

Institution: City, University of London
Unit of Assessment: B12 Engineering
<p>Overview</p> <p>Engineering, one of the three Units of Assessment (UoA) of the School of Mathematics, Computer Science & Engineering (SMCSE), has been an integral part of City, University of London, since its establishment in 1894. Our research aligns with the vision of the UK's Department of Business, Energy and Industrial Strategy: "ensuring that the UK takes advantage of major global changes, improving people's lives and the country's productivity. The first 4 Grand Challenges are focused on the global trends which will transform our future: AI and data; ageing society; clean growth and future mobility". The research reported in this UoA is grouped around five Research Centres (RCs) that focus on areas addressing the above-mentioned scientific, technological and societal grand challenges:</p> <ol style="list-style-type: none"> 1. Thermo-Fluids (TF) 2. Aeronautics and Aerospace (AERO) 3. Institute of Sensors and Instrumentations (ISI) 4. Systems, Autonomy and Control (SAC) 5. Sustainable and Resilient Civil Engineering (SRCE). <p>Our RCs contribute to the evolution of their disciplines, stimulate collaborations with other Schools, Universities, Research Institutions and leading industries and enterprises while implement interdisciplinary approaches crossing traditional engineering boundaries.</p> <p>During this assessment period we heavily invested in people (academic staff, Research Fellows and PhDs) as well as in research infrastructure and equipment. The total investments made in research, in addition to the externally raised research income, represent 10% of our annual turnover, which is more than double compared with REF2014. More specifically: (a) we allocated £7.84M in PhD studentships and training; (b) we renovated our laboratory infrastructure and space (£16.9M), equipment and high-performance computing (HPC) facilities (£5.39M). In addition: (c) we recruited and supported a significant group of academic staff to become research active; 45% of our Full-Time Equivalents (FTEs) are new compared with REF2014; (d) we allocated £14M (50% of our externally raised research income) to employ Research Fellows; (e) we enhanced our capabilities by giving our staff access to large-scale experimental and computational facilities not available within the School through our fostering of strategic partnerships with leading institutions and national laboratories internationally; this promoted not just discovery and invention but also <i>innovation</i> and supported industry. Our research strategy has resulted in steep increases <u>per FTE per year relative to REF2014</u> and has created impact, demonstrated via:</p> <ol style="list-style-type: none"> 1. A 178% increase in research income awarded to staff.

2. A 75% increase of PhD awards and a 109% increase of employment months of postdoctoral Research Fellows, which has contributed to their exceptional employability/career paths followed.
3. A 41% increase in published peer-reviewed journal papers and textbooks.
4. A 149% increase (from 288 in REF2014 to 718 in REF2021) of the number of peer-reviewed papers published in journals classified in Quartile 1 (Scimago database), indicating a positive quality shift since the last REF and resulting in high levels of citations, prizes and awards of esteem.

In the following sections, the research environment and measurable outputs from 49.5 FTE (51 academic staff members) are described, analysing in detail these significant improvements relative to the previous REF2014 submission and outlining our long-term research strategy.

Response to the COVID-19 pandemic

From March 2020 onwards we have moved all our research activities online. We have taken special care about the support for our PhD students by introducing additional online supervision sessions and the introduction of Zoom coffee rounds for the sole purpose of socializing to combat isolation. We made sure that PhD students have an adequate infrastructure to carry out their respective research by supplying them with laptops and writing pads, when needed. These were financed from research grants and central funding provided by the School. While most planned workshops and conferences had to be postponed, several members of staff took the initiative to engage in new activities. Members of staff have also re-directed some of their research activities to contribute to the tackling of the pandemic.

1. Unit context and structure, research and impact strategy

1.1 Research structure

Our groupings have been formed as the disciplines have evolved in order to create critical mass in each area and to support interaction and interdisciplinarity among them. Research is organised in the five aforementioned RCs:

Thermo-Fluids (9.25 FTE): Focuses on technologies that have a large impact on the reduction of CO₂ emissions: (a) Centre for Compressor Technology (Professor Kovacevic, RAEng/Howden Chair in Compressor Technology), established with the support of the Royal Academy of Engineering (RAEng) 25 years ago; (b) multi-phase flows and home of the International Institute for Cavitation Research (Professor Gavaises, Chair in Fluid Dynamics); (c) Turbomachinery and Energy Systems (Professor Sayma, Chair in Energy Engineering), focusing on solar-powered micro gas turbines, supercritical CO₂ and organic Rankine cycles and thermal energy storage, established in 2014.

Aeronautics and Aerospace (8 FTE): Established in 1910 and home of the Sir Frederick Handley Page Aeronautical Laboratory, it is part of the UK National Wind Tunnel Facility, contributing the Transonic/Supersonic T5 (TS3) and the Low Turbulence Wind (LS1) tunnels. Activities focus on: (a) experimental aerodynamics for bio-inspired flow sensing and flow manipulation for sustainable transport (Professor Bruecker, RAEng/BAE Systems Sir Richard Oliver Chair in Aeronautical Engineering); (b) direct numerical simulations (DNS) for aerodynamic flow control devices (Professor Pinelli, Chair in Computational Fluid Dynamics); (c) through-life engineering, self-engineering systems and digital manufacturing (Professor Roy, Chair in Engineering).

Institute of Instrumentation and Sensors (11 FTE): Established 40 years ago, it focuses on three areas: (a) design and development of fibre optic sensors (Professor Grattan, RAEng/George Daniels Chair; Professor Sun, RAEng/Favelley Brecknell Willis Chair); (b) biomedical instrumentation (Professor Kyriacou, Chair in Biomedical Engineering), engaging in interdisciplinary research on understanding, developing and applying medical instrumentation, biosensors and physiological measurements to facilitate the prognosis, diagnosis and treatment of disease or the rehabilitation of patients; (c) cybersecurity (Professor Muttukrishnan, Chair in Security Engineering) focusing on identification and access management, cloud security, Internet of Things (IoT) and sensor and network security.

Systems, Autonomy and Control (7.75 FTE): The multidisciplinary activities focus on: (a) Control Systems Theory (Professor George Halikias, Chair in Control Systems), established 30 years ago and currently expanding in the area of robust control and optimisation of challenging engineering problems in diverse areas such as control of district heating/cooling systems, control of chemical processes and automated infrared imaging techniques; (b) Robotics and Machine Intelligence group (Professor Nabil Aouf, Chair in Autonomous Systems), which is developing new AI-based solutions for autonomous vehicles including drones, space and ground robotics vehicles and cars; (c) Power Systems (Professor Keith Pullen, Chair in Energy Systems), developing high fidelity models for micro-grids and solutions for energy storage using flywheel rotor designs.

Sustainable and Resilient Civil Engineering (13.5 FTE): Focusing on areas prioritised by UKRI in “Resilient Nation” for structures, offshore wind, urban underground and foundation systems: (a) Civil Engineering Structure (Professor Ayoub, RAEng Chair of Nuclear Infrastructure), representing the UK in the development of the next generation of Eurocodes for seismic hazard mitigation of bridges and wind turbines and for retrofitting of existing structures; (b) Fluid-Structure Interaction (Professor Ma, Chair in Hydrodynamics) developing numerical simulation models for the nonlinear interaction between steep waves and floating structures; (c) Multi-Scale Geotechnics (Professor Sarah Stallebrass, Chair in Soil Mechanics) focusing on sustainable deep foundations and improving construction safety, in partnership with the Temporary Works forum.

1.2 Research strategy

Our research strategy is steered and approved by the Dean, the Associate Dean (Research and Enterprise), the Research and Enterprise Committee and the RC Directors, who encourage all academics to generate and refine ideas. Our research strategy is informed by continuous review of existing themes, a response to significant global trends and to our sponsors' strategies (e.g. Engineering and Physical Sciences Research Council (EPSRC), RAEng, Innovate UK, industry and the EU). The national priorities identified by this review include energy, sustainability, transport, aeronautics and aerospace, infrastructure, health care and data, communications and security and enhancing the environment.

