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WILLIAM GEMMELL COCHRAN 1909–1980

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W. G. Cochran died at Cape Cod on March 29, 1980 after several years of indifferent health. He retired from Harvard University in 1976 after a long and distinguished career and was working actively to the end. A quintessential Scot, his unwavering wisdom and good humour endeared him to all who knew him. His writings, especially his books *Sampling Techniques* and *Experimental Designs* (with Gertrude Cox), and his revision of Snedecor's *Statistical Methods*, have been enormously influential. The latter is by far the most cited statistical reference book.

Cochran was born on July 15, 1909 in the Royal Burgh of Rutherglen, Scotland to Thomas and Jeannie Cochran. Most of Rutherglen's population of almost 30,000 worked in factories which "belched smoke and fumes" and lived in tenements nearby. But close at hand were woods, hills, and fields where Cochran could walk with his older brother, Oliver, who gave (at the service for Cochran in Harvard Memorial Church on May 2, 1980) a vivid picture of their happy, but penurious, childhood.

Their father was the eldest of seven children and had (at age thirteen) to take a job with a railroad company. The family moved first to Gourock and then to Glasgow when "Willie" (pronounced Wully) was 16. Oliver became an accountant and later joined the Civil Service.

In 1927, Willie was first in the Glasgow University Bursary Competition, taking papers in English, Latin, mathematics, natural philosophy (physics), and chemistry. With this bursary, he was able to finance himself through the University; and, of course, to be first in this competition was always regarded as a very fine achievement. He graduated M.A. in 1931 with First Class Honours in Mathematics and Natural Philosophy, and shared the Logan Medal for the most distinguished graduate in the Arts Faculty. He was also awarded the George A. Clark Scholarship of £200 per annum for four years which was then enough to finance him through Cambridge University. Glasgow recognized their distinguished son with an honorary LL.D. in 1970.

Cochran entered St. John's College, Cambridge, in 1931 with four mathematical graduates of other universities—Keith Bullen from New Zealand, William Egner from Durham, Anton Hales from Capetown, and Frank Smithies from Edinburgh. Bullen soon became a research student of Harold Jeffreys and subsequently was knighted for his work in seismology. (Bullen taught me applied mathematics and recommended me as a graduate student to Cochran.) The other four, all becoming Wranglers (people who gained First Class Honours) in 1933, studied for the Mathematics Tripos before becoming research students. Smithies became an influential mathematical don in Cambridge, Hales became a well known geophysicist, and Egner was the head master of several schools and a scientific officer (O.R.) in the Royal Air Force in World War II. In pure mathematics, their Tripos supervisors were E. Cunningham, F. P. White, and M. A. Newman, and in applied mathematics, Sydney Goldstein, "who could solve any Tripos examination problem on the spur of the moment." This, no doubt, explains why Cochran's first paper [2] is on the flow

