The Future of Engineering Research

The Royal Academy of Engineering

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Foreword

Engineering research plays a pivotal role in our knowledge-driven society. It lays the foundation for the advances in technology that fuel economic development and improve our quality of life. Over the past year, it has been my privilege to chair a series of discussion meetings held by The Academy to explore the key issues that currently pertain to engineering research in the UK. The Academy, in seeking to promote engineering excellence, identified through these discussions various trends in the engineering research environment that demand closer attention.

On the one hand, the more robust connection between the providers and users of technology that typifies the newer modes of research serves to enhance the efficiency of the research process and is therefore to be welcomed. However, more disconcertingly, the appeal of engineering as a career continues to decline and rapid action is now required to prevent a serious skills shortage in coming years.

These are just two of the themes that we have highlighted in this report. In raising these issues at the present time, we hope to focus the attention of the members of the research community, and those who influence it through policy and funding, on the fact that the lay of the land has changed in engineering research: we need to recognise this and adjust our strategies and plans accordingly, to maximise our productivity and avert impending threats to our future capacity to carry out world class research.

There are many people who have made invaluable contributions to this document and I particularly wish to thank Professor P Hutchinson FREng, Professor D Wallace CBE DL FREng FRS FRSE, Sir Howard Newby KB CBE and Dr John Taylor OBE FREng FRS, for their stimulating presentations at the discussion meetings.

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August 2003

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The Future of Engineering Research

Executive Summary

Engineering research critically contributes to the creation of wealth, health and well-being and underpins innumerable developments that enhance our quality of life. It is therefore vitally important that the UK maintains and improves its capacity to carry out world-class engineering research.

Past years have witnessed significant changes within the UK engineering research community. Industry, responding to competitive cost pressures, has dismantled many of the large corporate research laboratories in favour of outsourcing and leaner modes of research, in turn stimulating the emergence of large numbers of Research and Technology Organisations (RTOs) and technology-based small and medium sized enterprises. This has resulted in a more efficient industrial research process, with tighter coupling of users and providers of technology, but has also tended to reduce industry spend on both speculative long term research and translational research to convert promising technologies into demonstrators.

This market failure has been compounded by the privatisation or closure of many public research institutes that formerly carried out invaluable research of national importance on a large scale. The disappearance of these public research institutes also impacts on the ability of Government to obtain expert, impartial advice to inform policy making in areas such as communications, defence, transport and energy, with considerable repercussions for the UK engineering industry and research infrastructure.

In academia, there is a growing emphasis on commercialisation of research output, both within the university, for example by spinning out companies, and through industrial partnerships. The potential benefits of business-university collaboration are widely acknowledged and the value of much university research has been enhanced through the closer relationship between the providers and users of the research and technologies. Nevertheless, the primary objective of academia should be education and training and it would be highly inappropriate for pressure to be exerted on universities to produce near term returns on their funding.

Clearly, the future ability of the UK to generate economic and societal benefits from engineering is entirely dependent on the continued supply of skilled personnel. However, there has been an alarming decline in applications to university engineering departments in recent years, which together with the funding and staffing crises afflicting many of these departments, provides cause for extreme concern. Indeed, 46 engineering and technology departments closed in the period 1996-7 to 2000-1. Effective action is now required as a matter of urgency to mitigate further deterioration of the UK engineering skills and knowledge base.

Key Recommendations

- *Safeguard the supply of skilled personnel by*
  - Improving the quality of mathematics and physical science teaching in schools
  - Further increasing remuneration for PhD students, postdoctoral researchers and lecturers
  - Expanding efforts to promote the recruitment and retention of women in engineering
  - Incorporating business and communication skills into engineering degrees, as well as providing opportunities for business students and professionals to gain expertise in harvesting technology for profitable growth

- *Ensure close coupling of researchers or providers of technology and users by*
    - Continued strengthening of links between industry and academia
    - Exploitation-oriented funding of research
    - Connecting up providers of technology (eg. RTOs) with suitable business partners, eg. through Regional Development Agency services

- *Stimulate industry expenditure on research by*
    - Increasing Government funding for technology demonstrator projects and long term speculative research based in industry
    - Expanding or modifying tax credits or introducing other fiscal incentives
    - Expanding support for small and medium sized enterprises, eg. through Regional Development Agencies and Corporate Venturing UK

- *Introduce an integrated national research strategy to identify UK strengths and vulnerabilities and promote effective distribution of resources through Government departments and agents and the wider research community*

Introduction

Engineering plays a pivotal role in generating wealth, improving our health and well being and protecting the environment. Yet the contribution of engineering to our quality of life is often drastically underestimated. Engineering enables us to drive cars, surf the Internet, use microwave ovens and mobile phones and makes a myriad of other features of modern life possible. New advances in medicine, such as retinal implants to remedy blindness and surgical robots for remote operations rely on engineering. Engineering is critical for public health, providing safe and effective water supplies and waste disposal systems, and helps protect the environment with cleaner technologies for generating energy and new techniques for managing oil slicks. Engineering contributes to processes and infrastructure, through activities such as designing and managing transport networks and systems for trading in goods and finance. Indeed, it is hard to overstate the importance of engineering input to modern standards of living.

