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

The School of Engineering & Mathematical Sciences excels in engineering research areas including reciprocating engines and combustion, computational fluid dynamics (CFD), turbo and positive displacement compressors and expanders, renewable energy systems, cyber security, systems safety and reliability, transportation, aerodynamics and aeroelasticity, marine technology, imaging, photonics, sensors and instrumentation and structures and geotechnics. Such diversity gives rise to a range of non-academic beneficiaries, encompassing engineering designers, manufacturers, analysts, policy makers, end-users and the public as a whole. The School has been successful in providing practical solutions to the following industries:

1) **Energy:** beneficiaries include energy producers (Shell, BP), energy system developers (Howden Compressors, Heliex Power) and energy providers (EDF Energy, E.ON)
2) **Aviation:** beneficiaries include aircraft and engine manufacturers (EADS, Rolls Royce) and air transportation system developers (BAE Systems, Qinetiq)
3) **Construction:** beneficiaries include infrastructure developers (ATKINS), steel manufacturers (Tata Steel), beam developers (Westok), safety and standard organisations (The Steel Construction Institute SCI, British Constructional Steel Association)
4) **Automotive:** beneficiaries include car manufacturers (Toyota, Nissan), systems and components manufacturers/developers (Caterpillar Fuel Systems, Delphi, Denso)
5) **Rail:** beneficiaries include systems and components manufacturers/ developers (Siemens, Bracknell Willis, Morganite Electrical Carbon, Lloyd's Register Rail), rail operators (Network Rail) and safety organisations (Rail Safety Standard Board RSSB)
6) **National Health Service:** beneficiaries include hospitals (St Bartholomew's Hospital, Great Ormond Street Hospital and St Andrew's Centre for Plastic Surgery and Burns), medical practitioners and patients
7) **Food:** beneficiaries include sorting machine and components manufacturers (Buhler Sortex, IMI Webber), food suppliers (Herba Foods), World Health Organisation (WHO) and the United Nation's Food and Agriculture Organisation (FAO)

The types of impact realised from our Research Centres (RC) are as follows:

(I) Economic: from (i) the ***Fluids Engineering Research Centre*** *(FLUIDS)* through the development of new designs of compressors and expanders (see **Impact Case 1**); fuel injectors (see **Impact Case 6**); advanced fuel compositions; energy efficiency (for example, heat exchanger and gas turbine); CFD codes and other software packages for the design of offshore structures. (ii) the ***Sensors & Instrumentation Research Centre*** *(SENS&INSTR)* through the development of novel designs of electro-magnetic ejectors (see **Impact Case 5**) and strain and temperature sensors. (iii) the ***Systems & Control Research Centre*** *(SYS&CTRL)* through the development of mathematical models and smart algorithms used by aero engine manufacturers (see **Impact Case 2**) and medical electronics (Phillips Medical Systems). (iv) the ***Structural & Geotechnical Engineering Research Centre*** *(STRUC&GEO)* through the development of new designs of structural beams (see **Impact Case 3**); composite materials and coating techniques.

(II) Practitioners and Professional Services: these relate to work undertaken by *FLUIDS, SYS&CTRL, STRUC&GEO* in providing advanced training on the use of our in-house software packages for engineers designing compressors/expanders (see **Impact Case 1**), fuel injectors (see **Impact Case 6**), structural beams (see **Impact Case 3**), medical devices (Phillips Medical Systems), aero engines (see **Impact Case 2**), energy systems and sub-systems (fuel cells, flywheels) as well as air and land transport modellers.

(III) Environmental: Studies within *FLUIDS, SENS&INSTR, SYS&CTRL* and *STRUC&GEO* have led to the development of (i) more efficient and hence less pollutant components/systems, such as gas turbines and heat exchangers (see **Impact Cases 1**, **5** and **6**). (ii) new simulators that enable less material usage and optimal processing for the chemical industries, aircraft and medical device manufacturers (see **Impact Case 2** and **3**). (iii) new sensors and monitoring techniques developed by *SENS&INSTR* that enable detection of environmental threats before they occur, such as corrosion and vibration. In the case of the latter, instrumented marine structures and propellers enable the minimisation of the effect of waterborne noise on sea life (funded by Wartsila).