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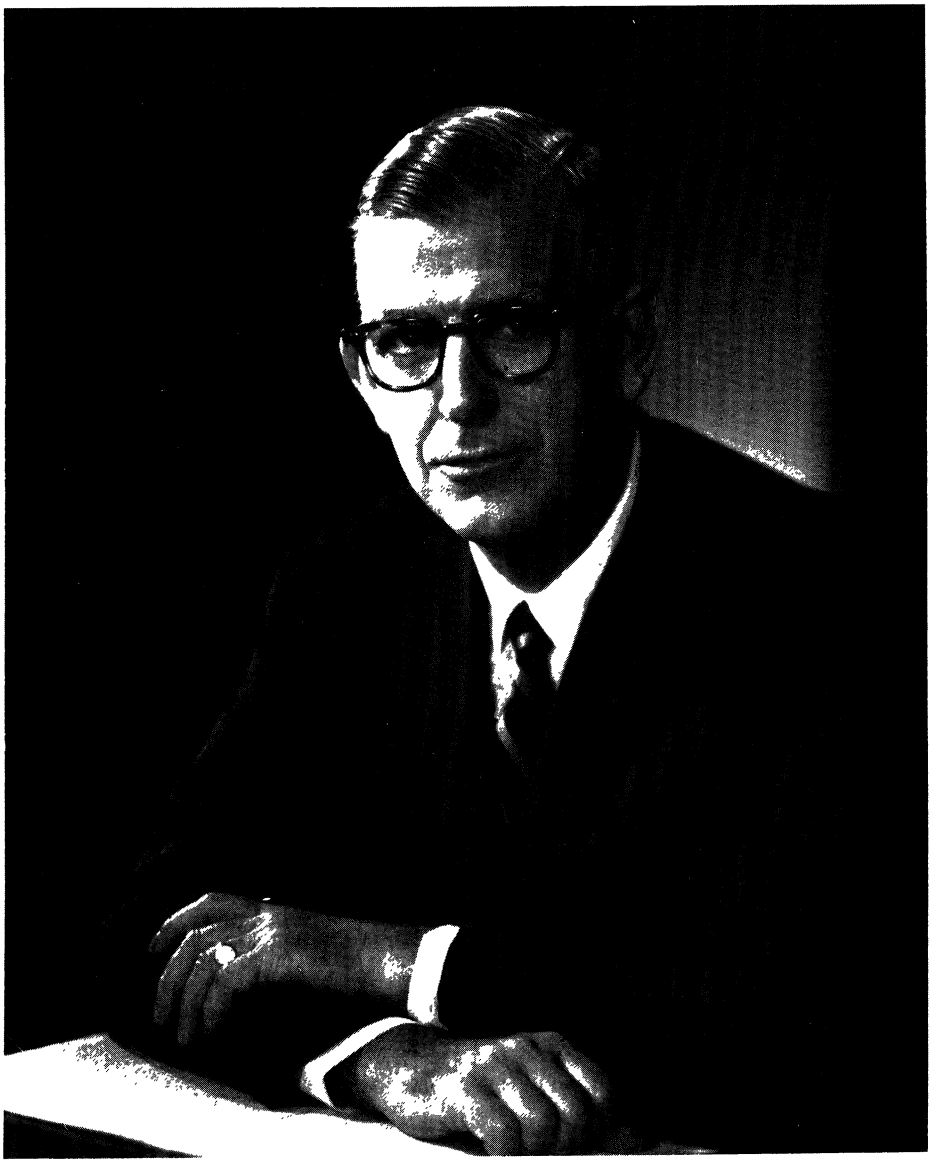
By action of the Council of the Institute of Mathematical Statistics, this issue of the Annals of Statistics is dedicated to the memory of

WILLIAM G. COCHRAN



due to a rotating disc, since Goldstein was a fluid dynamicist (who also ended his distinguished career at Harvard). Hales and Cochran played badminton together once a week, followed by tea and oatcakes.

The Tripos students had some required and some elective courses. Egner and Cochran chose as an elective the new course, "Mathematical Statistics," given by Wishart, who had moved from Rothamsted to Cambridge in 1931. Hardy and Besicovitch were Cochran's heroes then, so one wonders why he entered statistics. Egner tells me that the great depression (which must have been very apparent on Tyneside and on the Clyde) had interested him in the work of a Dr. Mess who advocated a thorough mathematical investigation of economic problems.

They agreed that this idea should be followed up by attending Wishart's course and also by taking his practical statistics course, offered in the School of Agriculture. Hales also recalls that they were aware that Fisher was doing exciting things and making statistics a branch of mathematics. Both recall that Cochran, who always did brilliantly in examinations, was very modest. Hales wonders, therefore, whether Cochran may have felt that he could not equal the success of James Hyslop, an analyst, who had also come to Cambridge from Glasgow a few years before Cochran. Hales remembers too the "acid exchanges" of Jeffreys and Fisher and the arguments these five students had about the foundations of statistics. Egner recalls that he and Willie attended two lectures by Wittgenstein in his rooms in Trinity. He describes them as a sequence of "two words and 10 minutes pacing up and down the room." He says that Willie was a member of the St. Johns Music Club, sang in the choir, and attended concerts.

