Institution: University of Surrey

Unit of Assessment: UOA 15 General Engineering

a. Overview

In RAE2008, engineering research at Surrey was submitted to Electronic Engineering (UOA24) and General Engineering (UOA25), with the latter return in particular reflecting the multi-disciplinary approach taken to engineering research. For REF2014, as a result of the broadened scope of UOA13 (to include Metallurgy and Materials), we are returning our materials scientists and engineers to UOA13 where there is a natural fit both to the UOA and with our Electronic Engineering activity. Notwithstanding the movement of this group, we are returning 54.75 FTE to UOA15 compared with 44.6 FTE to UOA25 in RAE2008, reflecting a considerable increase in staff numbers since 2008. *More than half* of these have been appointed since 2008. The recruitment of new staff has enabled the ambitions set out in RAE2008 to be realised fully.

Research is reported under four themes; (i) ***Fluids and Vehicles (F&V)***, encompassing Aerodynamics and Environmental Flow and Automotive Engineering; (ii) ***Infrastructure***; (iii) ***Water, Chemical and Bio-Systems (WCBS)***, comprising water and environmental engineering, chemical process and bio-medical engineering, and (iv) ***Sustainable Systems***. The themes bring together staff from different Departments in the Faculty of Engineering and Physical Sciences (FEPS) recognising that while FEPS comprises strong discipline-based Departments, research is co-ordinated in a multi-disciplinary and thematic way. ***F&V*** involves staff from Mechanical Engineering Sciences (MES) and Civil and Environmental Engineering (CEE); ***Infrastructure*** draws on staff from CEE and the Centre for Environmental Strategy (CES); ***WCBS*** encompasses staff from CEE, CES, Chemical and Process Engineering (CPE), Chemistry and MES, while ***Sustainable Systems*** includes staff from CES, CEE and CPE. Within CES there is a sub-group working on the social science aspects of sustainable development, which we are cross-referring to UOA17, highlighting the fact that the themes in this unit are genuinely multi-disciplinary. Further, there is close collaboration between researchers working in these thematic areas and those associated with other engineering activities returned to UOA13, activities within the wider Faculty such as Chemistry, Computing, Mathematics and Physics, and across the University, notably Business, Psychology and Sociology.

Highlights since RAE2008 include the award of the Queen's Anniversary Prize to the University for '*in depth research expertise improving access to safe drinking water and sanitation worldwide'*, renewal of our status as a WHO collaborating centre focusing on the protection of water quality and human health, continuation of our Rolls Royce University Technology Centre (UTC) in Turbo-machinery, continued recognition of EnFlo as a NERC-NCAS Centre for Atmospheric Sciences, the launch of a major new collaboration with BP (£5M), our ongoing collaboration with Thames Water and a grant from EPSRC (ca. £6 M) to establish the Industrial Doctorate Centre (IDC) in Sustainable Energy and Engineering Systems. Members of staff have also achieved international recognition at the highest level, with major Fellowships, many prizes (in particular for published work) and membership of numerous prestigious Advisory bodies.

b. Research strategy

Evidence of the achievement of strategic aims: The aim of our research is to solve engineering problems through the development of new knowledge and its application. We achieve this by managing staff in multi-disciplinary research groups with critical mass, recruiting and developing talented staff, building partnerships with end-users and targeting outputs into appropriate and high quality journals. During the period we have built on the areas of strength identified in RAE2008 to increase the volume and range of our activities. We have produced both theoretical and applied research of the highest quality and have continued to develop relationships with user communities to ensure that our research has real-world impact.

F&V: Led by Prof Chew and Profs Hills, Robins. Staff: Birch, Carpentieri, Fallah, Grüber, Hancock, Hughes [S], Kumar, Lu, Montomoli, Murua, Sorniotti.

At RAE2008, the ***F&V*** activity ended the review period with a strong grant portfolio, excellent industrial links and plans for growth both for the core fluids and the relatively new automotive

activity; these plans have been achieved in full. The Rolls-Royce UTC in Turbo-machinery has recently been extended until 2018 (£2M); research involves development of computational aero-mechanical modelling and internal air systems of engines, for the improvement of engine design and performance and the consequent reduction in emissions. The NERC EnFlo (Environmental Flow) Laboratory provides a unique national resource for the study of environmental flow and dispersion scenarios. The EnFlo Team have led the follow-up DAPPLE (Dispersion of Air Pollution and its Penetration into the Local Environment) project and participated in the subsequent DYCE and MODITIC consortia. Dyce focussed on the use of sensor networks and inverse modelling for source detection and MODITIC, which is a major European Defence Agency research project, takes the subject further in treating large-scale emissions. Research has also been undertaken on nano-particle dispersion at local and regional scales and with the EPSRC SUPERGEN consortium on aerodynamics of wind turbine arrays. The growing Advanced Vehicles Group (AVG) has been successful with major EU grants relating to dynamics and power sources for electric vehicles and has established strong industrial links with manufacturers such as Jaguar Land Rover (JLR) and Toyota Motorsport. New staff members are developing research in aircraft aerodynamics, aero-elasticity, aeroacoustics, automatic design and uncertainty quantification.

Infrastructure: Led by Prof Chryssanthopoulos and Profs Bhattacharyya, Lawson, Parke. Staff: Cavaretta, Cui, Elghali, Imam, Jesson, Matthews, Mitoulis, Mulheron, Sagaseta, Szyniszewski.

