Institution: City University London
Unit of Assessment: 15 General Engineering
a. Overview

a.1 Background and key achievements: City University London has embarked on one of the largest academic recruitment exercises in the UK sector as a major component of the implementation of its Strategic Plan 2012-2016. The £35M recruitment initiative has resulted in 141 new academic staff from across the world in post as of 31st October 2013. The University is also investing £35M and up to £130M in transforming its IT provision and its estate respectively. Details specific to General Engineering are reported below.

This submission covers all engineering research conducted within City's School of Engineering & Mathematical Sciences. The research output from 55 academics spans 4 fields of activity: Fluids Engineering, Structural & Geotechnical Engineering, Sensors & Instrumentation and Systems & Control Engineering. Much of the work is interdisciplinary, tackling grand challenges associated with energy efficiency, healthcare and cyber security. Over the past two years alone we have recruited 25 new members of academic staff to expand the School and modernised our main laboratories (4,000 m^2 laboratory/technical space, investing £9M in infrastructure and £2.3M in equipment). We have significantly strengthened our capabilities in computational engineering science. This work is predominantly large-scale, creating algorithms to run on multi-core computers, solving systems typically with more than a million unknowns. The School is home to 17 academics developing such code within all four of our fields of activity (see a.2). Their work embraces the nonlinear dynamics of structures, computational fluid dynamics (CFD), direct numerical simulations (DNS), multiphase flows, marine hydrodynamics, aerodynamics, photonics, biomechanics and novel numerical computations for algebraic problems. Furthermore, our continued successes in developing bespoke sensors and specialist instrumentation are reflected in research grants won in this area (£5.3M over the REF period). Other successes in innovative displacement compressor design led to the creation of the spin-out company Heliex Power Limited, which was funded by an £7M investment from BP Alternative Energy and ESB Novusmodus with a further £3M investment achieved by the end of November 2013. Changes to our research management processes have resulted in research grants to the value of £13.1M being awarded in 2012/13.

a.2 Research structure: Research in the School involves experimental, computational and theoretical studies. Our multidisciplinary approach to research is organised through four Research Centres which span our three Engineering Departments (Civil, Mechanical/Aeronautical and Electrical). Departments are responsible for organising and delivering undergraduate and taught postgraduate courses, while the Centres stimulate, organise and promote our research in the following areas:

● ***Fluids Engineering Centre*** *(FLUIDS)**:*** Computational fluid dynamics (CFD) and multi-phase flow; experimental fluid dynamics; engines and fluid machinery.

● ***Structural & Geotechnical Engineering Centre*** *(STRUC&GEO)**:*** structural engineering; geotechnical engineering.

● ***Sensors & Instrumentation Centre*** *(SENS&INSTR)**:*** sensors; photonics; biomedical engineering.

● ***Systems & Control Centre*** *(SYS&CTRL)**:*** control systems; cyber security; system analytics.

Each is led by senior academics and facilitates research by providing a forum for the organisation of research, exchange of ideas, mentoring and supporting staff and students, managing research funds and promoting a culture that responds quickly to research initiatives.

b. Research Strategy

b.1 Current position in relation to RAE 2008: Significant progress has been made between RAE 2008 and REF 2014, with a 60% increase in the number of academic staff who are engaged in excellent research. This has been facilitated through the recruitment of 25 new academic staff. We have invested our QR funding in research studentships and fellowships, refocused and strengthened the Research Centres and developed new interdisciplinary initiatives in biomedical engineering, cyber security and complexity science. Partnership with industry features in most of

our research. This reflects the importance to the University of focusing on the key questions facing society, policy makers and business and maximising the impact and relevance of the work undertaken in ways that are useful, including to the professions and public services. The key aims underpinning the RAE 2008 submission were: enhancing research quality; focusing resources in distinctive and important areas of strength; and restructuring our Centres to promote interdisciplinary activities. These objectives have been achieved and with the arrival of new staff we are in an excellent position to strengthen our research further in the post-REF period. The School is also fully committed to supporting open access to the research produced by its staff. In October 2011, a digital repository which incorporates bibliographic data was launched by the University (City Research Online). University policy requires the deposit of full text for all research articles (automatically Google indexed) published since January 2013.

The development of the School's vision and strategy is based on a recognition that contemporary science and technology have recently crossed important thresholds, changing the nature of many traditional fields in engineering. Numerous important challenges (these appear in EPSRC's Landscape Programme and the EU's 2020 Horizon Programme) are located at the boundaries between disciplines. Investigations linked to health, the environment, economy and society demand holistic approaches which make use of the latest advances in social science, finance and law, areas not previously linked to the traditional fields of engineering. Significant new research breakthroughs are required to handle the many-component, multi-scale aspects of these topics. We are well positioned to tackle such challenges. Our long-standing strength in systems and control engineering provides a sound theoretical framework to link our specialist skills in fluids and structural engineering and sensing and instrumentation with expertise in other Schools within the University, particularly the fields of Informatics, Law, Business and Health.

b.2 Research Vision: To be among the leading research institutions for integrated engineering solutions in energy efficiency, healthcare, cyber security and complex systems engineering.

