J. Fluid Mech. (2010), *vol.* 663, *pp.* 2–7. © Cambridge University Press 2010
doi:10.1017/S0022112010004167

BATCHELOR–CRIGHTON COMMEMORATIVE TALKS

George Batchelor: a personal tribute, ten years on

H. K. MOFFATT†

Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Wilberforce Road, Cambridge CB3 0WA, UK

Ten years have elapsed since the passing of George Keith Batchelor (8 March 1920–30 March 2000), formerly Professor of Fluid Dynamics at the University of Cambridge, and Founder Editor of the *Journal of Fluid Mechanics*. It is fitting to remind the readers of this Journal what a great scientist he was, both in respect of his own contributions to our subject, and even more in respect of his inspirational influence on generations of research students and younger colleagues, and also more widely on the international stage, on which he was a revered, if sometimes controversial, personality.

I have previously compared George Batchelor with his nineteenth century counterpart, George Gabriel Stokes, with whom I discern profound similarities of character (Moffatt 2005). I made similar parallel comparison between Stokes' contemporary Lord Kelvin, and Batchelor's contemporary Sir James Lighthill; I believe the passage of time will serve to reinforce these comparisons.

Stokes was Lucasian Professor of Mathematics for a record tenure 1849–1897; Batchelor similarly served on the Cambridge Faculty of Mathematics as successively Lecturer, Reader, Professor and Emeritus Professor from 1948 to 2000. Thus, like Stokes, he spanned half a century in his professional career and publications. At the same time, Batchelor devoted himself for more than 40 years to the *Journal of Fluid Mechanics*, just as Stokes had devoted himself for a similar period 100 years earlier to the *Transactions* (and *Proceedings*) of the Royal Society. As I wrote in 2005, both men were what could be described as *supremely conscientious*, with a strong personal commitment to the essential morality of science. Both made seminal contributions to fluid mechanics, in Batchelor's case, to the theory of homogeneous turbulence, and later to microhydrodynamics, this being appropriately the application of Stokes's theory to suspensions of particles, drops or bubbles in fluids.

Figure 1 shows Batchelor and his great mentor Sir Geoffrey Taylor, with the Cambridge turbulence research group in May 1952, when George was putting the finishing touches to his research monograph *The Theory of Homogeneous Turbulence*. This monograph (Batchelor 1953) established him as a leading world figure in the statistical approach to turbulence, and defined the course of research in this subject for the next decade.

† Email address for correspondence: hkm2@damtp.cam.ac.uk

https://doi.org/10.1017/S0022112010004167 Published online by Cambridge University Press



FIGURE 1. Cambridge turbulence group in May 1952. Back row: Chris Nichol, Ian Proudman, Tom Ellison, Bill Reid; front row: G. I. Taylor, G. K. Batchelor (Alan Townsend was also a member of the group, but absent on this occasion).

Figure 2 shows George in his office in the Old Cavendish Laboratory four years later in October 1956 at age 36. He had by this time founded *JFM*, and the first four monthly parts had appeared, containing papers by many current and future stars in the firmament of fluid mechanics, including Milton Van Dyke, P. G. Saffman, J. S. Turner, M. J. Lighthill, M. B. Glauert, M. S. Longuet-Higgins, T. Brooke Benjamin, Donald Coles, John Laufer, G. B. Whitham and C. S. Yih, as well as one, *On steady laminar flow with closed streamlines at large Reynolds number*, by Batchelor himself (Batchelor 1956); Parts 5 and 6, for November and December 1956, were already in the pipeline, containing papers by R. Betchov, Ian Proudman, W. V. R. Malkus, A. A. Townsend, H. P. Greenspan, R. W. Stewart, O. M. Phillips and J. A. Shercliff. Quite a catch for the first year of a new Journal in competition with *Proceedings of the Royal Society* and *Quarterly Journal of Mechanics and Applied Mathematics*! The fledgling *JFM* was obviously off to a good start, and so of course it was to continue. This was a result of George's unique style of management: delegation of authority to each of his compact team of Associate Editors, George Carrier (Harvard), Wayland Griffith (Princeton) and James Lighthill (Manchester) to individually accept or reject papers submitted to them; and meticulous attention to detail in all matters of layout and copy-editing, in which he was given vital support by his Assistant Editors, Ian Proudman and Brooke Benjamin.

