Institution: University of Cambridge

Unit of Assessment: UoA15 General Engineering

a. Overview

This submission represents the Department of Engineering (DoEng), which has pursued a fully integrated approach to research and teaching across engineering disciplines since its creation in 1875. Its high level of integration, size and quality are key strengths. Professor Dame Ann Dowling DBE FRS FREng has been Head of Department (HoD) since 2009.

The DoEng is in the School of Technology (SoT) at the University of Cambridge (UoC). It is the largest department in the UoC (149 academics) and structured in 6 Research Groups (RGs), which provide a consistent formal structure for the DoEng, bringing together academics working in cognate engineering disciplines. The RGs, Heads of RG and distribution of academics are:

RGa - Energy, fluid mechanics and turbomachinery (Professor Collings FREng, 31 academics)
RGb - Electrical engineering (Professor Milne FREng, 25 academics)
RGc - Mechanics, materials and design (Professor Langley, 25 academics)
RGd - Civil engineering (Professor Mair FRS FREng, 25 academics)
RGe - Manufacturing and management (Professor Sir Michael Gregory FREng, 15 academics)
RGf - Information engineering (Professor Maciejowski, 28 academics).

Long-term strategy, budgeting and investment decisions are made by the DoEng Academic Committee chaired by the HoD, rather than devolved to RGs, to maintain cohesion. The RGs are connected by 4 strategic themes, which bring together multidisciplinary teams across the DoEng to address major challenges, generate impact and encourage adventurous research, linking to other departments, universities and industrial partners. The themes and their leaders are:

T1 - Energy, transport and urban infrastructure (Professor David Cebon FREng)
T2 - Uncertainty, risk and resilience (Professor Duncan McFarlane)
T3 - Bioengineering (Dr Michael Sutcliffe)
T4 - Inspiring research through industrial collaboration (Dr Tim Minshall / Professor Rob Miller).

A great deal of freedom is granted to academics to join themes and make further connections with subgroups, centres and project-specific partnerships. Any academic can join any activity. The HoD and Heads of RGs, together with the Director of Research (DoR), drive and support initiatives that encourage participation and mixing across the DoEng and the wider UoC.

b. Research strategy

Strategy development is steered and approved by the HoD and the Academic Committee with the Director of Research (DoR) managing the work, engaging all academics to generate and refine ideas. This is a continuous process, but there was a major update in 2009/10. This was informed by a review of existing themes, an analysis of significant global trends and a summary of our sponsors' strategies (e.g. EPSRC, TSB, UK National Risk Register and EC). The national and international priorities identified by this review included energy, sustainability, transport, infrastructure, health care, data/communications and manufacturing. These priorities helped prompt and shape ideas for themes. The HoD and DoR managed the interplay with the UoC strategic themes and networks as they co-evolved with the DoEng's themes. The DoR also worked with the SoT, of which the DoEng is a member, to bring the themes neatly into alignment across all SoT departments. In this way, the DoEng themes strongly resonate across its groups, the SoT and the UoC. The DoEng strategy was reviewed both by a group of leading city business executives chaired by Lord Watson in 2009/10 and by the International Visiting Committee (IVC) chaired by Lord Broers in 2011. The IVC's members were Brady (Oxford), Broers, Brown (Eurostar Ltd), Delpy (EPSRC), Gardner (Warwick), Greitzer (MIT), Hibbitt (ABAQUS Inc), Hill (ARUP Trust and Crossrail Ltd), King (Aston), Lloyd (Rolls-Royce plc), McMeeking (UCSB), Murray (CALTECH), O'Rourke (Cornell), Zank (Dow Corning Corp), Hauser (Amadeus Capital Partners Ltd), Ion (Nuclear Energy Advisor), and Yoshikawa (JAIST). The IVC report stated, *"The Committee was hugely impressed with the performance of the Department, by the way it is now acting as a whole rather than a series of separate groups in its strategic thinking and planning, by its connections to other departments and its co-ordination of many major bids to the benefit of the wider university."*

The strategic aim of the DoEng changed in 2009/10 to place sustainability at the core rather than among its themes and is now, *"to benefit society by creating world-leading engineering knowledge that fosters sustainability, prosperity and resilience. We share this knowledge and transfer it to industry through publication, teaching, collaboration, licensing and entrepreneurship. By integrating engineering disciplines in one department, we can address major challenges and develop*

complete solutions, serving as an international hub for engineering excellence."

The RGs' strategic aims were refined during the REF period, with the oversight of the Academic Committee, and are now:

RGa Energy, fluid mechanics and turbomachinery - build on research in fluid mechanics and thermodynamics to develop a systems view of energy generation and utilisation, particularly in ground and air transport, to mitigate environmental impact

RGb Electrical engineering - pursue fundamental electrical, electronic and photonic research at the material, device and system levels with a focus on creating integrated solutions in the fields of nanotechnology, sensing, energy generation, energy conversion, displays and communications

RGc Mechanics, materials and design - extend fundamental and applied research in mechanics, materials, and design, exploiting cross-disciplinary partnerships across the University; and build on existing strengths to develop excellence in bioengineering and healthcare systems research

RGd Civil engineering - advance the mechanics of civil and structural engineering systems within the broader context of the design, construction and operation of sustainable infrastructure and the stewardship of Earth's resources and environment

RGe Manufacturing and management - develop new understanding of manufacturing technology, operations, strategy and policy, in close partnership with industry, in order to improve industrial performance

RGf Information engineering - develop fundamental theory and applications relating to the generation, distribution, analysis and use of information in engineering and biological systems.

Four strategic themes emerged from the 2009/10 review. They crosslink the RGs and have the following strategic aims directed at major global challenges with a multidisciplinary approach:

T1 Energy, transport and urban infrastructure - creating sustainable integrated solutions for the provision of energy, transport, information, buildings, water and waste treatment in the context of the urban environment

T2 Uncertainty, risk and resilience - developing modelling, simulation and analytical methods for understanding large complex systems and ensuring their resilience through new approaches to optimisation, decision-making and control that take full account of uncertainty and risk

T3 Bioengineering - applying the engineering approach to understanding biological systems and supporting innovation in healthcare, creating new knowledge, solutions for biological and medical applications, and biologically-inspired solutions elsewhere in engineering

T4 Inspiring research through industrial collaboration - significantly reducing the time from research to large-scale implementation through improved design and management of research collaborations and knowledge transfer, building on the DoEng's world-leading research.

The development and current status of these themes are described under the heading, "Progress compared with the 5-year plan in RAE2008", below. Each is at a different stage of evolution and the next steps to develop them are described under, "Plan for the next 5 years".

Recruitment and human resources (HR) strategy for both staff and students is driven by the aim to create *"world-leading engineering knowledge"*, so the DoEng seeks and attracts the best candidates in the world. Academics are sought who can both increase the strength of a research discipline within an RG and also connect across the DoEng through strategic themes. Recruitment is also used to maintain a healthy balance of new blood and experienced staff across the DoEng. In addition, there is a drive to increase the number of female academics. Students and postdoctoral researchers are an important output of the DoEng, but also provide excellent gearing for academics to build research capacity, so further growth in numbers and improved training is planned. Details are given in section c.

Research income strategy is driven by the intent to address systems-level research challenges with integrated, collaborative approaches. Larger grants of longer duration are needed, which matches the trend seen in sponsors' calls. The HoD and DoR prioritise resources to support such bids. However, income founded on fewer, larger grants could increase the risk profile of the DoEng, so the HoD and DoR encourage diversification to industry and EC funding. They play a leading role in building company relations, working closely with T4. The DoR also places emphasis on supporting early career researchers, who are seeking fellowships and starting to build their research grant portfolios. Details of support and achievements are given in section d.

Research infrastructure strategy is driven by the need to provide academics with sufficient high-quality space to accommodate their research students and staff, which has facilities for physical experiments alongside those for theory and modelling, reflecting a DoEng strength in the

fundamental analysis of physical phenomena. In addition to space for RGs focussed on their disciplinary strengths, the research income and thematic strategies have created a growing need for flexible multidisciplinary space, which is reflected in section d and the 5-year plan below.