Engineering *research* generates the bank of knowledge and information that feeds future engineering developments. In other words, engineering research creates the understanding and insight required for the design and production of new engineering products and systems. It is therefore axiomatic that the UK needs to ensure that engineering research is effectively supported and promoted. Unfortunately, quite the opposite has happened over the past several years.

The UK is now facing a highly uncertain future with regards to its capacity to conduct world-class research across the various engineering disciplines. Student applications to and staffing levels in engineering departments of higher education institutes (HEIs) have declined precipitously and many departments are severely underfunded. Meanwhile, in industry large numbers of in-house engineering research laboratories have been dismantled and new business models for carrying out engineering research have evolved. All this is occurring against a backdrop of continuing globalisation where UK companies have to operate on an ever more competitive world stage. In the light of these developments, this paper explores the challenges and opportunities currently facing UK engineering and seeks to address the critical question: what is the future of engineering research in the UK?

What is Engineering Research?

Engineering is based on the rigorous application of mathematics and science to solve real world problems and design products and processes that benefit society and help to create wealth. Engineering has been defined[1] as:

'the knowledge required, and the process applied, to conceive, design, make, build, operate, sustain, recycle or retire, something of significant technical content for a specified purpose: - a concept, model, product, device, process, system or technology.'

Engineering *research* is, therefore, the uncovering of the knowledge and understanding necessary for engineers to design, implement and improve solutions. This research involves fundamental investigation into processes, behaviour, materials, design, mechanics and other areas of engineering interest that may prove useful in future engineering projects and/or systems. The research is a continuous and iterative process whereby any new information is fed back to the appropriate stage of design or development in order to refine the product or output. Moreover, a good engineering research strategy will look beyond basic design and production and will make life-cycle support for a product a key priority.

Technology
The word 'technology' is often used interchangeably with 'engineering'. Strictly speaking, technology is defined[1] as an *enabling package* of knowledge, devices, systems, processes etc., created for a specific purpose. However, in practice, there is a significant overlap in the usage and interpretation of 'technology' and 'engineering' and they are sometimes used synonymously. But revealingly, whilst engineering has acquired the connotation of a dry, uncreative and dull activity, technology seems to be considered cutting-edge and exciting. This distinction epitomises the widespread misconceptions regarding engineering and its contribution to society. Regrettably, these erroneous perceptions in turn impede recognition of the central role of engineering in wealth creation and quality of life and serve to diminish the appeal of engineering as a career.

The Engineering Research Community

Changing face of the UK engineering research community
Industry and public research laboratories, together with academic laboratories, used to be the major players in the engineering research community. However, many public research laboratories have been privatised and there has been a reduction in public institutional funding for Research and Development (R&D). In addition, industrial in-house research has often been selected against as companies respond to rapid technological change, globalisation and other competitive cost pressures. Instead, companies increasingly seek to outsource R&D, resulting in a concomitant expansion of technology consulting services and the emergence of a plethora of Research and Technology Organisations (RTOs). In the academic research arena, universities are having to search for alternative sources of income and there is widespread acknowledgement of the need for commercial activities in academia. The research community also, of course, includes a small number of private inventors and highly innovative individuals who perform their own independent engineering research.

The result of this transformation in the engineering research community is a situation where market forces play a much stronger role in driving research, thereby producing a research process that is inherently more efficient, but also vulnerable to market failure. In particular, anecdotal evidence suggests that there is less investment in long and medium term research and the transitional research that brings promising technologies to the demonstrator stage. These areas therefore need special support from Government to protect the integrity of the engineering base and ensure commercialisation of technologies that have been developed in the UK.

Implications for Government policy
It is important that Government, as well as other players in the research community, give due consideration to the changing landscape of engineering R&D in the UK, in order to understand how the overall research infrastructure and resources can best be integrated and supported within this new framework. Government policy in areas such as transport, communications, energy and defence exerts a powerful influence on the engineering research community and Government needs, therefore, to explore and anticipate the wider implications for UK industry and the supporting research infrastructure when developing such policies.

Benefits of an integrated national research strategy
Furthermore, it may be timely to consider whether UK engineering research could benefit from an integrated national research strategy. Government expenditure on R&D is channelled via many routes, including both streams of the dual support university funding system and various Government departments. With limited funds available, Government must ensure that there is a holistic and integrated strategy for research that coordinates the activities of the relevant Government departments and agents, as well as taking account of the changing face of the research community in the UK. This should significantly alleviate the fragmentation of research

and funding that has occurred previously, improve the national research infrastructure and safeguard the quality of expert advice being used by Government departments for evidence-based policy making.

Lack of investment in research, especially in industry
It is, however, also vital to recognise the fact that there is a danger that the UK simply does not invest sufficiently in engineering research, particularly in industry, which has to satisfy the needs of the shareholder with a shorter time horizon, and no amount of redistribution of funds or reinforcement of relationships within the research community will be able to compensate for this level of underfunding.

Industry

Disappearance of the big industrial research laboratory
Major industrial research laboratories have become increasingly scarce in the last 10 or more years as industry has responded to competitive pressures and sought to find more effective ways to carry out its research. Formerly, these industrial laboratories carried out essential applied research, transforming concepts for products into demonstrators, as well as contributing to strategic research of national importance. Their loss has impacted significantly on the R&D environment. Increasingly, industrial R&D is being outsourced to academic laboratories and other companies and RTOs are playing an ever more important role. There are also alternative models being employed by businesses wishing to access new knowledge: taking warrants or equity stakes in companies in exchange for intellectual property and using intellectual property itself as currency are becoming progressively more common. In some cases, large companies acquire new knowledge and research capability through taking over small companies with expertise and intellectual property of relevance to them. Whilst there is concern that the closure of the large corporate research facilities has negative implications for UK engineering, some of the new modes of industrial R&D have the advantage of effecting a closer coupling of providers and users of technology.

