Institution: University of Manchester

Unit of Assessment: UoA 14 Civil and Construction Engineering

a. Overview

The 21.85 FTE returned to the UOA are drawn from the School of Mechanical, Aerospace and Civil Engineering, one of nine in the Faculty of Engineering and Physical Sciences. Research in the unit is organised around themes that address multidisciplinary challenges of industrial and societal importance: *Offshore Energy & Coastal Engineering, Climate Change, Structural & Fire Engineering.* These themes are underpinned by a cross-cutting theme in *Modelling & Simulation,* and discipline-based research groups in *Fluids*; *Structures, Building & Geotechnics;* and *Project Management & Climate Change*. Reflecting the multidisciplinary nature of these challenges, members of the Unit are also active members of Institutes and Centres that bring together strengths from across the University, particularly: Tyndall Centre Manchester (TM – Anderson, Director), Sustainable Consumption Institute (SCI), Manchester Institute of Biotechnology (MIB), Manchester Energy (ME), and Dalton Nuclear Institute (DNI). Significant achievements in the REF period include:

- Developing computational models of tidal stream generator systems, supporting £65m industry investment;
- Providing the scientific evidence that underpins UK Government policy to reduce carbon emissions by 80% by 2050;
- Providing new methods in fire engineering design, which were applied in The Shard, The Pinnacle, and other iconic buildings;
- Elected fellowships and prizes: Bailey (FREng); Bailey and Wang (Institution of Structural Engineers, Henry Adams Award, 2008 and 2011); Stansby (Lloyds Science of Risk Prize); Apsley and Stansby (ASCE Karl Emil Hilgard Hydraulic Prize); Cunningham (Institution of Civil Engineers' Brunel Medal);
- £8.9m research income, 60 keynote addresses, 379 papers in international journals, 58% of recent outputs amongst the 10% most cited in the field.

b. Research strategy

Vision

Our focus is on major challenges of industrial and societal importance to improve and sustain the quality of life and infrastructure. To address these, we maintain strengths across a broad range of engineering disciplines; engage with users of research to frame our research agenda, and establish multidisciplinary collaborations to draw on relevant expertise from across the academic spectrum. Our approach combines large-scale computational modelling and simulation with state-of-the-art experimentation and analysis of engineering systems.

Strategic Planning

The UoA research strategy is developed by a Research Committee led by a Director of Research, supported by a Head of External Affairs. Each Theme has an academic lead, who is responsible for developing a strategy for their theme, and is a member of the Research Committee. Similarly, each Discipline Group has an academic lead, who is responsible for staff development and is also a member of the Research Committee. The Committee consults widely with researchers in the unit via a range of mechanisms, including annual away-days. It also seeks input from industry partners on a regular basis.

The context for the UoA research strategy is set by a University Strategic Plan that includes: valuing research excellence for its own sake, investing strategically in research excellence, broadening the range of funding sources, giving parity of esteem to translational research, and providing world-leading postgraduate research training. UoA and Faculty strategies are public documents that are refreshed in an annual planning and accountability cycle that includes a formal performance review for each unit, against agreed key performance indicators (KPIs). Current KPIs include research income, industrial research income, PGRs and PDRAs per member of staff, and proportion of outputs in the top 10% of outputs in the field.

UoA Themes also contribute to broader University strategic priorities through involvement in multidisciplinary Institutes/Centres as follows: *Offshore Energy & Coastal Engineering (*ME, TM)*, Climate Change* (TM, SCI, MIB). The *Climate Change* and *Structural & Fire Engineering* themes were well-established at RAE08 and remain core activities. Within *Offshore Energy & Coastal Engineering*, Marine Energy has grown significantly over the period to a major activity, as a result of strategic investment and engagement with industry. Within *Climate Change*, Bioenergy is an emerging activity we intend to grow over the next assessment period. Research across all Themes ranges from applied industry-facing to blue skies; both are encouraged.

A key objective is to carry out research of the highest quality and disseminate it effectively through leading outlets. We have published 379 papers in international journals over the assessment period. As a broad indicator of progress since RAE08, the proportion of University of Manchester (UoM) papers amongst the 10% most cited in the field of civil and structural engineering rose from 31% in 2008 to 58% in 2011 (most recent year with reliable citation data). Papers by Anderson (2008), Thornley (2008) and Wilson (2009, 2012) have all been heavily downloaded.

