Institution: Loughborough University

Unit of Assessment: B12 Aeronautical, Mechanical, Chemical & Manufacturing Engineering

a. Context

Engagement with end-users, particularly industrial partners, is pervasive across this Unit; in HEFCE's annual Business and Community Interaction survey, collaborative research (last 3 years per fte) shows Loughborough University (LU) second only to Cambridge and this Unit contributes 50% of that activity.

A huge range of collaborating partners are the **main (non-academic) beneficiaries of the Unit's research,** demonstrating reach across diverse sectors and delivering significant impact on the international stage. Examples of key sectors / collaborators: aerospace (Rolls-Royce, Airbus, GE Aviation), automotive (Jaguar LandRover, Ford, Lotus), consumer products (Proctor & Gamble), healthcare (Lonza, TAP Biosystems, NHS), defence (BAE Systems, dstl, Thales), off-highway (Perkins Engines / Caterpillar), pharmaceuticals (AstraZeneca, GSK, 3M), energy (E.On, Alstom, Siemens), instrumentation and metrology (National Physical Laboratory, Taylor-Hobson, Mettler-Toledo), sporting goods (adidas, Nike, FIFA). There are many other similar examples and several hundred smaller and/or less well known organisations with which the Unit engages.

The main impacts created are economic through the introduction of new and improved products, processes or services to existing businesses, with further economic impact through jobs created in start-up businesses. Significant activity in low carbon vehicles, hydrogen fuel cells, energy efficient processes, remanufacturing in capital intensive industries and sustainable manufacture deliver an accompanying environment impact. Health impacts are increasing through pioneering work at the forefront of the emerging regenerative medicine industry, from environmental hygiene monitoring with NHS Trusts and in simulated surgery. Impact examples are evident in every research group.

b. Approach to impact

LU's reputation for working closely with business and the professions is long established with recent recognition found within high profile independent reviews of university-business collaboration, e.g. Lambert (2003), Wilson (2012). LU collaborative research activity is c.2.5 times the average level (income/fte) of all Russell and 1994 Group institutions. **This Unit's approach over the period 2008-13** favours multi-faceted engagements. Research and knowledge exchange programmes are core and complemented by e.g. taught programme interventions, short courses, Masters level provision and consultancy. Over the REF period, the Unit has engaged in 195 collaborative research projects worth £64M, 246 contract research projects worth over £16M, 36 HEIF-funded projects worth £700k, 25 KTA projects worth >£2M, has had over 50 patents granted and engaged in consultancy projects worth c.£300-400k/yr. Stakeholder engagement is of paramount importance and over 30 senior industrialists sit on the Unit's Advisory Boards.

Current University Strategy (2006-16) expresses commitment to achieving impact unequivocally as *'Research that Matters'*. This is supported organisationally through a professional unit specifically to support 'enterprise', defined as *'academic engagement with business, public and voluntary organisations to create social, cultural and economic impact through knowledge exchange'*, and led (since 2006) by a Pro Vice-Chancellor for 'Enterprise', PVC(E). PVCs for Research and Enterprise and co-located Research and Enterprise Offices ensure a smooth transition from de novo research to knowledge exchange with industry or commercialisation. This integrated approach is reflected in the University's 11 Schools where Associate Deans for Enterprise, AD(E)s, work with their counterparts for Research under the leadership of the Dean in the School Senior Management Teams. AD(E)s meet bi-monthly under the direction of the PVC(E), as do AD(R)s with the PVC(R), to ensure Schools and University senior managers share best practice.

This section provides numerous impact examples, in many cases additional to those featured in our submitted Case Studies, as substantiating evidence of the effectiveness of our approach.

Countless examples exist of relationships with end-users, on scales from individual academics upwards, but **this Unit's strategic approach to engagement with end users** is most effectively demonstrated by its major research centres and major collaborative projects. This strategy features: i) alignment at very senior levels in the companies, ii) senior advisory roles for Unit academics and iii) strategic investments in Unit facilities. Four key vehicles are described below:

1. ***Major publicly-funded Research Centres*** are at the heart of how this Unit delivers reach.

