Institution: University of Aberdeen

Unit of Assessment: 15 (General Engineering)

a. Overview

Engineering research at the University of Aberdeen extends from theoretical analysis through computational modelling to sophisticated engineering experiments. Operating within a General Engineering structure and philosophy, the Unit has substantially increased the size and range of its research since 2008. This is reflected in the increase from 31.1 FTE to 38.6 FTE submitted staff between RAE2008 and REF2014. A new research structure was implemented in 2009 (with further refinement in 2012) allied to the recruitment of a significant number of new academic staff and strong growth in research activities in both well-established and newly-emerging research directions. The structure underpins the School's commitment to enhance fundamental and applied research, support post-graduate research students and increase research income.

Researchers are affiliated with one or more of the Unit's five Research Groups (as indicated in REF1a). *Applied Dynamics* comprises 11 members (9.4 FTE) and 1 affiliate from another group of the Unit; *Environmental and Industrial Fluid Mechanics* comprises 9 members (9 FTE) and 1 affiliate from another group; *Materials and Chemical Engineering* comprises 3 members (3 FTE), 2 affiliates from other groups and 1 member submitted to UoA 8 (Chemistry); *Power Systems, Communications and Optics* comprises 10 members (10 FTE) and 1 affiliate from another group; *Solid and Granular Mechanics* comprises 8 members (7.2 FTE) and 6 affiliates from other groups.

The School of Engineering is home to 4 Research Centres: the *Centre for Applied Dynamics Research (CADR)* founded in 2003; the *Centre for Micro- and Nanomechanics (CEMINACS)* founded in 2004; the *Lloyd's Register Foundation (LRF) Centre for Safety and Reliability Engineering* founded in 2010; and the *Centre for Innovative Building Materials and Technologies (CIBMT)* founded in 2013.

b. Research strategy

The Unit aims to conduct fundamental and applied research that ranks amongst the best in the UK and internationally, making major contributions to engineering science and the development of new technologies. Our research strategy has four main elements. First, recognising that major breakthroughs require understanding and insights at the basic level, and that a strong base of fundamental research underpins capability for, and excellence in, applied research, we encourage and support fundamental and curiosity-driven enquiry across the groups. Second, we strategically develop the existing internationally-competitive research areas within the Unit while enabling the emergence of promising new directions that are consistent with the Unit's overall research scope. These two elements combine to influence heavily the Unit's investment priorities in terms of academic staff recruitment, PhD studentship allocation and investment in new facilities and equipment. Third, in keeping with the philosophy of General Engineering at Aberdeen, we encourage research across the engineering discipline boundaries; for this reason, many researchers within the Unit are active in more than one Research Group. Fourth, we proactively engage with industry and respond to government and industry initiatives for which we are well placed to make substantial and effective contributions. Accordingly, we are active in Proof of Concept (PoC), Knowledge Transfer Partnership (KTP) and Technology Strategy Board (TSB) research projects, participate fully in Scottish Funding Council (SFC) research pooling initiatives (The Northern Research Partnership, The Telford Institute, The Energy Technologies Partnership), and will play a major role in the new Scottish Government/Industry-supported Innovation Centres in Oil and Gas and in Sensors and Imaging Systems (CENSIS).

The 5 Research Groups help to maximise the activity and output of researchers, not only by promoting a strong research culture, but also through effective teamwork and mutual support, including the mentoring of Early Career Researchers (ECRs). Cross-group and cross-disciplinary research is frequent and encouraged. For example, KTP projects typically involve researchers from more than one research group and the project on Resonance Enhanced Drilling (RED) funded by ITI Energy (2008-13) involves researchers from four research groups. The Unit also makes significant contributions to the University's cross-institutional Energy research theme.

Each Research Group is led by a senior academic, who co-ordinates the group's activities and is a member of, and reports to, the School Research Committee. The structure, key appointments, and organisational adjustments of the Research Groups are considered by the School Director of Research and the School Research Committee, subject to approval by the Head of School. The School Research Committee also includes the School Coordinator for Postgraduate Research Students and a representative of ECRs. It oversees the strategies and activities of the Research Groups, monitors research performance and allocates School funds to promote the research culture and stimulate multi-disciplinary research, international collaborations, links with industry and commercialisation. Research group budgets support group-related research activities.

Targeted investment has enabled the Research Groups to develop substantially and to expand their range of activities. Key performance indicators since 2008 include:

- the average annual number of refereed journal publications per FTE of submitted staff is 3.2 - almost double the corresponding number for the RAE2008 period;
- the average annual research spend is £2.00m - a 52.5% increase on the RAE2008 period (£1.31m);
- the average annual postgraduate research student enrolments and successful completions have increased by approximately 20%.

