Institution: The University of Leeds

Unit of Assessment: 12

a. Overview

The School is internationally recognised for fundamental and applied research in Mechanical Engineering and has consistently achieved the highest rating in all previous RAEs, with 75% of staff rated internationally 'excellent' or 'world-leading' in RAE 2008. Our annual research income has grown during the REF period from under £4.7M in 2008/09 to an average of over £6.1M per year in subsequent years. We have exceptionally strong portfolios of research in energy, sustainability, medical technologies, lifelong health and wellbeing. To ensure critical mass and encourage multi-disciplinary collaborations, our research activities are organised into the following three distinct but inter-related research institutes:

Institute of Medical and Biological Engineering (iMBE) – is a collaborative activity between the School of Mechanical Engineering and Faculty of Biological Sciences (UoA5) and is one of the leading biomedical engineering research institutes in the world, recognised for its distinctive ability to translate internationally excellent research into social and economic benefits. iMBE focuses on the medical engineering solutions for the ageing population, which addresses the challenges of "fifty active years after fifty®". It is organised through three groups: (i) joint replacement and tissue substitution; (ii) tissue engineering and regenerative interventions and (iii) functional spinal biomechanics and interventions. Our research and innovation addresses major healthcare challenges in musculoskeletal and cardiovascular disease, and targets the following areas: (i) *in vitro* and preclinical biotribology and biomechanical simulation systems; (ii) longer lasting joint replacements for hip, knee and spine and (iii) biological scaffolds for regenerative therapies in cardiovascular and musculoskeletal disease.

iMBE has a strong record of translation, economic and healthcare impact supported by long standing collaborations with industry, e.g. DePuy, Simulation Solutions and Tissue Regenix and the NHS Blood and Transplant Services. It has a diverse funding portfolio from industry and from e.g. EPSRC, BBSRC, MRC, NIH, NIHR, TSB and the Wellcome Trust, as well as from the EU and the ERC. It hosts WELMEC, one of the four centres of excellence in medical engineering in the UK funded by EPSRC and Wellcome Trust. Two decades of world-leading medical engineering research and impact led to the award of the Queen's Anniversary Prize to iMBE in 2011.

Institute of Engineering Thermofluids, Surfaces and Interfaces (iETSI) – carries out multi-disciplinary research (both experimental and theoretical) in engineering application areas where heat transfer, single and multi-phase flows and/or reactions at fluid and solid interfaces are crucial. Our main areas of research and innovation include: (i) combustion (in engines, hazards and detonations); (ii) engine lubrication and tribology (lubricants, materials and tribochemistry); (iii) engineering optics (interferometric sensing and metrology); (iv) flow assurance in the oil and gas sectors (e.g. corrosion and erosion-corrosion); and (v) multi-scale flow experiments, modelling and Computational Fluid Dynamics (e.g. of coating and printing processes, data centres and electronics cooling, flows in porous media, free surface flows, reactive flows and wetting). iETSI has excellent funded research links with industry, ranging from SMEs to major multinationals across energy, manufacturing and processing sectors e.g. Amec, BG Group, BP, Clariant, GSK, Petronas, Petrobras, Rolls Royce, SASOL, Shell, Siemens and Statoil, with funding received from 30 companies during the REF period. It also has a strong funding portfolio from research councils and public bodies, including EPSRC, TSB, NHS and several major awards from the EU.

Institute of Design, Robotics and Optimisation (iDRO) – carries out multi-disciplinary research (both experimental and theoretical) that develops new theoretical frameworks underpinning design processes and applies them to the design of complex engineering products and systems. Our main areas of research and innovation include: (i) robotics (including rehabilitation technologies for restoring limb function and prosthetics); (ii) surgical technologies (laproscopic devices, haptic control); (iii) multi-disciplinary design optimisation (energy-efficient vehicles, lightweight composites); (iv) design sciences (product requirements and supply chains). iDRO has funded

research links with SMEs and major multinationals such as Airbus, Dassault Systèmes, EADS, National Instruments and Rolls Royce. In addition to direct funding from industry, iDRO has received major awards from the EPSRC, NHS and the EU.

