

Institution: University of Bristol
Unit of Assessment: 15 - General Engineering
<p>a. Context</p> <p><i>General Engineering</i> at the University of Bristol encompasses a wide range of research activities and consequently the resulting impact is diverse. Impact has always been a key part of the research agenda for <i>General Engineering</i> and significant enhancements have been made over the REF period to both facilitate and support it. The Faculty of Engineering has five broad research themes: Advanced Materials, Energy & Sustainability, Communications & Digital Media, Dynamics and Bio-Engineering & Health. In 2009, the Faculty restructured its research activities into 18 expertise-driven groups that span the traditional engineering disciplines, improving external visibility. This <i>General Engineering</i> submission includes activities from 13 of the Research Groups with the balance submitted to UoA11. Our research vision emphasises interdisciplinary approaches within engineering science and technology to achieve real-world application. One novel feature to facilitate this is the Faculty of Engineering's Applied Non-linear Mathematics group, which is embedded in <i>General Engineering</i> resulting in valuable mathematical expertise being applied directly to engineering challenges.</p> <p>The nature of <i>General Engineering's</i> impact varies across the research themes; however one major beneficiary of its research is industry. All Groups achieve significant impact through direct one-to-one contacts with our commercial partners. Long-term strategic relationships with key industrial stakeholders are emphasised at Group level, such as Toshiba (Communication Systems & Networks, CS&N) and Rolls-Royce (Advanced Composites Centre for Innovation & Science, ACCIS). <i>General Engineering</i> is a founding member of several industry-academic collaborative efforts such as the UK Research Centre in Non-Destructive Evaluation (Ultrasonics & Non-Destructive Testing, U&NDT) and the Nuclear Research Centre (Solid Mechanics). Also, ACCIS activities have been instrumental in setting-up the recently opened £60M National Composites Centre in Bristol.</p> <p>Beyond industry, our research achieves significant societal impact via health and safety advances, expert advisory activities, and committee membership. For example, Water & Environment (W&E) led the development of <i>Aquatest</i>, an on-site device for testing water quality which is now ready for commercialisation and also the development of a flood prediction tool used by the Environment Agency. Systems have influenced Treasury policy in relation to the National Infrastructure Plan. An example of our public engagement is the Earthquake & Geotechnical Engineering (E&GE) programme, <i>Introducing and Demonstrating Earthquake Engineering Research in Schools</i>.</p>
<p>b. Approach to impact</p> <p><i>General Engineering</i> has extensive interactions with a wide variety of end-users, placing emphasis on engagement with beneficiaries upstream in the research process, thereby promoting a two-way flow of information. As an indicator of the industrial value of our work, we have had more than £13M of direct industrial cash support for research since 2008. Over this time the University's Research and Enterprise Development (RED) team have managed 83 contracts for PhD studentships funded wholly or partly by end-users, 173 research contracts with end-users and 67 licences for exploitation of university-generated intellectual property for <i>General Engineering</i>.</p> <p>Impact Mechanisms</p> <p><i>Group-level Interactions with Industry:</i> A number of world-leading companies have collaborative agreements with <i>General Engineering</i>. Since 1998, CS&N have had a partnership with Toshiba via the Toshiba Telecommunications Research Laboratory, headed by Managing Director Craddock (from CS&N), who is 40% funded by Toshiba. Impact includes the development of MIMO-enabled wireless technology [REF3b: <i>Wireless LAN</i>] and a highly efficient linear amplifier system. University Technology Centres (UTC) with Rolls-Royce and AgustaWestland were set up in 2007 and have had industrial investment of £5.3M and £1.9M respectively (ACCIS and Dynamics &</p>

Control). As an example, our industrially-driven UTC research has led to composite failure models and a high-cycle fatigue testing and analysis software platform for Rolls-Royce. These tools, and two others, have all been formally awarded Technology Readiness Level 4 (TRL4) status via Rolls-Royce's *Critical Capability Acquisition Review* process within the REF period. Having achieved this status, Rolls-Royce placed them on its industrial validation path for development to TRL6, which is expected to be achieved by the end of 2013, for at least two of the tools. More recently, *General Engineering* has been appointed a Preferred Partner for Vestas Wind Systems (£1.1M, 2009), a Framework Partner for BAE Systems and a Strategic Partner with GKN (2012). In addition the University is one of three academic institutions supporting EADS Innovation Works UK (since 2007) and has signed a Strategic Alliance with AWE (2010) for which meetings are chaired by the Dean of Engineering.