- The reach of the Innovative Manufacturing and Construction Research Centre (IMCRC, 2001-11, £33M, 23 Unit academics, EPSRC's largest IMRC) extended across 400 collaborating organisations. Impact examples in diverse areas included: additive manufacture (3D modelling of the sinus to concrete printing in construction), sustainable manufacture (design for end-of-life management), sports technology (world's first personalised football boots).
- B12 leads the Innovative Electronic Manufacturing Research Centre (IeMRC, 2004-15, £16M, 11 Unit academics led by Conway), uniting 7 universities and >100 UK companies. Impact examples: processes (frequency agile microwave processing for curing polymers), supply-chain design tools (framework for coupled multi-physics, business process and heuristics), sustainable manufacturing (reducing silver use in interconnect materials), solutions for harsh environments (flexible fabric electronics for MHz communications, e.g. smart life jackets).
- The Centre for Biological Engineering (£20M income inc. £16M EPSRC, 6 Unit academics led by Williams) applies engineering strengths at the interfaces with biology and medicine. Following initial £1M LU investment (2009) in cell growth laboratories, impacts extend from the stakeholder guide for a viable regenerative medicine industry to an automated cell culture system generating c.£20M sales. The Centre is pioneering a whole new industry sector.

2. ***Major Research Centres with strategic industry partners*** offer unrivalled opportunities for 'significance' in impact creation through the deep, mutual understanding that stems from staff engagement at the most senior levels in the partner organisations. Examples include:

- Rolls-Royce (RR) University Technology Centre (UTC) in Combustion Aerothermal Systems (c.£1.5M/yr, 10 Unit academics) was the first UTC to obtain Supplier Advanced Business Relationships (SABRe) certification allowing research data to be used formally in the engine design and development process. Following continuous investment since 1991, investment in 2008 (LU/RR) saw opening of the £2.4M Unsteady Fluids Lab. Director Carrotte (RR / Royal Academy Chair) engages with Ken Young, RR Chief of Research and Technology (Combustion). Former director McGuirk chairs RR Propulsion and Power Systems Advisory Board (since 2008) and Independent Scientific Adviser to MoD (since 2007).
- Caterpillar Research and Innovation Centre (since 2009, £400k/yr funding, 7 Unit academics, 20 researchers plus Caterpillar secondees) is focused on engine and machine performance enhancement, e.g. fuel efficiency and exhaust emissions, and has delivered 10 patented inventions to date. As the only Centre of its kind in Europe, Co-directors Garner and Stobart engage at a very senior level (Steve Faulkner, Caterpillar Europe Research Manager, and Eric Fluga, Caterpillar Inc. Head of Energy & Power Systems Research USA). Garner is a member of Caterpillar Industrial Power Systems Division Technical Council.
- adidas Innovation Partnership has delivered every adidas tournament football since 2002 e.g. the revolutionary 2010 World Cup ball. Director Harland leads 7 Unit academics and engages with Engineering Director, Tim Lucas, and Global Senior Innovation Director, Gerd Manz.

3. The Unit's ***major publicly-funded research projects*** have engagement as a fundamental element, to deliver significance through the depth of the relationships. Examples include:

- SUPERGEN (EPSRC, 2008-12, £4.2M, 4 HE partners led by Thomson). Impact included tools to extend lifetime of fossil power generation plant and ensure reliability of future CO_2 capture plant. 10 industry partners including Alstom, Corus, E.ON, RWE npower, Siemens.
- Encyclopaedic (EPSRC, 2009-13, £2M, 3 HE partners led by Rahnejat) improved engine efficiency by reduction of parasitic losses. Partners included Ford, BP, Aston Martin, Ricardo.

4. ***Major Research Centres*** **that bridge the so-called innovation 'Valley of Death'** (Technology Readiness Levels TRL4-6) deliver impact with both reach and significance. Formation of such centres where location is off-campus, driven by user needs, is a distinctive element of our strategy:

- The Manufacturing Technology Centre (MTC) near Coventry opened in 2011 after £40.5M investment from 2 Regional Development Agencies. LU is one of 4 founder partners, working initially with 'Tier 1' Members Rolls-Royce, Airbus and Aero-Engine Controls. Now as part of the High Value Manufacturing Catapult, MTC's success has attracted new Tier 1 Members, e.g. Nissan, HP, Siemens, ABB. MTC inspires new research investigations, e.g. EPSRC Centre for Intelligent Automation (2011-16, £12M inc. £7M EPSRC). 9 Unit academics, including Parkin (Board Member), Jackson (automation theme leader) and Conway (electronics manufacture

theme leader), work alongside MTC staff. 193 jobs created to date.
- The Unit is lead academic partner for the High Speed Sustainable Manufacturing Institute (Dagenham, since 2012, with Ford and DCLG). Impact examples: implementation of radio frequency identification technology for product tracking; 11 jobs created so far.