Although many staff work across Institutes, the main affiliations of School staff to the Institutes are: iMBE Staff: Professor: Fisher (JF), Hall (RH), Jin (ZJ, 20% FTE) and Wilcox (RW); Senior Lecturer/Associate Professor: Jennings (LJ), Stewart (TS, 70% FTE), Tipper (JT) and Williams (SW); Lecturer: Jones (AJ); Brockett (CB) is an NIHR Senior Research Fellow.

iETSI Staff: Professor: Bradley (DB, 35% FTE), Dowson (DD, 35% FTE), Kapur (NK), Neville (AN), Priest (MP), Thompson (HT) and Towers (DT); Senior Lecturer/Associate Professor: Burluka (AB), Lawes (ML), Liskiewicz (TL), Morina (AM) and Summers (JS); Lecturer: Wilson (MW). Barker (RB) and Gilkeson (CG) are Teaching and Research Fellows.

iDRO Staff: Professor: Barton (DCB), Cockerill (TC), Levesley (MCL), McKay (AMcK); Senior Lecturer/Associate Professor: Querin (OQ) and Richardson (RR); Lecturers: Boyle (JB); Culmer (PC) is a BHRC Research Fellow in Surgical Technologies; Jackson (AJ) is a Teaching and Research Fellow.

In this document REF2 output papers submitted for assessment are referred to by the author's initials followed by the paper number – e.g. JF1 represents paper 1 of Professor John Fisher.

b. Research strategy

Strategic Aims for Research

At the end of the RAE 2008 period our core research areas produced world-leading research in the areas of: (i) biomedical engineering; (ii) combustion; (iii) engineering fluid mechanics and tribology; (iv) intelligent systems and (v) design and manufacture. The strategy outlined at RAE 2008 aimed to achieve growth and sustainability in our research funding by designing our research to influence, respond and engage fully in industrial (e.g. energy efficiency), societal (e.g. healthcare) and legislative (e.g. safety) initiatives and drivers. A key priority was to promote talented young researchers to permanent positions to strengthen our capacity for multi-disciplinary research.

Within iMBE, we aimed to achieve a major expansion of research at the life sciences interface in the areas of bio-tribology, bio-mimetics, bio-tribocorrosion, functional spinal interventions and tissue engineering. *Within iETSI*, we aimed to develop our core strengths in engineering science and engineering optics, to grow the areas of combustion, corrosion, micro/nano-fluidics and tribo-chemistry. *Within iDRO* (formerly the Institute of Engineering Systems and Design, renamed in 2013 to better reflect its key foci), the strategic focus was on design systems, design optimisation and robotics research to meet the developing healthcare and energy agendas. Our strategy is refreshed annually with input from our regular institute and School Research & Innovation (R&I) committee meetings and from the School's Industrial Advisory Board. The Director of R&I and institute directors are responsible for disseminating and implementing the research strategy. Our key strategic goals during the REF period have been to grow and improve the sustainability of research funding and to strengthen our capacity for excellent multi-disciplinary research.

Evaluation of the current UoA position with respect to RAE 2008

As envisaged, several talented young researchers have been integrated into our multi-disciplinary research teams and are playing a key role in the large multi-disciplinary consortia we have coordinated: e.g. AM, MW in the tribo-chemistry EU projects *2020 Interface* (grant no. 234324) and *ENTICE* (no. 290077), and JT, LJ in our WELMEC Centre of Excellence in Medical Engineering (WT088908/z/09/z) which collaborates with 10 departments and 250 academic researchers.

We have achieved a major expansion of research at the life sciences interface. Highlights include: (i) development of a SAFER (Stratified Approach For Enhanced Reliability) method for preclinical tribological simulation systems for joint replacements (JF1) that has supported the commercialisation of joint simulation systems and led to the EPSRC Centre for Innovative Manufacturing in Medical Devices (£5.6M, EP/K029592/1); (ii) research into lower wearing and longer lasting joint replacements has defined the lower wear performance in ceramic matrix

composite bearings (TS3), and in large diameter metal-on-metal hips which led to their withdrawal from clinical use (JF4); (iii) research on dCELL® biological scaffolds has been commercialised by our spin out *Tissue Regenix* and by clinical tissue banks in Brazil and UK (JF3); (iv) research and development of simulation systems for natural joints in the musculoskeletal system (JF2, RW2).

The anticipated growth in energy research has been realised. In the oil and gas sector, our research in corrosion has led to major improvements in the productivity and safety of major oil and gas pipeline networks (AN1,RB1). Through substantial EU funding, in projects such as *2020 Interface,* the ITN *ENTICE* and *FUTURE_BET* (no. 317334 with SKF, Netherlands), our research in tribo-chemistry has grown rapidly and is used by companies such as Volvo and SKF to increase the efficiency of automotive engines (AM2,MP1). Our combustion research has led to major advances in understanding of the fundamentals of flame propagation (DB1,DT1) and has been used to improve engine and gas turbine efficiencies and to minimise risk from fuel vapour cloud explosions in the Buncefield Enquiry (DB4). [text removed for publication].