1.2a Recruitment strategy

Our recruitment strategy is driven by the aim to create "world-leading engineering knowledge". We seek both to recruit colleagues who are internationally recognised and influential and to strategically replace retiring staff/leavers in order to increase the strength of our research disciplines by creating critical mass and connecting across the School and the University through strategic themes. Competitive salaries and relocation support mechanisms for individuals and their families are in place. Induction meetings and support for newcomers are in place. Recruitment is also used to maintain a healthy balance of new and experienced staff across the School.

1.2b Research Income (RI) strategy

Our RI strategy is driven by the need to attract funding from research councils, industry/corporations, charities and investors. We are committed to grow our research by increasing the number, quality and size of research grant applications; during the REF2021 period we have been submitting ~90/year (1.8 proposals/FTE/year), requesting ~£20M/year of RI, which is 3 times higher compared to REF2014. This resulted to 3.5 times increase (from £8M to £27.8M) of our RI compared with the previous reporting period. Larger grants of longer duration are subsidised by the School's matching funds. The research committee and senior academics play a leading role in building excellent relations with key industries/corporations who can partner on grants, e.g. from Innovate UK and the EU.

1.2c Research infrastructure strategy

Our research infrastructure strategy is driven by the need to provide academics with attractive, high-quality space to accommodate research students and staff, providing state-of-the-art facilities for physical experiments alongside those for theory and modelling. During this reporting period we have invested approximately 8% of our annual turnover and an additional 13% from research grants in building infrastructure, equipment and HPC, as outlined in Section 3.3. We will continue to ramp up our expertise in developing, manufacturing and setting up portable experimental

devices, considering the strictest health and safety regulations required for their transportation and the execution of experiments in large-scale facilities not available within the School. A striking example from this reporting period is a cavitating flow test rig used for obtaining complimentary measurements across various laboratories: bubble dynamics at EPFL (Switzerland); X-ray micro computed tomography at Bergamo University (Italy); and X-ray Phase Contrast Imaging and absorption measurements utilising the high energy X-ray synchrotron radiation light sources of Argonne National Labs (USA), which came together with an additional access to the Theta (Cray XC40) HPC facility.

1.2d Research internationalisation strategy

Our research internationalisation strategy builds on successful national and international partnerships through participating in major grants with leading institutions, industry and national laboratories worldwide – e.g. the EU, EPSRC, Newton Fund and overseas research councils – to expand our reach and enhance our research capability. Our staff thus become part of a large network of international experts, creating synergies, publications in prestigious scientific journals and delivering global impact.

Key examples include: (a) The secondment of Koukouvinis and Karathanassis (two years each) to the combustion facility of Sandia National Laboratories (USA) and their engagement with the experimentation performed at Argonne. A complimentary experimental campaign involving neutron measurements at the Paul Scherrer Institute (PSI), Switzerland, is temporarily postponed due to Covid-19. (b) Jointly supervised PhD programmes with leading experts in universities and industries specialising in interdisciplinary research areas; e.g. two PhDs were completed through working with Afton Chemicals Ltd and Virginia Commonwealth University, USA, resulting in new fuel property measurements, extending the National Institute for Standards and Technology (NIST) databases at extreme pressure and temperature conditions and developing relevant real-fluid equations of state. (c) City was one of the founding overseas partners in the \$38M Australia Research Council-funded Centre for Nanoscale Biophotonics, linking to Australia's key nanophotonics groups and building a global collaboration with a focus on advanced photonics methods required to advance biosciences.

1.2e Research publications strategy

Our research publications strategy is to foster a striking level of collaboration between our staff and academic/research institutions and industries/enterprises worldwide, thus increasing the number of publications in leading scientific/technological journals addressing multidisciplinary topics. We will continue building upon the success of this reporting period, where 68% of our peer-reviewed journal papers are co-authored with non-City collaborators and have been published in journals with a median impact factor of 3, which is higher than the discipline median of 2.0 (2020

data from Web of Science). Moreover, the two-year impact factor of our publications has increased linearly from 1.57 in 2011 to 2.775 in 2015 and up to 4.064 in 2020 (based on Scopus citation reports). This indicates the positive peer recognition of our research outputs at international level. Open access to publications is secured by our Library Services, which holds an institutional repository, City Research Online (CRO). The repository team proactively engages with researchers, advocating open access principles and benefits and also ensuring adherence to copyright and any other rights of research outputs.

1.2f Research dissemination strategy for scientific audiences

Our research dissemination strategy actively promotes dissemination across our peers in the scientific community. Our staff have delivered 46 invited/keynote presentations, receiving numerous best paper presentation awards, while more than 33 conferences/workshops have been organised/chaired by our staff, often involving major professional bodies, some of which have become international focal points of the corresponding communities. Our vibrant seminar series has attracted 200 talks from experts worldwide.

1.2g Research communication strategy informing the general public

Our research communication strategy actively promotes dissemination and outreach activities that aim to inform the community of our successes while, at the same time, encouraging young students (both male and female) to study engineering science. The City Press Office, through its Senior Communications Officer for SMCSE, promotes the School widely via communicating the most interesting and topical stories from SMCSE to different audiences – stories about the School's research, reporting on events, highlighting staff and student successes. Stories generated about the School are published on the City website and disseminated through contacts with journalists in the UK and further afield. The City Press Office facilitates proactive and reactive commentary from academics.

1.2h Research impact strategy

Our research impact strategy is realised by engagement with industry and medical/health institutions when addressing today's scientific, societal and technological challenges. Higher Education Innovation Fund (HEIF) funding is targeted at creating impact from research and pump-priming projects, helping to engage staff members with international networks, patents, licence agreements and spin-out companies. In order to grow these activities, the School has recruited a Business Development Manager (BDM), working alongside the University Enterprise Team and the City University Business Incubator, with a single focus on strengthening the enterprise portfolio of the UoA. In addition to our internal strategy relating to enterprise activities, we also have strong relationships with Innovate UK, Knowledge Transfer Partnerships (KTPs) and the Royal Academy.

1.2i Strategy in relation to academic workload for engaging staff in research

Our academic workload strategy has enabled our academic staff to focus on research through the following actions: (a) support for research centrally via the Research Contracts and Enterprise Office, the University's Doctoral College, the University Property and Facilities team and the University IT staff. The Departmental Laboratory Manager and Technical Services Manager help to align the provision of technical services to emerging research needs. In addition, project management staff supported by research programmes assist in the management of our research; (b) full implementation and close monitoring of a workload model that led to a 20% reduction of the teaching/admin workload of our staff. Currently, our average teaching-related contact hours and administrative workload per staff FTE is 650/year, which leaves more than 40% of the academic staff time to focus on research; (c) grant applications are incentivised by assigning 8% of the School's income from each research grant to applicant discretionary research-related spending, to support student bursaries, purchase of equipment and consumables and conference attendance.

1.3 Progress against the REF2014 plan

The commitments made in REF2014 (in *italics* below) for UoA have not only been met but in many cases exceeded, as outlined below:

1. *Attract the best quality researchers in key areas to strengthen our critical mass.* Success: we have recruited 19 research-active academic staff across all areas (38% of our FTE are new relative to REF2014).
2. *Invest in PhD Scholarships to attract the best quality students.* Success: we invested £7.84M in PhD Scholarships; these have supported nearly 100 completed PhDs during REF2021.
3. *Enhance our laboratory facilities (£6M) to support our research.* Success: we have invested £16.9M in refurbishment of our 4,000 m² laboratory area. In addition, we invested £5.39M on major equipment items over £10k and HPC clusters.

The following tables summarise important data underpinning the research successes during this reporting period. More specifically, Table 1 indicates the research income (RI), PhDs awarded, postdoctoral Research Fellows (RF) number and person-months of employment and research publications; a breakdown per research centre and the total figure for this UoA are listed.