Objectives:

- To improve the efficiency and reduce the environmental impact of transportation systems and to promote the development of environmentally friendly emerging new technologies
- To develop chemical and biological sensor technologies and transducers for industrial and medical applications by exploiting our expertise in advanced optical and photonics systems
- To develop decision- and control-oriented approaches and methodologies to manage complex engineering systems design throughout the process life-cycle.

Research strategy: We focus on activities which increase internationally-leading research output in distinctive areas aligned with our particular expertise in both fundamental and applied research. The strategy involves: creating and managing a small number of focused Research Centres; developing collaborative links with industry and undertaking industrially-relevant interdisciplinary research; advancing the fundamental understanding required for new technologies through novel experimental, theoretical and computational research; enhancing our laboratory and high-performance computer facilities; and supporting collaboration with internationally leading groups. Our successes in industrial partnerships are evidenced by links with leading global companies, hospitals and government offices (see d.3 and e.2)

b.3 Relationship of research structure to research activities: The four Research Centres provide a decentralised research management structure, overseen by the Dean, Associate Dean for Research and School Research Committee and supported by a Research Manager. Each academic, member of research staff and research student belongs to one of the four Centres. Participation in the activities of other Centres is strongly encouraged through bidding for interdisciplinary projects and joint supervision of research students. The Associate Dean for Research and the Research Manager of the School (supported by the University Research and Enterprise Offices) oversees Research Council and EU Calls, identifying opportunities for new proposals, organising meetings on new initiatives and financially supporting their development. The Centres are responsible for the training needs, working spaces and financial support (equipment and conference attendance) of research students. A regular programme of School and Centre-based seminars with internal and external UK and international speakers promotes interaction and the dissemination of research findings.

b.4 Capacity building and sustainability of research and University initiatives: Since 2008, the School has undergone transformational change. With significant investment from the University, we have grown by 25 FTE. We have attracted senior academic staff with proven track

records (including eight new professors) and junior staff with prior achievement and clear potential to undertake leading-edge research in areas relevant to our strategy. Fourteen early career researchers are included in our REF submission.

In appointing new staff, we value intellectual rigour, originality of thought and strategic fit while also seeking individuals who are excited by the prospect of collaborating between disciplines. During the expansion, several of our exceptional existing research-active staff were rewarded with promotion and/or a reduction in administrative/teaching duties. Fewer staff have left during this REF period than in the previous RAE period. 47% of staff returned in REF 2014 were here in 2008. Research sustainability has been supported by recruitment of Marie Curie Fellows (5 submitted) and appointment of world-leading Honorary Visiting Professors (for example, Professor Kirk Shelley (anesthesiology), Yale School of Medicine, USA; Dr Andy Petros (paediatric intensive care) Great Ormond Street Hospital; Dr Demos Katritsis (cardiovascular research), St Thomas' Hospital; Professor Richard Brook (EPSRC Chief Executive, Research and Enterprise Strategy); David Monk (Chairman of Industrial Panel, former Vice President, Texas Instrument, Europe)) who contribute to developing collaborative research projects, organising seminars and workshops, writing papers and shaping the Centres' research agenda. The School supports each Centre with an annual budget and returns a significant proportion of research project overheads to the Principal Investigator, any co-investigators and the Centre. This enables pump-priming of new research activities and support for bridging funding for research staff and student and staff conference attendance. During the REF period, University Interdisciplinary Centres have been created to promote the areas of cyber science and complexity science.

b.5 Activities and achievements of Research Centres:

Overall Research Performance During the REF Period by Centre

Research Centre	Res. Stud. (No.)	Research Students (FTE)	PhDs Awarded (since RAE 2008 census date)	Research Funding Spend	Grants Awarded 2012/13	Journal Papers & Books	Conf. Papers
Fluids Engineering	68	44	15	£2,861,483	£6,757,786	154	197
Structures & Geotech. Engg.	25	15	8	£537,095	£821,338	104	128
Sensors & Instrumentation	53	29	28	£3,271,720	£3,013,595	164	207
Systems & Control	59	35.5	37	£1,361,174	£2,231,431	185	167
Total	**206**	**123.5**	**88**	**£8,031,472**	**£12,824,150**	**637**	**704**

Centre visions, activities and plans:

Fluids Engineering: This Centre was established in 2000 to develop numerical algorithms for fluid flow simulation and experimental techniques to verify new physical flow models using advanced laser diagnostics measurements. It enjoys strong and long-established links with major international companies (see d.3).

Expertise and capabilities: The Centre specialises in the development of numerical codes and purpose-built experiments designed to validate the models and improve understanding of complex flow physics. Capabilities include the design of fuel injection systems, positive displacement machines, compressors, micro turbines, marine propellers, energy conversion systems and hydrodynamic analysis. Unique expertise exists in the area of multi-phase flows and cavitation, where fundamental physics related to bubble dynamics phenomena is investigated. Applications range from the traditional marine sector (erosion, noise); automotive and heavy-duty environmentally friendly new engines and their subsystems (such as direct injection gasoline engines and high pressure diesels); and cavitation in fluid machinery, lubrication and more

recently, bioengineering applications where cavitation can be life-threatening or used as a treatment method. Our work on compressors has a strong reputation in applied industrial Research & Development and consultancy services to industries worldwide (detailed in one of our submitted impact case studies).