Funded by grants from the Department of Health (e.g. ref K005, £460K), industry (e.g. Dassault Systèmes) and the EPSRC (e.g. EP/K020463/1) our research in robotics has grown and is improving the rehabilitation and coordination of stroke patients and children with cerebral palsy (PC1,MCL1) and the design of novel prosthetic devices. A large ERC Advanced Grant with Dundee University (ref. 268519, €1.3M to this UoA) has led to the growing area of surgical technologies, which exploits state-of-the-art haptic control to develop novel robotic devices for colo-rectal surgery. Our design optimisation research has led to the commercial development of highly-oriented polymer ropes (with Bridon and DuPont, DCB4) and droplet filtration systems (with Parker Hannifin, NK2), the latter winning the grand prix prize at the 2012 British Engineering Excellence awards. Our joint coordination (with Civil Engineering, UoA 14) of the *AMEDEO* Marie Curie ITN (€3.6M, no. 316394) is expanding our optimisation research for energy-efficient vehicles.

Our annual research income has grown from < £4.3M in 2006/07 to an average > £5.8M per year in the REF period. We continue to enjoy major successes from UK funders and have diversified our funding portfolio to achieve increased funding from the EU and international companies. Examples from the former include our coordination of 2 Marie Curie Initial Training Networks (*SPINEfx,* total €2.9M, grant no. 238690; *ENTICE*, €3.3M, no. 290077), the European Industrial Doctorate *FUTURE_BET* (€1.4M, no. 317334), the collaborative project *2020 Interface* (€3M, no. 234324) and the €13.3M award (€3.4M to this UoA) in *Life-Long Joints* (FP7-NMP 310477).

Vision and Future Research Strategy

Our future research strategy is integrated with our impact strategy outlined in REF3a and focusses on our key growth areas in the healthcare, energy and fluids processing sectors.

Within iMBE, our vision is to become the UK's leading centre for research and innovation in medical technologies. Our goals are to: (i) extend our SAFER approach to other joints (e.g ankle joints) and expand our natural joint simulation capability, moving to stratified and disease specific models; (ii) increasingly focus on biological scaffolds and regenerative interventions and their biomechanical and biotribological function; (iii) extend our computer simulation and modelling capabilities from the spine to the hip and the knee. We will target large project and equipment awards from the EPSRC and direct support from industry to achieve our goals. *Within iETSI*, our strategic focus will be in the energy sectors and in the corrosion and surface engineering challenges in the oil and gas industry. We will refocus iETSI into two smaller, complementary institutes: the first will capitalise on the growth of our corrosion and tribochemistry research and will focus on *functional surfaces* with a specific goal of becoming a leading UK centre of excellence in oil and gas corrosion, the second on key *thermofluids* challenges in combustion, cooling and flow optimisation. Our goal is to increase our industrial funding and exploit our excellent European and industrial networks to obtain large Horizon 2020, EPSRC and TSB awards. *Within iDRO* we will focus on robotics and design optimisation. Specific goals include: exploiting the world-class facilities in our National Facility for Innovative Robotic Systems to obtain further EPSRC funding in robotics to become an acknowledged, international centre of excellence; and obtaining Horizon 2020 funding to address the multi-disciplinary research challenges of energy-efficient vehicles.

c. People, including:

i. Staffing strategy and staff development

Staffing Strategy: As outlined in REF3a, our staffing strategy provides high quality people with the multi-disciplinary skills needed to undertake world-leading research and deliver impact in our key research areas. The School R&I committee coordinates our staffing strategy with the School's infrastructure by monitoring office and laboratory requirements for staff and students and prioritising investments towards strategically important areas. For example, staff and students on multi-disciplinary projects are housed together to promote collegiality and effective cross-discipline communications. The core elements of our staffing strategy are:

*Proactively supporting junior staff into academic positions***:** by giving them relatively light teaching and administrative duties, prioritising them for School-funded PhD studentships and providing an experienced staff mentor. We identify talented PhD students and PDRAs (both within and external to the School) and encourage them to apply for academic fellowships. For major opportunities (e.g. EPSRC fellowships) we carry out an initial screening of applicants. Unsuccessful applicants receive feedback and advice, while successful ones are assigned an academic staff mentor to provide further support. The School may guarantee a permanent academic position at the end of their fellowship for successful applicants who pass rigorous probation criteria. This approach is very successful: in the REF period RW has been promoted to Professor; AM, JT, LJ, TL, TS, SW to Senior Lecturer/Associate Professor; AJ and MW to Lecturer, from research fellowships.

