Institution: University of Nottingham

Unit of Assessment: UoA 15 General Engineering

Overview In August 2008 a new fully integrated Engineering Faculty was launched at Nottingham which merged the previous four Schools of Engineering. As a single budgetary unit led by an Executive Dean, this structure enables better strategic planning at Faculty level, facilitates a more multi-disciplinary approach to research activities (including development of critical mass in key areas), provides fully integrated Faculty-wide support services, and offers robust career paths for all staff groups. Research in Engineering at Nottingham is now organised into highly multi-disciplinary thematic research divisions, each comprising a number of related research groups. Through this change process we have removed significant discipline barriers, created critical mass in key research areas, and have become more aligned with strategies of our key stakeholders. In 2009, the School of Architecture and Built Environment joined the Faculty and their research has now been successfully integrated. These groups are returned for REF2014 under UoA16. Table 1 presents our research structure including those research groups covered under this submission.

Division Name	Research Groups
Electrical Systems & Optics	Applied Optics; George Green Institute for Electromagnetic Research; Power Electronics, Machines and Control.
Energy & Sustainability	Fossil Energy and Carbon Capture and Storage; Thermo-Fluid Mechanics; Industrial Microwave Processing.
Infrastructure, Geomatics & Architecture	Nottingham Geospatial Institute; Nottingham Transport Engineering Centre; Human Factors.
Manufacturing & Process Technologies	Advanced Manufacturing Technology; Additive Manufacturing and 3D Printing; Bio-renewables and Bio-Processing; Fluid and Particle Processes.
Materials, Mechanics & Structures	Advanced Materials; Nottingham Centre for Geomechanics; Polymer Composites; Structural Integrity, Dynamics and Bio-Engineering.

Table 1. Current Research Structure in the Faculty of Engineering. Note this table does not include groups from Architecture and Built Environment being returned under UoA16.

b. Research strategy Upon formation of the Faculty, a new comprehensive whole Faculty research strategy was developed. Led by the Associate Dean for Research and reporting to Faculty Research Committee, a representative task-force comprising academic, research and technical staff prepared a series of evidence papers to inform the process. These covered the "External Landscape" including the strategies of United Kingdom (UK) Research Councils, European Union (EU) and major charities, RAE 2008, knowledge transfer (KT) and business development, interdisciplinary research and the international and industrial landscape. Consultation on our draft strategy across the Institution and with key external stakeholders provided valuable feedback to improve its focus and it was implemented in September 2009. Our vision is one of research excellence and to be an international leader in our areas of expertise. We achieve this through:

- Multi-disciplinary teams delivering worldwide impact through fundamental and applied research;
- Inspired people who achieve success in a vibrant and supportive community;
- Providing an exceptional research environment;
- Building and sustaining momentum through targeted investment in strategic areas.

To support our vision a number of specific aims were developed, each containing a series of

operational objectives which are described in more detail below:

- *Aim 1*: Recruit and support exceptional people
- *Aim 2*: Work in partnership with key stakeholders for mutual advantage
- *Aim 3*: Invest strategically in our unique environment
- *Aim 4*: Maximise the impact of our innovation for all stakeholders

There are 3 main operational objectives under Aim 1; supporting and developing every person to do their best; supporting research fellows to offer career development opportunities and maximise their impact; recruit the most gifted PhD students internationally and from the UK. Delivery of Aim 2 is focused around being proactive in engagement with stakeholders; maximising our impact through strategic partnership with industry and academia, and implementing an outreach strategy to fully engage with the local community and wider society. Aim 3 has seen us identify and support key infrastructure and facilities which are accessible by all researchers and optimise our environment to deliver real value from interactions. Delivery of Aim 4 has led to scoping our future research growth areas in order to meet the medium and long term needs of industry through new engineering science and technology and it has also seen us recognise, celebrate and reward our successes. Each Division has a Head, responsible for all aspects of research delivery in their division and for providing strategic and operational leadership to staff in their area. Our divisions are also strongly aligned with University research priorities. Engineering leads University priorities in Aerospace, Advanced Manufacturing and Energy and is a major partner in Biomedical Imaging, Sustainable Chemical and Biological Processing and Operations in a Digital World. Each of our research groups has been supported in the development of their own research strategy which is directly based on the aims and operational objectives described in the previous paragraph. Therefore, whilst each individual group has its own strategy, each is consistent with the overall values and research strategy of the Unit. A summary of those strategies is provided under the description of activities provided below.

Key progress against Research Group priorities, goals since RAE 2008 and future research vision are summarised below:

Electrical Systems and Optics Division

Power Electronics Machines and Control Group (PEMC) – Head of Group Prof J Clare

Strategic Aims for Research During the Period The PEMC Group spans all key power electronics disciplines from power device and component technology to complete power conversion systems. Key strategic developments since RAE 2008 have been based around development of staff critical mass (2008: 3 Prof, 3 Ass. Prof, 2 Lect.), (2013: 5 Prof, 3 Ass. Prof, 3 Lect. and researchers and PhD students increased by ~30%), engagement with industry and development of facilities. Specific exemplars of activities are provided. The Group has expanded activities in Power Device Research with the appointment of Castellazzi (2008), which consolidated the Professorial appointment of Johnson in 2006, generating a portfolio of research worth ~£7.3M in power device technology. Expansion of the activities in Electrical Machines following the appointment of Gerada in 2008 (promoted to Chair in 2013) have seen the award of a RAEng Senior Fellowship (£162K), two new industrial innovation centres in Electrical Machines (£1.61M total) and a total portfolio of Electrical Machines research of £2.7M. The PEMC group has played a pivotal role in establishing the EPSRC National Centre for “Underpinning Technologies in Power Electronics” (EP/I013636/1, £4.7M to UoN) which was announced in March 2013. The Centre has its hub at Nottingham and brings together the 6 leading UK groups in this area. An EPSRC large capital equipment award (EP/K005138/1, £2.76M) for equipment to underpin power electronics research was awarded in 2013. **Strategic Plans:** Over the next 5 years key aims include the delivery of the hub (including appointment of several new academic staff) for the EPSRC National Centre and to play a lead role in establishing it as the internationally recognised centre of excellence for power electronics research in the UK; seeking new strategic partners at international level as a clear route to generation and maximising research impact; engaging pro-actively in proposed EU-Aerospace industry programmes (Cleansky 2); and establishment of a novel high impact research programme bridging the gap between advanced manufacturing and power electronics. Specifically, key topics will include structural and functional integration of power

electronics, assembly and manufacturing technologies, converters for high-power high-voltage applications, integrated and high power-density drives, power electronics-enabled power systems for terrestrial and transport applications and operational management and control design tools.