Progress compared with the 5 year plan in RAE2008 is as follows (original goal in italics):

1. *Invest in posts and infrastructure to maintain and extend core disciplinary strengths in line with group activities* – There were 34 new faculty appointments (see section c) of which 20 were to newly created posts. Over GBP23M was invested in infrastructure (see section d)
2. *Complete the laboratory for Engineering for Life Sciences and build stronger links between this theme and related activities in the Clinical School, and the Biological Sciences* – The laboratory was completed in 2008. The theme was renamed to become Bioengineering (T3) engaging over 25 DoEng academics. It linked to the UoC's Cambridge Cancer Centre, Neuroscience Strategic Initiative and "Public Health at Cambridge" Strategic Network. These are well connected with the Clinical School and Biological Sciences. Since the beginning of the REF period, the DoEng has made five lectureship appointments that connect to this theme: Sprekeler, Savin, Huang, Turner and Treece. Treece's post, the Evelyn Trust Lectureship in Engineering for Clinical Practice, was established in 2008, specifically to build links with the Clinical School and Addenbrookes hospital. The Evelyn Trust funding also gave pump-priming for novel research at this interface. Two of the other appointments were made possible by Wolpert winning the Noreen Murray Royal Society Research Professorship in Neurobiology in 2013. Other strategic grant applications resulted in winning 7-year Senior Investigator (Wolpert) and New Investigator (Lengyel) Awards from the Wellcome Trust, as well as two Wellcome Trust Clinical Fellowships (Turmezei in radiology and Seymour in mechanisms of analgesia). A bequest of GBP1.6M established the W.D. Armstrong Fund to support the application of Engineering in Medicine in the UoC and this has been used to support 3 studentships in the REF period.
3. *Develop the vision and plan for Cognitive Systems and build links from the Information Engineering Group into other groups across the University* – The theme was completely reshaped as Uncertainty, Risk and Resilience (T2) after the review in 2009/10 identified the management of uncertainty and risk as a priority throughout government and industry. Discussions revealed that their ultimate need was for a principled approach to understanding, measuring and developing resilience. Relevant DoEng expertise was significant, but disparate. Since 2011, the DoEng has tested and developed its ideas through a series of internal meetings and conversations with BP, Schlumberger, Anglo American and Boeing. The HoD committed two staff to help McFarlane lead the theme, which has engaged over 25 academics across the DoEng. There is now a growing number of T2 projects within the DoEng including: oil drilling uncertainty (Schlumberger); manufacturing resilience (Boeing); and initial exploratory work on agricultural demand resilience (G's Growers). The Judge Business School's Centre for Risk Studies, the Computer Lab, the Statistics Lab and the Departments of Philosophy and Architecture are partners. This collaboration led the SoT to name Uncertainty, Risk and Resilience as one of four initiatives in its strategy.
4. *Secure funding for posts in Sustainable Development, embed these posts in a network across the Department's group structure, and push ahead with the sub-themes of water and energy* – In the Centre for Sustainable Development, a new lectureship was created that is now held by Cruickshank (2011) and Guthrie's professorship is now supported from core DoEng funding. A Sharjah Fellow in Water Resources was appointed for 5 years (2009). Sustainability was written into the overall aim of the DoEng. The sustainability theme evolved into Energy, Transport and Urban Infrastructure (T1), which is the DoEng's unique contribution to the UoC strategic initiative on energy. Choudhary (2008), Barrett (2008) and Boies (replacing Barrett, 2011) were recruited as Lecturers to join the Energy Efficient Cities Initiative. Brilakis (2012) and Elshafie (2011) were recruited for infrastructure. Two new Lectureships in energy for T1 brought Cullen and Lestas (2013). Shwageraus joined to take the new Lecturership in nuclear energy (2013). In total, 70 academics are involved in T1. Theme meetings since 2010 have shared their current research, presented new ideas, created a structure for grouping them, and produced plans for major proposals. For example, Cebon developed a programme grant application to the EPSRC for a new Centre for Sustainable Road Freight, which was awarded in 2012 (more details in the section on collaboration). The DoEng made a strategic investment in consulting resource to assemble this complex application involving Herriot-Watt and 15

industrial partners. In another example, the DoEng led a successful bid for an EPSRC End Use Energy Demand Centre in 2012, with Bath, Leeds and Nottingham Trent Universities, and industrial partners, which aims to reduce the use of energy and materials in industry.

5. *Complete the new building for the Manufacturing Group in 2009* – the new building was completed as planned and, in addition, the Whittle Laboratory was extended by 370m^2.
6. *Complete the scoping exercise for the Department's main site, raise funding and build the first phase* – Approximately GBP8M of refurbishment work has been completed and funding secured for a GBP13M extension with contractors to be appointed in 2013.

An additional objective secured during the REF period, which was not in the RAE2008 5-year plan, was the creation of the theme on inspiring research through industrial collaboration (T4). It was launched in 2011 with an event attended by 75 people from 35 companies, supported by EPSRC "Pathways to Impact" (PIA) funding (GBP100k). This funding also enabled a programme of activities for disseminating good practice and building a community of engaged academics and industrialists. The work extended across the whole SoT, supported via a second PIA round (GBP50k) and HEIF5 (GBP220k). Over 100 researchers have attended the monthly workshops. Coaching support has been provided to multidisciplinary teams of researchers engaging with industry in pursuit of bids totalling more than GBP20M. The EPSRC Impact Acceleration Award (GBP220k) enables continuation. Three Royal Academy of Engineering (RAEng) Visiting Professors of Innovation joined the DoEng in 2012 for 4 years to provide industrial expertise and experience for this theme through teaching, training, coaching and advising. Primary research in the DoEng in this area has contributed to the theme, exploring the effect of evolving innovation processes, industrial systems and regulations/standards on technological emergence, industrial transformation and national economic growth. DoEng research resulted in roadmapping techniques, for instance, that have been used in the DoEng's EPSRC Integrated Knowledge Centres, in companies and in government.

The plan for the next 5 years is given below with reference to sections above in parentheses:

1. Secure donations and grants, use strategic funds and use other discretionary sources of income to invest in academic posts and research infrastructure to maintain and extend core disciplinary strengths in line with RG aims and activities (RG strategic aims)
2. As research income continues to grow, maintain the share from industry at one third, securing this income stream by building long-term strategic relationships (research income strategy)
3. Increase numbers of high-quality research students by winning new EPSRC Centres for Doctoral Training, securing more industrial funding and attracting more philanthropic donations (recruitment and research income strategy)
4. Increase the numbers of high-quality postdoctoral researchers by making an increasing provision for them in grant applications, so that they can provide gearing for academics and build research capacity (recruitment and HR strategy)
5. Improve the recruitment, induction, transferrable skills training and career development for research students and postdoctoral researchers
6. Progress from a bronze award to gold under the Athena SWAN programme and achieve measurable improvements in the numbers of women applying to posts, securing appointments and winning promotions (recruitment and HR strategy)
7. Invest to win significant funding for major projects under the T1 theme, build stronger links across UoC including social sciences and secure funding for new posts (strategic themes)
8. Shape the T2 theme in collaboration with industrial and academic partners to build a solid intellectual foundation for the theme and win funding for landmark projects (strategic themes)
9. Raise the profile of the T3 theme, forging ever stronger collaborations with the Schools of Biological Sciences and Clinical Medicine and Addenbrookes Hospital with the aim of growing research capacity by 50% through new academic posts, additional research staff and more research studentships (strategic themes)
10. Bring our research and practice of knowledge creation and transfer closer together in the T4 theme, take a leading role in the UoC, and embed the message that the DoEng excels in this field in its marketing (strategic themes)
11. Use UoC, DoEng and donated funds to create over 2500m^2 of new space in the DoEng for multidisciplinary research, over 2000m^2 specifically for RGb and improve the functionality and environmental performance of existing space (research infrastructure strategy).

c. People, including:

i. Staffing strategy and staff development

Academic recruitment is guided by the DoEng recruitment strategy (section b). The need to maintain a balance of new blood and experienced staff has been met with the mean age of faculty under 50, 23% under 40 and 19% over 60 (31 October 2013). In the REF period, 30 new Lecturers were appointed of whom 23 had not held established academic positions before.

Academic recruitment follows a structured process. The field is defined by the HoD in discussion with the Academic Committee to: (1) cover or develop a teaching requirement and build strength in the relevant RG's discipline in line with its aim; and (2) create multidisciplinary connections through the themes. Examples among new Lecturers of addressing the strategic drive to cover both RG and theme needs include:

- Choudhary, recruited in 2008 from an Assistant Professor position at Georgia Tech to join the Energy Efficient Cities Initiative under T1, as well as cover teaching needs in RGd
- Turner, appointed from his EPSRC Research Fellowship in the DoEng in 2012 to build links between the research on machine hearing, machine vision, signal processing and neuroscience in T3, in addition to contributing to teaching in these areas for RGf
- De Volder who came from IMEC in Belgium in 2013 to connect work in RGb on carbon nanotubes with the work in RGc, RGe and T4 on design, manufacturing scale-up, and the interface between academia and industry.

The DoEng elected 4 external candidates to fill Professorships with similar strategic intent:

- MacKay came from the Cavendish Laboratory to become the first Regius Professor of Engineering in 2013 – his work on whole system energy modelling and experience as Chief Scientific Advisor to the UK Department of Energy and Climate Change strengthens T1 and connects across all RGs
- Hunt (Gary) was recruited from Imperial College to become the Dyson Professor of Fluid Mechanics in 2013 – the post was created with Dyson funding to address modelling, design and efficiency of air-moving equipment at the smaller scales that pervade homes, offices and factories, cementing one of the DoEng's key industrial relationships and linking to T1
- Nathan came from UCL to become the Professor of Photonic Systems and Displays in 2011 centred in RGb, but also an Enterprise Champion with links in T4, as he develops his Centre for Large Area Electronics
- Sepulchre came from Liege to fill the chair in control engineering reinforcing the connections between engineered systems and the study of biological systems under theme T3.

The DoEng recruitment strategy (section b) to secure the "best candidates in the world" drives the process of international searches and intensive 2-day visits for interviews, presentations and discussion that was used for all 34 new appointments described above. 69% of those appointed were not British nationals, 60% gained their first degree outside the UK, 57% were awarded their PhD outside the UK and 37% were attracted to the DoEng from positions outside the UK.

