Institution: Swansea University
Unit of Assessment: 10 - Mathematical Sciences
a. Context

The UoA's research groups – Probability Theory (**PT**), Algebra and Topology (**AT**) and Partial Differential Equations (**PDE**) – undertake research in **pure** rather than applied mathematics but nevertheless deliver impact through collaborative relationships with both academic and commercial partners.

For instance, **PDE** research, in particular on stochastic PDEs, has over the last 20 years developed strong links with Swansea colleagues in Engineering, specifically in the areas of fluid and structural mechanics, and aerospace. Our collaboration with the College of Engineering (CoE) led to a 2002 international workshop *Probabilistic Methods in Fluids* funded by EPSRC, with proceedings co-edited with Engineering colleagues. The collaboration has since been strengthened further via the Welsh Institute of Computational and Mathematical Sciences (WIMCS, see below). Powerful PDE-based tools for image processing have also been developed, with potential applications in CAD modelling, medical imaging, and digital watermarking.

Research in **PT** has been applied to the optimisation of photon counting in particle detectors, and in Finance. More recently the theory of Levy processes has been applied in collaboration with colleagues in Biosciences to the analysis of animal motion.

Mathematics underpins virtually all science, and mathematical fluency among school-leavers is a key driver for the knowledge economy. Our relationships with schools are strong, with research staff delivering lectures and lessons in the community.

b. Approach to impact

The UoA supports staff to achieve impact through initiatives designed to encourage and promote impact-led research. A staff-loading model recognises participation in knowledge transfer and activities and industrial projects with consequent reductions in teaching load. Further, the College of Science (CoS) grants sabbatical periods to staff to enable them to concentrate on enhancing impact, while the University's academic career pathways scheme includes an enhanced strand for ***innovation and engagement***, recognising and rewarding staff who can demonstrate impact through knowledge transfer.

Staff have access to a range of **institutional facilities that attract commercial collaboration**, including the EPSRC National Mass Spectrometry Service Centre and MRI scanning facilities in the College of Medicine; the £22m Centre for Nanohealth (a collaboration between the Colleges of Engineering, Science and Medicine, delivering impact in the field of nanotechnology applied to novel healthcare innovations); the £40m HPC Wales supercomputing facility, and other supercomputing facilities on campus. Exciting new collaborative opportunities are anticipated with the opening of a Visualization Lab, sponsored by the Royal Society/Wolfson Lab Refurbishment Fund, which enables cutting-edge work into animal motion and behaviour, with potential further applications in Psychology and Sports Science.

The University also holds an **EPSRC Impact Acceleration Account** (2013-2016: £638k), which funds an institution-wide impact award scheme to recognise and celebrate research impact.

A key driver for impact is WIMCS, a pan-Wales collaboration initially funded by the Welsh Government with £5m, Swansea being the lead institution. WIMCS has established research clusters bridging subject areas and institutions. The clusters promote collaborative work with potential for impact; in particular in Computational Modelling (conducted by K. Morgan) and Stochastic Analysis (N. Jacob). Research carried out by Morgan, in partnership with BAE Systems forms the basis of Case Study I. At Swansea, WIMCS has supported three professorial staff and seven research fellows, whose remit includes facilitating knowledge transfer across the academic

community and delivering a programme of outreach activities designed to enhance interactions between Higher Education and schools. WIMCS and the Department jointly manage the Welsh Government-funded *Further Mathematics Support Programme Wales*, a pilot initiative designed to increase the number of schools and colleges in Wales offering Further Mathematics and to improve the transition of students from further to higher education courses in Mathematics or courses which have a significant element of Mathematics. The Programme runs to March 2014 (with a possible further extension) and has engaged with every school in the pilot area (originally south-west Wales (Carmarthenshire, Swansea, Neath Port Talbot and Pembrokeshire) with north Wales (Anglesey, Conwy and Gwynedd) added during 2013) through revision sessions, mathematics conferences, and workshops for GCSE and A-level students.

To support this approach, the **PDE** group was strengthened with the appointment of WIMCS research staff whose research has potential for impact. Professor K. Zhang and Dr. E. Crooks collaborated with Dr. A. Orlando (College of Engineering) in the development of convexity-based mathematical tools related to image processing, leading to the submission of a patent application; the inventors entered the UK national phase of the patent application process in June 2012.

With the help of a £20k of EPSRC *Pathways to Impact* funding administered via the CoS, Zhang and Crooks were able to secure the services of a PDRA to produce software useful for non-academic applications. In developing their suite of techniques they have collaborated with:

(a) clinicians from John Radcliffe Hospital, Oxford, in an assessment of non-invasive magnetic resonance technology for scanning the skulls of children;
(b) engineers at BAE Systems, to develop gap-detection techniques as a necessary step in adapting aircraft design specifications for fluid-dynamics simulations;
(c) a consulting company *Cadarn Technik* with extensive experience of dealing with electronics, chemical, materials, and life science companies, which expressed an interest in commercialising this technology.