Applied Optics Group (AOG) – Head of Group Prof M Somekh (FREng)

Strategic Aims for Research During the Period The AOG conducts multidisciplinary research in the application of optical, ultrasonic and instrumentation engineering spanning physical scales from the sub-molecular to the largest structures in the solar system. The strategic aim of the group since RAE 2008 has been to develop strengths in applications of measurement methodologies, principally optical, for use in the healthcare and advanced manufacturing industries. A key aim has also been to develop research staff through focused support for external Fellowships. Since RAE 2008 the Group has mentored key staff to apply for externally funded fellowships: Russell, promoted to Associate Prof., 2013 (RCUK Fellow), Mather (EPSRC Career Acceleration Fellow), Webb and Wright (RAEng. Fellows). Fellows from previous RAE periods now hold chairs (Morgan, Clark). The principal objective identified in RAE 2008 was to extend AOG's work to have impact at the interface of engineering and life sciences. This was delivered through the launch of the Institute of Biophysics Imaging and Optical Science (IBIOS) now celebrating its 5 year anniversary (Total UoN IBIOS income ~£18.6M). The AOG also supports 2 EPSRC Platform Grants (EP/G061661/1, £823K and EP/G005184/1, £797K) and 2 EPSRC Challenging Engineering Awards (EP/H022112/1, £1.069M and EP/D030129/1, £1.3M). **Strategic Plans:** The future strategy for the Group will be to build on its strong presence in the field of nano-biophotonics for sensing and manipulation by looking towards new methods to interface between the nano- and mesoscales for optimal deployment in real applications. The platform for this strategy has already been established with the award of multiple EPSRC Challenging Engineering Awards. Future research growth areas will include: New methods in high resolution microscopy, Quantitative material analysis using ultrasonics, Custom chips for four dimensional optical imaging, Integration of nanotechnology in current imaging platforms and Combining imaging with manipulation in optical systems

George Green Institute for Electromagnetic Research (GGIEMR) – Head of Group Prof T Benson (FREng)

Strategic Aims for Research During the Period The vision of GGIEMR is to provide strong foundations to fundamental methods and techniques in Electromagnetics (EM) which deliver impact in key application areas for example, lightning interactions with structures, and microwave circuits and antennas. Since RAE 2008, strategic aims have focused upon continued delivery of excellence through industrial and academic partnerships. During this REF period GGIEMR have continued >10-year collaborations with mathematics and engineering groups in the Ukraine and Russia including Royal Society Joint Projects, Royal Academy of Engineering Distinguished Visiting Fellowships, a Marie Curie International Incoming Fellowship (IIF), and the European Science Foundation (ESF) Network 'Newfocus' programme. The current research portfolio includes the EPSRC Grant 'Simplified models of emissions from electronic systems based on near field measurements', (EP/H051384/1, £462K). Other core research activity has seen focus on developing the multi-scale, multi-physics Unstructured Transmission Line Modelling (UTLM) method, and linked work on meshing for CAD linked to partnerships with CST Ltd and BAE Systems. The strategic appointment of Cools is already starting to pay off, allowing us to further develop hybrid Computational Electromagnetic Modelling tools that provide more holistic engineering solutions to our funders. GGIEMR have Preferred Academic Partner status with BAE Systems who regard the unstructured mesh, transmission line method pioneered in the group as a critical capability advance for industry-scale electromagnetic problems (£55K). Along with PEMC they are also partners in Clean Sky (€10M for Nottingham, see section e). **Strategic Plans:** Our future strategy is to balance a portfolio of research themes so as to provide the flexibility to manage and respond to changes in the funding landscape. The three themes are: (i) high impact, low-cost-overhead theoretical and computer work; (ii) experimental and interdisciplinary work with a strong EM component; (iii) industrial applications and knowledge transfer.

Energy and Sustainability Division

Thermo-fluid Mechanics Group (TFMG) - Head of Group Prof P Shayler (FREng)

Strategic Aims for Research During the Period The strategy of the Group since RAE 2008 has been to build on collaborative research with industry to improve the technology and efficiency of energy conversion and utilisation, targeting applications in automotive, aerospace and power generation. Specific developments since RAE 2008 include: The Rolls-Royce (RR) University Technology Centre (UTC) in Transmissions has achieved strong growth in collaborative activity in the thermodynamics area, with research funding rising by 50% in the past three years (£3.7M total income in this REF period). The Internal Combustion (IC) Engines theme has maintained strong links with Ford and developed broader links with the automotive industry, particularly through two major collaborative research projects funded under the TSB Low Carbon Vehicle programmes since 2008. Our internal combustion research activities have developed a unique piston-liner test facility to meet multiple needs for research on friction reduction measures for industry (investment of £250K by industry partners including Ford and BP). This research has defined advanced fuel injection strategies to improve cold engine behaviour, identified low friction design features for piston-liner interaction through experimental studies using the new test facility and has improved fuel economy during engine warm-up (Ford Motor Company £1.5M). **Strategic Plans:** Over the next REF period the Rolls Royce UTC will strengthen its lead in CFD modelling and design methodology for aero-engine transmissions, enhance the experimental facilities to support this, and expand research on heat and flow management within transmissions. The UTC will also seek closer links with other centres of excellence, notably Karlsruhe Institute of Technology. This and other aerospace research on wing control, drag reduction and numerical methods is aligned with the University strategy to grow aerospace research via our Institute for Aerospace Technology. IC Engines research will continue to focus on engine efficiency and reducing CO2 emissions, improved refinement and extended service intervals, particularly through research on soot-in-oil, from cold to fully warm operating conditions. Research on friction and lubrication engineering will build on collaborative research already underway, and links with industry will be expanded.

Industrial Microwave Processing Research Group (IMPG) – Head of Group Prof S Kingman

Strategic Aims for Research During the Period The IMPG is focused on development of novel, sustainable process technology utilising electromagnetic heating. The strategy set at RAE 2008 was one of sustainable growth with a focus on delivery of real impact to industry. Since 2008, focus has been on pro-active engagement with industry which is underpinned by a strategic collaboration formed with e2v plc. to develop robust supply chains for the development of industrial microwave processing systems (£1.15M with extension to 2018 agreed in principle) and a large strategic collaboration with Rio Tinto (~£9M, with AUS $10M extension to 2018 agreed) to develop microwave applications for minerals processing. The Group has also exclusively licensed 3 key pieces of IP around microwave processing, one of which has led to the building of the largest industrial microwave process ever (total project investment by the sponsor ~$50M). There has been major investment in equipment in this period (~£3M total investment by industry) and the group have co-located to significant (1500 m^2) new premises on a Nottingham business park due to the physical scale of activity and need for confidentiality around some of their test work programmes. **Strategic Plans:** Over the next period the Group will continue to support the commercialisation of its technologies in the minerals and oil and gas sector and will look to apply its proven technology scale up methodologies to its growing portfolio of chemical industry applications building upon continued long term funding from e2v plc. In particular, focus will be given to polymeric and pharma systems to build upon the skills of group members Irvine and Robinson and collaborations with the Schools of Chemistry at Nottingham, Queensland Australia and Graz in Austria.

Fossil Energy and Carbon Capture and Storage (FECCS) – Head of Group Prof C Snape (FRSE)

Strategic Aims for Research During the Period The overall direction of the research programme is shaped primarily on how fuel will be best exploited in the future with environmental controls. Coal utilisation was traditionally the major activity and it is envisaged that this will continue coupled with the global environmental drive towards zero emissions. However, as well as cleaner coal

technology the intention was to expand the multi-disciplinary portfolio to encompasses CO_2 mitigation, energy storage and applied geochemistry as major research topics. The current research portfolio encompasses a number of key projects and initiatives, including the EngD Centre in "Efficient Power from Fossil Energy and Carbon Capture Technologies" (EP/G037345/1, £6.8M) which is the UK focal point for PhD training in the field. The Group are members of the EPSRC/DECC UK Carbon Capture and Storage Research Centre (EP/F012098/1, £1.1M). Our strategic focus on international collaboration has led to the award of a number of EPSRC-E.ON and China grants. As well as cleaner coal technology, CCS and associated research on biomass, this multi-disciplinary portfolio also encompasses energy storage and super capacitors funded by E.ON (£820K). The Group lead the Energy theme in the International Doctoral Innovation Centre (IDIC), a £15M doctoral training centre spanning the University of Nottingham, UK and the University of Nottingham Ningbo China to train 120 of the brightest young PhD researchers over the next six years, with 50% of the total cohort working in Energy. A significant development in this REF period has been the re-location of much of the group's work to the brand new Energy Technologies Building on the University Jubilee Campus (described in section D). **Strategic Plans:** The vision is to enhance the group's reputation as an international centre for research in fossil energy and carbon abatement technologies. This will involve recruiting high calibre academic staff, maintaining and expanding the facilities base, continuing to publish high impact papers, maximising the impact of the research through industrial engagement, and continuing to lead our EPSRC EngD Centre covering fossil energy and CCS.