Within the Unit's overall research strategy, each Research Group has shaped its research priorities. The aims, activities and main achievements are summarised as follows:

The **Applied Dynamics** Research Group is focused on (i) modelling and analysis of engineering systems exhibiting non-linear responses, and practical applications of dynamics, control and condition monitoring; (ii) impact and explosion mechanics, including fundamental understanding of energy absorption, and deformation characteristics of materials and sandwich structures with metal foams and truss cores subjected to blast, shock or ballistic loading. This group has been re-organised since 2008, with Aphale, Ing and Omenzetter joining as new appointments, and Reid, Aleyaasin and Harrigan coming from another group of the Unit. Much of the group's research is strategically linked to the University's Energy theme. Energy-related research includes the RED project (Wiercigroch, Pavlovskaia, Ing), now exploring commercialisation routes; investigation of drill-string dynamics (Wiercigroch); pilot studies of pendulum dynamics exploring ideas of energy extraction from sea waves (Pavlovskaia, Thompson, Wiercigroch); and work on energy absorption by material and structures under impact loading (Reid, Harrigan, Aleyaasin). Group members are also engaged in the development of new models applied to a wide range of engineering systems, including nano-positioning (Aphale); pipe whipping (Aleyaasin); seabed impact of trawling gears (Ivanovic, Neilson); underwater cutting; condition monitoring of ground anchorages (GRANIT, see Impact Case Study 3) (Ivanovic, Neilson); dynamics and structural health monitoring of large civil engineering structures (Omenzetter); and modelling of vortex induced vibrations for catenary risers fatigue life prediction (Wiercigroch). The group's general approach to research is to develop new analytical tools and technologies based on sound understanding of the underlying fundamental physical phenomena; the RED and GRANIT technologies are good exemplars of this approach. Over the next 5 to 7 years the Group will maintain its emphasis on fundamental research underpinning practical application in industry, with particular focus on energy-related applications, e.g., drilling techniques, underwater cutting for decommissioning, and flow-induced pulsations in corrugated flexible pipes.

The **Environmental and Industrial Fluid Mechanics** Research Group studies two major interconnected areas: (i) hydrodynamics of free-surface flows, and (ii) mechanics of multiphase flows and transport. Both areas cover natural and industrial flows at multiple scales, from sub-mm to kilometres. The Group has doubled in size since 2008 (when it was named Environmental Hydraulics), with new appointments bringing advanced expertise in multi-scale dynamics and multi-physics modelling (Derksen, Gomes, Campbell Bannerman), geophysical flows and liquid-solid impacts (Hicks), and flow and transport in obstructed systems (Tanino). The key achievements in the area of free-surface flows lie in fundamental aspects of open-channel fluid mechanics (Nikora, Pokrajac, Tanino), coastal processes (O'Donoghue, Guo, Pokrajac), eco-hydraulics (Nikora), flow-porous-bed interfaces (Pokrajac), and liquid-solid impacts (Hicks). The Group's research on multiphase flows and transport concentrates on sediment dynamics in unidirectional and oscillatory flows (Nikora, O'Donoghue, Guo), flow-particle interactions and multi-fluid modelling (Derksen,

Gomes), and molecular fluids (Campbell Bannerman). The exemplar of the group's research impact is presented as Impact Case Study 5. The strategic goal of the expanded group is to advance fundamental knowledge of unidirectional and oscillatory rough-wall free-surface and multiphase flows in order to develop better understanding and predictive tools for enhanced design and management of natural and engineered fluid systems. Fundamental research on free-surface and multi-phase flows will continue to be a primary focus of the Group for the next 5 to 7 years, while expanding its energy- and environment-related areas of interest to include hydraulic and fluid mechanics aspects of carbon sequestration, enhanced oil recovery, aquaculture systems and the environmental impacts of marine renewable energy systems.

The **Materials and Chemical Engineering** Research Group has been established since RAE 2008. The group's research strategy involves building on its core strengths in materials chemistry and engineering to engage in wider interdisciplinary research across the University, while at the same time raising contributions through national and international collaborations. The group interfaces with petroleum engineering, chemistry and petroleum geology (all within the College of Physical Sciences), particularly in areas related to oil and gas and other energy-related research. The group's cross-discipline interactions are facilitated by the joint appointment of the research group leader (and University Energy theme leader) with a 50% appointment in chemistry (Anderson). The research combines experimental, computational and theoretical modelling approaches to the study of: reaction kinetics and vibrational spectroscopy to understand solvent interactions and adsorption and interfacial properties; innovative low operational and embodied energy systems and processes to reduce the carbon footprint of buildings; the thermophysical properties and phase behaviour of complex fluid mixtures under extreme conditions; and electrochemistry. These fundamental approaches are applied to novel construction materials and the built environment (Impact Case Study 2); Carbon Capture and Storage (CCS); CO_2 Enhanced Oil Recovery (EOR); supercritical technologies; catalysis, photocatalysis and environmental remediation; fuel cells; and renewable energy. Studies involving vibrational spectroscopy of ionic liquids (Kiefer), and their interaction with surfaces (Anderson, submitted to UoA 8 Chemistry) have demonstrated that these liquids can be located and structured within ordered structures, such as metal organic frameworks (MOFS). Recruitment of staff with expertise in thermochemical properties of fluids under high pressure high temperature (HPHT) conditions (Vega-Maza) brings experience of working on large scale CCS projects. Over the next 5 to 7 years the group will recruit further staff to enhance coherence and direction across the group's research areas, embrace opportunities arising from close alignment of its activities with the University-wide Energy research theme and continue to raise its profile through its publications and external collaboration.

