# The Advanced Railway Research Centre at the University of Sheffield

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## Development of Technical Railway Research in UK

Railways developed in England and acted as a catalyst to the country's remarkable economic development up to the latter years of the nineteenth century. The early technology was practical, empirical and pragmatic; in a way that mirrored engineering development as a whole. The practitioners were largely men of limited scientific education—the universities of the time were primarily concerned with classical and religious studies and played little part in the formation of railways. Indeed, they often adopted positions of opposition which, for example in the Cambridge of today, means that the city railway station is inconveniently sited away from the centre. What research existed was as fragmented as the then private ownership of the industry. Nevertheless, the railways of Britain have always been major users of industrial research, but in an opportunistic way rather than as promoters of fundamental research activity. The early railway laboratories, and some were established at very early dates, such as Crewe in 1864, were largely service departments, conducting 'defensive' research or development which was concerned with applying scientific knowledge and methods to existing railway practices. Only as recently as the early 1960s was a national programme of 'offensive' technical research pursued by a then nationalized British Railways. These activities were brought together on a single site with the opening of the BR Research Laboratories in Derby in 1964.

## Why did BR board set up Advanced Railway Research Centre?

About 3 years ago, the British Railways (BR) Board commissioned a study into both the quality and quantity of technology being provided by universities to help support railway operations. The results were disappointing; there was little recognition by the universities of the technical challenges in engineering, of the management of operations, of communications, of information systems, etc. Where there was involvement, it was generally uncoordinated, unfocused and lacking critical mass. As a result, BR was being increasingly poorly served by universities in terms of research findings, reputation and kudos, high-calibre graduates and technical training. The Board therefore decided that its corporate objectives would be best served by the setting up of a vehicle for an integrated university research programme, which was officially launched in April 1994 as the Advanced Railway Research Centre (ARRC) in the Department of Mechanical Engineering at the University of Sheffield.


■ Sheffield Supertram *(ARRC)*

The reasons for choosing the University of Sheffield were several, but amongst them was the personal contact built up with the BR Board over a number of years by the author of this article; contact included membership of the Board's Research and Technical Committee, participation in various investigations such as operations in snow conditions and the use of secondary door locks, and Chairmanship of the Steering Committee of BR's Crashworthiness Research Programme. Of greater importance, however, was the excellent reputation of the Department of Mechanical Engineering at the University of Sheffield. As the British Government has reduced the funding to UK Universities, it has taken a much closer interest in their performance. This has lead to programmes of assessment of the quality of research and the provision of teaching. By strenuous efforts over the past decade or more, the performance of the Mechanical Engineering Department at

Sheffield has steadily improved, culminating with the award of top ratings in both research and teaching—the only Mechanical Engineering Department in England to achieve such distinction. At the date of the launch of ARRC, the author was Head of the Department, but from 1 October 1995, ARRC has been supported by the award of a Research Chair from the Royal Academy of Engineering and British Rail, enabling him to combine the Chairmanship of ARRC with much closer day-to-day contact with ARRC's teaching and research activities. It is therefore with pleasure that the author records thanks for the support of the immediate past Chairman of BR, Sir Bob Reid and his Board Member for Engineering, Dr Peter Watson, for the confidence they have demonstrated in setting up ARRC and to the continuing support and enthusiasm of the present Chairman and Chief Executive of BR, John Welsby.

As these developments were unfolding over the last 3 years, the Government's plans to privatize BR were announced. As reported at length elsewhere, these plans involve a complicated split of the railway industry into an infrastructure company (Railtrack), vehicle-owning companies and many operating companies. Much effort has been expended in this reorganization and in the foreseeable future it is clear that long-term strategic research will not be high in the newly-created companies' priorities as they struggle to create a sound financial base. These events further emphasize the important role that ARRC can play in stimulating and encouraging research in the 'new' British railway industry.

