**Institution: University of Dundee**

**Unit of Assessment: 10 Mathematical Sciences**

**a. Context**

Research from the UoA has impacted on a range of non-academic user groups and beneficiaries and given rise to three main types of impact: **economic impact**, **health impact**, **societal impact**.

**Industrial users** across a broad spectrum of international companies have benefitted economically from research carried out in the UoA. This has occurred primarily via the improvement of existing performance through: (i) the adoption of mathematical techniques developed by members of the UoA, and (ii) transfer of highly-skilled member of the UoA to specialist roles that draw on the research skills they developed at the UoA. Specific sectors benefitting from the UoA's research include: finance (Deutsche Bank, JP Morgan), pharmaceutical (AstraZeneca), IT and computing (IBM), car and aircraft manufacturing (The Boeing Company, Ford Motor Company, General Motors), energy (ExxonMobil, Honeywell International), biotechnology (CXR Biosciences, Cyclacel Ltd.), telecommunications (Lucent Technologies), the International Atomic Energy Agency and The European Space Agency. The adoption of new clinical practices based on mathematical modelling developed at the UoA has benefitted **health professionals**. Specifically, clinicians in hospitals in the UK (Ninewells Hospital, Dundee) and USA (Moffitt Cancer Center, Tampa, FL) across a number of cancer specialisms (breast cancer, oesophageal cancer, colon cancer, genitourinary cancers) have benefitted from research carried out in the UoA. The impact of the research has also fed through to benefit **patients** with cancer due to improved treatments and drug delivery. Finally the UoA's research has impacted on the **general public** in both the UK and USA where protocols public engagement and interest in science has been stimulated through a series of public talks and articles explaining our latest research results. Examples include Chaplain's cancer modelling research lectures (*Can Calculus Cure Cancer?* Center of Cancer Systems Biology Public Evening Lecture Series, St. Elizabeth's Medical Center, Boston (inaugural talk, 2010) and *Meet the Mathematicians* at Birmingham, 2011 (MTM11)), and the Magnetohydrodynamic (MHD) group's talks incorporating their research at their *Our 21st Century Sun* event, Dundee Science Festival (2011) as well as their UK Solar Physics Nugget (2010), part of a series aimed at the general public and with a world-wide audience.

**b. Approach to impact:** The UoA's approach to interacting with non-academic users has been firstly to deliver excellence in all research activities and to maintain and promote its international reputation. Secondly, the UoA has targeted bespoke UK Research Council Industrial Schemes that are designed to enhance impact. Thirdly, from the UoA's platform of research excellence, staff have adopted a flexible approach to applications of their research to real-world problems in order to maximize the potential longer term impact. Finally, staff have engaged with non-academic end-users and intermediary organisations who work in areas most likely to enhance translation of research results.

Chaplain has received EPSRC Mathematics CASE PhD studentship awards and Davidson and Chaplain won an EPSRC "Mathematics for Business" grant. These grants initiated collaboration with key users in the Biotechnology (Cyclacel and CXR Biosciences) and Pharmaceutical (AstraZeneca and Pharmacometrics) industries. The collaborations not only led to the publishing of high-quality papers, but also to improvements in one of Cyclacel's anti-cancer drugs (CYC116) which is now currently in Phase 1 trials in patients.

Over the past decade, the Mathematical Biology (MB) group has had ongoing inter-disciplinary collaborations with clinical staff at Ninewells Hospital, Dundee (Profs. D. Adamson, J. Belch, A. Evens, R. Steele, A. Thompson, R. Wolf). Chaplain is now working as a Co-I with Thompson on a 5-year £850k *Breakthrough Breast Cancer* grant. Recently, a new partnership has been set up between ECR Trucu and Clinical Radiologists at Ninewells Hospital.

The UoA has also used consultancy work as an opportunity to develop impact with key users. For example, Fletcher has undertaken such work and provided advice for the following organisations: European Space Agency; IBM; NHS Tayside; DOT Products (now PAS); Millenium International LLC; ICI; Scottish Hydroelectric (now SSE); Electricité de France, and BAe systems. This consultancy is primarily in place to support the implementation and development of software packages written by Fletcher and co-workers (see impact case study).