Lifetime of company versus lifetime of product development
A recent comparison of UK and US companies in the engineering, automotive and aerospace sectors suggested significantly greater acquisitions activity in the UK relative to the US between 1997 and 2000[2]. The high numbers of UK acquisitions have contributed towards a situation where the average lifetime of a company before takeover, major change of business direction or equivalent is now likely to be shorter than the average timescale for conversion of an idea or technology into a viable product or service. However, the time to market for a product or service is becoming more and more critical. The mismatch of time frames has changed the dynamics of, and therefore the approach of industry to, engineering research. In general, companies have become reluctant to embark on pioneering research that is unlikely to mature for maybe 10 years, and may not be prepared to pursue high-risk projects even if these could, if successful, yield genuinely revolutionary technologies.

Industry reluctance to undertake long term research impacts on UK innovation
The time lag between an innovative concept and a wealth-creating product or technology can be extremely lengthy, whereas the criteria for investment decisions to satisfy shareholder expectations demand a much shorter timescale. This gives rise to a classic 'market failure', whereby industry is no longer able to commit to a long term approach to engineering research. As a result, the contribution of the outputs of academic engineering research, which traditionally follows a more protracted timescale, is increasingly important. Government nevertheless needs to consider the extent to which the disinclination of companies to undertake speculative, long term research will be an inhibitor of future innovation and growth and whether there is a need to provide dedicated funds or incentives to promote and support these kinds of projects.

Industry still makes a vital contribution to UK engineering research

The above issues notwithstanding, there is still a great deal of important engineering research carried out within industry. For example in the Aerospace sector, companies such as Rolls-Royce and BAE SYSTEMS have maintained a significant research capability and many others perform valuable in-house research on a smaller scale. Airbus UK are engaged in a major R&D programme on the use of carbon composites for application to future wings for civil aircraft, combining many aspects of materials research, design principles for composite structures and manufacturing technologies for large structures. The project is supported with company, Department of Trade and Industry and EU Framework funding, using in-house resources and involving a substantial supply chain (including academic partners). It illustrates the valuable and distinctive contribution that industry, supported by Government, can make to engineering research, integrating multiple disciplines across the whole spectrum from basic research to technology demonstration.

Growing numbers of small and medium sized enterprises

In some sectors of industry, there is a marked trend towards small and medium sized enterprises. Companies such as ARM Holdings are small, innovative and highly successful. For the most part, small and medium sized enterprises carry out highly focussed research and clustering of companies performing complementary or related activities has proved to be an effective way of generating the critical mass necessary for efficient wealth creation without the massive resources previously deployed for research in large companies. Regional Development Agencies are devoting significant attention to supporting the development of clusters of local small and medium sized enterprises, resulting in substantial regional regeneration and helping to give the UK a competitive edge in certain technologies.

Industry needs to play a leading role in engineering research

The UK economy is deeply dependent on the health of industrial R&D. However, UK companies invest substantially less in R&D than their international competitors: according to the 2002 R&D Scoreboard, UK companies averaged an R&D intensity (R&D as a percentage of sales) of 2.2%, compared with a US average of 4.3%[3]. Moreover UK is one of only a few advanced economies in which business spending on R&D fell in proportion to Gross Domestic Product (GDP) during the 1990s[4], although there are signs that the situation may now be improving[b]. Government has recently expanded its R&D tax credits scheme, which should help to stimulate investment in R&D. However, the causes for the relatively low R&D spend of UK industry need to be thoroughly investigated and comprehended, and additional measures may be necessary to specifically resolve these issues.

Importance of being an 'intelligent customer'

Finally, it needs to be remembered that it is in industry's best interest to preserve a core capacity for research, not least because through maintaining a degree of personal involvement in the research work, a company is invested with the ability to be an 'intelligent customer'. Industry will only be able to fully exploit the results of outsourced research if it retains sufficient competence to understand what is being researched and how to apply it to marketable products.

Publicly-Funded Research Institutes

Loss of public research institutes

In past years, Government was the primary employer of research engineers and funded a large number of important national research institutes including the National Physical Laboratory at Teddington, National Engineering Laboratory at East Kilbride, Central Electricity Generating Board research laboratories, Royal Aircraft Establishment, National Gas Turbine Research Establishment at Pystock, British Steel laboratories, Railway Technical Centre in Derby and National Institute of Agricultural Engineering at Silsoe. However, several of these organisations, which both carried out research and provided funds to other bodies, have since been privatised. As a result, many of them are now contract research organisations competing for funds with the rest of the research community.