Vision: To lead research internationally in computational and experimental fluid dynamics for turbulent multi-phase flows and to develop design tools for those flows with phase-change in complex mechanical, automotive, marine and aeronautical applications and bio-fluids.

Major achievements during REF period: We highlight three major achievements: (i) The establishment of the International Institute of Cavitation Research (www.cavitation-institute.org) which integrates the activities of nine academic staff members in collaboration with other major universities in the UK and abroad and funds a new member of academic staff. The Institute is supported by the Lloyd's Register Foundation and 17 current research projects. (ii) The continuation of the pioneering work of the Compressors Group, which provides consultancy to more than 30 companies worldwide (to the value of £1.3M during the REF period) and has established the very successful spin-off company Heliex Power Limited (also see d.6), in a joint venture with BP. (iii) Funding for two industrial Chairs from Delphi Diesel Systems and Howden Compressors.

Future Plans: Further development of laser diagnostics measurement techniques will enable new physical understanding and give rise to validation data for our advanced in-house computational fluid dynamics (CFD) codes. The successful combination of experimentation and modelling is strengthened by the appointment of additional academic staff who will simulate fundamental multi-phase fluid flow processes using large eddy simulations (LES) and direct numerical simulations (DNS) approaches. The work will be extended into bio-fluids to examine blood flow and investigate cavitation in life-saving components (such as artificial heart valves and blood circulation devices). This area of research is complemented by studies in marine hydrodynamics which deal with wave loading on offshore structures and floating body interaction with waves. These numerical capabilities will be tied to ongoing work in the area of ocean engineering where measuring devices are being developed for the detection of cavitation, bubble sonoluminescence and erosion of materials.

Structural & Geotechnical Engineering: Our research is focused on understanding the fundamental behaviour of geomaterials and on physically testing and simulating the deformation of both above and below ground engineering structures. Work is informed by strong links with industry, including British Energy, Balfour Beatty Ground Engineering, Cementation Foundations Skanska, Atkins and Pell-Frischmann.

Expertise and capabilities: The Centre has expertise in (i) predicting the stiffness and strength of structures under both operational static and dynamic loading; (ii) the analysis and design of complex geotechnical structures (many studies tackle issues associated with highly congested London sites). We undertake large-scale experimental testing of composite steel and concrete deck systems and support this with non-linear finite element analysis using in-house codes. We also perform structural health monitoring and advise on structural risk mitigation.

Vision: To strengthen further our international reputation in the novel foundation design (based on continued development of our centrifuge facility and underpinned by an appreciation of the physics of particulate materials) and expand our development of advanced finite element-based techniques which support the design of structurally efficient tall buildings and shell structures.

Major achievements during REF period: Pell-Frischmann consulting engineers chose City to sponsor a Royal Academy of Engineering Chair in Nuclear Engineering (2013-2018). This enables us to advance our inelastic finite element research into the damage induced in structures subjected to extreme loading. Research on novel long-span cellular beams and composite ultra-slim floor beams has resulted in significant reduction in structural floor heights. Innovative use of our beam centrifuge (able to represent an 80x100x60m volume) has allowed us to undertake carefully controlled testing of (i) novel forms of deep foundation; (ii) the reuse of foundations; (iii) ground movements associated with constructing underground structures. This has informed our ability to design deep shafts for the Crossrail development (the largest construction project in Europe). Pioneering micro-computed tomography studies examine the influence of the fabric on the deformation of soils and support the construction of thermodynamically consistent constitutive models. New analytical findings in the area of accurate stress integration techniques have led to efficient use of complex hyperplastic models within finite element analysis (FEA).

Future plans: The Centre is strengthened by the arrival of five new academic staff since 2012. Facilities for high quality physical model testing will remain a key feature of research in both geotechnical and structural engineering. The 2013 RAEng award will enable us to work closely with Pell-Frischmann to extend our research into the structural integrity of nuclear power plant. We are also turning our attention to the development of passive structural vibration control solutions for dynamically excited structures. We will grow our ability to combine advanced FEA techniques with bespoke, high-fidelity physical testing. In the area of particulate solids, we will provide closer links between the mesoscopic properties (grain shape/size/orientation) and macroscopic measures (porosity and permeability) to inform the development of more realistic anisotropic constitutive models. Future studies will make greater use of multi-core high performance computing to simulate multi-scale features such as initiation and propagation of discontinuities in geomaterials.

Sensors & Instrumentation: The Centre has an established international reputation in the areas of sensor development, optical systems, photonics, computer vision and biomedical engineering. The work builds on advanced experimental and theoretical developments to meet sensing challenges from industry and clinical practice.

Expertise and capabilities: There is particular expertise in novel optical fibre-based sensor design, photonics modelling, biomedical diagnostics, medical imaging, pattern recognition, microelectronics, instrumentation and signal processing.

Vision: To lead research internationally through innovation in sensing technologies, addressing challenges in healthcare technologies, energy and environmental change. We will explore the physical limits of sensing technology, producing new insights into natural and medical processes and developing novel instrumentation that can tackle environmental, security and health care related challenges.

