Annex I: Unit-level environment template (REF5b)

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Institution: University of Exeter

Unit of assessment: Engineering UoA12

Section 1. Unit context and structure, research and impact strategy

1.1 Context and structure

Engineering at the University of Exeter (UoE) is a growing, flexible, inclusive and multidisciplinary grouping consisting of all academics from the **Department of Engineering**, some staff from the **Camborne School of Mines** – both within the College of Engineering, Mathematics & Physical Sciences (CEMPS) – and the **Business School**. In terms of research, we seek to build on our strong international influence as well as cultivate a significant regional presence in the South West of England. We continue to pursue our reputation for delivering excellent research based around themed multidisciplinary groups and centres, exploiting existing areas of strength and developing new ones, developing strong partnerships with industry, and taking advantage of the emerging Exeter Science Park. In the lead-up to REF2014, Exeter Engineering invested in eight new chairs to optimise the alignment of the research groups with societal and industrial priorities. During the current REF period, this investment has consolidated our capacity in existing areas of strength, allowing us to exploit exciting interdisciplinary synergies, within and without the department, and to pursue innovation towards industrial and societal transformations. Since REF2014, Exeter Engineering has continued to build on these strengths through **34 new research-led appointments** that further advance our specialist fields of research.

Headline achievements over this REF period include:

- Substantial growth in the number of research-led academic staff increasing our REF submission from 44 FTEs in 2014 to 78.8 in 2020
- A significant increase in research awards (£68.7M v £28M) compared with REF2014
- 14 prestigious fellowships.
- 5 EPSRC Centres for Doctoral Training/Industrial Doctorate Centres
- A new Renewable Energy Engineering Facility in Penryn (£1.7M)
- A new Science and Engineering Research Support Facility in Penryn (£5.5M)
- A new Engineering Research Building on the Exeter Science Park (£7.3M)
- The EPSRC VSimulators Strategic Equipment award (£3.5M) and facility
- New engineering laboratories, makerspace and workshop (£6.5M)
- A new strategic partnership with Victrex plc (£1.5M)
- Research leadership in offshore renewables via the EPSRC Supergen ORE Hub
- Significant enhancement of the analytical capacities in the Responsible Mining Group

Exeter Engineering research is organised into eight research groups (Nano Engineering Science & Technology, Water & Environment, Materials & Manufacturing, Dynamics & Control, Engineering Management, Civil & Structures, Renewable Energy, and Responsible Mining) across two University campuses. Six of these are located on the Streatham site in Exeter. The Responsible Mining group is part of the multidisciplinary Camborne School of Mines – Europe's top Mineral and Mining Engineering school (2020 QS rankings). It is located, along with our Renewable Energy group, at Penryn in Cornwall. These two groups are so situated to maximise the benefits of resources at these locations: The Renewable Energy group operates a unique offshore facility at Falmouth for testing equipment, and Camborne School of Mines benefits from past and present on-site mining activities.

1.2 Research and impact strategy

***Strategy in REF2014 and during the REF period*:** The goals of our REF2014 research strategy concerned (i) development of critical mass and interdisciplinary strength in our research groups, (ii) wider and deeper industrial engagement, and (iii) internationalisation. These were complemented by our impact strategy which was to concentrate resources on our existing areas of impact strength and target new ones aligned with priority areas, and firmly embed and support impact as a 'third mission' activity of equal importance as education and research.

During this REF period, the university has continued to invest strategically in Engineering. This has enabled us to create a vibrant engineering research environment attractive to staff of the highest quality, to carry out internationally leading research, to leverage significant research funding from external sources, and to collaborate with a wide range of national and international academic and industrial partners.

(i) Critical mass & interdisciplinary strength: Major investments in additional staff and improved infrastructure and facilities have been made at both the Streatham and Penryn campuses (Section 3). For example, Exeter Engineering will return 78.8 FTEs in REF 2021 compared with 44 FTEs in 2014 further enhancing our critical mass. In addition, we have transformed our research facilities by building new laboratories and purchasing new experimental equipment for renewable energy, nanomaterials engineering, additive layer manufacturing, vibration engineering and structural health monitoring. This is underpinned by a £6.5M capital investment in the engineering laboratories at the Streatham campus and a complete rebuild and re-equip of the workshop facilities. We have implemented our interdisciplinary ambitions through research driven by real world problems and intellectual challenges in areas such as mitigating the effects of climate change, sustainable energy production, the development of advanced materials, the development of low power nanoscale electronic devices, and sustainable manufacturing. This has been underscored and enhanced by our leadership and/or partnership in our interdisciplinary Centres for Doctoral Training/Industrial Doctorate Centres (CDT/IDTs): WISE, STREAM, IDCORE, Meta-materials, and Sustainable Materials and Manufacturing. Furthermore, some staff have taken up key interdisciplinary roles (e.g. Dodwell is Data for Science, Engineering and Technology Theme Lead in the Exeter Institute for Data Science and Artificial Intelligence) and Ahmed-Kristensen (based in the University's Business School, but whose papers are cross-referred to UoA12) leads on Design Engineering and Innovation at the multidisciplinary INDEX Initiative for the Digital Economy (https://exeterindex.org).

(ii) Industrial Engagement and Impact generation: Engagement with industry has always been a key feature of Exeter Engineering, and our activity over the last REF period is no exception. Our key goals have been to both translate the research into valued end-use, and to stimulate research ideas. All eight of our research groups are industry facing. Engagement and impact generation has been extensive and growing as evidenced by the increase in industrial/government research awards from £9.5M at REF2014 to £14.3M today. Further details are given in Section 4, but these include: a £10.5M UKRPIF strategic partnership with £21M committed by South West Water, a £1.5M, strategic partnership with Victrex plc, a £7.3M industry-facing Engineering Research Building at the Exeter Science Park, and the £0.9M offshore renewable energy demonstration site (FaB Test) in Falmouth Bay. We have been awarded 34 Knowledge Transfer Partnerships since 2014 with partners ranging from local SMEs (Chelonia Ltd) to FTSE 100 companies (United Utilities). We have or have had 6 Royal Society Industry Fellowships and Royal Academy Industrial Fellowships linked with major companies, 2 Royal Society Entrepreneurs in Residence, 2 Royal Academy of Engineering Visiting Professors and 3 industry-funded academic appointments (Rio Tinto, First Quantum and British Geological Survey). Each of our 5 CDT/IDTs are extensively backed by industry partners including sponsored PhD studentships. Our CALMARE Business Technology Centre, funded by the European Research and Development Fund, has supported over 150 businesses on the use of

composites and plastics. We have also had significant involvement in 7 university spinout companies during the REF period (Section 4).

Embedding of impact was an important part of our impact strategy in 2014 and has been achieved to the extent that impact generation is now a fully established integral part of every engineering academic's career and thinking. Over this REF period, the University has reorganised its administrative support to academics and business through the establishment of the Innovation, Impact & Business directorate (IIB). Within the UoA, the new role of Director of Impact has been established with a remit to support and develop high quality Impact Case Studies and more generally to promote long-lasting impact activity in the discipline. Furthermore, academic recruitment, promotion and reward criteria now explicitly include recognition of excellent impact generation.

(iii) Internationalisation: As described in our REF2014 strategy, we have followed the '4th age of research' which argues that nations and institutions which prosper will be those which form international collaborations to drive forward innovation and impact. It is precisely these conditions that the University, with its 2018-22 Global Strategy, and the UoA have established and nurtured during the REF period, via targeted investment and support. Our internationally (including EU) funded research awards have increased from £4.7M at REF2014 to £20.6M for REF2021. In 2019, the University of Exeter was the top UK organisation (and ranked the 8th institution) in the EU in terms of budget participation in H2020 water-related research grants. We have had significant funding from the Global Challenges Research Fund (EP/P02839X/1) with projects and partners- particularly in India. During the REF period, we have initiated new research partnerships with the University of Queensland (Australia), the University of British Colombia (Canada), Tsinghua University (China) and the Chinese University of Hong Kong. Many international academics have visited the department, staff have visited overseas universities, and a number of staff were appointed as visiting professors (Section 4.4). In Exeter, we ran the 11th International Conference on Advances in Experimental Mechanics in 2016, and the 17th International Computing & Control for the Water Industry Conference in 2019.

***Future strategy for REF2021*:** It is increasingly clear that society at large is experiencing a 4th Industrial Revolution (Industry 4.0), as novel technologies such as the Internet of Things, smart factories, digital twins, additive manufacturing, data science and cognitive computing are being combined to transform manufacturing. In fact, these new technologies and ways of thinking and working are having a transformative impact upon all areas of engineering: civil, mechanical, electrical & electronic, mining and renewable energy as well as manufacturing and management. Here at the University of Exeter, our **research & impact strategic aim** is to be at the forefront of this new approach to engineering: what might be termed **Engineering 4.0**. To achieve this aim and to further ensure the sustainability and vitality of Exeter Engineering, we are prioritising three key **objectives** for the coming REF period: (i) Investing in people, space and equipment, (ii) enhancing and leveraging our interdisciplinarity, and (iii) new initiatives and core strengths. These broadly align with the institution's Research and Impact Strategy: see Section 2.1 in the Institutional-Level Environment Statement (ILES).

