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REVIEW

Collected Papers of Lewis Fry Richardson. Volume 1: Meteorology and Numerical Analysis. Edited by P. G. DRAZIN. Cambridge University Press, 1993. 1016 pp. £95.

Lewis Fry Richardson was one of those English eccentrics who, like Oliver Heaviside, worked largely outside the contemporary scientific establishment but made profound and seminal advances for which full recognition was too long delayed. His distinguished contributions include the criterion for the stability of a stratified shear flow, the 4/3 law for turbulent diffusion, and the anticipation of numerical weather prediction. He never held a university professorship (although he did teach for twenty years at the Westminster Training College and the Paisley Technical College and School of Art), and he devoted some twenty-seven years to research in psychology and the analysis of conflict compared with only thirteen in meteorology.

The present volume comprises most (61 papers and 2 patents) of Richardson's work in the physical sciences, with the major exception of his *Weather Prediction by Numerical Process* (Cambridge, 1922). Although subtitled 'Meteorology and Numerical Analysis', it covers a far wider range, including dams, oscillographs, seismographs, and the osglim lamp as a relaxation oscillator. It also includes a brief foreword by K. A. Browning, a 28-page general introduction and biography by J. C. R. Hunt (for a more extensive biography see Oliver Ashford's *Prophet – or Professor* (Adam Hilger, Bristol, 1956)), separate introductions to, and appreciations of, Richardson's contributions to meteorology, numerical analysis and fractals by H. Charnock, L. Fox and P. G. Drazin, a table of contents for volume 2, which comprises Richardson's papers on psychology and the analysis of conflict, and a check-list of publications not reproduced in either volume.

The Richardson number

The criterion for the stability of an inviscid, stratified shear flow of density $\rho(z)$ (z is the vertical coordinate) and mean horizontal velocity $U(z)$,

$$Ri \equiv \frac{g(-\mathrm{d}\rho/\mathrm{d}z)}{\rho(\mathrm{d}U/\mathrm{d}z)^2} > (Ri)_{cr}, \tag{A}$$

appeared originally in G. I. Taylor's Adams Prize essay in 1915; however, he did not publish this work until 1931. In the interim, Richardson (1920:3 in the reference style of the volume under review) independently deduced, from an energy balance of the type initiated by Osborne Reynolds, that $(Ri)_{cr} = 1$ provides a sufficient condition for stability with respect to arbitrary disturbances, and Ri now is universally known as the Richardson number (as proposed by H. Schlichting in 1935). Richardson is quoted by Ashford as finding 'the honour of having a number named after me ... embarrassingly personal', but I know of no meteorologist who would question the fitting justice of *Richardson number*, which, along with the parameters named after Rayleigh, Reynolds and Rossby, is central to our description and understanding of atmospheric dynamics.

Turbulent diffusion

Perhaps even more influential than Richardson's work on stratified shear flow was that on turbulent diffusion. In a much-quoted paper (1926:1), which Taylor (*Adv. Geophys.* vol. 6, 1959, p. 101) describes as having 'initiated the modern approach to the subject', Richardson begins with the rhetorical question 'Does the wind possess a Velocity?', goes on to comment 'This question, at first sight foolish, improves on acquaintance', and remarks that the conventional limit of $\Delta x/\Delta t$ may not exist in a turbulent flow. He then shows that $q(l, t)$, the number of particles per unit length, where l is the separation of a pair of marked particles, in a turbulent flow is governed by the diffusion equation

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial l}\left(K\frac{\partial q}{\partial l}\right) \tag{B}$$

and infers from an empirical fit of observations that, rather than being a constant as in molecular diffusion, $K \approx 0.6l^{4/3}$ cm^2 s^{-1} for l between 10^2 cm and 10^6 cm. This fit was based on only five points, and Taylor remarks that it 'reveals a well developed physical intuition [in the choice of] 4/3 ... but he had the idea that the index was determined by ... the way energy was handed down from larger to smaller and smaller eddies ... which, because of its universality, must be subject to some simple rule.' Perhaps surprisingly (especially in that he *had* applied dimensional analysis to convective cooling in paper 1920:5), Richardson makes no attempt to infer the exponent 4/3 from dimensional analysis. (In 1952:5 he comments that the 'observations could have been fitted passably by any index between 1.2 and 1.5, ... 4/3 was chosen partly as a rough mean and partly because it simplified some integrals.').

Richardson returned to the problem of turbulent diffusion in several later papers, notably one with Henry Stommel (1948:3) that opens with the statement that 'We have observed the relative motion of two floating pieces of parsnip' and concludes that (B) also holds in water, with $K = 0.07l^{1.4}$ cm^2 s^{-1}. In a *Note added in proof* Richardson & Stommel refer to two unpublished (at that time) manuscripts by 'von Weisaecker and Heisenberg in which the [present] problem is treated deductively ... to arrive at the 4/3 law', but they evidently were then unaware of Kolmogoroff's 1941 papers, in which the exponent is deduced from similarity hypotheses. Kolmogoroff did not mention Richardson in his 1941 papers but subsequently (*J. Fluid Mech.* vol. 13, 1962, p. 82) commented that 'The hypotheses concerning the local structure of turbulence ... developed in the years 1939–41 by myself and Oboukhov ... were based physically on Richardson's idea.' Indeed, Richardson's work on turbulence appears to have been widely appreciated in the USSR, and Monin & Ozmidov's *Turbulence in the Ocean* (D. Reidel, 1985) contains 20 citations of Richardson compared with 17 of Kolmogoroff and 5 of Taylor.

