Institution: Brunel University

UoA:12 – Aeronautical, Mechanical, Chemical, and Manufacturing Engineering

a. Overview

Engineering at Brunel University was set up at the founding of the institution to tackle problems that were fundamental to future economically important technologies, and more immediate industrial needs. To this day we maintain that vision.

Brunel draws together Mechanical Engineering, its applications, and its supporting sciences to form a coherent unit of 67 academic staff, 38 research staff, and 37 technical support staff. We are arranged in 6 centres in three themes:

Applied Mechanics: 21 staff (19.8 FTE).

CCAM – Centre for Computational and Applied Mechanics develops numerical solutions and constitutive models for applications in the aerospace, offshore, and medical engineering industries.

CED – Centre for Engineering Dynamics concentrates on vehicle and structural dynamics, systems integration, structural integrity, and fault-tolerant control.

Energy and Environment: 17 staff (17 FTE).

CEBER – Centre for Energy and Built Environment Research works on energy efficiency and reducing the environmental impacts of energy consuming equipment and buildings.

CAPF – Centre for Advanced Powertrain and Fuels is one of the largest and most active European groups, covering both experimental and modelling aspects of engine research.

Materials: 29 staff (26.47 FTE).

BCAST – Brunel Centre for Advanced Solidification Technology. BCAST conducts fundamental research in metals solidification science to develop technologies for sustainable recycling and circulation pathways for the global metal casting industry.

WCMP – Wolfson Centre for Materials Processing. WCMP conducts basic and applied research focusing on nanomaterials, electroluminescent displays, nanostructured carbon, biofuels, polymer extrusion, and biodegradable food packaging.

Operation

The Mechanical Engineering subject area (Applied Mechanics and Energy and Environment themes) is led by **Zhao**, **WCMP** by **Silver,** and **BCAST** by **Z. Fan**. All three units are part of the School of Engineering and Design (**SED**). The School management team agrees strategy and makes the principal recommendations for new appointments and infrastructure investment. The team comprises the Heads of Subject Areas, Director of Graduate Studies, and the Research Centre leaders.

Although our principal activities are high quality research and teaching, we promote the application of our research through technology transfer. We acknowledge our role in the public engagement of science and engineering, and our staff take part in public activities and are active within their professional institutions.

b. Research Strategy

Our approach to mechanical engineering research and training is that:

- it is a fundamental discipline for exploring the world around us,
- it is an enabler of technologies relevant to society,
- our staff engage with both fundamental problems and economically relevant technologies,
- we are equally engaged with fundamental and industry-related problems,
- all staff are expected to engage widely with other engineering, science, health, economics, and social sciences, and
- we prepare doctoral students to be flexible in the application of their new knowledge.

1. Vision and Strategic Plans

Our vision is:

to tackle challenges that are important to the economy, the environment, and society both nationally and internationally.

We aim to be a creative community that is inspired to work, think, and learn together to meet the challenges of the future. We aim to attract outstanding partners across a range of disciplines to complement and underpin the applied research and development activities. Our strategy is

formulated to maximise interdisciplinary, international dialogue and to enhance both basic engineering science and applied engineering-led research via continued focused investment in our research infrastructure, allowing us to be receptive to new opportunities arising from the changing landscape of national and international priorities such as "green" technologies.

Our unified research strategy is keyed into the overarching University strategy developed through consultation with Schools and Research Centres. Research theme strategy is developed by a team led by Wrobel (Deputy Head of SED, Research) and consisting of Centre leaders, plus representatives of ECR and MCR staff. External views are given by our Industrial Advisors who include: Dr. M. Short CBE FREng (O_2-Telefonica), Prof. N Jackson FREng (Ricardo), P. Jenkins (BT Innovate and Design), Mr. A. Balkwill (3M), Dr. N. Jefferies (Huawei Technologies), Prof. C. Firth (Thales), Dr. M. Bradley (National Grid), Ms R. Ali (BP), Mr. A. Harper (Jaguar-LandRover), Dr. R Horrocks (Ford), Mr. J. Laughlin (TSB), Mr. N. Mills (QinetiQ), Mr. J. Sellors (Lotus Engineering), and Dr. E. Suttie (BRE). Two examples of how our Advisors interact with the management team are 1) their support for investing in and growing the aerospace research area, and 2) starting an internal collaboration on building a network of researchers working on topics allied to the circular economy. Their advice has also been helpful in warning against starting certain activities as they were a poor fit with our strategy. Drawing on our strategic review in 2013, the highlights of our five year research strategy (from 2014) are to:

- draw together our critical mass of staff to establish two (university-wide) multidisciplinary research institutes in 'Energy Futures' and 'Materials and Manufacturing',
- build a new facility for, and create the first impacts from, the Brunel-led National Structural Integrity Research Centre,
- build a laboratory for the new EPSRC Centre for Sustainable Energy in Food Chains,
- ensure the long-term sustainability of our EPSRC IMRC for Liquid Metal Engineering,
- secure funding for a novel purpose-built Advanced Metal Casting Centre and facility,
- secure funding for a new computing facility for CCAM,
- expand staff and facilities in our Applied Mechanics and Energy and Environment themes,
- expand levels of international inward investment by industry for our research infrastructure,
- create mechanisms to further enhance multidisciplinary collaboration between the multidisciplinary institutes and mechanical engineering.

Our plans are designed to deliver constant and consistent improvement to 2020 and require significant additional inward investment. The strategy pursued from 2008 has proved successful and we will work to further improve our funding success rates across all types of funder. In this way, we can sustain the levels of improvement seen in the 2008-2013 period through to 2020. In addition, the fundraising activities are an integral part of the campaign to celebrate the University's 50th anniversary in 2016. Highlights from the specific strategies for the three themes are:

Applied Mechanics:

- Bring the departments of Maths and Computer Science into the same operational unit as Engineering and Design to create a larger, more coherent, and stronger fundamental base for computational mechanics and CFD research at Brunel. This will benefit both the Applied Mechanics and Energy and Environment themes.
- Expand aerospace, aeronautics, avionics, and aviation research by investment in laboratory facilities and new staff.
- Capitalise on recent investments and successes in structural integrity research.