The "Cochran's Theorem" paper [1] was written under Wishart after Cochran had finished the Tripos. In [86], Cochran tells an amusing story of how Wishart told him, at Fisher's request, to calculate the 1% significance points of Z. This probably explains [22]. Paper [1] calls upon a paper by Wishart and Bartlett. M. S. Bartlett spent the preceding year (his only postgraduate year) with Wishart before joining E. S. Pearson at University College. These were the only places where statistics courses were given in the British Isles, except perhaps courses by A. C. Aitken in Edinburgh. Thus, the teaching prospects for graduates were almost non-existent, even without the depression. Things were only slightly better then in the U.S. as Anderson (1965) explains in his obituary of S. S. Wilks, who spent 1932–33 with Pearson and moved to Cambridge in January 1933. H. O. Hartley arrived in Cambridge the year after Cochran left.

Fisher was, until 1933, at Rothamsted. Yates had taken Wishart's job there in 1931 when the latter moved to Cambridge. But in 1933 Karl Pearson retired, and his Department of Applied Statistics was divided into two departments. E. S. Pearson became the Professor of Statistics, and Fisher became the Galton Professor of Eugenics. Yates took over statistics in Rothamsted; he was soon able to hire an assistant, and he chose Cochran.

To quote Yates, "...it was a measure of his good sense that he accepted my argument that a Ph.D., even from Cambridge, was little evidence of research ability, and that Cambridge had at that time little to teach him in statistics that could not be much better learnt from practical work in a research institute." Cochran could, of course, have submitted a thesis from Rothamsted but was presumably too busy working and writing papers to do so. The Ph.D degree meant little in England then.

As mentioned above, there were few jobs for people with or without Ph.D.'s. Further, as is made abundantly clear in Joan Box's biography (1978) of her father, Fisher lived and spent a lot of time in Harpenden, so Cochran would have plenty of chances to meet Fisher. Thus, having gotten a great deal out of Cambridge, he proceeded to make the most of every minute in Rothamsted, so that when he left in 1939, he had written 23 papers and was a well known and accomplished statistician. He could go to London to meetings of the Royal Statistical Society and to lectures by Fisher at University College. He described some experiences of his trips to London in [92]. Although Neyman, E. S. Pearson, and Welch were also giving lectures at University College, those who attended do not recall seeing Cochran there. This was probably merely due to a lack of time and opportunity, not

to taking the Fisherian "side", because Cochran was always open-minded and fair—note, for example, the reference to power in [1].

At Rothamsted, Cochran met Betty I. M. Mitchell, an entomologist, and they were married at St. Columba's Church of Scotland (destroyed in World War II), Sloane Square, London, on July 17, 1937. Bill (Willie then became Bill) and Betty were there, as ever afterwards, very popular, participating in many social activities and making friends that would last a lifetime.

Hartley relates a good story of those days. "Shortly after Cochran's arrival at Rothamsted, he had been given the task of analyzing a crop fertiliser experiment. The results appeared to be very quaint. No main effects were significant, only one interaction and that barely so. He wrote a very detailed and careful report and submitted it to Frank Yates. It was returned to him within a day. His report was struck out by red pencil and there was just a two word comment by Yates, 'crop failed.' Bill added somewhat wistfully, 'had the results been recorded in 'cwt per acre,' I could have perhaps recognized this, but a low 'lbs. per plot' is not so obvious to someone new at Rothamsted.'"

Cochran's time at Rothamsted was climaxed by paper [23], "Long-term agricultural experiments," which was read to the Royal Statistical Society on May 25, 1939 with Sir John Russell, the Director of Rothamsted Experimental Station, in the Chair to propose a vote of thanks and R. A. Fisher to second it. Sir John recalled how, exactly 20 years before, he had asked a young mathematician whether it would be possible to get more information out of the unique long term experiments that Lawes had initiated—wheat in 1843, barley in 1852, and marigolds in 1876.