The **Power Systems, Communications and Optics** Research Group mainly focuses on power systems analysis, the design of robust internet transport protocols and holographic imaging. The group has increased substantially since 2008 with new appointments bringing expertise in network-collaborative video compression (Verdicchio), superconducting power transmission (Li) and new methods in power conversion (Ahmed, Hajian Foroushani). Since 2008, the group has established an electrical power laboratory with a state-of-the-art 900V DC grid demonstrator (funded by PoC and EPSRC projects), achieving major results in the development of MW-size DC/DC converters and DC circuit breakers (Jovcic, Hajian Foroushani) (see Impact Case Study 1), multi-terminal DC hubs (Jovcic, Hajian Foroushani) and DC fault tolerant VSC HVDC converters (Jovcic, Ahmed). Studies on integration of renewable energy sources are centred on inverter control and maximum power tracking algorithms (Ahmed). Internet engineering research (Fairhurst) developed new Internet Protocol (IP) standards, including the European DVB-RCS2 standard for IP-based satellite broadband (see Impact Case Study 4), and has provided substantial input to the University's RCUK-funded dot.rural Digital Economy Hub project. New work has pioneered hardware and software to enable deployment of sensor networks in challenging environments (Allen, Fairhurst, Verdicchio) and developed algorithms for image analysis and video processing (Allen, Verdicchio). In theoretical and applied optics, digital holography (Watson) and new applications of fibre optics (Kaliyaperumal) have been studied. Research in low-cost high-frequency band-gap semiconductors (Dunn) has led to the development of a novel Planar THz Gunn Diode. The group plans substantial development of core research facilities taking advantage of investment in new laboratories as a part of the Engineering building refurbishment in 2008-12, encouraging use of these as a platform for expansion and collaboration with European research partners. In the next 5

to 7 years, the group will consolidate areas of strength in power electronics, utilising new appointments for further expansion of its renewable energy-related research, and will strengthen its research capability in scaling the internet, seeking to explore issues surrounding Big Data and new techniques to meet the challenges of the growing volume of network video.

The **Solid and Granular Mechanics** Research Group addresses real-world problems that require a precise mathematical description of the mechanical behaviour of advanced and novel engineering materials. It includes studies of functionally graded materials (FGMs) (Kashtalyan), micro- and nano-composites (McMeeking, Guz, Akisanya) and the constitutive modelling of granular and ceramic materials (Chandler). This is achieved through analytical and numerical methods, with experimental verification (Akisanya, McMeeking). The group has evolved from the Mechanics of Materials group since RAE2008 with new appointments enhancing existing research strength in analytical modelling of composite and granular materials, and adding new directions in safety and reliability (Sriramula) and computational mechanics (Menshykov, Sands). All group members have a background in continuum mechanics and so use a common language and modelling philosophy to enhance the mathematical description of material behaviour by including previously ignored physical phenomena. Research highlights during the REF period include advances in dynamics of cracks with interacting faces (Guz, Menshykov); coupled problems of thermo-visco-elasticity, dissipative heating of structures with PZT actuators, and multi-scale modelling of nano-composites (Guz); studies of thermal barrier coatings and models predicting the performance and failure of fuel cells (McMeeking); and new elastoplastic models for soil (Chandler, Sands). Key achievements in the area of FGMs relate to sandwich structures, coating/substrate systems and exact solutions for anisotropic graded materials (Kashtalyan). Members of the group often use finite element (Kashtalyan, Sands) or boundary element methods (Menshykov) in innovative ways incorporating enhanced material models. The aim of the group is to increase fundamental knowledge, with the particular focus on internationalisation of research efforts. Over the next 5 to 7 years the group will continue growing its numerical analysis capacity, fully exploiting the University's new High Performance Computing cluster installed in 2013, and expanding its analytical capability through extensive international collaboration and new recruitment.

New research centres or groups may emerge in response to changing priorities (for example, a new research group was established, and two other groups, Applied Dynamics and Solid & Granular Mechanics, have significantly evolved since 2008). There is significant potential for further enhancement of our research portfolio through strategic re-investment, recruitment of new staff and continued development of our research culture, whereby researchers and students from all groups meet regularly to freely exchange ideas, initiatives, and approaches.

c. People, including:

i. Staffing strategy and staff development

Our staffing strategy is a combination of the career development of existing staff and recruitment of new staff bringing research expertise that aligns with or complements the strategic research directions of the Unit (Section b). Strategic expansion of the School's provision to include Chemical and Petroleum Engineering, coupled with the University's drive to increase its intellectual capacity and capability in energy research, has led to substantial growth in the Unit's research base: 45% of submitted researchers were appointed since 2008. The University investment in internationally-leading researchers, in particular, the more recent recruitment of Derksen (Alberta, Canada), and 50% relocation of Anderson (from Chemistry) has enhanced existing research and added new directions in solid-liquid suspensions and materials engineering. Professorial appointments have been strategically complemented by Reader and Lecturer appointments, including international appointments of Omenzetter (Auckland, New Zealand) to Senior Lecturer, Kiefer, Campbell Bannerman (Erlangen-Nuremberg, Germany) and Li (Kyoto, Japan) to Lecturer.