(IV) Health: The Biomedical Engineering group within *SENS&INSTR* has been successful in its development of a series of medical sensors (see **Impact Case 4**), biomedical instrumentation and imaging techniques (computed tomography, impedance, spectroscopy and microscopy)**.** Work from within *FLUIDS* also includes investigations on cardiovascular flow using CFD.
(V) National Safety and Security: this was achieved by (i) *SYS&CTRL* through the development of algorithms used in Cyber security (GCHQ, IBM). (ii) *SENS&INSTR* through the development of chemical sensors that detect harmful gases, explosives and drugs (UK Home Office) and (iii) *STRUC&GEO* through the development of design guidelines for composite structural systems (decking) and recommendations for ensuring the integrity of infrastructure associated with nuclear power plant.

b. Approach to impact

We typically engage with end users of our research in the following three ways.

Approach 1: where specialist staff are contacted by external beneficiaries in order to make commercial use of existing research findings or to work collaboratively to develop the research further to suit their particular needs. For example: (i) Shell Global Solutions were eager to work with *FLUIDS* (Experimental Fluid Dynamics) to improve fuel properties for developing the next-generation of diesel injectors and nozzles. This collaboration started in 2006 and we recently signed a five-year research framework, worth over £0.5M, to extend the studies. Our findings led to significant environmental and economic impacts; (ii) the Ministry of Defence funded *SYS&CTRL (*System Analytics) to develop the J-value framework to assess the rational level of protection against industrial accidents which have the potential to harm humans and the environment. The method applies to all industries, but it is particularly relevant to the chemical, oil, gas and nuclear industries. The award-winning work is being used to formulate policy following large nuclear accidents such as Chernobyl or Fukushima in conjunction with the Indian Department of Atomic Energy as part of the UK-India Civil Nuclear Power Collaboration. (iii) *STRUC&GEO* was approached and commissioned by Balfour Beatty Ground Engineering and Cementation Foundations Skanska to investigate the forces required to remove steel casings during bored pile foundation construction. Current practice uses a crane to pull the casing from the ground, but the force needed is unknown and unpredictable. Centrifuge model tests were conducted to investigate the magnitude of the force required to extract various diameters of casing, embedded to a range of depths. These results are being reviewed by the Federation of Piling Specialists and the Health and Safety Executive with a view to widening the study.

Approach 2: where an existing consortium partner shares research findings with other relevant industries leading to the establishment of additional collaborative projects between City staff and new partners. For example in **Impact Case 6**, City academics were working closely with Toyota Motor Corporation on the development of advanced fuel injection systems. The findings appeared to be critical for the design of one of the key components (the nozzle) of the injection system. Denso, the main nozzle manufacturer and supplier for Toyota, joined the collaboration and is currently manufacturing new nozzles on the basis of City's research findings. As a follow up of this work, Denso is currently supporting research at City on cavitation erosion and injector durability issues for high pressure fuel injection systems, which represent the next frontier in the field. These new developments are expected to reach production within the next 3 years.

Approach 3: where staff develop their own ideas and directly approach potential beneficiaries or users to create an impact. For example, *SENS&INSTR* (Sensors and Photonics) developed new temperature–compensated strain sensor that was embedded into a pantograph system to detect defects in the overhead power lines for electric trains. The group patented their design and approached train manufacturers and operators to enhance the design further and exploit its commerciality. This instrumented pantograph system has the potential of resolving one of the major technical challenges facing the rail industry today, improving the cost-effectiveness, safety and reliability of an electric train fleet. This work is funded by EPSRC and is ongoing. *SENS&INSTR* (Biomedical Engineering) patented new designs of blood oxygen sensors that were used by four NHS hospitals on more than 200 patients in clinical trials (see **Impact Case 4**).