Infrastructure, Geomatics and Architecture Division

Nottingham Transportation Engineering Centre (NTEC) – Head of Group Prof G Airey

Strategic Aims for Research During the Period NTEC supports a range of activities related to airfield, port and other specialist pavements, railway track, performance and asset management, risk analysis, sustainable construction, environmental impact and transport systems. Since RAE 2008, NTEC has delivered new related areas of research whilst developing existing areas of strength. Exemplars of delivery include a major new research programme in Infrastructure Asset Management including Risk and Reliability Engineering. This included a Chair funded by Network Rail and the Royal Academy of Engineering and 3 new academic staff. This activity carries a £2.2M research portfolio with Lloyd's Register Foundation providing around £700K to support specific research into risk and reliability engineering. Growth in interdisciplinary activities within NTEC have been achieved through EPSRC Platform Grant activities (GR/S64424/01, £421K and EP/F018045/1, £668K) and major joint EPSRC grants with Imperial College (EP/H24549/1; EP/F018045/1). Physicochemical research in road materials has been achieved through an EPSRC grant (EP/G039100/1, £296K). During the period the Group also delivered a strategic partnership with Shell Bitumen worth £5.2M. In the area of Coastal Engineering, the Group supports an EPSRC Fellow (Briganti, EP/I004505/1, £563K) who is focused upon modelling coastal floods in order to grow sustainable communities. PhD student numbers have grown in the period from 18 to 36 demonstrating the development and growth in new areas of research, increased strategic partnerships with academic institutions and industry, the successful recruitment of high calibre staff and the growth in critical mass of the group. **Strategic Plans:** Over the next 5 years the vision of the Group is to continue to diversify research activities to meet the long term demands of industry through additional academic appointments, continue to expand multi-disciplinary collaborations with other groups and expand application of risk and reliability research to other areas/sectors (e.g. aerospace, energy, chemical processing, security/anti-terrorism), and work towards establishing an NTEC presence at our Ningbo campus in China to take advantage of the transport infrastructure opportunities in China. A key further aim will be to become strategically aligned with the Transport Catapult Centre, particularly in Asset Management.

Nottingham Geospatial Institute (NGI) – Head of Group Prof T Moore

Strategic Aims for Research During the Period Following external review, the Nottingham Geospatial Institute was formed in 2011 from a merger of the Institute for Engineering Surveying and Space Geodesy and the Centre for Geospatial Science with strong input from the School of Geography at Nottingham. NGI are partners in the RCUK Horizon digital economy research hub and doctoral training centre (DTC). NGI is also leading the TRANSMIT Marie Curie Initial Training Network (ITN 264476, total €3.9M) and delivered an EPSRC ICT Large Grant (EP/G019533/1,

£625K). With support from East Midlands Development Agency (EMDA), GRACE (GNSS Research and Applications Centre of Excellence) was set up as a part of the NGI. Since then it has actively engaged 150 SMEs and over 800 individuals, creating 56 new jobs since August 2009. Through its work GRACE directly influenced the UK Space Innovation & Growth Strategy and the National Space Technology Strategy published by the Technology Strategy Board. Through membership of key strategic groups (Moore) GRACE has directly influenced TSB innovation policy to deliver a Satellite Applications Catapult Centre and a GNSS test bed. Based in their new building (section D), significant investment in equipment and facilities has been made through the EMDA grant and Capital Infrastructure Fund (CIF) funding. **Strategic Plans:** The strategy for NGI over the next REF period will be to continue pro-active engagement with industry both in the UK and China, to target key industrial partnerships to maximise the impact of the research and expand into new multi-disciplinary areas to advance the science and technology of positioning. Partnership with the Satellite Applications Catapult will be key to delivery of this strategy.

Human Factors Research Group (HFRG) – Head of Group Prof S Sharples

Strategic Aims for Research During the Period The HFRG conducts multidisciplinary research into our behaviours at work, home, travel and leisure to drive user-centred design for new products and systems. Over the REF period the strategy of the Group has been to increase industrial engagement, seek and develop key academic collaborations and to invest in high quality equipment and facilities. Exemplars of delivery include significant industrial collaborations, particularly in the railway industry with Network Rail. This has resulted in 9 co-sponsored PhD projects, and collaboration in the EU RESTRAIL project. The Group supports a total EU project portfolio of ~£1.5M. Involvement in RESTRAIL brings engagement with additional industrial partners: Railway Safety Standards Board, British Transport Police, Virgin Trains, East Coast Main Line, Samaritans. In the automotive sector engagement with Honda and Jaguar Land Rover has generated a direct income of around £300K. The Human Factors simulation laboratory has been equipped with a new 270^{o} field of view fixed-base car simulator, train simulator and motorcycle simulator (£250K). The HFRG are key partners in the funded Horizon digital research hub and DTC, which represents a £17 million RCUK investment and has over 40 industrial partners, providing internships and project support. **Strategic Plans:** The strategy for the Group now includes a period of consolidation where researcher numbers in the UK and international collaborations are maintained. Effort will be concentrated on developing a stronger international scientific profile which will be done in parallel with expanding the research activity into new related areas of science and technology including addressing the key government challenge of big data, including requirements for visualisation of large condition monitoring, sensor-rich data sets. Specifically, the HFRG will pursue links with China (Ningbo, ECUST) and the US (Virginia Tech) via collaborative PhD supervision and development of car simulation facility in Ningbo, and develop a strategic framework for continued collaborative research with Jaguar Land Rover Ltd in the area of Human Factors for in-vehicle technology whilst maintaining and extending links within the rail industry via engagement with the Transport Catapult (including staff placements).

Manufacturing and Process Technologies Division

Advanced Manufacturing Technology (AMT) Group – Head of Group Prof S Ratchev

Strategic Aims for Research During the Period The AMT Group conducts research at the forefront of manufacturing science and technology working in close cooperation with a number of strategic industrial partners and research centres worldwide. Key achievements since RAE 2008 are underpinned by the launch of the Institute for Advanced Manufacturing enabled by a £2M CIF investment. The Group has developed and maintained major industrial research partnerships with RR (the only RR UTC in Manufacturing Technology, £1.8M), Airbus (International Hub for Assembly Tooling and Fixturing, £1.1M), and BAE Systems (£1.4M). Outputs have been delivered through: successful completion of the second Nottingham Innovative Manufacturing Research Centre, (EP/E001904/1, £9.8M); establishment of the Manufacturing Technology Centre (MTC) jointly with Loughborough and Birmingham Universities and The Welding Institute (TWI), part of the High Value Manufacturing (HVM) Catapult; and establishment of the Nottingham Precision Manufacturing Centre with EPSRC and EU FP7 support. The Group has also been awarded 2 new, 5-year EPSRC research clusters in Cloud Manufacturing (EP/K014161, £2.36M) and

Evolvable Assembly Systems (EP/K018205/1, £2.15M) which commenced in 2013. The AMT group also leads an EPSRC Engineering Doctorate Centre (EP/I017933/1, £1.25M, plus £1.7M of industrial funding and in-kind contribution of £2.4M from MTC). **Strategic Plans:** Over the next REF period the focus will be to firmly establish Nottingham as a leading international research centre and preferred supplier to industry of research and innovation technologies in advanced manufacturing technology. Of particular importance will be delivery of effective PG training programmes and enabling impact for industrial stakeholders and partners. Specifically, focus will be given to global sustainable manufacturing (through links to our international campuses), composites manufacturing, high precision tooling and fixturing, customised high value assembly processes, technologies for healthcare manufacturing, low carbon energy technologies and food manufacturing in conjunction with the School of Biosciences at Nottingham who were recently awarded an EPSRC Centre for Innovative Manufacturing in Food in collaboration with Birmingham and Loughborough.