Table1: Research income, PhDs awarded, Research fellows (number and person-months (PM)), peer-reviewed journals, books/book chapters and conference proceedings for all research centres and the UoA

	TF	AERO	ISI	SAC	SRCE	UoA
FTE	9.25	8	11	7.75	13.5	49.5
1. Research income (£k)	£11,665	£3,210	£7,741	£2,817	£2,714	£28,146
2. PhDs awarded	45.0	14.2	66.1	38.5	30.1	193.9
3. Research fellows No & PM	31 (708)	3 (106)	29 (799)	26 (327)	14 (298)	103 (2,238)
4a. Peer-reviewed journals	192	158	314	140	290	1094
4b. Books and book chapters	13	4	20	11	21	69
4c. Conference papers	166	139	346	156	257	1064

The normalised values for those indicators per FTE and per year (/FTE/year) are summarised in Table 2, while Table 3 indicates the percentage increase relative to the corresponding values reported in REF2014. As can be seen, these represent significant, indeed steep improvements compared with the previous reporting period across all five RCs. Even more importantly, they demonstrate the successes of two of our RCs (Thermo-Fluids and Institute for Sensors and Instrumentation), showing figures for RI/FTE/year and PhD awards/FTE/year that are well above the REF2014 national average for this UOA; moreover, all RCs are supporting a significant volume of publications and high RF employment months, all at internationally competitive levels.

Table2: Normalised performance indicators (/FTE/Year) for all research centres and the UoA

INDICATOR/FTE/Year	TF	AERO	ISI	SAC	SRCE	UoA
1. Research income (£)	£180,154	£57,327	£100,529	£51,918	£28,716	£81,230
2. PhDs awarded	0.69	0.25	0.86	0.71	0.32	0.56
3. RF person-months	10.93	1.89	10.38	6.03	3.15	6.46
4. Publications (all)	5.7	5.4	8.8	5.7	6.0	6.4

Table 3: Percentage increase (i.e. (REF₂₀₂₁-REF₂₀₁₄)/REF₂₀₁₄) /FTE/Year, relative to our REF2014 submission; data for the TF and AERO RCs are compared against the corresponding numbers of the REF2014 Fluid's Engineering

INDICATOR % INCREASE	TF	AERO	ISI	SAC	SRCE	UoA
1. Research income	445%	73%	54%	183%	221%	178%
2. PhDs awarded	224%	18%	53%	53%	139%	75%
3. Research fellows (PM)	143%	758%	33%	1658%	95%	109%
4. Journal papers and books	81%	65%	28%	15%	90%	41%

1.4 The plan for the next reporting period is given below:

- 1. Recruitment:** Continue to attract and appoint research leaders, in order to enhance the areas of our success while ensuring critical mass is maintained across all research centres; we aim to increase our FTE in each RC.
- 2. Research income:** Targeted actions aiming to increase research income include (a) doubling our grant submissions from today's levels; (b) supporting our research leaders with a proven track record to develop larger research grants, e.g. national centres of excellence, programme grants and prestigious fellowships, involving strategic partnerships with industry; (c) fostering collaborations with academia and industry nationally and internationally,

participating in interdisciplinary consortia to apply for funding; (d) mentoring and/or training of the junior staff (60% of our FTE) to win research grants and early career fellowships.

3. *PhD numbers*: Continue to increase the numbers of high-quality research students by winning new EPSRC Doctoral Training Centres and Marie Curie Networks, securing more industrial funding and attracting more philanthropic donations. At the same time, we will continue to support studentships at higher levels compared to this reporting period.
4. *Research Fellows*: Continue to increase the numbers of high-quality postdoctoral researchers by making an increasing provision for them in grant applications so that they can provide gearing for academics and build research capacity.
5. *Equality and Diversity*: Engage fully with the Athena SWAN programme and continue the measurable improvements in the numbers of women applying to posts, securing appointments and winning promotions, awards and national recognition.
6. *Internationalisation*: Continue to build stronger links with Universities and research centres internationally, secure access to large-scale computational and experimental facilities and together secure new funding for new posts in interdisciplinary areas.
7. *Impact*: Collaborate with industrial partners to maintain and expand the solid intellectual foundation to solve industrial problems and create new business.
8. *Infrastructure*: Use University and School funds for multidisciplinary research and improve the functionality and environmental performance of existing space. We will continue to invest more than 12% of our annual turnover (20% higher than this reporting period) for research-related infrastructure and PhD studentships.

1.5 The RCs' discipline-specific future strategic aims were refined during the REF2021 period, building on our successes while aligning with Government national priorities, as follows.

Thermo-Fluids: With a focus on climate change and efficient conversion and utilisation of energy, supporting the 2050 targets for reduction of emissions, we will continue to develop advanced experimental techniques (optical, laser, X-ray and neutron diagnostics) and Computational Fluid Dynamics solvers coupled with real-fluid thermodynamics closure and Machine Learning tools. Breakthrough advancements are envisioned in the design of hydraulic components and fluid machinery (including compressors, solar-powered micro gas turbines and extreme pressure fuel injectors), cooling and heat-waste utilisation devices, Organic Rankine and supercritical CO₂ cycles for power generation, thermal management systems with relevance to the electrification of the transportation sector, renewable and synthetic fuels, as well as renewable energy storage systems.

Aeronautical and Aerospace: Focus will be placed on advanced designs and materials for civil aero-structures, unmanned aerial vehicles (UAV) and microfluidic monitoring technologies. A

holistic approach will be followed, combining advanced optical flow measurement technologies (wall shear-stress sensors, volumetric flow diagnostics via 3-D PIV and BOS Schlieren), Direct Numerical Simulation (DNS) and development of methodologies to realise design modifications via adaptive lightweight materials with sensory and self-healing functionality. We envisage breakthrough applications in technological areas where we have demonstrated leadership: (a) nature-inspired flow optimisation strategies and their integration into sophisticated flow management and flow control systems; and (b) testing adaptive materials and integrated sensor functionality under the condition of advanced digital manufacturing.

Institute of Sensors and Instrumentations: The Institute will continue to address the cutting-edge challenges needed for new, cost-effective solutions across the breadth of “sensors and instrumentation”, biomedical engineering, cybersecurity and IoT. This will be seen, for example, in our work on innovative instrumented railway pantographs, new solutions to multi-parameter sewer monitoring in such hostile environments, new solutions to propeller shaft measurement and a wider range of chemical sensor solutions, e.g. for homeland and airport security. The biomedical research will continue to advance research into photoplethysmography, spectroscopy and tissue optics, with its activities focusing on both basic and applied research of non-invasive optical sensor technologies for monitoring blood and tissue biomarkers used for the early screening of disease such as cardiovascular, mental health and sepsis among others. In cybersecurity, offering new searchable encryption solutions will protect sensitive data collected from industrial IoT settings and smart cities, hence helping organisations and governments to comply with GDPR requirements.

Systems, Autonomy and Control: With a focus on Systems Autonomy, Machine Learning and Intelligent Processing Algorithms in real-time hardware, Systems Theory, Control and Estimation, Communications and Power Systems will address complex real-world problems and emerging applications involving autonomous vehicles (air, space and ground). Theoretical and applied work with emphasis on integrated and innovative solutions needed to address design complexity will be applied to planning and decision making, navigation and guidance, cooperation between vehicles, real-time communications of autonomous agents, energy storage, high-fidelity microgrid modelling incorporating flywheels, as well as space, networks and power applications.

Sustainable and Resilient Civil Engineering: With a focus on resilience of infrastructure and complex civil engineering systems to natural and man-made hazards, we will develop and apply structure monitoring and lightweight inverter-based devices for vibration control. For improving sustainability of urban infrastructure, we will develop innovative energy storage foundation and regenerative dampers harvesting renewable energy from structure vibration, facilitating net-zero emissions. Development of multi-scale, multi-physics numerical tools, with the support of AI and

data science, will integrate hydrodynamics, structural and soil mechanics solvers for fluid-structure-soil interactions. This will contribute to the evaluation of the survivability of offshore and coastal structures, with or without mitigation techniques, and the reliability and survivability of the ocean renewable energy converters.