Major achievements during REF period: The development of novel optical fibre sensors for extreme and security/safety related conditions has made important contributions to the use of sensors in very high temperatures (>800 °C); high pH (>12) and ionising radiation; early fire and gas detection using tunable fibre lasers; drug/explosive detection (working with the UK Home Office) using molecular recognition techniques; and agri-food and environmental monitoring using surface-plasmon-resonance based sensors. In photonics we have developed new time-domain electro-magnetic and acoustic models for the characterisation of light-matter interactions, leading to the design and optimisation of novel guided-wave structures in both optical and THz regimes. In biomedical engineering we have developed new devices for detection of Hypoxic Ischaemic Encephalopathy in neonates; assessment of perfusion and survivability of free flaps in plastic reconstructive surgery; understanding of perfusion of abdominal organs in intensive care; assessment of skin hydration to aid patients with eczema and contact dermatitis; development of wavelet-based computational framework for the forward problem in Electrical Impedance Tomography; and automated analysis of cardiothoracic angiograms to study the relationship between local vessel geometries and the development of arterial lesions.

Future plans: The Centre will continue to develop novel technologies for sensing in medical, security and extreme environments (where conventional sensors typically fail). In the area of sensors, emphasis will be on novel chemical detection for security, agri-food, health and environmental monitoring. Research in photonics will concentrate on the integration of the various optical and physical models for the exploitation of plasmonics, metamaterials and graphene in photonic crystal fibres, solar cells and silicon photonic devices. In biomedical engineering, we will focus on chemical/biological sensing to improve understanding of disease and patho-physiological phenomena and machine vision methodologies linked to diagnostics. This involves an integration of topical principles of physics, signal processing, IT and medicine. Biomedical research will embrace new techniques including: development of smart multi-parameter sensors (for the early diagnosis of diseases, prevention and/or management of chronic conditions, to improve clinical management of neurodegenerative conditions); development of Sobolev/Besov based regularisation and reconstruction schemes for electrical impedance tomography, non-invasive fractional flow reserve measurements (to advance CT angiography); and multi-modal neuroprostheses and impedimetric microsensors.

Systems and Control: The Centre draws together staff from control theory and design, systems, operational research, systems engineering, networks and cyber security. Our research contributes to understanding engineering complexity and extends the engineering approach to systems integration by linking design and operations/management of industrial processes.

Expertise and capabilities: We deal with analysis and design methodologies aiming to manage engineering complexity in control systems, cyber security and system analytics. Expertise in control is in control theory and design, mathematical systems theory and computations. In cyber security, our expertise is in communication systems, modelling of cyber threats and data analytics. In system analytics, we have expertise in stochastic modelling, optimisation, reliability and risk. Three new academic appointments have enhanced our strengths in optimisation and decision modelling and allowed us to apply this knowledge to transport engineering.
Vision: To be an internationally leading Centre in the management of complexity in engineering design and systems integration by advancing our understanding of the fundamental principles and development of novel methodologies.
Major achievements during REF period: Our contribution during REF has been to develop fundamental principles and their application in selected areas. In control, we have introduced a new paradigm of structure evolving systems in the context of integrated design and a formal framework for the study of systems of systems. We have developed our original work in the field of approximate algebraic computations as a distance problem, contributed to robust control design (solution to super-optimal distance problem) and introduced the new design methodology for non-overshooting stabilisation. In cyber security we have contributed to the protection of critical infrastructures by advances in the modelling of cyber-crime using intelligence information gathering, natural language processing and automatic classification of network traffic for adaptive resource management. In system analytics, we have contributed to the fundamentals of stochastic optimisation and developed stochastic modelling for asset management of systems subject to degradation. We introduced a stochastic mathematical program with equilibrium constraints and a new Stackelberg leader-follower game for studying market competition, studied reliability and maintenance strategies and risk assessment (J-value) for processes. The results of this work have been applied successfully to the aerospace and nuclear industries.
Future plans: We will address the challenge of Complex Systems Engineering by developing methodologies tackling different aspects of complexity. In control we will study the approximate solutions of the determinantal assignment problem (through a Marie Curie Fellowship) and link this to methodologies for selection of systems of sensors and actuators. We will examine representations of structure evolving systems, evolution of their properties and robust decentralised stabilisation. In cyber security the protection of critical infrastructures will be the focus, involving modelling and identification of threats and protection tools for cyber-crime. Machine-machine communication systems and cooperative control is an emerging area. In system analytics, we will concentrate on robust approaches for stochastic data-driven optimisation and stochastic modelling for life-cycle issues in engineering systems. Risk assessment, inspection and maintenance strategies for deteriorating systems will be developed for infrastructure management.

