Institution: University of Nottingham

Unit of Assessment: 15 General Engineering

a. Context

The Unit delivers innovative and effective technological solutions to industry at local, national and international levels. We have focused our impact activities significantly since 2008, by building on existing strengths and diversifying into new areas. A cornerstone of our impact strategy is to grow research and knowledge transfer income as delivery of impact is directly related to this resource. Our total new awards secured directly from industry for research within the assessment period are £39.6M across 319 projects. We also receive funding from industry through, EU, EPSRC and other collaborative projects. Our total new awards for the assessment period are £146.3M (737 projects). The impacts of our research are cross cutting; but primarily economic, and increasingly reaching public policy, practitioners and professional services, society, health and the environment.

The beneficiaries for our impact are wide ranging; we impact upon global blue chip industry through to national and international SMEs, governments (including non-departmental public bodies), charities and public sector organisations. Major societal problems increasingly require multi-disciplinary solutions to realise major impact. Our research structure is deliberately designed to offer opportunities for researchers to work at the boundaries of disciplines (including basic sciences, e.g. Chemistry, Biosciences) with no hurdles to collaboration as well as in their core area. Therefore, our research is organised by themed research divisions, each of which comprise a number of area specific research groups; Electrical Systems & Optics, Energy & Sustainability, Infrastructure, Geomatics & Architecture, Manufacturing & Process Technologies, Materials Mechanics & Structures. Exemplars of delivered impact from each division are provided below.

b. Approach to impact

Knowledge exchange and pro-active stakeholder engagement are an essential component of the Unit's research strategy and are prevalent across all areas of research activity. The Unit's Research Board provides strategic direction to, and monitors the implementation and success of its knowledge exchange strategy encouraging a wide range of approaches across the Technology Readiness Level (TRL) spectrum in order to enable and accelerate impact. Our approach is exemplified under five key strategic themes:

Establishing strategic relationships with industry

Fundamental in our approach is collaboration with end-users, particularly industry (global corporates to SMEs), in the co-design and co-production of research to accelerate the adoption of new technologies for process improvement and new product development.

Exemplars of relationships across our research divisions include:

- **Network Rail (NR) (Infrastructure, Geomatics & Architecture Division).** Throughout the assessment period (started 1998) the Unit has run with NR an extensive programme of research into new tools for workload management and efficiency. The programme has been delivered through contract research and sponsored PhDs (18 to date including 9 in the assessment period). The resulting impact on workload practises for signallers etc. within NR is described in case study MAN02. A key feature has been the integration of both University and NR research teams. Many of the researchers are now NR employees, enabling transfer and application of new knowledge within NR. Our successful relationship led to Nottingham being selected by NR and The Royal Academy of Engineering to host a new chair in Infrastructure and Asset Management (2009, Andrews). This project also supports PhD and post-doctoral researchers, and has gone on to leverage over £2M of additional income. Asset management models developed by the Unit are now being applied to real time NR data, and are supported by integrated working between NR and the Unit to ensure accelerated transfer of knowledge and maximum impact. A further example of the collaboration with NR where collaborative research funding underpins further economic impact to NR is provided in Case Study IGD05 where major improvements in track bed maintenance intervals are demonstrated.
- **Rolls-Royce plc (RR) (Manufacturing & Process Technologies and Materials Mechanics & Structures Divisions).** The Unit hosts two RR University Technology Centres (UTCs) in

Transmissions (Case Study ESD01 outlines the efficiency and produce performance benefits accruing to RR and MMS04 outlines vibration control in aero-engines) and Manufacturing Technology. Engagement through the Manufacturing Technology UTC (Director, Axinte) comprises a programme of contract research, consultancy and sponsored PhDs (15 since 2008 including Industrial CASE, RR fully-funded and Dorothy Hodgkin Postgraduate Awards), with £1M from RR and £850k leveraged funding since 2008. Three researchers have assisted in the transfer of skills and knowledge through becoming company employees, and one other is employed within the UTC. Since 2011, twelve patents have been filed by RR based on intellectual property (IP) arising from the Unit's research (one of the top UTCs in terms of intellectual property output by number of UTC employees). IP arising from the UTC has subsequently been developed into two demonstrator systems, and other IP has been part of on-going development programmes reaching higher TRL levels. Axinte was awarded the RR Submarines 'Excellence through Innovation' Award in 2011 and the RR Best Patent Award in 2012, both related to the development of systems for in-situ repair, saving time and cost (in-situ repair costing approximately 10% of the replacement cost of a new engine) for RR.