(i) Investing in people, space and equipment: We have already demonstrated significant growth and investment in Exeter Engineering over successive RAE and REF periods. For example, staff numbers submitted to this UoA increased by 50% from 2008 to 2013 and by a further 77% from 2014 to 2021. Our research awards doubled, and then more than doubled again over the same periods. Post-COVID 19, we envisage further internal investment *and* externally funded growth over the forthcoming REF period to strengthen our critical mass and enhance our facilities. We have exciting new plans in terms of space and equipment. These include: a new Exeter Digital Enterprise Systems laboratory, a Centre for Future Clean Mobility, a Centre for Ocean Technology, a Smart Grids Research Group and a new Data-Centric Engineering Research Group. All these are described in detail in Section (iii) below. A summary of our existing core strengths and plans is given in the 'structure & staff' section which follows.

(ii) Enhancing and leveraging our interdisciplinarity: The UoE is known for its interdisciplinary research and this ethos pervades the whole institution- including Engineering. This operates across our local, regional, national and international networks. The university's College structure ensures 'no walls' between disciplines and 'thin walls' between Colleges. We use Institutes to co-locate and co-create interdisciplinary research across our Colleges. A number of Engineering staff currently have joint positions in our Environment & Sustainability Institute in Penryn, and Camborne School of Mines, exploring the strong synergies between engineering, earth and social sciences in the development of sustainable resource extraction. Over the forthcoming REF period, we will be looking to make further joint appointments specifically to enhance our interdisciplinarity. For example, we are working to create a joint appointment between Engineering (Centre for Water Systems) and the College of Life & Environmental Sciences (Geography) to support the development of the Centre for Resilience, Water & Waste (CREWW). Another strong candidate is a joint position between Engineering and the Business School to promote and develop research into entrepreneurship – a strongly emerging theme. In the future, we see a particular growth area for joint positions with our new Global Systems Institute. We currently have a joint lectureship in low carbon engineering (Tian) and expect others to follow, particularly in the area of climate change mitigation.

We will continue to drive and support virtual research networks to link and mobilise researchers working across broad thematic areas. Engineering is a key partner in Exeter Marine and Exeter Energy, and we would look to lead and participate in others (e.g., Materials). These allow emerging trends to be anticipated, critical mass to be assembled and large bids to be rapidly developed. We intend to build on our recent virtual event "Opportunities for Collaboration in Data-driven Engineering" run by Engineering and the Institute for Data Science and Artificial Intelligence and to take forward new interdisciplinary ideas in larger-longer scale projects. This agenda will be underscored and enhanced by our leadership and/or partnership in our interdisciplinary Centres for Doctoral Training/Industrial Doctorate Centres (CDT/IDTs).

(iii) New initiatives and expanding core strengths
We see many opportunities presenting themselves over the forthcoming REF period and indicate below a non-exhaustive list of our plans to open up new initiatives.

- Exeter Digital Enterprise Systems lab [Lead: Sucala]: This is a new facility that will focus on Engineering 4.0, the smart factory and the development of digital twins. It will include a state-of-the-art Industry 4.0 demonstrator, plus supporting computing hardware and software. It will underpin research in the Engineering Management group on industry digitalisation including holistic and digitalised data integration, monitoring and control systems, process and resource integration within large organisations and supply chains, and optimal application of digital twins.

- The Centre for Future Clean Mobility [Leads: Smith & Menon]: This is another new facility which will specialise in the simulation, optimisation and testing of full-scale non-fossil fuel powertrains, and unmanned smart functionality (autonomy). Industrial collaborations, notably in the marine, off-highway, HGV, rail, and defence sectors will ensure financial viability and early impact. This will be based in the Engineering Research Building at the Exeter Science Park.

- The Centre for Ocean Technology [Leads: Johanning & Thies]: This new centre will draw together our expertise, resources and facilities in Offshore Wind Energy to enhance our external exposure, strengthen internal organisational structures and channel targeted investments to underpin future funding. Exeter is at the heart of an emerging South West

Floating Offshore Wind Accelerator consortium and is seeking substantial funding from UKRI and industry.

- The Smart Grids Research Group [Lead Wang]: This new group will specialise in power system plant, focusing on power transformers, the connection of battery energy storage systems to the power network, environmentally friendly dielectric materials and insulation systems, and condition assessment and asset management of electrical networks. It will also be based in the Engineering Research Building at the Exeter Science Park and will be funded by the National Grid and a range of other companies.

- The Data-Centric Engineering Research Group: [Leads Dodwell & Tabor] This is an exciting initiative supporting our Engineering 4.0 ambitions and will join together our data-centric engineering research work which operates at the dynamic interface between applied mathematics and high-performance scientific computing, with our extensive computational engineering research in materials, fluid dynamics, offshore renewable energy, water systems and vibrational analysis. This will build upon our links with the university Institute for Data Science & Artificial Intelligence and the Alan Turing Institute.

1.3 Structure & Staff

As described earlier, Exeter Engineering research is organised into eight research groups. Each group has an Academic Lead (AL) who provides strategic direction, leadership and mentoring. The research groups provide critical mass that can attract scholars and funding from disparate sources within an international market. They also serve as a focal point for interdisciplinary collaboration.

Nano Engineering Science & Technology (NEST) (lead: Wright), includes the **Centre for Graphene Science (CGS)**. **Professors** Wright, Craicun, Hrkac, Nash, M Zhu, Y Zhu; **Associate Professor** Aziz; **Senior Lecturers** Luxmoore, Baldycheva, Neves, D Zhu; **Lecturer** Ott.

The research focus of this group is on the design and fabrication of novel electronic, photonic and magnetic materials and devices, the understanding, via modelling and experimental characterisation, of their properties and performance attributes, and their exploitation for a range of real-world applications; from electronic, magnetic and photonic memory and computing devices, to wearable and flexible electronics, light sources and detectors, medical diagnosis, energy storage, and high-strength composites. Future research directions will include a push towards fast, low-power, non-CMOS memory and computing devices, metamaterial/metasurface devices for electromagnetic beam control, exploitation of graphene and other 2D materials, ultra-high-density magnetic storage materials, energy harvesting devices and systems, and new magnetic materials development for automotive and energy generation.

Materials and Manufacturing Group (MMG) (lead: Ghita), includes the Centre for Additive Layer Manufacturing **(CALM)**, the Centre for Alternative Materials and Remanufacturing Technologies **(CALMARE)**, and Exeter Advanced Technologies **(X-AT)**. **Professors** C Smith, Dodwell, Ghita, Evans, S Zhang, Young; **Senior Lecturers** Xia, Holsgrove, J Chen: **Lecturers** Agathos, Tian.

The research of this group centres on how to develop, produce, and exploit the commercial benefits of new materials, innovative new products and high value, low carbon manufacturing processes. Established collaborations with industry, such as Victrex, Arkema and Invista on additive manufacturing, and Rolls-Royce for multifunctional materials for vibration damping, will continue and is slated to expand further. Partnerships with companies such as Victrex – on developing the next generation of high temperature polymers for Additive Manufacturing – and the National Additive Manufacturing Centre at the Manufacturing Technology Centre, will continue to deepen. Existing links with the Alan Turing Institute will expand further and support

the need for big data to aid manufacturing and its supply chain. The CALMARE Business Technology Centre funded by the European Research and Development Fund (ERDF) supported over 150 businesses on the recycling and remanufacturing of waste materials.

Water and Environment Group (WEG) (lead: Djordjevic), includes the Centre for Water Systems **(CWS)**. **Professors** Djordjevic, Butler, Savic, Kapelan, Memon, Fu, Tabor, Belmont; **Associate Professors** Farmani, A. Chen; **Senior Lecturer** Moxey.

CWS is an internationally leading centre for research into the planning, design, operation and rehabilitation of urban water systems, with particular expertise in hydroinformatics and urban water management. It has pioneered the development of many of the techniques and tools, such as evolutionary multi-objective optimisation, used by water professionals worldwide. CWS has long-term partnerships with key players across the sector including the Environment Agency, United Utilities, Northumbrian Water and Hydro International. Future research areas lie in developing sustainable and resilient solutions for dealing with future uncertainties, representing and engineering the global energy-food-water nexus and driving forward the digital water agenda. This will be underpinned by developing greater understanding, handling and exploitation of AI and 'Big Data' through digital innovation and the Engineering 4.0 agenda. It will continue to work closely with our research centre CREWW in terms of leadership, project development and delivery.

Dynamics and Control Group (lead: Brownjohn). **Professors** Brownjohn, Pavic, Reynolds, Edwards; **Associate Professors** Menon, Zivanovic; **Senior Lecturers** Alwi, Koo, Liu; **Lecturers** Papatheou, Monsalve.

