Institution: University of Chester

Unit of Assessment: 10: Mathematical Sciences

a. Overview

Research in mathematical sciences is undertaken by the Mathematics Research Group led by Ford. The Department of Mathematics within the University of Chester forms part of the School of Computer Science and Mathematics. Mathematics staff and research students are co-located with colleagues from Computer Science under a single Head of School with shared computer, technical support and administrative services. The University Research Strategy has identified mathematical sciences research as one of the University's areas of strength and has committed to support and invest in the work of the Unit. During 2013-14, the University is developing a new Science and Engineering Faculty and science park based upon the former Shell Thornton Research Centre. This will lead to a growth in the strength of Mathematics at Chester, which forms part of the new Faculty of Science and Engineering. New collaborative developments with Science and Engineering faculty members and R&D activities taking place on the science park play a key part in future plans.

b. Research strategy

The main research focus of the Mathematics Research Group is the analytical and numerical analysis of deterministic and stochastic functional differential equations. We currently have a focused group of researchers who work together and who collaborate with other research groups around the world – including several overseas mathematics groups with which the Group has established long-term collaborative research links. The aim is to consolidate this globally recognised expertise, produce further research results of high quality and exploit the opportunities to deliver impact to key technology areas for the UK economy such as engineering and life sciences.

Functional differential equations include various classes of ordinary, delay and partial differential equations, as well as fractional differential equations and some classes of integral and integro-differential equations. They define problems that are frequently characterised by long-term, delayed, or memory effects. This leads to their effective use in developing models of complex materials (polymers, etc., which may exhibit memory effects), biological and environmental systems (where delays and memory effects are common), financial markets (which exhibit both memory and uncertainty), and of the immune system. The inclusion of memory effects sometimes enables the development of models which explain observed phenomena more effectively than models of low to moderate dimensionality that lack delay or memory effects.

The main focus of the work is on developing and understanding effective numerical techniques and computer algorithms and simulations that are of use to applications experts in these fields, as well as contributing new and effective insights to assist with understanding the underlying mathematical problems. A key feature of the work is the investigation of asymptotic behaviour, stability and oscillatory behaviour of solutions, so as to ensure that these important practical features of the underlying real world systems are effectively reproduced in the models.

Key achievements during the census period for REF2014 have been:
The establishment of a Leverhulme International Network on stochastic equations with delay. This network was supported by a Leverhulme Trust grant over the period from 2008-2011 and focused on 4 research meetings held approximately annually. Members of the network include Xuerong Mao (Strathclyde), John Appleby (DCU), Uwe Kuechler (HU Berlin), Evelyn Buckwar (Linz). One key feature of the network meetings was engagement with experts from applications fields including financial mathematics, the biosciences, immunology and the environment. An outcome of the network meetings has been the development of a greater level of co-operation between members of the network and so the academic impact of the network activities has extended beyond the local Chester group. Further meeting of members of the network are planned; a meeting hosted by Strathclyde in June 2013 has already taken place.

The IWANASP (International Workshop on Analysis and Numerical Approximation of Singular Problems) meeting was held in Chester in September 2011, immediately after the 2011 Leverhulme Network meeting. This was the 4th meeting in the IWANASP series (previous meetings having been held in Portugal and Greece) and it attracted attendees from 16 countries.

Vision:
To continue to focus on numerical and analytical solution of functional differential equations;
To extend links with applications areas through continued collaboration (inter alia) with Freed and Bocharov;
To continue to co-operate with long-term collaborative partners in Lisbon, Vila Real, Braunschweig, Stockholm and to develop new partnerships;
To develop new collaborations through the new Science and Engineering Faculty and Thornton Science Park;
To extend capability through new staff appointments;
To develop expertise in rheology, materials modelling and robotics and to work with the new University Food Technology Group.