Staff development for academics starts with a five-year probation period for new Lecturers, which includes rigorous annual reviews by a Department-wide committee. This is supported by mentoring and a wide range of staff development opportunities. Young and mid-career staff are nurtured carefully with a comprehensive range of compulsory and voluntary training schemes, covering all aspects of research, teaching, administration and leadership. The UoC promotes the career development and progression of all staff members by offering participation in its Emerging Leaders Programme to an increased number of research staff, by introducing measures to increase participation in the career management programme for academic staff, and through its Senior Academic Promotions CV Mentoring Scheme. Further support is provided by colleges which can provide accommodation, opportunities to network with academics in other disciplines, and a social framework. Promotion to personal Readerships and Professorships requires evidence of a significant international research reputation, supported by objective criteria and external support. It is an annual competitive exercise with final decisions made by a Committee chaired by the Vice-Chancellor. Career progression was marked by 11 promotions to Professor and 15 to Reader in the REF period.

Fellowship and award applications by academics are strongly encouraged and supported, as they enhance career development. Successes include the following:

- EPSRC: Leadership Fellowship (Allwood, 2008); Early Career Fellowship (Crilly, 2013)

- Royal Society: Wolfson Research Merit Award (Ferrari, 2010; Sepulchre, 2013); Noreen Murray Research Professorship in Neurobiology (Wolpert, 2013)
- Wellcome Trust: New Investigator (Lengyel, 2011); Senior Investigator (Wolpert, 2012).

Sabbaticals for academics enabled faculty to refresh their research outlook and expertise, often at universities overseas, with the UoC/ DoEng frequently assisting with travel costs. These are often coupled with visiting academic positions at these institutions, reciprocal visits and collaborative research grants (see section e). This helps with staff recruitment/retention and international leadership in research. Staff are entitled to 1 term of sabbatical leave on full pay for each 6 terms of service so that 1 year can be accumulated by 6 years of continuous service. Staff took 119 sabbaticals during the REF period, which means almost all staff used their entitlement.

Departures of academics totalled 14 during the assessment period of whom 8 retired, 1 died, 2 left for industry, and 3 moved from lecturerships in DoEng to senior posts in other universities from where they continue to collaborate extending the Department's network, for example:

- White (David) went to a Professorship at the University of Western Australia
- Barrett went to an Assistant Professorship at MIT
- Drummond went to a Professorship at Monash University.

Retired academic staff that remain research active lend strength, coherence and continuity to DoEng activities, and help younger researchers to develop, for example:

- Professor Mike Ashby (FRS, FREng, CBE) retired, but remains employed by Granta Design Limited, visiting the DoEng approximately once per week to continue research on material selection with Cebon and others (Category C in REF2014)
- Professor Ken Bray (FRS) typically visits for half a day per month to work with Swaminathan on research and their co-edited book, "Turbulent Premixed Flames" published in 2011
- Professor Bill Stronge works in the DoEng approximately three times per week since retirement and is collaborating with McShane on the impact damage of composite materials
- Professor Bill Crossland (FIET) worked 1-4 days per month in the DoEng until March 2013 on liquid crystal technology with researchers Collings, Xu, Pivnenko, and Dyadyusha.

Research staff, including research fellows, who are employed by the DoEng, are not only a vital resource for research, but also an important output of research and means of technology transfer. DoEng employs 259 research staff, which is 13% more than the number in 2008 (1 April figures). They are recruited and managed by Principal Investigators (PIs) with administrative support and personnel advice from the DoEng Research Office. They all benefit from the Researcher Development Programme described in the section on the Concordat. In addition, the DoEng ensures that all research staff have a one-to-one career discussion with a professional from the UoC Careers Office soon after appointment. PIs also review their performance and discuss career plans regularly (on average, research staff have a review every other year). The aim is to enhance their ability to provide gearing for academics and develop to full independence for the long-term benefit of UK engineering. Promotion from Research Associate (RA) to Senior RA to Principal RA to Director of Research provides one route with the highest grade being equivalent to a professorship. During the REF period, there were 13 promotions to Senior RA and 2 to Director of Research. Another route is to gain academic positions directly or via a fellowship. The DoEng has also been particularly successful in winning: 3 EPSRC Postdoctoral Research Fellowships, 1 Leverhulme Fellowship, 2 Royal Society Research Fellowships, 5 RAEng Research Fellowships, 1 RAEng Enterprise Fellowship, 1 RAEng Daphne Jackson Fellowship, 2 Wellcome Trust Research Fellowships, 1 Wellcome Trust Intermediate Clinical Fellowship, and 6 European Commission Marie Curie Fellowships. The DoEng also attracted 6 Royal Society Newton International Fellows, 1 Whitaker Fellow, and 1 Japan Society for the Promotion of Science Fellow. Research fellowships at Cambridge Colleges play an important role too and 14 new College Fellows started in the DoEng in the REF period. Planning allows these opportunities to be precursors for recruitment to established academic positions. 11 members of research staff became University Lecturers in the DoEng during the period and 2 became Fixed-Term Lecturers, for example:

- Lestas was a College Fellow who won a Royal Society Research Fellowship in 2008 and was then appointed as a Lecturer in the DoEng in 2013 (RGb, T1)
- Treece was an RAEng / EPSRC Research Fellow who was appointed to the new Evelyn Trust Lectureship in Engineering for Clinical Practice in 2008 (RGf, T3)
- Elshafie was a Research Associate on a Knowledge Transfer Partnership project with

Crossrail who was appointed as a Lecturer in 2011 (RGd, T1).

67 research staff gained faculty positions outside the DoEng during the assessment period: 4 Professorships, 22 Assistant/Associate Professorships, and 41 Lecturerships. Examples include:

- Dr Kai Yu, a Senior Research Associate in the DoEng, became a Research Professor at Shanghai Jiao Tong University in 2012 under the 1000 Talents Plan instituted by the Chinese government with funding to establish his own research group
- Gerhard Reitmayr, a Research Associatein the DoEng, became the Professor for Augmented Reality at the Graz University of Technology in 2009
- Dr Paul Bruce, a Research Associate in the DoEng, became the Lecturer in Compressible Aerodynamics at Imperial College in 2011.

The Concordat has shaped the UoC and DoEng procedures and practices since its launch in 2008. A strategy, implementation plan, codes of practice and website have been developed for the UoC with active input from DoEng. The UoC is fully compliant and won a European Commission HR Excellence in Research Award for its performance in 2010 when the award was first introduced. The UoC, SoT and DoEng used Roberts funding to pilot a series of initiatives, which they have now consolidated to form the Researcher Development Programme. This is open to all research staff and research students. There are over 60 workshops/lectures including ones on: project management, time management, presentation skills and skills analysis. In addition, the Engineering Postdoc Committee was established in 2013, which organises events for the research staff community featuring invited speakers and discussions. At the top level, in 2013, the UoC created a new post, Director of Postdoctoral Affairs, to support the research staff community and started the North West Cambridge Development, which will create homes for up to 1500 University staff and accommodation for up to 2000 postgraduates (GBP300M first phase to open in 2015/16).

Equality and diversity is overseen by the UoC's HR Division and its Equality and Diversity Office. The DoEng has performed well with its number of female academics having risen from 9 to 14 during the assessment period. The percentage of female research staff has remained steady in the range from 20 to 24%. The DoEng recruitment and HR strategy (section b) gives priority to improvement. The DoEng participates in the UoC initiatives: "New Perspectives for Women" development workshops; mentoring schemes designed for female researchers; Gender Equality Group investigation of potential reasons for any gender-based unequal pay; and WISETI, which is a scheme designed to support women academics in STEMM subjects. In addition, the DoEng established a "Women in Engineering" initiative in 2011, subsequently creating a website and forum. The DoEng also makes full use of external schemes. During the REF period, the DoEng won a Daphne Jackson Fellowship from the RAEng (Ward 2011-2013) and held a Dorothy Hodgkin Fellowship won earlier (Hofmann 2006-2010). The UoC is committed to the Athena SWAN programme with the DoEng winning a Bronze Award in 2013. In 2011/12, the UoC won a number of awards for its work in engaging with staff, being ranked 11th, the highest for any UK HEI, on the Stonewall list (2012 and 2013) and winning an Employee Engagement Award from the Employers Network for Equality and Inclusion. These actions are supported by the UoC having more generous maternity/paternity/adoption leave provision than required by law. It also offers a graduated return to work plan, flexible working arrangements and recommends that major meetings should be held during core working hours to avoid exclusion. Furthermore, the University has recently introduced a new Returning Carers Scheme to help staff members resume their research work on their return to work following a career break arising from caring responsibilities, offering, for instance, funding for buying out teaching/administrative duties, conference attendance or supporting researchers. 3 research staff and 2 academics in the DoEng have used this scheme since 2012.