Energy and Environment:

- Expand research activity of end-use energy demand in buildings, particularly commercial sites.
- Draw together the transport energy use researchers more coherently across Brunel.
- Integrate work on emissions in CAPF and CCAM to develop expertise in the effects of transport in the built environment.
- Develop an industrially funded Doctoral Training Centre in Energy Use in Food Chains.

Materials:

- Bring together the materials and manufacturing groups into a single entity or Institute to further improve the pull-through of basic research. An emphasis will be placed on pilot-scale studies and scale-up testing.

- Build a new facility for large-scale metals reprocessing – the Advanced Metals Casting Centre.
- Integrate bio-processing scale-up research with manufacturing expertise.
- Develop an industrially funded Doctoral Training Centre in the Circular Economy of Metals.

2. Achievements of the Specific Strategic Aims from RAE2008

Our RAE2008 submission was to UoA28 (Mechanical, Aeronautical and Manufacturing Engineering). Our strategy was to i) expand the numbers of staff in the three themes to deepen each group's expertise, ii) nurture ECRs to be successful MCRs, iii) to increase both the total and per capita income, iv) invest in new facilities and refurbishment of existing laboratories, and v) improve the impact of our research. We summarise the evidence in this section, with the detail described in sections c), d), and e). Implementing our strategy has, since 2008, enabled us to:

- increase the staff head-count from 39 to 67 – a rise of 74%,
- treble our portfolio of grants won from £13.6M to £40.8M,
- more than double the annual per capita income from £51k to £115k,
- spend a total of £13.7M on infrastructure refurbishment,
- promote 6 RAE2008 ECRs (one to Professor) – together they raised £3.7M,
- build the 6th largest materials science and engineering research portfolio in the UK,
- build the 12th largest Technology Strategy Board portfolio in the UK,
- enter into strategic agreements with TWI and Jaguar-LandRover, and
- attract £5.52M of industrial inward investment.

The Research Support and Development Office (RSDO) provides the central support for each School's, and the University's overall, research strategies. Investment in RSDO staff since 2009 (from 11 to 15 people) and training has gone in-step with our substantial growth in the number, variety, and total income of grants. RSDO manages a Research Development Fund to support the development of major grant applications and the University's EPSRC Impact Acceleration Account. RSDO also supports the development of strategic research relationships with industry. For the protection and commercialisation of IP that originates from inside Brunel, RSDO arranges seed funding, sector-relevant management support, and patent filing.

c. People

1. Staffing Strategy and Staff Development

Our staffing strategy has enabled us to sustain a balanced age profile with approximately one third of staff in each of the bands of less than 37 years old, 38-50 years old, and more than 50 years old. The University staffing policy is designed to promote world-leading research and sustain a vibrant academic environment. Significant emphasis is placed on giving staff new to Brunel (ECRs and established) support to ensure that they are able to be productive as soon as possible – this contributes to the sustainability and vibrancy of our research environment. For example, our RAE2008 ECRs have won three grants each since 2009. Our staffing strategy is:

- to provide the opportunities and reasonable means for all staff to fulfil their potential,
- to identify gaps in our portfolio as research areas develop within the three themes,
- to reward research groups demonstrating grant income success with new posts,
- incentivise and financially reward staff for winning grants,
- to provide mentoring at <u>all</u> levels.

Our recruitment policy places strong emphasis on hiring outstanding researchers whose work complements one or more of our existing research centres. Candidates are expected to have a record of publishing high quality research commensurate with their experience level. Typically about 50% of applicants to academic posts are from overseas. Our recruitment strategy is:

- for senior staff – to only appoint those with internationally leading portfolios
- for MCRs – to only appoint those with internationally competitive portfolios and the potential to become internationally leading
- for ECRs – to only appoint those with some international experience and the potential to be internationally competitive / leading,
- to advertise posts internationally and to target active groups, particularly for ECR posts,
- to appoint those with proven multidisciplinary experience,
- all appointees must be able to demonstrate that either they have taken steps to apply their work to a cognate academic area, or engaged with public or private sector organisations.

Evidence of How our Staffing Strategy Relates to our Research Strategy

Since 2008 we have created 29 posts (9 ECR, 11 MCR, 9 SR). Of these, 6 were in the Applied Mechanics theme, 6 in Energy and Environment, and 17 in Materials. Success in research output and grant income has been such that 19 members of staff have been promoted since 2008, including 6 to Professorships. Two staff held RCUK Academic Fellowships: **Babu** (2006–2011) and **Coppo** (2007–2012).

The new staff appointed have raised a total of £7.33M with 45 grants. Further examples of their early productivity are: **Eskin** won the Warren Peterson Cast Shop for Aluminium Production Award, **Cairns** rose from Lecturer to Professor, and **Zhou** has won 4 grants. Our strategy for investment and staff support has attracted academics to move here either individually or bringing their whole groups. For example, **Bhattacharya** moved with 5 researchers from Engineering Science at Oxford, **Cashell** (Imperial College), **Cairns** (Mahle Powertrain Ltd), **Eskin** (Delft University of Technology), **Frampton** (Pharmorphix Ltd), **McKay** (University of Loeben, Austria), and **Triantafyllou** (ETH Zurich).

We have a total of 18 staff with visiting positions elsewhere. Exemplars of those made since 2008 are: **Atherton:** Visiting Research Fellow, LSE (2009). **Eskin:** Tomsk State University, Russia (2012). **M. Fan:** Associate at the Building Research Establishment (BRE, 2009). **Ray:** University of Science and Technology Beijing (2013). **Sermon:** University of Malaya in Kuala Lumpur (2012). **Stolarski:** University of Tokyo (2009). **Wrobel:** COPPE/Federal University of Rio de Janeiro, Brazil (Science Without Borders Programme, 2012).

Career Development Support

All staff are supported to attain the next level in their career. We undertake some activities which are subject specific whilst others are institution-wide and common across disciplines. For all levels of seniority, staff are mentored through the promotion process to help understand the requirements, preparation, expectations, and the final interview. The University process (overseen by Senate) actively rewards research excellence. As part of the process, the University organises workshops, led by the University Equality Champion, to support women intending to apply for promotion. The overall promotion process is subjected to an annual Equality Impact Assessment, which is used to drive improvements in the equity of the process.