General Engineering also takes a leading role in various consortia with industry that have been formed to undertake research in areas of common interest. For example, it is a founding member of the UK Research Centre in Non-Destructive Evaluation (RCNDE – **U&NDT**), which has led to a new ultrasonic NDT method that is now used by RCNDE industrial members and others [REF3b: *Arrays*]. Impact from residual stress measurement [REF3b: *Veqter*] and nuclear safety systems [REF3b: *Nuclear Safety*] has recently resulted in the founding of the Nuclear Research Centre with the University of Oxford and six major companies including EDF and Sellafield Ltd.

In addition, **ACCIS** research has informed the development of the Government-commissioned National Composites Strategy 2009, which identified the value of facilitating the transfer of cutting edge research through the TRL4-6 “gap” into industry. This Strategy led to an initial £25M investment by the European Regional Development Fund, the South West Regional Development Agency, and the Department for Business, Innovation and Skills to fund the National Composites Centre (NCC), which was opened in Bristol in 2011 and now employs more than 160 staff. The University owns and provides governance for this national facility, with the NCC Chief Executive reporting to the Dean of Engineering. **ACCIS** already has a strong record of research and impact, such as developing software for predicting tool shapes, failure and fatigue, with many of the companies involved with the NCC. Work on the behaviour of anisotropically tailored composite sections resulted in a new blade design that flies on a variant of the AgustaWestland EH101 helicopter [REF3b: *Structural Mechanics*]. The NCC will be a major vehicle for enabling impact from *General Engineering's* composites research; all aspects of the NCC Core Research Programme incorporate research outputs from **ACCIS**, e.g. [Potter-4]. The progress towards “entry to service” components has been so successful that the Centre has now received a total of £60M to provide, for example, high-speed production capability and facilities for supply-chain companies.

One-to-One Industrial Relationships: In addition to large group-level industrial interactions, we benefit from one-to-one interactions between academics and industrial collaborators. One mechanism for enabling these relationships are EPSRC CASE awards – we have had 65 awards with 25 companies, including 18 with Airbus since 2008. This ongoing relationship has led Airbus to part-fund Cooper's Chair (approximately 50%). Over the REF period, we have had long-term consultancy relationships, such as with NASA Langley to develop lightweight buckling-resistant composite space structures, with Cobham Mission Equipment to develop flight refuelling hoses and drogues simulation software, and with the World Bank on landslide risk management [REF3b: *MoSSaiC*]. We also encourage industrial secondments; for example, Rendall currently has a Royal Academy of Engineering industrial secondment, with Airbus [text removed for publication].

General Engineering finds that KTP and TSB awards are excellent mechanisms for achieving impact, especially with SMEs. One such award led to a new helicopter rotor track-and-balance technique, using an algorithm initially developed for finite-element model updating, and which is now used in Helitune's products [REF3b: *Helitune*]. Another allowed Fraser Anti-Static Techniques to reshape its business, changing it from providing low-tech products to high-specification ones employing power electronics. *General Engineering* won the TSB *Best KTP Partnership* and *KTP Engineering Excellence* awards in 2012.

EPSRC Doctoral Centres: Three Industrial Doctoral Centres involve *General Engineering*:

Systems, Non-Destructive Evaluation and Composite Manufacture. *General Engineering* is also involved with three Centres for Doctoral Training: Communications, Complexity Sciences and Composites. Both types of centre provide considerable impact to a large number of companies, including SMEs, in addition to embedding highly skilled engineers, with our research knowledge, within them. For example, since October 2006, the Systems Centre has enrolled 81 engineers with 45 companies. Their research has transformed the way companies integrate their corporate knowledge and apply this effectively throughout the business process and engineering life-cycle. The Group Director of Technology and Innovation at Halcrow Group stated that “*our Research Engineers [from the Systems Centre] are already contributing strongly to our strategic thinking, and are in close and frequent communication with Group Board members. They are already quite literally changing the way the company thinks.*”

Licensing: Over the REF period, *General Engineering* has had 67 active licences including the licensing of: ice pigging technology, via spin-out company PCIP, for cleaning pipes to Agbar [REF3b: *Ice Pigging*]; wheel array technology for ultrasonic NDT to Sonatest, resulting in [text removed for publication] [REF3b: *Arrays*]; and bone alignment software to Smith and Nephew plc.

Spin-out Activities: Our spin-out companies include: Imetrum, which supplies video-based metrology systems to, for example, Rolls-Royce, McLaren F1 and Network Rail [REF3b: *Imetrum*]; Veqter, which undertakes residual stress measurements for the nuclear and other industries [REF3b: *Veqter*]; and Micrima on novel medical imaging. The latter has recently completed a clinical evaluation of its new medical imaging technique for breast cancer diagnosis based on **CS&N** research on subsurface radar imaging that was originally developed for landmine detection [REF3b: *Antennas*]. In addition, Beelab (from **E&GE**) conducts and analyses advanced dynamic tests, including earthquake simulation, for the nuclear, aerospace, telecommunications and civil sectors.