The University's policy on EPSRC Doctoral Training Awards is to provide 50% funding, with researchers encouraged to obtain matched funds from industrial partners. The UoA has used this scheme to encourage researchers to actively seek new industrial collaborations. The approach has

not only led to DTA awards (Ptashnyk, Lin) but also to the development of new partnerships that are likely to have future impact (e.g. James Hutton Institute (JHI), East Malling Research, L'Oreal). Staff appointments have been made to ensure that researchers within the UoA have the skills and tools capable of tackling a broad range of applications and thus increasing possible impact opportunities. For example, an expert in applications to plant sciences was identified as a position that was subsequently filled by the appointment of Ptashnyk. Additionally, existing staff have been encouraged and supported to pursue challenges in different areas of application in order to target potential impact opportunities. For example, Davidson has used expertise developed in the modeling of fungal growth to work with Chaplain on the development of anti-cancer drugs (EPSRC Maths for Business) while Lin has expanded his application portfolio from primarily multiscale material modeling to include also big-data analysis of gene regulatory networks in plants (with JHI) and multiscale hierarchical retinal vessel segmentation (with Prof. E. Trucco, School of Computing). The latter is currently also part of a shortlisted EPSRC DTC medical image analysis proposal (with Edinburgh and Heriot-Watt Universities).

The UoA has a proactive policy of horizon-scanning to identify and take advantage of opportunities to set up new collaborations with non-academic users. One such recent case arose through Chaplain's contacts with the UK Public Service Review Magazine. Chaplain's Cancer Modelling Research Group sponsored part of the *SciTech Europe Conference 2012*, attended by over 630 delegates, with stakeholders from business, industry, the public sector, and politics alongside academics from across Europe. Chaplain's cancer modelling research was showcased through an insert presented in each delegate pack. Cancer modelling work carried out in the UoA has also been publicised in non-academic publications aimed at readers and potential users in the industrial, public and government sectors. These include (i) *The Parliament Magazine's Research Review* (published quarterly and distributed to all MEPs, Council of Ministers, all EU Commissioners); (ii) *Public Service Review: UK Science and Technology*, which also has a wide distribution throughout the public and government sectors; (iii) *Pan European Networks: Science and Technology*. Information regarding the modelling work of the MB group is also advertised through a banner-link at the Pan European Networks Health website.

The UoA supported and enabled staff to achieve impact through the use of differential teaching loads and direct teaching buy-out, thus liberating key researchers involved from much of their lecturing duties over a given period of time (Chaplain, Davidson, Lin). This gave staff the quality time needed to devote to meetings with the non-academic users and to undertake the collaborative research. The work of Davidson with Cyclacel was a primary reason for his promotion to Reader. Another mechanism of reward for staff was salary enhancement through contribution-related points.

The UoA has made use of its Research and Innovation Services (RIS) department, the University's technology transfer office, to put in place contracts to license Fletcher's optimization software to industrial and business users. RIS was also involved in drawing up IP contracts between researchers in the mathematical biology group and colleagues in the Biotechnology Industry (Cyclacel, CXR Biosciences), which facilitated the subsequent work carried out. RIS was also instrumental in facilitating contact between members of the MB group (Chaplain, Trucu, Eftimie) and clinicians at Ninewells Hospital. The MB group has now initiated a programme of regular meetings with cancer surgeons at Ninewells Hospital, where the Cancer Modelling Research Group have attended and observed breast cancer operations. This is the first stage in the development of future patient-based treatment protocols whereby predictive computational modelling of cancer spread informs surgical procedure.

**c. Strategy and plans**

The UoA will continue with the successful good practice detailed above. To broaden impact potential the UoA will build on these strategies in a number of ways as outlines below:

(i) The UoA will continue to work with intermediary organisations. For example, as outlined below Chaplain, Lin and Ptashnyk have joint PhD projects with colleagues at the James Hutton Institute (JHI). The problems addressed, along with the data provided by JHI, provide a potentially rewarding route to impact. Topics of research include plant gene regulatory networks, plant root and plant cell-wall biomechanics, and aphid-parasitoid interactions. This work therefore has the potential to impact on crop breeding and selection strategies including: how to breed plants to adapt to climate change; how to increase the yield to secure global food safety; and how to breed pathogen-resistant plants that can allow reduced chemical use and the protection of natural

resources.
(ii) The UoA will continue to develop its newly-established collaboration with Physiomics Plc. Eftimie (who has just been awarded a NRP Early Career Researcher Engagement & Exchanges with Business and Industry: *An Optimal Approach to Drug Design and Testing*) and Davidson will collaborate with Dr. H. Mistry from Physiomics Plc., with the goal of improving the development and testing of anti-cancer drugs. The grant will enable industrial and academic placements at Physiomics Plc. and at the UoA for Eftimie and Dr. H. Mistry, respectively.
(iii) Future grant applications will continue to target the development of collaborations with industry. For example, as a consequence of searching for external partners for matched DTA PhD funding, Ptashnyk has a new collaboration with Prof. P. Gregory at East Malling Research (modelling plant roots) and Murray has instigated collaboration with Dr. B. Bernard, Research Director, Hair Biology Research Group, L'Oréal, Paris (modelling the development and patterning of hair follicles).
(iv) The UoA aims to increase impact in MHD primarily by working together with intermediaries. For example, Pontin is presently PI on a proposal under consideration by the US Air Force for work to build capacity for predicting the timing and severity of Solar Energetic Particle events (crucial for Air Force activities since the events are a major hazard to satellites). The MHD group is also in contact with Dr F. Bouquet (Met Office) regarding possible collaborations on Space Weather forecasting and with Dr M. Freeman (British Antarctic Survey) for understanding the near-Earth environment in which satellites operate. A further aim is to seek collaboration with researchers in the Culham Centre for Fusion Energy, initially through an EPSRC DTA studentship.
(v) Fletcher will continue his broad portfolio of consultancy and actively engages with new partners. For example, a recent new project concerns work-force planning in the Department of Oncology, Ninewells Hospital with Dr. Douglas Adamson, Consultant Clinical Oncologist.
(vi) Researchers from across the UoA have started to consult with Vascular Flow Technologies, a local SME, on the modeling of fluid flow in blood vessels for application to patient treatment across a range of diseases (e.g. atherosclerosis).
(vii) Lin has recently started consultancy work with Oldbaum Services on a project concerning offshore renewable energy. Lin will provide expert advice on the numerical analysis and computational mathematics of complex fluid flow problems, with the company being interested in CFD simulation of wind farms.
The UoA will continue to make full use of the University's RIS office through close liaison with the UoA's dedicated Business Development Managers (BDM), Mr. N. Mather and Mr. R. Sharpe. This connection will be enhanced through use of the newly established **Innovation Portal**, created to promote and foster productive knowledge transfer between the University and Scottish industry. Its aim is to improve the competitiveness of local businesses by bringing together innovative companies with scientists and engineers keen to apply their expertise to the needs of industry.
The UoA will continue to place strong emphasis on impact in its training and mentoring of newly appointed Early Career Researchers (ECRs). In partnership with RIS, all new staff are introduced and exposed to the UoA's existing collaborative network with non-academics and industry and new non-academic partnerships are always being sought.
The UoA has now set up an **Impact Advisory Board** (IAB) in order to maximize future impact. The IAB members are currently drawn from **local SMEs** with an interest in applications of mathematical modelling and include Insights, Brightsolid, Vascular Flow Technologies, Axis Shield, Tayforth Consulting Ltd., CXR Biosciences, and Cyclacel Pharmaceutics Ltd. Further support will be obtained from Scottish Enterprise. The IAB will meet twice each year with all members of the UoA's research staff and representatives from the University's RIS office to discuss impact plans and identify new impact projects across the UoA's research groups. The inaugural meeting of the IAB is scheduled for early 2014.

**d. Relationship to case studies**

The UoA's case studies exemplify key aspects of its approach in maximising impact with non-academic users. These combined the academics' agile approach to the initial funding opportunities with industry, the use of RIS expertise in bringing the academics and industrial partners together and drawing up IP agreements, and the interaction of the academic staff with the industrial partners throughout the collaboration. In particular the *Cancer Treatment* case study informed the development of the UoA's approach and helped the UoA staff to become aware of and use the University's Innovation Portal, and to set up regular meetings with a dedicated BDM from RIS.