Fisher accepted the challenge, and "the rest is history," as they say. Russell went on to give a two page review of the impact of Fisher's ideas on agricultural experimentation which should be required reading. He mentioned, in passing, field experiments by Crowther in Egypt which Cochran subsequently analyzed [35]. Cochran was thus in the line of Fisher, Wishart and Yates and others yet to come. Fisher complimented Cochran (as did Wishart) on his mastery of and attention to the real agricultural problems. Wishart regretted that the speaker was soon to leave. These old trials were neither replicated nor randomized, and Cochran remarks that the former was a greater problem—some of the plots were inherently more fertile. Replication had to come with time. Interaction with seasons was an issue. This surely explains his three papers explicitly about the weather [3, 16, 20]. Fisher found no faults with the paper, though he queried a reference to lattices, then a new contribution by Yates. Papers [25, 29, 32, 39] deal with these designs. Bartlett and Hartley raised questions about analogous problems with animal experiments to which Cochran returned later—see [29]. Russell mentioned the importance of crop estimation which Cochran had discussed in [20, 28] and which leads naturally into his interest in sampling.

Yates proposed his correction for continuity for the binomial distribution and 2×2 tables in 1934. Counts of diseased plants (see [6]), insects, eel worms, etc., were important in Rothamsted. One sees here the beginning of his lifelong interest in these topics [8, 12, 26, 34, 38, 47, 48, 54, 64, 67].

When Cochran left Rothamsted, his place was taken by D. J. Finney who remarks that his own "career owes a great deal to Cochran having taken himself across the Atlantic at just the right moment for me, because openings for statisticians at that time were very restricted.... He (Cochran) followed the tradition that Fisher established and Yates continued of being widely available to anyone who wanted statistical help, whether a Head of Department, a very junior member of staff, or a research student working for a Ph.D. He contributed to the main stream of work on field experiments, notably with a paper on long-term experiments published not long before he left. He was also well in with the insecticide people, to whom he had given a lot of help; this was a responsibility that devolved upon me, so starting my own interest in probits, maximum likelihood, and biological assay. At that time, Rothamsted was very much a self-contained community, a group of scientists having much in common and living in a relatively small village...."

In 1938, Cochran visited Ames, Iowa and agreed to return in 1939 as professor. The imminence of World War II made him hesitate, but he felt bound to go. Snedecor had made Ames a great center for Fisher's new ideas and had persuaded the College (as it then was) that all experimental work should be properly treated statistically. This gave statistics there a status it had nowhere else in the world. The emphasis there in applied statistics was then on sample surveys and experimental design. Cochran lectured on both topics in his first quarter there, and these lecture notes over the next ten years or so matured into the well known textbooks.

The history of sampling before World War II is of interest, so I asked Yates. He replied:

> There was certainly much survey sampling at Rothamsted before the War in which Cochran played an active part. We were particularly interested in the sampling of agricultural crops for yield, etc., and of experimental plots. This work was indeed started before I came to Rothamsted. I expect he was also involved with me in the 1938/39 census of woodlands. . . . Also, he was involved in the Agricultural Meteorological Committee Scheme for sampling for the growth of wheat. A lot of our later work on sampling owes much to this early work.

There was then a close connection between Ames and the Bureau of the Census because of sampling developments at Iowa led by Jessen. Subsequently, Cochran was chairman for many years of a panel to provide guidance to the Census.

Cochran was also able to keep up an interest in plant and animal breeding at Ames. I recall his high opinion of J. Lush whom he missed later when in Raleigh. There is only one paper on selection [52], a topic on which he had a large but undocumented impact.

The first two of the three Cochran children, Elizabeth (Welsch) and Alexander Charles, were born in Ames on April 25, 1940 and April 24, 1942, respectively.