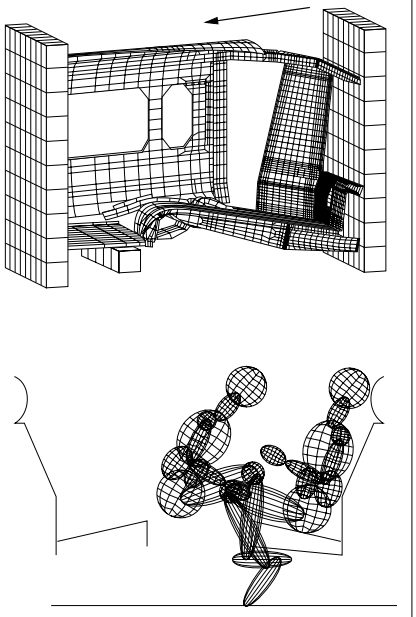
It is useful to state the three key objectives of ARRC before reviewing each one:

1. To establish a programme of research projects within universities addressing subjects of importance to the rail industry,
2. To provide an agency and information service matching the needs of industry to the resources of university departments and identifying suitable sources of funding, and
3. To establish a programme of conferences, seminars and training for the rail industry, especially an MSc programme in Rail Systems Engineering.

## University Rail Research

One of the first tasks undertaken by ARRC, was a review of university railway-related research being conducted in the UK. Among the major contributors are the Universities of Birmingham (Electrical Engineering), Leeds (Transport Studies Group), Loughborough (Suspensions and Dynamics), Newcastle (Mechanical Transmission), Nottingham (several areas of Mechanical, Electrical and Civil Engineering), Coventry (Manufacturing) and Imperial College, London which houses a BR-supported Railway Technology Strategy Centre. More than twenty other universities were identified which carried out significant work on rail systems. In an effort to gather these efforts together, ARRC organized a major meeting, 'The Railways: Challenges to Science and Technology' at the Royal Society in London in April 1995. Leading authorities from the railway industry made presentations based on the premise that factors such as cost, technology, quality and the environment will be instrumental in the railway industry of the future. In this way, barriers to the implementation of existing technology were determined, emerging technologies were identified and areas needing R&D were established.

This meeting generated considerable interest, over 200 delegates attended and contributed to an informal discussion. Both the presentations and edited discussions have been published as a book which will aid wider dissemination of the topics discussed. As a follow-up, ARRC will coordinate a university exhibition within the 1996 Railtech International Congress to be held at the National Exhibition Centre, Birmingham, in May. This will provide an opportunity for university research groups to display their work, illustrate how they are responding to the challenges identified at the previous meeting and to meet potential sponsors from the new players in the UK railway industry and elsewhere.



Structural and crash study simulations

## Rail Research at Sheffield

It is clear that for the foreseeable future in the UK, the primary requirements of rail technology will be to produce cost-effective solutions to customers' demands for transportation. Although some recognition of the wider social and economic impacts of rail systems are belatedly being recognized, the immediate problems revolve around reversing the decline of rail's mode share of passengers and freight, reducing costs of operations and applying existing technology to produce economic solutions. Considerations of a longer-term strategic view, will be discussed later. Accordingly four initial programmes of ARRC research were established:

Affordable and Safe Rail Vehicles
Train Control and Operations
Affordable Rail Systems
Low-Cost Infrastructure

Some idea of the diversity of the research currently being funded by ARRC can be gauged from the topics

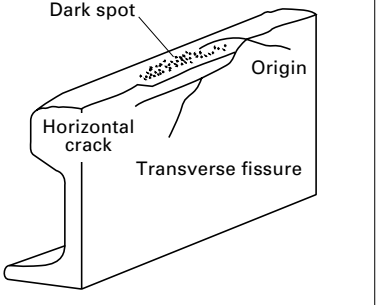
covered at a recent meeting of the Ph.D. students supported at the University of Sheffield by ARRC. The students, ten in total, all at various stages of their study, were asked to summarize the main objectives of their programmes.

Two students started their research before the launch of ARRC and one has been awarded the Ph.D. degree, the other will be examined in the near future. Both have been working on the crashworthiness of rail vehicles. Following two major accidents in the UK, concern arose about the basis of the structural design of railway vehicles and a major programme was instituted at BR Research, Derby, to investigate better designs to minimize the risk of death and injury of passengers. As part of this work, our students have been involved in the use of non-linear finite element (FE) calculations to predict the crush load against distance characteristics of vehicle ends, the use of lumped parameter spring/mass models to investigate the sharing of energy absorption at the interfaces of a rake of carriages, and in the FE modelling of the interactions of passengers with vehicle interiors during the inevitable secondary impacts arising from a train collision. A further student is now starting a project on the use of stainless steel in energy absorbing crashworthy structures. A specific part of this study will be dynamic crushing of spot-welded stainless steel structures undertaken to compare the effects of manufacturing joining methods on the geometry and hence the energy absorbing capability of the collapsing structure. Although stainless steel is used for rail vehicle structures in many countries, particularly the United States and Japan, its use in the UK is minimal. As sons of the city of Sheffield, the birthplace of stainless steel in 1913, we find this strange!