Participation in dedicated funding schemes is fundamental to the Unit's strategy for impact creation, with aligned professional support provided centrally. The Unit has been instrumental in attracting institutional EPSRC programmes: Collaborative Training Account (2004-13, value within REF period £1.5M), Knowledge Transfer Account (KTA) (2009-12, £3M) and Impact Acceleration Account (2012-15, £2M). Embedding impact activity from the early stages of research projects was prominent in LU's KTA submission, predating RCUK's new emphasis on Pathways to Impact. Secondments are a vital part of this approach, recognising the value of technology-push (seconding Unit staff out) and, distinctively, the industry-pull (where industry staff join Unit laboratories). Since 2008, the Unit has won one-third of all of this institutional funding, as well as 10 KTPs.

- Project examples: Regulation of regenerative medicine products (KTA, Williams, 2010-12) shaped new BSI regulations; decontamination following immense national concern over hospital acquired infections (KTP with Hygienics Biosecurity, 2009); novel cloud base recorder (LIDAR ceilometer) now commercially available (KTP with Campbell Scientific, 2009, Coupland).
- Secondment examples: Taylor Hobson Company Physicist spent one year from October 2010 at LU on scanning interferometry with Coupland, now adopted by NPL; Research assistant secondments e.g. i) *High density electroplated indium bump technology* Rutherford Appleton Laboratory, (Liu & Hutt, 2011-12) and ii) *Integration of a 'design for recycling' approach within the footwear sector*, C&J Clark International, Pentland Brands and Next, (Rahimifard, 2011-12).

EPSRC Industrial Doctorate Centres are also a critical feature in the Unit's portfolio, e.g. Manufacturing Technology (2011-18) and Efficient Fossil Energy Technologies (2009-18), with further significant user engagement in EPSRC Doctoral Training Centres e.g. Hydrogen, Fuel Cells and their Applications (2009-18) and Regenerative Medicine (2008-18).

Follow-through features prominently in our approach to impact. The *'Diffusion and Transformational Impact of IMCRC Research'* project (2011) explicitly recognised how impact successes may not be realised until well after project completion. In 2012, an independent review of LU's KTA programme was commissioned to identify lessons learned which included increased training and better objective setting and monitoring. The prestigious Queen's Anniversary Prize 2013 for High Value Manufacturing powerfully demonstrates significance in follow-through.

Evidence of an agile approach to opportunities is found in LU's creation of interdisciplinary Research Schools; Unit academics lead two (Health and Life Sciences, and Materials) and are extremely active in a third (Sustainability). Success in major awards can be directly attributed to the readiness of interdisciplinary teams, e.g. EPSRC DTC in Hydrogen, Fuel Cells and their Applications combines expertise in materials and propulsion (from this Unit) with chemistry and systems (from other Units). Furthermore, where outstanding opportunities exist to deliver impact, the Unit responds accordingly e.g. Rastogi has 80% secondment to Teijin Labs, Netherlands, (2008-14) to develop products based on ultrahigh molecular weight polyethylene.

Specific support from the Unit to enable staff to achieve impact from their research includes allocation within workload models for impact creation and active intervention by the School AD(E) who has formal responsibility for supporting colleagues in impact creation. AD(E)s work with a nominated Enterprise Office 'buddy' to maximise mutual awareness. Strategic funding for impact creation, as described below, is also available with the Dean's support required to ensure alignment with Unit strategy. Deans can propose staff, including early career researchers, for prestigious Enterprise Fellowships enabling concentration on impact projects with all costs met including salary. The first Fellow (2008, Raghupathy with Binner), developed nanostructured zirconia ceramics; Royal Society Brian Mercer Award followed and commercialisation is expected in 2014. McCall, graduate of the EPSRC DTC in Regenerative Medicine, is the latest Fellow (2013, with Williams), focusing on the reduction of risk and cost in the development of cell therapies.