2. People

2.1 Academic staff

2.1a Structure and changes compared with REF2014

We recruit academic and research staff that demonstrate the potential to rise to the level of professor or to take a leading industrial role. During this reporting period we have employed 19 academic (38% of the total FTE, eight from abroad) and 103 research staff from all over the world. We received 2,523 applications and 356 have been shortlisted and interviewed. At the same time, 22 FTEs (12 professors, 2 readers and 8 lecturers) left the School; the percentage of professorial staff ratio compared with REF2014 has been reduced from 57.6% to 42%. Overall, excluding the Research Fellows listed in the REF2014 submission, we return one FTE more compared with the previous reporting period. All staff submitted are listed below; new staff, either recruited or changed to a research profile relative to REF2014, are indicated as **New**:

Thermo-Fluids (9.25 FTE): Professors: Sayma, Nouri, Kovacevic, Gavaises. Senior Lecturers (S.L.): Zhang (**New**, 0.25 FTE). Lecturers: Koukouvinis(**New**), Karathanassis(**New**), White(**New**), Al Zaili(**New**), Read(**New**).

Aeronautics and Aerospace (8 FTE): Professors: Roy(**New**), Bruecker(**New**), Pinelli. S.L.: Yazdani(**New**), Sun(**New**). Lecturers: Omidyeganeh, Jagadeesh(**New**), Ponnusami(**New**).

Institute of Sensors and Instrumentation (11 FTE): Professors: Grattan, Kyriacou, Sun, Rahman, Khan(**New**), Muttukrishnan. S.L.: Triantis, Naher. Lecturers: Wu(**New**), May(**New**), Qassem(**New**).

Systems, Autonomy and Control (7.75 FTE): Professors: Aouf(**New**), Chen, Pullen, Halikias (0.75 FTE). Reader: Rakocevic. S.L.: Tomas-Rodriguez, Milonidis. Lecturers: Apostolopoulou(**New**).

Sustainable and Resilient Civil Engineering (13.5 FTE): Professors: Crouch, Ayoub, Ma, Stallebrass(**New**). Reader: Yan. S.L.: Gialaris, Goodey, Casado, Fu, Fonseca, McNamara (0.5 FTE), Micic(**New**). Lecturers: Mergos, Divall(**New**).

2.1b Junior staff recruitments include 14 lecturers and 2 S.L. All have a proven research track record via postdoctoral research (4.1 years, a figure similar to the HESA national average). Despite their junior position and an average of only seven years in research/academia since their PhD completion, they have co-authored an average of 20 journal papers/FTE; moreover, they have significantly contributed in this REF2021 submission via an impressive co-authorship of 211 journal (4.5/FTE/year) and 190 conference papers (4.1/FTE/year) over the average of 2.9 years of their employment.

2.1c Professorial staff recruitments include Professor Roy (Dean and Chair in Engineering) and Professor Aouf (Chair in Autonomous Systems), both from Cranfield University, and Professor Bruecker (BAE/RAEng Chair) from the University of Freiberg, Germany. They have provided new leadership in their fields demonstrated by the attraction of large research grants and the co-authorship of more than 307 journal and 470 conference papers during their academic career, with 41% of these published during the REF2021 period.

2.1d Academic staff career development is formally supported through the annual appraisal scheme, in which every member of academic staff meets with the appropriate RC Director to review performance and develop a tailored approach to research and career development. During this reporting period, four FTEs that were not included in REF2014 (including two females: Stallebrass and Micic) have been supported to become active in research and are included in this submission. We hold workshops in order to encourage staff to apply for promotion using criteria that are transparent, uniform across the University and in accordance with national standards. To assist in career progression at all academic scales, staff have benefitted from the management and leadership programmes of City's Learning and Development Centre, including one-to-one coaching, master classes and writing retreats. All our staff have participated in 100 training events, such as the Senior Academic Leadership Programme, which equips them with the practical skills and awareness required for organisational leadership. From the 12 staff eligible for promotion, six have been promoted to a higher academic position (Casado, Fonseca, Fu, Triantis and Gialaris from lecturer to senior lecturer and Yan from senior lecturer to reader). Progression within the four professorial bands is also encouraged; during this reporting period 1 progression from Band 1 to 2, 2 progressions from Band 2 to Band 3 and 2 progressions from Band 3 to Band 4 have been achieved.

2.1e Special arrangements for new academic staff

Practical start-up support for new staff comprises at least £5k of flexible pump-priming funding and an additional £10k of HEIF funding to underpin their EPSRC 'First Grant' application and Royal Academy of Engineering and Marie Skłodowska Curie Actions (MSCA) fellowship applications. During the REF2021 reporting period our staff have been supported with a total of £565k from the Global Challenges Research Fund (GCRF) (£131k), HEIF (£66k), Pump Priming

Fund (£129k) and PhD studentships (£238k), the large majority of which has been linked to the support of strategic initiatives within the RCs of the School. In addition, we hold workshops to help staff who are writing grants, including expert talks by members of grant-awarding panels and feedback on draft proposals. We also maintain a repository of exemplar grant proposals and provide mock interviews for all candidates shortlisted for funding interviews. Moreover, new staff have reduced teaching hours (half a module during the first year and no more than one module during the following two years), minimal administration, regular networking lunches with senior staff and priority in competitions for School/University-funded PhD studentships and equipment to enable them to build rapid momentum in research. All probationary staff have a mentor who gives advice and helps develop a research-funding strategy. The University's Research and Enterprise Office supports new staff by providing information for all new calls for identifying funding opportunities suitable to the research areas of individuals; it gives guidance on pre-award processes, costing, developing and submitting research grant applications. The Office also provides the necessary post-award support. Approximately 78% of our new lecturers (11/14) have secured a grant as PI within the first three years of their appointment. Successes include four EPSRC First Grant awards (Triantis, Yan, Fonseca, Sun), three EPSRC grants (Yan, Giaralis, Qiang), one five-year RAEng Research Fellowship (White), two MSCA Global Fellowships (Karathanassis, Koukouviniis). Moreover, 100% of non-professorial staff have achieved Co-Investigator status on larger research grants within two years of appointment. Compulsory cosupervision of PhD students and joint grant applications foster the mentoring of junior staff to develop as future research leaders.

2.2 Research Fellows (RFs)

During REF2021 we have secured funding to support employment of 103 postdoctoral RFs with contracts totalling 186.5 employment years (see Table 1); this corresponds to an average of three years and nine months of RF support per academic FTE. Like academic staff, RFs have annual appraisals and are encouraged to take University training courses; all are considered for annual discretionary pay awards. They are given the opportunity to teach, under supervision, with formal recognition by inclusion in our student online evaluation. Each RF is assigned to a Research Centre and peer support and mentoring are provided. RFs are encouraged to join and complete training from Learning Enhancement and Development (LEaD) to become an Associate Fellow of the Higher Education Academy (HEA). Moreover, PhD training is available for the RFs for their development, while each RF is supported to attend relevant conferences using the strategic research fund. Our RFs have won prizes, awards and fellowships – prestigious examples include: RAEng Research Fellowship (White), RAEng IC Fellowship (Silver) and Enterprise Fellowship (Vidakovic) and six MSCA Global and intra-European Fellowships (Karathanassis, Koukouviniis, Mitroglou, Theodorakakos, Strotos, Nikolopoulos).

Employability: Before the end of their contract, RFs receive a career consultation from an HR advisor and automatic shortlisting for relevant School vacancies. Their impressive career paths at the end of this reporting period include: 33 (32%) academic positions (in the UK and worldwide), 36 (35%) postdoctoral researchers and 34 (33%) in industries and enterprises.

2.3 Research students

The PhD programme is overseen by the Associate Dean of Research and Enterprise and a team of Senior Tutors Research (STR). The School's Research Degrees Committee (RDC), chaired by an STR, takes responsibility for an overview of the various progression stages through the PhD training years, including an annual formal progress review for every research student.