Influencing Codes, Standards and Government: Research in *General Engineering* has fed directly into safety and building codes, and electrical standards. For example, research findings from **Systems** have been included in the 2010 international nuclear safety standard IEC61508 [REF3b: *Nuclear Safety*] and **CS&N** have influenced wireless standards [REF3b: *Wireless LAN*]. **W&E** has developed a model of rainfall-runoff that is used by the Environment Agency for flood warning, and a methodology for reducing landslide risk that is used in the Caribbean [REF3b: *MoSSaiC*]. We also influence government thinking; for example, **Systems** contributed to the Government-commissioned, *Blackett Review of high Impact Low Probability Risks* (published 2011), have membership on the Treasury’s *Engineering and Interdependency Expert Group* and have influenced Treasury policy regarding the National Infrastructure Plan. McGeehan (**CS&N**) is a member of the EC’s *Advisory Group on ICT Infrastructure for Energy-Efficient Buildings and Neighbourhoods for Carbon-Neutral Cities*.

Media and Outreach Activities: These include the **E&GE** *Introducing and Demonstrating Earthquake Engineering Research in Schools* programme. This began as a local event for schools in 2000 and, with British Council support, has now become an international event with school competitions in India, China, South Korea and Taiwan. In China, the 2010 final was “televised” on the social network site qq.com and attracted 1.5 million hits. We have also had four displays at the Bristol *Discover* Exhibition and two at the *Royal Society Summer Science Exhibition*.

Impact Support

One way *General Engineering* supports its impact is through its Industrial Liaison Office (ILO), which was created in 2011 to assist with industrial activities for both researchers and students. It provides industrial mentors for all new undergraduate students, sets up internships and facilitates industrial involvement with postgraduate students. It provides organisational resources for running industrial workshops, organises research seminars for visiting companies and runs an annual *Research and Industry Reception*, which, in 2013, attracted 140 visitors. It also assists with developing strategic long-term relationships, such as a memorandum of understanding with GKN that is successfully enabling research and teaching collaboration.

General Engineering also makes use of the University’s resources. RED provides patent, licensing,

consultancy negotiation and business acceleration expertise, as well as support for industrially-focused research, such as KTP grants. Their Research Commercialisation Team works closely with academics to enable the transfer of research into commercial products through licensing, new business creation, translational grants and research collaborations. This team links to *SETsquared*, a Government-funded partnership between five universities for supporting early-stage knowledge-based businesses. The *Bristol SETsquared Centre* won the UK Business Incubation's *Established Business Incubator of the Year* award (2008) and its Director won its *Outstanding Contribution to Business Incubation* award (2012). Recently, the Centre provided assistance to both Veqter and Micrima. RED also provides support relating to research ethics/governance, contracts, project management and research development with each activity assisting knowledge exchange and shaping impact. The University provides training with regular courses through the Enterprise Education team and Staff Development programme on, for example, IP awareness and media training. The Centre for Public Engagement supports outreach activities such as Bristol's annual interactive exhibition *Discover*.

There are multiple sources of funds for developing and recording impact available to *General Engineering*. The University directly funds grants to record and capture impact via its Impact Development Fund. The University holds an EPSRC Pathways to Impact award, that has been used to develop [REF3b: *MoSSaiC*], and since 2012 a £2.4M Impact Acceleration Account. This is being used to competitively fund industrial secondments, encourage research commercialisation through proof-of-concept grants, further develop strategic collaboration and assist researchers through industrial-engagement programmes. These initiatives have funded, for example, work in **Robotics** on compliant colour-changing skin materials and work in **CS&N** on optical cross-point switching. Strategic industrial-engagement awards have been made in the areas of nuclear research (**Solid Mechanics**) and reconfigurable optical and wireless networks (**CS&N**). In addition, to emphasise the importance of impact to the University's research strategy, the Vice-Chancellor's Impact Award rewards the best impact across the University.

c. Strategy and plans

Our approach is based on the observations that impact can be facilitated, but not forced, and that it is often most significant when end-users and other stakeholders have input throughout the research process.

Strategic Alliances: A cornerstone of the Faculty's strategic plan for industrial engagement is to build long-term alliances with major end-users. The emphasis of such alliances is on developing mutual understanding and confidence, which yield significant impact over time. This is evidenced by the outputs of the 15-year relationship between **CS&N** and Toshiba. Since its creation in 2011, the ILO has been actively approaching collaborators who support multiple small-scale projects, with a view to building long-term strategic alliances. Recent results of this approach include the Faculty's Preferred Partnership with Vestas Wind Systems and Strategic Partnership with GKN.