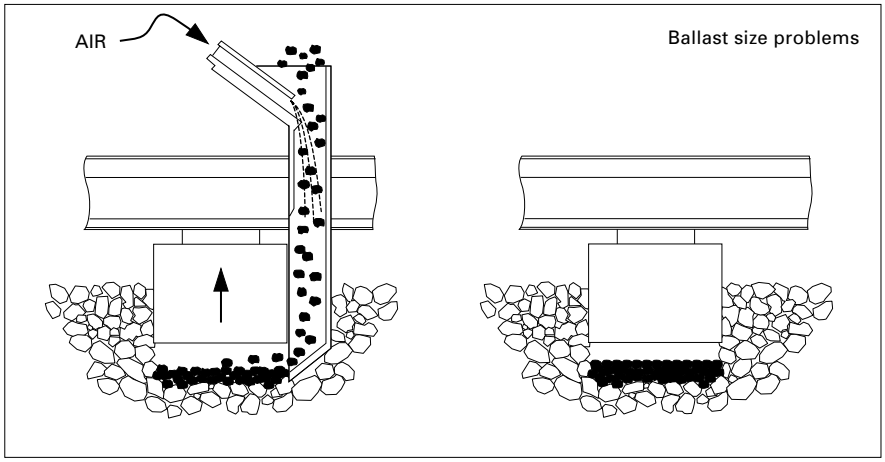
Many of the internal fittings of rail vehicles can be made from composites, designed to decrease weight whilst maximizing strength. Indeed, several recent vehicles have used composites for the main external structure. A programme is underway on the testing of sandwich composite materials, which are designed to be reliable and predictable, fail at a predetermined load level and provide stable progressive crushing with high levels of energy absorption. By linking the properties of these kinds of materials to bio-mechanical injury criteria and by controlling the forces resulting from deceleration by designing crushable vehicle ends, it is envisaged that the rail vehicles of the future will incorporate best engineering knowledge, without increasing manufacturing costs, in order to maximize passenger safety.

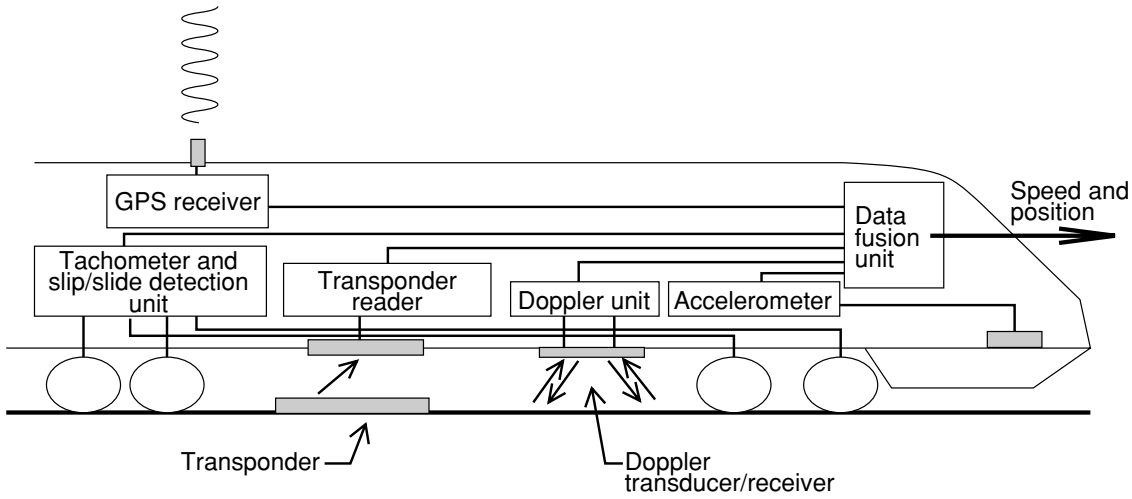
Several students are working with staff members Professor Beynon and Dr Kapoor on problems associated with damage accumulation and ways to minimize failure and improve the life of rails. These studies range from fundamental investigation of the mechanisms and mechanics of the initiation and propagation of rolling-contact fatigue cracks at and just below the running surface, to practical problems concerning the lubrication and grinding of rails to minimize wear or reduce the risk of fatigue failure. These studies build on the strengths of the Mechanical Engineering Department at Sheffield, where under the guidance of Professor Miller, a team of world experts has formed the Structural Integrity Research Institute (SIRIUS) with particular strengths in fatigue and fracture. Wear and the effect of lubrication on rail steel will be attacked both theoretically and experimentally, by the use of a disk testing machine available in our laboratories. It is worth noting that the grinding study is being partially supported by the Railway Technical Research Institute (RTRI) in Tokyo, who are interested in optimizing the depth of grinding cut and the frequency of grinding operations carried out to remove developing fatigue damage from the rail head. Although lubrication is often applied to reduce wear, it may accelerate fatigue damage by pressurizing developing cracks when oil becomes trapped within cracks during the passage of a wheel. One of the aims of our research is to assist the decision-making process by developing knowledge about the links between rate of crack growth, traffic levels and lubrication.