Wider consequences of privatisation
The privatisation and closure of these major public research institutes have significant ramifications for the UK. These public laboratories provided Government with important research capability, as well as being a crucial source of expert advice for informing Government policy. As mentioned above, there is a strong interdependency between, for example, defence, energy or transport policy and the underpinning and enabling science, engineering and technology. The ability of Government to design effective policy in these areas will be compromised by the absence of the services and resources provided by these facilities. Furthermore, public research institutes often generated innovative technology that proved useful to industry, thereby facilitating the creation of wealth and well-being in the UK. Meanwhile, senior management from major UK engineering companies report that it has become increasingly difficult to procure Government funding for research carried out in industry, driving many UK-based companies to transfer their research operations to other countries that are perceived to offer more favourable financial environments.

Research and Technology Organisations

What are RTOs?
RTOs are members of the engineering research community that are defined by the European Association of Research and Technology Organisations (EARTO) as:

'…organisations…which as their predominant activity provide research and development, technology and innovation services and which are managerially independent'.

RTOs play an important role in the new research environment
RTOs serve to link engineering research with industrial applications, supporting product and process innovation and developing new technologies. Critically, they provide industry with expertise, helping to compensate for the reduced intensity of in-house research and enabling companies to maintain a competitive advantage.

The UK has traditionally been perceived as having a world-class capacity for research but lacking in the ability to exploit the technology for the benefit of society. In other words, the UK has not been successful in reaping the wealth-creating potential of the technologies and ideas that it has developed. RTOs therefore serve a crucial function, assisting companies in this process of harvesting commercial (and societal) benefits from engineering research and technology.

Intermediate institutes, such as the Faraday Institutes, and other independent research organisations like the UK Aircraft Research Association and The Welding Institute are important parts of the UK engineering research infrastructure and some own major R&D facilities (e.g. the wind tunnels at the Aircraft Research Association) that are of strategic importance to the UK. There is an argument for Government, possibly via the Regional Development Agencies, to devote additional funds to facilitating collaboration between RTOs and industry - particularly small and medium sized enterprises - in order to further promote UK competitiveness through assimilation and best utilisation of technology in UK companies.

Academia: Research

A new role for academia in engineering research?
Academia has always been a key member of the engineering research community and the main sponsor of basic engineering research. However, with the decreasing numbers of large corporate laboratories, the narrowing focus and restriction of information emerging from the remaining industrial laboratories, and the privatisation of numerous public research institutes, academia is now having to provide additional capacity where generic engineering or issues relating to the public good are concerned. That said, the stronger links between industry and academia can be argued to have enhanced the value and relevance of much academic research and ensure that useful ideas and technologies emerging from universities have a more direct route to market. A close relationship between the research and user communities is of paramount importance in an applied subject such as engineering.

Distinctive nature of academic engineering research
Whereas industrial researchers may be expected to show a return on funding, Government (or its agents, such as the Research Councils) should not expect this in the short term but should recognise the 'training' element associated with academic research. The timescales associated with such work are too long and the connection between enabling technology and output too tenuous for Government investment to be generally considered as a commercial proposition. The key to industrial competitiveness is to move rapidly from research to a commercial product or capability.

Universities should be free to undertake near-market research where appropriate
Although it is extremely valuable that academic research has the freedom to focus on a much longer term horizon than is usually feasible for industry, there may be cases where it is appropriate for a higher education institute (HEI) to undertake research that is nearer to market. There are, however, reports of university applications to Research Councils being rejected on the grounds that the research is too close to market, the assumption being either that near-market research should not be carried out within an academic context, or that such research is likely to be of lower intellectual content. Both these suppositions are fallacious and result in the wasting of opportunities for the UK to regain competitive advantage in areas where national research may be strong but the relevant industry is weak.

'Public good' engineering needs support
A further important contribution that academia can make to engineering research concerns public good engineering. There are areas of engineering, such as construction, where technology may contribute to, but is not the major factor conferring, competitiveness. In these areas, research regarding regulations and codes of practice etc. can significantly impact on the sector, for example by ensuring best practice is followed by engineering companies and contractors. This type of research may also be undertaken collaboratively with professional bodies and trade associations, but irrespective, adequate funding opportunities must be made available.

Academia: Participation and Mission

Widening participation in higher education institutes
With Government aiming to raise participation levels to a point where 50% of young people enter higher education, it is clear that the university sector is set to continue expanding. Whilst The Academy considers the objective of increasing participation in higher education laudable, it is alarmed by the apparent drive to label all HEIs 'universities' and all tertiary education courses 'degrees'. For example, foundation degrees could provide much needed high-level vocational training, but the decision to brand them as 'university degrees' seems disingenuous

and is misleading both to the students and their potential employers. If degrees awarded by UK HEIs are perceived to have been devalued, there will be important ramifications in the global arena; UK students are likely to be disadvantaged in the international job market and the appeal of UK HEIs to foreign students will be tarnished.

Diversity of mission
Science and engineering research is more expensive than similar activities in the arts and humanities. With limited public funds available, there is a powerful argument that Government research support should be targeted to some extent on centres of excellence, rather than spread thinly around the whole higher education sector. This would require both the Research Councils and the Higher Education Funding Councils to increase their support, in relative terms, for the higher performing HEIs. International collaboration with other academic organisations should be the norm, as should cooperation with industry.