Supporting talented female researchers: we have a package of measures to pro-actively support female staff, e.g. PDRA support during return from maternity leave, which have contributed to their notable successes. In addition to LJ, AJ, JT and SW, all of whom have made successful transitions to permanent academic positions, RW has received 3 prestigious personal fellowships during the REF period and AN has received numerous personal awards, including a prestigious £2M, 10-year RAEng Chair in Emerging Technologies (ref. 10150, 2009-19). The Faculty of Engineering's Athena Swan Bronze award is providing further impetus to our support measures for female staff.

Recruiting staff with complementary skills from other disciplines: Excellent multi-disciplinary research requires staff with a range of skills from different disciplines. Eight staff have first degrees in computing, materials, maths and physics and TC and JT have joint staff appointments with other Schools. Within iMBE, over 50% of researchers are from disciplines outside engineering.

Encouraging staff equality and diversity: We ensure that all recruitment panel members have received equality and diversity training and offer flexible working arrangements, where necessary.

Staff Development:

We provide multi-disciplinary staff development both within our UoA and supported by the University's Staff and Departmental Development Unit (SDDU http://www.sddu.leeds.ac.uk/), which received the HR Excellence in Research Award from the European Commission in 2010. In addition to tailored training in core technical areas, staff can access training in e.g. research, academic leadership and professional skills. As described in REF3a, staff also receive training in enterprise, impact and innovation, through e.g. our Innovation and Knowledge Centre (IKC) in Medical Technology (http://medical-technologies.co.uk/), providing them with the skills needed to deliver the maximum impact. Contract research staff are mentored according to the Concordat guidelines by a member of staff other than their PI and can access training and development opportunities in e.g. attracting research income, impact and innovation. Post-probation, all research staff participate in our Staff Review and Development Scheme (SRDS) which provides a 2-way review of work progress, identifying this UoA's challenging expectations, providing feedback and planning appropriate career development. All academic staff have annual SRDS and academic review meetings, the latter with the Head of School, Director of Student Education and Director of Research & Innovation, where they receive further guidance and support.

We use our extensive networks to recruit high calibre international staff and visiting scholars (e.g. through our ITNs). Approximately half of our research staff are from overseas and we host visiting scholars from countries such as Brazil, China, India, Mexico and Nigeria. Many of our research

staff have gained employment with our collaborators, e.g. in DePuy, Rolls Royce and Shell, and we provide mentoring and teaching opportunities for researchers wishing to pursue academic careers.

The following staff in this UoA currently hold personal research fellowships:

- RW has a £1M EPSRC Challenging Engineer Award (EP/K020757/1) and a €1.5M European Research Council Starter Award (ERC StG 306615).
- AN has a £2M 10-year RAEng Research Chair in Emerging Technologies, an ERC Advanced Investigator Award (€1.3M, ref. 268519) and a Royal Society Wolfson Research Merit Award (ref. WM120101).
- JF has an ERC Advanced Investigator Award (€1.5M, ref. 267114) and an NIHR Senior Investigator Award (£90K, 09/15).

ii. Research students

The School R&I committee manages the budget for studentships (currently >£250K p.a.). Our strategic priorities are to achieve matching external funding for research students, to support newly-appointed academic staff with PhD studentships and to diversify our sources of funding. The latter strategy has provided funding for research students from: the EPSRC (via our Doctoral Training Centre (DTC) in Tissue Engineering and Regenerative Medicine (£7M, EP/500513/1)), the EU for our Marie Curie ITNs and a number of SMEs and multinationals such as DePuy and Shell.

Our DTC is led by Leeds in collaboration with the universities of York and Sheffield and has taken over 60 students so far. All students undertake their initial year in Leeds and move on to a multi-disciplinary PhD. We have also created our own internally-funded Centre for Doctoral Training (CDT) in Medical and Biological Engineering using EPSRC Doctoral Training Account funding and have already admitted 14 students in two years to this scheme. Students graduating from the DTC and CDT can apply for an EPSRC Landscape Fellowship in collaboration with Sheffield, York, Keele and Nottingham. Our Marie Curie ITNs have provided funding for a combination of doctoral, masters and visiting fellowship awards in the areas of spinal technology, low friction engines and multi-disciplinary design optimisation and have enabled us to recruit 13 excellent PhD students from Belgium, Canada, Croatia, Czech Republic, Germany, Iran, Italy, Kenya and Nigeria.