Sustainability of the research base has been a key priority within the Unit's recruitment strategy. Following the University's successful 6th Century Campaign to recruit internationally-leading senior researchers, the Unit has strategically placed strong emphasis on recruitment of promising ECRs:10 of the 18 researchers appointed since 2008 are ECRs (Ahmed, Campbell Bannerman, Hajian Foroushani, Hicks, Ing, Li, Sriramula, Tanino, Vega-Maza, Verdicchio). Developing the research skills and performance of ECRs is a core element of the School's strategy. This involves

internal support to assist their research, assigning a formal mentor, lighter teaching loads, priority in the allocation of PhD studentships and participation in the University's researcher development programme. The research groups maximise the research potential of their members by fostering a vibrant research culture, supporting and mentoring new staff and promoting effective teamwork.

Staff research is also supported in various ways at the University and College levels. At the institutional level, a Research & Innovation (R&I) unit advises researchers on available funding options, deadlines and application guidelines, sponsors frequent visits by representatives of funding bodies, and oversees the application process. The University also has a dedicated Researcher Development Unit (RDU) providing a progressive, institutional programme of personal, professional and career development opportunities for researchers at all levels, including many workshops and courses with an emphasis on support for ECRs. The induction programme is attended by all new researchers. All activities are aligned with Vitae's Researcher Development Framework, promoting progression through career phases. Positive career development has allowed 6 post-doctoral fellows of the Unit to become lecturers (Aleyaasin, Aphale, Hajian Foroushani, Ing, Menshykov, Sands) and one of them then a senior lecturer (Menshykov).

The University has been awarded a bronze Athena Swan Award for providing a supportive environment for female researchers. The institutional Equality and Diversity Policy is applied to all aspects of employment within the Unit, including recruitment, promotion, development opportunities and disciplinary procedures. All staff has access to Equality and Diversity training providing fundamental education in the legislative framework and its practical implementation. This training is mandatory for all staff with supervisory and recruitment responsibilities. The University holds an HR Excellence in Research Award, which recognises alignment and implementation with the Concordat to support career development of researchers (www.vitae.ac.uk/concordat), and an Investors in People Award (institutional bronze). It participated in benchmarking surveys through the Careers in Research Online Survey (CROS), the Principal Investigators and Researchers Survey (PIRLS), and the postgraduate research experience survey (PRES).

Six senior researchers (Akisanya, Fairhurst, Guz, Neilson, O'Donoghue, Pavlovskaia) have completed the University's award-winning International Leadership Development Programme, which is the University's flagship programme for enhancing the operational and strategic leadership skills of senior staff to enable the implementation of institutional strategic goals. Aspiring Principal Investigators (PIs) of the Unit have attended the residential PI Development programmes run by the University's RDU and focussed on developing research leaders and senior PIs, growing internal and external reputations, growing research teams and supporting the institution to strive for excellence. The Unit has a robust internal peer-review system for grant applications which addresses both the academic and ethical aspect of proposals. Since 2012, one of the Unit's senior researchers (Chandler) has been Chair of the College Ethics Board. Individual researchers have access to the School's Research and Teaching Enhancement (RTE) budget to fund research visits, conference attendance and research equipment. The Unit holds an annual off-campus Research Away Day discussing research strategy, support and performance.

The College of Physical Sciences has a Sabbatical/Research Leave policy which is strategically implemented for stimulating new research within the Unit. Staff taking research leave (Wiercigroch 2008, Jovcic 2008, Guz 2008-9, Watson 2011-2, Pokrajac 2013) have used the sabbatical time to generate external collaboration (largely international), conduct research, and produce research outputs. For example, Jovcic was awarded a Royal Academy Global research fellowship and held a 6-months visiting professor appointment at McGill University, Canada in 2008; Guz's sabbatical research in 2009 at Texas A&M University was supported by the Royal Academy of Engineering and at Monash University (Australia) by the Royal Society. Ivanovic (2011) has also been released for an industrial placement with Technip UK Ltd to improve links between academics and the oil & gas industry, one of our key application sectors. Akisanya (2013) worked at Nanyang Technological University (Singapore) supported by Tan Chin Tuan Exchange Fellowship.

The vitality and achievements of the research groups combined with the Unit's and the University's positive approach to career development have been reflected in research-led promotions: Guz to a 6th Century Chair; Watson to Established Chair of Electrical Engineering; Fairhurst, Jovcic and Pavlovskaia to Personal Chairs; Guo, Kashtalyan, Neilson, Pokrajac to Reader; Menshykov, Kaliyaperumal, Ivanovic and Kiefer to Senior Lecturer.

Since 2008, the Unit has hosted a number of prominent international visiting scholars, for example, Ribberink (Twente), Ballio and Radice (Technical University of Milan), Coleman (Auckland), Müller (Berlin Technical University), Zhuk (Timoshenko Institute of Mechanics), Piat (Karlsruhe Institute of Technology), Warminski (Lublin University of Technology), Banerjee (IIT Kharagpur) who engaged in collaborative research with the Unit typically spending from one month to one year in Aberdeen supported by the EPSRC, The Royal Academy of Engineering (including 3 prestigious Distinguished Visiting Fellowships), The Royal Society and The Royal Society of Edinburgh. The visiting scholars add substantially to the vitality of the Unit's research as evidenced by more than 50% of the submitted outputs having at least one international co-author.

ii. Research students

Funding for PhD study is provided through EPSRC (DTG grant) and College-funded studentships, and, increasingly, through full or partial support from industry. Topping up external funding of at least 50% of the cost of a PhD studentship with internal funding has proved successful in initiating collaboration with industrial partners, e.g., work on subsea riser dynamics with MCS Kenny. Examples of PhD projects fully funded by industry include research on HVDC grids (by Scottish and Southern Energy), and on offshore structure reliability (by Lloyds Register). Recruitment of PhD students is achieved through multiple routes, including selection of best in-house and Erasmus visiting students, world-wide advertisements, and personal international networks.