Those HEIs that are not considered to be top performers in research would then be endowed with an alternative mission, most likely involving a greater focus on near-market research and technology transfer. Applied research to develop demonstrators and trouble-shoot or refine existing technology to suit particular applications was formerly carried out by industrial laboratories, which as described above have become increasingly scarce. The less research-intensive universities could significantly contribute to this vital mode of research, without becoming service departments or 'dumping-grounds' for industrial problems. Indeed, the challenge is to render this kind of research attractive and valid and to avoid the impression that HEIs carrying out this work are of low status. The involvement of industry and companies coupled to the market will be crucial to the effectiveness of the translational process. Furthermore, support will be needed to help universities embarking on this alternative mission identify and build relationships with suitable business partners and vice-versa.

Obviously, this model does not exclude research-intensive HEIs from participating in knowledge transfer, for example through spinning out companies based on technology developed at that HEI and through industry-sponsored university technology centres. The proposal to develop HEIs with alternative missions envisages two types of HEI placing differential emphasis on either traditional research or translational and close to market activities, rather than two sets of institutions with mutually exclusive assignments.

Teaching and research should not be uncoupled
Furthermore, according to this model, in both categories of institution, teaching and research remain coupled, although the nature of research is distinct in the two types of HEI. The Academy is far from convinced that it is possible to maintain excellent standards of teaching in an applied subject such as engineering in an HEI that is not research active. This is especially true for the final years of undergraduate courses, as well as postgraduate courses.

Excellence should be funded wherever it occurs
The Academy fully acknowledges the potential benefits to be gained from developing centres of excellence. However, rather than attempting to artificially induce or assemble centres of excellence, existing centres of excellence should be supported and promoted. Centres of excellence are usually created by a set of exceptionally able people who for one reason or another find themselves in the same place. Sometimes they can be drawn to places by especially good facilities or particularly inspired leadership. Virtual centres of excellence can also evolve as a result of strong relationships between outstanding individuals or departments located in geographically dispersed locations. The Academy firmly supports the view that excellence should be funded wherever it is found. It is also worthy of note that centres of excellence could be established for HEIs carrying out world-class technology support and near-market research, in addition to the centres of excellence comprising research-intensive HEIs performing traditional engineering research.

Academia: Funding

Reform of the Research Assessment Exercise (RAE)
The Academy has previously highlighted the need for better metrics, which specifically take account of the wealth-creating nature of engineering research, for assessment of excellence in engineering research[5] and therefore welcomes the reform of the RAE that is currently under way. However, The Academy is apprehensive over the way that RAE ratings may be used to determine funding. Only approximately 40% of UK engineering departments were rated 5* or 5 in the 2001 RAE, so a policy removing funding from all but 5* and 5 rated departments would have grave repercussions for UK engineering, making mass closures of academic engineering faculties a very real possibility. Indeed, recent data has revealed that 46 engineering and technology departments were forced to close between 1994/5 and 2000/1[6]. Further loss of capacity would have potentially disastrous implications for the engineering skills and knowledge base of the UK.

Recognition of pockets of engineering excellence
Additionally, there are a number of engineering departments in UK universities that may not perform particularly well overall, but which contain small groups of engineers who are doing excellent research. These small research groups should receive strong support but regrettably are often overlooked. It is through these researchers and projects that the quality of a whole department can be raised. If blanket decisions are taken regarding the removal or drastic reduction of funding from all departments below a certain RAE grade, these pockets of engineering excellence will very likely be obliterated. For this reason, it is vital to incorporate a degree of flexibility when thresholds are being set for the allocation of Funding Council support.

Importance of incremental improvement
The current Engineering and Physical Sciences Research Council metrics seem to concentrate too much on the 'breakthrough' mentality and tend to ignore the goal of incremental improvement, which lies behind most examples of successful engineering that benefit the economy. Unfortunately, the 'incremental improvement' model is inconsistent with the erratic nature of competitive funding and the consequent lack of continuity for researcher development. It is therefore questionable whether the three year project-based research model is the most appropriate for serious engineering research.

The 'steward' model
One possible solution is the 'steward' model. According to this concept an individual or (preferably) a group of academics, deemed to be research-active, would be allocated an annual budget of £x for say a period of five years, based on an outline research plan. If the group is judged to be successful, their budget would go to £1.5x and if judged to be inactive, it would be reduced. A short annual or other report could be used to assess success or, conversely, inactivity.

An important advantage of such a system would be a substantial release of resources, which currently go into fundraising and the development of failed proposals. This is unproductive and dispiriting for all. System productivity might be considerably improved since a large proportion of academic research time is currently spent raising research funds and locating researchers. The Engineering and Physical Sciences Research Council has already gone some way towards adopting this model with the introduction of Platform Grants.

It is necessary to realise, however, that care must be taken to prevent this model of funding from inadvertently reinforcing past research ideas at the expense of providing support to new people and concepts. In addition, the stakes will be high in this method of grant awarding and the consequences for those who 'just lose out' could be very significant. It will be imperative to utilise a transparent and accepted scheme for assessment of steward grant applications and there must be access to other funding opportunities for those who do not qualify for steward model grants.

Importance of transparency
The complexity of the UK research funding system is not conducive to clarity and transparency. The need to confirm the existence of a funding gap in science and engineering research resulted in the 1998 Comprehensive Spending Review establishing a ‘Transparency Review’. This, in turn, led to the implementation of an activity-based costing system known as the ‘Transparent Approach to Costing’ (TRAC)[7]. HEIs now report annually to their Funding Council their aggregate costs relating to five areas of activity: publicly funded teaching; non-publicly funded teaching; publicly funded research; non-publicly funded research; and other activities.