Research Theme Strategies and Progress

Offshore Energy & Coastal Engineering is led by Stansby with 7 other staff. Our strategy outlined in RAE08 was to build capacity in the *Offshore Energy* component, which we have achieved through investment in staff and by more than doubling annual research income over the period, to give a total of £1.4m. The research strategy for this emerging activity was developed in close collaboration with the Energy Technologies Institute (ETI), ensuring industrial relevance. The research has two synergistic components: computer simulation of full-scale tidal stream turbines, with advanced turbulence modelling, and experimental studies of arrays of tidal stream turbines to support large scale deployment. The simulations have demonstrated the capability for realistic predictions of the performance at industrial scale as part of an ETI project leading to an investment of £65m in scaling up the technology. We also lead two major EPSRC Supergen Marine Grand Challenge consortia: X-MED, exploring extreme loading on marine energy generation devices; and Step-WEC exploring multi-body swell generator systems. In *Coastal Engineering*, the UoA led the coastal component of the EPSRC Flood Risk Management Research Consortium, underpinned by expertise in computational modelling for tidal flows and wave propagation, and is now involved in NERC programmes in long-term morphodynamics and tsunami impact. International impact is exemplified by the invited vision paper 'Coastal hydrodynamics – present and future' published in the Journal of Hydraulic Research.

Structural & Fire Engineering is led by Wang and 7 other staff. The main focus during the assessment period has been on methods for cost-effectively ensuring the structural integrity of buildings in fires. Our research takes a holistic approach, spanning the range from fire protection materials to structural design. There are very close links with the user community including Tata Steel, major architects, and through British Standards and Eurocode committees. Key contributions over the assessment period have been deepening understanding of the collapse of the World Trade Centre, and the Bailey-Method – a comprehensive suite of design guides, software tools (FIRESOFT) and web-based information that have underpinned a step-change in engineering practice. The design guide outlining the Bailey-Method (2500 copies) and associated software has been distributed in 17 languages, and the methodology has been adopted widely, with typical savings of 40% in fire protection costs. The Theme also includes Rehydroxylation (RHX) research led by Wilson. The original interest was in predicting the expansion of structural masonry, but recognition that the measurement and modelling methodology could be applied to the dating of archaeological ceramics has led to new interdisciplinary research in collaboration with English Heritage and other universities.

Climate Change research is led by Anderson and 5 other staff within Tyndall Manchester. Our research is at the forefront of analysis on emissions targets and carbon budgets. It brings together expertise on bioenergy and biomass, sustainable nuclear energy, renewable energy socio-economics, low carbon transport, agriculture, carbon capture and storage, and energy demand and networks, and involves working closely with industry and policy-makers. A notable achievement in the REF period was to demonstrate through a comprehensive modelling approach that the 60% reduction in CO_2 emissions, originally proposed of the UK Climate Change Bill was inconsistent with the Government's commitment to a temperature rise of no more than 2°C above pre-industrial levels. The research showed that an 80% reduction was necessary, that to be scientifically robust

policies needed to be based on cumulative carbon budgets and, contrary to previous assumptions, that it was essential to include emissions from aviation and shipping. These insights are now enshrined in UK primary legislation. A notable area of planned growth during assessment period has been in bioenergy and biomass, led by Thornley, where income has nearly doubled over the assessment period, and we now lead the Supergen Bioenergy Hub, which brings together industry (notably Drax Power, E.ON, and Renewable Energy Systems), academia and other stakeholders to focus on the research and knowledge challenges associated with increasing the contribution of UK bioenergy to meeting environmental targets.

Modelling and Simulation is led by Stansby with 4 other staff in this UoA. It is a cross-cutting Theme, shared with UoA 12b, that involves researchers from other Themes, and underpins research across both UoAs. Smoothed particle hydrodynamics (SPH) is a major area of development, and has underpinned major advances in this UoA in modelling marine systems, including dynamics of floating structures in waves, marine animal impact on tidal flow turbines, and water-air wave slam modelling. The latter is particularly exciting, because the models predict, with unprecedented accuracy, the very high impact pressures observed experimentally. Public domain versions of the software, including GPU-optimised versions, are part of the SPHysics suite, and have been downloaded 12,000 times since 2010. We have also successfully extended EDF's Code_SATURNE for tidal stream turbines in full scale conditions, with a novel sliding mesh scheme and massively parallel computing for applications mentioned above.