Brunel University received an Athena SWAN Bronze award in 2012, and is embedding the policy and practices across all disciplines. Newly introduced Athena SWAN Research Awards are open to staff returning from maternity, adoption or paternity leave (>4 months) to support research leave, equipment purchase, or to employ RAs. Awards are given on the basis of an internally reviewed proposal. The University appointed 'Equality Diversity Champions' to provide leadership in creating and maintaining an inclusive culture. The University operates a vibrant Women in Science and Engineering group spanning the whole University and all grades (including PGRs).

Specific Arrangements for Research Assistants (RA)

Brunel received the European Commission's 'HR Excellence in Research' award in 2011 in recognition of its commitment to the recommendations of the Concordat to Support the Career Development of Researchers. Brunel has a Concordat Action Plan and Working Group. RAs are offered programmes of personal and professional development through both the Graduate School and the Staff Development Unit as appropriate. Examples of courses offered are: 'Creating Research Impact', 'Understanding Patents, Licensing, and Standards', and 'Effective Public Speaking'. Before the end of their contract with Brunel, over 90% of our postdoctoral researchers and PhD graduates secure further positions. Typically about 20% of our RAs go to academic posts, 65% to an industry or sector related to their post at Brunel, and 15% take other positions (including teacher training).

Specific Arrangements for Early Career Researchers (ECRs)

On appointment, all ECRs are assigned a mentor, have reduced teaching and administrative responsibilities throughout probation, and are appraised annually by the Head of the appropriate Subject Area within the SED. ECRs receive priority in the allocation of our DTA and SED-funded research studentships. Start-up funding of up to £15k is available upon internal review of a short proposal. These awards are intended to initiate a project, acquire equipment, and to travel to conferences to create a network of collaborators. As a result, since 2008 **Cairns**, **Chong**, **Xia**, and **Zhou** built on these awards to go on and win an EPSRC First Grant. The project **Zhou** initiated has led directly to a share of the €3.78M EU collaborative project Nanotechnology Enhanced Extruded

Fibre Reinforced Foam Cement Based Environmentally Friendly Sandwich Material for Building Applications (FIBCEM), involving academic and industry partners in five countries. The start-up fund enabled **Cairns** to leverage a direct-funded PhD studentship from BP to examine the effects of future fuels and lubricants in boosted spark ignition engines. BP thereafter agreed to support Cairns' successful EPSRC First Grant application.

Specific Arrangements for Mid Career Researchers (MCRs)
All senior lecturers are appraised annually by the Head of the appropriate Subject Area within the SED. The Staff Development Unit's courses appropriate for MCRs include Research Ethics, Managing Research Staff, and Influence and Impact for Researchers.

Specific Arrangements for Senior Researchers (SRs)
Readers and professors agree their targets for the coming year with the Head of SED and their annual pay rise is linked to their performance. Senior academics looking for leadership roles are offered a six month programme to develop competencies in their areas. Two examples are **Zhao** in the lead up to becoming Head of Mechanical Engineering and **M. Fan** in relation to co-ordinating large-scale EU projects.

2. Postgraduate Research (PGR) Students
We celebrate the vital role PGRs play in sustaining research activities and stimulating adventurous new ideas. Since 2008, 80 PGRs have completed in this UoA. We receive approximately 9 applications per place. Our strategy for PGR is to:

- attract and select students with the greatest potential for high quality research,
- to create bilateral agreements with companies and research organisations to support PGR,
- train students to be flexible in the application of their new knowledge,
- to develop the transferable skills of all PGRs,
- to enable all PGRs to gain international exposure,
- to enable PGRs to engage with an appropriate business or industrial sector, and
- to give PGRs confidence in their abilities and achievements.

To support this strategy we have diversified the number and type of funding sources for the scholarships that we offer. In addition, the University has made a substantial financial commitment directly as part of several partnerships. For example, for UK Nationals we have secured 15 scholarships from the Thomas Gerald Gray Charitable Trust, which are topped-up by the SED.

We have entered into strategic agreements, for instance, with TWI who initially agreed to co-fund 5 PhDs in a pilot programme (2009-13) for NDT instrumentation, shared with Electronic Engineering. Due to the quality of the students recruited and their work, TWI agreed to support a further 10 PhDs with a 40%-60% funding split between Brunel and TWI (2011-15). Similar agreements have been made with NPL, National Grid, and Renishaw. The TWI agreement blossomed into a partnership which won the National Structural Integrity Research Centre (NSIRC) which is funding 10 PhDs per year at Brunel (with various companies). **Wrobel** was part of the 16 partner €2.94M Marie Curie Research Training Network for the Optimization of Systems, Energy Management, and Environmental Impact in Process Engineering (INSPIRE).

Between 2002-12 Brunel and Surrey jointly ran the EPSRC Engineering Doctorate Centre for Environmental Technology. To sustain the expertise generated and in accordance with the EPSRC's aims for the EngD Centres, from 2010, Brunel introduced an Industrial Doctorate Scheme for Sustainable and Environmental Technologies. The Research Engineers (RE) have the same working and financial arrangements with the supporting companies, and the Brunel Graduate School provides the transferable skills training. The model adopted is sustainable and the collaboration with Brunel is proving attractive to both the companies which were involved with the EPSRC-funded scheme and new ones. So far, 12 RE have embarked on the new scheme with the first due to complete their four year programme in 2014. Sponsors for this programme include: Buro Happold, Converteam, Mollart Engineering, NPL, and National Grid.

PGR Training and Support Mechanisms
Admissions are managed through the Brunel Graduate School. Specialist training, enrolment and progression is managed by the SED. Transferable skills are provided by the Graduate School, for example, ethics, research methods, and project management. The Graduate School is the hub for PGRs and plays an important role in bringing together the community through both academic and

social activities, supporting the development of cross disciplinary links. The Graduate School also collaborates with other universities in London (particularly UCL and KCL) to provide a broader context for researcher development, i.e. opportunities for inter-disciplinary learning, collaboration and networking across institutions.

SED organises an internal Research Student Conference (ResCon). All PGRs must take part and it gives PGRs a chance to speak, present posters, and allows supervisors to see how their PGRs defend their work before they go to an external conference. ResCon2013 involved 200 presentations over a three-day period (130 talks and 70 posters). For progression to year 2 each PGR gives a talk, presents a poster at ResCon, and is interviewed. Travel funds are available to ensure that all PGRs present their main findings at an appropriate conference. Since 2008, 14 PGRs have won conference prizes and 3 have won thesis prizes.

d. Income, Infrastructure and Facilities

Implementing our strategy, outlined in RAE2008, has helped to treble our total income and to invest a further £13.7M in laboratory refurbishment and new equipment.