At Iowa, Cochran wrote a series of papers on experimental design and produced important ideas on sampling surveys, as is evident from the dates in the bibliography.

In 1943–44, Cochran joined the Princeton Statistical Research Group directed by S. S. Wilks to work on specifically military problems (see T. W. Anderson, 1965, and R. L. Anderson, 1980). In 1945, he was a member of a team that surveyed the damage from allied bombing raids to access their efficacy.

Cochran recruited Alexander Mood to Ames in 1945 when he knew he was to leave. In a letter, Mood says of those days:

> Almost from the day he arrived he was the pre-eminent statistical consultant in the U.S. He was marvelous at it and to my judgment in a class by himself. No one else had the breadth of experience with data from so many fields of statistical investigation; no one else had such universal knowledge of statistical techniques; probably no one else was such a comprehensive reader of statistical journals. . . . Those of us who worked on wartime problems under Sam Wilks at Princeton had a wide variety of assignments: damage assessment of naval vessels under gunfire, torpedo attack, bomber attack and missile attack; optimization of naval firing doctrine; effectiveness of bombing of such targets as troops, highways, railroads, bridges, airfields and minefields; effectiveness of short range rockets on troops, tanks, artillery, minefields and logistic targets; sensitivity and reliability of various fuses and explosives; effectiveness of various special devices for clearing minefields; accuracy of various kinds of weapons. I have doubtless forgotten some of them, but the point is that with Bill among us I am sure that work on none of these assignments ever proceeded without first getting his counsel because all of us knew that if any similar problem had ever been tackled, then Bill was the person most likely to know about it. . . .
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> Before 1940 I do not think there were any statistics departments on U.S. campuses. Statistics generally referred to elementary descriptive courses offered by psychology, education and business administration departments.

> Math departments at a few major universities (Columbia, Princeton, Iowa, Michigan, California, UCLA, and maybe one or two others) offered a course or two in math. stat. I doubt that any survey sampling or experimental design was included in these courses. I think they used Rietz's book and probably switched to the Wilks notes when they became available in 1943. Parenthetically, I should remark that Rietz, at the University of Iowa, had a number of distinguished doctoral students in the early 1930's—J. Curtiss, A. T. Craig, C. C. Craig, S. S. Wilks. The only place where one could study sampling and design was Iowa State College where Snedecor had been developing the courses over a period of about ten years (say, 1930 to 1940). Snedecor pretty much singlehandedly brought modern applied statistics to the U.S. He was intensely interested in it and brought prominent statisticians from abroad (e.g., Fisher, Yates, Mahalanobis, Sukhatme) to Ames for a summer or a semester to educate himself and his colleagues. His efforts transformed research practices at the various agricultural experiment stations maintained at land grant colleges by the U.S. Department of Agriculture and also at the Bureau of Agricultural Economics which developed sampling methods for crop estimation....
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> The courses at Ames, although taught in the mathematics department, were quite unmathematical. Somehow, people introduced to statistics by Snedecor's book developed very good insights as to how to partition, purely arithmetically, sums of squares associated with very elaborate designs. Even the advanced sampling and design courses used essentially no mathematics or probability theory or mathematical statistics....

In 1946, Gertrude Cox, by now Director of the Institute of Statistics in North Carolina, persuaded Cochran to head the graduate program in Experimental Statistics at the State College in Raleigh. Hotelling was head of the Mathematical Statistics Department at the University at Chapel Hill. This formidable team organized two fine departments. Seven of the faculty there when I arrived in September 1947 subsequently became members of the National Academy of Sciences. The list of distinguished visitors seemed to us graduate students to be quite complete. Bill's research there followed the several paths he had established early in his career—sampling, design and analysis of variance, Chi-square, discriminant functions, combination of experiments. The problems of using estimated weights were then in his mind [50, 58]. The reviews [44, 45] showed his authoritative position in sampling and the analysis of variance. His paper with Bliss [46] on discriminant functions was written in this period, to be followed later by [81, 88, 96].

