

Institution: Keele University

Unit of Assessment: B10 Mathematical Sciences

a. Context: User groups and beneficiaries of Keele's applied work in the Mathematical Sciences include

- (i) the turbomachinery industry throughout Europe, via our leading role in two EU Marie Curie Initial Training Networks (TANGO and LIMOUSINE), in which we trained PhD students from many European countries;
- (ii) individuals with severe mucoidal lung problems, via our biomechanical research on flow-structure interaction during coughing and forced expiratory manoeuvres;
- (iii) mechanical engineering groups throughout Europe, especially aerospace groups, via our research on boundary-layer instability;
- (iv) Users of wave models and short-to-medium term wave forecasting, including marine scientists involved in observation, national Meteorological Offices, marine renewable developers, oil/gas offshore companies, marine services and consultancies, passenger and freight shipping companies, coastguards, fisheries, via our research on sea waves and, particularly, rogue waves;
- (v) Rolls-Royce, and everyone affected by aircraft noise, via our research on aeroengine noise, especially on duct aeroacoustics;
- (vi) the UK defence industry, notably MoD (Portland), BAE Systems, and Thales, via our work on underwater acoustics;
- (vii) individuals with susceptibility to arterial aneurysms, via our work on their nonlinear initiation, rupture, and sensitivity to imperfections;
- (viii) individuals with cartilage defects in the knee, via our research on cell growth and cell migration in the formation of cartilage tissue; and
- (ix) the worldwide railway industry, and everyone who travels by train or lives near a train or tram line, via our research which was instrumental in reducing rail-track noise.

This impact arises directly from the Keele Applied Mathematics Group's research in fluid and solid mechanics, especially those parts bearing on waves, stability, biomechanics, environmental science, and mechanical engineering. The research takes place in the context of long-standing scientific interactions (of over thirty years in some cases) between members of the Keele Applied Mathematics Group and individuals who now occupy leading positions in industrial, medical, and scientific institutions. The above indicative list demonstrates the considerable reach of the Group's impact.

b. Approach to impact: Our principal approach to impact over the REF 2014 assessment period has been to promote a very large increase in the amount of external collaborative research engagement, especially with industry, focusing on those areas of fundamental fluid and solid mechanics research which have the most profound potential practical implications. This approach has been a spectacular success, exceeding our most optimistic expectations, as exemplified by:

Impact template (REF3a)

- (i) LIMOUSINE, a grant of 4.15 Million Euro in which the industrial partners included (a) the DLR Aerospace Centre, and Siemens Power Generation, in Germany; (b) SulzerElbar, in the Netherlands; (c) Electrabel/Laborelec, in Belgium; and (d) ANSYS in the UK. This project provided a theoretical and experimental framework for the design and operation of large gas turbine engines, significantly reducing the risk of their mechanical failure.
- (ii) TANGO, an EU grant, of 3.73 Million Euro, for the development of clean combustion systems with reduced pollution. Although the development of such systems has been a priority for some time, they are prone to combustion instabilities, and an understanding of the physical processes responsible is urgently needed. This project concerns methods to predict and prevent these combustion instabilities. The full consortium involves twenty partners spread largely across Europe and India, with an even split between academic and industrial partners.
- (iii) Consultancy for the SUCCESSOR class submarine project, for which the expected research and manufacturing costs are £25 billion. Part of this work extended the research described in C. J. Chapman's Impact Case Study (on aircraft noise) to a new application area, namely underwater acoustics. Thus the impact of this research now extends to the government's plans for the next generation of nuclear submarines, an important part of the UK's future defence system.
- (iv) A grant from AMSTED Rail, a US railway company, to use neural networks to elucidate the dynamic characteristics of the forces within couplings. Advanced models of rigid body dynamics have been produced which will make possible the safe transportation of loads and aid the continual monitoring of structural integrity.
- (v) An EU grant of €240000 to develop a mathematical foundation for deterministic forecasting of rogue waves on currents in the ocean. The project resulted in identifying the situations in nature where a deterministic forecasting of rogue waves is possible and models able to forecast such events.