c. People, including:

i. Staffing strategy and staff development

For many years, staff submitted to this Unit have had their research focus in the Mathematics Department. Accordingly, the research needs in mathematics are taken into account in the appointment of all mathematics staff, and there can also be opportunities for collaboration with appropriate colleagues from computer science. A key question in the appointment of new academic staff is always how their appointment will contribute to the research work of the Mathematics Research Group. The acquisition of the former Shell Thornton Research Centre provides the base to develop a new Science and Engineering Faculty for the University and this has provided the opportunity for further growth in mathematical sciences. Appointments to the new areas of work have taken account of existing areas of research interest and strength and recent appointees to the new Faculty, whose work links with research in mathematical sciences, are therefore included in this submission. It is the intention that these links will continue to develop through future research collaboration within this larger group. Recent appointments in Mathematics include Gildea, whose future work on coding will integrate with computer scientists in the new Faculty, and Kavallaris, whose work on partial differential equations further strengthens the Group in this important area. Wilkinson, whose work on modelling in the life sciences, often with limited data, links closely with existing work on mathematical immunology, and Stewart, whose outputs include engineering applications using models involving differential equations with delay and uncertainty, and their numerical solution, will be based in the Science and Engineering Faculty.

The Department and the University are strongly committed to the development of all staff of the University. This was recognised externally by the recent award to the University of the HR Excellence in Research Award which demonstrates a commitment to implementation of the *Concordat to Support the Career Development of Researchers.*

All new academic staff of the University are supported through an accredited programme leading to a Fellowship of the Higher Education Academy. A particular feature of the Chester programme is that the compulsory core modules provide developmental support helping and encouraging newly appointed staff to understand the demands and opportunities of research supervision, and encouraging them to study a further optional module that develops skills in supervision to an even higher level.

Within Mathematics, every new member of staff is assigned a mentor who will help with settling into the Department and who will be available to provide day-to-day help and advice.

The probationary and induction programmes are interlinked and ensure that all new members of staff are introduced to a wide range of facilities and policies. These include access to colleagues

from the Research and Knowledge Transfer Office (who can provide assistance in applying for grants and setting up R&D contracts), and colleagues in the Graduate School who can help to advertise research projects and to interview and admit potential research students.

The two most experienced members of the Department staff (Baker and Ford) hold regular meetings with all colleagues to assess how their research is progressing, and provide support and guidance in moving on to the next stage in their careers.

There is a formal and annual Performance and Development Review (PDR) process which involves a paper-based preparation exercise and then a detailed discussion of objectives with a line manager. The objectives established through this process can lead to further training and development opportunities and frequently provides access to funding for research collaborations, for conference travel and encouragement to advertise PhD and other project opportunities on the University web site.

The University has established (through the Research Committee) a forum for early-career staff to enable networking across subject and discipline boundaries and to help identify and address common problems and allow issues to be raised at policy-making level. There is also a new group, chaired by Ford, to explore and encourage collaborative research between existing researchers and members of the new Science and Engineering Faculty.

The University's Annual Staff Conference is an all-day event held each year and attended by a majority of academic staff. Research is featured within the conference through several parallel sessions which showcase successful projects, explore opportunities to develop impact, and a sharing of good practice in grant applications and management, collaborative initiatives, and understanding good research governance.

The University has also established the International Research Excellence Awards (funded through the Santander Universities scheme), which offer grants to encourage international research collaborations. These can help support short-term and long-term research visits between University staff and collaborating universities. The scheme is used regularly by Mathematics academic staff to support ongoing collaborative links. Mathematics also provides its own separate budget to support research visits, conferences and other opportunities that might fall outside of the International Research Excellence Awards, so that researchers in mathematical sciences are particularly well-supported in their work. Erasmus exchange programmes have also been established to enable research students and supervisors to exchange with the Department's regular collaborating partners.

Staff development weeks are held twice per year and seek to address needs identified through the annual PDR process, as well as to introduce new systems and policies. Research grant applications processes, mentoring and supervision skills feature regularly in the programmes.

Ford was successful in an application as Host Academic for a Leverhulme Visiting Professorship award at Chester to support E E Tyrtyshnikov from INMRAS, Moscow from 2010-12.

Ford held a Leverhulme Trust grant to establish the Leverhulme International Network on stochastic equations with delay from 2008-11.

D. Savostyanov from Moscow was awarded a Leverhulme Trust Visiting Fellowship from 2011-12.

Jingyu Xiao was successful in obtaining a Chinese Scholarship Council award to research at the University of Chester from 2010-11.

Laila Assas, from Umm Al-Qurah University, Saudi Arabia, and Najwa Joharjee, from King Abdulaziz University, Saudi Arabia, won awards from their home institutions to undertake post doctoral study for a year with the Mathematics Research Group in Chester.