1. Specialist infrastructure and facilities for each theme

We currently operate a total of 9,500m^2 of research space (plus 4,000m^2 for offices and teaching), which, with the firm **PLANNED** investment, will increase the research space to over 11,500m^2. In 2009 we opened a 4,500m^2 facility to house several groups and to provide state-of-the-art space for PGRs at a cost of £16M (SRIF3 / HEFCE). The strategic decision by the University to create this building freed up space for the SED to start a 10-year programme of refurbishment. Our workshop facilities are supported by 37 staff with 10 specialist technicians in research laboratories. SED has 4 dedicated administrative staff for research support. Our research and high performance computing facility is supported by 11 dedicated technical staff. Brunel is a Worldwide LHC Grid Tier 2 site and part of the European Grid Infrastructure. Our Tier 2 has currently 1300 cores and 650 TByte of on-line storage. It is internally networked at 10 GB/s and connected to JANET at 4 GB/s.

Applied Mechanics:

CCAM has a dedicated computing cluster with over 130 cores, plus access to the Grid Tier 2 facility. The current dedicated cluster replaced a three cluster (256 core) facility in 2011.

CED's dynamics and structures laboratories comprise: an instrumented road car to correlate the dynamic response of the vehicle to the driver's inputs during limit handling, a rolling road vehicle dynamometer for motorbikes and smaller vehicles, a laser vibrometer, a GRAS 43AG Ear and Cheek Simulator with KEMAR ear pinna for realistic reproduction of the acoustic properties of the ear of an average human, and a 70m^3 anechoic chamber. The experimental aerospace and aviation facilities include: a supersonic (Mach 2.0) wind tunnel (10cm square cross-section), a unique reconfigurable 'open circuit' 40ms^{-1}wind tunnel (50cm square cross-section), a 6 axis flight simulator for studying pilot behaviour under stress conditions, and a fully instrumented 3-translation and 2-rotation scale helicopter rotor. The experimental structural integrity facilities include: a 3D scanning vibrometer and an extensive non-destructive testing laboratory shared with TWI.

Energy and Environment:

CAPF is equipped with 12 engine testbeds and facilities for gaseous and PM analysis, optical diagnostics to IC engines, engine simulation, and combustion CFD. These include: 6 eddy current dynamometers, 6 AC motor dynamometers, 2 Ricardo Hydra single cylinder CR diesel and DI gasoline optical engines, a switchable 2/4 stroke camless DI gasoline engine with an AVL supercharger system, a full optical access engine, a highly downsized 120kw/l single cylinder DI gasoline engine, a single cylinder HD CR diesel engine, I4 and I6 gasoline and diesel engines, 2 Horiba 7100DEGR exhaust analysers, AVL smoke and SMPS/Impactor type PM size analysers, FTIR and GC/MS analysers, 6 in-situ combustion analysers, 2 high power Nd:YAG lasers, 2 high power Excimer lasers, 3 ICCD cameras, high speed video camera and intensifier (30kfps), and a range of optics for PIV, PLIF, LIEF, SRS, and LII measurements.

CEBER has unique facilities for energy in the built environment and food industry research. These include, a 100 kW gas turbine based combined heat and power and trigeneration facility, unique CO_2 refrigeration equipment for CO_2 system, component and controls research and two 80m^3 environmental chambers that provide controlled conditions of air temperature, humidity and flow rate for research and test and development work under ISO23953 conditions. Other facilities include heat transfer rigs for single phase and boiling and condensation research in microchannels.

The hydrogen handling laboratory houses a SOFC test bench for electrical characterisation and interactions with storage devices. It operates up to 750^{o}C, 15atm, and 100Wcm^{-2}. Additional facilities include a PEM electrolyser, a high pressure Parr reactor for preparing colloidal metal nano-particles (for catalysts), a high energy ball mill (1000rpm), plus TGA and DSC for thermal characterisation (also used for our work on phase change materials).

Materials:

WCMP is the only UK university research centre to achieve BS EN ISO 9001:2008 UKAS Quality Management 015 standard (including equipment calibration test certification). The principal electron microscope is a new Joel 2100 FEG-STEM for sub-nanometre imaging. It is equipped with X-ray analysis, electron energy filtering, electron energy loss spectrometry, tomography and cathodoluminescence capability (specimen holder connected by fibre optic to a remote spectrometer). This instrument is unique in the UK and only one of two in the world. The electron microscopy and analysis suite also includes: FESEM Zeiss Supra VP FE-SEM able to operate at weak vacuum conditions and with uncoated specimens; scanning probe microscopy; AFM, and a ToF-SIMS. The display materials analysis suite includes: Horiba Laser Raman spectrometer with mapping, Horiba fluorimeter, and a large integrating sphere for luminous efficacy measurements of emissive devices, a Perkin Elemer 650s UV-Vis spectrophotometer with reflectance determination and thermal trap measurement of luminescent centres, and FTIR and UV/VIS/NIR spectrometers. A Class 100,000 cleanroom houses a pilot-scale OLED manufacture, and coatings laboratories for inorganic / metals and powder handling for thin film deposition and printed coatings. The analytical suite has equipment for thermal, rheological, chemical and structural analysis including micro and nano characterisation, mechanical and related physical testing. Industrial processing techniques for polymer mixing, extrusion and moulding technologies, including unique mixing and injection moulding techniques developed at **WCMP**. These are housed in a purpose-built processing hall.

BCAST operates a unique and comprehensive combination of casting and melt conditioning equipment and techniques for characterising metals in the liquid and the as-cast states. Casting equipment includes: a commercial (Frech) 450t clamping force high pressure die casting (HPDC) machine (the only HPDC machine in a UK university); a lab-scale direct chill casting machine capable of casting light alloy billets of ~100 mm diameter x 1 m in length; and two twin roll casting machines uniquely designed for casting thin strip. Melt is supplied via electrical resistance furnaces of varying sizes and types with protective cover gas distribution, and a 125 kW induction furnace with two remote melting heads. Ultrasound generators with sonotrodes and a rotary degasser are also used for melt conditioning. Processing equipment includes: two *unique* rheoextrusion machines, one each for aluminium and magnesium profiles directly from the melt; and a 550t extrusion press. Characterisation facilities include: a pressurised filtration unit for examining inclusions, a reduced pressure test unit and a probe to assess H_2 content in melts, two rheometers specially developed to measure the viscosity of liquid metals, X-ray diffractometer for liquid metals with a unique miniature twin screw device for investigating liquid structures developed during high shear, creep and tensile testing differential scanning calorimeter, and an optical emission spectrometer.