At RAE2008, we identified management of risk and reliability in civil engineering structures as being a key area. Building on this, the ***Infrastructure*** theme has flourished, with significant investment in staff and facilities, including the recent establishment of a strong soils activity. Research encompasses the characterisation and modelling of damage processes through asset life-cycles, the simulation of complex structural systems under cyclic, dynamic and extreme loads, the interaction of structure and soils with their surroundings, and performance management of large infrastructure networks. It has informed the development of codes and design practice in diverse areas, such as local loads in concrete slabs, progressive collapse and characterisation of composite materials for civil applications. We have collaborated closely with a range of infra-owners, including Thames Water (a major partner for more than 15 years), Network Rail and RWE Innogy to support investment in maintenance and renewal strategies. Examples include corrosion damage assessment of cast iron pipes from London's water mains, the development of a historical load model for, and characterisation of fatigue damage in, riveted bridges as well as structural health monitoring, long-term adaptation and repair of railway structures and their foundations. A major activity in geomechanics concerns dynamic soil-structure interaction of on/offshore structures, coupled with soil particle testing and characterisation, including inter-particle friction and contact modelling of irregular grains. In collaboration with Surrey Space Centre, we have studied aspects of extra-terrestrial soil mechanics and Martian soil simulants.

WCBS: Led by Profs Hughes [M], Khu, Thorpe and Profs Kirkby, Lian, Seville FREng, Sharif, Taylor, Wu. Staff: Abasolo, Campbell, Charles, Chenoweth, Cirovic, Forte, Labeed, Ouki, Pedley, Saroj.

In line with the RAE2008 vision, a University-wide network of water researchers (SWIRL – Surrey Water Innovation Research & Learning) has been established and facilitated and the majority of this activity sits within the ***WCBS*** theme. Water research is focused on meeting Millennium Development Goals for the sustainable provision of safe drinking water and sanitation, developing low-carbon footprint treatment solutions, optimising life-cycle, infrastructure network management and understanding complex societal attitudes to water. The work has been recognised through a Queen's Anniversary Award to the University in the Diamond Jubilee round 2010-12 for *'in depth research expertise for improving access to safe drinking water and sanitation worldwide'* and the re-designation of the relevant parts of our activity as a World Health Organisation collaborating-centre for the Protection of Water Quality and Human Health for the period 2011-2015. We work through the UNICEF WASH cluster group of relief agencies, with research undertaken in more than 45 countries and recent involvement in four major cities in Sub-Saharan Africa. Our studies have addressed social and economic barriers to sanitation in peri-urban slums, and assessment of water safety demands in poorly resourced regions. Recognising the increasing tension between supply and demand, our research in sustainable water management encompasses water use by the tourist industry and water foot-printing methodologies. Research on Surrey's novel and sector-

leading Manipulated Osmosis Desalination process continues with an increased emphasis on issues of implementation and scale-up which emerge from demonstration plants in Qatar and Gibraltar. Other technologies being created and developed by this group are accessing the energy content of waste water in the UK in collaboration with Thames Water. The Chemical Process sub-theme has two further foci: particle technology and the 5-year, £5M grant for the new BP Research Centre for Petroleum and Surface Chemistry. Notable in the former is Wu's co-ordination of the EU FP7 Marie Curie Initial Training Network (MCITN) consortium (€3.8M), IPROCOM, on the development of *in silico* models for pharmaceutical manufacture, with pan-European industry participation. Collaboration between systems engineers in Chemical Process and the clinical community has led to a suite of mathematical models (funded by EU MCITN PARTNER [€5.6M] and ENTERVISION [€3.5M]) of the growth of cancer tumours and the clinical decision-making process (what treatment is applied and when) and finally models to predict national demand for radiotherapy which incorporates a measure of whether a clinician is using best practice. This work is having significant impact. Other strands in Bio-Systems Engineering have been further work on dielectrophoresis (DEP) for cell detection, which has reached the stage of a product at market, fluid dynamics related to the human body, specifically the dynamics of cerebrospinal fluids, and new areas of activity in signal processing, in particular relating to the diagnosis of Alzheimer`s disease.

Sustainable Systems: Led by Prof Leach and Profs Hunt, Jackson, Morse, France, Murphy. Staff: Chen, Druckman, Hagen-Zanker, Lee, Sadhukan, Yang.

The ***Sustainable Systems*** theme is based around the Centre for Environmental Strategy (CES), one of the most well-established such groups in the UK, and has built on the strengths identified in RAE2008, i.e. a multi-disciplinary approach, integrating engineering science with insights from the social sciences to develop action-oriented, policy-relevant responses to long-term environmental and social issues. The Industrial Doctorate Centre in "*Sustainable Energy and Engineering Systems*", established in 2008 (EPSRC £6.5M) as the successor to the EngD Programme in Environmental Technology, is run out of CES, with the associated projects spanning the whole Unit, making it a key part of our multi-disciplinary research environment. The Research Engineers act as "vectors", bringing understanding of commercial concerns into the University and transferring current thinking and research results into sponsoring companies. The £3.5M EPSRC-funded ERIE project typifies the close collaboration within Engineering and with reach out to Maths on complexity and Sociology on agent-based modelling; this represents one of the largest efforts towards establishing Industrial Ecology methods internationally. The group have capitalised on the development of systems approaches funded primarily by EPSRC and ESRC to take a leading role in EU research (e.g. coordinating a consortium on low carbon transitions, and partnering in others relating to the Green Economy). The social science research in Sustainable Systems advances conceptual thinking on sustainability and strengthens the base of empirical evidence, underpinning the systems research. It builds upon existing links within the Faculty and across the University, in particular with Psychology, Sociology, Economics and Law, developed through the major ESRC funded RESOLVE consortium completed in 2012 and its successor Sustainable Lifestyles Research Group project, funded by Defra and the Scottish government. A new programme on the relationship between economic growth and the environment has begun through Jackson's ESRC Professorial Fellowship to study Prosperity and Sustainability in the Green Economy (PASSAGE), underpinned by his highly acclaimed and influential book 'Prosperity without Growth' (published in 57 languages), which discusses much of the wider work of the group.