TRAC has confirmed the existence of a funding gap but does not quantify its magnitude. It is necessary to combine the TRAC data with the income stream for the activity under review to reveal the real situation. The results for the five areas of activity in 2000-01 demonstrated that research was being cross-subsidised by income earned from non-publicly funded teaching and ‘other’ activities. Unfortunately, the TRAC data does not permit greater clarification of the cost adjustments of publicly funded research and non-publicly funded research. The Academy therefore would support the introduction of an agreed set of accounting standards for universities with the objective of achieving greater transparency in the use of public funds. If the source and destination of funding were more readily apparent, then confidence in university finances would be greatly strengthened. Adherence to these requirements would be a precondition of receipt of public funding.

Full economic costs of research projects
In recent years there has been a significant growth in research sponsored by third parties i.e. charities, industry, Government departments, EU. This has revealed a lack of clarity in the purpose of the Funding Council support of HEI research since it is not clear whether this is limited to supporting ‘blue-skies’ research and Research Council project funding or should subsidise other research sponsors as well. This uncertainty is now a major contributor to the funding gap, as HEIs are not incentivised to charge the full economic costs and non-Research Council sponsors do not see the need to pay more for overheads than that paid by the Research Councils. Clarification of the role of Funding Council support for research is therefore of fundamental importance. In addition, universities need improved financial management systems to enable them to cost research projects accurately.

The Academy welcomes the fact that the Office of Science and Technology is reviewing various aspects of the dual support funding system, with the intention of moving closer towards a system based on the full economic costs of a research project. The Academy is also pleased that Government has commissioned an investigation to identify mechanisms for reducing the burden that research funding systems exert on English universities.

Third-stream funding (knowledge transfer)
A knowledge driven economy demands the transfer of knowledge concerning ideas, research results and skills between universities, research organisations, business and the wider community if innovation is to flourish. Government has restated that the Higher Education Innovation Fund (HEIF) should form the basis of a permanent third stream of funding i.e. in addition to existing funding for teaching and research. The HEIF money is targeted at: work to promote enterprise in universities and networking between universities, business and other users of the outputs of research; the infrastructure to transfer knowledge through applied research, technology, knowledge development and consultancy; and the formation, through

seedcorn funding, of companies to spin out new knowledge, or the development of commercial enterprises to pursue the above activities.

Under the Comprehensive Spending Review 2002 settlement supporting these initiatives, including HEIF, total spending on knowledge transfer from the science base is to increase from £64 million in 2002/3, to £84 million in 2003/4, to £100 million in 2004/5, and to £114 million in 2005/6. There is a need therefore for a properly managed administrative structure to ensure that these funds are directed at those institutions active in this area.

Business – University Collaboration

It is clear that collaboration between industry and academia is necessary to ensure the best use of the total resources available for engineering research and can yield significant benefits for both parties, as well as for the UK economy. Collaborations can assume many guises including: industry sponsored undergraduate, postgraduate and foundation degrees; Knowledge Transfer Partnerships (formerly TCS, or the Teaching Companies Scheme); continuing professional development courses run by universities for industry; secondments of academics to industry and vice-versa; industry sponsored research projects, students, postdoctoral researchers and research chairs; major partnerships between universities and large companies; and major joint ventures, including regional centres and institutes. There are now several examples of best practice in business-university collaboration, for instance university technology centres, which have produced rewards for both industrial and academic partners.

Increase flow of personnel between business and academia
The exchange of personnel between HEIs and business should be facilitated and promoted, since this results in the transfer of skills, knowledge and technology and also improves mutual understanding and awareness between academia and industry. All of these serve to enhance the health of engineering research and can in turn facilitate the creation of wealth and societal benefits.

Obstacles to collaboration
Intellectual property is a common stumbling block and, not infrequently, a drastic mismatch in the expectations of the academic and industrial partners produces an impasse. Guidelines in the form of case studies, model agreements or a code of practice need to be constructed to inform future intellectual property negotiations.

University industrial liaison, administration and finance departments are heavily criticised by many industrialists. Academics, meanwhile, lament the short-term approach of some companies and the associated lack of continuity and follow up during a project. Additionally, both businesses and universities report that shortage of time restricts their ability to collaborate effectively. A further disincentive, particularly for academics, concerns the absence of formal recognition of and reward for successful collaborations.

Recommendations for successful collaboration
Constructive relationships demand mutual trust and a sound understanding of and respect for each partner's motivations and rewards structure. It is essential to formally agree the project aims, conditions and deliverables, with expected timescales, at the earliest possible opportunity and the construction of a collaboration roadmap can be of great utility.

Government funds and assistance for identifying potential areas and partners for collaboration, providing high quality management and administrative support and advice and promoting the interflow of personnel between academia and industry would certainly make a positive impact on business-university collaboration. Access to the available support also needs to be simplified and Regional Development Agencies could play a central role in delivering these services, especially since many of the most successful collaborations operate at a local level.

Safeguarding the Supply of Skilled Graduates

Dwindling popularity of engineering degrees

Accepting that the future of the national wealth creating capability depends substantially on the knowledge and skills of the working population, the dwindling supply of engineering graduates is a cause for extreme concern. In 1991, engineering attracted 10.7% of all accepted domestic higher education applicants processed by the Universities and Colleges Admissions Service – by 2001, this figure had fallen to 5.2%[8]. The Academy is extremely disturbed about the potentially detrimental impact that the introduction of student contributions to degree courses could have on these already dismal statistics, particularly if fees were allowed to be adjusted to account for the relative costs of the subject course. Engineering is an unavoidably expensive subject and hefty fees would produce a highly undesirable scenario in which participation was effectively limited to students from more privileged backgrounds.