2. Evidence of Investments in Infrastructure and Facilities and Future Plans

The **CURRENT investments** are those made between 2008-2013. Through implementing our strategy, articulated in RAE2008, these investments have helped us to:

- treble our portfolio of grants won from £13.6M to £40.8M,
- more than double the annual per capita income from £51k to £105k (including ECRs),
- spend a total of £13.7M on infrastructure refurbishment,
- win one of the six EPSRC End Use Energy Demand Centres,
- win an EPSRC Innovative Manufacturing Research Centre,
- build the 6th largest materials science and engineering research portfolio in the UK,
- build the 12th largest Technology Strategy Board portfolio in the UK,
- win 9 EPSRC CASE awards totalling £476k.

The increase in funding won in this period led to further investment in people (Section C), upgrading existing facilities to meet current demands and to create new facilities to lay the foundations for work post 2020. For the **PLANNED investment** we have already raised more than £29M towards our goals – the strategy is outlined in Section B. The new-build facility for the £12M

RCUK Centre for Sustainable Energy in Food Chains (CSEF) will free up 700m^2. This space will be refurbished and converted for work in aerospace engineering. Exemplars of investments since 2008 and firm commitments for each theme include:

Applied Mechanics:
CURRENT: structures laboratory (£360k), dedicated computer cluster with over 130 cores (£52k), the Grid Tier 2 high-performance computing (HPC) and data centre refurbishment (£570k), equipment for vehicle/e-bike dynamics laboratory (£55k), and Polytec 3D scanning vibrometer (216k).
INCOME: the grants won total £6.4M. Exemplars: vortex induced vibration, fatigue, and structural integrity of deep water flexible risers (**Bahai**, EPSRC, £1.1M) with Brunel leading a consortium of Imperial, Oxford, Southampton, BP, Lloyds Register, and Shell, numerical techniques for characterising obstructions in sewer pipes (**Kirby**, EPSRC, £309k), and CFD and Lagrangian dispersion methods for airport emissions mapping (**Wrobel** EU-FP7, €155k).
PLANNED: Upgrade of computing facilities for CFD research (£50k agreed), rebuilt and upgrade of the anechoic chamber (£150k, agreed), particle image velocimeter and high frame-rate camera, a large cross-section 70ms^{-1} wind tunnel, equipment for the National Structural Integrity Research Centre (NSIRC, £15M already raised), aerospace engineering laboratory (£1.3M est), HPC and data centre upgrade (£550k est).

The current and planned investments will enable the members of this theme to: improve the experimental facilities for aeronautics and avionics and enable practical collaboration between aerospace and electronic systems researchers. The major plan for this theme is the National Structural Integrity Research Centre.

National Structural Integrity Research Centre (NSIRC)

Brunel leads NSIRC with a unique, integrated approach to research and PGR training. The **total project value of £82M** comprises £15M (HEFCE), £45M (industrial partners), and £22M (Regional Growth Fund). The initial partners are BP, Cambridge, Lloyd's Register, Manchester, Network Rail, TWI, and UCL. It will be housed in a purpose-built 4,500m^2 facility at the TWI site outside Cambridge. NSIRC will advance the underpinning science, develop novel technologies, innovate in the value chain, conduct holistic product design, and demonstrate solutions for asset management. It will accelerate the translation of science into commercially relevant products and services. The investment in **new** equipment will include: metallic and polymeric materials analysis and characterisation, high pressure testing for pipes and vessels, testing in aggressive environments, re-configurable large-scale facilities for specialised structure testing, process simulation, and modelling of structural performance and lifetime prediction.

Energy and Environment:
CURRENT: equipment upgrade of IC engines emissions monitoring facility (£596k), new hydrogen and fuel cells handling laboratory (£162k), upgrade of vehicle powertrains laboratory (£190k).
INCOME: the grants won total £13.5M. Exemplars: a project on the integrated design of closed-loop cooling systems for devices operating at high heat fluxes including cooling of aircraft devices (**Karayiannis**, EPSRC, £520k), a study into the micro-explosions of fuel blends for low carbon Diesel engines (**Megaritis**, EPSRC, £721k), a cost-effective regenerative air hybrid powertrain for low carbon buses and delivery vehicles (**Zhao**, EPSRC, £456k), the EU WOODRuB project is creating construction materials from wood and rubber waste (**M. Fan**, FP7, €1.8M total, €0.4M Brunel), and the Grow2Build project for bio-based building materials (**M. Fan**, European Regional Development Fund, £595k), integrated thermal energy storage in food refrigeration equipment for energy and CO_2 emissions reduction (**Tassou**, DEFRA, £501k).
PLANNED: new equipment and laboratory for the EPSRC Centre for Sustainable Energy in Food Chains (£1.2M agreed), a hydrogen titration system and equipment for kinetic / thermal and cycling properties of metal hydrides (£65k est), and upgrade of equipment for electric powertrains (£220k est).

The current and planned investments will enable members of this theme to: expand CAPF's electric and hybrid powertrains work and to collaborate better with power electronics researchers. The major plan for this theme is the EPSRC Centre for Sustainable Energy in Food Chains.

EPSRC Centre for Sustainable Energy in Food Chains (CSEF)

Brunel leads CSEF (an End-Use Energy Demand Centre) with Manchester and Birmingham. The **total project value of £12M** comprises £5.7M (EPSRC), £4.5M (industrial partners), and £1.8M (universities, £1.2M is Brunel investment). Examples of the 24 industrial partners are Tesco, Heinz, Iceland Foods, Kellogg, and Buro Happold. The Brunel investment includes: a **new** 1,000m^2 building, and purpose-built environment chambers to test and develop full-scale commercial refrigeration and energy recovery systems.