Future Plans

Our strategy is to consolidate current Themes, expanding research in *Bioenergy*, and *Offshore Energy* – extended to include offshore wind as well as marine energy. Building on recent appointments (see below), *Structural and Fire Engineering* will also expand to include materials for extreme environments, including nuclear power plants (synergistic with UoM strengths in other UoAs), and offshore structures. This will be linked with the new $100m BP International Centre for Advanced Materials (Hub at UoM), the NW Composites Centre and the EDF Modelling and Simulation Centre. Research in geotechnical and water engineering will be re-invigorated with new appointments including a Chair and Lecturership in water resources appointed post the REF census date who will contribute to the University-wide multi-disciplinary Water@Manchester network. Across the board, we will continue to build capacity in *Modelling and Simulation* since we see large-scale computational research with supporting experimental validation as a key strategy, underpinning all our research. Complex fluid-structure interaction problems will be tackled, particularly exploiting SPH with the novel efficient and inexpensive parallel computing provided by GPUs (graphics processing units).

c. People, including:

(i) Staffing strategy and staff development

Staffing Strategy. Our staffing strategy over the period has been to recruit and deploy staff across the core disciplines in the UoA to underpin our cross-cutting thematic approach and, given the multidisciplinary nature of our Themes, open up interfaces between them and to disciplines outside the UoA. Specific objectives have been to develop capacity in the marine energy component of *Offshore Energy & Coastal Engineering*, reinvigorate *Structural & Fire Engineering* – enhancing the interface to the other Themes, and to continue the growth in *Climate Change*. A more general aim has been to increase our capacity in the cross-cutting theme of *Modelling & Simulation*, by targeted appointments in the other Themes. Details are as follows.

Offshore Energy & Coastal Engineering: Senior Lecturer (Rogers*) and Lecturer (Afgan*) in computational fluid dynamics. *Structural & Fire Engineering:* Senior Lecturer in computational mechanics (Yang*); Lecturer in coastal structures (Cunningham); Lecturer in structural analysis and composites (Katnam), Senior Lecturer (Abuel-Naga) and Lecturers (Lam, Syed) in geotechnical engineering. *Climate Change:* Lecturer in renewable energy socio-economics (McLachan); Research Fellows in the socio-economics of climate change mitigation (Mander, Wood). *Modelling and Simulation:* No dedicated appointments reported in this UoA, but appointments marked * contribute to this cross-cutting Theme.

Career Development. Staff at all levels are encouraged to develop their skills. For research staff, the EPS Faculty Researcher Development Programme provides over 70 training workshops and events each year in 5 categories: Research & Enterprise, Communication, Career Management,

Leadership and Management, and Teaching and Learning. For example, the 2011/12 programme included Project Management courses (leading to a Certificate in Applied Project Management), and the 2012/13 programme introduced a course on Supervising for Researchers. Since the programme was introduced in 2011/12, research staff have participated in training events 34 times. The website *An Academic Career*, developed by the UoM Careers Service, is a comprehensive guide to working in higher education and was the winner of the Times Higher Education 2011 Award for Outstanding Support for Early Career Researchers.

All new academic staff undertake the New Academics Programme, which involves around 50 contact hours over an 18 month period, and a collection of associated mentoring and development activities. The research elements include grantsmanship, managing a research portfolio, publication strategy, and postgraduate recruitment and supervision. Also, recognising the importance of knowledge transfer and non-academic impact, the programme covers intellectual property rights, collaborating with industry, regional development and public engagement. New members of staff are introduced to key people, policies and resources through a school induction pack, and new academics have a personal mentor within the school, as well as a mentor associated with the New Academics Programme. New staff are also provided with travel funds. A senior member of staff takes responsibility for mentoring staff in relation to promotion. For more senior staff, the University offers the Headstart leadership development programme (Leadership Foundation for Higher Education), preparing research leaders for more senior academic roles.