It should be remarked here that Cochran wrote many reviews during his career, and these were all influential. On re-reading his work, I am struck by its clarity and modernity. The lead-in to every paper always puts the problem in perspective.

His most remarkable course in Raleigh was, I believe, one in which he presented and made us analyze a series of data sets, none of which quite fell in standard categories, so it was always necessary to return to first principles. His departure from Raleigh was a severe blow to the Institute.

His daughter, Teresa, was born on June 10, 1946 in Durham, N.C.

As Chairman of the Department of Biostatistics in the School of Hygiene and Public Health at Johns Hopkins from January 1949 to the Summer of 1957, he was faced with medical rather than the agricultural problems of his former positions. In this period, *Sampling Techniques* and *Experimental Designs* were finally published. The Kinsey Reports (1948–1953) sponsored by the National Research Council (NRC) received worldwide attention but were roundly criticized on methodological grounds. The NRC asked the ASA to appoint a committee to assess the report, and it chose Cochran, Mosteller and Tukey, all of whom had been together in Princeton during World War II. The result was the book, *Statistical Problems.* It does not seem that Cochran had much contact with research in the medical school, but he was a constant source of help to faculty and graduate students in public health. However, he was faced with the difficulties of sampling human populations and of getting reliable information out of observational, rather than experi-

mental, data [65, 66, 84, 90, 93, 95, 96, 102, 105]. These seemed to become his dominant new interest for the rest of his career. Hopkins recognized his services to them and to the statistical profession with the honorary degree LL.D. in 1975.

When the Department of Statistics was established at Harvard in 1957, Cochran was appointed. Together with F. Mosteller, H. Raiffa, J. Pratt and, later, A. Dempster, he helped to create their curriculum and style. Cochran continued his old research interests but pursued even more actively his work on observational studies. One new interest was sequential methods for estimating the median effective dose [83, 86, 89]. Another series of papers belonging to this period deals with measurement errors [95, 99, 101]. The motivation of this series is that, particularly in human observational studies, many variables are poorly defined, so that (linear) relationships between them will be hard to determine. Cochran never took extreme positions on any issue, least of all on inference, but he usually wrote as a frequentist. There are, however, two papers [85, 87] on the Behrens-Fisher test.

Cochran was honored by professional societies. He was president of the Institute of Mathematical Statistics in 1946–47, president of the American Statistical Association in 1953–54, president of the Biometric Society 1954–55, and president of the International Statistical Institute in 1976–81. He was elected to the American Academy of Arts and Sciences in 1971 and to the National Academy of Science in 1974.

One of Cochran's last jokes, when gold went over $700 per ounce, was "Gather up my medals, now is the time to sell," for he had quite a collection: Gourock High School 1924, Glasgow High School 1924, Cunningham Medal for Mathematics and the Issac Newton Medal for Natural Philosophy, 1930. He also won the McLaurin Medal for Mathematics in 1929 and the Logan Medal mentioned earlier. But he was most proud of the Guy Medal of the Royal Statistical Society, 1936, and the Wilks Medal of the American Statistical Association, 1967.

He could have spent his life on committees, since many sought his advice. However, he accepted only those he felt were right for him and for which he could spare the time. Foremost of these was the committee that produced the Surgeon General's Report on Smoking and Health (1964).

This brief account of the life and work of Cochran should convey to those who did not have the good fortune to know him, the love and affection, as well as professional admiration, which those of us who did all felt for him.

For the writing of this Memorial article, I received helpful letters and information from Oliver Cochran, Betty Cochran, Richard L. Anderson, Maurice S. Bartlett F. R. S., William E. Egner C. B. E., David J. Finney F. R. S., Anton Hales, Morris Hansen, the late H. O. Hartley, Oscar Kempthorne, Alexander M. Mood, Frederick Mosteller, Mildred (Barnard) Prentice, S. David Silvey, G. Tintner, and Frank Yates F. R. S.

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