Future strategy and goals: The research strategy for the Unit is aligned with the strategies developed for the University and the Faculty for 2012-2017. Key elements are research excellence, high-quality outputs, user engagement and a commitment to interdisciplinary research aligned with national/international needs. Research themes are monitored to ensure their alignment with strategic objectives and as part of this process are periodically reviewed with champions identified to promote new cross-disciplinary opportunities. Various parts of the Unit connect with key RCUK research themes in Energy, Food Security, Living with Environmental Change and Transport; we contribute fully to University-level strategic networks concerned with Energy, Food Security, Health and Water. The University also seeks to enhance its research agenda through its international strategy and associated activities. In particular, the University Global Partnership Network (UGPN), comprising North Carolina State University (NCSU), University of Sao Paulo (USP) and University of Surrey is a vehicle for international research

collaboration and research student mobility. The UGPN has committed more than £350k for seed funding (this unit has secured funding for collaborative projects in ***F&V*** and ***Sustainable Systems***) and have invested significantly in staff mobility to develop engagement.

In ***F&V***, the next few years will see an increased role for the newly appointed staff (see section c) in the Rolls-Royce UTC and EnFlo together with strengthening research in new strands of aerodynamics and developing new collaborations with Airbus and others. The UTC will continue to develop advanced computational modelling with virtual engine simulation and future engine requirements providing a focus for collaboration with the company and partner Universities. EnFlo will extend collaboration with the Norwegian Defence Research Institution and UK DTC, and continue to work with the University of Reading, with whom we have recently been successful in a joint NERC DTP bid, and build on successful academic collaborations investigating nano-particle dispersion. Ongoing investment in staff (two more appointments in automotive engineering are planned) and laboratory hardware provides a platform for extension of our current FP7 activities in vehicles in collaboration with automotive companies and key players such as Siemens for the Horizon 2020 electric vehicles call. Current collaboration (e.g. JLR, McLaren) will continue and we plan to build new partnerships with Skoda Auto (control systems development) and Hyundai-Kia.

Our research in ***Infrastructure*** will continue to embrace the whole life-cycle approach for integrated asset management at different scales, ranging from individual structures to stocks and networks. Working with established partners, such as Thames Water and Network Rail, and by building new connections, e.g. through EU consortia partners, we will focus on emerging technologies, such as the integration of novel sensor technologies with uncertainty modelling and data management techniques. Taking full advantage of Surrey's multi- and cross-disciplinary research environment we will exploit the fusion of advanced engineering concepts with environmental and social analysis tools. By working closely with industry networks and end-users, both providers and beneficiaries, at national and international level, our aim is to contribute to the design, procurement and delivery of the next generation of smart infrastructure, as well as the safe life extension of ageing assets. Through new collaborations and targeted appointments, we will grow our research in inter-dependency and resilience, combining existing knowledge on extreme loads and loss estimation with expertise in infrastructure systems and demand forecasting.

Within ***WCBS***, four new appointments will strengthen further water and process systems activities, and support the BP Research Centre. We will continue our integrated approach towards understanding how human activities affect the water environment, from source water microbial detection technology and pathways of contaminants in the urban environment, to advances in treatment technology using nano-materials and other energy-saving techniques, and impacts via global climate change. A new research strand in chemical process concerns multi-scale modelling of process systems, including manufacturing processes for complex products such as pharmaceuticals and their *in silico* testing. Work on models to enable product developers to design better products for administering to, or through, the skin, will be developed, to include multi-scale physics models of such products. In Bio-Systems the work on computational oncology will develop, in particular through strong interactions with clinical groups across the UK, notably at Addenbrooke's Hospital. Research on human movement will use biomechanical techniques of the upper and whole body to study ballet and to improve stability in old age. The Movement Laboratory will see extended use in fields as diverse as vehicle dynamics (chassis integrity) and sports movement. At the molecular level, the use of DEP will become increasingly important and is being commercialised via DEPtech Ltd (a spinout company). Clinical studies will extend our work on cancer stem cells and oral cancer cells (Eastman Dental Hospital). Activities in applied signal processing, exemplified by application to EEGs, will move into new areas.

In ***Sustainable Systems***, through Jackson's ESRC Professorial Fellowship and EU grants, we are setting a new agenda for Green Growth, developing models linking energy and material use to industrial performance, living standards and the macro-economy and exploring key socio-political questions about how best to attain improvements in 'prosperity'. We will capitalise on Surrey's reputation for systems research and the investments made in people and infrastructure for energy research, to expand the current bioenergy activities and establish leadership in related energy and materials flow analysis, through Industrial Ecology. We will build on links with the Surrey Space Centre and commercial partners to apply remote sensing capability into carbon management; we

have already won a place on DfIDs preferred bidder list for major funding opportunities in this area. Following secondment of a staff member to the UN to set up the new African Climate Policy Centre in Ethiopia, Surrey is leading a new £2M EPSRC/DfID-funded consortium seeking rapid expansion of access to modern and clean energy services in sub-saharan Africa, utilising existing agro-industries as the kernels for local/community scale energy systems.

c. People:

i. Staffing strategy and staff development

Academic staff changes in period: Our staffing strategy has been to maintain core expertise in our chosen research areas and to grow our activities by recruiting complementary expertise, while ensuring that we have a good balance of staff at different stages of their academic careers. In this way the staff structure is sustainable. Since RAE2008, a number of staff have moved to senior positions elsewhere (*e.g.* Oxford, UCL, National Technical University of Athens), reflecting their research excellence achieved at Surrey, while others have left us to take up roles in industry and elsewhere. A total of 33 (30.2 FTE) staff, including 6 Early Career Researchers (ECRs), have been recruited to underpin and extend our research capability. Growth on this scale represents significant University investment. We have also ensured that those retiring, some of whom did not have a strong research presence, were replaced by fully research-active colleagues. Of the new appointments made in period, 8 (Bhattacharya, Khu, Lian, Morse, Murphy, Seville, Taylor and Wu) joined at professorial level, 4 (Abasolo, Cavaretta, Druckman and Montomoli) joined as senior lecturer (SL), 20 joined as lecturer, most as first academic appointments, while Jesson has been appointed as an independent researcher.