Basic mathematics and physical science skills

A recent survey of UK Deans of Science conducted by Save British Science indicated that on 70% of undergraduate physical science courses, less than 50% of students were considered to possess the required level of mathematics skills[9]. Indeed, the current low standards of basic mathematics and physical science education in the UK are having direct repercussions on the capacity of undergraduate engineering students to meet the demands of their courses. The inadequacy of the numerate skills being produced by the primary and secondary education systems therefore needs to be rectified as a matter of extreme urgency. This is likely to require both alterations to the curriculum and further incentives to augment the recruitment and retention of able and well-trained mathematics and science teachers.

Modernisation of degree courses

At the degree level, modernisation of university degree courses through the incorporation of subjects such as business and communication skills into the syllabus could help to broaden the appeal of engineering, as well as producing more rounded graduates. Several companies who employ large numbers of engineers and technical staff have been forging close links with universities, for example by sponsoring degree courses and offering placements for students, in order to propagate the supply and improve the quality of engineering graduates. This practice has yielded positive results for both the sponsor and the university and should be encouraged.

Image of engineers

More generally, engineering has a fundamental image problem, being commonly perceived as an uncreative, unattractive and materially unrewarding career. As industry has increased the outsourcing of R&D activities, the status of the technical specialist has fallen even further, deterring ambitious, high quality graduates from aspiring to this position. Furthermore, the poor career progression and salary prospects for those engineers who remain in academia provides another disincentive to those making career choices. Increased recognition of the value of technical specialists, and engineers in general, requires a change of culture and attitude as much as an improved remuneration package.

Promoting participation of women in engineering

The dearth of female engineers, especially at higher levels, is at last beginning to receive much needed attention. The Government has recently launched a range of initiatives, costing a total of £1.5 million, to support women in science and engineering. This is a promising start, but much remains to be done to render engineering a genuinely attractive career for women.

Multiple approaches are needed to target school-aged children, university applicants and students, women who are already taking career breaks and women who are returning from career breaks. The programmes to encourage girls to pursue engineering as a career must be backed up by concrete schemes to remove the obstacles that have caused many women to abandon engineering careers. For example, grants should be available for women returning to work after career breaks to undergo a short, intensive period of training to update their skills and knowledge, and women taking career breaks should be given access to relevant journals and other sources of information to enable them to keep abreast of important developments during their time away from work. In addition, provision of female mentors has proved invaluable for helping young women in engineering to succeed in the, largely male-dominated, workplace.

Shortage of high calibre domestic PhD students
The reluctance of engineering graduates to remain in academia (even in the short term) has a significant impact on engineering research. Research groups cannot find high quality PhDs and indeed many supervisors have remarked that overseas candidates are of better calibre and in more plentiful supply than UK-domiciled students[10]. However, the UK funding system and the difficulty of obtaining work permits (for non-EU students) impede the ability of UK laboratories to attract foreign doctoral students, even if they are exceptional candidates. These policies threaten the capability of UK research groups to maintain world-class standing, whilst the lack of UK-based students of sufficient quality endangers the supply chain of skilled personnel into UK industry and academia.

Demographic time bomb for UK university engineering departments
Indeed, there is a 'demographic time bomb' for engineering caused by growing numbers of academic staff reaching retirement age by 2010 and exacerbated by the lack of UK engineering students wishing to follow academic careers. Staff numbers in university engineering departments are steadily falling and an increase in recruitment rates of between 22% and 36% over the next seven years is required just to maintain the current numbers of staff[7]. In reality, many institutions already have severe difficulty in recruiting and retaining staff in engineering-related subjects.

A yet more pressing concern is that the percentage of younger academics in engineering departments is falling even more rapidly than the other age categories, with the percentage of staff under 30 almost halving between 1995 and 2000[11]. Collectively, these data herald an impending crisis in staffing levels at university engineering departments. The Academy has already identified a number of issues that are detrimental to engineering staff recruitment and retention, such as low salaries, working conditions of lecturers and the inappropriate use of short-term contracts. Many of these were also highlighted in the Roberts' Review of the supply of people with science, technology, engineering and mathematics skills[12]. Some of Sir Gareth Roberts' recommendations, such as increasing PhD stipends, are starting to be implemented, but many more measures urgently need to be undertaken to address these problems.

Lack of skilled entrepreneurial technology managers
Harnessing technology for profitable growth depends on the UK developing both business people who are technologically literate and entrepreneurial engineers. This should result in a technology 'push' and business 'pull' that synergise to expedite the process of wealth generation from new or improved technology. Business and entrepreneurial skills are already beginning to be injected into engineering courses and it is vital that such moves are supported and complemented by expanding the opportunities for business students and managers to develop expertise in harnessing technology for wealth creation.

Conclusion

Engineering research provides the foundations for many aspects of modern life. The economic and societal benefits of a thriving and dynamic engineering research community in the UK would be considerable. Conversely, the demise or deterioration of UK engineering research would have dire and far-reaching consequences for the ability of the UK to compete in the global marketplace. The current vulnerability of the position of UK engineering research is therefore a cause for serious concern.