Training for PhD students is provided by the College Graduate School and follows the Research Councils' Joint Statement on generic skills training, combining courses designed by the University's RDU with discipline-specific courses. The courses map closely to the RCUK standards and the QAA Code of Practice. The Graduate School also provides training for new and experienced supervisors, with refresher training undertaken every 5 years. In some cases, more focused training is provided within research groups or project teams, as, for example, in the case of the dot.rural Hub project, which has a dedicated Training and Outreach Officer to enhance the team's external engagement and cross-disciplinary research.

PhD students register initially for MPhil, with transfer to PhD depending on a written report and oral examination by two assessors (not the supervisors) within the first year; a second year written report is examined by the same assessors and 6-monthly, form-based reporting is used at other times. All PhD students follow a personal development plan linked to their professional aspiration. They present their work at research group seminars at least once per year, at the annual one-day PGR Symposium and, in many cases, at one or more major international conference during their period of study (e.g., at the 7th Euromech Solid Mechanics Conf. in Lisbon, 2009; the 17th Int. Conf. on Composite Materials ICCM17, 2009; the 5th Int. Conf. RiverFlow2010, Germany, 2010; the 10th International Conference on Flow-Induced Vibration & Flow-Induced Noise, Dublin, 2012).

d. Income, infrastructure and facilities

The Unit has maintained a strong record of external research funding throughout the REF period. The funding portfolio consists mainly of research council (RCUK and ERC) and industry awards, reflecting the Unit's commitment to fundamental research underpinning engagement with industry. Substantial growth in the Unit's activities resulted in the value of live research grants increasing from £8.3m in 2008 to £12.3m in 2013 (this increase is not reflected in the REF4 spend profile because spend associated with recent major awards is not yet effected). RCUK funding has increased since RAE 2008 and now constitutes 35.5% of total research spend (£3.528m) over the REF period. Exemplars of funding for each of the Research Groups are:

Funding for the *Applied Dynamics Research Group* is dominated by substantial industry support for research that builds on the group's established strengths in non-linear dynamics. A Scottish Enterprise ITI Energy award (£4.6m, Wiercigroch, Pavlovskaia, Ing) for a five-year programme to develop and commercialise a Resonance Enhanced Drilling system (the RED project) provided a major focus for the group's oil and gas related activities. The RED project is complemented by industry funding from BG Group for research on drill string dynamics (£228k, Wiercigroch). Other major awards include ITF (Industry Technology Facilitator) funding for underwater laser-cutting with application to decommissioning of offshore structures (£256k, Neilson) and EPSRC funding

for research on the integrity of ground anchorages (£267k, Ivanovic, Neilson).

The Environmental and Industrial Fluid Mechanics Research Group has maintained its excellent record of research council funding throughout the period, with EPSRC grants in excess of £1.9m supporting research on swash zone hydrodynamics and sediment transport (£285k, O'Donoghue, Pokrajac), turbulence-induced sediment erosion (£439k, Nikora), coastal water mixing (£145k, Guo), unsteady rough bed boundary layer (£100k, O'Donoghue, Pokrajac), sand transport under breaking and irregular waves (£685k, O'Donoghue), migration of supercritical CO_2 in porous media (£100k, Pokrajac) and memory effects on coastal flooding events (£173k, Pokrajac). Support for research in eco-hydraulics has also come from the Leverhulme Trust for work on flow-biota interactions (£218k, Nikora) and from FP7 to study hydrodynamic transport in ecologically-critical heterogeneous interfaces (€596k, Nikora). The group has also been involved in two KTP projects since 2008 (£300k in total). New EPSRC funding will support research on bed friction for rough-bed free-surface flow, commencing in 2014 (£530k, Nikora).

The research funding portfolio of *the Materials and Chemical Engineering Research Group* is growing as the new group (founded after the 2008 submission) becomes more established. The highlights are the EPSRC-NSF(USA) grant for research on ionic liquids in heterogeneous environments (£289k, Kiefer, Anderson) involving collaboration with Queen's University Belfast on neutron scattering experiments and with computational scientists at Carnegie Mellon (USA); and a £3.3m award from the Qatari Gulf Organisation for Research and Development (GORD) to support a 4-year research project on low carbon cement formulations, cement production processes and novel uses for recycled concrete aggregates (the Green Concrete project).