In ***F&V***, turbomachinery research has benefited from Hills' Royal Academy Fellowship and the appointment of Montomoli whose research in uncertainty quantification is also applicable to other areas. Hills has recently taken over directorship of the UTC from Chew. Environmental flow has been supported with the appointments of Kumar, with particular expertise in dispersion of nano-particles, and Carpentieri, with succession planning in place for a new a Director of EnFlo in advance of Robins' retirement. Aerodynamics research has been further strengthened and broadened with expertise in fluid mechanics and sensors (Birch), aeroelasticity (Murua) and aeroacoustics (Lu). Automotive research has been reinforced with the appointments of Grüber (tyre and vehicle dynamics) and Fallah (vehicle systems), complementing Sorniotti's expertise and establishing a young group of international standing. The new appointments to ***Infrastructure*** provide expertise in various aspects of civil engineering materials and asset management with Imam providing expertise in railway infrastructure, Mitoulis supporting work on pre-stressed bridge design concepts and Jesson providing expertise in materials sustainability issues while also playing a leading role in the work for Thames Water on cast iron. Szynizewski provides specialist knowledge of metallic foams, an important emerging class of material with wide ranging applications, and expertise in advanced simulation of progressive collapse in structural systems, while Sagaseta has a growing track record in structural modelling of reinforced concrete, specifically localised loading and dynamic response. The appointments of Bhattacharya, Cavaretta and Cui, together with significant investment in new experimental facilities, have enabled us to re-establish a soils activity of critical mass and expertise, with particular strengths in dynamic soil-structure interaction and discrete element mechanics. In ***WCBS***, water research has benefited from the appointment of Khu to lead the University activity (SWIRL), together with Charles and Saroj, with particular expertise in the developing world water agenda and wastewater treatment, respectively. The appointments of Seville (who joined the Faculty as Dean) and Wu give renewed impetus to activities associated with particle technology, granular dynamics and pharmaceutical engineering, while the latter area will also be supported by Lian, who has joined the University as a joint appointment with Unilever. Taylor and Forte have been appointed to lead the research activities associated with the BP Centre. In Bio-Systems Engineering a new line in biomedical signal processing has been developed with the appointment of a senior lecturer (Abasolo). ***Sustainable Systems*** has been strengthened through new appointments in engineering systems modelling (Chen, Hagen-Zanker, Sadhukhan, Yang), life cycle assessment (Murphy), socio-economic analysis (Druckman) and sustainability metrics and stakeholder participation (Morse).

Of the new recruits, several join us from the University of Cambridge (Campbell, Kumar, Lu and Montomoli) and Imperial College (Birch, Murphy and Murua). We have also recruited

internationally: Abasolo (University of Valladolid, Spain), Chen (NTU, Singapore), Cui (University College Dublin), Fallah (University of Waterloo, Canada), Mitoulis (Aristotle University of Thessaloniki), Sagaseta (EPFL, Switzerland), Saroj (UNESCO-IHE, Delft) and Szynizewski (Johns Hopkins, USA). Our commitment to develop our own researchers to the next level is demonstrated by 6 members of research staff (Carpentieri, Charles, Druckman, Grüber, Imam, Jesson) having been appointed to permanent positions following the usual robust and open process. There have also been a number of internal promotions. For senior promotions the main criterion is research excellence, and full endorsement by international external referees is an essential part of the process. During the period 7 staff have been promoted to Senior Lecturer (Chenoweth, Elghali, Hughes [S], Imam, Kumar, Labeed, Sadhukan), 2 have been promoted to Readerships (Mulheron, Pedley) and 3 to Chairs (Hills, Hughes [M], Kirkby).

In terms of personal research fellowships held by staff during the period, Hills holds a Rolls-Royce Royal Academy of Engineering Senior Fellowship (2009-2014) in Computational Engineering and Jackson holds an ESRC Professorial Fellowship (2013-2015), Prosperity and Sustainability in the Green Economy (PASSAGE). During the early part of the REF period Lawson was the Steel Construction Institute Professor of Construction Systems and Carpentieri held a Marie Curie Fellowship (2008-10). Prior to joining the University of Surrey, Birch held a personal NSERC (Canada) Fellowship, Campbell held the post of Hertha Ayrton Research Fellow (2007-2012) in Chemical Engineering at Girton College, Cambridge, while Wu held an EPSRC Advanced Research Fellowship at the University of Birmingham.

Staff Development: New members of academic staff undertake the Graduate Certificate in Learning and Teaching (GradCert) during probation. This is a two year accredited qualification covering teaching, research and enterprise. We develop and mentor new staff with the aim of establishing their research early in their appointment. The Faculty Research Support Fund helps new staff by providing pump-priming funding and funds for travel and conference attendance. New members of staff are preferentially allocated research studentships (from the Doctoral Training Account and other sources) and the policy is to ensure that staff are relatively lightly loaded during their period of probation (normally 3 years), so that they can establish their research credentials. There are University-wide development courses for mid-career academic staff. Established members of staff have annual targets set as part of the Staff Appraisal process, which assists with career development. Sabbaticals are available on the recommendation of the line manager and Dean of Faculty with an individual case made by the staff member to show the institutional and personal advantages. The vast majority of members of academic staff attend at least one international conference a year (and some many more). Occasionally there are international secondments – e.g. during 2014 Sharif will be seconded to Qatar as Director of the Qatar Environment and Energy Research Institute – and sometimes staff members are invited overseas for a short period – Chryssanthopoulos was awarded a JSPS (Japan Society for the Promotion of Science) short-term fellowship and visited several Universities and infrastructure asset owners.

The Faculty Research Strategy makes clear that post-doctoral researchers are essential contributors to the research output of the Faculty and for its succession planning. The strong research staff base in the unit (more than 30 FTE at October 2013) plays a key role in the support of PGRs and provides a continuity of expertise which is vital for the success and sustainability of our research. In 2011 the University of Surrey developed an action plan and undertook a gap analysis to support the implementation of The Concordat to Support the Career Development of Researchers. This led to the HR Excellence in Research Award in early 2012. Research staff are encouraged to use the same development courses as academic staff and to work with mentors.