c.I People, including: staffing strategy and staff development

c.I.1 Staff changes since 2008: Since RAE 2008 we have restructured the Centres to unify activities, create critical mass and generate improved synergies. For example, staff in the area of marine hydrodynamics engineering joined the *FLUIDS* CFD group and those in materials and structural dynamics have joined *STRUC&GEO*. Transport research has joined *SYS&CTRL*. Cyber security has been developed as a new activity, also within *SYS&CTRL*. Since 2008, eight staff members have left the School, three of whom were included in RAE 2008. Twenty three of the twenty five new academic staff appointed during the current REF period are included in this submission. The remaining two are experienced practising engineers who have joined us from industry to support our taught postgraduate degree provision and are in the process of building their research profile. Research activities were strengthened by our successes in winning six Marie Curie Fellowships (MCF) in the area of fluid engineering and control theory. The submitted staff are as follows; underlining denotes a post-2008 permanent appointment:
Fluids Engineering: Professor C Arcoumanis; Professor M Gavaises; Professor A Pinelli; Professor Q Ma; Dr S Yan; Dr K Vogiatzaki; Dr M Omidyeganeh; Dr A Theodorakakos (MCF); Professor J Nouri; Professor J Carlton; Dr S Prince; Dr R Lockett; Professor K Pullen; Professor A Sayma; Professor A Kovacevic; Dr N Mitroglou (MCF); Professor G Bergeles (MCF); Dr N Nikolopoulos (MCF).

Structural & Geotechnical Engineering: Professor A Ayoub; Professor A Kappos; Professor C D'Mello; Professor R Banarjee; Dr A Giaralis; Dr F Fu; Dr P Mergos; Dr S Naher; Professor R Crouch; Dr A McNamara; Dr J Fonseca.
Sensors & Instrumentation: Professor KTV Grattan; Professor T Sun; Professor BMA Rahman; Professor P Liatsis; Dr C Reyes-Aldasoro; Dr A Agrawal; Dr F Surre; Professor P Kyriacou; Dr J Philips; Dr I Triantis.
Systems & Control: Professor N Karcanias; Professor G Halikias; Professor J Fothergill; Dr E. Milonidis; Dr J Leventidis (MCF); Dr L Economou; Professor D Stupples; Professor M Rajarajan; Professor TM Chen; Dr V Rakocevic; Professor M Newby; Professor H Xu; Professor PJ Thomas; Dr I Kaparias; Dr A Evans; Dr M Tomas-Rodriguez.

c.I.2 Staffing strategy, development and performance management: We support, encourage and reward high quality research within the School through the distribution of research overhead. In addition, we have increased research income through more effective School management and support for proposal development from the University Research Office. Evidence of staff publications, income and engagement is collected systematically in assessments of individual research performance. These are used in annual performance and promotion appraisals. We use the same criteria when assessing the performance of Centres to measure their effectiveness and address their staffing, space and technical support needs. The research management team (Associate Dean for Research and Heads of Centres) oversees these activities and advises the School Executive Committee. Members of academic staff may apply for sabbatical or study leave for a period of time up to a maximum of one-seventh of service at the University. The primary purpose of this leave is to provide an intensive opportunity to progress research. All sabbatical applications are considered and approved by Senate.

c.I.3 Support for new members of staff and early career researchers: City has been fully committed to the Concordat to Support the Career Development of Researchers since its original publication in 1996 and re-launch in 2008. The University received the European Commission HR Excellence in Research Award in May 2012 on the basis of its Concordat implementation plan. A key component was the introduction of new terms and conditions of employment for research staff from August 2012. These have made continuing contracts the norm for research staff in place of fixed-term contracts and introduced parity with academic staff on pay progression, annual leave and access to promotion opportunities. The appraisal of research staff includes consideration of career development needs alongside performance. City received a mention in the May 2013 Vitae review of HR Excellence in Research implementation plans as an example of good practice. Each new member of staff (academic and research) and ECR is assigned to a Centre with a mentor who provides support and facilitates integration within the School. The RCUK “Roberts” funding was used to establish a University-wide Research and Enterprise Development Programme. Since 2010/11 this has been enhanced to provide an annual budget of up to £100,000. The programme supports researchers at all levels from PhD to professorial and includes individual tailoring for those staff and students to build their research profile. Staff are encouraged to take advantage of the training which covers supervision of research students, enterprise and commercialisation skills, workshops on applying for funding, writing proposals and impact of research. Senior staff also contribute to these sessions. The Centres use their financial allocation from the School and research overheads to support new members. We encourage the submission of applications to the University pump-priming fund for ECRs (more than 15 awards annually), support the development of First Grant Applications to Research Councils (for example, Dr Giaralis‘ EPSRC First Grant award EP/K023047/1 in 2012) and advise on costing for research grants. The School uses its QR funding (see c.II and d.2) to support each new research-active member of staff by providing a full doctoral studentship. Arrangements for effective development of staff research also include peer support at Centre level. Academics have an opportunity to discuss their research proposal and receive feedback at workshops before submission. Grant applications undergo a rigorous internal review by the Associate Dean for Research and academic peers in accordance with University policy to address RCUK demand management requirements.

c.I.4 Industrial Chairs: The School has a long tradition of links with industry. One industrial chair is supported by Delfi Diesel Systems (CFD cavitation), a second by Howden (compressors) and a third by Pell-Frischmann and the Royal Academy of Engineering (structural engineering). The Lloyd’s Register Foundation supports a lecturer in the area of computational fluid dynamics.

c.II Research students

Our research students are fundamental to the research culture of the School. In the current REF period we have enhanced the quality of training, increased student numbers and improved the PhD completion rate. The University doctoral studentship scheme has provided around eight awards annually to Engineering out of 70 across the University. The School supports a further twelve full and partial awards each year. There has been growth of 28% in the number of research students during the REF period. The new staff appointments in 2012 and 2013 will have a further positive impact on numbers in the next REF period. We have awarded 74 PhD degrees since RAE 2008, with an additional 14 PhDs in the RAE-REF gap period (August 2007 to July 2008). We have over 200 research students (~120 FTEs). Numbers are expected to stabilise at around 3 students per academic with a total of around 160 FTEs by 2016.