Bio-renewables and Bio-Processing Research Group (BBPRG) - Head of Group Prof G Stephens

Strategic Aims for Research During the Period A new research group since RAE 2008, formed to complement key strengths across UoN in Bioenergy and Sustainable Chemistry. Since formation, the Group has already expanded from 3 to 6 members, and has been supported with major (>£750K) investments in laboratories, infrastructure, equipment and support staff, to provide a new Bio-processing Laboratory (recently doubled in size to 235 m^2) and a new Laboratory for Chemical and Water Processing of Biomaterials and Bio-wastes established in 2012 (206 m^2). In 2010, Stephens was appointed to a new chair in Industrial Biotechnology, bringing a BBSRC Research Development Fellowship in Biorenewables (BB/G023581/2, £154K). The Group's overarching theme is Sustainable Bio-processing, with a primary emphasis on bio-based routes to renewable chemicals. Training forms a key component of our strategy, via partnership in the £5.4M BBSRC Doctoral Training Partnership (BB/J014508/1). **Strategic Plans:** Future activities will be based upon overcoming the limitations of bio-catalytic processing. One approach builds on integration of bio-catalysis with chemo-catalysis, to expand the range of bio-derived chemical products. A second approach is to overcome restrictions on productivity of bio-chemical processes by integrating biocatalyst improvement with bioprocess intensification.

Additive Manufacturing and 3D Printing Research Group (AMRG) – Head of Group Prof R Hague

Strategic Aims for Research During the Period The AMRG were recruited to Nottingham in 2012 as part of our strategy to support multi-disciplinary teams who can deliver worldwide impact through fundamental and applied research. The group currently consists of 3 Professorial staff, 1 Associate Professor and 2 Lecturers (not all Category A) plus a number of researchers and technicians. The vision of the Group is based around creation of multi-material, multifunctional products and components enabled by Additive Manufacturing (AM) to amalgamate electrical, optical and structural properties within a single manufacturing process. The activities of the Group are supported through the award of the EPSRC Centre in Innovative Manufacturing in Additive Manufacturing (EP/I033335/1, £5.6M). In addition the University has made a £1M investment in new equipment for Additive Manufacturing research. This has enabled an expansion of the Group's activities into multi-physics modelling of additive manufacturing processes and components, computational design optimization and increased understanding of additive manufacturing processes and materials. The group was recently awarded £2.7M via the EPSRC Capital for Great Technologies call to underpin multi-functional additive manufacturing in collaboration with the School of Pharmacy. **Strategic Plans:** Future strategy is focused upon expanding the group and collaborators to further extend the science base and developing the collaboration base to facilitate the transfer of next generation multi-functional AM to industry. This will be underpinned by our leadership of additive manufacturing R&D within the MTC. Another key aspect of the strategy moving forward will be to establish a hub of Additive Manufacturing Research at our Ningbo Campus in China in order to exploit the huge opportunities for this technology in that region.

Fluids and Particles Processing Research Group (FPRG) – Head of Group Prof R Wildman

Strategic Aims for Research During the Period Since RAE 2008, there have been significant

changes to this Group driven by the opportunities arising from formation of the Faculty and retirements and secondments of senior staff. The research strategy of Fluid and Particle Processes remains centred on the development of a multi-scale approach for all combinations of fluids and particles. Longstanding activities in multi-phase flows continue to thrive e.g. Multi-scale Exploration of Multi-Phase Physics In Flows with Imperial College (EP/K003976/1, £4.9M) and direct industrial collaborations e.g. Transient Multiphase Flow consortium (Imperial, Cranfield, Bristol) where research is funded by 12 major oil companies (~£100K). The Group is also focused on new applications of fluids and particle technology, exemplified by Wildman's collaboration in 3D printing with AMRG, Rigby's MRC-funded optimised drug delivery system for patients and Hewkandamby's project on an airlift bio reactor to ensure live organism survival. The continuing importance of chemical processing, particularly at the nano-scale, points to a need for growth in Fluids and Particles Processing. The membership of the group is relatively early career and senior appointments will be made to develop a strong presence in the area. In turn this will attract high calibre researchers that are required for the execution of sophisticated multi-scale combined experimental-numerical approaches. **Strategic Plans:** A goal of the group is to develop an increasing alignment with industrial and manufacturing processes where fundamental challenges still lie. In particular, the development of clean continuous chemistry, micro/nano fluidics for drug delivery and separation and biosensor technology all require fine control and understanding of fluid and particle behaviour. Particle technology has been recognised as an area of investment for funding bodies. However, it is not perceived as a growth area. The group will reposition itself to seek a widening of applications of fluid and particle applications and focus on those areas where control and understanding is currently a barrier to manufacture and production, for example in food processing.

Materials Mechanics and Structures Division

Nottingham Centre for Geomechanics (NCG) – Head of Group Prof H S Yu (FREng)

Strategic Aims for Research During the Period NCG is a multi-disciplinary research institute that brings together expertise in mathematics, and civil and mining engineering to address issues across the full range of geotechnical engineering areas. The NCG is established for research in the areas of soil plasticity, micro-mechanics and DEM modelling of granular materials, the shakedown approach to pavement design, numerical modelling of ballast for railway foundations, and analysis and centrifuge modelling of pile foundations and cone penetration tests. The strategy of NCG since RAE 2008 has been to further grow staff numbers, increase the number and quality of academic and industrial engagements and commission further experimental facilities for the validation of numerical modelling. In the last three years, four new academic positions in the Group have been created. Industrial engagement is a significant feature of the research conducted in NCG with involvement in at least 15 international and UK collaborative projects. Such international projects include GEOSOFT, LOWCARB, MISSTER and COMEX, all EU-RFCS projects (Research Fund for Coal and Steel) which include partnerships with industry from Spain, Poland, Slovenia, Germany, Greece and France. The NCG are also partners in TRACK 21 an EPSRC Programme Grant, (EP/H044949/1, £3.1M total, £697K to UoN) with the Universities of Southampton and Birmingham and various railway industries. More than £250K has been spent on new equipment and facilities in the REF period. NCG successfully led an EPSRC-funded UK-China Network on Geotechnical Engineering involving all the leading geotechnical groups in both countries (EP/E03991X/1, £191K). **Strategic Plans:** The future strategy for the group will focus on continuing to expand the engagement with industry in the UK and internationally to deliver real impact from fundamental geo-mechanics approaches, further developing collaborations with leading international university partners and expanding research staff numbers. Specifically, the group will focus on fundamental research on theoretical and computational mechanics for soils and granular materials, further development of advanced laboratory testing and railway/pavement analysis facilities, and continued development of engineering applications of theoretical and computational work to pavement and railway foundations, mitigation of natural hazards, rock excavation stability and underground mining and pile foundations.