Three of Keele's institutional facilities which have been most helpful in promoting the above impact are (a) the Research Institute structure, especially the research institute for the *Environment, Physical Sciences, and Applied Mathematics (EPSAM)*, and the *Institute for Science and Technology in Medicine (ISTM)*; (b) the Keele Central Research Team, especially Research and Enterprise Services, which provides dedicated specialist support for business and enterprise engagement (c) Keele's use of external consultants to offer specialist advice on how to target grant applications to areas of most likely impact and funding, especially for very large EU schemes. The use of (c), vigorously promoted by Keele at the institutional level, was vital for the success of collaborations (i) and (ii) above; consultants provided expertise at every stage of the application process.

c. Strategy and plans: Keele has greatly increased its corporate investment in matters related to the impact of research, and plans to increase this still further. In particular, Keele has recently (a) created a Directorate of Marketing and Communications; (b) enlarged the role of Enterprise Development Managers and Technology Transfer Managers within Research and Enterprise Services, to encompass thematic impact priorities; (c) appointed externally a new Technology Transfer Manager; (d) appointed externally a new Head of Employer Engagement; and (e) made plans to enhance even further the interaction of Keele University researchers with companies in the campus-based Keele Science Park which houses around 45 companies employing more than 700 staff.

Impact template (REF3a)

The above mentioned corporate investment is rapidly helping to embed the impact agenda within staff thinking at all levels. Impact activities form part of the Annual Review of Research and are a key element of the research planning process. A university impact strategy has been established, with the appropriate key elements relating to the impact agenda included within the university's overarching strategic map. These key elements are listed below:

1. To have significant social, cultural, environmental and economic impact, working with external partners and collaborators to benefit society
2. To effectively communicate our research successes regionally, nationally and internationally to promote our distinctive contribution, raising our external profile and reach
3. To foster innovation and enterprise engaging with business and external partners
4. To foster relationships with research users and external stakeholders to facilitate the dissemination, impact and promotion of research outcomes

Within the RI, over and above central support, appropriate resources are allocated to support impact activities. At an individual level, discussion of, and targets for, impact activities form part of the annual appraisal process. Impact activity is now embedded in promotion criteria and an important part of the mentoring process for new appointments and early career researchers.

A number of mechanisms have been put in place to help support staff and PGR students in respect of the impact agenda. The PGR training programme has recently been strengthened to provide explicit training on researcher development and impact. *The Learning and Staff Development Centre* was established in 2011 with an externally appointed head. New courses have been developed related to maximising impact, communication skills, writing skills, enhancing use of social media for research. Additionally, some existing courses have had an increased focus on achieving impact and understanding, developing and commercialising IP.

d. Relationship to case studies: The impact of the research within the case study relating to aircraft noise illustrates two aspects of the power of the Keele Applied Mathematics Group's approach to achieving significant impact, namely (a) emphasis on tackling fundamental problems, of generic applicability; and (b) maintenance of long-term contacts with the research-workers in many scientific and engineering communities. In this case study, entitled 'The reduction of sound from aircraft engines', certain aspects relating to the acoustics of aeroengine ducts are detailed and have become widely known and used. However, the method and results obtained are generic, in that they apply equally to underwater acoustics, with allowance for the different values of the key engineering parameters. This led, via long-term scientific contacts, to Chapman's services being called on for consultancy work for the next generation of the UK's nuclear submarines, the SUCCESSION class. This is a very large project, involving a likely total spend of £25 billion, and the propulsor duct acoustics are of fundamental importance for security. Chapman's consultancy work has provided a valuable early input to the current Assessment Phase which terminates with 'Main Gate' in 2016.

The second case study on the rail-track noise of trains, entitled 'The modelling and control of curve squeal', arose from long-lasting collaboration with industry on a variety of sound and vibration problems. Contact with the company LB Foster Friction Management enabled Keele's analysis of the underlying stick-slip friction mechanism to be used in the development of a commercial product, Keltrack Top of Rail Friction Modifier, now used on railways around the world. This product has been of great significance in alleviating noise problems for millions of commuters and city-dwellers.