Institution: University of Sussex

Unit of Assessment: UoA 15 General Engineering

1. Overview

The four groups comprising the Unit are engaged in research in a range of fields utilising facilities and experience that are, in several case, unique. The four research groups are:

- Dynamics, Control and Vehicle Research Group (***DCVRG***), which undertakes automotive research and fundamental work in dynamics, control and tribology;
- Industrial Informatics and Signal Processing Research Group (***IISPRG***), which develops signal processing techniques, primarily of images, for a range of applications;
- Sensor Technology Research Centre (***STRC***), which works on the fundamentals of sensor development, and application scenarios; and
- Thermo-Fluid Mechanics Research Centre (***TFMRC***), which undertakes aerodynamic and heat transfer research in the area of gas turbine technology.

To heighten each group's focus and ensure that complementarities co-exist, the five groups presented in RAE2008 have evolved into four, which have a vibrant interdependency, primarily through the *enabling* research *(*e.g. Sensors, control, simulation and signal processing) and experience.

2. Research strategy

The **strategic aim** is to undertake research recognised for quality, adopted by the wider research community and, where appropriate, beyond – hence, to enhance the Unit's excellent reputation, attract foresighted researchers and collaborators, and develop future generations of researchers. The groups utilise regular research planning at individual, group and cross-group levels to:

- maximise the advantages of co-existing engineering subject expertise;
- maintain currency through horizon-scanning to inform five-year rolling plans, including exploitation points; and
- ensure enabling technologies and methods permeate all groups and are available to other disciplines, thus ensuring sustained creativity, quality and continuity.

***DCVRG*:** With transport as a key societal challenge, the strategy has been to link excellent science through academic collaboration and industry–academia partnerships. On *Dynamics* the emphasis has been on energy-efficiency improvements in internal combustion and aircraft engines, plus vehicle structural-weight reduction through improved analysis, leading to lower CO_2 emissions; on *Control,* the emphasis has been on energy recovery and system security using robust non-linear control and smart systems; and, on *Tribology*, the emphasis has been on emissions reduction, nano-technology for lubricants, and a deeper understanding of friction mechanisms.

The Group's strong working relationships with research-based commercial organisations – including vehicle manufacturers – combined with published policies and targets in documents such as the 2013 EU policy publication *Towards a Green Economy in Europe: EU Environmental Policy Targets and Objectives 2010–2050* influence the strategy. The Group's expansion in line with its rolling plan has seen academics employed to bolster expertise in control, tribology and analysis. With a commercial research organisation, the Group is currently undertaking a study to determine the feasibility of joint appointments to maximise bi-directional research and knowledge transfer.

***IISPRG*:** In order to remain focused, the Group's strategy has been to develop signal acquisition and processing techniques for novel and often noisy environments in the context of two application fields: medical and security.

- In the case of medical imaging, this includes the advancement of Fluorescence Lifetime IMaging (FLIM) hardware and software for applications including the study of intercellular

protein interactions; and developing texture-analysis algorithms for CT and MRI image diagnosis and prognosis, application emphasis being cancer, schizophrenia and autism (REF3b case study 1).
- For security applications, specifically surveillance and tracking, there is a hardware focus on integrated multi-camera systems resilient to light changes and occlusion; and software development for tracking variable-velocity bodies, with variable observable cross-sections, in cluttered backgrounds.

***STRC*:** In the RAE2008 submission, sensor research was a part of the Physical Electronics and Quantum Technology Group. As the Electric Potential Sensor (EPS) research became increasingly significant as a generic measurement technology, resources were very successfully channelled into sensors and the creation of the Sensor Technology Research Centre.

As the success of the EPS work grew, the planning and horizon-scanning process resulted in strategic decisions being made to embed telematics within the Centre, and to increase the breadth of sensors researched, thus enabling multi-type sensor research, integrated data-handling and transmission to be applied to key global issues, including the aging population, healthcare, and safe energy provision. Hence, new appointments have been made in the areas of human computer interaction, wearable sensors, and semiconductor radiation sensors. In addition, existing communications research (mobile communications, wireless networks and embedded systems) is now embedded within the Centre, and an additional appointee will start in 2014.