Visitors: The unit benefits from many visiting staff from academia, industry and professional bodies from the UK and overseas. There is a formal appointment process for visiting staff which requires a case to be put forward that demonstrates both the calibre of the individual and a potential contribution to the research agenda. Each research area has its own cohort of visitors. For instance associated with the Water research activity there are visiting staff from the Drinking Water Inspectorate (Colbourne), University of North Carolina (Bartram), a former Oxfam employee (Sherlock) and a former member of staff with expertise in sanitation engineering (Clarke). The Unit also hosts visiting scholars who typically come to the University for a period of a few weeks up to one year. During this REF period for example, the Sustainable Systems group has hosted visitors

from Kunming University, North China Electric Power University and the Ministry of Knowledge Economy, Republic of Korea.

Equality and Diversity: The University of Surrey recognises the benefits of a diverse community and aims to ensure that it can fully harness the talents, creativity and skills that people bring, and maintain its continuing commitment to equality and diversity across the broader community. As a public body the University is also committed to meeting its legislative responsibilities under the requirements of the Equality Act 2010. The University is committed to the Athena SWAN scheme and made a successful submission for Bronze status in April 2013. The Faculty is also an active WISE partner. The University is committed to ensuring that effective equality and diversity training is undertaken by all staff. A flexible working policy has been implemented and promoted across the University; staff returning from maternity or paternity leave are offered flexible working times.

ii. Research students

The number of registered Postgraduate Research Students (PGRs) at the date of submission is ca. 160; i.e. ca. 3 per FTE. The number of Degrees awarded over the REF period is 125. Over half the academic staff have been appointed since RAE2008, so the number of staff supervising students in the earlier years of the review period was much lower. The University and Faculty Research Strategies recognise that PGRs are essential contributors to the research output and we aim to recruit high quality PGRs and to provide them with an excellent environment for research, with first class training, supervision and facilities. PGRs are part of the Faculty Graduate School and are managed locally through Directors of Post Graduate Research (DPGR), who deal with PGR admission, progression, completion and training. Each PGR has two academic supervisors, with terms of reference relating to supervision; the initial scope of the research, resources and funding details are agreed by all parties at the inception of the research programme. Students are issued with a student handbook on registering and attend mandatory induction and research methods courses. Records are kept of supervisor-student meetings (monthly) and progress is monitored formally via six monthly and annual reviews; reports are completed by student and supervisors followed by a review meeting. The outcome is monitored by the DPGR. Students develop personally and professionally via a University-wide PGR skills programme and use Action Planner software, developed in-house and mapped on to the VITAE researcher development framework (RDF), to tailor their training programme to their own particular needs and aspirations. Action Planner is completed on an annual basis so that training and development needs are reviewed and developed throughout the PhD. Action Planner has recently been extended for postdoctoral and early career researchers to ensure that training and development continue and are interwoven with career development and progression. PGRs also have access to specialist MSc modules from the portfolio offered by the Faculty. PGRs deliver seminars in research group-based seminar series and participation at conferences is actively encouraged and supported. Formal matters relating to PGRs are overseen by the Faculty Graduate School Committee, which meets every other month. It is chaired by the Graduate School Director and attended by DPGRs from across the Faculty and PGR representatives. This committee interfaces with the Faculty Research Committee and at University level with the Research Degrees Committee. EngD Research Engineers (REs) based in the Industrial Doctorate Centre (IDC) follow a similar process to PhD students, but with important differences. The REs are based full-time in the sponsoring company and have industrial supervisors from the company and academic supervisors from the University. In addition, the specialist and skills training is a fully integrated part of the 4-year Programme. The IDC Advisory Board has a majority of end-user representatives and is chaired by a senior industrialist.

The PGR environment also benefits from researchers from overseas coming for placements through a range of funding sources, including Erasmus, Santander and UGPN. In this way we have welcomed PGRs from many Universities internationally including NCSU, USP, Mississippi State University, University of California (Irvine), University of Science and Technology (Beijing), Peking, Tsinghua, Genoa, Padua, Poitiers, INSA Strasbourg, Politecnico di Torino. In accordance with the University International Strategy, we envisage the development of Dual PhD programmes with overseas partners within the next few years, initially within the UGPN.

d. Income, infrastructure and facilities

Research funding portfolio: The data returned show a total research income in the relevant period

of £14.5M. This equates to a nominal average per FTE submitted of ca. £55k pa, but it should be noted that the number of new staff appointments in the Unit is high and through much of the period the number of staff was less than the submitted number. Looking at the figures in more detail, the income has in fact increased significantly over the REF period, from £2.48M in 08/09 to £3.65M in 12/13. This is a result of a strategic decision in some parts of the Unit to engage much more with EU opportunities – EU income for the Unit has increased by almost 300% on a per annum basis over the period. Although Research Council income is down slightly over the REF period on a per annum basis, UK central government funding has increased as a result of work for Defra (in **Sustainable Systems**) and the Home Office (EnFlo in ***F&V***). UK industry funding has increased strongly over the last two years, reflecting the developing relationships with Rolls-Royce, Thames Water, BP and others.

In addition to the research income discussed above, this Unit hosts the IDC in Sustainable Energy and Engineering Systems, SEES (Director: France), which was funded by EPSRC in 2008 at over £6M with additional industrial funding of £2.4M. Staff in ***Infrastructure*** also supervise students on the Micro- and Nano-Materials and Technologies IDC (Director: Yeomans, returned under UOA13), which is also funded at over £6M with additional industrial funding of £2.4M. At the start of the REF period, the University supported its EngD Programmes through the EPSRC Collaborative Training Account (Director: France) which at over £10M was one of the largest such accounts. Staff have increased research impact through engagement with the EPSRC Knowledge Transfer Account (award value £3.85M) and the follow-on Impact Acceleration Account (2012-2015, value ca. £1.0M), both won by the University in partnership with the National Physical Laboratory. We have also benefited from EPSRC High Performance Computing support to the value of £300k.