To review career development and plans, the university implements a Performance Development and Review (PDR) scheme, which includes a written preparation document, a one-to-one discussion, and an agreed written conclusion. All staff, whatever their level of experience, are expected to have an annual PDR.

Concordat to Support the Career Development of Researchers. The university has developed a Concordat Implementation Plan that has received an HR Excellence in Research Award from the European Commission. The University participated in the Careers Research Online Survey 2011 to find out the views of research staff and has incorporated the results into the Concordat Implementation Plan, especially through improving research staff representation on University committees and expanding training opportunities (see above). The UoA also has an active programme supporting promising researchers to apply for personal fellowships, providing bridging funding, and tenure-track appointments for successful candidates.

Research Fellowships. During the assessment period, Rogers (now Senior Lecturer, UoM) held an RCUK Academic Fellowship.

International Staff Appointments, Visitors and Sabbaticals. The school is an international community. For example, 40% of our academic staff, 33% of our research staff and 61% of our research students originate from outside the UK. Reflecting the strong international profile of the school, 6 of the 11 academic appointments made during the REF period were from outside the UK.

To foster new collaborations and share best practice, the UoA has an extremely active visitor programme. During the REF period, 29 people from overseas held visiting positions in the UoA. These included visitors from 8 international universities and from a wide range of commercial organisations.

The UoA also runs a sabbatical scheme; during the REF period, 15 staff have been on sabbatical for periods ranging from a semester to a year, visiting international universities and research institutes, and industry.

Equality and Diversity. The University is committed to the advancement of equality in employment and career development for its staff, and equality data monitoring and action planning is embedded into annual performance reviews. All staff are encouraged to undertake equality and diversity training, and 29 did so in the assessment period. All those involved in recruitment and promotion panels are required to undertake more specialised training – 19 in the period.

WiSET (Women in Science, Engineering and Technology), formed in 2005, is a network for all female students and staff in the EPS Faculty. It is funded by the Faculty and aims to encourage more women to enter and develop careers in science, engineering and technology. There has been an improvement in the gender balance of the UoA with 4 women submitted in this exercise compared to 1 in the equivalent grouping in RAE08.

To ensure that all groups are well equipped to engage with the promotions process, Academic

Promotions Masterclasses are held annually. These sessions provide an overview of the academic promotion route at the University, the role of the School and the Faculty Promotion Committees, CV hints and tips (with the offer of 1:1 guidance), and academic promotions case studies.

(ii) Research students

The unit sees the development of the next generation of researchers as central to its mission. Over the period our PhD graduations per annum have more than doubled, with 106 awards in total. Of these, 7 received the extended training experience delivered by the Manchester Doctoral College in Engineering for Manufacture EngD programme, also enhancing our engagement with industry. Funding for research students is from a variety of sources, reflecting the fundamental-to-applied research portfolio of the UoA, with students receiving funding from: EPSRC DTG (5%), CASE (3%), EngD (7%), industry (1%), EPSRC project (15%), UoM (13%), overseas (56%).

Recruitment. The unit has a Student Recruitment and Admissions Office that manages publicity and student recruitment. The unit seeks to attract the highest quality candidates by advertising projects widely on www.findaphd.com and on its own web site, as well as actively promoting research opportunities at graduate careers events. The University International Office also attends many overseas recruitment events, and uses local agents to promote and triage applications. UoM-funded President's Scholarships and Dean's Scholarships, advertised internationally, are designed to attract elite students with an enhanced training package and stipend; the UoA has benefitted from these schemes through a resulting improvement in the quality of applicants. The UoA receives applications from all over the world (normally ~70% overseas). Applications are made online, to ensure efficient processing, and all applicants meeting a strict entry threshold are interviewed, sometimes using Skype or telephone if overseas.

Training and Support. Every research student has a supervisory team consisting of a main supervisor, a co-supervisor and an advisor; the two supervisors are responsible for technical guidance and progress, whereas the advisor is principally responsible for mentoring and pastoral support. Specialist courses are drawn from the School of Mechanical and Aerospace and Civil Engineering' s extensive portfolio of MSc courses.

Skills training is provided by the Researcher Development Programme (shared with research staff), offering a broadly based foundation in reusable skills (more than 70 workshops per annum – see above), including topics specifically aimed at research students such as: managing PhD progression, working with your supervisor, thesis writing, viva preparation, library and IT use, and PhD careers. Research students have participated in training events 622 times over the assessment period.