The University recognises and celebrates impact creation across all Units in its annual Enterprise Awards. In 2013, this Unit won 3 of the 5 awards. Licensing of "turbo-discharging" (Williams & Garner, depressurisation of IC engine exhaust system to improve fuel efficiency) won

the Intellectual Property category. Materials Characterisation Centre won the Consultancy category, for support to e.g. Brush, 3M, Tata and BAE Systems, and re-creation of the skull of Richard III by additive manufacture won the Cultural Impact category (Harris), having attracted 85,000 visitors to Leicester Guildhall. Now in their 4th year, the Awards have been vital in building the impact culture over this REF period. Impact creation is now embedded in all key HR processes e.g. job descriptions, annual performance review, salary enhancement and promotion criteria.

The Unit's approach to maximising impact makes full use of institutional resources. Alongside integrated professional support, HEIF funds of £750k/yr support proof-of-concept and commercialisation (patenting, business planning etc.) projects with the aim of knowledge exchange, licensing or spin-out. In the last 3 years, >30% of this funding has been competitively awarded to B12 which is also active in regional development projects e.g. Transport iNet (Regional Development Agency, 2009-13, £4M and ERDF, 2013-15, £3M) has supported c.700 businesses and created c.300 jobs in the regional transport sector. Project example: working with Hardstaff Group to develop a unique 'dual fuel' (diesel and natural gas) product for existing vehicle adaption.

LU Science and Enterprise Park (LUSEP), hosting LU Innovation Centre, is a major resource in the University's innovation strategy. LUSEP is home to 1500 staff in over 40 partner organisations.

- B12 spin-out companies, e.g. Intelligent Energy (Ranked 15th in the 2103 Deloitte Fast 50, 1333% revenue growth over 5 years), Micropore, Phase Vision, Laser Optical Engineering, have enjoyed Innovation Centre support. 7 spin-outs from the Unit are currently active, employing > 350 staff. Intelligent Energy, c.300 staff worldwide and based on LUSEP, underlines our ability to create a whole new industry sector (hydrogen fuel cells) and jobs.

Unit strategy encourages staff to provide **expert input to companies and advisory bodies** to extend reach of the latest research outcomes across user audiences. Examples: Thring is Board Director of the Low Carbon Vehicle Partnership; Rielly is consultant to BHR Group's industrial fluid mixing processes consortium; Petzing is member of the National Measurement Office Engineering and Flow Working Group; Thomson is a member of the Materials Advisory Group for the National Physical Laboratory (NPL); Haworth is a member of NPL Industrial Advisory Group on Polymer Processing; Garner is the sole academic member of the Automotive Council UK Internal Combustion Engine group alongside directors of e.g. Bentley, BMW, Ford, Jaguar LandRover; Garner is also Special Academic Advisor to the Energy Technologies Institute (ETI) Heavy Duty Vehicles Group; Harland was Technical Advisor (Balls) to England and Wales Cricket Board (to 2012); Williams is expert member of Johnson & Johnson Regenerative Medicine Scientific Board.

c. Strategy and plans

Our 5 year strategy recognises that creation of research impact can take considerable time and has three vital ingredients: i) on-going, active engagement with industry partners ii) dedicated funding and professional support and iii) personnel exchange is critical to knowledge exchange.

Proven systems will be refined by evaluation based on submitted Impact Case Studies. These systems are characterised by comprehensive staff and student training opportunities, professional support (for business development, partnership management and IP commercialisation), significant dedicated project funding, celebrating achievements and continuing investment in physical infrastructure. **New developments will enhance B12's approach to impact:**

- LU's inaugural Impact Festival will take place in Jan. 2014, bringing staff, students and funders together to share best practice on pathways to impact, public engagement and exploitation.
- Following the independent review of KTA, support staff will consult with collaborating companies on follow-through to identify impacts and this will become routine for (internal) enterprise grants.
- Through our Glendonbrook Centre for Enterprise Education, we will enhance training opportunities for PhD researchers and early career staff (academic and research). In particular, the Unit is leading development of a dedicated programme targeted at PhD students and early career staff for delivery both within our Centres for Doctoral Training and more widely.
- Having engaged fully in the Witty Review of Universities and Growth (2013) and embracing his hypothesis that universities can drive regional economic growth, LU is currently working with the Leicester and Leicestershire Enterprise Partnership to develop its regional innovation strategy. The Unit's research is central to the emerging strategy.