A civil engineering aspect of infrastructure research is covered in our project on the investigation of the dynamic behaviour of a two-layer ballast system. This relates to the tendency of smaller ballast to accumulate under sleepers (ties) during tamping operations carried out to restore track geometry. Repeated



Rolling contact fatigue of rails





New train control system under R & D

tamping exaggerates this tendency, causing the supporting layer to become weaker, leading to an increased frequency of tamping, etc. This project aims to quantify the behaviour of this graded ballast and to seek palliatives to overcome its weakened action.

A further infrastructure project is being conducted in the Department of Automotive Control and is concerned with the measurement of position and speed of trains in order to maximize the benefits of Automotive Train Protection (ATP). The benefits of efficient ATP to maximize infrastructure utilization are well known and include decreased headway, increased capacity and decreased energy consumption. This project is an investigation of the merits of several position/speed measuring systems, such as Doppler frequency shift, spatial patterns of radiowaves and satellite technology, to investigate a sensor fusion technique coupled with Kalmen filtering, to produce a result of greater accuracy and stability than would be obtained from any one method above.

Although these projects cover aspects of mechanical, civil, electrical and control engineering applied to railways, in no other project is the 'systems' approach better illustrated than in our studies of the technical aspects of railways environmental impact. A major review of the environmental effects of railway systems has been undertaken. Although concentrating on technical issues associated with noise generation and pollution production, 'soft' or policy issues concerned with land take, visual impact and costs associated with accidents were included. The importance of the system boundary used to compare rail with competing modes of transport was emphasized. It is becoming obvious that worldwide railways have an important role to play in overcoming the problems of congestion and pollution caused by automobiles. It is also apparent that to optimize the advantages of rail travel, load factors need to be high and that continual improvement needs to be made to match the improving pollution performance of modern automobiles. It was also identified that in order to make useful comparisons the techniques of 'cradle-to-grave' life-cycle costing based on energy and material use need to be redefined.

## ARRC as Agency and Information Service

There are specific funds available in the UK and EC for research at universities and ARRC has a role in promoting the direction of these funds towards research in rail transport. Very often these funds are accessible to partnerships between university and industrial research collaborators, and ARRC can act as the 'middle ground' to initiate and strengthen such partnerships. Seminars have been held for industrial contacts at which the available routes to European funding have been emphasized. ARRC has also become a focal point for European research projects in land transport for small-to-medium sized businesses. The UK government has announced the setting up of a new programme of research within a larger grouping called Innovative Manufacturing Initiative (IMI), directed towards the land transport industry to stimulate more innovative approaches to production methods. ARRC has produced a report on the rail sector, laying out proposals for a programme of research in light and heavy rail. The production of this report entailed widespread consultation with UK industry and elsewhere.

A pilot issue of an information-briefing bulletin has been produced containing titles and summaries of published railway research from a worldwide range of journals, reports and conference proceedings. With many new small players entering the UK rail industry, it is felt that this kind of rapid technical dissemination of knowledge will be much needed. It is our intention to develop this service and offer a subscription-based circulation to interested parties.

At the time of writing, the BR Research Centre at Derby is in the process of being sold from Government ownership as part of the rail privatization process. Whilst the details of its future ownership are not

yet known, ARRC is committed to work in close partnership with BR Research, to assist wherever possible in forming linkages with new sources of funding and generally to promote the cause of railway research to increase the potential market. In order to maintain a close relationship, the Managing Director of BR Research, Dr Maurice Pollard, sits on the ARRC Management/Steering Group. Several joint projects are being formulated and this programme will be expanded when circumstances permit.