Polymer Composites Research Group (PCRG) - Head of Group Prof N Warrior

Strategic Aims for Research During the Period The PCRG focuses on fundamental and applied research relating to the processing and performance of polymer matrix composites. Since RAE

2008 the strategy of the Group has been to expand the number of researchers to develop critical mass, develop new relationships with international industry, and continue to provide a lead for composites manufacture in the UK. Implementation of this strategy has led to new collaborations with Boeing around carbon fibre recycling ($1M per annum for 5 years), and Airbus, Audi and Bentley for composites manufacturing. The Group has established widespread aerospace sector engagement across multiple AVIC (Aviation Industry Corporation of China) subsidiaries including ACC (AVIC Composite Corporation Ltd) and ACAE (AVIC Commercial Aero Engines). The Group leads UK activity in composites manufacturing research via the EPSRC Centre for Innovative Manufacturing in Composites (EP/I033513/1, £5.9M) and our partnership in the EPSRC Industrial Doctorate Centre in Composites Manufacture, based at the National Composites Centre (NCC). Investment in facilities has been a strategic focus since RAE 2008 (~£1M). During the REF period the group held 2 EPSRC platform grants (GR/T18578/01, £445K and EP/F02911X/1, £824K). **Strategic Plans:** Future strategy is one of sustainable growth. The Group will continue to deliver high quality research outputs in the fields of composites manufacturing, multi-scale modelling, recycling and increasingly composites bio-engineering. We aim to expand these numbers via increased research funding enabled through closer working with industry, EU and Research Council programmes. Specific areas of interest will include; structural and functional integration of power electronics, assembly and manufacturing technologies, converters for high-power, high-voltage applications, integrated and high power-density drives, power electronics-enabled power systems for terrestrial and transport applications, operational management and control, and design tools.

Advanced Materials Research Group (AMRG) – Head of Group Prof D Grant

Strategic Aims for Research During the Period The overall strategy of the AMRG since RAE 2008 has been to expand collaborations both within the Faculty and externally in academia and industry to enhance research and development in the area of advanced materials and bio-engineering. The AMRG are heavily involved in the Faculty collaboration with the Chinese aerospace company ACEA (AVIC Commercial Aircraft Engine Company Limited) who have established their first overseas University Innovation Centre at Nottingham (total value to UoN £3.2M). Walker and Grant have developed a portfolio of research in energy materials such as novel thermal stores funded directly by E.ON (£1M) and TSB as well as metal hydride hydrogen storage projects (£0.9M) funded by UK-India and UK-China collaborations. Seddon's work on novel photonic glasses continues via partnership in the FP7 MINERVA project (total value to UoN £735K). AMRG are partners in the EPSRC Centre for Innovative Manufacturing in Medical Devices (EP/K029592/1, £5.7M total). **Strategic Plans:** The vision is to lead in materials research by developing novel processing and characterization of new materials working with the energy, transport and medical industries. The group's objectives are to collaborate with large multinational industrial partners while maintaining a strong portfolio of SMEs, support new infrastructure, develop new characterization facilities and consolidate and grow expertise in materials science and engineering.

The *Structural Integrity, Dynamics and Bio-Engineering (SIDBE) – Head of Group Prof A Becker*

Strategic Aims for Research During the Period Since 2008, research into creep fracture behaviour in welds has made significant advances with support from several initiatives including EPSRC's SUPERGEN 2 (EP/F029748/1, £1.1M to UoN and GR/S26965/01, £413K to UoN): The group is heavily involved in the delivery of our Rolls-Royce UTC in Transmissions. Exemplars of research include studies on inertia friction welded aerospace metals which underpin the first ever use of dual-alloy shaft designs in Rolls-Royce aero-engines. This also incorporates advanced constitutive material models for the RR Trent 1000 engine and high strength steels into the DEFORM finite element software which was achieved for axisymmetric elements. Garvey's work on energy storage is recognised through collaboration in an EPSRC Programme Grant (EP/K002228/1, £3M total, £187K to UoN) and funding via the EPSRC Capital for Great Technologies call (£500K to UoN from £1.7M total). Further compressed air storage for off-shore wind energy has been demonstrated in sea trials, a floating wind turbine concept has been patented and a spin-out company established to exploit this (Nimrod Energy Ltd.). Bio-engineering activities have led to transfer of research to industry and the Group have collaborated with Ranier

Technology to deliver 2 total disc replacement devices through pre-clinical and clinical trials, CE marking and now commercially marketed. **Strategic Plans:** Our future strategy includes the development of experimental facilities to further enhance the definition of the material/system characteristics; specifically, there is a need to characterize fretting responses at higher temperatures, and higher frequencies, under higher pressures to allow fretting damage predictions to be applied. Additionally, interests will include development of multi-scale modelling methods that will address new materials and future challenges in power generation, development of new indentation approaches to measure material property degradation, and novel testing techniques for industry to enable measuring material properties of small zones. We will also investigate the determination of non-linear material properties under high temperature using indentation techniques and to quantify the link between multi-scale materials modelling and bulk material behaviour. In bio-engineering a key future goal will be to develop a multi-segment implant using flexible composite technology.

c. People, including:

i. Staffing strategy and staff development

Our aim is to recruit and support exceptional people. The Faculty research strategy and the need for sustainable staffing guide every academic appointment. Emphasis is placed on nurturing staff at the beginning of their career. We will excel at both teaching and research. Tensions between these are moderated by the use of our Faculty workload allocation model which enables fair distribution of teaching load and administration duties with significant reduction in the first 3 years. We also employ 15.44 FTE teaching-only staff in order to maximise staff research time. The academic staff profile is well balanced and sustainable with 60 at Lecturer, 41 at Associate Prof. and Reader and 57 at Professor. Recruitment and retention of high calibre staff is based on business cases which balance research opportunities and strategy, and requirements for specific taught courses and the workloads of existing staff. Priority for new appointments is alignment with Faculty strategy and fit with UoN research priorities, enabling us to align incoming staff with areas of research strength and sustainable funding opportunities. Since RAE 2008, we have made 44 FTE additions to our academic staff, with notable international recruitments including: Castellazzi from ETH, Zurich, Tian, from the Chinese Academy Of Sciences, Bournas from the European Lab for Structural Assessment, Kazerani from Ecole Polytechnique, Federale de Lausanne, and Scase and Turnbull from Cornell University, USA. We have also recruited a number of staff from industry including Kinnell from General Electric and Simmons from Rolls-Royce.

We have developed and implemented divisional and group-based grant mentoring systems to improve success rates for all staff levels. We have developed a formal multi-year programme to provide research leadership training for early career academic staff (14 per year at the moment at Lecturer and Associate Prof, with roll out for researchers in 2014) which is focused around leadership foundations, strategic planning, networking and team development. One of our research staff was also selected to join the first cohort on the joint University of Nottingham/University of Birmingham Leadership Programme for Early Career Researchers. Professorial staff are able to take advantage of focused leadership training provided by the University as part of the recently introduced “Research Leaders Programme.” We have also introduced a baseline package for all new early career appointments which consists of financial support for equipment and consumables and guarantees of PhD student funding and mentorship. Since RAE 2008 we have also implemented a formal academic/research leave process and formal induction processes for all new members of staff. In this REF period we have promoted 23 academic staff from Lecturer to Associate Prof., 14 staff from Associate Professor to Reader and 18 to Chair. Personal Development and Performance Review (PDPR) is the process employed by UoN to ensure staff are developed, managed and rewarded appropriately in line with the wider Faculty and University objectives. All staff set and monitor their own objectives within Faculty priorities, and drive their own development and performance improvement, with the support and guidance of their manager. All staff meet at least every 3 months with their reviewer to monitor their progress against key, quantitative performance indicators.