- **Boeing (Materials Mechanics & Structures Division).** The Unit established a £650K p.a. strategic partnership with Boeing to develop carbon fibre composite recycling technologies to minimise the environmental impact of aerospace manufacturing processes, building on work initially developed for the automotive industry and leveraging the £900k collaborative TSB/MoD AFRECAR project (Pickering, £573k to Unit). This investment by Boeing in research staff, students and equipment includes the development of a pilot recycling facility, housed within the Unit's Aerospace Technology Centre and drawing directly upon the Unit's work. The Unit introduced two companies to Boeing: GAME Engineering Ltd (local SME), a beneficiary of the Unit's European Regional Development fund (ERDF)-funded Institute for Aerospace Technology, and Anguil Environmental an SME based in USA. Both companies have subsequently become suppliers for the bespoke pilot facility, gaining additional knowledge/capability and benefitting economically.
- **TQC Ltd (Manufacturing & Process Technologies Division)** Through two EU projects (E-Race and EUPASS), the Unit established a partnership with Nottingham-based TQC Ltd, who are leading designers of assembly and test solutions, resulting in the implementation of the Unit's concepts, methods and processes within their operations from 2009. The partnership with TQC continues through the EU project 'PRIME' (2012 – 2015) and the £2.2M EPSRC-funded 'Evolvable Assembly Systems' project (EP/K018205/1) through which the company will provide industrial input and a 'use case' to test methodologies arising from the project.
- **e2v plc (Energy & Sustainability and Electrical Systems & Optics Divisions)** Our relationship with e2v started in 2003 through membership of the High Power RF Faraday Partnership and complementary expertise in high power microwave processing. The objective of the collaboration was to create a robust industrial supply chain for high power microwave equipment which has already delivered new sales business, a significant number of jobs created and a strategic business partnership for e2v (Case Study PED03). The developing relationship led to e2v's funding of the e2v Centre for Industrial Microwave Processing in 2008 at Nottingham (Director, Kingman) (£1.1M over 5 years, phase 1, phase 2 agreed at similar funding level up to 2018). The collaboration started with process engineers at Nottingham and has expanded to include a sponsored lectureship and PhD's in Power Electronics focused on power supply design for industrial microwave systems; this multi-disciplinary approach providing e2v with a multifaceted approach to solving key industrial challenges. The relationship has been extended to include our School of Physics who are now actively collaborating with e2v in the area of semiconductor devices.

Impact is embedded in our postgraduate research programmes. An exemplar is outlined in Case Study MAN02 where workload assessment tools for signallers and engineers within Network Rail, developed as part of sponsored PhDs have been implemented. All of our research divisions are participants in research council-funded doctoral training centres. The Unit leads two Industrial Doctorate Centres (Efficient Fossil Energy Technologies EP/G037345/1 (Energy & Sustainability Division), MTC Engineering Doctorate Centre EP/I017933/1 (Manufacturing & Process Technologies Division)) and are partners in two further IDCs, in Non-Destructive Evaluation (Electrical Systems & Optics Division) and Composites Manufacturing (Materials Mechanics &

Structures Division). Relationships with companies are enhanced through these centres and partners include Alstom, Doosan Power Systems, E.ON, Tata Steel, Johnson Matthey, RWE, CPL, NPL, Air Products, Jaguar Land Rover, Rolls-Royce, Airbus and Aero Engine Controls. The Unit is also a partner in other doctoral training centres: Horizon (Digital Economy - Infrastructure, Geomatics & Architecture Division), Hydrogen Fuel Cells (Energy & Sustainability Division), and the BBSRC funded-Biosciences Doctoral Training Partnership (Manufacturing & Process Technologies Division). Since 2008, industry has supported 194 PhDs in the Unit through full or part (e.g. CASE) funding.

Maximising knowledge exchange funding for innovation

The Unit has been highly successful in securing funding from a range of sources to accelerate innovation and drive impact. Notable examples include:

- **Knowledge Transfer Partnerships (KTPs).** Since 2008, the Unit has partnered with businesses in 25 KTPs to build collaborative relationships which enable step change products and processes to be developed. Exemplars include; Northern Foods - subsequently reduced their environmental impact, achieving a Lord Stafford Award for Innovation in sustainability (2008); GKN - project developed a novel technology for de-icing composite aeroplane wings, resulting in annual cost savings estimated at £800k; Baldwin and Francis - resulted in the launch of a new product, and drew on the Unit's extra support through the academic supervisor (Wheeler) travelling to China on behalf of the company to support technical development.
- **Technology Strategy Board (TSB)**. Competitively secured collaborative funding is a key feature in the Unit's approach to facilitating greater impact from its research. In the period we have been members of 23 TSB projects. Nottingham is a key academic partner in the UK Government's £103M 'Next Generation Composite Wing' programme led by Airbus. Our expertise in active tooling and fixturing for wing manufacture led to the delivery of validated prototype tooling that has been adopted by supply chain partners for commercial manufacture. Examples of these supply chain partners include the Hyde Group who have ultimately benefitted economically, through the up-skilling of their workforce and retaining a Business Unit within the organisation originally planned for closure, and a strategic change for a US-based material handling and automation equipment manufacturing company, DE-STA-CO, by opening up a new market sector (aerospace) for its business. The Unit is highly active in Knowledge Transfer Networks; e.g. Wheeler in the Aerospace, Aviation & Defence KTN, (member of advisory board of the National Aerospace Technology Programme) and Clare in the Electronics, Sensors and Photonics KTN. We are a founding and active member of the Manufacturing Technology Centre, part of the High Value Manufacturing Catapult and Nottingham Geospatial Institute (Moore) has directly influenced the UK Space Innovation and Growth Strategy, the National Space Technologies Strategy and the TSB innovation policy to deliver a Satellite Applications Catapult.
- **EU Collaborative Projects.** Dedicated Research and Business Development Manager (RBDM) support, provides mentorship to funding application to this area and network facilitation, drawing on additional Unit and central resource as required. In this period we have been a member of more than 140 consortia, and co-ordinated 16 projects. Exemplars of our involvement include the "Cleansky" and "SHYMAN" projects. SHYMAN has taken our nano-materials manufacturing technology (Case Study PED01) to a wider industry base including securing commitment from Solvay AS to build the world's largest pilot plant and also widening their current knowledge base. Within the Cleansky programme we have been working with industry to develop a new electrical taxiing system for aircraft. EU funding offers direct routes to impact, therefore, our strategy has been to increase levels of EU funding; our portfolio of awards has risen from £4.1M in 2008/2009 (the date of implementation of direct RBDM leadership for EU funding) to £6.9M in 2011/12. Critical review of the current Unit portfolio and strategy has enabled us to identify reasons for success and barriers to participation, for example, we provide travel funds for staff to develop consortia and funds for all staff to attend networking meetings and conferences to meet partners, coupled with grant mentoring and review and network facilitation support.
- **Regional Development Funding**. The Unit has been very successful in securing funding from ERDF and the East Midlands Development Agency (EMDA) to establish and expand centres providing direct access for local SMEs to capitalise on the Unit's research base. Since 2008,

this represents an investment from ERDF and EMDA of almost £12.2M. The Environmental Technology Centre, Advanced Manufacturing Technologies East Midlands Centre, Global Navigation Satellite System Research and Applications Centre of Excellence, Accelerating a Low Carbon Economy and Institute for Aerospace Technology have all capitalised on this investment, establishing over 100 new business-Unit relationships and created more than 110 jobs since 2008. An example includes a partnership between the Unit and the companies Datalink and Nemaura Pharma Ltd. to develop a diagnostic and drug delivery patch for the management of diabetes, leveraging a £1.3M TSB award and resulting in the development of new licensed IP.

Engaging with Government, executive agencies and regulatory authorities

The Unit extends its approach to a range of non-commercial partners, recognising the impact of its research particularly in the public sector. Exemplars include: providing cited evidence to Transport Select Committee report, Cost of Motor Insurance: Whiplash (McNally); working with the Environment Agency on Thames Estuary flood risk that contributed to the policy document, the Thames Estuary TE2100 Plan (Case Study IGD01); research contributing to the General Lighthouse Authority 'Radio Navigation Plan' and '2025 & Beyond' strategy; an evaluation of equipment that shaped Ordnance Survey receiver procurement strategy; DTI-funded research that resulted in the NICE guidelines 'Design for patient safety'.

Supporting and empowering staff to facilitate impact

The Unit supports knowledge exchange from laboratory to delivery. Dedicated funding and staff drive engagement and researchers benefit from mentoring and recognition to actively encourage activities that lead to impact.

