Professor Dudley Brian Spalding, FRS, FREng

It is with sadness that we report the death of Professor Brian Spalding FRS FREng on 27th November 2016 after a short illness. Brian Spalding was born on 9th January 1923 in New Malden, England. He graduated with a BA and MA in Engineering Science at Oxford University in 1944 and after one year with Shell spent the year 1945-46 with the UK Rocket Propulsion Establishment in Germany near Braunschweig. In 1948 Brian accepted an ICI Fellowship at Cambridge University to study for a PhD, which he obtained in 1952. The subject of his thesis was the combustion of liquid fuels and this is where he developed his lifelong interests in fluid flow, combustion and heat and mass transfer. Brian Spalding joined the Department of Mechanical Engineering at Imperial College as a Reader in Heat Transfer in 1954, was promoted to Professor of Heat Transfer in 1958 and subsequently also became Head of the Computational Fluid Dynamics (CFD) Unit. He held both positions until his retirement in 1988. He became a Fellow of the Royal Society in 1983 and a Fellow of the Royal Academy of Engineering 1989. At various times, he has been visiting Professor at MIT, the University of California, Berkeley, and the University of Minnesota; in the late 1970's he was Reilly Professor of Combustion at Purdue University.

Brian Spalding was a truly outstanding researcher and teacher who was widely recognised as being one of the leading authorities in his field and who made many important and innovative contributions in a broad range of subjects. He was the author of several books including the undergraduate level texts. His contributions to science and engineering were wide ranging and ground breaking. For example, his early research, circa 1950, led to a general model for evaporating and burning liquid fuel droplets that is still used today. Indeed, generality and industrial applicability were hallmarks of his research throughout his career, in which he strived to produce widely-applicable methods for predicting flow, heat transfer and combustion in a wide variety of circumstances. Another early example is his work on developing a unified analytical theory for jets, wakes and boundary layers, collectively known as thin shear layer flows.

However, his greatest contributions were probably in the area of what is now termed Computational Fluid Dynamics, CFD. In the mid 1960's Brian was amongst the very first to realise that the developing power of the digital computer could be used to devise discrete methods for solving the partial differential conservation equations describing fluid motion, combustion and heat and mass transfer. Moreover, the methods could take into account the myriad possible complexities of geometry and boundary conditions and could therefore provide engineers with the means to analyse problems in detail far beyond the limited scope of analytical solutions. Brian had also recognised that the development of this methodology required knowledge and skills in a number of different areas, including numerical solution techniques; the modelling of turbulence, heat transfer, mixing and chemical reaction; computer programming; and experimental verification. To this end, he had assembled a team of talented researchers with expertise in these areas at Imperial College under his leadership who formed what was then known as the Heat Transfer Section - all, perhaps uniquely, in the academic field working towards a common goal.

Brian and his group first focussed on numerically solving the thin-shear-layer equations, developing and publishing a general computer program known as GENMIX for this purpose. They then turned to the much more challenging problem of the equations governing general recirculating flows including heat and mass transfer and combustion, for which they devised a number of different solution
methodologies, initially in two dimensions and later for full three-dimensional flows. The most successful of these methods, the SIMPLE algorithm, developed by him together with S Patankar is still widely used. A number of computer programs were developed based on these methods. Some, like the TEACH program were used for teaching purposes and distributed widely in open-source form, perhaps the first of this kind. Others were applied internally to industrial problems, some of considerable complexity, such as gas turbine combustors. As a result of these efforts, Brian Spalding and the Heat Transfer group revolutionised the analysis of fluids in motion through CFD computer modelling, enabling application to real industrial problems. Brian was thus one of the most influential persons in the development of CFD, and also stimulated and contributed to the parallel development of mathematical models of turbulence, combustion and multiphase flows.

In the early 1970s it became apparent to Brian Spalding that CFD simulation had reached a level of maturity that would allow it to be used by industrial engineers, if available in a commercial-standard program with full documentation and support. In 1974 he founded Concentration Heat and Momentum Limited (CHAM), a world-leading consulting company, to develop and market such a program, called PHOENICS, the first general-purpose tool of its kind, sold in more than 25 countries. Indeed, it can be said that Brian Spalding is the ‘father of commercial CFD’ since most of today’s other commercial CFD programs trace their origins to the work he and his group carried out in the decade spanning the mid-60s and mid-70s.

CHAM’s clients continue to use Brian’s pioneering software. Brian was Chairman and Managing Director of CHAM and, until his death, he was actively engaged in improving various aspects of the CFD methodology in PHOENICS on which he often gave talks and seminars. One of the last lectures Brian delivered was at ETTM in Sicily (September 2016); an extract of which is contained below.

As well as being an outstanding researcher, Brian was also an inspirational educator, who placed strong emphasis on communication skills and he led by example. In addition to his own extensive teaching, presentations and publications, he encouraged the dissemination of the innovative research of the Heat Transfer Section in other, novel ways including organising short ‘post-experience’ courses and making available open-source software. These activities attracted students from all over the world to a stimulating environment and led to many of these pursuing doctoral studies with him.