2.3a Recruitment and scholarships

We attract outstanding students with diverse backgrounds in engineering, mathematics, physics, material sciences, computer science and medical sciences. Applicants must submit a research statement to allow an assessment of their creativity and independence and all shortlisted candidates are interviewed by at least three academic staff and a Human Resources staff representative. Only the top candidates are selected. Evidence of the quality of the PhD students is that more than 82% have been awarded competitive scholarships while 18% are self-funded. During the REF2021 period there have been 193.9 PhD awards (18% home, 28% EU and 54% overseas). Please see Table 4. The School has fully funded 67 PhDs and waived the fees for a further 23 students; a small number of PhDs have EPSRC DTP funding (awarded in September 2017); 33 PhDs have been fully funded from research councils, including Erasmus-Mundus, five MSCA Innovative Training Networks (ITN) and one MSCA European Industrial Doctorate (EID) Network. In addition, we have established a Doctoral Training Centre in cybersecurity funded by EIT Digital. As part of our strategic goal of increasing interactions with industry, the School has set up its own industrial PhD scheme, which provides matched funding with industry for tuition fees and bursaries; 14 PhDs have been fully funded and 6 cofunded by industries during REF2021. In addition, six external PhDs funded by the MSCA programmes have been working at the premises of our industrial partners (Perkins Engines/Caterpillar, Delphi Technologies, 2 at Afton Chemicals, 2 at AVL List, Mitsubishi-Hitachi) and ten more have been seconded to industrial collaborators for a period of two to six months, while seven more have been sponsored by foreign governments. [REF4a data adjusted to meet HESA +10% Rule, as previously communicated to the REF Policy Team].

2.3b Training and support mechanisms

The School has established and launched a comprehensive PhD training programme, open to all full- and part-time PhD students. The programme aims to enhance the skills of our research

community as well as enhancing the PhD students' transferable skills and employability. The programme is divided into five categories (Supporting Your Research, Supporting Your Career, Supporting Your Teaching, Information Literacy and IT Skills, Departmental Training). The School is currently working closely with the recently established Doctoral College to embed and complement our School's training programme with the University-wide training programme.

All PhD students have two supervisors and access to the Senior Tutor Research (STR) to provide further pastoral support. The students elect representatives who bring collective concerns to the STR. They attend both a University and School induction training day and receive a School PhD Handbook (also available online). Funding for conference attendance (£1,000/PhD) is provided by the School in addition to conference funding offered by the RCs to which the students belong. PhD students are supported to apply for awards and funding. All our students have attended at least one conference during their studies; for funded programmes (82% of our PhD students), the average participation in conferences is 2.6. We complement supervision with: (a) School/departmental courses and seminars; (b) courses and seminars taught elsewhere in the School or through dedicated summer school training camps, where external experts give talks on specialised topics; and (c) seminars/courses from the School, which provide transferrable skills/professional development training. For students supported by funded projects, there is a compulsory presentation at scheduled meetings that typically take place every six months. Where industries are involved, an external PhD advisor is also appointed; there is a requirement that external advisors coming from industry also hold a PhD and have a record of peer-reviewed journal publications. Typically, such industry-based external advisors are influential figures in their corresponding industries, supporting the links with universities at global scale, offering mentoring and often facilities support as well as advice on industrial directions and job opportunities.

2.3c Involvement in publications and dissemination and outreach activities

Our PhDs have published, as first authors, 421 journal papers during the REF2021 period (38.3% of the journal papers published). Engaging with the general public is considered a crucial training and career development opportunity for PhDs and the engagement process covers five areas: (1) Planning: impact goals, target audience, appropriate means are defined; (2) Training: the PhDs receive training (presentation skills, dissemination to a lay audience, etc.); (3) Collaborating: the PhDs in collaboration with supervisors identify the specific outreach/communication activities they will implement. The targeted message and the language that will be used in each activity are also identified. The personality and interests of each student are taken into consideration when planning the activities at this phase; (4) Implementing: the activities are implemented by the PhDs in collaboration with a trainer where needed (e.g. to learn how to write a speech or a lay article); (5) Evaluating: the implemented activities of each project are evaluated every six months.

During the REF2021 period, our PhDs have implemented numerous communication and outreach activities individually or in collaboration with other students from partner universities participating in collaborative projects. The variety of implemented activities includes presentations to university students, participation in science events for a lay audience, creation of multimedia releases, producing content for websites or social media accounts of the research projects and teaching material for high school students. It has been estimated (head counts at events, visitors to websites) that more than 25,000 people have been reached, including high school and university students, scientists from various fields, industry and the general public. A striking example is the participation in the Researcher's Night at London's Science Museum.

2.3d PhD employability

From our close contact with recent PhD alumni (179, 92% of PhD awards), we can report an impressive employment record soon after graduation: 33 (17%) have already obtained an academic position; 54 (27.8%) have continued to postdoctoral research, 83 (42.8%) have found jobs in industry and 11 (5.7%) have successfully started their own businesses. Indicative success stories from this reporting period include: Dr Abay: awarded the 2020 STEM Britain Gold medal; Dr Saadatbeheshti: CEO, MPLD Holdings, UK; Dr Idress: CEO, Cynosure Technologies, UK; Dr Adamsky: Full Professor, Hof University of Applied Sciences; Dr Pantelous: Assistant Professor in Econometrics and Business Statistics, Monash University, Australia; Dr Tomic: Senior Lecturer in Cyber Security, University of Greenwich; Dr Martin White, Lecturer with a Royal Academy of Engineering Fellowship; Dr Pagani is Ass. Professor at the University of Torino and an ERC grant holder.

2.4 Visiting scholars

During the REF2021 period, 21 visiting scholars (ten professors) have been hosted at City and closely collaborated with our academic staff for their sabbatical period, while more than 30 collaborators have paid shorter visits, contributing to joint proposals and publications. Notable examples of professors hosted for more than six months include: Professor Mohsen Assadi (University of Stavanger, Norway); Professor Nicos Makris (Southern Methodist University, USA); Professor Chang-Geun Cho (Chosun University, Korea); Professor Guojun Liu (Sichuan Agricultural University, China).

2.5 Support for equality and diversity

Our UoA has identified that Athena SWAN "leads" to progress in School applications and detailed work is underway, while Equality & Diversity have been identified in all Schools and Professional Services. In terms of gender balance, our submission includes a 16% to 84% female to male academic staff ratio, which is an encouraging shift from the 9% to 91% ratio of the previous

REF2014 submission. During this reporting period, one female staff member (Fonseca) has been promoted to Senior Lecturer while two more (Professor Stallebrass and Dr Micic) have been supported to become research active and they are both included in this submission. Female staff have significant leadership roles in the School; Stallebrass: Head of Civil Engineering Department 2012–2018; Micic: Associate Dean for School Education and Student Satisfaction; Tomas: Year 1 Programme Director; Professor Sun (who is a female) has been elected Fellow of RAEng. At the same time, 28% of our PhD graduates were female, which is almost double compared with the 14.7% of the previous reporting period. Moreover, Professors Sun, Grattan and Rahman won the 2016 Royal Society Athena Runner Up Award for diversity. There are special schemes for adoption, surrogacy and maternity leave and there was £250 support to assist with childcare costs when attending research conferences.