City Graduate School: The University established its Graduate School in 2012, led by a Dean and linked to all Schools. The School supports high quality research training and skills development and promotes a stimulating environment for research students. A University framework for the acquisition of research and enterprise skills complements the subject-specific provision delivered within the Centres. This enhances the student experience and prepares research students for the workplace.

Research student recruitment: PhD applicants are encouraged to discuss their research plans with academic staff before applying. Those satisfying our qualification standards (which typically require an MSc/MEng) are reviewed by staff to assess their potential and to identify appropriate supervisors. Successful applicants are assigned two supervisors and associated with a Centre. The School approves two categories of supervisor, based on experience, to meet the QAA Code of Practice. Increasing the quality of the intake and improving PhD distribution amongst research active staff are important issues. The recruitment of good applicants is helped by the availability of School and University studentships. Industrial projects and CASE Awards provide additional financial support. The School welcomes part-time students who are based in industry, hospitals or the service sector if they are able to tie their research to their workplace activities.

Research student training: Students are assigned to a lead and second supervisor who are responsible for supporting them and identifying training needs throughout their studies. In their first year, students attend relevant MSc and advanced modules recommended by their supervisors and participate in theme-oriented study groups. From their second year, students are required to attend advanced training courses and doctoral symposia and to present papers at international conferences. The Conference Attendance Fund, coordinated by the Graduate School, supports students in this endeavour. They have access to relevant University research and enterprise development events for staff and programmes dedicated to research student needs. The PhD Research Conference, led by the Graduate School, is held every summer, giving second and third year students the opportunity to present papers and win a £1,000 prize. Research students are also required to attend and participate in Centre and School research seminar programmes.

Progress monitoring: Since 2012, online software (RaP) has been introduced to monitor research supervision and progress. RaP reports are produced annually and action is taken where problems arise. At the end of Year 1, students prepare a research report for evaluation by a transfer panel comprising the supervisors and two senior academics to determine progression from MPhil to PhD registration. Improving completion rates has been an important focus. We have developed more transparent guidelines on the transfer process, clarifying expectations for research planning and supervision and offering additional support in terms of specialised research training. These processes are overseen by the Senior Tutor for Research Students, the Heads of the Centres and the Associate Dean for Research.

d. Income, Infrastructure and Facilities

d.1 Strategies for generating grant income: To increase funding we are: (i) working closely with the University Research Office to identify opportunities for funding applications; (ii) targeting Marie Curie Fellowships by submitting strong candidates; (iii) mapping the expertise of our academic staff and generating a database of research proposal concepts for further development; (iv) evaluating national and international links and developing alliances that will support funding applications; (v) providing expert advice for costing and reviewing research proposals and monitoring expenditure

for current projects; (vi) collaborating with an external technology group to develop research concepts into full EU funding proposals (resulting in the award of five major EU grants, value ~€2.4M, in 2012/13).

d.2 Research investment strategy: 60% of QR funding has been invested in full or partial PhD studentships, research fellowships, bridging funds for research staff between contracts, networking activities and developing research proposals. We reward academic staff by returning part of the overheads from their funded research to all project participants with a share to the Research Centre. Funds are used by Centres to enable the development of strategic research initiatives and provide support for ECR staff with no other means to develop their work.

d.3 Research funding: Our average spend from research income during the REF period has been ~£1.6M per year, including grants and contracts from industry and from EPSRC, EU, NIHR and RAEng. Of the £8M of income received, Research Councils have contributed ~£3.7M, industry ~£1.9M, EU ~£0.8M and charities and public organisations ~£1.6M. The School's focus on funding applications, with dedicated University support, has resulted in new grants totalling ~£12.8M awarded during 2012/13. ~£5.9M is from the EU, including six Marie Curie Fellowship awards (value ~€3.5M), enabling us to attract experienced researchers to work at City collaboratively with key partners across Europe. A further success was the recent award of a £1.5M grant from NIHR for developing medical sensors. Our research funding from charities has led to links with major medical institutions including Great Ormond Street Hospital, St Bartholomew's Hospital and St Andrew's Centre for Plastic Surgery and Burns. Our *FLUIDS* Centre collaboration with industry (including Perkins Engines/Caterpillar, Caterpillar Fuel Systems, Delphi, Denso, Toyota, Wartsila, BP, Shell, Lubrizol, Afton, Howden, AVL, BAE Systems and Holroyd) is of particular note. For example, our collaboration with Shell on improving fuel properties for enhancing combustion systems has led to a new five-year funding framework agreement worth over £0.5M.