With regard to future planning, the expected average income figure for an established member of academic staff will be between £80k and £120k p.a., dependent upon discipline area, and we anticipate significant growth in research income over the next few years. We will engage further with European funding opportunities and will work across the Faculty and the wider University to engage effectively with broad thematic areas and the associated grand challenges and EU and RCUK priority areas. We will also seek opportunities to work with our partners internationally within the developing UGPN and will continue to develop end-user relationships.

Consultancies and Professional Services: Members of staff in the unit undertake a wide variety of specialised Professional Services work in their areas of expertise, and this often involves use of our experimental facilities. The WHO partner status of our water activity (***WCBS***) means that we are much in demand for testing of water and the development of standards (the associated work is worth ca. £0.75M over 5 years). In mechanical characterisation (***Infrastructure***), consultancy has been undertaken for (amongst others) ERA Technology, Gnosys, Gordon Murray Design, Morgan Sindall, Surrey Satellite Technology Ltd., Thames Water, VerdErg and Vestas. Consultancy in ***F&V*** has included studies for Chingford Fruit, Cleantech Advisory, CONCAWE, DSTL, English Institute for Sport, Gordon Murray Design, McLaren Automotive, Ferrari, National Health Service, Norwegian Defence Research Institution, Oerlikon and Rolls-Royce. Our expertise in energy (***Sustainable Systems***) has led to work for, amongst others, the Association of Manufacturers of Domestic Appliances, the Combined Heat and Power Association and Richmond Borough Council; work in the area of agriculture has led to a study for the International Institute of Tropical Agriculture on seed systems for yams. We have advised Thames Water regarding sludge powered generators and carried out work for an overseas government (***WCBS***). We use the engagement afforded by consultancies to look to develop more long-term relationships, so for example an initial consultancy with the Norwegian Defence Research Institution (***F&V***) has lead to collaboration in a major research project (MODITIC). Specialist short courses, where delegates have the opportunity to use our experimental facilities, are another means of engagement; in particular in the Chemical Process area (***WCBS***) we have supported the Associate Programme of the OPCW (Organization for the Prohibition of Chemical Weapons, winner of the 2013 Nobel Peace Prize) for 14 years, educating representatives from over 100 countries in both the chemical engineering skills and the team work and leadership skills that are required to be effective inspectors and members of their National Authorities (associated income is ca. £80k p.a.).

Infrastructure and Facilities: Since RAE2008, more than £3.5M (from HEFCE SRIF-4 and the University) has been invested in infrastructure and facilities associated with this Unit. A number of

staff, especially ECRs, also benefited from the successful bid by the Faculty to the EPSRC Small Scale Equipment initiative (total bid value ~£500k). Academic, researcher and PGR offices are for the most part housed within three adjoining buildings on the University of Surrey main campus. The Bio-Systems Engineering activity is located in a building that is part of the Faculty of Health and Medical Sciences, which facilitates collaboration. The vast majority of the space is in an excellent state of repair having benefitted greatly from a major HEFCE grant and substantial SRIF and University investment over the past 12 years or so. The most recent refurbishment involved moving CEE and MES staff into a new location in 2009 (£400k). Major facilities are described below (***Sustainable Systems*** does not require dedicated laboratories).

In the ***F&V*** area, the CFD activities of the Rolls-Royce UTC demand high quality computational equipment and this has been upgraded significantly over the REF period. The current UTC computational facilities consist of 3 main high performance PC Linux clusters installed over the last 6 years, the most recent addition (2013) a 1024 core PC cluster with infiniband network. In addition there is a small research cluster using graphical processing units. The NERC EnFlo laboratory, with its ability to measure pollution dispersion around model structures, is well established as a unique national and international resource. Capability has been enhanced, for example by increased automation and monitoring, incorporation of PIV and development of improved sensors. Specialist equipment has been purchased (£80k) for fieldwork on airborne nano-particulates. Development of the vehicles and aerodynamics facilities included a £900k SRIF investment. Two state-of-the-art hardware-in-the-loop test rigs for electric drivetrains have been installed in the vehicle laboratory, allowing efficiency measurement, driving cycle simulation and drivability characterisation and experimental assessment of vehicle braking and stability control systems. A new wind tunnel with a rolling road section has been constructed and fully integrated into the Fluids laboratory, supporting analysis of aerodynamic aspects of vehicles including ground effect for the optimisation of downforce. Specific sensors and simulation software have been purchased and are used for vehicle testing activities within EU FP7 projects.

Within the ***Infrastructure*** activity, the Materials and Structures Laboratory provides a wide range of facilities related to the manufacture and testing of materials. The area was refurbished in 2009/10 at a cost of ca. £1M to provide a high-quality working environment, a new SATEC testing machine and commonality of software across all test frames. As a result we can test samples ranging from a single carbon fibre up to a 5 m concrete beam. This facility is the result of a long term strategy to co-locate all mechanical testing equipment in the Faculty in a single location with a dedicated manager to train users and ensure best practice. We have also purchased a water jet cutter (ca. £75k), essential for cutting cast iron pipes and preparing test coupons. The GeoMechanics Laboratory has been established (ca. £450k) with a range of equipment for the characterisation of soils including the macro- and micro-mechanics of granular materials using image analysis. Facilities are also available for the study of soil-structure interactions, such as pipelines and piles in liquefiable soils and the foundations of off-shore wind turbines.

Within the ***WCBS*** theme a total investment of ca. £650k has been made for new laboratories and equipment. The Centre for Research into Osmosis and its Applications now has a pilot scale rig for research into forward osmosis including trialling membranes. There is a particle technology laboratory with a shear cell and particle characterisation equipment. In terms of pharmaceutical powder equipment we have an instrumented roll compactor, an instrumented high shear granulator and a die filling rig. To support work in Bio-Systems Engineering, there is a Class 2 cell culture laboratory and a micro-engineering laboratory for fabrication of a range of artefacts including microelectrodes for neural processing and components for the novel dielectrophoresis well plate assembly for cell analysis. There is also a well-equipped Gait Lab. for research and external work.