Since 2008, *the Power Systems, Communications and Optics Research Group* has received over £2.5m from a combination of European, industry, and EPSRC sources (including 1 TSB and 4 EU Framework Programme awards) for research in Internet Engineering spanning sensor networks, transport technology, broadband satellite, and TV delivery. Cross-disciplinary research is supported by the SATNEX consortium, established in 2004 to form a long-lasting integration of key European research centres across the field of satellite communication. An EC award, Reducing Internet Transport latency (RITE, €689k Fairhurst), brings together industrial and academic partners to develop and standardise mechanisms for enabling the Internet to effectively support video-conference, on-line gaming and financial applications. Research funding for the group's work in power systems research has exceeded £1.4m, mostly from ERC and EPSRC. A Scottish Enterprise PoC project resulted in a 30kW prototype and 3 patents for a family of DC/DC converters (£167k, Jovcic). In 2011, the group joined RenewNet, an ERDF/SFC-funded consortium (£155k Aberdeen share) linking the Scottish power industry with academia. High-power DC transformers are being developed within an EPSRC project (£297K, Jovcic) and an EPSRC/NSFC(China) award supports research on DC Networks and DC/DC converters for integration of large renewable sources (£500k, Jovcic, Ahmed), in collaboration with 3 Chinese institutions (China Electric Power Research Institute, HuaZhong University of Science and Technology and Shanghai Jiao Tong University). An ERC Starting Grant (€718k, Jovcic) supports the research on modelling platforms for high-power DC hub and power networks.

The Solid and Granular Mechanics Research Group's strategy in developing international research partnerships resulted in several pilot joint projects (funded by the Royal Society, Royal Academy of Engineering and The Carnegie Trust for the Universities of Scotland), with, for example, Berlin Technical University (Kashtalyan, Guz), University of Bremen (Guz), Monash University (Guz) and the Timoshenko Institute of Mechanics, Ukraine (Kashtalyan, Guz), as well as externally-funded research visits to Harvard, Texas A&M, Tufts Universities, UC Santa Barbara (Guz) and University of Siegen, Germany (Menshykov). Previous small-scale projects led to two major EPSRC grants involving international collaboration with Germany on 3D elastodynamics of interface cracks (£300k, Guz, Kashtalyan, Menshykov) and with Ukraine on thermo-electro-mechanical coupling in inelastic layered structures (£375k, Guz, Kashtalyan). KTP funding has supported the group's industry-focused research on friction grip design (£108k, Akisanya), novel structural and sealing components for use in sectional tanks (£200k, Guz, Akisanya, Menshykov), application of composites for oil and gas operations (£125k, Guz, Akisanya, Kashtalyan) and print drying for healthcare applications (£230k, Chandler).

Funding from The LRF for research in safety and reliability engineering (£1.18M, O'Donoghue,

Sriramula, Omenzetter, Harrigan), and the Scottish Funding Council (SFC) award for the Scottish Intelligent Sensor Network (SISNET, £525k, Neilson et al.) is shared across a number of Research Groups. Our participation in the £11.8m RCUK dot.rural Digital Economy Hub (Fairhurst) – one of the six RCUK cross-council priority areas – supports engineering projects exploring social aspects of digital inclusion, technologies for and impact of universal service commitment, and environmental monitoring.

Engineering research at Aberdeen finds also many other wide-ranging industrial applications, from satellite networks to fluid flow in pipes. A high proportion of research is based on direct interaction with and funding from industrial partners, with projects spanning direct industry funding (e.g., EADS-Astrium, Thales Alenia Space) and joint funded programmes (e.g. 5 ESA ARTES Awards). Arrangements for knowledge transfer and supporting research with industry are well developed, in particular, through the North of Scotland KTP Centre and through the University's R&I Office. There is a strong consultancy portfolio (examples include support by ESA to building expertise to standardisation, by Astrium on evolution of mesh military satcom). Other consultancy work relates to engineering problems within the oil and gas industry and draws on expertise from across the Unit's research groups. Researchers' engagement in consultancy work for external clients is supported by a dedicated Consultancy Coordinator within the University's R&I Office.

The Unit's activities are supported by the University's and the School's research infrastructure. Excellent University-wide computing provision (including a new HPC cluster commenced in 2012) is complemented by engineering-specific hardware and software computer clusters and major engineering computing packages FLUENT, ABAQUS, SOLIDWORKS, MATLAB and CADENCE). Specialist facilities support key areas of experimental research, the most notable of which include:

– A High Pressure-High Temperature (HPHT) facility for in-situ testing of materials and components at pressures and temperatures up to 200MPa and 550K respectively;
– Two large test rigs for full-scale experimental research on drill string dynamics and resonance enhanced drilling (new since 2008);
– Two large vibration tables for dynamics research, with capacities up to 500kg and 12kN rated sinusoidal thrust;
– The Aberdeen Open Channel Facility: a 20 m-long, 1.2 m wide water flume, equipped with a computerised instrumentation carriage and a state-of-the art, multi-mode particle image velocimetry system;
– The Aberdeen Oscillatory Flow Tunnel: a 16 m-long water tunnel for studying the fluid mechanics of large-scale oscillatory flows, such as those generated by ocean waves; it is one of the few facilities of its kind in the world;
– The Power Electronics Laboratory: a facility housing 5-converter (30kW each), 2-voltage levels (900V/200V) DC network demonstrators, with capacity for testing DC faults and novel AC/DC converters (new since 2008);
– The Satellite Applications Laboratory: a testbed based on 8 satellite terminals providing accessto networking and satellite equipment for applied research, housed in a purpose-designed environment within the newly refurbished labs;
– Network emulation and internet engineering testbed facilities – based on CISCO and HP routers and switches and linux hosts, used in collaborative EC and ESA projects;
– Optical Engineering laboratories with vibration-isolated optical tables and pulsed, frequency-doubled Ng-YAG and gas lasers, used for holographic reconstruction, underwater laser-cutting and laser-based diagnostic research.

