Samuel S. Wilks and the Army Experiment Design Conference Series

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ABSTRACT

A biography of Professor Samuel Stanley Wilks (1906-1964) of Princeton University, with particular attention to his early life, notes on the persons who shaped his professional development, review of his many facetted professional career, and his role in initiating and launching the U.S. Army's annual series of Conferences on the Design of Experiments in Army Research, Development, and Testing.

1. BIRTH, FAMILY, AND EARLY YEARS

Sam Wilks was born on the 17th of June 1906 in Little Elm, Denton County, Texas, the first of the three children of Chance C. and Bertha May Gammon Wilks. His father trained for a career in banking, but after a few years chose instead to make his livelihood by operating a 250-acre farm near Little Elm. His mother had a talent for music and art; and a lively curiosity, which she transmitted to her three sons. The predilection of their father, Chance C. Wilks, for alliteration is manifest in the given names of all three: Samuel Stanley, Syrrel Singleton, and William Weldon (Wilks).

Syrrel, less than two years younger than Sam, was his boyhood companion; studied biology (B.S., 1927) and physiology (Ph.D., 1936); became Associate Professor of Physiology at the Air Force School of Aviation Medicine; and passed away early this year (1974). In consequence of Sam's and Syrrel's initials being the same, their publications are sometimes lumped together under "S.S. Wilks" in bibliographic tools, e.g., in the successive volumes of the *Science Citation Index*.

Sam's "baby brother," William, was eight years younger. He also took a B.S. degree; became a research advisor to Bell Aircraft Company in Fort Worth, Texas; and is still living. The choice of "Weldon" for his middle name is merely a happenstance of his father's effort to achieve a triple alliteration, and has no genealogical significance: there is no known connection between the Chance Wilks family and that of the pioneer biometrician, W.F.R. Weldon (1860-1906), who died in London in April of the year in which our biographee was born; or with any other Weldons.

Sam began his early education in a typical one-room rural school house where, in the seventh grade, he had as his teacher William Marvin Whyburn, who became a distinguished mathematician, the president of Texas Technological College (1944-1948), and the chairman or head of two university departments of mathematics (UCLA, 1937-1944; University of North Carolina, 1948-1956; 1960-1965) – the first of an extraordinary number of prominent people who had a part in Sam's education. He attended high school in Denton, the county seat and the site of North Texas State Teachers College (now North Texas State University), and of a College of Industrial Arts for women (now Texas Woman's University). During the week he roomed in Denton, and went home on weekends, walking the 15 miles to his father's ranch when necessary. During his final year of high school, it was noticed that he was absent repeatedly from study hall. Inquiry revealed that he was skipping study hall in order to take a mathematics course at North Texas State Teachers College.

Following graduation from high school, Sam continued his studies at North Texas State Teachers College, where he followed an industrial arts program, with particular attention to mathematics. He received an A.B. in architecture in June 1926, a few days before his 20th birthday. A large drinking fountain, designed by Sam and a friend, on the campus of the College attests to his talent and serves as a reminder of his one-time interest in architecture. But believing his eyesight inadequate for the life of an architect, he turned to a career in mathematics.

2. TEACHING AND GRADUATE STUDY

During the school year 1926-1927, Wilks taught mathematics and manual training in a public school in Austin, Texas, and began graduate study of mathematics at the University of Texas there. He continued his studies at the University of Texas as a part-time instructor in mathematics 1927-1928; and received a M.A. in mathematics in 1928. His first course in advanced mathematics at the University of Texas was set theory, taught by R.L. Moore (1882-1974), renowned among mathematicians for his research in topology, his unusual methods of teaching, and the vigor and resoluteness of his opinions. Wilks was fascinated by the unfolding of this beautiful theory from a few simple definitions and axioms, but Moore's espousal of pure mathematics as a discipline wholly divorced from application, and Moore's scorn of applied mathematics as work on a level with washing dishes, were incomprehensible and unacceptable to him. Had Moore's attitude been otherwise, Sam might have become a topologist. But, as Alex M. Mood[1] has said in his note on Sam's philosophy about his work, "Sam's character demanded that his work be immediately and obviously useful [and] Moore was the last man to persuade him that point set theory was useful." (MOOD 1965, p. 953) Much more in keeping with his "character" were probability and statistics, to which he was introduced by Edward L. Dodd (1875-1943), an inspiring teacher and distinguished scholar, noted for his researches on mathematical and statistical properties of various types of means.[2]