Materials:

CURRENT: EPSRC Centre for Innovative Manufacturing in Liquid Metal Engineering (LiME), (£1.91M); Joel 2100 FEG-STEM system (£2.43M), nanotechnology laboratory (£354k), OLED production machine and cleanroom (£680k), and ToF-SIMS instrument (£320k).

INCOME: the grants won total £20.7M. Exemplars: the EU SUPRA-BIO project is about making sustainable products from the economic processing of biomass in highly integrated biorefineries (**Bhattacharya**, FP7, €17.5M total, €2.1M Brunel), high temperature radiation hard detectors (**Fern**, EPSRC, £797k), high-tin aluminium plain bearing alloys produced by intensive melt shearing technology (**Stone**, TSB, £239k), the EU 'Light Touch Matters' project is designing and constructing touch-sensitive materials (**Coppo**, FP7, €5.5M total, €0.3M Brunel), upgrade of small equipment for ECRs (**Babu**, EPSRC, £476k). Building the liquid metal processing facility enabled **Z. Fan** to attract more than 15 contracts from the automotive industry, which laid the foundation for winning the EPSRC LiME proposal. This led to further major investment by EPSRC, Government, and industry for the AMCC.

PLANNED: Micro-processing and characterisation of electroluminescent devices plus large format EL screen printing (£360k secured from the Wolfson Foundation), 100,000 clean room (£245k agreed), a RF, DC and E-beam sputtering machine with heated sample to 900^{o}C and RF substrate cleaning (£138k agreed), electron backscatter diffraction and energy dispersive X-ray analysis equipment (£440k agreed), a new building and equipment for the Advanced Metal Casting Centre (£14M already secured), and renewal and upgrade of SEM and AFM facilities.

The current and planned investments will enable the members of this theme to: expand our electron microscopy and imaging capacity to service better the growing demands of the collaborations and projects combining materials researchers with those in electronic systems and biomedical engineering, in particular. **BCAST** will be in a stronger position to seek renewal of funding for the EPSRC IMRC for Liquid Metal Engineering (LiME) and to expand the large-scale processing facilities by establishing an Advanced Metal Casting Centre (AMCC).

Advanced Metal Casting Centre (AMCC)

A unique national scale-up facility (1,500m^2) for light metal casting research to bridge the gap between fundamental research and automotive and other industrial applications. £14M has been secured already including £3.7M from EPSRC, £5.25M from industrial partners including Jaguar-LandRover and Constellium. Brunel will provide the new £5.4M building. **New** equipment will include: a 1600t HPDC machine, a LPDC machine for casting thick sectioned components up to the size of an engine block, a twin roll caster with integrated melt conditioning device, a 1600t extrusion press for full-scale trials and real-time X-ray inspection.

3. Consultancy, Professional Services, and Patents

Our staff attracted £781k for consultancy work for industry. Examples include: AWE, BRE, Cambridge Display Technology, E.On, GE Global Research, Google, Imperial College, Jaguar-LandRover, London Underground, NPL, Red Bull Technology, Thales, TWI, and Unilever.

Staff in this submission hold over 85 patents. The Brunel strategy is to only file an application if there is a business case for the invention, we do not file patents speculatively for all inventions our staff bring forward. As a result, many of our patents and licensing arrangements evolve from grants and consultancy activities. For example, the Brunel tasks in the EU project WOODRuB led to **M. Fan** filing two EU and two international patents. Exemplars of patents granted since 2008 are: **Atherton:** 'Noise cancellation device' (GB11035565). **Babu:** 'Method of Reforming Metal Alloys' (US2013248050). **M. Fan:** 'Process for making composites from natural fibres' (WO20090233104). **Z. Fan:** 'Apparatus and Method for Liquid Metals Treatment' (US2013228045). **Fern:** 'Phosphor Electroluminescent Devices' (US2009167145). **Sermon:** 'Zeolites and Composites Incorporating

Zeolites' (WO2013001296). **Silver:** 'Protection of Plastics' (WO2009053692). **Tarverdi:** 'Method and Apparatus for Defibrillating Cellulose Fibers' (US2012187226). **Zhao:** 'Engine for an Air Hybrid Vehicle' (US2010307440). Exemplars of commercialisation: Members of **BCAST** have developed and patented high shear melt conditioning processes embodied in twin screw and rotor-stator forms and have built and installed a number of these units of various sizes adapted for integration with our casting processes. **Tarverdi:** twin screw extrusion technology to pulp and refine cellulose fibres, with InterfaceFLOR resulting from a TSB funded project. **Tassou:** phase change materials for portable freezers developed from a DEFRA-funded project. **Zhao:** Engine RegenEBD is a regenerative braking system optimised for buses and coaches and licenced to Yuchai Corporation.

e. Collaboration and Contribution to the Discipline or Research Base

Our strategy for Intra- and Inter- Disciplinary Collaboration operates at three levels: local, national, and international. The aim is to have every member of staff active in at least one network. This is implemented through programmes to enhance collaboration at different scales. These are differentiated to support staff at all stages in their careers. For example, our strategy for ECRs is to start by improving local collaboration and to ensure that they are helped by their mentor or other MCR / SR to engage in external networks or to create new ones. For established researchers, we have a strategic agreement with PERA to co-ordinate European research networks on our behalf.

Local: To initiate collaboration across disciplines (and UoAs) Brunel organises 5 university-wide Collaborative Research Networks (CRNs). We contribute to two – Innovative Manufacturing, and Energy and Environmental Sustainability. These CRNs bring together experts into multidisciplinary teams to address important 'grand challenges' through a series of events and workshops. For example, the Innovative Manufacturing CRN brought together **Bhattacharya** with Saunders (Bioscience) to apply synthetic biology techniques to biofuel production; Saunders is now working on a task with an industry partner in the SupraBio EU project. Brunel appointed David Riley as Entrepreneur in Residence to foster entrepreneurial culture and commercial engagement. RSDO organise events to help stimulate research activity including the annual 'Buzz' event, run in conjunction with RCUK, to develop proposal writing skills and cross-disciplinary research.