The vibration engineering team within this group aims to improve structure performance for reduced financial and environmental impact, including the use of alternative materials. Developed research expertise has been applied, mainly via the spinout Full Scale Dynamics (see below), to enhancing the dynamic performance of new-build footbridges, football stadia, floors and tall buildings, through optimal design, experimental evaluation and inclusion of vibration mitigation devices. The very strong link between human comfort and design of these structures has led to the establishment of the VSimulators experimental facility (see Section 3.2) for which applications will go beyond engineering into medicine and humanities. Research on ageing infrastructure has included a project on condition assessment of Victorian lighthouses and dynamic assessment of telecoms masts. Our control team tackles problems associated with dynamic structures, such as aeroplanes and space craft, and the modelling of human bodies for medical and structural applications. The group has strong on-going collaborations with AIRBUS and the Japan Aerospace Exploration Agency.

Engineering Management (lead: D Zhang). **Professor** D Zhang; **Lecturers** He, Melville-Shreeve, Yang, Yuce, Luis, D Wang, S Zhang

This group focuses on methodologies to support the design, analysis and management of strategies, operations and supply networks for engineering businesses. Research topics include manufacturing strategies, supply chain management, business model innovation, digital manufacturing, organisation and entrepreneurship, open innovation and smart systems. Industrial collaborations include both large international businesses: for example, with CIFUNSA (Mexico) on supply chain optimisation and inventory management, and with the Beijing General Research Institute of Mining and Metallurgy and Beijing COMPO on agile and lean manufacturing strategies, as well as local SMEs. The future strategy of the group is to work on methodologies to support the design and operation of new forms of manufacturing systems in the digital and cyber age, as well as research on new business models and strategies to support the transition to the new technology era (Industry 4.0).

Civil & Structures (lead: Kripakaran). **Professor** Javadi; **Senior Lecturers** Kripakaran, Eames, Wadee; **Lecturer** Vinai.

This group brings together expertise in civil and structural engineering subjects such as building physics, computational geomechanics, structural stability and bridge hydraulics, to address challenges related to the design and management of a sustainable, low carbon-built environment. The group's research is strongly inter-disciplinary and spread across a range of topics including health and wellbeing in buildings, hydraulic fracturing, groundwater management, waste and recycled building materials and bridge management. The group has an excellent track of generating impact: notable examples include (i) weather design data that is now embedded within building regulations, and (ii) a methodology for assessing bridge scour risk in Highways England guidance. Future research in the group will aim to provide solutions for the following major challenges: 1) adapting infrastructure for climate change; 2) enabling a circular economy for the built environment; and 3) creating smart and resilient built environments.

Renewable Energy Group (REG) (lead: Johanning). **Professors** Johanning, Mallick, Li, Z Wang; **Associate Professors** Abusara, Thies, Connor; **Senior Lecturers** H. Smith, Sundaram, Tahir, Yan; **Lecturers** Ashton, Pillai, Ghosh, Matharage.

The group follows a holistic, integrated and interdisciplinary approach to advance sustainable energy engineering through innovative and applied solutions. It embraces the topic areas of power generation, energy storage, power transmission and control, as well as energy policy and lifecycle assessments. Specific research strengths lie in the area of i) offshore energy generation ii) solar energy iii) electrical and thermal energy storage iv) smart glazing v) power control for energy engineering and vi) energy policy and energy-nexus system assessments. As a core member of EPSRC's SuperGen ORE hub, the Joint UK-India Clean Energy Centre (JUICE), the UK & China Centre for Offshore Renewable Energy and the TUS-ORE Catapult Research Centre, the group partners with leading international universities and businesses. Particular impacts have been achieved in supporting regional and national companies through applied research solutions and technology development. The Penryn campus hosts a Technology Innovation Centre, facilitating co-creation between researchers and companies, and hosts world-leading and unique solar and offshore testing labs that are used for academic and industrial research alike.

Responsible Mining Group (CSM) (lead: Coggan). **Professors** Coggan, Glass; **Associate Professors** Foster; **Senior Lecturer** Eyre; **Lecturers** Crane, Fitzpatrick, Diallo, Vogt.

The group concentrates on the multidisciplinary challenges of responsible mining, including energy and resource efficiency, ore deposits and critical metals, health and safety, resources for the circular economy and social and environmental protection. The group's research strategy is to ensure continued access to metal and mineral resources using extraction techniques that minimise environmental harm and maximise societal benefits (Diallo, who specialises in mining, politics and social insecurity, has been cross-referred to UoA14). Rio Tinto and First Quantum each sponsor a Chair, the British Geological Survey sponsors a Lectureship in Critical and Green Technology Metals (part of the Critical Metals Alliance). The group has a strong record of funding from industry (e.g., Anglo American, First Quantum, BHP), EU Horizon 2020, EU INTERREG, and the EU Research Funds for Coal and Steel. A recent £1 million donation by Centamin PLC (the Richard Osman Memorial Fund) will support 40 scholars over a 20-year period.

1.4 Open Research

The University's Open Access Research and Research Data Management policy was revised in 2017 to reflect the institutional commitment to and broader support of Open Research (Section 2.8 in ILES). It is aligned with external policies encouraging open access to other outputs not mandated by REF and requiring all UoE outputs to include a data access statement. Since 2016, the University has facilitated immediate (gold) open access (OA) to non-funded outputs with the

creation of the Institutional APC Fund. The Institutional Repository, ORE, reached more than 5 million downloads, placing it in the Top 10 of UK repositories (participating in IRUS-UK). Support is provided centrally, courtesy of the library, who proactively manage journal copyright requirements, in consultation with the Director of Research. Since April 2016, it has been made mandatory for all staff to submit open access compliant versions of their papers to ORE within 3 months of the paper's acceptance. During the REF period, the UoA has deposited 1808 papers. Between Jan 2014-June 2020 there have been 194,000 downloads of Engineering papers, which represents 48% of the total number of downloads from within CEMPS as a whole.

1.5 Research integrity

The University upholds the highest standards of scientific, scholarly and professional integrity, including ethical, social and environmental issues arising from its research activities, supported by comprehensive policies and strategies. These include an Ethics Policy, a Research Ethics Framework, a Code of Good Practice in the Conduct of Research, Misconduct in Research reporting guidance, and a Public Interest Disclosure "whistleblowing" policy.

Exeter Engineering conducts a range of research and consultancy work from experimental laboratory-based investigations, through fieldwork studies to non-invasive research with human subjects (e.g., questionnaires, surveys). This is carried out to the highest scientific and ethical standards following the guidelines mentioned. All projects require ethical approval at the application stage and each project PI must ensure compliance with the Research Integrity policies set out by the University and funders. The UoA has a dedicated Ethics Officer able to offer advice and support.

Section 2. People

We recognise that our staff are our greatest asset, and we endeavour to create an environment in which they feel valued, can thrive, and are rewarded for their success. As outlined in our REF2014 plans, we have grown our submitted staff numbers by 78% during the REF period to 78.8 category A staff. This is in line with our REF2014 Research & Impact strategy and the University's recruitment strategy over this period, i.e., to build its research power to deliver its research, education and global strategies. In addition to recruiting new staff, a further strengthening of our research profile has been achieved by developing the research performance of our existing staff. Together with new recruitment focussing on inter-disciplinarily, international research partnerships and industrial partnerships, we have sought to achieve the right blend of capabilities to tackle grand challenge research questions at scale.

2.1 Staffing strategy

Within the REF period, 34 new members of research staff have been appointed in the UoA: 28 at lecturer level (L), 3 senior lecturers (SL), 2 Associate Professors (AP) and one new full professor (P). These new academic posts and their associated appointments reflect our evolving research objectives. Typically, potential new posts are discussed by the Engineering Strategy Group to consider the fit to our UoA strategy and the balance of staff across our research groups. Vacated academic posts are not simply re-advertised, but instead, a full scientific and business case is made to the University to seek approval. During the REF period, we have introduced new policies to ensure non-discriminatory appointment procedures. Single gender appointment panels are strongly discouraged for post-doctoral level appointments and prohibited for staff level appointments. Applicant selection lists are also closely scrutinised. The success of our recruitment strategy in terms of hiring up-and-coming research stars is demonstrated by the large number of prestigious fellowships awarded to new staff during the REF period (see Section 2.9). This growth has led to a significant change in the department's demographics, with a major influx of early career researchers appointed at lecturer and senior lecturer level. In our REF2014 submission, the UoA demographic took the form of 18Ps, 6APs, 9SLs and 11Ls. The current

profile is 29Ps, 8APs, 18SLs and 22Ls. We have retained 79% of the staff submitted in 2014 – many of whom have been promoted during the REF cycle. In 2014, our female staff profile took the form 1P, 1AP, 2SLs, 3Ls. Now it is 5Ps, 2AP, 4SLs, 2Ls (see Figure 1). We have encouraged and achieved a significant improvement in female staff at more senior levels.