Facilities for staff are presented in the section on infrastructure.

ii. Research students

Applications for research studentships have risen by 25% during the reporting period as a result of proactive efforts by the Head of Graduate Studies and his team of 3 staff to: run regular recruitment campaigns among Russell Group universities, in China and in India; run open days; offer Undergraduate Research Opportunities (UROPs) to generate interest in PhDs; improve the website; and improve the efficiency of back office processes. A stronger profile now means that applications come from over 140 countries and there are approximately 4.8 applications per place. These efforts to secure the best research students in the world, in line with the recruitment strategy

(section b), are important because they are both a key output and research resource.
Admissions have risen too with places created by drives for funding from industrial sponsorship (see research income strategy in section b), the Cambridge Overseas and Commonwealth Trusts, College research studentships, philanthropy, an increased internal allocation of EPSRC Doctoral Training Grant awards, Gates' scholarships and involvement in 3 EPSRC Centres of Doctoral Training (CDTs in Photonic Systems Development with UCL, Ultra Precision with Cranfield and Nano Science/Technology with 3 other UoC departments). There is now a record number of research students registered – over 650 PhDs plus 16 research MPhils (April 2013). Industry plays a key role with over 25% of studentships funded directly by industry (April 2013 figures). During the REF period, DoEng has won over 25 CASE studentships. The DoEng plans for further growth (see recruitment strategy in section b), having submitted 5 full proposals for CDTs to the EPSRC in 2013 of which 4 were funded. In addition, the DoEng is a partner in 2 successful bids for CDTs led by other UoC departments and 1 successful bid led by another institution.
Support for research students admitted is well resourced. Every student has a supervisor and an adviser, together with a College tutor (colleges also provide a vibrant multidisciplinary social environment with a range of events and facilities). The annual formal review of student progress has been tightened to require successful completion of two modules and attendance on personal development courses, in addition to oral examination of a research report, which cannot be resubmitted in the event of failure. This high-quality support combined with a strict first year hurdle ensures excellent process for the great majority of students and well-managed exits for those for whom it is not in their best interests to continue. The ensuing process has been enhanced by the Head of Graduate Studies to drive students, and their supervisors, to ensure submission of theses within 4 years with the result that 75% of all students now reach this target. The REF4a shows underlying growth in the number of PhDs awarded albeit with natural statistical fluctuations and a dip in 2012/13 resulting from campaigns to push for completion in the preceding two years.
The DoEng is creating a stronger sense of community/cohort among students for each year of entry through the formal development programme and other opportunities described below. This, in turn, encourages students to submit their theses at the same time and on schedule in their fourth year. The plans for CDTs will reinforce this successful approach.
The Researcher Development Programme includes workshops/lectures for first-year research students on topics such as: how to write a first-year report; project management; time management, presentation skills and skills analysis. Students in years 2-3 should attend a variety of classes offered by the UoC and one Grad-School. In years 3-4, students are recommended to attend the UoC course, “Finishing up and moving on”. These opportunities are augmented by DoEng Research Skills Lectures and a range of weekly DoEng Research and Communications Clubs. The students’ experience is further rounded by opportunities to serve as student members on major committees (e.g. the DoEng Graduate Teaching Committee and Faculty Board), engage in undergraduate teaching, get involved in entrepreneurship (see below), and join the UoC Graduate Society. RG seminar/colloquium series and RG conference days further cement their involvement in the DoEng. The students, and staff, also benefit from the DoEng having its own Language Unit that offers courses on 5 foreign languages, currently attended by 120 research students, as well as courses on technical English for both native and non-native speakers. Funding from trust funds and research grants enables almost all students to present their work at least once at international conferences during their studies, which improves their skills and networks.
Success of the students in academia and employment is underpinned by the quality of: the students, their research, and the DoEng programme. Many win prestigious awards, for instance:

- Andrew Jackson won the Institution of Civil Engineers (ICE) Graduate and Student Papers Competition in 2008 for his paper on jacked piles
- Sithamparanathan Sabesan won the Connected World category of the EPSRC ICT Pioneers Competition in 2011 for his work on real time location systems
- Prashant Kumar won the World Meteorological Organisation’s Young Researcher Bursary Award in 2009 for his work on street-scale modelling of nanoparticles.

Their work is often translated to industrial practice, for instance, Microsoft recruited Jamie Shotton, who used results from his PhD, published in a seminar paper with Cipolla, in the development of the Xbox 360 Kinect, which generated multi-billion dollars of new business.
96-97% of leavers each year during the REF period reported that they were in employment or study in the UoC Careers Office’s Destination of Leavers from Higher Education annual survey.

The last three annual reports have shown that 50-58% of those that gained employment did so in research and manufacturing (latest report for leavers in 2010/11).

Entrepreneurship engenders strong interest among academics, research staff and research students. The Researcher Development Programme described above gives basic training in protecting and commercialising inventions for research staff and research students. This is augmented by the work of Cambridge University Entrepreneurs (CUE), Cambridge University Technology Enterprise Club (CUTEC), the Judge Business School's Centre for Entrepreneurial Learning (CfEL), and CfEL's Enterprise Tuesday events, which offer talks, networking, training, coaching, etc. Cambridge Enterprise (CE), the UoC's wholly owned subsidiary for commercialising its discoveries, offers further advice and support (more information is presented in REF3a).

Together, these activities result not only in academics taking an active role in investorship and entrepreneurship, but also their research staff and research students:

- 21% of invention disclosures in the REF period include students among the inventors
- 46% of invention disclosures in the REF period include research staff among the inventors
- 42 research students have joined multi-disciplinary i-teams working with academics and experienced business mentors to investigate the commercial prospects of their inventions.

Facilities for research students are presented in the section on infrastructure.

d. Income, infrastructure and facilities

Income from research grants is driven by the research income strategy (section b). The drive for larger grants, industrial sponsors and diversification of funding sources is supported by the DoR who manages the Research Office. This office publicises calls for proposal in the weekly e-bulletin emailed to all staff and presented on the intranet. The DoR works with teams of academics to identify calls that are a particularly good fit with strategic themes, group plans and individual research interests, so that resources are given to the best opportunities. The Academic Committee plays an important role in supporting major applications to restricted calls. When a response involves several departments, then the DoR coordinates with the Pro-Vice-Chancellor (PVC) for Research and the UoC Research Strategy Office benefitting from their support.

The Research Office provides a full and expert service to PIs to ensure the compliance of proposals and costings with the sponsor's and the University's procedures. The DoR reviews all proposals to help refine them. Guidance and advice are also provided on the DoEng intranet. The DoR encourages academics to review each other's proposals and, when an interview is required, a mock interview is held. During this process, the DoR helps the PI consider connections and integration with the research of other PIs in DoEng and other departments.

This strategic drive for larger grants has influenced performance. The number of grant applications/proposals per year has fluctuated around an average of 220 per year during the REF period, but, in 2012, the total value of applications/proposals exceeded GBP140M, compared with less than GB50M in 2008. The proportion of total value attributed to applications/proposals of over GBP5M rose from 11% to 33% in the same period. 2012 may have been an exceptional year, but the underlying trend is clear and can be seen to continue in the year-to-date figures for 2013.

Turning to data for awarded grants, the total DoEng value of active grants in which funding is shared with other UoC departments rose from 5% of the DoEng total portfolio to over 25% during the REF period. The grant income data in REF4b from 2008/9 to 2012/13 shows that income from industry, commerce and public corporations has risen by 28% during the period to become 33% of total income, which is remarkable considering the effects of the economic downturn on the engineering sector. EC funding has increased by 68% to become nearly 13% of income. There was overall increase in DoEng income of 14% across the period (with a one year dip from this trend in 2009/10 caused by the end of some major projects and difficulties faced by some of our industrial sponsors). Growth is poised to surge as applications in 2012 have led to GBP65M of grant activations in 2012/13 compared to GBP32M in 2008/9.

The T4 theme has been instrumental in gathering, sharing and developing best practice in working with industry (see section b) and this work is closely aligned with the Researcher Development Programme and other training activities. The DoEng has worked closely with the PVC Research and the UoC Research Strategy Office to bring its industrial liaison practice to the SoT and the wider UoC. More information on industrial collaboration is given below.

As well as applying for grants in response to calls, the DoR helps academics identify and approach potential new industrial sponsors (see collaborations with industry). The Research Office disseminates research news and encourages dialogue, which builds the DoEng's profile and also

provides marketing material for approaches to companies. Two Marketing Officers released over 400 stories during the reporting period on the DoEng's news webpage (over 2 million hits in 2012 compared with approximately 1 million in 2008), twice yearly newsletter (distributed in hardcopy to over 17,000 external contacts), and email service for alerting journalists of new stories (over 100 subscribers). The DoEng Flickr site holds over 1600 images, which have gained over 240,000 hits since its creation in 2010. DoEng videos on the UoC's Youtube channel have received over 350,000 views. The DoEng team recently launched its own Youtube, Twitter, Facebook and LinkedIn accounts. Collaboration with the UoC's Communications Office has brought prominent coverage in the media, for example: BBC, Sky News, NBC News, Independent, Telegraph, Wired and many others including trade press.