- The Unit employs 9.2 FTE professional staff to identify and facilitate knowledge exchange. The Research and Business Development Managers (RBDM) are the cornerstone of the impact strategy, drawing initially on HEIF funding but now fully embedded within the Unit (FTE has increased by 50% since 2011) and under the strategic leadership of a Business Manager. Recent additions of two training-level roles, underpinning the work of the RBDMs, and an Innovation Manager (focused on IP development) demonstrate further Unit investment (now totalling £640k p.a. for the Unit). We also have project officers to support researchers with consultancy and industrial contract research costing and delivery.
- Research groups are assigned funding to be used flexibly and locally to create and respond to opportunities for knowledge exchange such as industry-focused events, symposia and conferences to establish initial contacts, with further extensive funding available for travel to partners.
- Engagement is also supported by our dedicated Marketing Team (5.4 FTE) to develop externally-focussed materials (hard copy and electronic) and provide outreach, an events organiser to support conferences and workshops (such as the opening of the Institute for Advanced Manufacturing by the Minister of State for Universities and Science in 2012).
- New academics and early career researchers are provided with mentorship at Faculty, Divisional and Group-level to develop contacts and build experience in collaborations, drawing on specific RBDM support.
- Secondments of key staff are actively supported by the Unit and the University to successfully spin-out technologies. Examples include: Hayes-Gill's secondment for two years to Monica Healthcare (ESO02) as Chief Research Officer and Lester's 40% secondment to Promethean Particles (PED01). Both spin-outs are exemplars of the Unit's commercialisation strategy.
- To reward successful technology commercialisation, staff receive a share of generated license income (typically 50% up to £25K and 40% thereafter). Staff are also allocated 50 days per year to deliver external consultancy and financial reward mechanisms for professional services (e.g. industry use of facilities and testwork) are in place. Licences, consultancy and professional services are often inter-twined with academic engagement throughout.

Our investment supports the Unit to implement an agile and flexible, multi-faceted strategy enabling responses to both technology pull (e.g. through strategic partnerships), and technology push (e.g. through collaborative research partnerships and PhDs) to maximise the impact of our research.

Utilising local and institutional facilities, expertise and resources

The University's Partnerships Team works in collaboration with Unit's academic and RBDM staff to ensure that relationships with strategic industrial partners are co-ordinated across the University (e.g. e2v collaboration) and assist in the identification of potential partners for research and knowledge exchange activity. The University's Technology Transfer Office and the Unit's Innovation Manager identify potential intellectual property arising from the Unit and implement procedures for the commercialisation and exploitation of IP through our joint IP committee. The Unit recently established a Faculty-based Technology Demonstrator to showcase our technologies, in response to the huge success of our involvement with the University Technology Demonstrator which reaches around 200 companies per annum through visits and events. For instance, our super capacitor technology exhibit resulted in a new collaboration (£212k) with Season Long Environmental (Chinese business), to develop a novel product for the automotive sector. Since 2008, 88 patents based on the Unit's research have been filed by the University with many more filed by research sponsors with Nottingham inventors, 28 patents granted, five license deals completed and c.£1.3M direct IP income received. Our IP portfolio has also leveraged over £7M of further research income. The Unit also benefits from hosting a dedicated contracts officer to ensure contracts are expedited both efficiently and professionally, connecting with the central contracts service where required. Owing to the direct route to impact we also support dedicated KTP officers located within the Unit (1.5 FTE) to establish new business relationships (and since 2010 have maintained a 100% success rate (14 awards)) which offer an opportunity for short to medium term impact.

The Unit's staff and facilities are the primary assets for engagement and enabling impact. Through the expert support of Nottingham University Consultants our staff have delivered over 140 consultancy projects with industry since 2008, generating well over £1M fee income. In the same period we have provided our stakeholders with professional services support through over 480 separate projects worth over £13.5M. This includes testing for the construction industry, becoming a preferred supplier of testing services (from routine quality analysis to complex performance analysis of existing and new materials) to the British Board of Agremont (construction industry standard) and other structural testing and certification; bitumen and oil pipeline deposit characterisation and geochemical analysis for oil prospecting, and process and plant design. Many professional services type projects have underpinned relationship-building with industry.