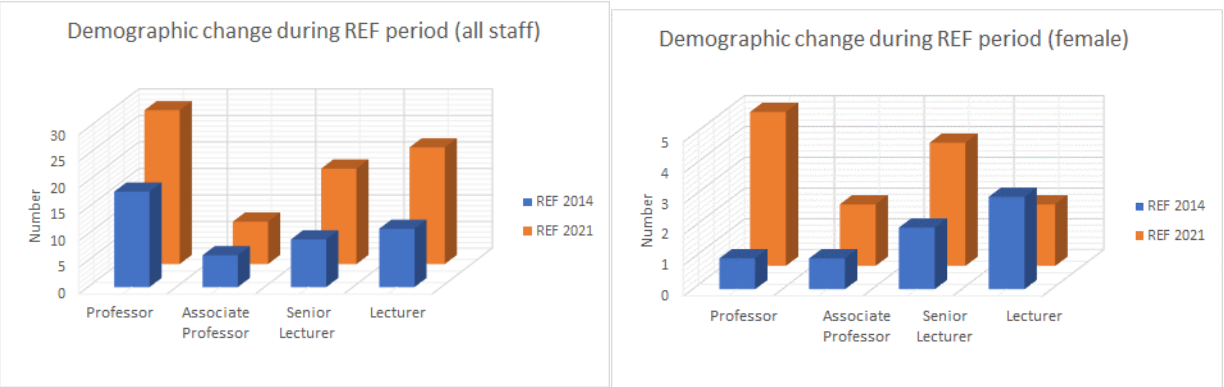


Figure 1: Demographic changes

2.2 Early Career Researchers (ECRs)

Our ECRs (PhD students and Postdoctoral Research Fellows) are a critical part of the UoA's world class research aspirations and are at the heart of the University's research culture. Our Doctoral College has an active support mechanism via an ECR network and an online 'ECR Hub'. We seek to develop world-class ECRs and ensure that they have a 'voice' across the University and are involved in the development of strategies to support this cohort of researchers. The University has signed the Researcher Development Concordat which aims to ensure all UK researchers work in healthy and supportive research environments within a decade. Every two years the University conducts an internal review to assess its performance in meeting obligations under the Concordat and to gauge progress against actions arising from the previous evaluation. An action plan, drawn up based on the responses of internal questionnaires, outlines how further improvements can be achieved. Some of the recommendations are described in the following sections. As described above, during the REF period, Exeter has led or partnered in five EPSRC CDTs and these have resulted in crucial inputs to the associated research groups and helped create further critical mass. Engineering was instrumental in the creation of an institutional 2nd year PhD conference to advertise and promote interdisciplinary research ideas and also a Women in Science seminar series. Our Researcher Development Programme run by the Doctoral College has a sector leading training and development programme (for details see Sections 3.9-3.13 in ILES).

2.3 Support for new / young staff

During the REF period, (as a University wide policy) the probation period for new Lecturers has been shortened from 5 to 3 years. Our mandatory induction training covers topics such as Equality and Diversity, Information Security and Health and Safety. Engineering also offers specific local inductions including building tours, lab facilities, and staff introductions. Newly appointed academic staff receive support through 'ramped' teaching loads, providing relief from teaching during their first three years. In their first year, staff are encouraged to develop their collaborations within and beyond the University and, in particular, to apply for an EPSRC New Investigator Award (NIA). New appointments are generally provided with internal seed funding and access to a PhD student, to support their NIA applications. They are also given intensive additional mentoring from research support staff and academic leads. We believe this package has been instrumental in our success in terms of winning NIAs (5 within the REF period). We also actively support the ECR/Lecturer transition process – particularly through our ECR

Network. In addition, the ECR Hub draws together different aspects of support through training and development, funding, initiatives and competitions.

2.4 Personnel development

As part of our People Development Strategy, the University has focused on increasing staff awareness of the importance of managing their career, and we have enhanced our development opportunities to support them. New activities include 'Taking control of your career' workshops, CV writing skills sessions, shadowing opportunities, 360 assessments, and one-to-one career coaching. 'Research Weeks' have been regularly organised led by the professional services team and directed towards all active researchers. They provide an opportunity to disseminate 'intelligence' about likely future calls from RCUK, specific training on topics such as grant writing skills, provide opportunities to share good practice, and create an environment in which to nurture potential cross discipline consortia and build new contacts.

Our new institution wide 'One Step Beyond' mentoring scheme has seen tremendous take up: 60% amongst staff at senior lecturer level and below. The mentoring scheme provides an opportunity to develop knowledge in areas such as building informal teams and collaborations, citizenship development, Leadership & Management Development, and covers topics such as managing personal/family life with professional/career aspirations and Research Development.

All staff undergo a rigorous personal development review (PDR) every year with their Academic Lead. In these meetings any problems are discussed, solutions sought, and research plans are made and reviewed for the academic year. Annually, all staff are invited (and encouraged) to apply for study leave. Applications are considered and are awarded on merit.

2.5 Staff recognition and promotion

Staff retention and contract type are monitored and there is a University policy to reduce the percentage of fixed term contracts with a move to permanency for ECR cohorts. Gender balance is also monitored and reported to the Engineering Inclusivity Working Group. Staff are provided with clear, transparent and objective information about the activities and standards that academics should focus on at each stage of their career. Applications for Associate Professor and Professor are subject to internal interview prior to seeking external references, before a final assessment by a University academic promotions panel. Staff are regularly made aware of the promotion criteria, which are discussed during annual their PDR. A departmental promotions committee comprising the Head of Department, Academic Leads, and Directors of Research and Education, identifies staff that are viewed as credible promotion candidates and advises them to apply – a process that mitigates against the potential gender bias of a system that relies on self-promotion. At all career stages, we put a strong emphasis on career progression, to retain and reward hardworking and high-performing staff from lecturer upwards. During the REF cycle, in terms of promotions, the following transitions took place: 8 AP→P; 7 SL→AP; 15 L→ SL.

2.6 Equality, diversity and inclusion

We are committed to creating an environment where all staff can flourish. We want our commitment to equality, diversity and inclusivity to underpin how we operate, how we think about our strategies, how we implement our actions and how we interact and communicate at all levels (see sections 3.14-3.17 in ILES). Equality, diversity and inclusion is seen as particularly important in Engineering, which has suffered from a historical lack of diversity and gender imbalance. We already have a foundation of recognised good practice in some areas reflected in our Institutional Athena Swan Silver Award, and a bronze award for the Department of Engineering and the Camborne School of Mines. Our gender positive policies are having a significant and measurable effect. For example, since 2015, the UoA has increased the

proportion of female staff from 16% to 25% and we now have five female full professors. We recently facilitated a Black Lives Matter workshop and a new PhD scholarship will be introduced to take students through UG/PGR to academia to increase the number of black academics within the discipline.

We offer leadership and personal development courses specifically for women, including Aurora (aimed at Lecturer/Senior Lecturer level staff) and Springboard (aimed at ECRs). Engineering and CSM encourage and support staff to attend these courses. There have been five attendances on Aurora since 2014. Where a member of staff has taken a break for maternity or caring responsibilities, adjustments are made to the quantity/volume of activities which are assessed, while maintaining the quality standards. The numbers and success of applications for progression are monitored by protected characteristics to ensure that the University's equality, diversity and inclusion standards are reflected in the decision-making progress. The University has developed gender equality actions plans to support our Athena Swan commitments and to address the gender pay gap. Childcare support is provided across both campuses. A salary sacrifice scheme is in place to support staff to meet childcare costs using childcare vouchers. Sports Holiday Camps for children, already run in Exeter during vacation periods, have now been extended to the Penryn Campus.

The UoA has a clear policy on adjusting performance/promotion targets for part-time workers: the quantity but not the quality of targets is reduced based relative to the reduced working hours. We have a policy of informal flexible working, such as working from home and flexible working hours. The University has a detailed policy on flexible working, which is available online as a 'toolkit' for all current and prospective employees. The toolbox can be accessed from the department's website. The University is currently consulting on staff preferences since the widespread adoption of working from home during the coronavirus pandemic.

Every two years the University organises an externally run anonymous Employee Engagement survey. The survey covers a range of topics including: my role; career and personal development; rewards benefits and recognition; inclusivity and culture; management; and my university. In the last survey, engineering had an 80% response rate and indicated 85% of its staff had good working relationships with their colleagues and 84% felt their role contributed to research excellence. Overall, 81% felt positive about the inclusivity, behaviours and culture within the discipline. The results from the survey have been reflected on, and changes agreed and actioned, including developing an overall vision "Engineering the Future@Exeter".

A committee comprising professorial staff, all with previous REF experience, reviewed the staff-nominated outputs. The committee received externally provided unconscious bias training arranged by the University. In a series of formal meetings, the committee ranked and selected our submitted outputs based on a projected grade for each paper and the quality of the accompanying 100-word statement. In the case of indistinguishable perceived ranking, the papers associated with ECRs were included preferentially, and effort was made to balance the number of papers across research groups. The final submission has a profile in which female staff have an inclusion rate of 2.9 papers per FTE (compared to 2.4 per FTE for male staff).