3. Income, infrastructure and facilities

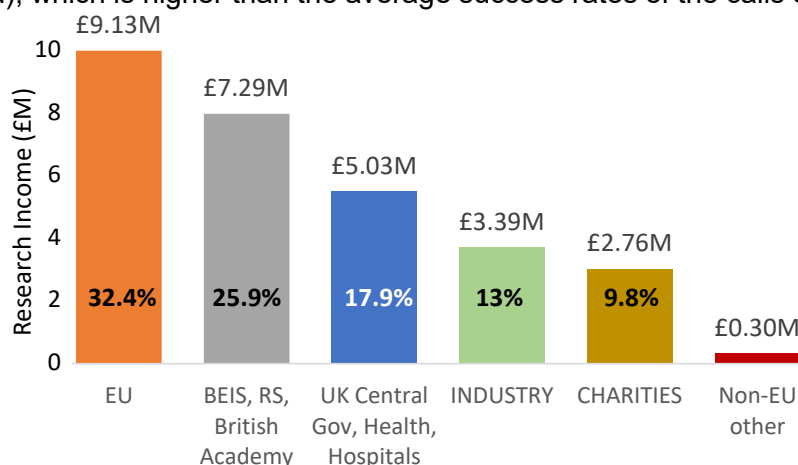
3.1 Research income (RI)

As already mentioned, the REF2021 external income amount is £28.14M; the RI/FTE/year has increased by 178% compared with REF2014. The RI awards and spending show a consistent trend, despite the fact that 45% of our staff have been appointed during the REF2021 period, are predominantly at junior level and are developing the skills to bid successfully for larger grants. The 193 grants include: 38 EPSRC, 33 EU, 48 UKRI/Innovate UK/RAEng, 21 industry and 53 charity and other funders – 90% of them are collaborative proposals with other institutions across the UK, EU and internationally, with the large majority of them coordinated by our staff. Our success rate in the competitive schemes like EPSRC and various EU calls is ~30% (in terms of both RI applied and number of proposals awarded), which is higher than the average success rates of the calls of the corresponding research

councils. Moreover, 77% of the RI has been contributed by staff who were also included in the REF2014 submission and who have developed into international research leaders;

for example, Prof Gavaises has contributed ~0.95M/year, while

the top eight earners (Gavaises, Sayma, Kyriacou, Sun, Muttukrishnan, Kovacevic, Pullen, Grattan, representing 38% of our professorial staff) have contributed an average of £315k/FTE/year.



3.2 Sustainability

Sustainability of our research is guaranteed by the £12.6M of research income that has been already awarded within the REF2021 period but will be spent and reported in the next reporting period. The School currently has 131 registered PhD students and employs 30 Research Fellows who will be carried forward to the next reporting period. Moreover, our sustainability is strengthened by having a balance of funders: ~54% of funds are obtained from UK funders, ~33% from the EU and 13% from industry. These figures suggest that our research for the next reporting period is on track to be at levels/FTE/year that will be higher compared with REF2021.

3.3 Infrastructure and facilities**3.3a University/School investment during REF2021**

In 2013 SMCSE bid for and was awarded newly refurbished space for offices, laboratories and desks that will match with current and planned growth. This space is contiguous and provides staff with high-quality research facilities. All academic staff have individual offices that are large enough for tutorial meetings. All RFs have desks in shared offices to the same high standard. As already mentioned, during REF2021 we have doubled our investment in space and equipment relative to the previous reporting period (see paragraph 1.3). This comes in addition to the free access we have been given, as part of our funded collaborative projects, to some of the world's fastest supercomputers: (1) the ten-petaflops Theta (Cray XC40) supercomputer at Argonne National Laboratories, (2) the BP Skylake facility at Houston super-computer in Houston Technology Centre (the world's most powerful supercomputer for commercial research), and (3) the supercomputing facilities of Sandia National Laboratories; more than 1M central processing unit (CPU) hours have been supported during this reporting period. The School holds competitive internal equipment funding rounds and provides the institutional component for equipment on RCUK applications. Moreover, via collaborations with scientific software vendors, numerous free HPC licenses have been provided (for example, 400 of ANSYS tools for six years, which represent an in-kind contribution of ~£300k). Finally, our equipment has been strengthened by the donation and relocation to our laboratories of ~£1M test rigs from the Physical Measurements Laboratory of Delphi Diesel Systems Research Centre at Gillingham.

3.3b Major laboratory facilities

An indicative list of facilities and equipment available in our laboratories (of substantial cost) that have been utilised for the research included in this reporting period include the following.

Facilities:

- Oil-injected air screw compressor test rigs that meet the CAGI and PNEUROP test standards and ISO 1706 testing procedures, certified by Lloyd's register

- Oil-free test rig for screw compressors suitable for optical/laser diagnostics
- Organic Rankine Cycles expanders including supersonic flow in turbo expander optically accessible nozzle guide vanes
- Micro gas-turbine thermodynamic, mechanical and electrical performance characterisation
- Characterisation of encapsulated phase change materials thermal energy storage systems for low and high temperature applications
- Optical test rigs for real-size and enlarged replicas of fuel injectors worth in excess of £1.2M (including the equipment donated by Delphi Diesel Systems, UK)
- Optical diagnostics test rig for components suitable for hydraulic oil and flow additives, part of large vehicles and battery thermal management systems for EVs
- T5 transonic/supersonic wind tunnel achieving Mach numbers 1.5
- T2 low speed wind tunnel (up to 45 m/s with 1.2m×0.8m×2m test section)
- T7 industrial wind tunnel (maximum speed up to 25 m/s and 3.4m×1.5m×8m test section)
- Gaster low-turbulence tunnel (40m/s maximum speed and 0.91m×0.91m×3m test section)
- CHB open surface water tunnel with 1m/s maximum speed; heavy structures testing facility for static and pseudo-static experiments – 100m² strong floor area, six double-acting 113kN servo-hydraulic actuators with +/- 250mm stroke four large-capacity reactive loading frames
- Unique to the UK, a high-volume (0.5m³) concrete mixer with moisture control for high-performance concrete including fibre-reinforced mixes
- a large concrete curing room with temperature/humidity control; the geotechnical centrifuge facility.

Equipment:

- Five high-speed cameras (up to 250fps), 3D PIV system with tomographic capability: 4xPhantom M310 high-speed camera plus Litron LDY 300 double pulse laser (30 mJ/pulse)
- Low-speed PIV system (17fps) plus Litron Bernoulli high-power low-speed double pulse laser (200mJ/pulse)
- 3D LDA-DANTEC Dynamics Fibre Flow Measurement System
- Digital cameras for photogrammetry-based measurement of displacements
- Four OSAs, two excimer lasers, one CO₂ laser
- Two tunable semiconductor lasers
- Eight optical-sensing interrogators
- Two climate chambers
- One dip coating machine
- UV-Vis spectrometer
- Lambda 35 UV/Vis spectrometer

- Fluoromax-4 spectrofluorometer with TCSPC, polarizer and integrating sphere
- Four USB2000 Mini spectrometers
- Sputter Coater S150B
- Elemental Analyzer-mod 1106
- Three ultrasonic baths
- Glovebox (nitrogen)
- Three centrifugers
- Two pH meters
- Melting point apparatus
- Whirl mixer (vortex)
- Eight hotplates
- Four vacuum pumps.

3.4 Technical staff and librarian support

We employ a dedicated Research Computing Support Officer and have established the post of Laboratory Manager to oversee technical support and health and safety systems. We operate a shared laboratory system: labs are defined by function and are open to all. Specialist infrastructure is run as bookable facilities supported by our nine technical staff (same number as in REF2014).

Research is also supported through library collections and resources in print and online. Researchers have access to 317 specialist databases including Scopus, Web of Science, British Standards Online and ScienceDirect. In addition, Library Services subscribes to thousands of online journals that provide researchers with access to an extensive range of current and archived titles. These collections are maintained by a current annual budget of approximately £220,000 for specialist resources in addition to £2M spent on cross School and Department content in the form of journal and e-book bundles as well as reference materials. Researchers are also able to request books for purchase through the Library Read for Research scheme. The Library is a partner in the research process and has a dedicated Research Librarian for SMCSE, who is a member of the University Library Services Research Service Group, and a Subject Librarian also supports the School. They offer one-to-one support for researchers in addition to running workshops in key areas such as literature searching, citing and referencing and specialist database support. A dedicated research hub and specialist online library guides have been created to support researchers and Library Services deliver a termly newsletter and run a dedicated research blog and Twitter feed.