It is apparent that the rail industry is rapidly blossoming from national units to become much more international. ARRC intends to be a thoroughly international organization, both in its research, its contacts and in its role in technology transfer. Although good links have already been forged with many countries, our links with Japan are perhaps the strongest. Over a period of several years, we have had close contact with JR Central, and latterly with JR East. An innovative course in Mechanical Engineering with Japanese Studies has involved some of our undergraduate students being guest trainees at JR Central's maintenance depots after a period of language/engineering training at Kyushu University with prof. Y. Murakami. An invitation was extended by JR Central for a team of young engineers from the UK to spend four weeks with the team testing the 300-X experimental train. Accordingly, in November and December 1995, one ARRC research assistant and two engineers from BR Research, Derby, participated in a highly-successful testing programme in Japan—an opportunity for which we are very grateful.

## Training and Education

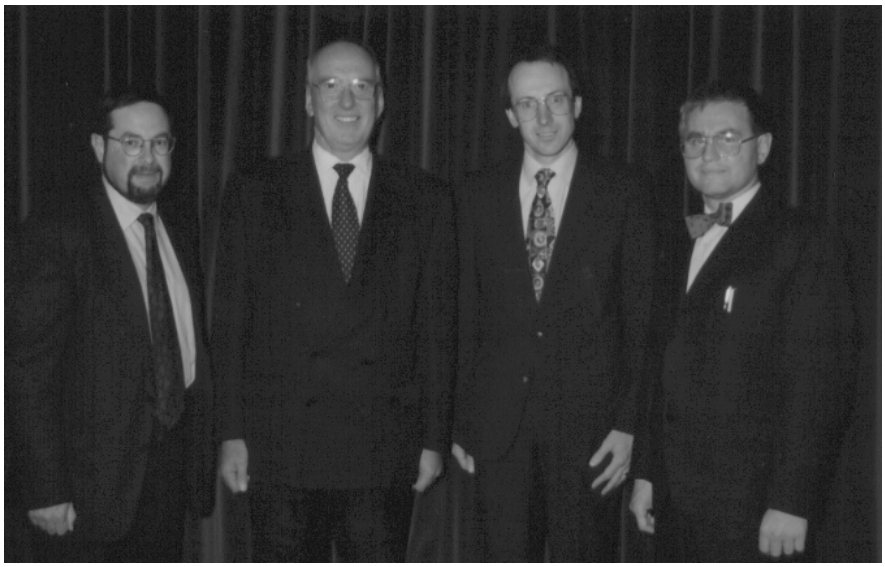
The major educational role played by ARRC is its Masters degree course in Railway Systems Engineering. This course was launched by the Chairman of BR early in October 1995. Both he and the previous Chairman hold the view that engineers should be trained across engineering boundaries, because the complexities of railway technology of the future will not be restricted to, for example, Mechanical, Electrical and Civil boxes. It was felt appropriate that specialists in any one branch should have more than a nodding acquaintance with the techniques and the technologies of other areas and that communication between practice of these specialties would be much improved by cross-boundary knowledge.

Accordingly, the staff at ARRC have planned a Masters' course meeting these requirements. Mindful of the need to minimize absence from the workplace, the course has been designed for flexible delivery of modules, which can be spread over 1 or 2 years. The course includes major input from the Universities of Birmingham, Loughborough and Imperial College. To ensure that the lecturers are the best available, they have been recruited from a wide industrial and university base.

Although the course was launched because BR recognized the need for professional training, the first group of registered participants have demonstrated that the need is much more widely felt. Of the 30 students registered so far, 12 are sponsored by BR, some come from companies such as GEC and ABB, while internationally, we have students from Hong Kong, Singapore, Egypt, Switzerland and China. Amongst the BR companies represented are Intercity Cross Country, The Engineering Link, BR Research, British Rail Safety Directorate, Regional Railways, North East, Crossrail and BR Freightliner. This spread of students gives them the opportunity for 'networking' early in their careers and we see this as an important selling point in promoting the course worldwide. We anticipate the numbers on the course in subsequent years to stabilize to about 35; the first intake of 30 exceeded our wildest expectations.

The main mode of course delivery is through lectures arranged in intensive week-long modules, augmented by technical visits to such sites as Sheffield Supertram, BR maintenance depots, ABB Derby, BR Research at Derby and the GEC Alstrom test bed at Preston. One module will be a Northern European Tour including visits to railway sites in France, Belgium, Holland, Germany and Scandinavia.