The very successful relationship between the Centre and Plessey Semiconductors, technology licensees, has demonstrated the influence of development activities on research. It is into this Centre that the first two of the Unit's newly recruited 'Technical Developers' are being deployed with the intention of further enhancing exploitation of the seven internationally filed patent families and ensuring currency and a symbiotic interaction with commercial research.

The ***TMFRC*:** has built on its strong RAE2008 position by continuing to work in the areas of aerodynamics and heat transfer, typically applied to gas turbine technology, other rotating-machinery and non-standard flow and heat-transfer applications.

One of the significant beneficiaries of the work undertaken by the Centre is the aero-engine industry. When working in this area, to remain current and to have sight of the commercial-in-confidence research, it is essential to be aligned with the research (and research finance) planning of the major engine designers. The Centre has a strategic alliance with GE Aviation and previously with Rolls-Royce plc (REF3b case study 2). To enable the Centre to engage in such alliances it is essential to ensure that the unique and comprehensive experimental facilities are maintained to validate theoretical work. Hence, the ratio of experimental to theoretical academics is maintained, and mirrored in additional appointments – most recently, an experimentalist and a theorist.

3. People, including:

3.1 Staffing strategy and staff development

The Unit's staffing strategy is based around appointments to research groups to build on and/or complement existing strengths, maintain critical mass in each area and across the enabling technologies and, where appropriate, to enhance or develop new collaborations. Posts are advertised and appointed to in line with University procedures within which equality is fully integrated, as it is in all University procedures, including promotion and staff development. In addition, Sussex is a member of the Athena SWAN charter for the advancement and promotion of the careers of women in STEM subjects, and has a supportive policy on flexible working.

All new permanent staff are provided with research equipment set-up funds and funding for their first PhD studentship, and are given a reduced teaching load and no substantive administrative roles. Those taking up their first academic position have a probationary period, the goals and targets for which are agreed between the probationer and the line manager, with progress reviewed at regular intervals. On completion of probation, the progress reviews are replaced by standard annual appraisals, which are used to help to assess progress against previous objectives

and aspirations, hence to revise goals and targets to reflect an individual's position on their career trajectory, with the aim of achieving and maintaining research of significant international influence.

Early-career researchers have a senior member of staff as a mentor, and are supported and guided by colleagues within their research group. All staff must also submit potential external grant applications for rigorous internal review. This review and feedback process ensures that less-experienced staff rapidly develop grant-writing skills under the guidance of senior colleagues.

Formal Staff Development is provided by the University's Staff Development Unit through a comprehensive programme of courses and activities for enhancing research and professional skills which are fully compliant with The Concordat to Support the Development of Researchers. The University's Research and Enterprise Division also runs regular training on research-related topics, often led by external specialists.

As careers develop, targeted support from experienced senior colleagues is used to help individuals attain the next level, as defined by promotion procedures. At the most senior levels, staff continue to be supported by special training opportunities provided by the University. Staff development at all levels is greatly enhanced by a strongly supportive and collaborative culture within the research groups which enables the exchange of ideas and best practice. This culture allows privileged access to research resources and the extensive national and international network of senior colleagues – a network that saw 57 scholars, including senior professors and government advisors, visiting from across the globe during the REF period, all of whom enrich the research environment and partake in lasting collaborations.

During the REF period there have been 11 new academic appointments, nine of which, including two women, are in post. Two others will start at the beginning of 2014, and a further four positions are to be advertised. For a considerable number of the new staff, this is their first permanent academic position.

3.2 Research students

The doctoral programme is the path followed by research students. Its aims are:

- to provide students with the full breadth and depth of knowledge and skills required to be independent researchers; and
- to prepare students for careers in academia or the commercial and public sectors.

Applications to study with the Unit come as a result of academics' reputations, and nationally and internationally advertised research projects and studentships. Annually the Unit typically offers 3 EPSRC studentships, awarded through the University's central allocation competition. The Unit also submits the very best students for the University's Chancellor's scholarships. In addition, the Unit typically offers 4–6 of its own PhD scholarships per year, exceeded when new staff are appointed and their first PhD studentship is funded by the Unit. In all cases the acquisition of match funding from external sources is encouraged.