The University has a programme of ongoing investment in research laboratories. A current SFC- and University-funded £13M refurbishment to the Engineering building, including a £2.5M investment in laboratory upgrades, was completed in 2011. This included a full refit of all teaching and research laboratories, and the creation of a new Chemical Engineering Laboratory and purpose-designed accommodation for postgraduate research students (The PGR Centre). Other highlights of investment in major equipment are: a Dantec 2D Laser Doppler Anemometry (LDA) system complete with 3D positioning (£90k, EPSRC and the University) and a custom-designed, 100 Hz, 4-camera, multi-mode Particle Image Velocimetry (PIV) system (£100k, EPSRC, Leverhulme Trust and the University), both for fluid mechanics research; DC convertors and DC grid demonstrator (£100k, EPSRC and Scottish Enterprise) for new research on power systems; and a core-flooding facility to support new research in petroleum engineering (£300k, the

University). Further investment is underway: £950k has been secured from the SFC through the Oil and Gas Academy of Scotland for new equipment (MicroCT scanner, rheometer, potentiostat, interfacial properties rig) to support the Unit's growing research on the physical properties and behaviour of reservoir materials and fluids, primarily with application to reservoir engineering, enhanced oil recovery and CO_2 sequestration.

The work of research laboratories is supported by 15 technical support staff. The mechanical workshop has a well-equipped machine shop where precision manufacturing is undertaken. The electronics workshop is a modern facility which, as well as traditional electrical/electronics, offers services in technical computing and microcontrollers. Workshop capability is high: many of the Unit's major experimental facilities (e.g., the large wave and water flumes and the large-scale drilling facility) have been designed and built in-house.

e. Collaboration or contribution to the discipline or research base

In all its activities the Unit seeks to maintain a high level of national and international collaboration and influence within the broad disciplines of Engineering. Alongside the Research Groups, the School of Engineering is home to four internationally-recognised Research Centres. The *LRF Centre for Safety and Reliability Engineering* is a centre of excellence for the study of practical and theoretical problems related to the safety and reliability of engineering systems. The Centre places Aberdeen within a network of LRF research centres in the UK (Cardiff, City, Imperial, Lancaster, Nottingham, Open, Southampton, UCL) and worldwide (Athens, Dalhousie, Pusan, Seoul, Singapore, Twente, Western Australia). The *Centre for Applied Dynamics Research (CADR)* is a multi-disciplinary research centre focused on the application of nonlinear theory of dynamical systems to science and engineering. The *Centre for Micro- and Nanomechanics (CEMINACS)* was founded jointly with Timoshenko Institute of Mechanics to create a critical mass of experts for tackling modern challenges in solid mechanics, mechanical engineering and material sciences. The *Centre for Innovative Building Materials and Technologies (CIBMT)* has as its primary focus the reduction of conventional energy use and carbon emissions in buildings.

The high level of international collaboration, which was a feature of the Unit's RAE2008 submission, has been maintained. There are formal agreements with the Timoshenko Institute of Mechanics, Kiev (involved in two EPSRC projects and three Royal Society and Royal Society of Edinburgh International Joint Projects) and the Indian Institute of Sciences, Bangalore (research visits funded by the Royal Academy of Engineering). Since 2008, the School has received more than 100 international and UK research visitors, most contributing lectures to the School's seminar series and many engaged in on-going collaborative research projects with the School. Exemplars of internationally-leading collaborators with joint publications, grants and/or visits to/from Aberdeen include: Uhlmann and Rodi, Karlsruhe Institute of Technology and Frohlich, Dresden Technical University supported by EPSRC/DFG; Ferreira, IST Lisbon supported by the Portuguese Foundation for Science and Technology; Talreja, Texas A&M University supported by the Royal Academy of Engineering; Steigmann (UC Berkeley), Lapusta (Caltech) and Dorfmann (Tufts University) supported by the Carnegie Trust; and Falzon (Monash) supported by the Royal Society.

The Unit contributes to the discipline and research base through participation in external activities, including engagement with learned and professional societies, journals, conferences and advisory groups. Wiercigroch (2009), Reid (2011) and Nikora (2011) were elected Fellows of the Royal Society of Edinburgh; McMeeking was elected Fellow of the Royal Academy of Engineering (2012) and is a Member of the US National Academy of Engineering; Thompson was elected member of both the Hungarian Academy of Sciences (2010) and the Academia Europaea (2010); Wiercigroch received a Doctor Honoris Causa degree from Lodz University of Technology (2013).

Other highlights of our contributions to the wider discipline include:

Prizes: State Prize of Ukraine in Science & Technology (Guz, 2009); American Society of Civil Engineers (ASCE) Hunter Rouse Award (Nikora, 2010); Hinshelwood Prize of the British Section of the Combustion Institute (Kiefer, 2013); Johnson Gold Medal of the Advanced Manufacturing and Production Technology (AMPT) Conference (Reid, 2013).

Membership of the EPSRC Peer Review College (Guo, Imbabi, Kashtalyan, McMeeking, Nikora, Wiercigroch); EU FP7 Aeronautics panel (Guz, 2008, 2012, 2013).