University of Chester International Research Excellence Awards funded by the Santander Universities scheme were awarded to Ford and Lumb (outgoing) and (incoming) to Lima (Lisbon) and Morgado & Henriques (UTAD, Vila Real).

Other visiting scholars during the period have included:
L. Shaikhet (Donetsk, Ukraine), A. Freed (Saginaw Valley State University), G. Bocharov (INMRAS, Moscow), K. Diethelm (GNS, Braunschweig), M. Rebelo (New University of Lisbon), M. Rodrigues (Aveiro), F. Rihan (UAE).

Other ongoing collaborators not listed above include T. Diogo (Lisbon), S. Lasson (Chalmers University of Technology, Sweden), V. Barbu, (Iasi), D. Coca (Sheffield), J.M. Ferreira (Lisbon), S. Pinelas (Azores).

The University of Chester supports activities promoting equality and diversity. There is a long-established annual University Diversity Festival to which all staff and students are invited. The University has a Disabled Staff Group that has been active since 2007 and provides a safe and supportive environment in which to discuss issues relating to disability. The Human Resources Department monitor regularly for equality issues as part of the recruitment process for staff and funded research students, and the University is currently working towards an Athena Swan award.

ii. Research students

The Mathematics Research Group has a regular population of PGR students studying on the MPhil/PhD programme. Since the Group does not currently qualify for a DTA allowance from EPSRC, students are predominantly from overseas, or self-supporting part time home students. The Group's approach to recruitment is to focus on publicising the Group's research focus to potential students to ensure that there is a close match between applicants' and supervisors' research interests. Applicants who meet the entry requirements are interviewed by at least two members of the Department's staff, and a decision as to whether a place should be offered is made based on their experience, quality, and the fit of their research interests. The Department offers a taught MSc in Mathematics and it is, of course, common for students to apply for doctoral study on completion of their MSc programme.

The University meets the requirements of Chapter B11 of the QAA Quality Code: training and support for PGR students is a shared responsibility at Chester, between the Graduate School (with responsibility for providing generic training and support) and the subject department which provides supervision and specialist training and support. PGR students are offered face-to-face training sessions by the Graduate School, supported by a Moodle site providing on-line access to training materials written and contributed by academic staff from across all subjects and faculties. Students experience both a central University induction, and a local induction within their department, so that they have a full understanding of the regulations and services provided by central support departments as well as of the local support staff and facilities in the building where they are studying. All students undertake a skills audit to help them to identify their training needs, and they are welcome to attend taught sessions from within the postgraduate mathematics curriculum, as well as seminars and training sessions specifically designed for PGR student needs. Students who will be involved in teaching are expected to undertake specific training to prepare them for this activity, and may, if they wish, undertake modules leading to Associate Fellowship of the Higher Education Academy, which provides a good basis for future applications for academic posts.

Each faculty holds an annual Research Conference for staff and postgraduate students to present their work in seminars and posters. Members of the Mathematics Research Group take part in the Applied Sciences event which is well-attended and provokes a lively discussion and generates interactions that can lead directly to new collaborative and interdisciplinary projects for students and staff.

Data collected as a result of the Postgraduate Research Experience Survey indicates a significant level of satisfaction with the service and support provided to PGR students. In previous surveys, an

action point was noted to improve preparation for viva examinations. Further training sessions with this focus have been offered recently, and in the most recent PRES survey 100 per cent of students responding to the survey considered that they had been well-prepared for their examination, which we believe demonstrates the University's and Department's commitment to providing an excellent environment for PGR students.

Every student is supported by a team of at least two approved supervisors, one of whom is designated Director of Studies, and who has supervised at least one student to successful completion of the award. Supervision meetings take place frequently, with at least one meeting per month being recorded with outcomes and targets. Following a probationary period of 6-9 months, student progress is reviewed formally. If the student's registration is confirmed at the probationary review, a termly meeting of the full supervisory team reviews progress with the student subsequently and a Progress Review (chaired by an independent academic staff member and held in every year of study) reviews progress against objectives and expectations on an annual basis before the Annual Progress Board meeting. Students must submit a report, give a seminar and attend an interview before their upgrade from MPhil to PhD status can be confirmed. There is a similar rigorous process to consider applications to transfer to 'writing up' status. Each faculty has at least one Faculty Postgraduate Tutor who is available to see PGR students by appointment and to resolve any issues or questions they may have. Postgraduate Tutors represent their faculty and its students at the regular Graduate School meetings and also represent the Graduate School as appropriate in their faculty.