The School allocates appropriate resources to the four Research Centres with laboratory facilities and technical services available to every researcher. Additional laboratory space is allocated for services-rendered projects, to enable researchers to build collaboration and trust with partners (e.g., the work of Balfour Beatty Ground Engineering and Cementation Foundations Skanska mentioned in Approach 1). The School also provides funds to support promising projects

at an early stage of development and a later stage of commercialisation. For example, the School employed additional PhD and postdoctoral researchers to progress further projects associated with the temperature-compensated strain sensor (mentioned in Approach 3) and the corrosion and vibration sensors (mentioned in 1.c). The School funded a patent application in this area. A similar approach was followed in most of our impact cases. For **Impact Case 1** (using Approach 1) the School provided *FLUIDS* with the necessary testing facilities (75kW frequency converter compressor test rig with a 4500 rpm electric motor, refrigeration/expander test rig with 100kW frequency converter, and a further 11kW compressor rig) for conducting experiments and also the venue to host their biennial International Conference on 'Compressors and their Systems' (where more than a hundred world compressor manufacturers meet to address the latest technology issues). For **Impact Case 6** (Approach 2) the School supported the establishment of the first International Cavitation Institute which has its headquarters (with office space for 17 staff and visitors) at City University London. For **Impact Case 4** (Approach 3) the School provided *SENS&INSTR* (Biomedical Engineering) with new 300^{2}m laboratory for the development and experimental testing of new sensors. The reward for this investment was almost immediate, with the recent £1.5M funding success from the National Institute for Health Research (NIHR) to extend the development of these sensors.

c. Strategy and plans

Maximising the impact and relevance of our work in ways that are useful to the economy, cultural life, public services and policy-making is at the heart of what we do. We produce research that is recognised throughout the world for its relevance to contemporary intellectual challenges and its shaping of future research agendas. The School's strategy for maximising impact, aligned with the University Framework for Impact, is based on three main elements: resources support, staff incentives, and business development and partnerships.

(I) Resources support: this involves direct investment in facilities and staff and improvement of organisational mechanisms and functions. For example, the University Research Office will assist Principal Investigators in the formulation of proposals to meet funder requirements for impact, including any eligible costs to realise impact during the life of the project, and by planning for impact at the research proposal stage. We will continue to bid for research funding which promotes impact, in particular through follow-on initiatives. Furthermore, we make use of City University London Innovation Vouchers (of value up to £10,000) to enable the development of relationships with businesses and other knowledge users.

Academic and research staff receive advice on the most appropriate publication strategy for their work, in order to submit articles to academic journals of the highest quality while also reaching a wide practitioner audience. City Research Online allows the publication of the full text of our research articles with automatic Google indexing. The University Press Office provides coverage of research achievements through press releases and other promotional material. Potential business partners are able to access our web-based staff profiles and expertise database which identifies areas of specialism. Our public dissemination of research also benefits from the University hosting The Conversation UK (http://theconversation.com/uk), where UK academics write about their research for a lay audience.

(II) Business Development and Partnerships: in 2009, we set up an Industrial Partnership Panel (IPP) which helps to build links with industry and accelerate the transformation of research ideas into innovative business opportunities. The IPP comprises a group of ten senior practising engineers which provides our academic and research staff with the latest information about research needs in the industrial world. It also evaluates the potential of our intended new research proposals against business expectations. Successes in impact inform our regular reviews of School and Research Centre plans.