The Faculty is committed to embedding the principles of the Concordat to Support the Career Development of Researchers in its policies and practices. This agenda is driven by the University's

Research-only Staff Group (RoSG) and the Engineering Research Staff Group (ERSG) and delivered through representation on the Faculty Research Committee. Evidence of our support is found in implementation of formal processes to provide support for early career researchers, including developing formal guidelines for promotion for research staff, implementation of formal induction processes for all new research staff, implementation of a bridging funding system in order to retain researchers at the end of fixed term contracts, and formal recognition for PhD supervision and access to funded PhD scholarships for all research staff. In this REF period, 29 of our researchers have been promoted from Research Fellow to Senior Research Fellow and 6 have been promoted to Principal Research Fellow. We have introduced a formal Research Fellowship strategy with modules in CV preparation, proposal writing and interview practice now being delivered at least twice per year. Since RAE 2008 we have supported numerous externally funded Fellowships funded by Royal Society (Mariya Bivolarska – Newton Fellowship – August 2009 – August 2011); RCUK (Melissa Mather – EPSRC Career Acceleration Fellow – 2011-16, Ricardo Briganti - EPSRC Career Acceleration Fellow – 2010-15, Gill Stephens – BBSRC Research Development Fellowship – March 2010 - Sept 2012); joint EPSRC and Royal Academy of Engineering Fellowships (Kevin Webb - EPSRC/RAEng - 2009-14, Chris Gerada – RAEng – 2011-16); Anne McLaren Fellow (Catherine Harvey October 2013 - September 2016). Noah Russell and Mark Pitter also held RCUK fellowships during this REF period. The Faculty is also actively engaged in the internally-funded Nottingham Advanced Research Fellowships, with 2 such Fellows moving to permanent academic roles within the Unit during the period of assessment (Gomes, Barney). The UoN strategic plan (2010-15) sets clear goals to increase numbers of minority ethnic staff and female senior staff. All staff involved in leadership have been formally trained in processes relating to diversity and equality, this includes (but is not limited to) all Heads of Research Division, and Heads of Research Group. In addition, all UoN staff participate in targeted awareness communication and training for equality and diversity. Our commitment in this area is exemplified by the Faculty being the first Engineering Faculty in the UK to be awarded an Athena Swan Silver Award which was followed by an institutional award in 2013. UoN was also awarded the 2009 Scientist Best Places to Work in Academia Award, and UoN has recently been awarded the EU “HR Excellence in Research” badge in recognition of our commitment to development of researchers.

ii. Research students

Recruiting excellent postgraduate students and training them to a high standard is a core function of the Faculty. The Associate Dean for the Graduate School (Engineering) coordinates the admission of postgraduate students to the Faculty with a team of 10.5 staff. In order to encourage more application from HEU undergraduates the Faculty runs a high fliers scheme in which our top 8% of UG students take part in research related events, (805 students over the period). We also run a formalised Summer Internship Programme which has enabled approximately 60 top class UG students per year to undertake research placements, of which 47 have gone on to study for PhD degrees at Nottingham and elsewhere. In order to attract the best overseas students we have implemented the “Dean of Engineering Scholarship Programme” which provides for 20 full and partially funded overseas scholarships each year. The quality of our students is a notable feature with many winning prestigious awards, for example Yang Wei and Qi Liu both won Chinese Student of the Year awards from the Great Britain China Trust awarded to outstanding Chinese students at UK Universities, and Darshill Shah won the European Sustainable Solutions Award, 2012.

The Faculty of Engineering has developed a structured programme of training for postgraduate research students which meets the EPSRC statement of expectation and also supports the researcher development framework. The programme aims to: provide a clear indication to students and supervisors of available training activities and resources from a range of providers, provide guidance regarding areas of training in which students are expected to demonstrate competence, enable collection and sharing of good practice and opportunities for training across the Faculty of Engineering. A key element of the Engineering Postgraduate Research Training Programme is the process of reflective audit. Each doctoral student is required to complete a ‘training needs audit’, in collaboration with their supervisor, within six weeks of registration. The programme identifies three training categories, research, professional and technical. All training activities are recorded in an

audit document and completion of the training programme is a compulsory part of progression. All Research Divisions run colloquia and also have an annual poster competition. All research students also take part in the 2-day Faculty Annual Research Student Conference. The Unit uses its Doctoral Training Grant (DTG) to support strategic initiatives, encourage links with industry, enable new staff to develop a research base and encourage multidisciplinary collaborations with other UoN Schools. Funding for research studentships is decided by a Faculty Group which has non-professorial representatives from all Divisions, thus ensuring staff from all levels of seniority have involvement in the decision making process and in a transparent manner.

The Faculty holds research student Progression Boards to review PGR students' performance and formally approve progression to the next year. The board is informed by training records, evidence of completion of supervision record forms, and the results of a formal progress assessment based on a written report and viva. Each Division has a PGR student advisor who is available to provide impartial, confidential advice in case of difficulty supported by the central University counselling and support networks.

d. Income, infrastructure and facilities

We believe that world class facilities are vital to delivery of the highest quality research. The Unit benefits from ~14,000m^2 of laboratory space. Since RAE 2008, we have created ~2700m^2 of new lab space in our new Energy Technologies Building (ETB) (capital investment £7.2M by the European Regional Development Fund (ERDF) (28%) and CIF (72%)), Nottingham Geospatial Building (capital investment £4.9M by EMDA) and Aerospace Technologies Centre (capital investment £5.2M by ERDF and UoN). In addition, we have invested ~£2.6M of our own resources on general refurbishment of existing space to ensure that it is of the highest quality. The ETB provides 760m^2 of laboratory space plus corresponding facilities for research and development in the following areas: clean fossil energy, renewable energy generation and storage, flexible electrical systems, hydrogen storage and energy-conversion, bio-fuel extraction and energy-conversion from non-food stocks, demand side reduction in the built environment, environmental and social management. The 400m^2 Prototyping Hall in the ETB also provides a world-class facility for the construction and testing of full-scale prototypes. Our GNSS/Galileo Research and Application Centre of Excellence (GRACE) was established in the Nottingham Geospatial Building, a new state-of-the-art facility on the University of Nottingham Innovation Park (UNIP). It comprises research laboratories, testing facilities, industrial outreach and business development, project units, training facilities and the offices of national GNSS projects.

The scale, quality and future growth prospects of our Aerospace research portfolio already marks this area as being of strategic importance to the Faculty and this has underpinned the creation of the Aerospace Technology Centre (ATC). The ATC is a research facility located at UNIP, which forms the focal point for the wider Institute for Aerospace Technology. The new building provides facilities for application-focused research (TRL 4-6) of significant size and complexity. Initial projects include a pilot plant for recycling and re-use of carbon fibre composites, a novel tooling and fixturing demonstrator for aerospace structures, and a prototype engine-less taxiing system for the "more electric aircraft".

The Faculty of Engineering was awarded £3.1M as part of CIF which was used to support key strategic research areas: Ubiquitous Positioning, the Institute for Advanced Manufacturing, CAMERA: a Faculty wide initiative to provide advanced measurement facilities for Engineering research, the Energy Technologies Research Institute and expansion of other key space including the Aerospace Research Centre.