Income from consulting and other professional services is supported by the DoEng because these services transfer research knowledge to industry and generate new research questions. The DoR and 2 academics are Enterprise Champions offering advice to staff about consulting, undertaking test work and providing training. The DoR also manages general enquiries to the DoEng requesting such services. Staff can elect to use CE for handling the necessary contracts, invoicing and insurance, or they can elect to make their own arrangements. During the REF period, CE executed approximately 40 consulting agreements per year for the DoEng, which had a contract value of approximately GBP750k per year of which approximately GBP100k per year was gift aided to the DoEng. In addition, the DoEng manages a wholly-owned subsidiary of the University, IfM Education and Consultancy Services Limited (ECS), which translates research, principally from RGe, but increasingly other RGs, into consultancy, executive education, events and publications. ECS staff and associates deliver these services with academic oversight. ECS's annual turnover during the period has risen from GBP2.3M to over GBP3.5M with ECS making the transition from needing grant support to being financially self-sustaining, gifting over GBP1.3M to the DoEng during the assessment period to fund future research. The figures above greatly underestimate total activity, as private consulting outside CE and ECS is not reported.

Income from donations is sought by the HoD, academics and the DoR in close partnership with the UoC's Development and Alumni Relations Office, diversifying income and funding projects that could not otherwise progress. Over GBP11M was pledged to support research during the REF period, including:

- Gatsby Charitable Foundation donated GBP5M in 2008/9 towards the new building for RGe, adding to the Reece Foundation's earlier pledge of GBP5M in 2007 before the REF period
- Laing O'Rourke donated GBP5M in 2010, in addition to sponsoring collaborative research, to establish the Centre for Advanced Construction, the Masters in Construction Engineering, a Professorship (first 10 years) and associated posts
- Dyson donated over GBP1.4M to support a Professorship in Fluid Mechanics (for 10 years) in 2012 and also funds collaborative research projects including over 4 studentships
- Mathworks and Qualcomm have provided unrestricted funds for 8 PhD studentships during the period and the Man Group has provided top-ups for 9 PhD students
- Evelyn Trust gave GBP0.2M in 2008 which combined with a private donation to create the new Lectureship in Engineering for Clinical Practice
- Kirby Laing Foundation gave GBP2M in 2011 to support a Professorship of Civil Engineering
- 2 donations totalling GBP1.2M funded 2 Sharjah Fellows for five years in 2009.

Other contributions to income include access to HECToR, the Research Council's High-End Computing Terascale Resource, using GBP2.5M worth of capacity during the REF period. In the process of research, development and technology transfer, the DoEng has gained access to a wide array of corporate research facilities, products, factories, infrastructure and operational data at no charge. Such in-kind benefits include running experiments on full-scale development rigs and the altitude test facility at Rolls-Royce, being supplied with experimental new materials for photonic and electronic devices from Dow Corning, undertaking vibration tests on rigs in Schlumberger's Paris facility, deploying sensor networks in tunnels owned by London Underground, and gaining access to data and operations in manufacturing and design.

Infrastructure and facilities have been improved during the REF period with an investment of over GBP23M: over GBP13M from UoC funds (including DoEng reserves, SRIF and CIF awards), GBP350k from industry and GBP10M from donations. The total area of research and office space increased by 650m^2 to over 30,000m^2 with over 3500m^2 newly built or refurbished. Plans for the next 5 years are given in section b. In addition, over GBP3.5M of UoC and CIF funding was

invested in equipment during the REF period. RG facilities are presented below.

RGa (energy, fluid mechanics and turbomachinery) has subsonic and supersonic wind-tunnels, large-scale rigs to investigate turbomachinery, and combustion and engine test rigs. Over the REF period, new rigs have been built and others significantly enhanced with investments of over GBP1.5M in diagnostic equipment for flow and combustion measurements. Highlights include:

- a new Energy Laboratory opened in 2012 for research into nano-particles, lean burn combustion, fluidised bed combustion and carbon capture processes, new mezzanine area and office refurbishments (GBP1.7M)
- two unique axial flow rigs, for studying unsteady flow effects in compressors and turbines, which are unique in having leakage and seal flows identical to those found in modern aero engines (TSB and Rolls Royce funding totalling USD1M)
- Graphical Processor Units worth GBP0.3M for CFD acceleration, which in 2009 gave unique capability, were donated by NVIDIA, when it selected the UoC as the first NVIDIA Centre of Excellence in Europe (a further GBP0.2M order for GPUs has been placed in July 2013)
- state-of-the-art computer-controlled force measurement system for the largest wind tunnel, which uses a six-component, sting-based force balance, and gives a complete characterisation of the aerodynamic loads on a wind-tunnel model (GBP80k)
- distinctive aerosol analysis capabilities for in-situ particle and emissions analysis built from 2011-2013 with industrial, Royal Society and EPSRC support (GBP0.2M).

RGb (electrical engineering) occupies approximately 4300m^2 of purpose-built space including 1400m^2 of clean rooms with class 10,000, 1000 and 100 areas. Facilities include advanced materials synthesis and device micro- and nano-fabrication equipment, and state-of-the-art materials, device and system analysis rigs. During the REF assessment period, over GBP7M of equipment has been purchased including:

- Bruker Dimension Icon atomic force microscope and accessories (GBP300k)
- FEI high-resolution scanning electron microscope (GBP600k)
- Agilent PNA microwave test engine together with impedance analyser, signal generator, oscilloscope, Fourier Transform Infrared spectrometer, VDI THz modules, etc. (GBP1.6M)
- Plasmaquest HiTUS sputter system for (GBP400k).

RGb won GBP13M from the EPSRC to fund a new Graphene Centre in 2013, which will be accessible to all researchers in the UK working on Graphene and related research. GBP8M of the budget is for equipment. GBP2M has been spent in the REF period and negotiations are under way to spend the remaining GBP6M.

RGc (mechanical engineering, materials and design) occupies teaching and research laboratories with a total floor area of approximately 2500m^2. Facilities range from those for testing the dynamics of heavy goods vehicles to those for micro-electromechanical systems and cellular biomechanics. During the REF period, investments have included:

- building a series of computer-controlled and instrumented heavy good vehicles in collaboration with industrial partners for tests (GBP0.3M plus donated equipment)
- refitting and upgrading the materials testing and characterisation laboratories, which included commissioning a new Zeiss Evo LS15 Scanning Electron Microscope, a Hysitron UBI Nanoindenter, a PerkinElmer Spectrum 100 FTIR Spectrometer with ATR and an X-TEC HMX X-ray machine (total cost of approximately GBP1M)
- re-siting the DoEng superconductivity facilities, including a Quantum Design MPMS-XL Squid, Oxford Instruments 7T and 9T magnets, LabSYS evo-calorimetry system capable of DTA, TGA and DSC at temperatures up to 1600^{o}C (GBP300k in the REF period)
- completing the dedicated Bioengineering Laboratory to Class 2 biosafety standards with full cell/tissue culture facilities and optical microscopy (GBP60k in the REF period).

RGd (civil engineering) occupies a total of 4800m^2 of space including the Schofield Centre for Geotechnical and Construction Process Modelling (1100m^2). The Schofield Centre contains the 10m Beam Geotechnical Centrifuge and many other testing facilities. The Structures Laboratories contain large-scale test equipment with capacities ranging up to 5000kN in compression. During the REF period, refurbishment has been completed and new equipment purchased including:

- new geomechanics laboratories and offices for the IKC in Smart Infrastructure (GBP830k)
- new servo-controlled 2-axis actuators for simulating a range of civil engineering operations and a new servo-hydraulic shaking table for the 10m beam centrifuge, following a 2-year

GBP400k programme of refurbishment and upgrade, which completed in March 2008
- Spotlight 200 FTIR Microscope (GBP64k)
- Structures Laboratory datalogging equipment (GBP77k).

RGe (manufacturing and management) – occupies a 3200m^2 building, purpose-built in 2009, which includes modern accommodation for researchers and 870m^2 of laboratory space, dedicated mainly to research on industrial automation, industrial photonics and inkjet technology. During the assessment period, the following investments were made in research capability:
- full rebuilding and upgrading of manufacturing conveyor system equipped with robots, turntables, assembly and test cells and a 5-axis Mazak machining centre, instrumented with RFID readers, PLCs and vision systems (total GBP250k)
- new laser processing laboratories housing high-power modern industrial lasers, including ultrafast fibre laser facilities, ranging from 20W to 4kW (total GBP420k)
- holography suite for photonics processing (total GBP140k)
- new nanofabrication laboratories housing thin film device preparation, optical and electron metrology and laser beam diagnostics, with new Focused Ion Beam machine (GBP250k)
- new laboratories for high-speed imaging and diagnostic techniques for inkjet research including micro-PIV and high-speed holography, as well as facilities for lab-scale inkjet printing, including new instrumentation (total GBP400k).

RGf (information engineering) is mainly engaged in computational modelling with very substantial computing resources (see below) and it does not typically host its own experimental rigs, but, instead, collaborates with others to gain access to specialised facilities (e.g. engine cells in the Energy Group and 'wet-labs' in the Departments of Plant Sciences and Genetics). Nevertheless, it does have a sensorimotor research laboratory equipped with virtual reality systems with state-of-the-art robotic interfaces, medical imaging facilities and acoustic rooms. The group's Fallside Machine Intelligence and Signal Processing laboratories were refurbished with upgraded networks, new offices and new experimental space during the REF period.

Equipment sharing is encouraged and facilitated. The UoC committed to the Science and Engineering South Equipment Sharing Project, which started in 2011 with RCUK funding, to develop a database and share equipment across the UoC and its partners (UCL, Imperial, Oxford and Southampton). The UoC database holds details of over 1800 items of equipment.