At a University level, all doctoral students are supported by the Doctoral School and are required to participate in transferable and professional skills training, tailored to the individual's needs. They also have the option to participate in a range of other academic and professional training opportunities. The Student Life Centre provides coordinated access to a full range of special-study, personal and financial support services. Within the Unit, doctoral students are supported by a Director of Doctoral Studies and his/her associated administrative team. The Unit runs a two-term research-training module for all first-year students, focused on skills at a level designed specifically to bridge those provided at a University level and specific training provided within research groups – the primary communities for research students. The specific training related to students' research draws upon the on-going research activity of their group and is supported by research fellows and experienced fellow students within the group.

To ensure research students experience a flavour of research undertaken beyond engineering, a weekly joint seminar series is held with members of this Unit and those comprising Unit of Assessment 11, Computer Science and Informatics, at which visitors, staff and research students

all present. As an example, recent international speakers presented by the DCVRG include Prof. J. Gajewski and Dr M. Glogowski (2011), Wroclaw University of Technology, Poland; Prof. J. Sugimura (2011, 2012 and 2013), and Prof. Y. Sawae (2012), both Kyushu University, Japan. Every student is also given the opportunity to present at an international conference, and hence is required, in preparation, to present his or her research as part of the in-house seminar series.

The research degrees undertaken cover the spectrum of activities offered by and across groups, and other disciplines. Examples of work extending beyond the Unit include rock movement/structural-health monitoring using Electric Potential Sensors (EPS) supervised jointly by STRC and the University's geomorphologists, and a range of medical image-processing projects supervised jointly by IISPRG and the Schools of Life Sciences and Psychology, and the Medical School.

There are typically 70 PhD students associated with the groups at any one time, with each permanent member of staff supervising approximately 3 students. The ethos of submission within 3–3.5 years is promoted actively. Students have at least one formal supervision meeting per month (usually many more), which the student minutes. All students have at least two supervisors, with the relevant expertise. In the first year of study, supervisors conduct a six-month interim appraisal and each year a formal annual review is held, which includes a substantial report and a *viva*-style interview. The submission rate within four years is greater than 70 per cent.

4. Income, infrastructure and facilities

Infrastructure and Facilities

A specialist technician resides within each group, and the Unit has well-maintained mechanical and electronics workshops. The technical infrastructure is maintained through a combination of the technical-infrastructure elements of external funding and University funds.

Each group has essential software including: ANSYS; CAD (mechanical and electronic); MATLAB and toolboxes; Multisim; LabVIEW; and mobile and wireless development platforms. In addition, each group has a local high-performance computer cluster and access to the University's HPC facilities – Apollo (installed 2010, £2.4m University investment), ~800 cores to which another 128 (£12k) were added by the Unit in 2013. The Unit partially funds an HPC specialist to maximise the potential of the facilities. Sussex is certified as a GridPP Tier-2 site, supporting the ATLAS Virtual Organization and is fully integrated with the Worldwide LHC Computing Grid.

***DCVRG*:** The Group has specialist laboratories. The engine-focused laboratory – estimated equipment-replacement value £3m – contains four engine test facilities:

- a heavy-duty diesel test-cell, with transient dynamometer, currently being used for research funded by the EU involving a 7.2L I6 Caterpillar engine;
- a gasoline test-cell, with steady-state dynamometer, currently being used for industry-funded research involving an I3 DISI engine;
- a steady-state multi-cylinder production engine test-bed with dynamometer, various uses; and
- two single-cylinder engine test-beds – current use (i) a Ricardo Hydra test engine, and (ii) a Ricardo E6 variable compression ratio test engine.

The laboratory also contains specialist instrumentation and diagnostics for IC engine research – PIV and PDA in-cylinder flow diagnostic tools – dSpace hardware, emissions measuring equipment, real-time cylinder pressure measurement, engine-block acceleration measurement and Holomodal (ESPI-Laser-based) structural noise, vibration and harshness measurement systems.