The University recognises the value of conference participation for all PGR students and has established a fund to provide a contribution to conference attendance. Each year applications are invited and all successful applicants are provided with financial support.

d. Income, infrastructure and facilities

The University of Chester Seaborne library is a key resource for mathematical sciences research. We subscribe to over 1,000 printed journals and more than 13,000 electronic journals which can be accessed online. There are approximately 260,000 printed volumes and 15,000 e-books. In the library, there is 24/7 access to computers, printing and quiet study space throughout the year

The IT infrastructure provides all the usual facilities for staff and students, including office-based and open access computer facilities with relevant software, including Latex, Matlab, SPSS, and the NAG Fortran library. A Remote Desktop facility means that all the software can be accessed by users remotely as well as when present at the University campus.

The University of Chester has a long-standing institutional commitment to invest QR income in departments that earn it, and this has led to clear research benefits in departments that have gained funding from RAE outcomes in the past. For example, specialist computer facilities in Mathematics support those who wish to work on parallel computing problems; there is a specific fund to support visits, visitors and conferences; and there is a commitment to reduce the teaching load for all research staff.

At the Thornton site, which will be a major base for the University's Science and Engineering Faculty, there will be an investment of £22 million over the next 3 years in a site with an existing value of in excess of £120 million. The arrival of major companies on the new Thornton Science Park adjacent to the Faculty, and the significant investment in new facilities on the site presents an exciting opportunity for the Mathematics Research Group to grow, to engage in new collaborations with researchers from engineering and technology and to develop new areas of research impact. With this in mind, the University Senate has established a working group, chaired by Ford, to promote and develop these collaborative links.

e. Collaboration or contribution to the discipline or research base

Support for collaborations lies at the heart of the Unit's resource planning. Work with long-term collaborators (see above) is supported through a research support fund maintained by the Department. The fund can be used to support travel for collaboration and conference attendance, and is augmented through the University funding provided through the International Research Excellence Awards, for example. The most significant current collaborative links are those with Diethelm and Freed (on Fractional Calculus), with Larson (on partial differential equations), with Bocharov (on Mathematical Immunology), with Tyrtyshnikov and Savostyanov (on model reduction and tensor trains), and with Lima and Morgado (on functional differential equations). Recent appointments to our Group bring with them new collaborators (including Lacey (Heriot-Watt), Suzuki (Osaka) and Souplet (Université Paris 13)).

The Leverhulme International Network on stochastic equations with delay (based in Chester) successfully brought together those with interests in stochastic problems, differential equations with delay and memory and those with modelling and simulation expertise. This grouping has produced a significant number of collaborations which are already leading to new insights and outputs.

The IWANASP workshop in 2011 was hosted in Chester and brought together experts from singular problems and approximation. By hosting the meeting adjacent to the Leverhulme Network meeting, further interactions between the groups were enabled and (for example) R. Gorenflo from Berlin gave lectures at both events.

Baker and Ford have held Guest Editorships of two special edition volumes of the Journal of Computational and Applied Mathematics during the census period.

Journal Editorships:
Baker: Journal of Computational and Applied Mathematics; Honorary editor, Communications on Applied Nonlinear Analysis; Member, Accreditation Board, Computer Abstracts.
Ford: Journal of Integral Equations and Applications, International Journal of Computer Mathematics, Fractional Calculus and Applied Analysis, Computational Methods in Applied Mathematics, Fractional Differential Calculus.
Lumb: Journal of Applied Mathematics and Bioinformatics.
Yan: Journal of the Franklin Institute.

Reviewers for Mathematical Reviews (Ford, Kavallaris and Yan) and Zentralblatt MATH (Ford and Lumb).

EPSRC Peer Review College members: Baker and J. Ford (honorary staff).

Expert adviser to UEFISCDI (Romanian Research Council): Ford.

Research Executive Agency of the European Commission: FP7 funding panels Vice Chair and Expert (Ford).

FIMA (by invitation of the President of the IMA 'for Services to Mathematics'): Ford.

External Examinerships: Ford (Lisbon, PhD, 2012; Huddersfield, PhD, 2009). Wilkinson (Imperial College, PhD, 2010 and 2012; University College London, PhD, 2011; Kings College London, PhD, 2012).

Marie-Curie award: Kavallaris (2010-14).