3.5 Data management

Research data management is overseen by the University's Research and Enterprise Office. It manages the storage, access and preservation of any data produced to underpin research. Research data management supports high-quality research while ensuring the reproducibility and security of data. We have made it easy for our researchers to find out how to organise, plan and reuse their data during their projects. We comply with Open in research, which is data that is freely accessible, used, modified and shared, provided that there is appropriate acknowledgment. Open data safeguards good research practice because nothing is hidden. Thus, it enables high-quality research and facilitates innovation. For example, researchers with fresh perspectives can use data in innovative ways or companies can use data to help them develop new products. This can lead to substantial economic and social benefits and help growth.

4. Collaboration and contribution to the research base, economy and society**4.1 Research collaborations****4.1.a. Support for and exemplars of research collaborations**

During the REF2021 period our staff have been successful in coordinating £10.0M HEB-CI consortia, six EU-funded MSCA Research/Training Networks with a total budget of over €25M, one EU-funded Industry Academia Partnership, one Pathways programme (€2.5M) and one EU-funded Future and Emerging Technologies (FET) (€3M). We have expanded our partnerships significantly compared with REF2014, in numerous joint projects with more than 30 UK institutions, 40 European universities and research centres as well as more than 30 universities and research centres internationally.

4.1.b Support and exemplars of interdisciplinary research

The School has a multidisciplinary ethos that can be demonstrated by the establishment of four interdisciplinary units at University level, aiming to cross traditional discipline boundaries and in which our academic staff play a leading role.

Interdisciplinary Research Centre in Data Science (CityDSI) seeks to foster collaboration in advancing techniques to gather and interpret data. The Centre is committed to conducting world-leading research across the data science spectrum with a focus on tangible outputs and socio-economic impact in health and well-being, transport, finance, business, the creative industries and energy.

Institute of Cyber Security: This recent initiative brings together long-established University groups within Engineering and Computer Science (CompSci), The City Law School (Law) and The

Business School. Engineering contributes in information security, communications, systems engineering and cryptography. The Institute has contributed to securing an EPSRC Doctoral Centre.

The International Institute for Cavitation Research (IICR): The IICR was founded with £1.2M of support from The Lloyds Register Foundation in 2012, in partnership with Loughborough University and TU Delft (The Netherlands). During the REF2021 period the Institute expanded and currently represents a network of 30 partners including universities, research institutions and industries worldwide. Through joint applications coordinated by City (Professor Gavaises), IICR has secured €22M of EU funding in the five MSCA-ITN/EID grants, supporting 75 PhD students across various EU countries. In a strong interdisciplinary approach, IICR explores the following: (1) the physics of bubble dynamics and cavitation erosion of marine propellers, hydraulic turbines and fuel injectors; (2) the physics of atomisation during injection of fuels for diesel, gasoline and dual-fuel IC engines, gas turbine combustors, rocket engines and oil burners; and (3) the physics of flow and thermal processes of high intensity focused ultrasounds and their applications in lithotripsy, histotripsy and drug delivery.

London Space Innovation Centre (LSI Centre): As the UK space sector currently has 6.5% of the global space market and has set itself the target of 10% by 2030 and at least 30,000 new jobs, supporting approximately £350bn of UK GDP, City's LSI Centre, was established in 2020 as a hub for coordinating and promoting multidisciplinary research, education and enterprise projects in space-related fields. The LSI Centre's main focus is on the quality assurance and provenance of data, legal frameworks for regulation and commercial transactions, risk management and ethics. Ultimately, this focus of the LSI Centre will tackle challenges and opportunities in upstream operations, including launch of space vehicles and satellites and their on-board equipment, and downstream applications exploiting data and images obtained from space, playing an important role in the supply chain of the space and related sectors.

4.2 Collaborations with research users and how they inform research

We collaborate with internationally leading industries through sponsored PhD studentships and cosupervision and RFs' participation in collaborative projects. Our industrial partners are active in the global product standards and regulations dialogue, participating with standards-developing organisations such as ISO, SAE and CEN as well as governmental regulating agencies globally to inform standard-setting bodies and regulators. They also collaborate with policy-making organisations influencing the direction of research councils.

Examples include formal exchanges encouraged for senior staff between the School and industry or clinical practice: **Professor Kovacevic's** RAEng Chair, funded by Howden Compressors (UK)

since 2010; **Professor Bruecker** holds the RAEng/BAE Systems Sir Richard Oliver Chair on Aeronautical Engineering at City. **Professor Grattan** holds the George Daniels Professor of Scientific Instrumentation RAEng Chair. **Professor Sun** holds the Faiverly Brecknell Willis RAEng Chair. **Professor Ayoub** holds the RAEng Chair of Nuclear Infrastructure, 2013–2018; **Professor Pullen** has been awarded the RAEng Enterprise Fellowship.

We have developed long-lasting collaborations with leading multinational industries:

Automotive, automotive components and heavy-duty engines: Perkins/Caterpillar Engines (US and UK) and Caterpillar Fuel Systems (US) since 2005, Delphi Technologies (UK and LUX) since 2001, Denso Gmbh (DE), Volkswagen AG (DE), Bosch Gmbh (DE), Renault (FR), Volvo Cars (SE), Delphi Technologies (LU), AVL List (AT), Woodward L'Orange (GE), Delta Motorsport (UK), HiETA Technologies (UK), Nissan Motor Manufacturing Ltd (UK).

Energy: Hitachi-Mitsubishi Power Industries (GE), Andritz Hydro (CH), Abengoa Energia SA (ES), Exergy SPA (IT and CZ), Kelvion Thermal Solutions SAS (FR), Samad Power Ltd (UK), Supcon Solar Technology CO. Ltd (CN), Compower AP (SE), Onnova (IT), GE Baker Hughes (IT).

Marine: BAE Systems (UK), Wartsila (NL), StealthGas (GR).

Fuels: BP International Ltd (UK) since 2008, Shell Global Solutions (UK), Lubrizol Ltd (UK) since 2013, Afton Chemicals (US), OMV (AT).

Aeronautical/aerospace: Rolls Royce (UK and GE), BAE Systems (UK), Airbus (UK), Jigsaw/Google (UK), Vestas (DK), Stellar Tech (UK), Azko-Nobel (NL), QinetiQ (UK).

Compressors: IND Kirloskar Pneumatic Co Ltd (IN), Howden Compressors (UK), Rolls Royce (UK), Chongqing Yuejin Machinery Co Ltd (CN).

Construction and hydrodynamics: Target Fixings (UK), AKT-II (UK), Westok (UK), Highways England (UK), Department of Transportation (UK), Keltbray (UK), Lloyds Register (UK), GL-DNV (UK), Saipem (UK), Bureau Veritas (FR), ABS (US), Balfour Beatty (UK), Skanska Cementation (UK), Costain (UK), Wentworth House Partnership (UK).

Sensors: Sydney Water (AU), CRRC/Dynex Ltd (CN), Teignbridge Propellers (UK), Faiverly Brecknell Willis (UK), Sengenita Ltd (UK).

Biotechnology: Catapult (UK), Precision Acoustics (UK), Dornier MedTech Systems Gmbh (GE), AVOptics (UK), Schurter Electronics (CH), Medtronic (US), Samsung (KR).

4.3 Consultancies and professional services

Approximately 20% of School staff have been involved in consultancy for industry during the REF2021 period. Consultancy projects are managed by the University's Research and Enterprise office. Examples include Airbus, Continental, Jaeklin GmbH and Leonardo, among many other corporations. A striking example is Heliex Power, a spin-off from City's Centre for Compressor Technology (established in the previous reporting period), which was originally funded by British Gas, Scottish Entrepreneurs and City. A new system for the recovery of power from engine

exhaust gases and other waste heat sources, using the expansion of wet steam, is the result of years of work at the Centre. The company has been further supported by BP Ventures with £12M investment and has already installed over 30 systems worldwide, including the district heating project near Milan in Italy and at a chemical plant in north of England. The company has been recognised as “One to Watch” in the GP Connect Award and was a finalist in the VIBES Awards in Scotland.