The tribology laboratory, commissioned in 2012 – estimated equipment value of £400k – contains: PCS Instruments Optical interferometry test rig for EHD film measurement; optical interferometry rig for dynamic testing of liquid films, and high-speed imaging system; Solartron A1260 impedance/gain-phase analyser, suitable for corrosion studies, fuel cells, solar cells, LCDs, bio-materials, composites, rheology studies; high-pressure viscometer with a pressure range of up to

1.4 GPa; an Anton-Paar viscometer SV3000; a rotational viscometer, range 0.0002 to 20 Pa.s; and an industry-standard mini traction machine (£36k) for friction measurement under various load, temperature and kinematic conditions, adaptable for the study of hard or soft contacts, wear measurement and electrical-capacitance measurement.

***IISPRG*:** The Group has well-equipped laboratories containing three 2.4m by 1.8m vibration-isolated optical tables; a custom-built x640 fluoresce microscope (SPIM); a Photek CDIR detector photon-counting camera; several CMOS SPAD cameras; 2 Nvidia GPUs; 10 Xilinx FPGAs donated by Xilinx; a frequency-doubled Nd+3:YAG laser, Casix LDC1500; Picoquant PDL800D pulsed laser diode; Power Technology Inc Laser diode; four Uniphase He-Ne and diode laser; Boulder Non-linear Systems liquid crystal spatial light modulator for the production of dynamic computer-generated holograms and correlation filters; a CCD-based beam visualisation system; micro-positioning translation stages, interferometers, optics, Uniblitz shutters, various optimised object illumination light sources, CCD and CMOS cameras, and data acquisition and processing tools.

***STRC*:** The main laboratory suite (£100k) was commissioned in 2011 and contains:

- a surface mount PCB fabrication facility;
- two PCB milling machines, including the new LPKF PROTOMAT S103 (purchased 2013, £26k) to allow the use of high pin density IC's and ball grid arrays;
- a single enlarged commercial screened room with filtered mains supplies, separate earthing and DC lighting, with provision for total isolation from mains power;
- microwave and RF test and measurement equipment, spanning audio frequencies to 22 GHz;
- low noise, low frequency test and measurement equipment, including spectrum analysers and noise measurement apparatus;
- modelling and simulation tools OPNET, and NS3; and
- other items, including a coil winder, surface polisher, high-temperature furnace, high-impedance component and dielectric characterisation equipment, and an impedance analyser.

Additional specialist laboratories include:

- a clean room containing resist spinners, optical lithography and e-beam lithography, ion etching, thermal evaporation, sputtering, plasma etching and chemical/wet bench equipment;
- a new radiation laboratory, £37k investment 2013, containing high (370 MBq) activity radiation sources for semiconductor radiation detector characterisation; X-ray, signal processing and data collection equipment for use with the semiconductor radiation sensors.

The ***TFMRC*:** occupies a dedicated building (refurbished 2011, £20k) containing the following rigs:

- a multiple cavity rig, to investigate flow and heat transfer in high-pressure compressor internal air systems (stacked titanium discs 220 mm radius, heated outer ~180°C, max 8000 rev/min);
- a rim-seal effectiveness rig, to investigate ingestion of hot mainstream gas into a turbine rotor-stator cavity (an engine-representative single stage axial turbine, rated 400 kW, pressure ratio ~2.7:1, outer rim radius ~150 mm, annulus height 25 mm, driven by air from the DART compressor, maximum speed 14,000 rev/min); and
- a bolt windage rig, to investigate flows around rotating bolts (single titanium disc, 220 mm radius enclosed within a sealed steel pressure casing. Optical access for PIV; measurements of torque are made on the drive shaft, driven up to 10,000 rev/min).

The rigs are driven by a range of high-pressure compressors: Rolls-Royce DART aero engine-driven (10 kg/s, 3.5 bar, believed unique); Atlas CopCo ZT250 (0.8 kg/s; 7 bar, gauge-cooled and dried to 25 ºC); or Atlas CopCo screw type (0.6 kg/s; 7.5 bar, gauge-cooled and dried to 25 ºC).