We are also extremely pro-active in recruiting high quality international research students and respond to all applications within 48 hours. We interview all potential research students (via skype or telephone for international applicants) to ensure students have the necessary motivation and skills. Other initiatives include the establishment of our Centre for Mechatronics and Robotics with a target intake of 10 PhD students p.a. and our contributions to two new CDTs in Tribology and Fluid Dynamics. We graduated an average of 23 PhD students p.a. during the REF period and our recent initiatives have led to an increase, with 34 doctoral degrees awarded in the 12/13 session.

Most of our research students have more than one supervisor and all have an independent academic advisor, who can act as an advocate for the student. All first year PhD students take a number of compulsory training courses and additional courses as required. Students agree a training plan with their principal supervisor within one month of starting and use the University's online Postgraduate Development Record System (PDRS), which provides a training needs analysis tool based on the UK's Researcher Development Framework. The PDRS also provides a formal progress monitoring mechanism, including supervision meetings, training courses attended and the formal progress reviews. Each student must pass formal assessments after 10 months (based on a report and viva) and 24 months (based on a paper prepared from their research).

We provide extensive training and development opportunities for research students, based on the Next Generation Researcher programme, and use the experience gained by training cohorts of students on our DTC, CDT and ITN programmes to provide an effective mix of transferable and technical skills training. The former includes training in the PhD process, presenting research, writing and publishing, teaching and learning, career management and public engagement, with a particular emphasis on enterprise, impact and innovation. The University monitors carefully the quality of its research student training and development by encouraging our students to participate in the Postgraduate Research Experience Survey (PRES). A number of actions were put in place following the outcome of the 2011 PRES, including requiring:

- the PGR tutor to report to School board meetings on PGR matters;
- a mock viva at the end of year 2 based on the student's year 2 progress report;
- the PGR tutor to coordinate opportunities for teaching and demonstration opportunities;
- the PGR tutor to monitor closely transfer and annual report submissions to identify and intervene early in problem cases.

In the 2013 PRES 85% of our students were either satisfied or very satisfied with their experience.

Most research students present their work at academic conferences and all have the opportunity to present their research at the School's research seminars and at the University's annual PG conference. We have other regular events for our PhD students, e.g. Research Excellence Seminars where our most successful academic staff and PhD students talk to PhD students about achieving research excellence. Research students are also benefiting from our significant infrastructure investments (see below) and from our vibrant seminar programme, which has included talks by Rolls-Royce, Shell, US Naval Research Laboratory, EADS-Atrium and a number of leading UK and international universities. We also use our networks to provide career pathways for our research students and many have gained employment in e.g. Rolls-Royce, Airbus, Shell and Parker Hannifin, and as research staff in leading UK and international universities.

d. Income, infrastructure and facilities

Income: Starting from the rising income levels reported in RAE 2008, annual research income has grown substantially during the REF period, from under £4.7M in 2008/09 to an average of over £6.1M in subsequent years. We continue to enjoy major successes with UK funders and have increased the sustainability of our funding portfolio, with a sharp rise from the EU and international companies. The main contributions to our income during the REF period were: UK Research Councils: 38%, Industry: 18%, UK Government: 16%, UK Charities: 15%, EU Government: 10%.

Funding highlights during the REF period with this UoA's staff as PI include EPSRC funding of:

- A Doctoral Training Centre in Tissue Engineering and Regenerative Medicine (£7M, EP/500513/1);
- An Innovation and Knowledge Centre (IKC) in Medical Technology funded by EPSRC, BBSRC and TSB (£10M, EPG0324831, EPI0191031, EPJ0176201);
- An EPSRC Programme Grant in Biotribology of Cartilage and Cartilage Substitution (£4.5M, EPG01121721);
- WELMEC Centre of Excellence in Medical Engineering, collaborating with 10 departments and 250 academic researchers (£11.2M, Wellcome Trust and EPSRC, WT088908/z/09/z);
- Projects on thermal energy management in the process industries and forced and natural wetting (total £700K, EP/G058504/1, EP/F065019/1);
- Challenging Engineering Follow-on Award to RW (£990K, EP/K021729/1);
- A joint industry award on self-tuning fully adaptable lower limb prosthetics with energy recovery (£1M, EP/K020463/1);
- Centre for Innovative Manufacturing in Medical Devices (£5.6M, EP/K029592/1).
- A National Innovation Playground for Tribological Vapour Deposition Coatings (£2.6M, EP/H050027/1)
- A National Facility for Innovative Robotic Systems (£2.6M, EP/J021156/1)

and TSB projects on: flow assurance in the oil industry (TP14/OAG/6/I/BE036F, £1.2M, with BP and Expro); and next generation tablet manufacture in the pharmaceutical industry (TP/14/HVM/6/I/BD352J, £1.1M, with GSK and Durham University).