d.4 Investment in infrastructure: The University has embarked upon an ambitious £135M programme of estate renewal since 2012. £17M has been invested in the School, with £9M allocated to the engineering laboratories and a further £2.3M on specialist equipment for research (for example, a new wind tunnel and a 440-core high performance computing cluster). This investment has transformed the laboratory and workshop areas to provide superb facilities. Part of the equipment investment has included new computer-aided manufacturing capabilities (rapid prototyping and CNC machines). The remaining £6M is to be spent on a complete reorganisation of the accommodation for academic and research staff to modernise the working environment, improve collaboration and generate a sense of community among the research groups. This will be achieved by the co-location of academic offices and open-plan research staff areas, supported by shared break-out and amenity spaces. These changes will further enhance our capabilities to undertake cross-disciplinary research consistent with our vision. In addition School strategy includes investment of 2% of annual turnover in maintenance and renewal of facilities. Strategic investment funds averaging £2M per annum have been allocated to the library, £1.5M of which is spent on collections including e-journals. This has brought Library expenditure/FTE in line with Russell Group Universities. A Graduate School Library Centre provides a dedicated study space for Postgraduate students and academic staff with 70 silent study spaces.

d.5 Research student space: To supplement this investment in infrastructure, a programme of enhancing the existing working and community space for postgraduate students began in 2012. New research spaces provide PhD students with a stimulating environment that combines personal desk space with dedicated breakout areas to facilitate exchange of ideas, promote collegiality and enhance cross-disciplinary initiatives. Two such areas have already been created, housing 31 and 43 PhD students together with visiting researchers.

d.6 HEIF Support for Knowledge Exchange and Enterprise activities: HEIF funding has been used for enterprise activities by supporting research staff involved in commercialisation and the development of patents. Among such activities we highlight: (i) Heliex Power Ltd., a University spin-out company created in 2009 to exploit new technologies developed by the Compressors Group within the *FLUIDS* Centre. The business is built around enhancing waste heat recovery using steam screw expanders. The company has created 22 jobs and made its first sales, achieved Carbon Trust Incubator status, was named in the 2013 Global Cleantech 100 list and aims to become a world leader in energy recovery; (ii) Instrumented Railway Current-Collecting Pantograph. This collaborative project (supported by EPSRC) between City and rail companies Siemens, Brecknell Willis and Morganite is building a instrumented pantograph (patented work)

that will identify emerging overhead wire defects before a system failure occurs. This makes use of City's novel strain and temperature sensors; (iii) 36 patents spread across medical applications, sensor technologies, energy saving and energy production; (iv) London City Incubator. The School participates in this University Enterprise Office programme which trains MBA, MSc and PhD students (MBA 32, MSc 12, PhD 14) as interns to develop technology transfer and commercialisation opportunities arising from research outcomes.

d.7 Framework for good practice in research: The School follows the University Framework which complies with Research Council requirements, including the approval of ethical implications arising from research proposals. A member of the School sits on the Senate Research Ethics Committee.

e. Collaboration and contribution to the discipline or research base

e.1 Professional activities and fellowships: Our academic staff contribute to professional activities by participating in, chairing and providing keynote lectures at international conferences; organising invited sessions; being external examiners to PhD theses; reviewing scientific journal papers; evaluating research proposals; and becoming Programme Committee members at international conferences. Here we highlight only activities in addition to those listed above. We have:

● 3 FREng (Arcoumanis, Grattan, Carlton)

● Past presidents of professional institutions: Grattan, Thomas (Inst MC), Carlton (Inst. of Marine Engineering), Crouch (UK Association for Computational Mechanics)

● 5 Editors in Chief of International Journals (Arcoumanis; *I J Engine Research*, Grattan; *Measurement*, Karcanias; *IMA J Math*. *Control and Inform* and special volume Editor of *International J Control*, Chen; *IEEE Networks*, Kovacevic; *IMechE, Part E*)

● 25 members of Editorial Boards of at least one international journal

● 2 Fellows of IEEE; 6 Fellows of Institute of Mechanical Engineers; 5 Fellows of Institute of Physics; 4 Fellows of Institute of Mathematics and its Applications; 6 Fellows of Institute of Engineering and Technology; 4 Fellows of Institute of Measurement and Control; 1 Fellow of Royal Aeronautical Society; 1 Fellow of Institute of Civil Engineers; 1 Fellow of Optical Society of America; 1 Fellow of Royal Society of Medicine; 1 Fellow of Anaesthetic Research Society.