There are also measurement and telemetry capabilities to capture and transmit data including: liquid crystal techniques; Scanivalve DSA systems; Laser-Doppler Anemometry; Particle Image Velocimetry; hot wire anemometry. Datatel radio telemetry provides non-contact transmission of rotating thermocouple signals. In addition, temperature and pressure calibration equipment, enhancement investment £7k, 2013.

Computation is undertaken using in-house structured staggered grid-based LES solver for both compressible and incompressible flows such as combustion, and a highly parallel unstructured compressible LES-solver for aero acoustics and heat transfer. A wind tunnel and 3D printing facilities also enable validations of certain simulations to be undertaken.

Income

Table 1 is a statement of external income, excluding doctoral training awards, attributable to the Unit during the REF period. The level is healthy and sources diverse, with the industrial element (UK and non-UK) demonstrating the significance and impact of the Unit's work over a significant sectorial range. Key industrial partners include: GE Aviation; Jaguar Land Rover; Roll-Royce plc; and Plessey Semiconductors. The 'Other' category includes QINETIQ, RAE, and the Wellcome Trust.

Funder	Value/Unit £	#
UK industry	4,602,247	30
EPSRC	2,130,184	8
EU	1,437,421	7
MOD & HMGCC	1,315,756	10
Non-UK industry	1,075,725	14
TSB	397,532	3
Royal Society	121,112	4
STFC	60,000	1
Other	783,660	8
Total	**11,923,637**	**85**

Each individual's five-year plan contributes to his or her group's and the Unit's plan, which includes anticipated funding and exploitation points. The entrepreneurial environment is evidenced by the formation of TexRAD Limited in 2011, and the licence agreements with Plessey for the Electric Potential Sensor (EPS) generic measurement technology. The improving income level ensures a sustainable position and demonstrates the currency of the work.

5. Collaboration or contribution to the discipline or research base

The Unit's research strategy strongly supports interdisciplinary and collaborative work resulting in numerous collaborations. Across the Unit there are a significant number of inter-group collaborations, PhD co-supervision, joint projects and papers.

The ***DCVRG*****:** research is key to the long-term activities of a number of commercial organisations, evidenced by three collaborations of more than a decade with: Jaguar Land Rover Engineering Centre – adaptive cylinder-pressure reconstruction for production engines; SKF, the Netherlands – bearing tribology; and Hadley Industries, UK – cold-rolled forming design and analysis. Commercial collaborations of two or more years include those with: CDH AG, Germany – analysis of vehicle body noise and vibration (researchers and three PhD students also completed a secondment with CDH); Inawa, France – transmission research, academic is now a company board advisor; BAE Systems and AVL UK – electric vehicle range extender research; and BAE Systems/SEIC – fault tolerant systems. The Group works with the Transport Knowledge KTN and a range of universities, including: Beijing Information Science and Technology University, China; Eylül Üniversity, Turkey; Politehnica University, Romania; University of Houston, Texas; University of Technology, Malaysia; University of Picardie, Amiens; and UK universities.

In-line with the ***IISPRG'***s image-processing focus, the development of texture analysis software for medical applications resulted in long-term collaborations with Brighton and Sussex Medical School, and the Sackler Centre for Consciousness Science; as a result of TexRAD Limited's formation (REF3b case study 1), those trialling the software included the University of Mississippi Medical Centre, USA, and Aarhus University Hospital, Denmark.

Other medical collaborations include those with the Mexican Government and Utah University, USA, in the integration of an Electronic Health Record system with OpenCDS – a Clinical Decision Support system designed by the Group. On the hardware side, collaborations exist with companies and research institutions across the world in CMOS Single Photon Array Detector (SPAD)-based fluorescence lifetime imaging microscopy.