Postgraduate Research Poster Display days are a highlight of the year. These are attended by industrial sponsors and provide both an opportunity for students to place their work in a broader context, and preparation for conference participation. Prizes are awarded to the best posters. Students are expected to present at one international conference at least during the course of their degree, and are funded to do so. For the most promising students, UoM offers EPSRC-funded Doctoral Prize (was PhD+) awards, that support successful applicants for 6 months to 1 year in the transition to independent researcher, with two such awards in the UoA over the assessment period.

Progress Monitoring. The online progression monitoring system, eProg, provides all research students with direction on the critical milestones for their degree. eProg captures engagement with training, and includes quarterly progress reports with elements completed by students and supervisors. Prior to progression to a new year of study, each student provides a written report that describes their progress and plans, and both gives a presentation and is interviewed by a panel. Where progress towards a PhD is not considered appropriate, there are exit points to research masters degrees.

d. Income, infrastructure and facilities

Research Income

Research income for the UoA totalled £8.9m, with annual income roughly constant (± 15%) over the assessment period. The three main sources of funding are research councils (53% – EPSRC, NERC), industry (32% – including EDF, ETI, Tesco), and central government (8%), with the balance between sources remaining roughly constant throughout the period. Income was also roughly balanced between the three primary themes, with *Offshore Energy & Coastal Engineering*

£2.0m, *Structural & Fire Engineering* £2.7m, and *Climate Change* £2.1m. This overall profile hides important trends. As a result of our investments in capacity-building, marine energy income (within *Offshore Energy & Coastal Engineering*) more than doubled between 2008-09 and 2012-13, totalling £1.4m, and Bioenergy (within *Climate Change*) nearly doubled, totalling £430k. Most of the appointments in *Structural & Fire Engineering* were too late in the period to affect income significantly, but we expect the investment to pay off in the next period. Over 70 consultancies with a total value of £374k were also undertaken during the period, often pump-priming research collaborations. These funding outcomes demonstrate significant progress in reshaping our funding portfolio to align with our strategic objectives.

Our future funding strategy will be to continue growing funding for marine energy and bioenergy, whilst exploiting our investment in *Structural & Fire Engineering.* We expect, as a result of all our investments, to increase the overall level of funding, and will specifically target growth in EU funding, supported by a strengthened specialist support team.

Infrastructure

The University's estate is the largest single campus of any Higher Education institution in the UK providing 850,000 m^2 with a replacement value in excess of £2b. Since 2004 the University has completed a £750m capital investment which has transformed a major part of the estate providing state-of-the-art buildings, contemporary refurbishments and public realm works fit for a 21st century research HEI. The University has recently begun work on a new Estates Masterplan, including an investment of £250m (funding secured) to collocate all engineering and science on a single campus by 2018.

Currently the UOA is housed primarily in the Pariser building, with some facilities in the nearby George Begg building. Members of staff, including research fellows, have individual offices, clustered according to research activity; research students are in open-plan 'villages'. Research associates are either in a village or a room close to their laboratory. There are rooms for video conferencing, seminars and meetings. Both buildings have a small café ideal for informal meetings and networking.

Facilities

These buildings house excellent laboratory facilities, supported by a large workshop with standard machining and a CNC machine. There are state-of-the-art laboratories for hydrodynamics and hydraulics, heavy structures, fire engineering, concrete testing, geotechnics and building science. There has also been an investment in improving colocation of Tyndall Manchester, further facilitating interdisciplinary research.

The hydrodynamics laboratory houses a computer controlled wave generator (a £20k UoA investment) for a wide wave/current flume with excellent instrumentation and computer-controlled traverse gear, funded by industry through ETI projects. Researchers also have access to a recently refurbished wind tunnel. The structures laboratory has three state-of-the-art furnaces, a cone calorimeter for materials testing and human-structural dynamics testing facility. The construction science/RHX laboratory has highly accurate micro-balances for estimating water content in ceramics. The UoA has investek in Thermal Gravimetric Analysis for research on RHX dating and fire-resistant materials. Equipment sharing is facilitated via the N8 shared database.