● 12 members of the EPSRC Peer Review College

● 5 members of EU research review panels

● 3 members of Government Committees: Stupples (MOD: Defence Procur. Agency; Defence Sci. Adv. Com.; Defence Integration Authority Adv. Board; GCHQ Advisory Board); Grattan (BIS: Meas. Adv. Com.; Chairman: Optical Radiation and Photonics Work. Parties); Thomas (Chairman: Nuclear Technology Education Consortium)

e.2 Collaboration with external bodies and enrichment of research environment: Our collaborations extend to include standards organisations like the Rail Standard Safety Board (RSSB) and the Steel Construction Institute (SCI). These connections enable our research findings to inform new standards and policies. For example, work with SCI led to development of new Design Guides and software tools that are heavily used by professionals in the construction industry. The School is one of the principal organisers of the European Global Product Realisation programme (www.egpr.org) which requires engineering research students from five European universities to solve complex design challenges posed by industrial partners.

e.3 General international collaborations: A portfolio of active overseas links with China, India, the Middle East and the Balkan States assists in building research capabilities in the areas of photonics and optical sensors. This has been funded through EU Erasmus Mundus, ICI Education Cooperation, British Council UKIERI programme, Royal Society/Royal Academy of Engineering and EPSRC, with a total value of ~£12M during the REF period. Two EPSRC grants in the area of Information Security involve links with institutes in India and the USA (Purdue University and University of Arizona). City University London is a founding member of the World Cities World Class (WC2) academic network between universities (City University New York, Hong Kong Polytechnic University, Northeastern University, Politechnico di Milano, St Petersburg State Polytechnic University, Technische Universitat Berlin, Tongji University, Universidad Autonoma Metropolotana, University of Delhi and University of Sao Paulo) located in major world cities. Two dominant research themes within WC2 are global health and transport. This fits very well with our

research capabilities in biomedical engineering and our specialist skills in developing low carbon solutions (*FLUIDS*), plus our work undertaking novel Operational Research work in the transport area (*SYS&CTRL*).

e.4 Organisation of seminar series, conferences, public events: The School has a well-established programme of seminars, public engagement events (such as the George Daniels lecture and others listed below) and collaborations that promote our overall research activities. Interdisciplinary seminars were recently launched in the area of Complexity Science. We have extensive links with the City of London Livery Companies who support annual or biennial public events such as the Edwards Lecture (Worshipful Company of Scientific Instrument Makers); the Constructors Lecture (Worshipful Company of Constructors); the Bridge Lecture (Worshipful Company of Engineers); and (iv) a lecture supported by the Honourable Company of Master Mariners. Public events have been organised in cooperation with leading institutions (such as IEEE SMCS on "Engineering Sustainability") involving international speakers and the EU Commission. Major conferences organised by the School include: the 12th, 13th, 14th Jack-Up Platform Design, Construction & Operation Conferences; the 2009, 2011, 2013 Compressor Conferences; the 26th (2013) International Liquid Atomisation and Spray, Systems Conference; the 12th (2013) Conference on Present and Future of Automobiles and the 1st Workshop (2012) of the International Institute of Cavitation Research.

e.5 Industrial collaborations and influence on research activities: The School has a long-established record of industrial collaboration stimulating new research. Examples include: (i) our work on internal combustion engine design and fuel composition (see d.3); (ii) our EU-funded investigations into the integrated design of Process Systems working with ICI and Motorola, which have motivated current research in the area of Structural Evolving Systems; (iii) our work on the design of optical sensing technologies for safety systems which has been driven by the needs of the rail industry; (iv) requirements from the construction industry (SCI, see e.2) to design slim, efficient decking systems for high rise buildings; (vi) research in the design of electromagnetic ejector valves for the food industry (Buhler Sortex and Herba Foods, see impact case study).

e.6 Interdisciplinary activities: Interdisciplinary research forms a central part of our strategy which contributes to our distinct identity. Examples of School and University initiatives include:

● Biomedical Engineering. This research takes place mainly in *SENS&INSTR* (instrumentation, medical imaging), *SYS&CTRL* and *FLUIDS* (bio-fluids). An international initiative in cardiovascular research over the last six years (supported by charities), has searched for vulnerable coronary segments with high risk of atheromatic plaque rupture (Katritsis (Visiting Professor), Gavaises, Theodorakakos, Liatsis, Karcanias), with six journal papers published in high impact medical journals to date. The project is now being extended to consider large deformation fluid-structure interaction to simulate the dynamic (patient-specific) behaviour of a human heart (*STRUC&GEO*).

● Cyber and Security Sciences. This recent initiative brings together long-established University groups within engineering, computer science (CompSci), The City Law School (Law) and Cass Business School. CompSci contributes in computing and software reliability, *SYS&CTRL* contributes in information security (a new chair has been appointed), communications, systems, systems engineering and cryptography. Cass contributes to risk and audit and Law advises on the legal framework.

● Complexity Science and Risk Management. This work fits primarily within *SYS&CTRL*, where cross-disciplinary research is essential to answer questions about the broadly defined complex engineering systems. One such example involves an Engineering-Law-Business School research collaboration on risk management. Research on the fundamentals of complex systems has also been initiated through the organisation of interdisciplinary seminars resulting in collaboration between *SYS&CTRL*, CompSci, Law, Mathematics and Psychology.

● City Collaborative Transport Hub. This interdisciplinary unit promotes research on transportation systems and links activities within *FLUIDS* (IC engines), *SYS&CTRL* (Operational Research and systems), *SENS&INSTR* and CompSci.

e.7 Engagement with funding bodies: Eleven academics are members of the EPSRC College and three participate on government research committees, one is a government advisor on security (see e.1), five have been reviewers/evaluators for EU research projects and another has participated on the EU Panel for shaping the 2020 HORIZON programme on Complex Systems.