It was in this office on the old Cavendish site in Free School Lane that I first met George in 1958; this was still a year before the foundation of Department

https://doi.org/10.1017/S0022112010004167 Published online by Cambridge University Press



FIGURE 2. George Batchelor, aged 36, in his office in the old Cavendish Laboratory in October 1956, the first year of publication of the *Journal of Fluid Mechanics* (photograph: Rudolfe Wille).

of Applied Mathematics and Theoretical Physics (DAMTP), and George's research group had the use of a scattering of borrowed rooms, courtesy of the Cavendish Laboratory. I had been supervised in Applied Mathematics by Ian Proudman, who sent me to see George when I expressed an interest in undertaking research in Fluid Mechanics. George took me on more or less immediately and with minimal fuss. It was a wonderful opportunity, because he gave me a pre-publication copy of his paper *Small-scale variation of convected quantities like temperature in a turbulent fluid. Part I, General discussion, and the case of small conductivity*, which was to be published in *JFM* in 1959 (Batchelor 1959), back-to-back with *Part II, the case of large conductivity*

https://doi.org/10.1017/S0022112010004167 Published online by Cambridge University Press

co-authored with I. D. Howells and A. A. Townsend (Batchelor, Howells & Townsend 1959). Ian Howells was at that time a Research Fellow of Trinity College; he left soon afterwards to become a Jesuit priest in Australia. Alan Townsend had been Batchelor's close colleague and collaborator since about 1946, both having come from Australia to work on turbulence with G. I. Taylor immediately after the War.

George had hoped to come to Cambridge much earlier on completion of his Melbourne Master's degree, but this hope was thwarted by the outset of World War II, during which he was retained in Australia to work on very applied aeronautical problems for CSIRO (the Commonwealth Scientific and Industrial Research Organisation). Before the War ended, however, he did manage to make the journey with his newly wedded wife Wilma to London, a long sea voyage in the merchant vessel *SS Umgeni* in part of a naval convoy. Once arrived in Cambridge in April 1945, this is where George and Wilma settled for the rest of their lives.

I have written elsewhere (Moffatt 2002*a*, *b*) of George's seminal contributions to the theory of turbulence during his early research years (up to 1960). I can focus here on more personal aspects. His relationship with G. I. Taylor is of particular historical interest: in the preface to his PhD thesis (1948) *The Statistical Theory of Isotropic Turbulence*, Batchelor writes:

> 'Speaking for the moment of the work as a whole, I should like to pay tribute to the wise counsels of my mentor, Sir Geoffrey Taylor. It is impossible to say how much of the work which I claim as original has been evolved as the result of stimulation provided by contact with him. His assistance has not been in detail, but if, as I believe, I have used a fruitful and realistic approach to the problem of turbulence, it is largely due to the influence of his published work and his verbal discussion. In general, this dissertation represents superstructure built on his foundation work on the use of statistical theory and the significance of isotropic turbulence.'

It is true that Taylor's papers of the 1930s (Taylor 1935, 1938*a*, *b*) provided the starting point for Batchelor's development of the statistical theory, later expounded in his 1953 monograph (Batchelor 1953); but George's most striking contribution of these post-war years was his brilliant exposition and interpretation of the papers of Kolmogorov (1941*a*, *b*), which had remarkably found their way to the library of the Cambridge Philosophical Society before the War ended. Barenblatt (2001) relates that volumes of *Doklady* and other Soviet publications were used as ballast for ships on their return voyage from northern Russian ports having carried armaments for besieged Russian cities on the outward voyage. However that may be, Batchelor alighted on these papers in 1945, as he wrote nearly 50 years later (Batchelor 1992):

> 'Like a prospector systematically going through a load of crushed rock, I suddenly came across two short articles, each of about four pages in length, whose quality was immediately clear.'

The Kolmogorov's theory of turbulence, although flawed in the manner indicated by Kolmogorov himself (1962), remains an essential starting point and foundation for any discussion of the subject; and it was Batchelor's great achievement to reinterpret this work and bring it so effectively to the attention of the Western World, and indeed, as Barenblatt reveals, even to that of the Russian scientific community, for whom the Kolmogorov's papers had previously remained impenetrable if not inaccessible.

Barenblatt (2001) has also forcefully argued for Batchelor's priority in recognizing as early as 1953 that, in idealized two-dimensional turbulence, while enstrophy (or mean-square vorticity) is transferred to high wavenumbers, energy is preferentially transferred to low wavenumbers through a process of amalgamation of like-signed vortices. In a few throw-away lines in the penultimate chapter of his monograph

https://doi.org/10.1017/S0022112010004167 Published online by Cambridge University Press



FIGURE 3. George, setting off from his home *Cobbers* for Cambridge University Press, with the completed ms of his famous textbook *Introduction to Fluid Dynamics* (1967).

(Batchelor 1953, pp. 186–187), George's understanding of this fundamental process, confirmed by direct numerical simulation (DNS) decades later, is abundantly evident.