The emphasis in the Unit strategy on engagement within major grants and centres, including with

off-site TRL4-6 Centres will remain prominent. **New developments** in this respect include:

- The EPSRC / Jaguar LandRover Programme for Simulation and Innovation (2013-17, £1.8M) in collaboration with Cambridge, Warwick and Leeds Universities.
- c.£10M expansion of RR UTC facilities to create a unique international experimental facility.
- An MoU with the Cell Therapy Catapult was signed in January 2013 for projects in cell therapy manufacturing and delivery using unique Unit capability.
- EPSRC Centre for Doctoral Training awards in 2013 for "Fuel Cells and their Fuels", "Gas Turbine Aerodynamics" and "Additive Manufacturing", each with multiple industry partners.
- HPC Midlands (EPSRC, £1.25M, shortlisted for the 2013 Times Higher Education Awards for "Outstanding Contribution to Innovation and Technology"), 3,000 core supercomputer centre launched in 2013 to support academia and industry. Early success documented in case studies with E.ON, Tata Steel, RWE npower and Airbus http://hpc-midlands.ac.uk/case-studies/.

The Unit aims to increase its return from IP commercialisation and has significant projects currently receiving intensive professional support. The Unit has pioneered the use of external expertise in decision making. This **selection of specific projects** will be prominent over the next 5 years:

- Licensing of High Speed Sintering, a disruptive additive manufacture technology.
- Commercialisation of nanostructured ceramics (bio-replacements, electronics. ballistic armour).
- Applications of recently licensed turbo-discharging technology.
- Manufacturing platform for adherent cell culture in regenerative medicine.

From 2014, the University will embark upon a major reorganisation of its research activity to focus its resources across 6 agreed interdisciplinary research challenges under the guidance of the PVC(R). Each theme will have a senior academic lead supported by a challenge manager working across research and enterprise. The Unit has contributed significantly to development of this strategy and will remain active in its delivery. The sharper focus will **extend reach and significance over the next REF period**. The challenges will combine underpinning science with end-user application. This major initiative will be undertaken in a context that includes an extensive £60M redevelopment of the buildings, space and facilities used by a large proportion of this Unit.

d. Relationship to case studies

The success of the Unit's approach is evident in the selected Case Studies. "Manufacturing systems for therapeutic human stem cells …" (Williams), "Process simulation, monitoring and control …" (Conway), "Project HOTFIRE .." (Garner) and "High-performance, low emission diesel engine …" (Garner/Hargrave) result from **major publicly-funded research projects** or **centres**. For **major Research Centres with strategic partners**, "Acoustic damping systems …" (Carrotte) and "… design methodology for aero-engine design methodology for aero-engine combustor aerodynamics" (McGuirk) have emanated from the Rolls-Royce UTC and "…performance of elite tournament footballs …" is from the adidas Innovation Partnership. "Process simulation, monitoring and control …" (Conway) has involved the MTC, an example of a **major Research Centre designed to bridge the 'Valley of Death'**. Amongst the three vital ingredients we listed for impact creation, more than half of our Case Studies underline the importance of active (and often long term) **engagement with industry partners**: Rolls-Royce and adidas examples above, "… handling and safety for Jaguar Land Rover drivers" (Best), "Disentangled polyethylene …" (Rastogi with Teijin), "Understanding vibro-impact systems …" (Silberschmidt with JCB), "A 60% reduction in diesel use …" (Coupland/Hargrave with Hardstaff Group), "High-performance, low emission diesel engine …" (Garner/Hargrave with Caterpillar) and "Drivetrain noise and vibration refinement …" (Rahnejat with Ford). **Dedicated funding and professional support** to create impact were pivotal in "Fuel cell research powers zero-emission vehicles" and "Changing how high value particles are produced" (spin-out companies), "Environmental hygiene monitoring …" (KTP), "Fuel cell research powers zero-emission vehicles" also emphasises the long haul nature of impact creation on a large scale. "Understanding vibro-impact systems …" and "Disentangled polyethylene …" exemplify the power of **personnel exchange in knowledge exchange**.

While the case studies primarily reflect the Unit's approach, two case studies underline the need to be flexible. For "Disentangled polyethylene …", an exceptional long-term secondment was necessary while, in "… handling and safety for Jaguar Land Rover drivers", we see the importance of supporting high quality work wherever it is found, in this case from outstanding early career individuals working with excellent supervision but a modest budget.