Technical support is provided by over 70 technicians, electrical engineers and mechanical design engineers. The team can design and manufacture major test rigs, for example, the RGa flow rigs and RGd centrifuge actuators/tables described above.

Computing support is provided by 11 computer officers and 6 technicians supporting the DoEng computing infrastructure and a further 10 computer officers in the RGs giving direct support to academic activities. The DoEng manages a central server room, set up as a Small Research Facility (SRF) in 2010 for intensive research computing with 26 racks available for RG use. The current total value of equipment in the SRF is approximately GBP1.5M of which almost all was purchased in the REF period. The DoEng centrally maintains the network infrastructure, core file server, web servers and various other essential infrastructure services. This represents an investment of about GBP1M and again the majority of this was made in the REF period. In addition, approximately GBP1.5M per year is spent on a wide variety of computing equipment (e.g. workstations and clusters), peripherals (e.g. printers and scanners) and software distributed across the DoEng and its RGs. The DoEng also made extensive use of the UoC High Performance Computing service throughout the REF period, during which time it has maintained its position as one of the leading facilities in the UK. In June 2012, following an upgrade, the system achieved a sustained Linpack performance of 183.379 TFlops (90.6% of peak) making it the fastest (publicly disclosed) x86_64 cluster in the UK. A new facility was commissioned in August 2013 maintaining its leading position.

Over 90 administrative staff are also provided across the DoEng to support academics.

General facilities for staff and students include access to a central common room offering hot drinks, sandwiches, free newspapers, and magazines related to science, technology and education. Common rooms are also available in the laboratories on the West Cambridge Site. They provide good opportunities for academics, staff, students, technicians and administrators to mix and share ideas. Staff and students can also use the social spaces and sport facilities provided by colleges and UoC centrally e.g. the University Centre by the River Cam and the GBP16M Cambridge Sports Centre on the West Cambridge Site (phase 1 completed in 2013).

All staff and students also have access to the DoEng library, which provides engineering research literature from world sources; advises on the use of online resources and other UoC libraries; uses national and international library lending and copying services to provide literature which cannot be obtained from local or online sources. The central UoC library is a copyright library that is open to all staff and students.The UoC spends over GBP4M/y on online journals, mostly technical, and a similar sum on hardcopy and other resources.
The UoC also provides a subsidised bus service linking all its facilities across the city.

e. Collaboration or contribution to the discipline or research base

Collaborations with other disciplines are essential given the DoEng strategic aim to "address major challenges and develop complete solutions" and its 4 multidisciplinary strategic themes (section b). The DoEng theme leaders have forged strategic links with other disciplines:

- Architecture, Computer Lab, and Land Economy were all represented in the offsite event to develop the T1 theme in 2011
- the T2 theme has brought together academics from the DoEng with those in Philosophy, Architecture, the Judge Business School, the Statistics and the Computer Laboratory
- partners in the Schools of Clinical Medicine and Biological Sciences are established collaborators with DoEng under T3 and the DoEng provides pump priming for collaborations
- T4 has been funded by the UoC to support academics across the School of Technology.

The DoEng is strongly committed to multi-school networks organised by the UoC such as:

- Ghahramani, Lengyel, Rasmussen and Wolpert (RGf and T3) are all members of the UoC Cambridge Neuroscience Strategic Initiative and Wolpert was the Co-Chair (2011-2012)
- Singh is our leading member of the Cambridge Statistics Initiative
- Byrne, Cipolla, Gales, Woodland and Young are members of the Cambridge Language Sciences Strategic Initiative and Woodland sits on the Initiative's Steering Committee
- Treece leads the Biomedical Engineering topic within the theme T3 and is a founding member of the Engineering for Clinical Practice initiative between the Engineering Department and the Clinical School (2008-). He is also on the steering committee for the Cambridge Cancer Centre Strategic Initiative (2011-) and was involved in the recently successful bid for a Cambridge-Manchester Cancer Imaging Centre (2013-)
- Clarkson is the Deputy Chair of the Public Health @ Cambridge strategic network which was launched in 2013 and involves all six schools of the UoC
- Allwood, Amarantunga, Collings, and Hochgreb are champions for the Energy @ Cambridge Strategic Initiative (established in 2010), Dowling is on its Strategic Advisory Board and 70 DoEng Principal Investigators (PIs) are members of the initiative, closely linking to T1.

The DoEng fosters interdisciplinary academic collaborations among its groups and with other UoC departments through an extensive programme of approximately 300 seminars per year.

Collaborations with other leading institutions are also encouraged, given the DoEng strategic aim to be "an international hub for engineering excellence", with the DoR helping to put memoranda of understanding in place with other institutions when appropriate. Over 20 agreements have been signed during the assessment period with leading organisations outside the UK, for example, with the universities of Keio, Nanyang and Tsinghua. The DoEng supports many other international academic partnerships on specific projects, for example:

- Pullan (RGa) accepted a Visiting Associate Professorship at MIT in 2011 to collaborate with MIT's Gas Turbine Laboratory. Their work won the ASME Best Compressor Paper prize in 2012 and continues with funding from Mitsubishi Heavy Industries held by the DoEng
- Amaratunga (RGb) was appointed as the Tan Chin Tuan Centennial Professor at Nanyang Technical University (NTU), Singapore in 2012 and was a leading member of the UoC team that worked with Singapore's National Science Foundation to set up the CREATE and Cambridge Centre for Carbon Reduction in Chemical Technology (C4T) along with NTU and the National University of Singapore.
- Deshpande (RGc) was formally elected to be a Visiting Professor at the Eindhoven University of Technology in 2009 and M2i (formally known as the Netherlands Institute of Metals Research) has funded 2 PhD students at the DoEng since 2008. The collaboration at Eindhoven has been extended to include McShane (RGc) during the REF period
- Allwood (RGd) is the Cambridge Director of the Tsinghua-MIT- Cambridge Low Carbon Energy Alliance, which has involved Scott (RGa), Soga (RGd) and others in collaborations

- Throughout the REF period, McFarlane (RGe) has been Research Director at Cambridge of the Auto ID Labs, which is a collaboration between MIT, Cambridge, KAIST, ETH Zurich, Keio, Shanghai and Adelaide. The research on RFID, automated identification and "Internet of Things" solutions is funded by GS1, the body that coordinates standards in this field
- The Speech Group led by Woodland (RGf) have distinguished themselves by holding major grants on US DARPA funded programmes via Raytheon BBN Technologies and IBM, which have involved collaboration with Colorado, Columbia, John Hopkins, MIT, Pennsylvania, Stanford and many others. The grants include DARPA GALE (2005-2011) and DARPA BOLT (2011-2016). The contract value of these two grants alone total GBP5.6M for the DoEng.

Collaborations include those with other leading UK institutions. EPSRC Programme Grants have created new partnerships and reinforced existing ones, with HoD and DoR support, for instance:

- Innovation in industrial inkjet technology (I4T) led by DoEng with UoC Departments of Chemistry and Applied Mathematics plus Durham and Leeds (DoEng budget 1.9M awarded in 2009 involving RGe)
- Control for energy and sustainability led by Imperial College (DoEng budget GBP2.2M awarded in 2009 involving RGf under T1 and T2)
- Natural speech technology with Edinburgh (lead) and Sheffield (DoEng budget GBP1.9M awarded in 2011 involving RGf under T2)
- INTelligent Energy awaRe NETworks (INTERNET) with Leeds (lead) and the UoC Computer Laboratory (DoEng budget GBP1.7M awarded in 2010 involving RGb)
- Ultra-parallel visible light communications (UP-VLC) with Strathclyde (lead), Edinburgh, St Andrews and Oxford (DoEng budget GBP0.8M awarded in 2012 involving RGb)
- Engineering Nonlinearity with Bristol (lead), Swansea, Sheffield and Southampton (DoEng budget GBP0.7M awarded in 2012 involving RGc under T2)
- Centre for Sustainable Road Freight Transport led by DoEng with Herriot-Watt (DoEng budget GBP4.5M awarded in 2012 involving RGa, RGc, and RGf under T1).

Ferrari (RGb) is the Director of the Cambridge Graphene Centre, which has many links to other institutions. In 2013, Ferrari (RGb) and Hofmann (RGb), as PIs, won three EPSRC grants from the Graphene Engineering call, totalling over GBP12M, in collaboration with the UoC Department of Chemistry, UoC Cavendish Laboratory and Queen Mary University of London. Ferrari (RGb) with the universities of Lancaster and Manchester (Graphene National Institute) won the ERC Synergy Grant Hetero2D for GBP11M (DoEng share GBP4.5M) in 2013. In addition, Ferrari (RGb) leads for the UoC, as one of nine core partners in the EC Graphene Flagship project, which is coordinated by Chalmers University of Technology in Sweden and includes Manchester and Lancaster in the UK, the European Science Foundation, AMO GmbH, Nokia and others. The total budget is EUR1B of which EUR54M has been released for the first 30 months since its 2013 launch. There are many other partners outside the core with 126 research groups involved across 17 countries. Industrial partners for this Centre are presented in the next section.

