry Collaborations
25	27	55	160	25	27	130	102	>200

Due to our national and international standing we have 27 Members and 25 Fellows of the professional societies, institutes and institutions (e.g. IChemE, IMechE, IMMM, RSC, SB). Most notably Profs David Williams, Nick Medcalfe and Jim McGuirk are Fellows of the Royal Academy of Engineering and Prof Jon Binner is a Fellow and current President of the IMMM. Further examples include Prof Memis Acar who is a FASME and a Member of its Global Communities Operating Board; Prof Christopher Hewitt is a FIChemE, was Scientific Meetings Officer and Member of Council of the Society of General Microbiology; and Prof Chris Rielly is a FIChemE and Chairman of the Fluid Mixing Processes Subject Interest Group.

Reflecting our strategic aim to carry out industrially relevant research we have 55 members of staff who have senior positions on industrial and agency partner Advisory Boards helping to develop their future strategic aims and policies. Examples include Prof Mike Jackson who is an invited member of the Flanders Mechatronics Technology Centre's Scientific Advisory Board, Belgium; and Dr Jon Petzing has been a member of the Scientific Advisory Board for the Centre of Excellence in Metrology for Micro and Nano Technologies (CEMMNT).

27 members of staff hold honorary appointments at international universities providing independent governance and advice on developing their research programmes. Examples include Prof Rob Parkin who is a visiting Professor at University of Wroclaw, Poland; Prof Victor Krylov visiting Professor at the Universite du Maine, France; Prof Changqing Liu who is a visiting Professor at Harbin Institute of Technology, China; Prof Victor Starov Honorary Professor, Moscow State University of Food Industry, Russia; and Dr Goran Vladisavljevic Humboldt Visiting fellowship at Karlsruhe Institute of Technology, 2012.

Our staff provide 160 members of Editorial Boards of internationally renowned Journals. Examples include Prof Shahin Rahimifard who is Editor-in-Chief, International Journal of Sustainable Engineering; Prof Chris Hewitt who is Executive Editor Biotechnology Letters; Prof Gianluca Di Puma Editor, Journal of Hazardous Materials; Prof Paul Conway who is Associate Editor, ASME Journal of Electronics Packaging.

25 members of staff have won prizes and awards for the quality of their work, notable examples include Profs Paul Conway and Andy West who won the Innovation Italy Award for Sustainability in 2012; Prof Vadim Silberschmidt was awarded the President of Tokyo University of Science Prize 2102 for his work on the fracture analysis of advanced materials; Prof Jon Binner who won the Verulam Medal and Prize, Institute of Materials, Minerals and Mining, 2011; Dr Hemaka Bandulsena who won the IChemE Senior Moulton medal for the best published paper 2009 and Prof Zoltan Nagy Journal of Process Control Best Paper Award.

102 members of our staff have been invited to act as session Chairs at world renowned conference events that span our entire research remit these include, Prof. Jon Huntley who was a co-chair of Photomechanics 2008 (Loughborough, UK) and 2011 (Brussels, Belgium); and Prof. Russ Harris who was a Chair at the Rapid Prototyping Conference 2013, Amsterdam.

Our staff have been invited to deliver 130 keynote/plenary lectures at internationally leading conferences. Examples include, Prof Jim McGuirk Royal Aeronautical Society Lanchester Lecture 20103; Prof Jenny Harding, Keynote Lecture at International Conference on Advances in Supply Chain and Manufacturing Management (ICASCMM 2011) India; Prof Vadim Silberschmidt, 10th World Congress on Computational Mechanics, Brazil; Prof Gianluca Di Puma Keynote Lecture at International Conference on Recycling and Reuse, 2012, Turkey; Prof Chris Hewitt Plenary Lecture at 10 Annual Bioproduction conference, 2012, Germany and Prof Jon Binner Keynote lecture 13th International Conference of the European Ceramic Society, France, 2013.