Editors: ASME J Appl Mech (McMeeking, 2002-12); J Hydraulic Research (Nikora, 2011-); Int J Mech Sci (Reid until 2012, Wiercigroch, 2013-); Phil Trans Royal Society (Thompson); Royal Society Series on Advances in Science (Thompson); Acta Mechanica Sinica (Wiercigroch, 2009-).

Editorial Boards: Advanced Ceramics (Chandler); Archive Appl Mech (Guz, 2008-); J of Nanomater & Mol Nanotechnol (Guz, 2012-); Int Appl Mech (Guz); J Multifunctional Composites (Guz, 2013-); Comput Mech (McMeeking); J Computer-Aided Materials Design (McMeeking); Mech Compos Mater & Struct (McMeeking); Int J Fatigue (McMeeking); Water Resources Research (Nikora 2006-12; Pokrajac, 2011-); J Hydraulic Engng (Nikora, 2006-12); Proc Inst Civil Engineers: Engng & Comput Mech (O'Donoghue, 2009-); Int J Math Problems in Engng (Pavlovskaia, 2007-11); Int J Mech Engng Education (Reid, Wiercigroch); Int J Impact Engng (Reid), J Mech Engng & Design (Reid), Proc R Soc A (Thompson, 2012-4); Bifurcation and Chaos (Thompson, 2008-9); Optics & Lasers in Technol (Watson); Optics & Lasers in Engng (Watson); J Holography & Speckle (Watson); Advances in Engineering Monographs Series (Wiercigroch); Automation & Mech Engng: Russian Int Journal (Wiercigroch); Int J Non-linear Mech (Wiercigroch, 2008-); J Dynamical & Control Systems (Wiercigroch, 2009-); Proc Inst Mech Engng – Part C: J Mech Engng Sci (Wiercigroch, 2008-); Theor & Appl Mech Letters (Wiercigroch, 2010-).

External Working Groups and Professional Bodies: U.S. National Committee on Theoretical and Applied Mechanics (McMeeking, member-at-large); Transport and Services (TSVWG) standards working group of the Internet Engineering Task Force (Fairhurst, Chair); IETF Transport Directorate (Fairhurst); EU working group for offshore and onshore grid development (Jovcic, 2010-); 3rd Worldwide Failure Exercise WWFE-III (Kashtalyan); IAHR Committee on Experimental Methods and Instrumentation (Nikora, Chairman and later leadership group member); Expert panel on urban groundwater management, World Water Day (Pokrajac, South Africa, 2011); EUROMECH (Guz, member, 2009-); IEEE (Jovcic, Senior Member); Hydrogen and Fuel Cells SUPERGEN Hub (Kiefer, Science Board member, 2013-).

Academic congresses and committees: Int Union for Theoretical and Applied Mechanics (IUTAM) Executive Congress Committee (McMeeking, Secretary, 2012-); Director, Int Congress on Fracture (McMeeking, 2005-9); American Academy of Mechanics (McMeeking, Secretary, 2005-10); IUTAM Symposium (Wiercigroch, Chair, 2010).

Plenary addresses and Distinguished Lectures: Isaac Newton Institute, Cambridge (Thompson, 2010); Royal Statistical Society, London (Thompson, 2010); Rouse Lecture at World Env Water Res Congress (Nikora, USA, 2010); JF Bell Distinguished Lecturer, Johns Hopkins University (McMeeking, 2011); Mechanical Engineering Distinguished Lecturer, University of Maryland (McMeeking, 2011); Jerzy L. Nowinski Distinguished Lecturer, University of Delaware (McMeeking, 2011); Warren Series Lecturer, University of Minnesota (McMeeking, 2011).

Examples of keynote talks at international conferences include: 4th Eur Conf on Comput Mech ECCM-2010, France (Menshykov); 2nd Int Workshop on River and Reservoir Hydrodynamics, Portugal, 2011 (Pokrajac); Int Conf on Comput & Exper Engng & Sciences ICCES-2012, Greece (Guz); 4th Int Conf on Application of Physical Modelling to Port and Coastal Protection CoastLab 2012, Belgium (O'Donoghue); Euromech Colloquium 541, Italy, 2013 (Pavlovskaia); 3rd Int Conf on Dynamics, Vibration & Control ICDVC-2010 China (Wiercigroch).

Invited talks/seminars at leading universities: Harvard, Caltech, Berkeley, U of Texas at Austin, Monash (Guz); Imperial College, Southampton (Sriramula); Xi'an Jiaotong, Madrid, Bath (Pavlovskaia); TU Berlin (Kashtalyan); Tokyo, U of Hong Kong, Nanjing University, IIT Bangalore, TU Delft, INRIA Grenoble (Wiercigroch).

Invited Editorials: "Continuum Solid Mechanics at Nano-Scale: How Small Can It Go?", J Nanomater Mol Nanotechnol (Guz, 2012); Guest Editor, Int J Nonlinear Mech (Wiercigroch, Pavlovskaia, 2008).

With support from School funding, staff in the Unit regularly participate in international conferences as a means of disseminating their work, sharing the results of existing collaborations and providing opportunities to develop new ones. In addition the Unit has hosted several international conferences since 2008, most notably the IUTAM Symposium on Nonlinear Dynamics for Advanced Technologies & Engineering Design (July 2010); the 9th Conf on Boundary Integral Methods (July 2013); and the Int Conf on Nonlinear Dynamics in Engineering (August 2013).