OBITUARY

LESLIE FOX

Leslie Fox was born in Yorkshire in 1918, and spent most of his professional life in Oxford, as Director of the University Computing Laboratory and as the first Professor of Numerical Analysis in the University.

His mathematical education began at the Wheelwright Grammar School in Dewsbury, which produced a number of distinguished mathematicians and scientists at about the same time as Fox under the influence of an inspiring Headmaster and teacher (Leslie Sadler). Fox went to Oxford in 1936 as a scholar of Christ Church, and he gained a First Class Honours degree in Mathematics. He continued his studies for a DPhil under the direction of Professor Sir Richard Southwell, with a project in the area of computational and engineering mathematics which initiated some of the main interests of his career. His first appointment was at the Admiralty Computing Service in 1943; here he learnt the skills of table-making which he later used in a number of publications.

In 1945 Fox and several colleagues moved to the new Mathematics Division of the National Physical Laboratory. It was recognised at that time that the emerging technology of automatic computation would lead to requirements for effective mathematical methods which exploited the new machinery. The Mathematics Division embarked on an extensive programme of research in computational methods, in parallel with the construction of the Pilot ACE machine, which carried out its first computations in 1950. The Division remained a major source of ideas and methods in numerical mathematics for many years, with Fox taking a leading role until he was appointed to set up the Computing Laboratory in Oxford in 1957.

He saw clearly that there would be a need to educate the next generation of mathematicians in computational work, and he took up his new post in the University with energy and enthusiasm. The first computer (the Ferranti Mercury) arrived in 1958, and by that time Fox had built up an active group of academic staff who helped to expand teaching, research and advisory work across the science and engineering departments. He was particularly concerned to get numerical analysis established in the undergraduate curriculum, and to attract research students into this expanding field. His work in all these areas was recognised by his appointment as Professor of Numerical Analysis in 1963, a post which he held until his retirement in 1983. During the early years in Oxford he established close links with leading numerical analysts in the US, where the subject was also developing rapidly as computing machines became available. He made extended visits to Berkeley in 1956–57 and to Illinois in 1963–64, and maintained a large network of friends and collaborators in America and across the world.

The Oxford Computing Laboratory expanded during the 1960s and 1970s, and naturally the non-numerical aspects of computing came to play a larger part in teaching and research. Fox encouraged this development though he did not take part

Bull. London Math. Soc. 31 (1999) 241–247

in it personally, his chief interest remaining in the area of mathematical computing. He and his colleagues collaborated with members of the Mathematical Institute in Oxford, particularly those working on problems with an industrial background. This led to the formation of the Oxford Study Group with Industry (with Alan Tayler and others), which has continued to flourish on the interface between applied mathematics, numerical analysis and industrial applications. His election to a Professorial Fellowship at Balliol College in 1963 gave him further opportunities for cross-disciplinary contacts through the college community.

He led a very active life in Oxford, including teaching, supervising research students, editorial work, collaborations and consultancy, and the organisation of summer schools and conferences. Among all his professional commitments he found time to keep up a strong interest in sport, moving from cricket to golf and organising an academic golf team in Oxford in his later years. His friendships and social contacts were very wide, and he was excellent company in many different surroundings. On his retirement in 1983 he became an emeritus Fellow of Balliol, and he continued his involvement in academic affairs with scholarly work and publications until his death in 1992.

We now turn to a more detailed consideration of Fox's mathematical research. His early work with Southwell was concerned with the numerical solution of certain partial differential equations arising in engineering problems. These problems were quite intractable by analytical methods, because of their geometrical complexity and other features. Southwell's students and colleagues developed the art and science of 'relaxation methods', which produced numerical solutions of high accuracy by semi-iterative procedures. At that time the only aid to computation was the desk calculator, and it was essential to develop short-cuts and checks on accuracy in order to obtain practical and reliable solutions. Fox and his fellow workers became experts in this type of computation and solved many difficult engineering problems, though some of the results were not published immediately because of wartime restrictions. Fox's contributions were particularly notable because he combined practical skills with theoretical advances in relaxation methods, which foreshadowed a number of later developments in numerical analysis. One of his main concerns was with accuracy and the validation of results, and he saw how the approximate solution could be used to estimate and control errors through the difference correction, to which we return below. Of course, the skills required for hand computation were completely superseded during the 1950s by the automatic computer, which posed a rather different set of implementation problems. But the basic approach of modelling a partial differential equation by a discrete algebraic form still requires the careful attention to accuracy and error estimation which was the theme of Fox's early papers.

His work at the Admiralty Computing Service and later at the National Physical Laboratory led to a number of projects for the computation of special functions, and he produced several tables in the series published by the Royal Society and the NPL. This field has also been transformed by the computer, so that instead of using extensive tables we require precise and efficient algorithms for computing special functions. However, Fox's work characteristically used the practical problem as the starting-point for developments which have a much wider application, such as interpolation, stability of recurrence relations and asymptotic behaviour. His standards of accuracy were very high, as always, and he appreciated the need for cross-checks on computer output, a need which is sometimes difficult to convey to modern students.

During the 1950s the NPL group was concerned with the basic problems of computational linear algebra, and this work eventually led to the publication of a series of high-quality algorithms by Wilkinson and others. Fox's contribution was in elucidating the computational forms of the matrix operations, and he published a textbook in this area in the early 1960s. He was not directly involved in algorithm production, but he supported the emerging science of mathematical software and recognised that it would provide a major challenge for numerical analysts.