2.7 Individual Wellbeing

Wellbeing needs are kept in focus during departmental decision-making, with data from both University- and College-level staff-surveys considered (see above). ALs encourage individuals to look to their wellbeing and can direct them to the university's 'Mindfulness' and 'Stress-management' workshops and web-based resources. During the pandemic, in contrast to the normal term-time patterns, shorter weekly virtual staff meetings were organised in the run-up to the new academic year and in the first term. These were designed to help circulate plans and discuss the unfolding narrative, but also to try to engender a collegiate spirit in the face of the

unprecedented situation. During these meetings, staff were encouraged to raise and discuss issues. Both UoA Heads of Department (Engineering/CSM) operated open door policies for staff.

2.8 Research Students: Recruitment, Support and Training

As shown in Figure 2 below, our PGR recruitment numbers have increased year-by-year since REF2014 including significant growth in international student numbers (from e.g., China, Saudi Arabia, Egypt). This has led to a rich and diverse PGR research environment that strengthens and underpins the work of the UoA. The unit has been successful in deriving studentship funds from a variety of internal (e.g., University, College) and external (e.g., DTP, CDT, industrial, government) sources indicating that this growth is sustainable in the long term.

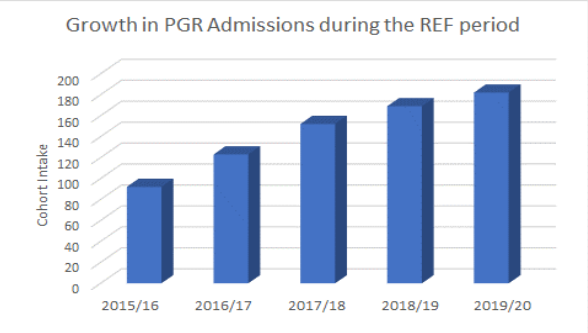


Figure 2: PGR recruitment numbers

Recruitment campaigns are organised by the University, with selection being devolved to Engineering. Initiatives include offering fully or partially funded studentships, specific agreements with partner universities, and networking with alumni. A first stage on-line application in which a preferred area of study or pre-advertised project is specified, is then sent to Engineering. Once applicant and potential supervisor have reached agreement, an offer is made subject to financial support (considered separately).

As part of their induction, all PGRs complete mandatory online training courses in Health and Safety, Equality and Diversity, Information Governance and Security and Research Integrity. Each of our CDTs also has their own extensive training programme covering both technical and professional topics. The programme focuses on teaching core skills that equip PGRs to undertake and complete a research degree, and to develop and articulate transferable skills for their future career. The quality of training and supervision is captured in a yearly exercise, during which the student, as well as the supervisor, report on progress and training needs, as well as their achievements. The reports are collected and then assessed by the College and Department Directors of PGRs. A web-based database (MyPGR) provides the mechanism by which the student support system is articulated. It includes: minimum supervisor contact expectations; a record of supervisory meetings; a record of supervisory agreement, training needs analysis and regular progress monitoring.

The funding associated with the CDTs has given us an opportunity to review and enhance our PhD training within all of Engineering. As part of the Metamaterials CDT, our industrial partners were closely involved in helping us design and deliver new training material on specific topics of direct interest to them We have also introduced bespoke training activities in 'professional and transferable skills', including, for example a very well-received Project Management course (run by Fistral Ltd), a Science Writing course (run by Write About Science), a Leadership course, and an innovative course in Cognitive Behavioural Coaching and Creative Thinking. Alongside formal technical and transferable skills training, we have developed a seminar series "Beyond a PhD" for students to learn about working in non-academic environments (e.g., Starting your own SME; Teaching; Business Management; Media; Defence; Intellectual Property; and Policy). By ensuring they develop other skills valued by industrial (and increasingly academic) employers, students make themselves both more employable and of more value to their future employers. Also, organised through the STREAM CDT, an open invitation STREAM symposium and a Challenge Week take place each summer including transferrable skills training, and guest lectures from leading industrialists and scientists. WISE organises an annual week-long residential Summer School, which includes students' research presentations and poster

displays, based on primarily a water-themed 'challenge', site visits, and talks from leading academic and industrial partners. IDCORE delivers research-orientated summer schools at the partners' facilities. CDT good practice is disseminated through a number of routes including mixing of cohorts with non-CDT funded PhD projects.

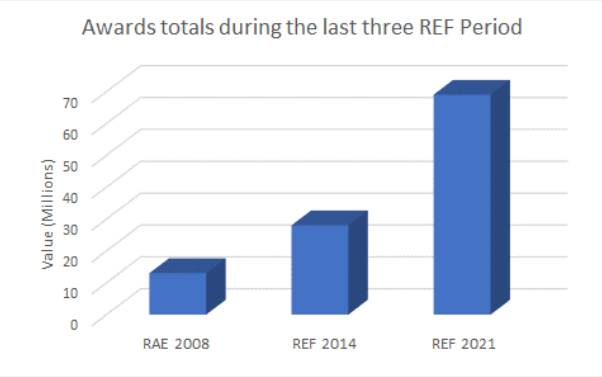
2.9 Significant Fellowships in the REF Period

The winning of a significant number of fellowships has been one of our key research strategies during this REF period. Success has allowed the appointment of new staff to cover the teaching and administrative duties of an individual during their fellowship period. Examples are:

- Craicun: EPSRC Engineering Fellowship for Growth, 2014
- S. Zhang: Royal Society Industry Fellowship, 2014
- Hrkac: Royal Society Fellowship, 2014
- Y. Zhu: Royal Society Fellowship, 2015
- Hrkac: Royal Society Fellowship, 2016
- Neves: EU Marie Curie Fellowship, 2016
- Luxmoore: EPSRC Innovation Fellowship 2018
- Holsgrove: Robin Ling Fellowship, Royal Devon & Exeter NHS Foundation Trust, 2018
- Alwi: Royal Academy of Engineering Industrial Fellowship, 2018
- Aziz: Royal Academy of Engineering Industrial Fellowship, 2019
- Dodwell: Turing Artificial Intelligence Fellowship, 2019
- Fu: Royal Society Industry Fellowship, 2019
- Farmani: Royal Academy of Engineering Industrial Fellowship, 2019
- M Zhu: Royal Society Industry Fellowship, 2020

Section 3. Income, infrastructure and facilities

3.1 Income (overview)



Research income for Exeter Engineering has increased significantly over the REF period in comparison to earlier ones (Figure 3). The current level of £68.7M in awards compares with £28M for REF2014 and £13M for REF2008. One factor in this success has been the excellent appointments made over this period and the quality of the candidates we have been able to attract as part of the virtuous circle of research level enhancement over the last 10 years.

Figure 3: Awards

The UoA has invested time and effort to increase its research income by:

- Supporting applications to win large grants
- Encouraging staff to apply for prestigious fellowships
- Increasing in our level of industrial income
- Organising workshops on grant writing skills
- Increasing the general level of quality of all RCUK applications through a rigorous internal peer review process.

3.1.1 Large Grant Successes

In response to the changing funding climate, the UoA has formulated strategies to apply for and win large grants. The University has made significant co-creation investments in applications for large grants and encouraged the creation of internal consortia through the organisation of workshops, sandpits and briefing sessions. Our most significant awards during this period are:

- VSimulators: Human Factors Simulation (Brownjohn), EPSRC, £3.5M
- Fun-COMP Functionally scaled computing technology (Wright) H2020 project, €4.0M
- Team-A: The Tailored Electromagnetic, (Nash), EPSRC, £2.5M
- Centre for Future Clean Mobility (Smith), Heart of the South West LEP, £2M
- Composite Material for Advanced Building Fenestration to Enhance Energy Efficiency (Tahir), EPSRC £1.6M
- Victrex Strategic Research Partnership (Ghita), Victrex Manufacturing Ltd, £1.5M
- Emergency Flood Planning & Management (Butler), EPSRC/GCRF, £1.5M
- Zero Power, Large Area Rail Track Monitoring, (M Zhu), EPSRC, £1.4M
- Engineering Fellowships for Growth (Craciun), EPSRC, £1.1M
- ESIF - ERDF Marine-I, (Johanning), ERDF, £1M
- Disruptive Optoelectronic Manufacture, (Nash), EPSRC, £1M
- Lobster Grower 2 (Johanning), Innovate UK Facilities, £0.8M

Furthermore the Responsible Mining group has played a key role in several large grants from EPSRC (DISTINCTIVE EP/L014041/1, £4.9M), H2020 (STOICISM: 310645; €8.6M), and the RFCS-funded grants (SLOPES: 752504; €3.3M; INDIRES: 748632, €3.2M; PRASS III: 752504, €3.1M; TEXMIN: 847250, €3.1M) contributing in particular specialised expertise in mineral recovery, geomechanics, health and safety, environmental and social aspects of mining, to address global challenges for the mining and excavation-related industries to maximise resources, improve safety and minimise risks.