The theory of turbulence and Batchelor's own career reached a watershed at the famous Marseille meeting on turbulence in September 1961. I know because I was there, that George was the driving force behind this remarkable Symposium. Seven sessions of lectures were held, and the animated discussions that followed the lectures are fully recorded in the Proceedings (*Editions du CNRS*, **108**, 1962). Kraichnan's then revolutionary theory (Kraichnan 1959) (involving his Direct Interaction Approximation) caused a particular stir, attracting trenchant criticism in the following lecture by Ian Proudman (Proudman 1962); I believe now that George's progressive disillusion during the 1960s with purely theoretical approaches to turbulence may in fact be traced to his failure (widely shared) to come to terms with Kraichnan's theory at this meeting.

https://doi.org/10.1017/S0022112010004167 Published online by Cambridge University Press

In fact, this may have been a blessing in disguise. Throughout the 1960s, George was preoccupied on the one hand with building up DAMTP, particularly on the fluid dynamics side; and on the other with writing his *Introduction to Fluid Dynamics* (1967), a textbook that now ranks with Lamb's Hydrodynamics as one of the great classics of the subject. Figure 3 shows George setting off in triumph for the Press with the completed manuscript of this book, which was soon to establish itself as the bible of the subject at advanced university level.

The effort of completing this book led George into the second great phase of his research career, in the subject that he effectively created, microhydrodynamics. His visionary activity in this field opened up a huge area of study pursued by his research students of the 1970s and 1980s, and by many senior visitors to DAMTP over three decades. His legacy lies in his great contributions in both turbulence and microhydrodynamics, and in the work that he inspired in his colleagues and collaborators in these fields.

I thank Adrienne Rosen and Bryony Allen, who kindly provided the photographs in Figures 1, 2 and 3.

REFERENCES

Barenblatt, G. I. 2001 George Keith Batchelor (1920–2000) and David George Crighton (1942–2000): applied mathematicians. *Not. Am. Math. Soc.* **48**, 800–806.

Batchelor, G. K. 1953 *The Theory of Homogeneous Turbulence*. Cambridge University Press.

Batchelor, G. K. 1956 On steady laminar flow with closed streamlines. *J. Fluid Mech.* **1**, 177–190.

Batchelor, G. K. 1959 Small-scale variation of convected quantities like temperature in turbulent fluid. Part 1. General discussion, and the case of small conductivity. *J. Fluid Mech.* **5**, 113–133.

Batchelor, G. K., Howells, I. D. & Townsend, A. A. 1959 Small-scale variation of convected quantities like temperature in turbulent fluid. Part 2. The case of large conductivity. *J. Fluid Mech.* **5**, 134–139.

Batchelor, G. K. 1992 Fifty years with fluid mechanics. In *Proceedings of Eleventh Australasian Fluid Mechanics Conference* (ed. M. R. Davies & G. J. Walker), pp. 1–8. University of Tasmania.

Kolmogorov, A. N. 1941*a* The local structure of turbulence in incompressible viscous fluid for very large Reynolds numbers. *C. R. Acad. Sci. USSR* **30**, 301–304.

Kolmogorov, A. N. 1941*b* Dissipation of energy in locally isotropic turbulence. *C. R. Acad. Sci. USSR* **32**, 16–19.

Kolmogorov, A. N. 1962 A refinement of previous hypotheses concerning the local structure of turbulence in a viscous incompressible fluid at high Reynolds number. *J. Fluid Mech.* **13**, 82–85.

Kraichnan, R. H. 1959 The structure of isotropic turbulence at very high Reynolds numbers. *J. Fluid Mech.* **5**, 497–543.

Moffatt, H. K. 2002*a* G. K. Batchelor and the homogenisation of turbulence. *Annu. Rev. Fluid Mech.* **34**, 19–35.

Moffatt, H. K. 2002*b* George Keith Batchelor 8 March 1920–1930 March 2000. *Biog. Mem. Fell. R. Soc. Lond.* **48**, 25-41.

Moffatt, H. K. 2005 Stokes and Kelvin a century later. *EUROMECH Newsl.* **28**, 17–25.

Proudman, I. 1962 On Kraichnan's theory of turbulence. In *Mecanique de la Turbulence* (ed. A. Favre), vol. 108, pp. 107–112. Editions du CNRS.

Taylor, G. I. 1935 Statistical theory of turbulence. Parts 1–4. *Proc. R. Soc.* A **151**, 421–478.

Taylor, G. I. 1938*a* Production and dissipation of vorticity in a turbulent fluid. *Proc. R. Soc.* A **164**, 15–23.

Taylor, G. I. 1938*b* The spectrum of turbulence. *Proc. R. Soc.* A **164**, 476–490.

https://doi.org/10.1017/S0022112010004167 Published online by Cambridge University Press