Our EPSRC Impact Acceleration Account (£600k) is being used for research within the automotive sector, building upon the existing strengths of **BCAST** / **CAPF** and their collaborative projects with industrial partners. Our aim is to draw upon researchers with expertise relevant to the automotive sector, but who are not yet working closely with the sector – including Brunel researchers working in Electronic Systems (UoA15). This will achieve a demonstrable impact by creating strategic alliances across the automotive value chain at the institutional level. Other examples of collaboration across UoAs in Brunel are: 1) **Karayiannis** with Cheng in the Manufacturing Systems Group (UoA15) on an EPSRC project on the integrated design of closed-loop cooling systems for boiling heat transfer (this project is also in collaboration with Edinburgh); 2) **Ge**, **Kolokotroni**, and **Tassou** of the EPSRC **CSEF** are collaborating with Bourlakis (UoA19) in the Business School on supply chain dynamics; and 3) **Fern** has an EPSRC project with Hobson (Sensors and Instrumentation Group, UoA15) on high temperature radiation-hard detectors.

National: As part of the remit of EPSRC IMRC for Liquid Metal Engineering, **BCAST** is providing large-scale processing and characterisation facilities to the UK light metals R&D community and encouraging new research collaborations. Our collaboration with TWI has been built up over 10 years with multiple researchers. This relationship culminated in our **Applied Mechanics** team winning the **National Structural Integrity Research Centre** which now becomes a much wider collaboration with the Universities of Cambridge, and Manchester and UCL, and various companies. **BCAST** also leads the 'Towards Affordable, Closed-Loop Recyclable Future Low Carbon Vehicle Structures' consortium (£4.2M). The consortium comprises Brunel, Coventry, Exeter, Imperial, Manchester, Nottingham, Oxford Brookes and Strathclyde; the industrial partners include Ricardo and Lotus Engineering. The consortium (led by **Tassou**) for the EPSRC Sandpit for the integration of active and passive indoor thermal environment control systems to minimise the carbon footprint of airport buildings comprised Brunel, City, Kent, Loughborough, and Reading. **Xia** (ECR) is a member of the 16-strong EPSRC Consortium on Turbulent Reacting Flows.

The Brunel repository of full text research outputs is ranked 12th of all UK universities by usage and content. We have an Open Access mandate in place, and an Open Access Publishing Fund. Additional measures relating to the accessibility of research data are being put in place in line with RCUK requirements.

International: The Royal Society-NSFC international joint project grant (JP101064) supports **Ray** to work with Prof. Y. Zheng in the Sch. Materials Science and Engineering, Univ. Science and Technology, Beijing, China. The EU-funded SUPRA-BIO project (€17.5M) is co-ordinated by **Bhattacharya**; it has 17 partners with about half being industry. **BCAST** is a key partner in the 27 member European consortium on Physical Processing of Molten Light Alloys under the Influence of External Fields (ExoMet). The strategic partnership with PERA has assisted all 3 themes to win more than 20 EU FP7 proposals since 2008 with, for example: Tampere U. (Finland), Turino Polytechnic U. (Italy), Aachen U. (Germany), Steinbeis Innovation GmbH (Germany), Union Fenosa (Spain), Fraunhofer IWES (Germany), KU Leuven (Belgium), Volvo (Sweden), U. Queensland (Australia), European Space Agency, TU Graz (Austria), and Oslo U. (Norway).

Visiting Scholars: We have hosted 31 overseas scholars since 2008 (total of 54 for SED). Of these, 19 were visiting professors plus 12 other senior scholars. Exemplars: Y. Boukari (Universite de Aix-Marseille, France), J. Deen (McMaster U, Canada), H. Fredriksson (Royal Institute of Technology (KTH), Sweden), B. Hudson (Syracuse, USA), Q. Jiang (Tianjin University, China), E. Kosior (Melbourne, Australia), F. Loureiro (Federal University of Rio de Janeiro, Brazil), D. Pal (NERIST, India), Y. Pyo (Korea Institute of Energy Research), S-K. Ro (Korea Institute of Machinery and Materials), and A. Sisamon (Universidad Nacional de Mar del Plata, Argentina).

Exemplars of interdisciplinary research: Brown and **Wang** work directly with clinicians on the fixing of bone screws and knee replacements, respectively. **Atherton** and Gobet (Psychology, Liverpool) collaborate on the robustness of complex networks. They are working on network structure, redundancy, distributed functionality and self-organisation. **Axon** collaborates in a global programme co-ordinated by Arup to examine an economy's capacity to make low carbon investment with specialists in built environment (S. Roberts, Arup), business and finance (B. Warr, INSEAD, France), modelling and data visualisation (N. Goddard, Edinburgh U), and economics (B. Foran, Charles Sturt U, Australia). **Kolokotroni** works on the 'split incentive' problem in commercial buildings with specialists in law (S. Bright, Oxford), property finance (T. Dixon, Reading), and energy policy (K. Janda, Oxford).

Influence of Research Users: Collaboration with research users has given Brunel confidence that our long-term strategy of pursuing industry-facing topics has been the right one for us. Advice and additional funding from both large and small industry partners led Brunel to continue investing in areas such as refrigeration engineering and metallurgy. For example, in creating CSEF, **Tassou** was able to draw on a pool of over 30 companies in the food sector such as Tesco, Waitrose, Marks and Spencer, PepsiCo, and Heinz for immediate and substantial support. They recognised the need and the time to bring together biochemical and chemical engineers, and value chain researchers. Another prominent example is how the collaboration with TWI grew into a partnership. TWI assisted us both strategically and practically in re-organising parts of our research in **Applied Mechanics**, **Materials**, and Electronic Systems to create a coherent programme on structural integrity across different application areas. The resulting strategy was supported financially within Brunel. The success and dedication of staff in implementing the strategy gave confidence to both TWI and Brunel to enter into a Strategic Partnership – resulting in forming the **National Structural Integrity Research Centre**. The long-standing relationship with Jaguar-LandRover has steered the research strategy of **BCAST** towards increasing the effort devoted to scale-up. This advice gave Brunel confidence to invest in specialist infrastructure to support their work.

Our relationships with Rolls Royce, Lotus, and Mollart Engineering have shaped our strategy for engaging with the TSB. Our strategy is to support a wider range of our groups orienting part of their work towards higher TRLs. This has led to both a greater number of proposals and a higher success rate. The consequence is that Brunel now has the 12th largest TSB portfolio in the UK.