On the one hand, the UK engineering research community has much to be proud of and encompasses a large number of highly-skilled and talented individuals who have made significant achievements over past years. The future capability of the UK to maintain this reputation is, however, under real threat due to a multiplicity of factors. The dwindling supply of skilled graduates, the staffing and funding crises in HEI engineering departments, the inadequate levels of investment in engineering research, particularly in industry, and the decline of public research institutes have all conspired, within the context of increased global competition, to place UK engineering research in an extremely precarious position. The gravity of this situation must be recognised. Lessons must be learnt regarding how the erosion of the UK infrastructure and personnel supply came to pass. Steps, such as those suggested below, must be taken to reverse these negative trends, before the attrition becomes irrevocable.

Key Recommendations

Supply of skilled personnel

The future of engineering research in the UK is wholly dependent on a continued supply of well-trained personnel. Although several other countries are also suffering from the waning popularity of engineering degrees, there is evidence suggestive of a relative abundance of high-calibre overseas applicants for UK-based PhD studentships compared with UK-domiciled applicants. The Academy urges Government to:

- Improve the quality of mathematics and physical science teaching in schools
- Further increase the remuneration for PhD students, postdoctoral researchers and lecturers
- Expand efforts to promote the recruitment and retention of women in engineering
- Incorporate business and communication skills into engineering degrees, and provide opportunities for business students and professionals to gain expertise in harvesting technology for profitable growth

Close coupling of researchers and users

One of the most positive changes that has occurred in relation to UK engineering research is the progressively closer coupling between those who fund and carry out research and the end users of the technologies. This must be built upon and enhanced in coming years, for example by:

- Continuing to strengthen the relationship between industry and academia by increasing the interflow of personnel and supporting business-university collaboration. Establishment of a code of practice for collaboration, including guidelines for intellectual property negotiations, and the introduction of an agreed set of university accounting standards would greatly facilitate this process
- Funding research in HEIs in such a way that the exploitation of research is rewarded and researchers are encouraged to interact with the potential users of the outputs of their research
- Helping to connect up researchers and providers of technology (eg. RTOs) with suitable business partners, for example through Regional Development Agencies

Stimulating R&D in industry

Industry has a leading role to play in UK engineering research by carrying out important strategic research, as well as bringing technologies and concepts to market. Government needs to address the factors which are currently inhibiting business expenditure on R&D and introduce measures to stimulate industrial research spending. These should include:

- Increasing the Government funding available for technology demonstrator projects and long term speculative research based in industry
- Exploring benefits to be gained from further tax credits and other fiscal incentives likely to augment business expenditure on R&D
- Expanding support for small and medium sized enterprises, for example through Regional Development Agencies and Corporate Venturing UK

National research strategy

Government has to combine short term research priorities with longer term objectives that safeguard the integrity of the national research infrastructure. In addition, Government must retain a sufficient research capacity of its own to inform policy making on a wide range of vital topics, both now and in the future. Considerable complexity is imparted to these tasks by the multiple routes for dissemination of Government funds to scientists and engineers. It would therefore seem that the UK would benefit from having a national research strategy to identify UK strengths and vulnerabilities and promote effective distribution of resources throughout Government departments and agents and the wider research community.

References

1 'The Universe of Engineering – A UK Perspective' (2000), The Royal Academy of Engineering, London http://www.raeng.org.uk/policy/reports/

2 'Total Shareholder Returns from acquisition growth contrasted with those from organic growth based on R&D investment' (2002), Harding B, in conjunction with the 2002 R&D Scoreboard http://www.innovation.gov.uk/projects/rd_scoreboard/harding/harding.htm

3 '2002 R&D Scoreboard' (2002), DTI and Company Reporting Ltd http://www.innovation.gov.uk/projects/rd_scoreboard/introfr.html

4 'UK Competitiveness: moving to the next stage' (2003), Porter, ME and Ketels, CHM, Department of Trade and Industry Economics Paper No. 3

5 'Measuring Excellence in Engineering Research' (2000), The Royal Academy of Engineering, London http://www.raeng.org.uk/policy/reports/

6 'Science dies out in English 'deserts'' (2003), Fazackerley, A, The Times Higher Education Supplement 11July 2003

7 'Transparent Approach to Costing (TRAC)' Volumes 1 and 2 (2000), Joint Costing and Pricing Steering Group (JCPSG), Higher Education Funding Council for England

8 'Digest of Engineering Statistics 2002' (2003), Engineering Council (UK) and Engineering and Technology Board, London http://www.engc.org.uk/publications/statsdigest/Digest2002.pdf

9 'Skills and knowledge of science students entering higher education' (2003), The Save British Science Society, London http://www.savebritishscience.org.uk/texts/documents/2003/SBS0313.htm

10 'Doctoral Level Research Students in Engineering: a national concern' (2002), The Royal Academy of Engineering, London http://www.raeng.org.uk/news/publications/submissions/

11 'Academic staff: trends and projections' (2002), Higher Education Funding Council for England http://www.hefce.ac.uk/pubs/hefce/2002/02_43.HTM

12 'SET for Success' (2002), Sir Gareth Roberts, commissioned by HM Treasury, DTI and DfES

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