Since June 2013 a potential application of their work has emerged in the area of digital watermarking. The partner company *Fortium* not only want to apply the software for watermarking in the film industry, but are also willing to consider funding a PhD-student to work on developing the project. This work forms the basis of Case Study II.

Another example of industrial collaboration arose when Dr. M. Kelbert of the **PT** group was contacted by Dr. Tony Wright, an industrial physicist interested in the optimisation of the timing of photon bursts detected by scintillation counters used in, e.g., particle detectors and PET scanners in medical imaging. Kelbert and Wright were able to improve on a well-known but intuitive result first published in 1950, that timing is best done using the first photon, since the variance is minimum. In fact, within a couple of minutes of Wright outlining the problem in the tearoom of the National Gallery in London, Kelbert was able to provide the exact solution, essentially on the back of a napkin. The pair subsequently published two papers, which have been well-cited in the physics literature, including those reporting experiments based at CERN.

In addition, the UoA has initiated interdisciplinary PhD projects in research deemed likely to have impact. Jacob (Mathematics) and Wilson (Biosciences) lead a team investigating and modelling the movement of insects in walls, with significant impact on the understanding of health care problems, particularly in sub-tropical countries. The University and CoS jointly support this project with approximately £60,000 for a stipend (including fees) for a PhD student. I. Davies (Mathematics) and Webster (Engineering) co-supervise a PhD–student in Computational Non-Newtonian Fluid dynamics.

c. Strategy and plans

The UoA recognises that for a department with a history and tradition of research in pure mathematics radical changes are required to respond to the Impact Agenda. Central to the UoA's future strategy is enhancing existing collaborations, especially with the Colleges of Engineering, Science, and Medicine, and to provide expertise to teams conducting research that leads to genuine societal impact. Building on the foundations laid by WIMCS, it was decided in 2012-13 to

expand Mathematics in Swansea with 5 new positions, of which 4 are filled, and the 5th will follow in early 2014. This has resulted in the appointment of four applied mathematicians to broaden the portfolio of interests represented in the UoA. Of the four new appointments, one specialises in computational modelling cognate with interests in Engineering (exemplified by Case Study I), and one develops models of plant structure relevant for Biosciences. Each new staff member is integrated into one of our existing groups, with the prospect of eventually establishing a new group in computational mathematics spinning off from the **PDE** and **PT** groups.

Simultaneously, a strategic new partnership with Biosciences has allowed the development of biological modelling in both Departments, reinforced by 6 additional cognate appointments in Biosciences; cross-fertilisation of ideas and grant applications have already begun. A major priority is to establish a Centre for Mathematical Modelling where biologists, mathematicians, engineers and computer scientists will work together, exploiting the facilities of the new Visualisation Lab.

We anticipate a further expansion of staff aligned with major new themes in high-performance computing, stimulated by HPC Wales in partnership with Welsh Government and Fujitsu, and through the acquisition of a major HPC facility for Swansea associated with the Extreme Weather Event Research Centre in cooperation with the UK Met Office.

We will continue our successful policy of fostering inter-disciplinary partnerships with colleagues in the Colleges of Science, Engineering and Medicine via joint supervision of PhD studentships co-funded by the Colleges and the University.

More effective support for staff in seeking and creating opportunities will be key. Within 2-3 years the UoA will undergo a radical change through relocation, along with our sister department Computer Science, to Swansea University's new, £250m **Science and Innovation Campus**, providing purpose-built facilities supporting enhanced interaction with industrial partners and end-users. The 31,000 m^2 facility will open in 2015 and is predicated on an open innovation model, co-locating industrial R&D activity with academic research. The University aims to establish **a £15m ICT Innovation Precinct** on the new campus to provide additional routes for exploitation and knowledge transfer. The 5,000m^2 facility will house the Department and commercial tenants ranging from multinational organisations to microbusinesses, as well as our industrial and business support projects. The aim is to facilitate impact through:

- Enabling research collaborations with private and public partners;
- Encouraging and enabling academics to locate their research in the commercial world;
- Creating and managing projects that help transform and grow the Welsh economy;
- Developing a strong entrepreneurial culture around research and development.
- Engaging in/creating global and regional networks of technologists, users and policy makers.

The ICT Innovation Precinct will enable the UoA to expand and deliver its research, teaching, outreach and impact strategies, and to enhance its contributions to public debate, policy development, and lobbying for Mathematics through partnerships with professional and trade bodies, think tanks and charities (e.g., *London Mathematical Society, Institute for Mathematics and its Application, Computing in Schools*, *Foundation for Science and Technology*, *Learned Society of Wales*, *Institute for Welsh Affairs, Wales Quality Centre*). It will become a focus for knowledge exchange for mathematical and computational science in Wales.

d. Relationship to case studies

Case I (Computational Electromagnetics in Aerospace Design): This case spins off our longstanding collaboration with Civil and Computational Engineering at Swansea University under the aegis of WIMCS.

Case II (Geometric Convexity-based Methods for Image and Data Processing): This case applies new convexity-based methods developed in the **PDE** group in collaboration with engineers working in the Computational Modelling cluster of WIMCS, and the requisite software development has been fostered by support from an EPSRC *Pathways to Impact* grant.