For computational modelling, parallel processing is an essential resource and the School has invested £475k in 950 cores on the University's Computational Shared Facility; it also has access to the 5200 core N8 HPC facility, and makes extensive use of the national facility HECTOR for parallel processing with 1000s of cores. On EDF projects use is often made of their Blue-Gene parallel processing facility also with 1000s of cores.

As a designated National Research Library, the UoM Library offers a range of tailored products and services, providing access to an unparalleled range of electronic resources including over 40,000 e-journals and a complete range of research databases. Through Manchester e-scholar, it offers researchers a premium resource to both deposit and disseminate research outputs; it also provides researchers with a comprehensive research data management service, launched in 2013. The Library also delivers a range of bespoke training services to researchers, supporting all aspects of the research life-cycle.

e. Collaboration or contribution to the discipline or research base

Collaboration

The multidisciplinary nature of the challenges represented by UoA's research Themes mean that collaboration is fundamental to our research. Collaborations cover the complete spectrum: large-scale collaborations with other UK HEIs, international collaborations with centres of excellence, interdisciplinary collaborations to tackle broad industrial and societal challenges, and collaborations with users of research to frame our research agenda and drive impact. As an indication of the success of our approach, 16% of the outputs in this return involve an author from industry, 22% from another discipline (in UoM), 24% from another UK university or research organisation, and 26% from outside the UK.

Supporting research collaboration. The UoA has a wide range of mechanisms to support and encourage collaborative research. These include a visitor programme (29 visits of more than 3 months during the REF period), and a sabbatical programme (15 sabbaticals during REF period). The University provides a dedicated service to support researchers in applying for EC funding and, as a member of the N8 partnership of research intensive universities, proactively explores opportunities for collaboration (eg N8 HPC, supporting high-end computational modelling and simulation). The UoA has also developed long-term strategic relationships with users of research (eg EDF, ETI, Tesco), establishing partner-of-choice status.

Supporting interdisciplinary research. All the mechanisms described above for supporting research collaboration in general, apply to interdisciplinary research. In addition, the University provides direct support via its multi-disciplinary Research Institutes, which provide a cross-institutional focus for challenge-led research. As outlined previously, Tyndall Centre Manchester, the Sustainable Consumption Institute, the Dalton Nuclear Institute, and Manchester Institute of Biotechnology (MIB) are all of direct relevance to this UoA. There is also an overarching University of Manchester Research Institute, that provides seed-corn funding (around £1m pa) to support new interdisciplinary collaborations. Financial and administrative arrangements are also designed to remove barriers to cross-institutional collaboration, with a unified Research Support Service across the institution. The UoA's participation in multidisciplinary Doctoral Training and EngD Centres, provides another route for seeding collaboration, with joint supervision (across disciplines, or with industry) compulsory.

Examples of Collaborative and Interdisciplinary Research

National collaboration. A prime example of a major national collaboration is the UoA's leadership of the EPSRC-funded Supergen Bioenergy Hub, a partnership which brings together 9 universities (including Newcastle, Bath, Imperial), and industry (including Drax, North Energy, Dalkia) to address the challenges associated with increasing the contribution of UK bioenergy to meet strategic environmental targets. Another example is provided by a large EPSRC-funded project on quasi-brittle fracture, with Oxford Bristol and Delft, HSE, and 5 major companies (including EDF, Arup, SERCO).

International collaboration. International collaborations have been pursued via the FP7 programme. For example, COMPFIRE is a partnership with Sheffield, three European universities, Tata Steel Tubes, and Desmo Ltd exploring the design of composite joints for improved fire robustness. WEC Wakes is a project on wave energy conversion, with Ghent, Ecole Centrale de Nantes, Queen's Belfast and Edinburgh.

Interdisciplinary collaboration. The UoA's research Themes, are fundamentally multidisciplinary, and are pursued in collaboration with colleagues in other disciplines. Most prominently, our work on *Climate Change* involves working with the full range of engineering disciplines, computer modellers, social scientists, behavioural scientists and economists. As an example of a specific project, the RESNET resilient electricity networks project with academic and industrial partners involves modelling weather patterns, understanding weather and climate impact on electricity supply-demand, and exploring societal implications and barriers to adaptation.