Industrial Input: To strengthen direct links with industry, we are actively seeking further industrially-funded and Royal Academy of Engineering funded Chairs. The Faculty now has three Royal Academy of Engineering Chairs, including one of only two nationwide in Emerging Technologies. Chairs in biomedical engineering (funded by Toshiba) and composite manufacture (part-funded by the NCC) are currently being recruited. In addition, [text removed for publication].

Significant impact arises from mutually-beneficial one-to-one interactions with end-users that have developed over many years – for example Quarini's relationship with Bristol Water has resulted in [REF3b: *Ice Pigging*]. To assist academics in developing such relationships, particularly those at an early career stage, the ILO now provides a database of industrial contacts, and acts as the first point of contact for both academics and potential industrial collaborators. In addition, we are extending the idea of having advisory committees for large grants by actively encouraging the formation of industrially-driven steering committees for our wider research activities. The aim is to facilitate industrial feedback on our research at an early stage, hence maximising its future industrial relevance. These committees now exist for **ACCIS**, **Systems**, **U&NDT** and, most

recently, the nonlinear dynamics research within *Dynamics & Control*.

Cross-faculty Collaboration: Formal cross-faculty collaborative links are being actively pursued by *General Engineering*, which views these as valuable mechanisms for addressing major challenges. The University has launched the Cabot Institute (2011), bringing together researchers in *General Engineering*, Chemistry and the social sciences to address “risks and uncertainty in a changing environment.” Directly engaging with NGOs and Government partners, the Institute will play a defining role in the future delivery of impact. In addition, the Elizabeth Blackwell Institute for Health Research has recently been formed (2012). This Institute, which is funded both by the Wellcome Trust (£750k for 2013) and the University, brings together researchers from the University’s health and non-health related disciplines to find innovative solutions for some of the most pressing health challenges. It has a particular focus on translating the research into effective health outcomes and provides fellowships and pump-priming funds.

Strategic Support for Doctoral Centres: Doctoral centres generate significant impact for *General Engineering* and an important part of our research strategy is to extend our portfolio of centres, as shown by the newly announced EPSRC centres for doctoral training in *Quantum Engineering*, *Future Autonomous and Robotic Systems* and *Water Informatics*. To maximise their effectiveness, University-funded *Industrial Fellows* are employed to facilitate early industrial engagement. The aim is to more closely align projects with industrial needs. As well as provide recruitment opportunities, this leads to a greater two-way commitment that benefits all parties. In parallel, we actively seek CASE conversions for DTA studentships.

Impact Director: This role was introduced in 2010 to advise on current and future opportunities, and to work with RED’s Impact Expert Support Team towards enhancing our impact-related activities. Additionally, the Impact Director assesses impact on an annual basis. This helps identify emerging impact, which the Impact Director subsequently supports by providing advice to colleagues on recognising and evidencing impact and assisting with its further development, via, for example, internal funding opportunities.

Strategic Appointments: While recognising that the pathways and timescales for impact vary across our research portfolio, potential impact generation is considered when making strategic appointments. For example, R. Smith, an expert in NDT for composite manufacture, was recruited from QinetiQ into *U&NDT* via the University’s Professorial Exceptional Talent route. His appointment further enhances the collaboration between *U&NDT* and *ACCIS* and facilitates rapid impact, via the NCC, using his industry contacts with NCC partner companies.

d. Relationship to case studies

There is a two-way relationship between our case studies and our impact strategy. Firstly, the effectiveness of our approaches for enabling impact is demonstrated through our case studies. In addition, lessons learned from the case studies are now used as a resource when updating our impact strategy.

Significant impact has been achieved through our strong collaborative links with industry such as our partnership with Toshiba, see [REF3b: *Wireless LAN*]. Regarding groups of companies, [REF3b: *Arrays*] arose from research part-funded by industrial members of the UK Research Centre in Non-Destructive Evaluation and the industrial case for developing the Nuclear Research Centre was partly driven by the impact reported in [REF3b: *Veqter* and *Nuclear Safety*]. The impact reported in [REF3b: *Helitune*] resulted directly from a KTP and has resulted in further KTPs with Helitune and its sister company Beran which, based on progress to date, is anticipated will lead to a future case study. Research commercialisation has also resulted in significant impact: Veqter and Imetrum are spin-out companies and ULTra PRT began as the spin-out company Advanced Transport Ltd (see [REF3b: *Veqter*, *Imetrum* and *ULTra PRT*] respectively). In addition, ice pigging technology was licensed to Agbar via the start-up company PCIP, see [REF3b: *Ice Pigging*].