In addition to the facilities highlighted above, staff and students within the Unit have access to facilities within the Faculty that are reported under other UOAs. In particular, researchers in ***Infrastructure***, but also other groupings, use the materials characterisation facilities returned to UOA13. With regard to University infrastructure supporting research for staff and students, a £13.2M Library extension opened in 2011, followed by redevelopment of research space for archives and special collections in 2012. The next phase of refurbishment relocates and upgrades facilities for researcher training and development in response to PGR feedback through PRES.

e. Collaboration or contribution to the discipline or research base

Collaborations

F&V: In addition to the long term relationships with NCAS (EnFlo NERC-supported National Atmospheric Science facility est. 1993) and Rolls Royce (UTC est. 2003) the group has participated in, and led some, funded research consortia supported by EPSRC (e.g. SUPERGEN - Hancock), EU (including 5 in the automotive group), DTI, Home Office (e.g. DAPPLE), TSB and European Defence Agency (e.g. MODITIC). Many of these projects are multidisciplinary; for example, DAPPLE2 and MODITIC involve meteorology, chemistry, computational modelling, aerodynamics and epidemiology. Collaboration and engagement with end-users are ingrained in the group's strategy with some of the research consortia being industrially led, and some research projects and studentships funded directly by organisations such as Airbus, Force India F1, JLR, McLaren, Oerlikon, National Health Service, Rolls-Royce, Shell, Surrey Sports Park, Toyota and Williams F1. Several staff members have previously worked in industry. Funded international academic collaborations have been undertaken with Karlsruhe IT, Beijing IT, IIT Delhi (UKIERI project), NCSU (Murua), Northwestern Polytechnical University and USP.
Infrastructure: The group has strong links with UK infrastructure owners (Thames Water, Network Rail – Imam/Hagen-Zanker) through directly funded projects and collaborations in EU consortia (e.g. CoPatch, Mainline, Smarten). It also works closely with the Steel Construction Institute and European steel producers in several RFCS projects and has undertaken collaborative research with Arup, COWI, TRL, TWI, Morgan Sindall, HR Wallingford and Surrey County Council among others. There are strong academic partnerships with EPFL (concrete), DTU (risk), RWTH Aachen (steel), Johns Hopkins and U. Massachusetts (metal foams), National Research Council of Canada (cast iron pipes – Mulheron/Jesson), U. Yamaguchi and U. Tonji (liquefaction) among others.
WCBS: Collaborations include Addenbrooke's Hospital (Kirkby/Chen), RSCH, Gray Institute (Oxford), CERN (computational oncology) and U. Bergen (bio-systems); DWI, WHO and universities/government bodies in China through the EU-China infrastructure project SPRING, Medicor Foundation and Qatar Foundation (water); U. Amsterdam, TU Graz, Heinrich-Heine-University, Fraunhofer Institute for Mechanics of Materials, Ecole des Mines d'Albi, NTU Athens, AstraZeneca plc., Mölndal, Res. Centre Pharmaceutical Eng. GmbH, Johnson Matthey plc., Bayer Schering AG, Sabic UK Petrochemicals, (chemical processes). International consultancies have been conducted for Coca-Cola (US), Braskem SA (Brazil), Deloitte and the UAE Government.
Sustainable Systems: Multi-disciplinary collaborations epitomise this group, transcending academic, professional and national boundaries. Sponsors include BBSRC, Defra, DfID, EPSRC, ESRC, EU, Gates Foundation and NERC; we have participated in initiatives by UNEP, UNDP, UNDESA and UNIDO/ILO on lifestyles, green economy and cleaner production, as well as the US EPA, the European Environment Agency and Parliament on waste prevention, green GDP and energy policies; project partners include African Energy Policy Network, BBSRC Sustainable Bioenergy Research Centre, Cambridge Dept. Architecture, TU Delft, Imperial College, Oxford's Environmental Change Institute, Sussex's SPRU, Tsinghua University and York U. (Canada).

Membership of Boards, Panels and Committees

F&V: ASME IGTI Heat Transfer committees, UK Aerodynamics National Technical Committee, Rolls-Royce Power and Propulsion Advisory Board, TSB assessment panels (Chew); ASME IGTI Turbomachinery committee (Chew, Hills); APRIL – ultrafine particles theme leader (Kumar); Japan Technical Committee for Nuclear Safety, BIS-Blackett review committee, ESDU wind engineering panel, Chair dstl external assessment group 2009 (Robins).
Infrastructure: ISO 2394: Structural Reliability, Joint Committee on Structural Safety (Chryssanthopoulos), Chair SCI Light Steel Forum, Eurocode 4 project team (Lawson); DTI Sector Committee for Codes and Standards, BSI committee B/-/12: Construction Fire Standards, IStructE Council (Parke); fib Task Groups 4.2.1&4.2.3, DAfStb-ACI group on concrete shear (Sagaseta), TSB Sustainable Innovation AG, EngD Assoc. steering group (Elghali), Sustainable Development Group IoM^3 (Jesson).
WCBS: IET Healthcare Tech. Network executive (Abasolo), Int. Water Assoc. UK national committee (Charles), IoP Dielectrics and IEEE BioMEMS committees, IEEE Nanotec Council and Eng. in Med. And Bio. Society (Hughes [M]), VProf. Peking U. Tianjin U. Chinese Inst. Water Res. (Khu), expert Spanish CONSOLIDER funding programme and Italian Abilitazione Scientifico Nationale (Ouki), IChemE Council, European Fed. Chem. Eng., RAEng Education and Training

Committee (Seville), Chair-Tech. Committee, Modern Water plc. Royal Soc. Technology Workshop, Int. Experts Panel Qatar Foundation (Sharif).
Sustainable systems: EPSRC SAT Manufacturing the future (France), ICARB Adv. Board, IPCC-WG3 invited expert (Druckman), lead expert DIUS Foresight SEMBE project (Hunt), Sustainable Development Commissioner, Chair-Adv. Board New Energy Solutions Partners, Adv. Board Ellen MacArthur Foundation, International Adv. Board Wuppertal Inst., UNEP Sustainable Lifestyles Taskforce (Jackson), VProf. Imperial College, VPres. Energy Institute (Leach), BSI Materials Supply WG (Lee), Council for the Frontiers of Knowledge board member (Morse), BRE adv. Panel and Defra-HSAC (Murphy).