Aside from his academic work Brian was also an avid poet and over the years authored many poems some of which are published in the books\textsuperscript{4,5,6,7}, also translated into Russian. Here we quote part of “A Last Poem” written by Brian just before his death:

\begin{quote}
I shall have no regrets when I am dead  
Of deadlines none will matter but my own.  
Unwritten papers? Hopelessly misled  
Inheritors? All claimants I’ll disown.  
Yet hope, while still alive, there’ll be but few  
Who think: I was a fool to trust him.  
Now that he’s gone, what am I going to do?  
None I would hope; but guess the chance is slim.  
Yet, in that soon-to-close window of time,  
There’s much I want to do; and think I can.  
Always too optimistic is what I’m
\end{quote}
Dismissed as. To disprove it is my plan.

Brian Spalding's awards include the Institution of Mechanical Engineers' James Clayton Prize, the American Society of Mechanical Engineers' Bernard Lewis Medal, The International Centre for Heat and Mass Transfer's Luikov Medal, the Global Energy International Prize and the Benjamin Franklin Medal (Franklin Institute). In 2014 he was awarded an Honorary Degree by Imperial College London. Brian is survived by his wife Colleen, five sons and a daughter, children grandchildren and great grandchildren.

References
7. My Sail Hoistings, Brian Spalding, Polytechnic University, (2011)

"Turbulent-chemical-reaction models: old and new; and which way forward?"
Brian Spalding
ETMM11, Palermo, Sicily, September 2016

Background
Much of the world's power is generated by way of furnaces and engine combustion chambers; and many of its materials are created in large paddle-stirred chemical reactors. The flow in all these equipment types is invariably turbulent. Yet, of current research on turbulence, the proportion devoted to chemically-reacting flows is very small.

Probably this is because such research has little success to proclaim; and the cause of that, the author suggests, is that it has been restricted to the employment of models of the kind introduced by Kolmogorov three-quarters of a century ago. That seeks to describe turbulent flows by way of time-average distributions of statistical quantities such as energy k, dissipation rate e, Reynolds stresses such as $u'u'$, concentration fluctuations $c_\alpha c_\beta$ etc. These distributions are hypothesised as being governed by partial differential equations, which, when discretised in respect of space and time, can be solved numerically.

The reason for the 'little success' is that chemical reaction rates depend on time-average values of more complex statistical quantities such as $r c_\alpha c_\beta T^n$; and no-one is ever likely to be bold enough to propose partial differential equations for them. Therefore researchers' interest in the subject has understandably dwindled.

There is however a quite different approach to turbulence; and one which is at least as successful for turbulent chemical reaction as the Kolmogorov one is for the hydrodynamics. It treats a turbulent fluid as a discretised population; and its hypotheses concern the interactions between the members of that population.

The discretised-population approach (called DP in what follows) is also not new. It was used by Smoluchowski a whole century ago to quantify the implications of Einstein's theory of Brownian
motion for the composition of colloidal dispersions. Its use for turbulent combustion first made its appearance in 1973 as the 'eddy-break-up model' (i.e. EBU); for DP terms EBU can be described as involving a two-member population. Not until twenty-five years later, however, was it followed by its four-member, fourteen-member and finally multi-member successors. Sometimes the pace of science is glacial.

The two members postulated for the EBU population were: (1) a wholly unburned fuel-air mixture: and (2) its fully-burned counterpart of the same enthalpy and atomic composition. The composition of fluid present in all parts of the domain differed only in the relative proportions of these two components. Typical present-day multi-member populations still use the extent-of-burnedness and atomic composition as member-distinguishing dimensions; these dimensions are now sub-divided into as many intervals as are needed for at least qualitative realism. CFD simulations based on DP modelling, therefore explore not only the four space-and-time dimensions, but also two more.

The present contribution. This multi-dimensional aspect of the DP approach may appear daunting. Therefore a prime aim of the author’s contribution to ETMM11 is to explain that, on the contrary, the computational task associated with DP can be less burdensome than that of the current practice. This comes about because:

- the two approaches can be used in combination, with Kolmogorov’s only for velocities and DP only for chemical composition;
- the whole calculation can be conducted in steady-state mode, the more expensive LES for the hydrodynamics adding nothing to the overall realism;
- the linkages between the hydrodynamic and the chemical-reaction parts of the total model are simple, in that the former supplies the mixing rate as an e/k distribution;
- it then receives from the latter distributions of time-average density, temperature and composition;
- the DP calculation needs to be carried out only in those parts of the domain in which the time-average temperature is high and therefore the volumetric release rates of energy (good) and NOx and smoke (bad) require accurate calculation;
- attention to relatively few typical locations suffices, when the uncertainty of the underlying chemical-kinetics data is acknowledged.

These arguments will be explained in sufficient detail during the presentation to enable any proficient CFD specialist to implement them in their computer code. Further, illustrations will be provided which should persuade their combustor-designing colleagues to encourage them to do so, having concluded that the discretised population approach can already provide the guidance to design improvement which they need.

The latter is indeed the author’s main aim; with air pollution and global warming among the main threats to humanity, any advances in turbulent-reacting-flow science should be exploited promptly by engineers.

W P Jones/A D Gosman
9/07/2017