The teaching and learning experiences offered by the course will combine technology with human issues, whilst strongly emphasizing the systems nature of railways. It is hoped that some of the kinds of fragmentation difficulties seen in the early stages of rail privatization in the UK can be overcome by all-embracing courses like this. A major feature of the course so far has been the active



■ Author (left) with John Welsby, BR chairman, (centre left) at launch of ARRC Masters course. *(author)*

participation of the delegates, who generally speaking, are so experienced in the railway industry it is inappropriate to call them students. Sharing of collective experience has been a very positive feature of the teaching/learning experience enjoyed by both participants and lecturers.

In addition to the Masters course modules, ARRC has run a series of seminars on technical and managerial issues of concern to the railway industry. Keynote speakers have addressed topics such as Public Transport and Social Benefits, The Future of Light Rail, Passenger Interfaces and Cost Implications of Track Dynamics and Wear. We were privileged to have visitors from JR East talk about the half-life, half-weight, half-cost Series 209 commuter cars. At this and other seminars, a wide audience from both university and industry, was able to learn about and debate current developments. Future seminars include Advanced Control of Railway Dynamic Systems, Technological Challenges of the Environment and Train Simulation and Control.

Students from Germany and Austria have joined us in Sheffield for periods of study lasting up to 6 months. Their projects have included studies of cost-effective light rail systems and the progress of rail privatization in the UK.

## Links with National Research Policy

The UK government has recently launched 'The Technology Foresight Programme'. Some 10,000 individuals have been involved in the first round of Foresight, which aimed to identify opportunities for wealth creation and improving the quality of life 10-20 years hence. The main questions addressed by the Foresight process include:

What are the likely social, economic, environmental and market trends over the next 10-20 years?

Which areas of R&D and underpinning science, engineering and technology best address these future trends?

How best can public funds be used to sustain an innovative science base to support future material prosperity and quality of life?

To what extent should regulation, skills, educational facilities, and other factors be taken into account?

Fifteen panels have been formed covering subject areas including Transport, Communications, IT, Energy and Manufacturing Materials. The panels canvassed viewers through a wide variety of means: a large-scale Delphi survey, 60 regional workshops, conferences, interviews, written submissions and interaction with relevant overseas bodies. ARRC participated fully in this process.

The report of the Transport Panel made the following key recommendations:

To develop technologies to manage more effectively the interfaces between and within transport modes for people and freight - the application of IT will be particularly relevant, and identified that further work was needed in the following key generic technologies and scientific research:

a. High-strength, lightweight materials
b. Safety critical software
c. Environmental improvements: fuel efficiency, noise reduction and energy recovery
d. Precise position location, including sensor systems simulation and modelling
e. Pattern processing and recognition systems
f. Understanding travel requirements and transport problems in society
g. Impact of telecommunications on transport problems in society
h. Human/machine interface and passenger/driver behaviour
i. Improved transport system modelling.

It proposed that the following Foresight Projects be implemented:

THE INFORMED TRAVELLER: Providing better travel information with associated booking and payment facilities
THE FORESIGHT VEHICLE: Environmentally-friendly with no compromise on safety, performance or cost
THE URBAN CLEAR ZONE: Developing transportation for 'livable' urban centres

The following items were identified as long-term issues:

Environmental regulation;
Impact of IT and telecommunications on transport market;
Business process re-engineering in vehicle manufacturing sector as competitive weapon;
Balancing access and mobility with transport capacity and environmental constraints;
Export opportunities for UK solutions.

ARRC will build its future research plans around these areas and act to bring together relevant university expertise and industrial partners to further the Foresight process.

## Conclusion

The last 2 years have seen the establishment of ARRC on the international railway research scene. We aim to further strengthen our position and to promote the cause of railways as an efficient and environmentally-friendly mode of transport. We welcome enquiries about our current and future research and training plans, and particularly encourage international links. ■


**Roderick A. Smith**

Professor Roderick A. Smith is the Royal Academy of Engineering/British Rail Research Professor at the University of Sheffield, and Chairman of the Advanced Railway Research Centre. He was a Fellow of Queens' College Cambridge from 1975-1988. He is the author of nearly 200 articles, papers and books on the fatigue of metals, crowd engineering and, latterly, railway engineering. He has been a regular visitor to Japan and a student of Japanese railways since 1975.