Weather prediction

As Charnock tells us in his introduction, 'Richardson's major meteorological papers ... can be fully appreciated only in the context of his most important work, ... *Weather Prediction by Numerical Process*'. Charnock gives a succinct summary of that book, but anyone who wishes to comprehend Richardson's contributions to weather prediction should read George Platzman's authoritative and insightful review of the 1965 Dover reprint ('A retrospective view of Richardson's book on weather prediction,' *Bull. Am. Met. Soc.* vol. 48, 1967, p. 514).

Weather Prediction concludes with a fully detailed, sample forecast that predicts a surface-pressure change of 145 mb in 6 hours. This wildly unrealistic result took Richardson (in Charnock's words) 'the best part of six weeks to ... work out ... in an office consisting of a heap of hay in a cold rest billet on the Western Front of the great war of 1914–18' (Richardson, a life-long Quaker, was a driver in the Friends' Ambulance Unit during 1916–1919). The failure was, in part, a consequence of inadequate upper wind data (as Richardson recognized), but also, as Platzman points out, from 'a more fundamental difficulty which he did not seem to realize clearly at the time ... the impossibility of using observed winds to calculate pressure change from the pressure-tendency equation. ... However, he did point in the direction in which a remedy was later found: suppression or smoothing of the initial field of horizontal velocity divergence.' Nevertheless, Platzman opines that 'Richardson's book surely must be recorded as a major scientific achievement' and remarks that:

> A comparison of Richardson's model with one now in operational use at the US National Meteorological Center shows that, if only the essential attributes of these models are considered, there is virtually no fundamental difference between them. Even the vertical and horizontal resolutions of the models are similar.

The US Weather Service began issuing numerical forecasts in April, 1955 (less than two years after Richardson's death) using a quasi-geostrophic model initially developed by Jule Charney, but in 1966 they went over to a model based on the primitive equations. Charney, in a 1967 letter to Platzman (*Bull. Am. Met. Soc.* vol. 49, 1968, p. 496), tells us that although 'my own work in numerical prediction followed a different path from Richardson's ... I had read his book and could contrast my approach with his with the advantage of a quarter century's more work .... Indeed, von Neumann and others first proposed to use Richardson's method [but] when my own quasi-geostrophic approach appeared to circumvent [the] difficulties connected with initial data and computational stability [it] was followed instead.'

Numerical analysis

Many of the papers in this volume, as its subtitle implies, are on numerical analysis. I am not competent to evaluate those papers here, but I note that Richardson introduced the respective adjectives 'marching' and 'jury' to describe algorithms for the numerical solution of hyperbolic and elliptic partial differential equations and that his work on elliptic equations (1911) anticipated Southwell's more extensive development of the *relaxation* method.

Fractals

Richardson's work on fractals is only indirectly represented by the papers in the present volume – notably in the 4/3-law paper (1926:1) cited above and in his recognition of, and emphasis on, self-similarity in turbulence ('big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity'). His perception that the measured length of a wiggly coastline depends on the resolution of the measuring instrument and his introduction of fractal dimension to describe that wiggliness anticipated the current vogue of fractals, and Benoit Mandelbrot, whose *The Fractal Geometry of Nature* (Freeman, 1982) initiated that vogue, and who coined the term *fractal*, gives explicit credit to Richardson for the stimulus of some of his own research.

The editors have done an admirable job in making this collection available. On the whole, it meets the high standards we have come to expect from CUP, although it lacks (presumably reflecting the expense of) the uniform format of such beautiful exemplars as Rayleigh's *Scientific Papers*. It is a fitting tribute to a great scientist and should grace the shelves of every scientific library.

JOHN MILES

The following volumes of conference proceedings have also been received:

Waves and Turbulence in Stably Stratified Flows. Edited by S. D. MOBBS and J. C. KING. Clarendon Press, 1993. 465 pp. £65.

Recent Developments in Theoretical Fluid Mechanics. Edited by G. P. GALDI and J. NECAS. Longman Scientific, 1993. 162 pp. £23.

EUROVAL – **An European Initiative on Validation of CFD Codes.** Edited by W. HAASE, F. BRADSMA, E. ELSHOLZ, M. LESCHZINER and D. SCHWAMBORN. Vieweg, 1993. 531 pp. DM 148.

3D-Computation of Incompressible Internal Flows. Edited by G. SOTTAS and I. L. RYHMING. Vieweg, 1993. 233 pp. DM 88.

Flow Simulation with High-Performance Computers I. Edited by E. H. HIRSCHEL. Vieweg, 1993. 407 pp. DM 128.

Singularities in Fluids, Plasmas and Optics. Edited by R. E. CAFLISCH and G. C. PAPANICOLAOU. Kluwer, 1993. 348 pp. £107.

Imaging in Transport Processes. Edited by S. SIDEMAN and K. HIJIKATA. Begell House, 1993. 621 pp. $135.

Instabilities in Multiphase Flows. Edited by G. GOUESBET and A. BERLEMONT. Plenum Press, 1993. 344 pp. $89.50.

Circuit, Component and System Design. Edited by C. R. BURROWS and K. A. EDGE. John Wiley & Sons, 1993. 435 pp. £95.

Fluid Power. Edited by T. MAEDA. E. & F. N. Spon, 1993. 785 pp. £135.

Numerical Methods for Fluid Dynamics. Edited by M. J. BAINES and K. W. MORTON. Oxford University Press, 1993. 604 pp.