Further strategic investments in facilities and high quality researchers have also been made in this REF period through accessing the University of Nottingham Strategic Development Fund (SDF), a £6M p.a. initiative aimed at ensuring the University delivers against it strategic plan. Through SDF we have been awarded £475K for recruitment of a new Chair in Aerospace Technologies and associated lecturers and researchers. In conjunction with the School of Molecular Medical Sciences we were awarded £655K to recruit a new Chair (currently being recruited), 4 lecturers and 3 technicians to support our growing multi-disciplinary activities in Bio-Process Engineering. Additional SDF funding was also provided to support our National Hub in Power Electronics

(£946K, equipment and facilities plus 2 FTE academic posts ~£100K per annum), and for additional staff and infrastructure to support our Rolls-Royce Manufacturing Technology UTC (£757K). The Faculty also successfully bid to SDF for resource to recruit a team in Additive Manufacturing and 3D Printing to extend our competencies in this area (£1.59M total). This investment has underpinned the recruitment of staff described previously, £1M of state of the art equipment and the refurbishment of 350m^2 of lab space to create a state of the art additive manufacturing facility where over 14 research fellows and 20 PhD students work. A number of new advanced manufacturing research laboratories with state of the art equipment for distributed manufacturing, reconfigurable assembly systems, precision (micro and nano) manufacturing technologies and ultra-precision metrology have been also developed with a total investment in excess of £5M by industrial sponsors and the University.

Our research equipment is managed through the "Kit Catalogue", an online database of all available research equipment at Nottingham. For general use within the Faculty we maintain laboratories with universal testing machines for static, cyclic, creep and high temperature performance testing up to 2000 kN with up to 2m test daylight. Geotechnical facilities include a large centrifuge (a 50g Tonne machine capable of creating model acceleration of up to 150g) and a range of triaxial soil/ballast testing systems. Advanced measurement equipment is available including Digital Image Correlation (DIC) systems (high resolution and high speed), Electronic Speckle Pattern Interferometry system, Time-resolved Particle Image Velocimetry (PIV) system, 2D Laser Doppler Anemometry (LDA) system, Phase Doppler Anemometry (PDA) system, Thermoelasticity System, Hand-held and tripod mounted Infra-red cameras, High Speed cameras, Electrical Capacitance Tomography (ECT) system and a suite of input-output devices for data logging. Good microscopy facilities are available including electron beam instruments (ESEM, SEM and TEM), X-ray spectroscopy (X-ray diffraction, micro-tomography) and analytical testing equipment. A well-equipped composites manufacturing lab includes liquid moulding equipment, floor mounted presses, an autoclave system, automated composites manufacturing cells and laboratory scale fluidised bed plant and supercritical fluid rig for recycling studies. To support work in Infrastructure Geomatics and Architecture we have made significant investments in state-of-the-art laboratory facilities. These include a dual source 2D and 3D X-ray CT machine, a pilot-scale pavement testing facility, dynamic vapour sorption apparatus and servo-hydraulic and pneumatic pavement materials' testing equipment. In addition, facilities available in NGI include: the enhanced GNSS simulation facility, a mobile positioning test vehicle, Midlands Real Time Kinematic (RKT) GPS network, rail track for mobile positioning and high precision laser scanning equipment. To support work in microwave processing the Unit has industrial microwave generators with a combined power output of up to 600kW along with state of the art dielectric characterisation facilities allowing measurement up to 1500°C and 350 bar. Power electronics is supported through dedicated electronic supplies for emulation of variable frequency generation systems up to 270 kW, dynamometers from 850 kW at 1500 rpm to 49 kW at 120,000 rpm, and flexible micro-grid and network emulation capabilities including unique facilities for multi-terminal DC (to 5 kV and 3 MW) and variable frequency AC networks.

Our research equipment is supported by 1510m^2 of workshops and we have 123 workshop and technical staff to support research including a full time Safety Manager who is responsible for all safety training and processes within the Unit. We also operate a highly successful Technician Apprenticeship Scheme to ensure sustainability in our technical staff. Two of our trainees (Ben Shaw and Joe Ellis) came first and second in the World Skills UK competition for CNC milling and CNC turning; Ben Shaw went on to represent the UK in the World Competition.

Our research awards from 1/1/2008-31/7/2013 were £146.3M from 737 projects including approximately £49M in 2012-13. Due to significant change to our organisational structure, direct comparison with RAE 2008 is not valid. The overall portfolio, however, is diverse and comprises 38% from Research Council, 26% from UK and EU Government grants, 33% from industry and 3% from other sources. In addition to research funded through traditional routes e.g. EU and RCUK we also deliver services rendered (SR) or professional services activities. These are projects which generally do not meet the VAT definition of research but are still externally sponsored. Projects up to the value of £13.5M were delivered by the Faculty of Engineering over the REF period. The

amount of activity varies by Division and the typical project varies significantly in size from a few thousand to several million pounds. Over the REF period over 480 separate professional services projects have been delivered by the staff within the Unit. Direct consultancy activities are handled for academic staff through a separate commercial entity, NUC (Nottingham University Consultants Ltd.); in this REF period our staff have delivered well over £1M of external consultancy work to third parties.

Our future plans are to grow our research income in a sustainable manner. Our target is to increase our income by approximately 10% over the next 5 years. We will do this primarily through increased and more targeted business development support, increasing support mechanisms to improve RCUK and EU success rates, a robust and focused mentoring programme for academics of all levels and recruitment of further high quality staff in strategically important areas.

e. Collaboration or contribution to the discipline or research base

The Unit fosters numerous interdisciplinary collaborations amongst its Groups as these are vital for the delivery of innovative solutions appropriate for the industries we support and the challenges that society faces. Since RAE 2008, we have made major investments in our Research and Business Development Team from 6.2 FTE to 9.2 FTE, fully funded by the Faculty. This group works closely with academic staff and the Business Engagement and Innovation Services and Research and Graduate Services divisions within the University to identify and communicate opportunities, facilitate introductions and provide contract support for new external collaborations. Research strategy is founded on the principle of seeking large scale, often multi-centre funding including national and international networks of excellence. Exemplars (in addition to those identified in Section B) of our UK collaborations include:

- UKCCSRC - The United Kingdom Carbon Capture and Storage Research Centre (EP/K000446/1), with BGS, Cambridge, Cranfield, Durham, Edinburgh, Imperial, Leeds, Newcastle and Plymouth Marine Laboratory); 2009-2013 (£10.1M total, £1.1M to UoN) ;
- EPSRC Centre for Innovative Manufacturing in Composites (EP/IO33513/1) – with partners at Bristol, Cranfield and Manchester Universities (£5.9M, total);
- Midlands Energy Graduate School, a collaboration with Universities of Loughborough and Birmingham (Funded by HEFCE, £1.57M);
- EPSRC Centre for Innovative Manufacturing in Additive Manufacturing (EP/I033335/2) – with University of Loughborough (£5.6M);
- Underpinning Power Electronics 2012: Hub, (EP/K035304/1) a collaboration with Imperial College, Newcastle, Manchester, Greenwich, Bristol and Warwick Universities (£17M total, £4.1M to UoN).

Multi-disciplinarity is vital to the our successful delivery of our strategy and the Unit supports academic collaboration through joint appointments: exemplars include 4 joint lectureships with Chemistry under the Driving Innovation Between Chemistry and Chemical Engineering (DICE) initiative (EP/D501229/1), and a Joint Chair with Geography in NGI. The Faculty enters into numerous interdisciplinary collaborations on specific projects, exemplars include:

- Horizon: Digital Economy Hub at the University of Nottingham (EP/G065802/1) with Schools of Computer Science, Mathematics, Psychology, Nottingham University Business School, and Culture, Film and Media and Nottingham Trent, Exeter and Cambridge Universities and the Open University (£12.5M, October 2009-September 2014);
- Science and Innovation Award, DICE: Driving Innovation in Chemistry and Chemical Engineering Research in the UK (EP/D501229/1) with School of Chemistry (£3.4M, ended 11/2011);
- EPSRC Centre for Innovative Manufacturing in Regenerative Medicine (EP/H028277/1) with School of Pharmacy at UoN and Universities of Loughborough and Keele (£5.8M total);
- EPSRC Centre for Innovative Manufacturing in Medical Devices (EP/K02952/1, £5.6M

total) with Universities of Leeds, Sheffield, Newcastle and Bradford.