c. Strategy and plans

The Unit's vision is to deliver measurable impact from its research to as a broad beneficiary group as possible. Deriving maximum stakeholder benefit from our research is our goal, and in developing our impact strategy further we are now seeking to focus our delivery as outlined. This aligns and builds on the University's Knowledge Exchange Framework. The Unit's strategy will be to achieve impact through a series of targeted Global Challenges, based around current and new areas of research excellence, delivered through high quality, extensive and collaborative partnerships e.g. our collaboration with Virginia Tech in the USA. Each Global Challenge reflects an objective driven by (or with clear potential for) stakeholder engagement and requiring a multidisciplinary approach to its achievement which will, by its nature create revolutionary opportunities. Each challenge will draw on discovery-led research (including wider University collaboration) through application-led development, and working with end users to ensure robust and timely implementation. Additional emphasis during the translational stage through directed expert support will ensure additional success in bridging the traditional 'valley of death' in this stage of development. Current Global Challenges include Factory of the Future, More Electric Aircraft and Engineering our Future Cities. In Q1 2014, the Unit will conclude its most recent challenge mapping exercise, drawing on input from a wide variety of stakeholders. This strategically-important information will be drawn on to inform the Unit's future Global Challenges, and will be updated on a regular basis. Underpinning this strategy will be core pillars of; people, leadership, training, performance measurement, mentorship, investment and processes and systems.

- ***People –*** the Unit will continue its focus on the recruitment and support for exceptional people. Strategic investment in staff in support of Global Challenges will be made while opportunities for key staff to take each challenge through the research process outlined will be reflected through systems such as extended leave schemes and workload modelling. An example of our investment in staff in line with an identified Global Challenge (Factory of the Future) is the

addition of Additive Manufacturing expertise (2012) to continue to strengthen our broad ranging Advanced Manufacturing capability within the Unit.

- ***Leadership –*** recognising the different skills required of successful leaders in this extended developmental environment, the Unit will identify and support the development of impact leaders to steer its Global Challenges. The Unit's 'Future Leaders Programme' already provides a framework of opportunities and skills to create such multi-skilled leaders, equipped to provide the skills necessary to deliver this long-term visionary approach to successful delivery of the Global Challenges. This programme will be extended to a wider staff group and the importance of commercialisation and other routes expanded.
- ***Training –*** experience-led training for staff specifically focussed to support the research process from discovery to adoption will be provided, building on our existing provision. This will be an essential part of continuing to drive wider engagement within the Unit.
- ***Performance Measurement*** - Success is monitored throughout the process through indicators (to which further impact-driven indicators will be added) both direct (new and additional industrial income and increased engagement of academic and research staff throughout the research lifecycle, new company formation, licence income) and where possible, indirect (new jobs created, stakeholder profit arising from the Unit's research).
- ***Mentorship –*** This will underpin our strategy drawing support from a wide range of individuals. Experienced academic staff, external industrial experts (including our cohort of Honorary Professors) and Unit support staff all provide mentorship to aspects of the research-to-commercialisation process. This is supplemented by additional and specific skills as required (e.g. Business Angels) and we will continue to develop our support structure as driven by the demands of our activity. As our pool of experience grows further we will ensure that the value drawn from these activities shapes our future.
- ***Investment –*** The Unit will strategically invest in infrastructure to support Global Challenges both in terms of pump priming early stage research developments but also crucially to provide technology demonstrators to help bridge the "valley of death".
- ***Processes and Systems –*** We will further develop our processes and systems to ensure that these meet our needs as an impact-driven Unit. Building on the lessons learned from REF2014, the Unit will invest further in systems required to support impact on a daily basis.

d. Relationship to case studies

Many important relationships are developed through collaborative EPSRC grants and case studies where this has played an important part include our work on improving the efficiency of power plant maintenance (MMS03). Several illustrate the use of EU FP7 funding as part of our activities to bring about impact. For the Promethean Particles spin out company described in PED01 the EU "SHYMAN" project is providing an important mechanism to develop and expand their customer base as well as enabling the scale up of a pilot production plant to industrial scale. TSB funding has been crucial in the development of the collaborative work with Aston Martin described in MMS01. Our use of effective IP protection through patent followed by licensing is exemplified in the development and commercial implementation of efficient mineral processing technologies (PED03). Impacts as a result of spin-out formation are exemplified by Monica Healthcare (ESO02) and Promethean Particles (PED01). Consultancy and services rendered work have played an important part in the impact arising through the development of novel techniques for the manufacture of nanoparticles (PED01). Industry-funded collaborative projects have enabled the development of the important impacts for spinal surgery patients described in MMS02. Our work with the mineral processing industry and its supply chain (PED03) and on aero-engine vibration and gearbox efficiency with Rolls-Royce (MMS04 and ESD01 respectively), are examples of the impacts arising from our strategic partnerships with key external users. Case studies exemplifying our input to policy on flood risk (IGD01), improving the maintenance intervals of rail track beds (IGD05) and on the use of composite steel beams in construction, reducing material usage (MMS19) illustrates our input to, and influence on policy and professional practice in the areas of the environment, transport and construction.