We have received substantial NIHR funding e.g. for the Leeds Musculoskeletal Biomedical Research Unit, co-hosted with the Medical School (£13M, lmbru.leeds.ac.uk) and a £790K Health Technologies Cooperative Network for Colorectal Therapies (Ref. 10114, Scientific Director, AN).

European Funding is also growing strongly and is demonstrated by our coordination of:

- the €3M EU FP7 Collaborative Project: *2020 Interface*, with industry partners Lubrizol, SKF, Sulzer & Volvo, 2009-2012;
- 2 Marie Curie EU ITNs of total value €6.2M: (Spinefx and ENTICE) and the European Industrial Doctorate Scheme: FUTURE_BET (€1.4M, with SKF Ltd, Netherlands);

- The ERC Advanced Grant *CODIR: colonic disease investigation by robot hydro-colonoscopy* (ref. 268519) with Dundee University, of value €1.3M to this UoA;
- The ERC Advanced Grant *REGENKNEE* (ref. 267114) with Biological Sciences (UoA5) of value €1.5M to this UoA.
- a recently-awarded €13.3M project (€3.4M to this UoA) in *Life Long Joints: silicon nitride coatings for improved implant function*.

In addition, each of the institutes has excellent funded research links with industry. *iMBE*, for example, has long-standing funded collaborations with DePuy (£4M between 2001-14), Mathys (£200K, 2008-13), Simulation Solutions and the University Spin-out Tissue Regenix. *iMBE* also has funded international collaborations with China, Japan, Australia, India and the US. *iETSI* has itself received direct industrial funding from 30 companies during the REF period to support several PhD students (e.g. Sandvik, Statoil), highly successful applied research projects (e.g. a Yorkshire Forward-funded project on *jet pump technologies for diesel filtration products*, with Parker Hannifin, value £750K) and postdoctoral researchers (e.g Shell, Clariant). *iETSI* has recently signed a 5-year framework agreement with Shell (expected minimum £30K p.a.) to work with them on fuel combustion [text removed for publication]. *iDRO* has enjoyed a number of collaborative research projects with companies such as Rolls Royce and National Instruments and a number of successful Knowledge Transfer Partnerships (KTPs) with SMEs (e.g. Surgical Innovations, CGI) and multinationals (e.g. EADS UK). More generally, with 5 KTPs running at the start of the REF period and a further 11 awarded during the period, this UoA has received £1.79M in KTP funding.

Our future funding plans are aligned with the strategy described in section b). We will target large awards from the EPSRC that will enable us to: (i) extend our tribological simulation systems to patellae-femoral and ankle joints; (ii) develop disease specific models for joints; (iii) extend our computer simulation capabilities to the hip and knee; (iv) expand and support the capability of our newly-established National Robotics Facility. We will exploit our excellent EU networks to develop Horizon 2020 proposals in e.g. surface engineering, tribo-chemistry, data centres, medical robotics and multi-disciplinary design optimisation. We will also target increased funding for our corrosion and flow assurance research from the oil and gas industries, particularly in Latin America.

Infrastructure and Facilities: Our continuous programme of infrastructure investment ensures that our facilities remain internationally-leading and we invest ~£400K p.a. in the replacement of research equipment. All strategic decisions relating to government funding for infrastructure and facilities are coordinated from the University R&I Board through the Faculty and School R&I committees. The School R&I committee takes the strategic investment decisions on research infrastructure and facilities. Our computational research is supported both through the University's centrally provided 4500 core HPC facility (45 TFlops, with planned biennial investments of £1M) and the additional resources provided by the £2.6M regional N8 facility of 5312 cores (110 TFlops).

Within iMBE, the University has contributed £3M to a new Medical & Biological Engineering building, which provides accommodation for 100 researchers and over 500m^2 of Class 2 Clean Room Laboratories, housing over £5M of simulation equipment. Additional funding for equipment has been supported by the EPSRC, Wellcome Trust and the Wolfson Foundation. Our joint simulation facilities are the largest academic facilities in the world for tribological studies of hip, knee and spine joint replacements. Collaboratively with Leeds Teaching Hospital Trust, through the Leeds Musculoskeletal Biomedical Research Unit, iMBE has also invested £3M in a 3T clinical MRI scanner, and the University has provided additional tissue engineering and cell culture laboratories in the Faculty of Biological Sciences to support multi-disciplinary expansion.