Fellowships, Awards and Prizes
F&V: Rolls Royce/RAEng Senior Research Fellowship (Hills); Glory of India award (Kumar); Marie Curie Intra-European Fellowship (Carpentieri), Lloyd's Science of Risk Prize (Montomoli).
Infrastructure: JSPS short-term Fellowship, Transport Res. Foundn. Fellowship (Chryssanthopoulos); 2013 ICE Palmer prize (Bhattacharya); 2009 ICE Manby prize (Elghali), 2011 ICE Palmer Prize, 2011 ICE Howard Medal (Lawson); fib achievement award, Mag. Concr. Res. best paper award 2012 (Sagaseta); IABSE Conf. 2008 best paper award (Szyniszewski).
WCBS: British Science Assoc. Media Fellowship (Charles), IoP 2008 Perkins Prize, best paper award MEDSIP2012 (Abasolo), 2009 Best PhD research award in the field of water, AMGA foundation (Saroj), 2009 IMechE Bulk Solids Handling Award for Innovation (Thorpe), 2011 IChemE senior Moulton medal (Taylor), 2011 Hinshelwood prize (Campbell), 2012 IChemE Project of the year and outstanding achievement awards (Seville), 2013 Christopher J Wormald Prize (Forte), 2008 pan-European ACES award, 2011 IChemE water award (Sharif).
Sustainable Systems: Academician, Academy of Social Sciences, ESRC Professorial Fellowship (Jackson); 2013 ICE Telford premium prize (Elghali, Lee, France), 2008 ICE Telford premium prize and 2011 ICE Baker medal (Leach), 2011 IChemE junior Moulton medal (Sadhukhan), UK Scopus 2011 Young Researcher Award for Env. Sci. (Druckman). Hon. Doctorates at Université Catholique de Louvain (2011) and University of Brighton (2013) (Jackson). Invitation to join the De Tao Masters Academy to help **enhance** China's cultural, economic and social development (2013, Jackson); Metcalf Innovation Fellow, Metcalf Foundation, Ontario, Canada (2012-2014) (Jackson).

Journal Editorships and Conference Organisation, Keynote/invited lectures
F&V: Editor in Chief – *Proc. I MechE Part C: J. Mech. Eng. Sci*., Vanguard Chair ASME Gas Turbo expo 2010, 13, 14 (Chew); Guest Ed.: *Progress in Aero. Sci*. (Hills), *Int. J. Powertrains* (Sorniotti); Exec. Editor: *J. Civil & Env. Eng*. (Kumar); Editorial Boards: The Open Environmental Engineering Journal (Carpentieri); *Sci. Total Env*. (Kumar); *Atmospheric Env.*, *J. Wind Eng. and Ind. Aero*. (Robins); *Int. J. Powertrains* (Sorniotti). Invited lecture HiperNano 2012 (Birch); Tire Technology 2010, 2011 (Gruber), Int. Conf. EU-China Env. Sci. 2012 (Kumar), SAE Symp. 2011 (Sorniotti).
Infrastructure: Editor *J. Constr. Steel Res*., Joint conference organiser IABSE-IASS 2011 (Parke), Assoc. Ed. *Struct.& Infrastruct. Eng*. (Chryssanthopoulos), ASCE *J. Computing in Civil Eng*. (Cui); Editorial boards: *Soils & Foundation* (Bhattacharya); *J. Earthquake Eng*., *Struct. Safety* (Chryssanthopoulos); *J. Eng. Geology and Hydrogeology* (Matthews); *Int. J. Construction Eng. & Management* (Mitoulis); *Hormigon y Acero* (Sagaseta). Keynote Int. Symp. Offshore & Coastal Eng. Conf 2013 (Bhattacharya), ICE-TRF Annual Fellows Lecture 2013 (Chryssanthopoulos).
WCBS: Editor-in-chief: *IEEE Trans. Nanobioscience* (Hughes M), *Powder Tech*. (Seville); Assoc. Ed. *Water Policy* (Chenoweth); Editorial Boards: *J. American Water Res. Assn*., *Sustainable Env. & Res*. (Khu); *Desalination* (Sharif), *J. Env. Mngt* (Ouki); *J Water & Health* (Pedley); organiser PARTEC 2013 (Seville), Int. Symp. DEM Particulate Media 2012 (Wu). Invited lectures: Fluidization XIII (Seville), 2nd Int. Conf. Sustainable Water Supply, 7th Industrial Simulation Conf. (Sharif), 3rd and 4th Int. Conf. Multi-scale Systems (Seville/Yang).
Sustainable Systems: Editorial Boards: *Energy Journal* (Hunt), *Energy Policy* (Jackson), *J. Carbon Mngt*, ICE Energy (Leach), *Sustainable Development*, *Systemic Practice and Action Research*, Open Agriculture Journal (Morse), Conferences: Chair Heat 2012(Leach), co-chair ISIE2015 (Lee),Total Food 2014 (Murphy). Invited lectures: EU DG Environment Expert Workshop, DECC workshops, British Association for Sustainable Sport Conference (Druckman), Umea Renewable Energy Conf., Int. Symp. Green Chem. & Biomass, 4th World Biofuels Symp., 10th Intl Conf on Renewable Resources and Biorefineries (Murphy), United Nations Parliamentary Hearing, New York 2013 (one of more than 50 keynotes) (Jackson).