We deliver continuing professional development programmes, undertake specialist consultancy and pursue commercialisation of our intellectual property as part of our enterprise activities. With respect to our intellectual property, our approach is to gain the greatest social and economic benefit from our breakthroughs. With support from the University Enterprise Office, the School assesses the commercial viability of research projects and their development needs. The Enterprise Office also facilitates the establishment of new spin-out companies, as seen in **Impact Case 1.**

The School supports staff participation at major international conferences, to help them engage with the widest possible range of professional activities including consultancy (for example,

Professor John Fothergill's role as the lead technical expert in a €0.2B European industrial arbitration case), services rendered and collaborative research projects. The establishment of the International Cavitation Institute and the hosting of two major international conferences, as described in **Impact Cases 1** and **6**, have provided excellent platforms for staff to interact with industry experts, businesses and public organisations.

Three industrial professorships have been funded during the REF period (The Howden Chair in Engineering Design and Compressors Technology in **Impact Case 1,** The Delphi Chair in FIE Fluid Dynamics in **Impact Case 6** and the Pell-Frishmann/RAEng Chair in Nuclear Infrastructure Engineering). Such appointments are of great strategic benefit in creating opportunities for future research in similar or new fields of development. For example, the work with Howden has progressed well beyond the original agreements and additional funding of around £100,000 annually has been allocated for further research over the next five years.

(III) Staff Incentives: our policy is to encourage staff to achieve real impact in their research activities. The School carries out annual performance assessment of academics whereby they are rated according to their research outputs and contribution to enterprise. Collaboration in research and external engagement with businesses are important criteria as part of the School's academic promotion policy. Information about the number of partnerships and the level of collaboration, consultancy work, participation in conferences and workshops, publications in journals or conference proceedings are all fed into the School's performance model. These data are used for workload allocation and to reward staff. University policy allows one day per week for staff to undertake institutional consultancy and services-rendered projects with School approval. This policy has helped staff to remain up to date with the latest industrial development needs and in some cases consultancy projects have led to longer-term research collaborations as demonstrated in **Impact Cases 1** and **3.** Training on developing consultancy skills for researchers is provided by the University Enterprise Office. Similar support is also given to doctoral students, to enable them to explore the impact of their work and to equip them for the workplace post-graduation.

d. Relationship to case studies

The collaborative approach (explained in section c) forms a crucial part of the School's research strategy. Working closely with research users and beneficiaries has proved to be very effective both for improving research through knowledge exchange and identifying the best possible ways for implementing our findings in practice. The work carried out in **Impact case 4** demonstrates the effectiveness of this approach. A multidisciplinary research team comprising engineers, scientists, clinicians and beneficiaries (patients) collaborated to achieve this impact. The expertise brought by the uniquely qualified academics, clinicians and medical instrumentation manufacturers led to efficient solutions which met market demands (in a multi-billion pound business) and receiving high satisfaction from the users during the clinical trials.

The School recognises the importance of **delivering industrially relevant research** (underpinned by sound science) as a prime enabler for economic growth and sustainability. The software package DISCO© (Design Integration for Screw Compressors) developed within *FLUIDS* demonstrates the above principle (**Impact Case 1**). This software combines computational fluid dynamics with computer aided design (CAD) to deliver an integrated approach for the development and analysis of new screw compressors. DISCO© is used by the majority of screw compressor designers who are using an 'N' rotor profile in their machines. The software helps improve the efficiency and reliability of both conventional and new compressor and expander designs. For example, using this software it was possible to optimise the design of the Italian VMC compressor in order to reduce noise by 10dB, without any loss of power consumption. Recently DISCO© was used by Howden Compressors Ltd to design the largest rotors in their range and secure the single largest contract in the history of company. Similarly, the software 4Cast (**Impact Case 2**) simplified the design process for Rolls Royce Aero Engines by allowing designers themselves to (i) capture formally and quantitatively their relevant knowledge and experience; (ii) evaluate the effect of design decisions on engine failure and disruptions to service; (iii) evaluate maintenance strategies; and (iv) provide the basis for determining the life time cost of ownership of an engine.

The lessons learned from our engagement with industry and end-users have shaped our strategic thinking on research within the School. We focus on developing collaborations that offer lasting, long-term research partnerships whereby we are able to influence engineering practice and address stakeholders' needs.