STRC: Electric Potential Sensor (EPS) technology-driven collaborations: Plessey Semiconductors, research and licensing (EPIC sensor, at: www.plesseysemiconductors.com/products/epic/); Philips Healthcare (electro-encephalogram using EPS); British Geological Survey (structural monitoring);

Rescon Ltd (DARPA) (through clothing cardiac monitoring); Meggitt Sensing Systems and Plessey (gas turbine engine monitoring); Kodak European Research (unshielded EPS applications); Plessey (non-contact control, gesture identification); STFC (ionising radiation measurement); MOD (electric fields for position and movement sensing, people); and the Home Office (forensic fingerprinting). The Group works with the Electronics, Sensors, Photonics and ICT KTNs and a range of key academic collaborators including: Oxford Institute of Biomedical Engineering (foetal monitoring); University of Sheffield (MRI instrumentation); Cardiff School of Optometry (electro-retinograms); and the Universities of Leicester, Newcastle and Sheffield (radiation sensing).

The ***TFMRC***'s primary aero-engine collaborators have been Rolls-Royce Plc, and GE Aviation, with a smaller arrangement with Mitsubishi Heavy Industries for industrial gas turbine engines. Key academic collaborators include: the University of Cambridge; Beijing University, China; Shanghai University, China; and the University of Nantes, France.

Academics within the Unit contribute to their disciplines in a range of ways:

- Fulfilling roles on the editorial boards of journals including: Editor, *Automation and Control*, *Central European Journal of Engineering*; Associate Editor, *IEEE Transactions Control Systems Technology*; Editorial Board Member, *Acta Tribologica*; Editorial Board Member, *Journal of Sound and Vibration*; Editorial Board Member, *International Journal of Computational Methods and Experimental Measurements*. Reviewing for 40 different journals associated with this Unit.

- Reviewing for international funding bodies, including the Romanian National Research Council; Slovak Research and Development Agency; US National Science Foundation; Government of Qatar; Nigerian Space Agency; and the EU.

- Holding senior roles within 38 conferences, including as Associate Editor, IEEE Conference on Decision and Control (CDC) series: 2009–12; Associate Editor, IET Proceedings Control Theory Application: 2013; Associate Editor, IEEE American Control Conference (ACC) series: 2009–13; Editorial Board Member, IEEE Control Systems Society Conference Editorial Board, 2008–; Chair, Local Organising Committee, International Symposium on the Computational Modelling and Analysis of Vehicle Body Noise and Vibration, 2012; Organising Committee Member, 2nd and 3rd International Symposia on Jet Propulsion and Power Engineering; Scientific Committee Member, 4th International Conference Nonlinear Dynamics, 2013; Scientific Committee Member, 10th International Conference on Vibration Engineering and Technology of Machinery (VETOMAC X), 2014; and Vanguard Chair for the ASME Turbo Expo 2012 and 2013 conferences on Structures and Dynamics.

- Accepting visiting professorships at the University Polytechnic of Madrid, Shanghai University and Nanjing University of Aeronautics and Astronautics, and acting as PhD examiners for universities in China, Egypt, India, Malaysia, Norway, Pakistan, Singapore, Sweden and the UK.

- Presenting 20 invited and keynote presentations at, *inter alia*, IUTAM Symposium on the Vibration Analysis of Structures with Uncertainties, 2009; 9th International Conference on Vibration Engineering and Technology of Machinery, 2013; 9th International Joint Conference on Computer Science and Software Engineering, 2012; 15th International Conference on Computational Methods and Experimental Measurements, 2011; and the 2nd International Conference on Fluid Mechanics, Heat and Mass Transfer 2011. Receiving five 'best paper' awards at the American Control Conference; 2012 and the Heat Transfer Committee Best Research Paper of the Year Award, ASME Turbo Expo 2011.

- Utilising expertise to influence national policies through, for example, contributing to the UK Automotive Council report on the current state and capability of UK university IC engine research, 2012; acting as a member of a UK government-sponsored Energy Mission to Israel; undertaking, for the Italian Research and University Evaluation Agency (ANVUR), an Evaluation of the Quality of Research Process (VQR), 2012–2013; and being recognised, for example by the award of the IET Measurement in Action Prize, 2011, for the EPS sensor.