3.1.2 Industry Income

With an increasing proportion of future government investment likely to be linked to the needs of the UK economy, we have worked hard to increase our interaction with industry. Most of the large projects listed above have industry links – some with substantial monetary contributions from our industry partners, both in-kind and cash. Research funding from Industry has grown since REF2014, increasing by 6% overall to £3.7M, with strong growth in funding from industry from outside the EU (7-fold), and from in the EU (3-fold). Furthermore, we are now making a much greater impact in terms of Knowledge Transfer activities as evidenced by our steep rise in the number of KTPs (34 in this REF cycle compared to 6 in the previous one), and the numbers of companies engaged in collaborative work with us. This uplift has resulted in part from the creation of a budget-holding post specifically facing Industry (deputy Associate Dean Research Industry), who has responsibility across the College for raising the profile of industry research both with industry itself and amongst staff.

3.1.3 Development support for applications

A workload model exists to ensure the balancing of teaching and research requirements. A minimum research allowance for all staff (20% of all allocated time) ensures that research active staff have time to write grant proposals (and research papers). We provide multi-layered support for grant applications. Early on in the REF cycle, additional discipline specific research manager posts were created in the UoA. These staff were employed to help act as ‘case officers’ to manage the process of developing large grant proposals. A ‘pipeline’ system was created to help manage the application development and facilitate resource allocation at key stages. Academics were encouraged to flag potential ideas early on and identify hard deadlines to allow for internal

review and proposal polishing. Furthermore, we have established a rigorous internal peer review college to provide internal expert feedback on bids prior to submission, and, post-submission, to support the applicant's response to the reviewer's comments. A robust internal sifting process for the most competitive schemes, such as fellowships and ERC starting grants, ensures only candidates with a relatively high chance of success move to full application, thereby effectively managing demands on time for both academics and support staff. Any bids leading to panel interviews (e.g., fellowships) are supported by internally run communications training sessions and mock panels.

3.2 Infrastructure

In addition to increased external income, there has also been investment by both the University and external funders in infrastructure and facilities during the REF period:

- Alongside a £13.5M programme of maintenance work within the Engineering building on the Streatham Campus (2019-2021), a £6.5M programme of improvements to workshop space, facilities and equipment is underway. This will involve a refurbishment and remodelling of laboratory and workshop space, new project and storage space and the purchase of new and replacement equipment.
- The new Engineering Research building on the Exeter Science Park offers 1128 m^2 gross internal area. The project budget to deliver the building and car park was £7.3m. This will be home to the Centre for Future Clean Mobility and the Smart Grid research group.
- VSimulators [leads Brownjohn & Pavic] (also based on the Science Park) is a recently opened, EPSRC-funded, unique experimental facility and comprises a 4x4 metre, six-axis high-frequency low amplitude motion platform equipped with an array of force plates, a motion capture system and multi-user virtual reality. The specification originated from a broad industry-identified requirement to better address poor management of human factors in structural design. VSimulators is also intended to service non-engineering research in physiology, sports science and healthcare and has already opened up new exciting interdisciplinary opportunities.
- The Metal Additive Manufacturing laboratory is also located at Exeter Science Park. It came into use in 2018 based on a total facility equipment investment of £400K. It has four main machines:
    - an EOS M100 Direct Metal Laser-Sintering (DMLS) machine (the AM platform) capable of printing parts in stainless steel and titanium alloy
    - a PFG-1545AH horizontal spindle surface grinder
    - a Vecstar Heat Treatment Furnace to perform heat treatment on printed parts
    - a Guyson Formula F1200 blast system to perform finishing operation on printed parts.

  This is the only metal AM facility in South West England and aims to attract and develop industrial collaborations with local companies. This facility complements CALM's research which is focused on polymer materials.

3.3 Usage of major external, national and international facilities

Funded by EU H2020 projects, Alwi & Edwards were given access to unique international facilities for flight testing new fault tolerant controllers. As part of the H2020 funded project RECONFIGURE, controllers created by Exeter were developed to flight certification standards and industrially assessed by AIRBUS on their ground-based Validation & Verification integration test facility at Toulouse (which constitutes a real aircraft cockpit representative of the AIRBUS fleet). The follow-on project VISION further increased the controller Technology Readiness Levels by a series of piloted flight-tests on an experimental fly-by-wire aircraft (Mupal-alpha) owned by the Japan Aerospace Exploration Agency (JAXA). The Mupal-alpha research aircraft allows the integration of new flight controllers within an experimental fly-by-wire system and allows flight evaluation of new novel configurations. This is a unique world-wide test facility.

Staff working in computational engineering make extensive use of the Isambard high performance computing facilities based at Bristol. This unique new service run by the GW4 Alliance, together with Cray Inc. and the Met Office, and based on a £3M award by EPSRC, provides multiple advanced architectures within the same system in order to enable evaluation and comparison across a diverse range of hardware platforms. It is a Cray XC50 system with 20,992 cores and is the 2nd largest ARM-based supercomputer in the world. Tabor was Co-I on Isambard Phase 2; (EP/T022078/1, £4.1M). The group also exploits the ARCHER UK National Supercomputing Service. ARCHER provides a resource to allow researchers to run simulations and calculations that require large numbers of processing cores working in a tightly coupled, parallel fashion.

3.4 Facilities at Exeter

The UoA hosts several unique research facilities which have been nurtured over several years in addition to those described above.

Additive manufacturing facilities: CALM includes facilities for laser sintering (EOS P800, EOS P100 Formiga, DTM 2000 SinterSTation), material extrusion (STratasys Dimension768, 3D Systems Projet HD 300) and Powder analysis (Freeman Ft4 Powder Rheometer). Investment in this area has been further boosted by the recent Victrex plc strategic partnership.

Scour testing facility: This facility consists of an Armfield sediment recirculation tilting flume – 60cm wide, 70cm deep and 14m long. A magnetic flow meter allows the control of a pump capable of producing discharges up to 170 litres/second. The flume is equipped with state-of-the-art instrumentation for flow and erosion measurements including a digital point gauge for surface profiles, particle image velocimetry, a Doppler velocimeter for measuring flow velocities, and an echo sounder for measuring scour depth. This facility has helped secure and support projects such as: EPSRC EP/M017354/1 Risk Assessment of Masonry Bridges Under Flood Conditions; and EP/J010138/1 Optimal Design of Very Large Tidal Stream Farms.

Renewable Energy: has access to significant specialist resources and equipment applicable to the renewable energy sector. Most of our unique facilities relate to ocean energy research:

- Falmouth Bay test site (FaBTest): is a pre-consented test area for offshore renewable energy, located within Falmouth Harbour. This 2.8km^2 nursery facility is sheltered from extreme sea conditions and enables device developers to test full-scale devices in a moderate wave climate.
- Dynamic Marine Component test facility (DMaC) is a purpose-built test rig that aims to replicate the forces and motions that components are subjected to in offshore applications. It can be used to replicate axial tension/compression forces, and has a headstock with three degrees of freedom representative of x- and y-bending and torsion.
- The group operates three wave buoys, two 4-beam and one 5-beam ADCPs for recording in situ wave and current data to support offshore research projects and FaBTest operation.
- Additional instrumentation includes a VideoRay Pro 4 remotely operated vehicle (ROV) for underwater surveys, a WASSP multibeam sonar and SeaPro dropped and towed cameras.
- A dedicated 32 node Beowulf cluster to support running software such as the SWAN wave model and Delft3D Flow, this facility enables us to run state-of-the-art modelling simulations for resource, engineering and environmental impact analysis.

These facilities have helped secure and support large ocean energy research projects such as: EU H2020 FLOTANT, No. 815289 and the EPSRC research projects EP/S000747/1 and EP/R007519/1.

Centre for Metamaterial Research and Innovation (CMRI): The CMRI is host to an extensive suite of laboratories for materials and device fabrication and characterisation, including four special purpose electronic and photonic clean rooms (Class 100 to Class 10000). Facilities include state-of-the-art e-beam lithography, laser lithography and plasma-etching for device fabrication (funded via a £1.1M EPSRC equipment grant (Wright, EP/K017160/1), along with a full range of materials deposition equipment (e.g RF and DC sputtering, evaporation, CVD and PECVD) and materials and device characterisation (e.g. XRD, AFM, SEM, STEM, TEM, Raman spectroscopy, TERS, X-ray CT, VSM, Kerr-microscopy, FTIR) equipment.

Imaging Suite: These facilities are heavily used by several groups within this UoA (and indeed from other UoAs within the University). In particular, members of NEST (Baldycheva, Craicun, Nash, Neves, Wright, Zhu), Renewable Energy (Li, Tahir, Mallick) have used the equipment to deliver results from a number of significant grants. The available equipment includes:

- a TESCAN VEGA3 Scanning Electron Microscope with Energy Dispersive Spectrometer (EDS), and an Oxford Instrument X-MAXN EDS detector.
- A xT Nova Nanolab 600 Focused Ion Beam unit capable of low- and high-resolution scanning electron microscopy, scanning ion microscopy, as well as ion beam and electron beam lithography.
- The JEOL 2100 Transmission Electron Microscope provides a point resolution of 0.25 nm and lattice resolution of 0.14 nm in theory, generating atomic resolution images.
- The Bruker D8 advanced X-Ray Diffractometer has wide applications in analysing powders, bulk and thin film materials, quantitative phase analysis, unit lattice parameters, crystal structure.
- The Bruker Innova Atomic Force Microscope is a high-resolution scanning probe microscopy facility for true 2D and 3D surface profile, with sub nanometre resolution.
- The X-Tek CT is a non-destructive X-ray inspection technique capable of producing 2D and 3D maps/structures of materials without damaging the samples.