Within iETSI, the integration of tribology, corrosion, thin film, microfluidics and optical metrology facilities is unique. iETSI has: the *Dowson Tribology Laboratory* with tribometers and specialised simulation rigs for the study of lubrication, friction and wear; the *Bradley Combustion Laboratory* contains optically accessible engines, special combustion vessels including a unique high speed fan-stirred bomb for investigating high temperature and pressure combustion, state-of-the-art laser diagnostic techniques and 3D imaging; a refurbished *Erosion and Corrosion laboratory* with rigs for oil and gas applications, mineral scaling research and bioengineering systems; a *Surface Analysis*

Suite including atomic force microscopy, nano-indentation, mass spectroscopy, X-ray photo-electrono-spectroscopy, infrared spectroscopy and quartz crystal microbalances; an *Optics Laboratory* developing novel imaging and metrology techniques; and a *Microfluids Laboratory* featuring micro particle image velocimetry and high-speed photography. Our £1.5M share of the EPSRC National Innovation Playground Grant for PVD Coatings (EP/H050027/1) has led to a new *Advanced Coatings Laboratory* with a Hauzer PVD System and a dedicated Experimental Officer.

Within iDRO, our facilities include: a *Charterhouse Rehabilitation Technologies Laboratory* with a motion tracking system to support development of novel restorative rehabilitation technologies; a *Design Systems Laboratory* including soft metrology facilities and a *Design Observation Suite* to study human-centred and emotional design concepts. We also have excellent new facilities for characterising the dynamic behaviour of materials, including £200K Instron test machines, small-scale dynamometers for evaluating novel brake and clutch materials and a high speed thermal imaging camera. Our recent EPSRC award to create a *National Facility for Innovative Robotics Systems* will provide further state-of-the-art robotics facilities, including a £650K 3D printer, a £550K precision water/laser jet cutter and a 3D visualisation studio for real-time motion tracking.

Within this UoA our current and planned investments include:

- A £650K investment (with an additional £320K from the University) in lab refurbishment and equipment to support our National Robotics Facility.
- A £150K investment in a laboratory expansion for corrosion in the oil and gas industries.

Consultancy and Professional Services: As described in REF3a, we recognise the importance of these activities and incentivise and reward staff who undertake them, both through our Enterprise and Innovation promotion criteria and through additional financial payments. Over 20 of our staff have provided consultancy during the REF period and we have had both long-term consultancy contracts with companies (e.g. DePuy: joint replacements, £4M, 2001-14; Mathys: tribology of ceramic hips, £200K, 2008-13; GT Group: analysis of exhaust brakes, £120K, 2009-11, One North East/LCRD/ 09/004) and several smaller ones (more than 90 in the REF period). The latter include fuel combustion and engine testing (Shell), corrosion testing (Clariant), sprays testing (P&G) and PVD coatings (Caterpillar). Our professional services focus on short CPD courses and tailored training, e.g. our orthopaedic bio-mechanics and fire safety and hazards courses and our tailored courses on spine biomechanics (for DePuy) and the efficient processing of soft solids (for GSK).

e. Collaboration or contribution to the discipline or research base

Collaborations with researchers outside this UoA

UK Collaborations: In addition to numerous bi-lateral collaborations with UK industry (e.g. DePuy, GSK, Parker Hannifin, Shell,…) and the NHS Blood and Transplant Services, examples of large UK research collaborations and networks which this UoA's staff are leading include:

- Our DTC in Tissue Engineering and Regenerative Medicine with the Universities of York and Sheffield, the Leeds Teaching Hospitals NHS Trust and 10 companies.
- The IKC in Medical Technology which is working with 5 other universities and 34 companies to create new regenerative therapies and devices.
- Centre for Innovative Manufacturing in Medical Devices, working with the universities of Bradford, Newcastle, Nottingham and Sheffield and 14 companies.
- The RegeNer8 consortium (www.regener8.ac.uk), working with the Northern 8 Universities and a network of 200 companies in the regenerative medicine industry.

Our staff also have major leadership roles in: (i) the Leeds Musculoskeletal Biomedical Research Unit (www.lmbru.ac.uk) with: Leeds Institute of Molecular Medicine, Biomedical Sciences Research Centre and the Clinical Trials Research Unit; (ii) AN is Scientific Director of a £790K NIHR Health Technologies Cooperative network in colorectal therapies (ref. 10114, 2013-16).