These formal arrangements are greatly outnumbered by long-term informal relationships between individuals, which involve distinguished academics coming to the DoEng for extended visits. There were over 1000 visits per year by researchers staying for one month or more during the REF period. These visits were generally associated with reciprocal visits. The DoEng won 7 RAEng Distinguished Visiting Fellowships in the REF period.

Collaborations with industry have been refreshed and extended in the strategic drive to diversify income (research income strategy in section b and income from research grants in section d). Methods for fostering collaborations have been studied and developed under the T4 theme described in the strategy section. Within this theme, DoEng secured 3 concurrent RAEng Visiting Professors of Innovation to guide teaching, training, research and practice in this area based on their industrial experience: Mitchell (ex-Philips and Domino Printing Sciences); Knook (ex-Vodafone) and Beale (ex-Rolls-Royce). The DoR manages a directory of over 90 company relationships providing support to the academic leads assigned to each company. A selection of major relationships is presented below:

- the University Gas Turbine Partnership (UGTP) is a rolling five-year agreement with Rolls-Royce, which provides half of the GBP3.4M annual funding for 80 research projects and over 75 research students and post-doctoral research associates, as well as supporting academic staff (2 professors and 2 lecturers) in RGa. The matching funding comes from the EPSRC,

TSB and EU. The UGTP builds on a longstanding collaboration covering turbomachinery aerodynamics, noise and vibration, combustion, heat transfer and advanced cycles under T1. During the assessment period, research from the UGTP won over 13 best paper awards and The Engineer 2009 Technology and Innovation Award for the Environment for the FlowTool computational simulator. The UGTP employs formal processes for technology and people transfers. Successful transfers of research results during the period include: SPINTHIR code for predicting ignition probability maps; validated combustion models for non-premixed and partially premixed combustion incorporated; methodology to characterise in-service blade deterioration and performance applied to the Trent 700 compressor; improved understanding of turbine blade film cooling and loss mechanisms; and novel turbine rim seals being tested for incorporation into Trent XWB. The collaboration has also operated at the strategic level during the REF period with DoEng academics across 3 RGs serving on 3 of the 4 Technology Advisory Boards that report to the executive members of the RR Board: Amaratunga (Electrical Systems), Dawes and Dowling (Propulsion and Power Systems) and Fleck (Materials, Manufacturing and Structures), who has chaired his Board since 2011

- in 2008, Mitsubishi Heavy Industry (MHI) and the DoEng began a Strategic Research Initiative and research activity increased dramatically. MHI now funds 2 full-time University Lecturers in turbomachinery, a College Fellow at Girton College and 14 research projects. The range of research has also increased from turbomachinery aerodynamics to combustion, noise, materials and finite element modelling, involving a range of academics across RGa and RGc in theme T1. The contract value of the grants associated with these activities is now GBP5.3M. In 2010/11, MHI provided GBP350k toward the GBP1.1M project to extend the laboratory and office space at the Whittle Laboratory. In 2012, work by MHI, MIT and Cambridge on the origins of compressor stall won the ASME Best Compressor Paper prize
- during the REF period, Schlumberger has funded a sequence of research projects, with a total contract value over GBP1M, in: drill string dynamics and active control; impact dynamics of the bottom hole assembly; uncertainties in the analysis of impact dynamics; and control of the drilling process. Schlumberger is also currently participating in a project funded primarily by the EPSRC on the theme of Autonomous Intelligent Systems (contract value of GBP850K). The projects draw on expertise from two research groups (RGc and RGf) and interface with theme T2. Successes include significant enhancements in the ability to detect, predict, model and design around potentially damaging dynamic events downhole during drilling, and assessments of possible drilling control strategies to avoid such events
- the DoEng has a longstanding relationship with Jaguar Land Rover (JLR). During the REF period, there have been collaborations on: tyre vibration; friction joining of dissimilar alloys; simulation, knowledge mining and abstraction, and minimising energy use in materials. The total contract value of these projects is approximately GBP300k and they involved RGa, RGc, RGd and T1. The DoEng led a one-day workshop in 2010 and follow-up activities built stronger links. JLR became a member of the CAPE Consortium (see below) in April 2011 connecting to RGb. New work has started on composites and driver interaction.

There are many more examples of such relationships with industry including: Boeing, CrossRail, Dyson, Laing O'Rourke, McLaren, Nokia and Toshiba.

Most of our industrial sponsors support studentships within funded projects, but some have been exceptionally generous in giving donations for studentship schemes, for example, gifts from Mathworks and Qualcomm for research studentships were described in section D under "Income from donations". Many of our most trusted partners also grant excellent access to their facilities and examples are given in section d under "Other contributions to income".

EPSRC Integrated Knowledge Centres (IKCs) and Centres for Innovative Manufacture (CIMs) have provided an good way of bringing industry and university research together, for example:

- the Cambridge Integrated Knowledge Centre (CIKC) in advanced manufacturing technologies for photonics and electronics exploiting molecular and macromolecular materials was led by DoEng RGb, with UoC collaborators RGe, Cavendish Laboratory and Judge Business School. The 6-year grant started in 2007 with GBP6.7M EPSRC funding and nearly GBP7M of cash and in-kind contributions from industry. From 2008, the CIKC: developed a portfolio of 6 device platforms from which 42 commercially focussed projects were developed in cooperation with 81 industry partners; facilitated the formation of 4 start-up companies; generated 23 patent applications; supported 237 young researchers with training in entrepreneurship skills. CIKC

also played an important role in policy issues, such as the plans for Catapult Centres

- DoEng RGb won funding for the new EPSRC Centre for Innovative Manufacturing in Large-Area Electronics, with the UoC Cavendish Laboratory (Physics), Swansea, Imperial, and Manchester. The award was announced in February 2013 with a total budget of GBP5.6M and the grant scheduled to start on 1st October 2013. It builds on the CIKC success
- in 2011, DoEng RGd won a GBP9.5M EPSRC IKC grant, plus GBP7M in industrial support, for the Centre for Smart Infrastructure and Construction (CSIC), in collaboration with RGe, RGf and the UoC's Computer Laboratory and Department of Architecture. It aims to use advanced sensor networks to understand the performance of built assets. The Centre has over 40 industry partners including all levels of the construction industry supply chain: (a) UK's leading consultants and contractors (e.g. Arup, Atkins, Mott MacDonald, Halcrow); (b) UK largest infrastructure asset owners and operators (e.g. Crossrail, Transport for London, Humber Bridge); and (c) leading technology providers (e.g. Toshiba, IBM, Thales). In 2013, the CIKC had achieved 39 field demonstrations and case studies
- the Centre for Innovative Manufacturing in Industrial Sustainability started in 2011 and aims to rapidly reduce the resource and energy-intensity in the production of goods. DoEng RGe leads the GBP5.2M grant with academic partners at Cranfield, Loughborough and Imperial College. There are 9 industrial partners including Toyota and Unilever
- O'Neill (RGe) is a Co-Investigator in the Heriot-Watt-led Centre for Innovative Manufacturing in Laser-based Production Processes that started in 2013 with academic partners Cranfield, Liverpool and Manchester, and 20 industrial partners including EADS Airbus and GE Aviation
- Gregory (RGe) is a Co-Investigator in the Strathclyde-led Centre for Innovative Manufacturing for Continuous Manufacturing and Crystallisation with academic partners Bath, Edinburgh, Loughborough, Heriot-Watt and Glasgow, and 10 companies
- DoEng academics from RGb and RGe are Co-Investigators in the Cranfield-led Centre for Innovative Manufacturing in Ultra Precision that started in 2013 with 7 industrial partners.

The Cambridge Graphene Centre was described earlier. It features a high-level of industrial collaboration. Industrial support declared in the EPSRC projects alone is worth GBP13M from over 20 partners, including DuPont, Johnson Matthey, Nokia, Dyson, Plastic Logic, Philips and BAE Systems. Nokia and AMO are among the nine core partners for the EC Graphene Flagship project, but there are over 70 other industrial members of the wider consortium such as BASF, Hitachi Europe, ST Microelectronics and Thales.

Industry clubs generate ideas, projects and funding. The DoEng provides encouragement and support, including mechanisms for funding research by subscription. Examples include:

- the Cambridge Vehicle Dynamics Consortium is a DoEng partnership of 14 companies (including Volvo Trucks, Firestone, Haldex, and Goodyear), which develops safer, more fuel efficient and more 'road-friendly' heavy vehicles. Company subscriptions are enhanced by EPSRC and Isaac Newton Trust funding and yield a total of GBP200-300k annually. In the last 5 years, 4 patent applications have resulted from the research and agreements have been signed with 2 of the member companies to exploit research outputs
- the Cambridge Service Alliance was founded in 2010 by Neely (RGe) to research new ways to provide, implement and employ complex service systems. The consortium members are BAESystems, IBM, Caterpillar, and Pearson. The income is approximately GBP1M/y. In parallel, the GBP2.2M EPSRC-funded KT-Box grant led by Neely, developed practical tools for industry in partnership with: the Universities of Bath, Cranfield, Exeter, Nottingham and Warwick; and the companies BAE Systems, Bombardier, IBM and Rolls-Royce (2009-12)
- RGe formed consortium of aerospace organisations in 2008 comprising Boeing, BAA, Manchester Airport, Easy Jet, Fly Be, SITA and IATA to research airport operations, which led to ongoing research with Boeing (contract value GBP500k), research at Heathrow Airport (GBP200k) and involvement in independently overseeing trials at Heathrow (2011-2013)
- RGb created the Centre for Advanced Photonics and Electronics (CAPE) in 2004 as a strategic partnership of companies with DoEng to set industry agendas for the convergence of photonics and electronics and undertake the necessary research. The current CAPE partners are Dow Corning, Jaguar Land Rover and Disney with Carl Zeiss as an associate. Successes include developing practical holographic projectors and Smectic A bistable display technology suitable for the mass market.