HPC Facilities: The University of Exeter has invested £3M in the flagship HPC facility ISCA to serve the advanced computing requirements for all research disciplines. ISCA combines a traditional HPC cluster with a virtualised cluster environment. This provides 398 computational nodes, including standard compute nodes (16 or 20 cores), high memory nodes and GPU nodes available for use by research groups across the university. Significant research grants facilitated by this include Moxey's participation in "PRISM:Platform for Research in Simulation Methods" (EP/R029423/1) and "ELEMENT – Exascale Mesh Network" (EP/V001345/1), Tabor's "Data-Driven Surrogate-Assisted Evolutionary Fluid Dynamic Optimisation" (EP/M017915/1) and the CCP-WSI+ network (EP/T025782/1).

Responsible Mining Group (CSM): On the Penryn campus, the college has significantly expanded the research infrastructure through the purchase of two scanning electron microscopes with automated mineralogy software (2014 and 2018), optical microscopes (2015), laser ablation ICP-MS (2016), an ICP-OES (2017), and a stable isotope facility in 2015. These facilities have underpinned the delivery of, for example, the CoG3 (NE/M011372/1) and SoS RARE (NE/M011429/1) projects.

Section 4. Collaboration and contribution to the research base, economy and society

4.1 Collaboration with end users

UoE is key to economic stability and growth in Devon and Cornwall (see Section 1.11 in ILES) with 1 in 14 jobs in Exeter dependent on the University. The University's Innovation Impact and

Business (IIB) directorate directly engage with academics to capture potential impact case studies and help embed and support an impact culture within the unit. Impact Incubator events have been organised, and staff have sought and received College/UoE funds to support Impact Case Studies (ICS) development. The focus of the Business engagement strategy involves supporting collaborative R&D services, developing highly skilled people and regional innovation which recognises Exeter's key role within the South West's innovation ecosystem.

In addition to our chosen ICS, all our research groups have produced other notable impact and collaboration with end users. For example:

- Hrkac has developed a new low rare earth permanent high energy magnet for Hitachi. These magnets are now in use in the Prius hybrid model and lead to a significant reduction of CO2 and make the electric motor part of the hybrid 20% more efficient.
- Zhu is working with Network Rail, Babcock and AIRBUS on the development of energy harvesting powered wireless sensor system technologies.
- Nash has developed a new generation of high-performance thermal infrared emitters and is working with QinetiQ on deploying these devices for a range of applications.
- Memon is leading research on smart water systems for rural Africa in association with eWaterpay, focussing on advanced system failure prediction for proactive maintenance.
- Tabor and Moxey are working with a wide range of companies to develop capabilities in applying CFD to their specific problems (e.g., Hydro International, Oxford Instruments, McLaren Racing).
- Smith has developed fretting wear prediction codes for Rolls-Royce for use in R&T and design departments, which could facilitate significant reduction of weight in 125,000 components in gas turbines.
- Ghita's partnership with Victrex is delivering new high-performance polymer products for the Additive Manufacturing industry of which AM200 is the first material commercialised.
- Holsgrove is collaborating with surgeons at the Royal Devon and Exeter Hip Unit to utilise wearable sensors to improve patient recovery and rehabilitation. Zhang also collaborates with the South Devon NHS Foundation Trust, Guy's and St Thomas' NHS Foundation Trust, London, on developing next generation graphene-based anti-cancer nanomedicines.
- Reynold's developed and implemented a $2M active vibration control system to reduce problematic vibrations at a concert venue in the US due to crowd induced loads during concerts.
- Alwi & Edwards have worked with AIRBUS Toulouse and Prismatic Ltd (one of the world's leading developers of High-Altitude Long Endurance aircraft) on the development of flight control systems.
- Belmont & Edwards are collaborating with MOD/dstl and a wide range of commercial partners (e.g., BAE Systems, Babcock, Leonardo Helicopters) to bring the technology of Deterministic Marine Environment Prediction to marketable products.

4.2 Spin-Out Companies

The UoA is directly involved with a number of spin-out companies:

Simpleware Ltd: a software spin-out led by Young, was sold to Synopsys, Inc. in 2016. Young continues in his role as engineering director. He was named as one of the top 50 entrepreneurs by the SETsquared university business incubator. Joint research with the US Army Research Labs (on Image based Material Homogenisation) has resulted in 3 software products with NASA.

Full Scale Dynamics: Brownjohn, Pavic & Reynolds are directors of the University of Exeter spin-off Full Scale Dynamics Ltd (FSD), providing international consulting services in vibration serviceability management and structural health monitoring of full-scale - primarily civil

engineering - structures. FSD's work and support feeds into research proposals (e.g., the EPSRC-funded VSimulators) and streamlines the application of research outcomes in industry.

SEAMS: Based on the outputs of the first of a suite of collaborative research projects led by Savic, a spin-out company SEAMS Ltd., which focuses on data analytics and asset management, was set up by the University of Exeter in 2002. The company has since delivered support for over £120 billion of infrastructure investment decisions worldwide, providing savings of up to 20% in capital and operational costs to clients. In January 2018, SEAMS Ltd. was acquired by Arcadis for £11.4 million.

Concrene: Craciun and her research group have developed a technology that consists of proprietary formulations and methods for producing concrete reinforced with graphene. The technology has established proof of concept in trials with a multinational corporate cement manufacturer. Concrene® - Graphene Reinforced Concrete, an innovative material for the construction market with higher durability, strength and water resistance, is being commercialised successfully via the spin-off company Concrene Limited.

BuildSolar: By developing new innovative more efficient solar technologies, Mallick and his group have facilitated the deployment of solar technologies in the UK and abroad. Building integrated Photovoltaics have been developed and are being promoted towards commercialisation as construction materials through a spin-out company (BuildSolar) in partnership with National Rail and HS2.

OTA: Melville-Shreeve's research into remotely operated rainwater harvesting systems led to a spinout, OTA Water. OTA delivered proof of concept projects for three UK water companies, modelled the benefits of rainwater systems in a range of settings, and installed 50+ smart rainwater harvesting devices in the UK and Spain. The company developed a hardware and software platform 'StormSense' that helps reduce wastewater discharges. To facilitate scale-up, the company was sold to a water industry SME in January 2020.

Bodle: Wright sits on the board of Bodle Technologies based in Oxford. Its core technology is centred on the creation and manipulation of colour reflected off a surface by changing the refractive index of ultra-thin functional layers. This highly enabling piece of engineering was first published in Nature in 2014 in a paper co-authored by Wright. Bodle Technologies is now partnering with leading manufacturers to deploy its technology for use in reflective displays for a range of applications.

4.3 Strategic Partnerships

VICTREX strategic partnership: Building upon the successful relationship fostered over the last few years, Victrex plc and the CALM have engaged in a five-year partnership. The aim is to further develop the next generation of PEEK polymers for Additive Manufacturing and to commercialise novel material solutions throughout the supply chain. In so doing, the University of Exeter will play a pivotal role in the development of the UK Additive Manufacturing (AM) sector.

South West Water: The Centre for Resilience in Environment, Water and Waste has been established to undertake research into some of the most pressing environmental challenges in our time – namely how we can manage our precious natural resources in ways which are sustainable and resilient in the face of climate change and population growth. The research is a multidisciplinary endeavour undertaken by academics from several different disciplines including Engineering, Geography, Biosciences, Economics, Psychology. These staff work with industry, government and NGOs to develop a shared understanding of the issue.

4.4 Academic Collaborations

Engineering staff hold honorary positions in other overseas organisations including i) Beijing Compo Advanced Technology Co Ltd; ii) a visiting professorship at Harbin Institute of Technology; iii) a visiting Professorship at UNESCO-IHE (Delft, The Netherlands); iv) Dodwell holds the Romberg Guest Professorship at Heidelberg in the area of Data-Centric Engineering (this position supports development of the high performance finite element package "DUNE"); v) Young is a Guest Professor at the China University of Geosciences (Wuhan) China; vi) Edwards is Visiting professor at ESNEA Paris France; vii) Young has been visiting professor at Chongqing University, China; viii) Butler is a visiting professor at Xian University of Architecture & Technology, China; ix) Johanning holds a chair at the UK-China Centre for ORE (UK&CHN |CORE) and is Visiting Dean of the Yantai Research Institution Harbin Engineering University.