International Collaborations: Examples which staff in this UoA have or are coordinating include:

- The €3M FP7 project *2020 Interface* (www.2020interface.eu) developed energy-efficient automotive powertrains with University of Groningen, Netherlands; Josef Stefan Institute in Slovenia; and companies (Sulzer, Switzerland; Volvo, Sweden; SKF, Netherlands).
- Our €2.9M *Spinefx* ITN (www.spinefx.org), is working with 3 European universities (ETH

Zurich, Technical University Hamburg-Harburg and Bern) and companies in Denmark, Germany and Sweden in the areas of spinal biomechanics and vertebral fracture.
- Our €3.2M *ENTICE* ITN (www.enticeitn.eu) in tribology and tribochemistry, working with Ecole Centrale Lyon, France; University of Ljubljana, Slovenia; the Austrian Center for Competence in Tribology and TOTAL, France; SKF, Netherlands and Mercedes, Germany.

This UoA's joint coordination (with Civil Engineering, UoA 14) of the *AMEDEO* ITN (http://www.amedeo-itn.eu/) with partners such as TU Munich, Germany; TU Delft, Netherlands; Von Karman Institute, Belgium; Rolls Royce, UK and Airbus, France is developing advanced multi-disciplinary design optimisation methods. Other examples include: (i) collaborative support for the joint simulation systems run by academic institutions around the world (in UK, China, India, Australia and France); (ii) corrosion research, funded by BG Group, in collaboration with the Universidade Federal (UFRJ) and Pontifícia Universidade Católica (PUC) of Rio de Janeiro, Brazil.

We seek pro-actively the views of our research users to ensure that our research activities and strategy remain closely aligned to key industrial and societal challenges and funding priorities. We use a variety of mechanisms to achieve this, e.g. hosting regular end-user focussed days and conferences and by including key end-users on our Industrial Advisory Board. The intelligence gathered is fed into the research strategy using the approach described in part b) above.

Leadership roles within the discipline

The majority of staff in this UoA have leadership roles within their disciplines e.g. on international standards committees, including RH (UK nominated expert on ISO TC150 Implants for Surgery); JT (Co-lead for ISO 17583 International Standard for Particle Isolation and member of ASTM F04 Medical and Surgical Materials and Devices) and LJ (IMechE representative on ISOTC 150). We also have individuals with a number of very important leadership roles, e.g.

- JF is a member of the EPSRC council, chair of EPSRC Peer Review Committees, member of the RAEng Research committee, founding chairman of *Tissue Regenix Ltd* and a board member of Leeds and Partners, the city's development vehicle.
- AN is an expert witness in the BP Deepwater Horizon litigation, co-chair of the ARUK Task Force into Corrosion in Hip Joints and a General Engineering Panel Member for REF2014.

Contributions to Learned Societies, Professional Bodies, Journals and Conferences:

Two staff (DD and DB) are FRS, 7 are FIMechE, 4 are FREng (DD, DB, JF, AN), and one is a FMedSci (JF). Staff are very active in professional institutions and societies, through committee memberships, e.g. in the Royal Society (DB); Spine Arthroplasty Society (RH); IMechE Tribology Group (AM); the IoP's Optics and Photonics Division (DT). All staff review papers for leading mechanical engineering journals and act as external examiners at major UK and international universities. 12 staff are/have been on the Editorial Boards of over 20 leading journals, including: Proc IMechE Part D (DCB), Tribology – Materials, Surfaces & Interfaces (Editor-in-Chief AN, MP, TL, AM). We have created and chaired a number of new international conferences during the REF period, e.g: 1st International SPE Oilfield Nanotechnology Conference, June 2012, 1st International Conference on Oncological Engineering, Leeds Sept 2011 (AN, RH, MCL); Datacentre Transformation Conferences, 2012, 2013 (JS, HT) and chaired major international conferences, e.g. Leeds-Lyon Tribology Conferences (MP) and Eurobrake 2012 & 2013 (DCB).

Fellowships, Awards and Prizes

Highlights include:

- RW's £1M EPSRC Challenging Engineer Award (EP/K020757/1, 2013-18) and a €1.5M European Research Council Starter Award (ERC StG 306615).
- AN's prestigious £2M 10-year RAEng Research Chair in Emerging Technologies (2009-19), an ERC Advanced Investigator Award *CODIR* (€1.3M, 2011-16), a Royal Society Wolfson Research Merit Award and the Donal Julius Groen IMechE prize in Tribology in 2011.
- JF's ERC Advanced Investigator *REGENKNEE* (€1.5M, 2011-16).

Two decades of world leading medical engineering research and impact have also led to the award of CBE to JF and the Queens Anniversary Prize to iMBE in 2011.