Collaboration with users. Much of the UoA's research involves collaboration with users of research; several examples have already been given under other headings. The partnership with ETI, and industry members BP, Caterpillar, EDF, E.ON, Shell and Rolls-Royce, in *Marine Energy* is also important. In *Climate Change*, we have also collaborated with government agencies and NGOs, to influence public policy, providing the scientific evidence that led to the inclusion of

aviation in the 2008 Climate Change Act, and subsequent recognition by government that shipping should also been included.

Impact of collaborations on research activities and strategy. Our research strategy is fundamentally aligned with industrial and societal priorities, with Themes that address the challenges of specific industry sectors. Over the REF period we have developed our capability to support these Themes, in consultation with, and often funded by, our partners. Much of our research involves collaboration with users of research, and that interaction helps to shape our research strategy and tactical decision-making. Through long-term strategic relationships with companies, we have more formal mechanisms for developing a shared research agenda, though joint governance Boards. We also invite industry partners to participate more broadly in the life of the UoA, interacting with research students at postgraduate poster display events, and advising the Research Committee on overall research strategy for the UoA.

Contribution to the discipline and research base

At the highest level, contribution to the research base has been recognised by an election as Fellow of the Royal Academy of Engineering in 2012 (Bailey).

Recognition for notable contributions to the research base has been through major awards/prizes: Institution of Structural Engineers Henry Adams Award 2008 (Bailey) and 2011 (Wang and Bailey); ASCE Karl Emil Hilgard Hydraulic Prize 2010 (Apsley and Stansby); Lloyds Science of Risk Prize 2012 (Stansby); The Institution of Civil Engineers' Brunel Medal for the Blackpool Central Area Coast Protection Scheme, Halcrow Prize 2013 for same scheme (Cunningham).

Because of their reputation in research UOA members have played major external leadership roles. Anderson was Director of the Tyndall Centre nationally during 2009-2011 and has otherwise been Deputy Director with the Director based in the University of East Anglia. He engages widely across all tiers of government; advising the Prime Minister's office on Carbon Trading having contributed to the development of the UK's Climate Change Act. Thornley, also in Tyndall Manchester, leads the Supergen Bioenergy Hub, a £4m EPSRC programme with 10 industrial and 6 University partners. Stansby led the coastal flooding component of the Flood Risk Management Research Consortium, a £9m programme with funding mainly from EPSRC and the Environment Agency (2008-2012). He also leads two Supergen Marine Challenge Projects which are part of the UK Centre for Marine Energy Research. Rogers leads the Steering Committee and is webmaster of Smoothed Particle Hydrodynamics European Research Interest Community (SPHERIC); he leads the SPHysics consortium of the University of Manchester, Universidada de Vigo (Spain), Università degli di Studi di Parma (Italy) providing highly successful open source SPH codes (12000 downloads since 2010).

Notable contributions to external advisory boards have been made. Anderson sits as commissioner on the Welsh Government's Climate Change Commission and is a Director of Greenstone Carbon Management. Stansby was a member of the DECC expert panel for the Severn barrage and the Peel Holding panel for the Mersey barrage. He led the international review of Mechanical Engineering research at Technical University of Denmark (DTU) and was a member of the LABEX 2011/12 subjury for Matter Science and Energy Science for Agence National de Recherché. Bailey is the only academic member of the Standing Committee On Structural Safety (SCOSS) which is an independent body, supported by the Institution of Civil Engineers, the Institution of Structural Engineers and the Health and Safety Executive. He was a member (2009-2013) of the Contract Management Board of the UK's National Nuclear Laboratory (NNL) which consisted of a consortium made up of Serco, Battelle and University of Manchester. Thornley was an expert advisory group member for Defra biochar project (2009), on DECC and Defra committees, and the Climate Change Committee.

There is leadership in the broad research base through journal editorial panels: as associate editors of the Fire Safety Journal (Bailey), International Journal of Ventilation (Edwards), Biomass & Bioenergy (Thornley). Staff hold positions on 7 editorial boards.

Early dissemination of research is made through international conferences and the UOA has played a leading role by hosting the following successful conferences at Manchester: the 5th International SPHERIC workshop 2010 and the Association of Computational Mechanics in Engineering (ACME) conference 2012. Members have given 60 keynote and invited presentations at international conferences.