As a result of our involvement in European projects, we have collaborated with many prestigious European institutions including ONERA (France), DLR (Germany), SZTAKI (Hungary), TU Delft (The Netherlands); ETH Zurich (Switzerland), University of Augsburg (Germany), Politecnico di Milano (Italy), Universidad Politécnica de Madrid (Spain); Technical University of Denmark, Copenhagen; Luleå University of Technology (Sweden), Greenland Institute of Natural Resources (Greenland); and the Norwegian Geotechnical Institute, NGI, (Norway).

Exchange visit students, funded by the Newton-China scholarship and British Council Newton Funds, have facilitated collaborations with Tongji University; the Chinese Academy of Sciences (Beijing); Southeast University (Nanjing); Tsinghua University; Harbin Institute of Technology; and Dalian University of Technology; Xi'an University of Architecture. The WISE CDT promotes and funds student exchanges with internationally leading universities (e.g. University of California, USA; Tsinghua University, China); and our Metamaterials CDT has exchange and placement arrangements with both universities (e.g. Oxford, Southampton, IMEC, ETH Zurich) and industry (e.g. QinetiQ, dstl, Dyson, IBM Zurich).

In order to promote exchanges and research collaborations, a number of Memorandums of Agreement are in place. Recent examples include MoUs with IIT-Madras and the Technical University of Munich, and an agreement with the University of British Columbia. Engineering has been successful in bidding for Initiator Grants and funded joint PhDs under our University of Exeter/University of Queensland (QUEX) Partnership.

The UoA itself funds short term international academic visits. We also encourage and support hosting of internationally leading academics. Recent examples include our support to Prof Rodney Stewart's (Griffith University) Leverhulme Trust Fellowship application from Australia for his placement at Exeter. We regularly support international research placements using other opportunities such as the Newton Fund and the British Council Institutional Links programme.

Thies is a Co-Director of the Supergen ORE hub. This is a £9.1M strategic investment by EPSRC to provide research leadership connecting academia, industry, policy and public stakeholders and to inspire innovation and maximise societal value in offshore wind, wave and tidal energy.

4.5 Membership of Advisory panels and Societies

Eleven of our current Engineering staff have sat on governmental advisory bodies, such as i) UNESCO's International Federation for Information Processing, ii) NATO's Vessel Motion Prediction SG61 Committee, iii) *MOD's Virtual Ships Advisory Group, iv)* the Chinese Natural Science Foundation. Staff have also contributed to review bodies for example i) Canada NSERC, ii) Israel Science Foundation, and iii) EU frameworks. Pavic was invited to attend the by-invitation-only IABSE Henderson Colloquium on adaptable structures and serviceability, to discuss and strategize about the future of the area.

Nationally, 15 Engineering staff have been EPSRC College members during the REF period. Butler sat on the EPSRC Engineering Strategic Advisory Team and is a full member of the REF UoA 12 sub-panel. Seven staff sit on advisory, national or professional bodies including: i) The Institute of Materials Minerals and Mining; ii) the HSE Quarry National Joint Advisory Committee; iii) the IStructE stadia guidance working group, iv) the BSI Mechanical vibration, shock and condition monitoring committee; iv) chair of the IEEE Technical committee on Variable Structure Control. Furthermore, Glass is Chair of the Mineral Processing and Extractive Metallurgy division of the Institute of Materials, Minerals and Mining (IOM3).

Several staff are Fellows of the following societies: the Royal Academy of Engineering, the Royal Society of Chemistry, the Institution of Mechanical Engineers, the Institution of Civil Engineers, the Institute of Engineering Technology, the Chartered Institution of Water and Environmental Management, the Institute of Materials, Minerals and Mining, the Geological Society, the International Water Association and the Institute of Electrical and Electronics Engineers.

4.6 Prizes and awards

- Butler was elected fellow of the Royal Academy of Engineering
- Wang was elected a fellow of the IEEE
- Dodwell won the SIGEST Prize for best paper in the SIAM/ASA for uncertainty quantification
- Fu won both the 'Best Research-Oriented Paper' and ‘Best Practice Oriented Paper’ from the ASCE Journal of Water Resources Planning and Management
- Fu & Butler’s PhD student – Dr Chris Sweetapple won the Scopus Young Researcher UK Award in the area of Environmental Science 2015
- Kapelan won the Environmental Water Resources Institute’s Best Policy-Oriented Paper Award (2017)
- Moxey received two best paper awards from ACME (2015) and the International Meshing Roundtable (2017)
- Sundaram won the IAAM award in the Global Graphene Forum, 2019, Stockholm, Sweden
- Vogt won the Silver medal, awarded by the SAIMM for a paper in its Journal in 2017
- Yang won Best Developmental Paper Award at the British Academy of Management Conference, 2017
- Johanning has a China Academy of Science Presidents International Fellowship Visiting Scientist award
- Eames won the Napier Shaw Bronze medal (best paper) in the Building Services Engineering Research and Technology Journal
- Monsalve won the 2019 Doak Prize awarded by the Journal of Sound and Vibration
- Tian was identified as one of WES’ Top 50 Women in Engineering 2020
- Coggan received the IOM3 Medal for Excellence 2020
- Zhang was given an Emerald 2017 Citation of Excellence Awards in Business Management.

4.7 Conference organisation and talks

Staff have given invited, plenary and keynote talks at more than 50 international conferences, including: the 2nd World Drone Congress, Shenzhen, China, 2018; 10th International Perspective on Water Resources and the Environment, Cartagena, Colombia, 2018; 11th International Conference on Urban Drainage Modelling, Palermo, Italy, 2018; IFAC SAFEPROCESS Workshop, Warsaw, 2018; UKACC Control, Loughborough, 2014; 2nd Joint WDSA-CCWI conference, Beijing, China 2020; 13th International Conference on Computing and Control for the Water Industry (CCWI), Leicester, 2015; the 3rd UK Energy Storage Conference, University of Birmingham, 2016; Anglo-French Acoustics conference, Marseilles, 2017; Photon 2018, Birmingham, 2018; the 7th World Conference on Structural Control and Monitoring, 2018; the 6th European Conference on Structural Control 2016; International Conference on Recent Advances in Non-conventional Energy Resources using Solar Based Technologies, New Delhi,

India 2019; the 13th OpenFOAM Workshop, Shanghai, 2018; 2nd International Workshop on Hydraulic Structures, Coimbra, Portugal 2015; Council for Geoscience Conference, 2016; ECCOMAS VipIMAGE Tenerife, 2015; Annual Energy Harvesting Society Meeting, Philadelphia, USA 2018; 6th International Conference on Experimental Vibration Analysis for Civil Engineering Structures, Dübendorf, Switzerland, 2015; 8th Experimental Vibration Analysis for Civil Engineering Structures, 2019, Nanjing, Chin;, IASTED International Conference on Modelling, Identification and Control (MIC 2015), Innsbruck 2015.

4.8 Editorships

Staff edit (as editor-in-chief or lead editor) and serve on the editorial boards of a diverse selection of top journals. This includes Butler who is the founder & Co-editor-in-Chief of the Urban Water Journal, and Reynolds who is Editor-in-Chief of the Experimental Techniques Journal. Other staff serve as Associate Editors for (amongst many) the IEEE Transactions on Automatica Control, the IEEE Transactions on Control System Technology and the IEEE Transactions on Aerospace and Electronic Systems; Proceedings of the Royal Society A; Journal of Water Resources Planning and Management;; Advanced Engineering Informatics; Nature Scientific Reports; Journal of the Southern African Institute of Mining and Metallurgy; Energies Journal; International Journal of Robust and Nonlinear Control; IET Renewable Power Generation, Journal of Hydroinformatics, International Journal of Optimisation and Control; Geomechanics and Engineering; Journal of Water, Journal of vibration science and engineering. Staff have also served as Guest Editors of journal special issues.

4.9 Patents

- Aziz (PB152465GB) a sensor & sensing method for detection of defects in ferromagnetic structures
- Dodwell (GB252400) a method of designing and manufacturing a composite component
- Kaplan (US080898) decision support for real-time detection, diagnosis and remediation of bursts
- Zhu (WO2018220406A1) a method of controlling an energy harvesting system
- Zhu (GB1904599.6) Energy generation
- Young (US20170249529A1) Image processing method
- Mallick (UK PCT/PB151946GB) Construction block with photovoltaic device
- Monsalve (GB2003251.2) Elastomeric isolator
- Craciun (WO2019171061A1) Electrically conductive material
- Craciun (WO2019175564A1) Graphene Reinforced Concrete
- Craciun (US9865369B2) Graphene-based material
- Craciun (US10053772B2) Doped graphene
- Craciun US20190385841A1 HfO2 devices

4.10 Responsiveness to national/international priorities and initiatives

We actively respond to national/international priorities including winning grants from

- Global Challenges Research Fund (e.g., EP/P02839X/1) – where we have active projects with partners in India (IISc Bangalore) and Thailand (e.g., Asian Institute of Technology)
- Multiple submissions to the UKRI Call on “UK Climate Change Resilience”

We also have a database of international links, enabling us to promptly respond to any engineering-related initiatives.