Leadership in the Academic Community – (Inter)national Advisory Board Membership
Axon: Associate Director, James Martin Institute for Carbon and Energy Reduction in Transport, University of Oxford (2008-13). **M Fan:** Reviewer, Austrian Science Fund; Evaluator, EU ERA. **Karayiannis:** Reviewer, Qatar National Research Fund. **Kathirgamanathan:** UKTI mission on Plastic Electronics to Korea (2012). **Kolokotroni:** Member, IEA Air Infiltration and Ventilation Centre, Brussels. **Megaritis:** Advisor, Italian universities research output on behalf of the Italian Ministry of Education. **Silver:** Evaluator, Chair Candidates for Fatima Jinnah Women University, Pakistan (the first Public Sector University for women in Pakistan) in 2013. **Song:** Advisory Panel Member, Canadian Foundation of Innovation. **Wrobel:** Reviewer, National Research Foundation,

South Africa; Board Member, Steering Committee of the CFD Centre, University of Leeds.
Leadership roles in Research Councils, commerce, learned societies and professional bodies: Since 2008, 21 of our staff are or have been members of the EPSRC college. Other notable positions are: **Axon:** Chair, Institute of Physics Energy Group. **Bhattacharya:** Non-executive Director of Sharda Motors, India. **Brown:** Member, BSI Committees MHE/9 and CB203. **Z Fan:** Chair, Casting Division, Institute of Materials, Minerals & Mining. **Fern:** Chair, RSC Mossbauer Spectroscopy Group. **Karayiannis:** Member, Energy Institute accreditation panel. **Kathirgamanathan:** Scientific Advisor, Merck; Vice President (Europe), Society for Information Displays, USA. **Kolokotroni:** Member, 3 CIBSE Technical Committees. **Megaritis:** Member, IMechE Academic Assessment Committee. **Song:** Member, Advisory Panel DEFRA Renewable Materials Programme. **Sermon:** Technical Director, NewCat Co. **Tassou:** Member, EPSRC EUED Centres Steering Group. **Zhao:** Chair, UK Universities Internal Combustion Engines Group.

International Conference programme chairs: exemplars are: **Z. Fan:** 5th Int. Light Metals Tech. Conf, Germany (2011). **Karayiannis:** 9th UK-Japan Seminar on Multiphase flows, London (2013). **Kathirgamanathan:** Printed Electronics, Santa Clara, USA (2012). **Sermon:** 15th Int. Congr. on Catalysis, Munich (2012). **Silver:** Phosphors in EL at the Int. Display Workshop, Kyoto (2012). **Zhao:** 11th Int. Conf. on Present and Future Engines for Automobiles, Shanghai, China (2010).

Invited keynote lectures at international conferences: since 2008, 28 staff have given one or more invited keynotes. Exemplars: **Eskin**: European Industrial Technologies Conf, Aarhus (2012). **M. Fan**: Int. Conf. on Composites/Nano Engineering (ICCE17), Honolulu (2009). **Z Fan**: 9th Int. Conf. on Magnesium Alloys and their Applications, Vancouver, Canada (2012). **Huang**: European Materials Research Society Fall Meeting, Warsaw (2012). **Karayiannis:** ECI Int. Conf. on Heat Transfer and Fluid Flow in Microscale, Canada (2008). **Kathirgamanathan:** Organic Semiconductors 08, Frankfurt (2008). **Kolokotroni**: AIVC Int. Conf, Brussels (2011). **Sermon:** Australian Ceramic Society PACRim9, Cairns (2011). **Scamans**: Aluminium Surface Science and Technology 6, Sorrento, Italy (2012). **Silver:** Phosphor Global Summit, San Diego (2010). **Wrobel**: 7th Pan American Workshop in Applied and Computational Mathematics, Computational Science and Engineering, Choroni, Venezuela (2010).

Election to membership / fellowship of learned societies: all staff are Members or Fellows of either: IMechE, RAeS, SAE, IOM3, EI, CIBSE, IET, RSC, or IOP. Examples of recent elections are: **Axon**: Member, Energy Institute (2013). **Kolokotroni**: Fellow, Chartered Institute of Building Services Engineers (2012) and is one of only 15 female CIBSE Fellows worldwide, out of a total of approximately 980 Fellows. **Zhao**: Fellow, Society of Automotive Engineers (2011). The SAE fellowship, established in 1975, is awarded to less than 20 worldwide recipients each year. He is only the 7th UK academic to have achieved such recognition in the last 30 years, and one of only three SAE Fellows who are still active in a full time post in the UK.

Journal editorship: exemplars since 2008: Editor or Editor-in-Chief: **Atherton**: Int. J. Design & Nature and Ecodynamics. **Bahai:** Euro. J. Computational Mechanics. **Eskin**: J. Alloys and Compounds. **Ray:** IET, Devices, Circuits and Systems. Associate Editors: **Kathirgamanathan:** IEEE J. Display Tech. **Kirby**: J. Acoustical Society of America. Guest Eds: **Karayiannis:** App. Thermal Eng (2011); Heat Transf. Eng. (2011). **Wang**: Int. J. Mech. Sciences; Int. J. Impact Eng.

Fellowships, awards and prizes: since 2008, 14 staff have won paper and conference prizes. Major prizes received are: **BCAST** awarded membership of the International Light Metals Alliance, which consists of the top international research organisations (2010). **Eskin:** Warren Peterson Cast Shop for Aluminium Production Award (IOM3, 2012); Light Metals Technology Award (TMS, USA); Highly commended paper award: Int. J. Numerical Methods for Heat & Fluid Flow (2010). **Z Fan:** Dowding Medal and Prize (IOM3, 2012); Diploma (Institute of Cast Metals Engineers, 2012). **Jabbal:** Young Person's Achievement Award (Royal Aeronautical Society, 2013). **Kolokotroni:** Most Cited Article in *Building Services Engineering Research and Technology* for 2009 and 2010. **Sermon:** Brian Mercer Feasibility Award (Royal Society, 2011). **Tarverdi:** Rushlight Award for the TSB-funded REFLECT project. **Wang:** PraxisUnico Collaborative Impact Award for his invention of a successful knee implant for ACL fixation (2011). **Zhao:** LowCVP Technology Challenge Prize for the RegenEBD Technology (Low Carbon Vehicle Partnership, 2009); Islands of Excellence Prize (World Automotive Congress, 2012); DSc by Brunel University, 2009.