4.4 Leadership

4.4.a Exemplars of individual leadership in the academic community

Our staff have given more than 46 plenary/invited talks in leading or well-established conferences worldwide during the REF2021 period. Moreover, examples of prestigious positions include:

Three FREng (Grattan, Sun, Carlton).

Two presidents. Kyriakou: the European Alliance for Medical and Biological Engineering and Science; **Grattan:** International Measurement Confederation (IMEKO) (2015–2018).

Five past presidents of professional institutions (acting within REF2021 but left before the consensus date and are not included in this submission): Grattan, Thomas (Inst. MC), Carlton (Inst. of Marine Engineering), Crouch (UK Association for Computational Mechanics), Atkin (Royal Aeronautical Society).

Eleven editors/co-editors of international journals: **Grattan/Sun:** *Measurement*; **Kovacevic:** Co-Editor in Chief, *Proceedings of IMechE, Part E: Journal of Process Mechanical Engineering*; **Kyriacou:** Editor, *Journal of Biomedical Signals Processing and Control*, Deputy Editor, *Biomedical Physics and Engineering Express*, Associate Editor, *Sensor Review* (Emerald Publishing), Associate Editor, *International Journal of Biomedical and Clinical Engineering*; **Mergos:** Associate Editor, *Frontiers in Built Environment – Earthquake Engineering*; **Qiang:** Associate Editor, *ASME Journal of Thermal Science and Engineering Applications*; **Fonseca:** Associate Editor, *Canadian Geotechnical Journal*; **Fu:** Associate Editor, *ASCE Journal of Performance of Constructed Facilities*; **Ma:** Editor-in-Chief, *Ocean System Engineering*, Associate Editor, *Journal of Ocean Engineering and Marine Energy*; **Halikias:** Associate Editor, *IMA Journal of Mathematical Control and Information*; **Gavaises:** Associate Editor (2015–2019), *International Journal Engine Research*.

Twenty-two members of editorial boards of at least one international journal.

Thirty-six Fellowships: IEEE: two; IMechE: six; IOP: five; IMA: four; IET: six; Institute of Measurement and Control: four; Institute of Civil Engineers: two; Optical Society of America: one; Royal Society of Medicine: one; Anaesthetic Research Society: one; Board of Directors of The International Society of Offshore and Polar Engineers: one; Institute of Structural Engineers: one; American Society of Civil Engineers: two.

Memberships: EPSRC Peer Review College (12); EU research review panels (5).

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).

Major awards/prizes: **Sun:** Royal Academy of Engineering Silver Medal (2016) for engineering achievement; Officer of the Order of the British Empire (OBE) for services to engineering; THE Research Supervisor of the Year 2019. **Grattan:** Officer of the Order of the British Empire (OBE) for services to science; Wolfson Research Merit Award from the Royal Society. **Kovacevic:** IMechE James Clayton Prize for contribution to Fluid Machinery. **Ma:** CH Kim Award from International Society of Offshore and Polar Engineers. **Professors Rahman, Sun and Grattan:** Royal Society Athena Runner Up Award (2016) for promotion of excellence and diversity. **Dr White** received the IMechE's 2019 Geoffrey Soar Award.

4.4.b Research highlights

Highlights of significant contributions from our leading research activities during this reporting period include the following.

TF (Compressors Centre): The use of computational fluid dynamics in positive displacement machines by novel methods for grid generation of numerical meshes for deforming complex domains has resulted in the software suite SCORG, which is now widely used for improvement of existing and development of new efficient compressors and expanders. It is used globally by many major manufacturers of these machines, by research centres and in education. Its use has contributed to the reduction of carbon footprint in such machines.

AERO: With work supported by BAE Systems and the RAEng Chair of Professor Bruecker, we have demonstrated the physical mechanism by which peregrine falcons perform highly complex flight manoeuvres at full speed during swoops from high altitudes to attack their prey. The research has been published in several high impact journals including *Nature Communication Biology*. The findings can inspire future aeronautical technologies in the framework of the ongoing collaboration with BAE Systems.

ISI (biomedical): We have pioneered the design and fabrication of the first prototype point of care device for sensing lithium in blood. This transformative technology is to be used by mental health patients and, more specifically, by bipolar disorder patients. The research was funded by the National Institute of Health Research (NIHR) and has attracted wide national and international interest as engineering solutions in mental health are still in their infancy.

ISI (fibre optic sensors): Work with the rail industries has enabled the development, laboratory evaluation and in-situ testing of optical fibre sensors instrumented in a “smart” pantograph system coupled to user-friendly software. It provides key data to train users and maintenance personnel on contact force between the overhead wire and the pantograph, the position of the pantograph in relation to the overhead wire(s) and vibration issues with the pantograph, all in real time, in use of test trains and coupled to GPS data. City holds key patents on the inventions and established a new spin-off company, Sentech Analytics.

ISI (cybersecurity): A patented searchable homomorphic encryption technique has been developed that allows any enterprise to search through a large number of encrypted databases without decrypting the content and while protecting sensitive personal data in the Cloud. The product is commercialised through Intelligent Voice. The encrypted search functionality is also incorporated into security analytics tools and is currently being used by many European police and intelligence services. The research has contributed directly to build the cybersecurity capability of BT, Intelligent Voice, IBM, Metropolitan Police, SO15 and the Cabinet Office.

SAC: Research work related to autonomous space and air vehicles jointly with the European Space Agency (ESA) and the Defence Science and Technology Laboratory (DSTL, UK) has resulted in innovative solutions related to distributed cooperative robots suitable for in-situ space construction, GPS-denied, vision-based navigation for drones and AI Deep-Learning-based relative navigation protocols for satellites. These developments are now reaching a higher Technology Readiness Level (TRL) and have been deployed and used in real autonomous vehicle operations.

RSCE: We have patented and commercialised City’s hollow pile through an Innovate-UK-funded project. This new type of foundation will transform the way in which piles are constructed, changing them from mere building foundations into assets that will provide heating and cooling and, importantly, design for future reuse. The new piles are smaller and use much less raw material than current foundations.

4.4.c 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. 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 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. Moreover, we have organised major well-known conferences as well as establishing and running new ones:

- 12th, 13th, 14th Jack-Up Platform Design, Construction & Operation conferences
- 2015, 2017, 2019 Compressor Centre conferences
- 4th (2016), 5th (2017), 6th (2019) and 7th (2020) Workshops of IICR
- 5th International Symposium of Innovations & Applications of Monitoring Oxygenation & Ventilation (IAMPOV 2020)
- 2019 UK ACM Conference on Computational Mechanics
- 1st, 2nd and 3rd International Conference on Nuclear Power Plants: Structures, Risk, and Decommissioning (2017, 2018, 2019)
- 2017 UK Fluids Network Workshop – High Speed Experimental Aerodynamics Special Interest Group
- IMEKO World Congress in 2018 in Belfast
- Workshop on Photonics in 2019
- 9th International Conference on Physical Modelling in Geotechnics, 15th GM3 Geomechanics
- Professor Sayma is the Chairman of the advisory board of the European Micro Gas Turbine Forum and a member of the Technology Board of the European Turbine Network since 2012
- Professor Gavaises has participated in the organisation committee of the International Liquid Atomisation and Spray Systems Conference (ILASS-Europe) since 2011, the IMechE Conference on Fuel Injection Systems for Passenger Cars, the Cavitation Symposium, the SIA Conference for Diesel Powertrains, the tri-annular Conference on Internal Combustion Engines for Vehicles.

4.4.d Media engagement

Our research is communicated to the wider public via our media engagement team. Since 2015 there have been: 740 media mentions, 96 mentions in Tier 1 national media and 26 instances of

broadcast coverage. A striking example is the broadcast of Professor Bruecker's research on the aerodynamics of the peregrine falcon's flight which was the focus of the BBC2 Natural World episode *Super Fast Falcon*, first aired on 26th April 2018. Finally, in January 2020, the School launched its Twitter page, @CityUniSTEM.