The idea of the difference correction arose out of his experience with partial differential equations, though it has much wider applications. The approximate solution obtained on a particular mesh contains implicit information about the accuracy of the solution, which can be extracted by estimating the local errors and using them in an iterative process of correction. The procedure may be compared with iterative refinement for linear algebraic equations, where the residuals are used either to estimate or to reduce the errors arising from the finite word-length. However, the problem is considerably more difficult for differential equations, because the error estimates and the correction terms are asymptotic in character. Thus they will give improved results for 'sufficiently small' values of the mesh-length, under various smoothness assumptions, but it is not easy to incorporate them into an automatic algorithm. In the days of hand calculation one could use judgement at each stage, but this appeared to be infeasible in the computer. However, the line of approach which started with Fox's paper in 1947 was taken up in several directions, notably in Victor Pereyra's work on error-correcting algorithms for boundary-value problems and in Stetter's results on defect correction and the resulting order of convergence. The main focus of interest in partial differential equations has now shifted to finite-element representations, and the problem of the discretisation error appears in a somewhat different form. But there is still a need to validate the accuracy of the solutions, which is addressed with varying degrees of success by modern software.

Another of Fox's interests in the area of partial differential equations was the treatment of singularities, on which he published a number of papers (some with research students). He also considered methods for the Stefan problem and other cases of free and moving boundaries. Many of these problems arose from his collaboration with industrial mathematicians in the Oxford Study Group, and he contributed ideas and advice over a much wider field than that shown by his published work. He was well aware of the difficulties and limitations of mathematical modelling, which is the first stage in considering industrial problems, but his major concern was to ensure that the mathematical and computational treatment was reliable, so that attention could be focussed on the underlying physical situation.

Apart from his own research writings, Fox had a wide influence on the development of numerical analysis, particularly through teaching and the supervision and encouragement of research students. His direct teaching was mainly to students at Oxford, though he also made significant contributions to course material for the Open University. He produced several textbooks on computing methods (two with David Mayers), and an expository text (with Ian Parker) on the use of Chebyshev polynomials. He lectured in many places on 'meaningless answers', describing some of the pitfalls of computation which resulted from the uncritical use of obvious methods. In 1972 he participated in an IMA conference on the teaching of numerical analysis, and at that time he felt that the subject was making rather slow progress in university degree courses. One way in which he thought the position could be remedied was through specific degree programmes in applicable mathematics, and these have since become widely available. But he recognised that numerical analysis, which requires a combination of analytical and practical skills, was not an easy subject for undergraduates, and he devoted a great deal of his effort to postgraduate teaching and the training of research students.

During his time at Oxford he supervised 19 DPhil students either wholly or in part, and he influenced very many more who did their postgraduate work in the Computing Laboratory. For several years Oxford was the principal centre in Britain for postgraduate study in numerical analysis, until other universities began to develop groups in this area, some of them recruiting their academic staff from among Fox's former students. Computational methods were also promoted among engineers and theoretical physicists in Oxford, and the subject has now become much more of a common currency among research workers, with wider appreciation of the need for good mathematical software.

Fox played a significant part in the early days of the Numerical Algorithms Group (NAG), which set out as a collaborative venture between several universities to provide a high-quality library of mathematical routines. The Oxford Computing Laboratory was one of the founder members of NAG when it started in 1970, and Fox supported it strongly by making resources available in Oxford for its work. He continued to take a close interest in its activities, with contributions to NAG meetings and publications, and he became a member of the Council when the Group was incorporated in 1976. He continued in this capacity as the Oxford representative until 1984. The Group is now an independent company with international activities, but it retains the academic links and mathematical orientation of its origins.

During the 1960s Fox was the initiator of some influential Summer Schools in Oxford, the first being on ordinary and partial differential equations, and later ones on particular areas of computation including non-numerical programming. The published proceedings provided up-to-date accounts of recent developments and were influential as textbooks and reference books, in the days before specialised journals in numerical analysis began to proliferate.

Leslie Fox was an active member of the Institute of Mathematics and its Applications from its beginnings, as a member of the Council and as an editor first of the main IMA journal and later of the *Journal of Numerical Analysis*, which started in 1981. His retirement from Oxford in 1983 was marked by a special IMA symposium on 'The contributions of Leslie Fox to numerical analysis', at which many of the speakers were his former research students. He was elected to an Honorary Fellowship of the IMA in 1989.

He travelled widely to attend conferences and held a number of visiting appointments, and he was recognised as a leading figure in numerical analysis throughout his career. His interests included mathematical teaching in schools; he was concerned in major revisions of the school syllabus through the Schools Mathematics Project, and was also active in the local branch of the Mathematical Association, of which he was President in 1964. He was always willing to share his extensive experience, and to talk to people at all levels with a concern for the subject which excluded any display of superiority. Many people benefited from his generosity with advice and stimulating ideas.

A lasting memorial to his influence on the subject is the Leslie Fox Prize for Numerical Analysis. This was initiated at the time of his retirement following a suggestion by Gene Golub, with the aim of giving encouragement and recognition to young research workers. The prize fund was enthusiastically supported by friends and colleagues of Leslie Fox, and it has been administered by the IMA since its inception. Eight competitions have been held, and all have attracted excellent candidates from Britain, the US and other countries. The list of topics, finalists and prize-winners provides a conspectus of the important advances being made in the subject and of the next generation of leaders in research. It is appropriate to record that the first winner of the Fox Prize in 1985 (Lloyd Nicholas Trefethen) recently succeeded to the Oxford chair in Numerical Analysis which was created for Leslie Fox in 1963.

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