International collaboration is at the forefront of our strategy and a key delivery mechanism for the Unit in this area is engagement in EU projects. Over this REF period the Faculty of Engineering has been a member of over 140 EU funded projects; exemplars of these projects are listed below:

- SHYMAN - Sustainable Hydrothermal Manufacturing of Nanomaterials (FP7-NMP/280983, 2012 - 2016 (€9.7M, 22 partners, UoN lead);
- MiRoR - Miniaturised Robotic Systems for Holistic In-situ Repair and Maintenance Works in Restrained and Hazardous Environments (FP7-NMP/284959, 2012-2016, €5M total, 9 partners, UoN lead);
- TRANSMIT - Training Research and Applications Network to Support the Mitigation of Ionospheric Threats (FP7-PEOPLE/264476, 2011-2015, €3.9M, 9 partners, UoN lead)
- INNOVATE - The Systematic Integration of Novel Aircraft Technology (FP7-PEOPLE – 2013, £2.81M, UoN lead);
- E-BREAK - Engine Breakthrough Components and Subsystems (FP7-Transport), 2012-2016 (€29.9M total);
- Clean Sky: associate partner in the Systems for Green Operations (SGO) ITD, with 12 ITD Leaders: 2008-2017, (€10M for Nottingham, total €1.6Bn).

Our industrial partners are a key part of our strategy to maximise the impact of our innovation. In this REF period we have continued or established collaborations and partnerships with numerous industrial partners, exemplars include:- e2v technologies ~£1.2M for research across microwave processing and high power electronics; Rolls-Royce £6.5M, to support research across 2 University Technology Centres (Manufacturing Technology and Transmissions) and various other projects, Boeing Company ~$1M per annum for carbon fibre recycling projects, Cummins Generators ~ £0.6M for high power electronics, E.ON AG and E.ON UK plc, £2.9M for energy-related research, Ford Motor Company Ltd ~£1.5M for engines-related research, Ministry of Defence, ~£1M portfolio of projects, Network Rail, £1.3M for strategic partnership and support of Royal Academy of Engineering Chair in Asset Management, Rio Tinto Technology ~£9M (Further AUS$10M agreed from October 2013 to September 2018), related to energy efficiency in mineral processing, Shell UK, ~£5.2M for Bitumen-related research and AVIC Commercial Engine Aircraft Company~£3.2M for aerospace-related research. Other new/renewed strategic partnerships with international industry partners include: £1.5M for our Cummins Innovation Centre, £1.15M Alstom Grid Centre of Excellence, £566K Nowforever Drives Innovation Centre China, and a £2.7M Wahaha China Innovation Centre.

During the assessment period 13 plenary addresses were given along with 65 keynote speeches. Exemplars include:

- “From heavily degraded oil to black carbon: the diverse analytical applications of hydropyrolysis” at the 19th International Symposium on Analytical and Applied Pyrolysis, Linz, Austria, May 2012 (Snape);
- “Serial and parallel approaches to laser ultrasonics”, 15th International Conference on Photothermal and Photoacoustic Phenomena, Leuven, Belgium (Somekh);
- “Prediction, measurement and significance of reinforcement permeability", 10th International Conference on Flow Processes in Composite Materials (FPCM-10), Ascona, Switzerland (Long);
- “Wear of cermets and cermet coatings – the role of microstructure”, International Conference on Wear of Materials, April 2013, Portland Oregon (Shipway).

Over 225 invited papers, speeches, lectures and seminars were given in the assessment period with 23 best paper awards being received. During the assessment period members of staff also received 56 prizes, awards and honours, exemplars include:

- IChEME Energy Award 2011 (Joint with e2v) (Kingman);
- Bielby Medal and Prize, Awarded by the Royal Society of Chemistry, the SCI and Institute of Materials, Minerals and Mining, 2011 (Kingman);
- Royal Academy of Engineering Silver Medal 2009 (Warrior);

- Chandra Desai Medal, International Association for Computer Methods and Advances in Geomechanics 2008 (Yu);
- The Royal Institute of Navigation (RIN), Gold Medal, RIN's highest honour for outstanding contributions to navigation, 2013 (Moore);
- 16th Schoemacker Award by the International Association of Hydraulic Research (IAHR) in 2009 for best paper published in journal over the previous two-year period (Morvan);
- 2011 IET Ambrose Fleming Medal for Achievement in Information and Communications (Christopoulos).

The Faculty has also won a total of 5 awards given annually by the Engineer Magazine with teams led by Snape (2008), Kingman x 2 (2008, 2011), Sewell (2009), and Hague (2010).

Members of Faculty have also participated in 16 standards or advisory bodies or groups, exemplars of contribution include:

- Member Aerospace Electrical Power Systems, National Technical Committee (TSB) (Wheeler);
- Member of AGRRI, Advisory Group for Rail Research and Innovation (Andrews);
- Member, US Transportation Research Board, committee AFP70 "Mineral Aggregates", Transportation Research Board, US Academy of Sciences (Dawson);
- Technical Committee member, International Society for Soil Mechanics and Geotechnical Engineering (Yu);
- Member of the technical steering groups for the technology chapter of the DECC CCS roadmap (Drage);
- Mission to Japan (Nov 2011), funded by British Embassy in Tokyo, visiting Japanese companies and universities to discuss developments in manufacture of polymer composites (Long);
- EPSRC Manufacturing the Future Strategic Advisory Team (Sharples);
- BBSRC Strategy Panel on Industrial Biotechnology 2012 and BBSRC Expert Panel on Industrial Biotechnology 2010, and Bioscience for Industry Strategy Panel review of the BBSRC Technology Strategy (2008) (Stephens).

Faculty members hold 28 positions on Editorial Boards, exemplars include:

- Editor-in-Chief (Founding Editor) of Proceedings of the Institution of Mechanical Engineers, Part O, Journal of Risk and Reliability (Andrews);
- Editor-in-Chief – Geomechanics and Geo-Engineering: An International Journal, Taylor & Francis (2006 to date) (Yu);
- Co-Editor in Chief, Wear (2013 to date) (Shipway);
- Editor-in-Chief, Optical and Quantum Electronics (Benson).

Members of the Faculty also hold key leadership roles, exemplars include:

- International expert on IEA Hydrogen implementation agreement Task32: "Hydrogen-based energy storage" (Grant);
- UK delegate and Member of the TC5.1 and TC5.2 of IFAC – the International Federation of Automatic Control and member of the UK TSB Manufacturing Committee (Ratchev);
- Advisor, TSB Special Interest Group on Additive Manufacturing, 2011/12 (Hague);
- Advisor to DSTL on Forecasting Advances in Design, and Manufacture, 2011/12 (Hague);
- Member of UK Composites Leadership Forum – Reporting to Department of Business, Innovation and Skills (Long).

Twenty six members of our academic staff are also current members of the EPSRC College of Peers and 5 of our staff hold Fellowship of the Royal Academy of Engineering (Yu, Benson, Hyde, Christopoulos, and Somekh). In 2013 Moore was inducted as Fellow of the United States Institute of Navigation, only the 3rd British person ever.