The DoEng embeds companies on its premises to incubate new companies and develop relationships with established ones, for instance, in addition to the examples given in the REF3a:

- one of Dow Corning's engineers works alongside research staff and students in the DoEng, and has done for ten years, playing a key role in the CAPE consortium (described above)
- RedBite is a spin-off company which has placed 2-3 engineers in the DoEng over the last 5 years, while technology is trialled and transferred (Wind Technologies, Magnifye, Cambridge Flow Solutions and others have also incubated in the DoEng during the REF period).

In addition to collaborating with companies through research, the DoEng and its wholly-owned subsidiary, ECS, work with a wide spectrum of companies by providing consulting and other professional services (see section d). Some of these services are particularly focussed on helping smaller companies. ECS manage ideaSpace, which is a hub for early stage innovation, providing space and resources to a community of innovators and entrepreneurs. It was set up in December 2010 with GBP2M funding. Over 100 members use the ideaSpace facilities on the UoC's West Cambridge site and a second site opened in Cambridge city centre in May 2013 with 30 members. ECS has also worked on over 500 projects with small and medium size manufacturers during the period to develop their strategies and capabilities using the results of DoEng research.

Collaborations outside industry and academia are important to realise the DoEng strategic aim of developing "complete solutions" (section b). Such collaborations include collaborative research grants won during the REF period sponsored by DSTL (GBP300k), US Office of Naval Research (GBP1M), and US DARPA (GBP3.7M). They also include the DoEng work with the UoC Centre for Science and Policy described in the REF3a, advisory roles of DoEng academics in government bodies as described in the final section, and projects undertaken by ECS to apply DoEng research to government strategy. Examples of relevant ECS assignments in the REF period include working with the Technology Strategy Board (TSB) on the High-Value Manufacturing Landscape that informed the development of plans for the Catapult Centres.

The collaborations with industry, academia and government bodies described above not only create excellent research projects, but are also used by the DoEng to inform its strategy. This is exemplified by use of the DoEng International Visiting Committee described in section b.

Contributions to the discipline of Engineering by the DoEng are evidenced below and in line with the strategic aim to be an "international hub for engineering excellence" (section b). The figures are based on returns made by DoEng researchers and are a lower bound of total activity.

In July 2013, current DoEng researchers hold 108 elected fellowships (40 newly elected in the REF period) of learned societies and professional institutions, which give evidence of good engagement with their discipline. For example, these fellowships include: 9 (2 new) Fellows of the Royal Society (FRS), 26 (11 new) Fellows of the RAEng (FREng), 5 (2 new) Fellows of the Royal Aeronautical Society (FRAeS), 19 (7 new) Fellows of the Institution of Engineering and Technology (FIET), 12 (3 new) Fellows of the Institute of Physics (FInstP), 6 (1 new) Fellows of the Institution of Mechanical Engineers (FIMechE), and 3 (1 new) Fellows of the Institution of Civil Engineers (FICE). The total includes elections to overseas bodies, for example, 2 (1 new) Foreign Associate Members of the US National Academy of Engineering, 3 (2 new) Fellow of the Academia Europea, 1 (new) Fellow of the American Institute of Aeronautics and Astronautics, 1 (new) Associate Member of the Royal Academy of Belgium, and 10 (6 new) Fellows of the Institute of Electrical and Electronics Engineers (FIEEE). The DoEng has 57 Chartered Engineers, Physicists and Mathematicians.

DoEng researchers helped such bodies as those listed above, together with research councils, trade associations and similar, by serving on 400 committee posts during the REF period. 318 were new positions for the researchers. Highlights include: Dowling on the Royal Society Council (2009-10); Amaratunga (2011-), Mair (as Senior Vice-President 2008-11) and Gregory (2013-) on the Council of the RAEng; Williams on the Awards Committee of the RAEng (2010-13); Clarkson on the Policy Committee of the RAEng (2013-), Welland on EPSRC Council (2008-12); White on the EPSRC Strategic Advisory Network (2011-); Juniper (2011-), O'Neill (2012-) and Prager on EPSRC Strategic Advisory Teams (2008-); MacKay on the RCUK Energy Programme Scientific Advisory Committee (2010-13); Wolpert on a Wellcome Trust Expert Review Group (2010-); and Dowling on the European Research Council Identification Committee (2010-12).

Researchers also help government by holding positions as advisors, for example: Dowling is a member of the UK Home Office Science Advisory Committee (2011-); Gregory is a member of the UK Government's Ministerial (now Analytical) Advisory Group on Manufacturing (2009-); Kelly was Chief Scientific Advisor for the Department of Communities and Local Government (2006-2009);

MacKay is Chief Scientific Advisor in the UK Department of Energy and Climate Change (2009-) and served on the World Economic Forum Global Agenda Council on Climate Change (2008-2009); and Welland was Chief Scientific Advisor in the UK Ministry of Defence (2008-11). Details on the DoEng engagement with the UoC Centre for Science and Policy and its visiting fellows from politics, the civil service and industry are given in the REF3a.

DoEng researchers contributed to the process and quality of academic publication by holding 22 positions as Editor/Editor-in-chief and 86 as members on editorial boards during the REF period. Evidence of leadership is provided by the researchers having been invited to give 95 plenary addresses and 83 keynote speeches during the REF period, including: Bolton gave the British Geotechnical Association Rankine Lecture in 2012; Ferrari gave the plenary address at the IEEE Photonics Conference in Arlington, Virginia in 2011; MacKay gave the Clifford Paterson Lecture at the Royal Society in 2010; and Wolpert gave the Fred Kavli Distinguished International Scientist Lecture at the Society for Neuroscience in Chicago in 2009.

Contributions to the discipline were recognised with 164 honours, prizes and awards to DoEng researchers during the REF period. Examples include:

- Dowling was listed among BBC Radio 4's top 100 most powerful women in the UK (2013), won the UKRC/WISE Woman of Outstanding Achievement Award for Inspiration and Leadership in the academia and research category (2011) and was listed in The Times' Eureka 100 for the most important people in British science (2010)
- Fleck won the ASME Koiter medal for International Leadership in Mechanics (2013) and the Humboldt Research Award (2011)
- Gregory awarded a Knighthood (2011)
- MacKay was listed in The Times's 100 most important UK Scientists (2010), won Royal Society Clifford Paterson Prize (2010) and won the Energy Institute Melchett Award (2013)
- Mair awarded a CBE (2010) and Singapore Public Service Medal (2011)
- Smith won the Institute of Measurement and Control Sir Harold Hartley Medal (2009)
- Travis (2008) and Udrea (2012) won RAEng Silver Medals
- Welland awarded a Knighthood (2011), Gold Medal of the US Department of Energy (2011) and US Secretary of State of Defense's Award for Exceptional Public Service (2011)
- White won the IEEE Photonics Society Aron Kressel Award (2011)
- Wolpert won the Minerva Foundation Golden Brain Award (2010)
- Young (Steve) won the EURASIP Individual Technical Achievement Award (2013) and the International Speech Association Medal for Scientific Achievement (2010).

The DoEng also wins prizes as an institution for its leadership role in the discipline, for instance, it won the Elektra (European Electronics Industry Award) for best Electrical/Electronic Engineering Department of the Year (2011).

Academics have written books addressing issues of significant policy and public interest, which also increase understanding of the engineer's role in society:

- "Sustainable Energy – Without the Hot Air" by Mackay (2008) was described as *"this year's must-read book about tackling our future energy needs"* by the Guardian (2009). It broke into the top 60 bestsellers list on Amazon.co.uk. It has been translated into eight languages. It inspired DECC's 2050 Calculator for UK energy policy makers. 2050 Calculators have since been developed for China, Korea, Portugal and Belgium.
- "Sustainable Materials: with both eyes open" by Allwood and Cullen (2011) sold over 1000 hardcopies and more than 4000 readers have read the free copy online. New Scientist's review (2011) stated that *"…for policy-makers trying to cut emissions, and anyone in manufacturing, it should be required reading."*

Researchers also help the discipline by generating public interest in engineering:

- Wolpert gave a TED Global Lecture achieving over 800,000 views (2011) and MacKay and Minshall have given TEDx lectures (2012)
- Dowling and Mair were the subject of programmes dedicated to exploring their lives as engineers in the Radio 4 series, "The Life Scientific" (2012 and 2013, respectively)
- Hunt (Hugh) has featured regularly on television explaining engineering and, together with Windfall Films, won the Royal Television Society (RTS) award for the best history programme for their documentary, "Dambusters: Building The Bouncing Bomb" (2011).