An aside on Sam's views with respect to pure mathematics and pure mathematicians seems appropriate at this juncture, before taking up the next step in his education. To this end I can do no better than to quote further from Mood's note:

> "Wilks … saw little sense in pure mathematics unless it had some ultimate application. He generally believed that most pure mathematics would eventually justify itself in this way and was delighted when that did happen in his own work or that of others … The set theoretical foundation of probability theory developed by Kolmogorov gave Sam no end of pleasure partly because of that early course, perhaps, but more likely because it was a good piece of evidence that pure mathematicians were not, after all, wasting their time.

> “While Sam was generally optimistic about the eventual utility of pure mathematics he became less and less patient over the years with pure mathematicians themselves – especially those in the United States. For one thing he believed that their general refusal to apply their intellects even briefly to important practical problems was less than patriotic, to say the least. He rarely missed an opportunity to point out that almost all top-level Soviet mathematicians had at one time or another turned to an important field of application thus placing themselves, in his eyes, quite above many of America’s leading mathematicians.
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> “The thing that particularly annoyed Sam about pure mathematicians was their snobbishness about pure mathematics and, worse, their success in generating the same sort of snobbishness in every mathematically talented student that came along. Sam was a very even-tempered man but this was a subject that could summon loud indignation from him. He believed that for reasonably even balance in the development of mathematics a substantial proportion of the most talented students should go into mathematical statistics, mathematical physics, applied mathematics, econometrics, etc. As it was, he believed that pure mathematics preempted over nine out of ten of the most talented students thus completely deforming mathematical progress in the United States. In his later years he maintained that it was impossible for him to persuade enough sufficiently promising college graduates to undertake work in statistics at Princeton and therefore he had to go to Britain and Canada to find good students whose attitudes had not been corrupted by pure mathematicians in the United States.” (MOOD 1965, 953-954)

When Sam completed the requirements for his M.A. in mathematics at the University of Texas in 1928, Professor Dodd encouraged him to pursue further study of mathematical statistics at the University of Iowa[3] under Henry L. Rietz (1875-1943)[4], the leader of his generation in American mathematical statistics[5]. Wilks stayed on at the University of Texas as an instructor in mathematics during the summer of 1928, and the academic year 1928-29; applied for a fellowship at the University of Iowa; and to pick up some ready cash, served as monitor for State bar exams given at the University.

In due course, Sam was offered, and accepted, a fellowship at the University of Iowa, in Iowa City. He arrived in Iowa City in the summer of 1929 to begin a two-year program of graduate study and research leading to a Ph.D. degree in mathematics, with a minor in education. During the second summer (1930), he was joined by two others whose names were later to become well known in probability and mathematical statistics circles: Allen T. Craig and John H. Curtiss.

Curtiss had just received his A.B. in mathematics at Northwestern University, and had come to the University of Iowa to study actuarial mathematics preparatory to choosing actuarial work as a career. He was assigned to one of two desks arranged back-to-back in the Mathematics Department Library, the other occupied by Sam. He has a close-up picture of Sam taken from this vantage point.[6]

Allen T. Craig, in contrast, had returned to the University of Iowa in the summer of 1930 for the express purpose of completing his doctoral thesis, "On the Distribution of Certain Statistics Derived from Small Random Samples." I say "had returned to the University of Iowa" because Craig had been there during the academic year 1928-29, but had left Iowa City in the summer of 1929 to accept a position as an Instructor in mathematics at his alma mater, the University of Florida, in Gainesville, for the academic year 1929-30. Drawn together by common interests, Allen Craig and Sam Wilks immediately became close and lifelong friends. Craig, in his thesis (CRAIG 1932), gave a number of general results on the distributions of such statistics as the arithmetic mean, harmonic mean, geometric mean, median, quartile, decile, and range of samples of small *n* items selected at random from a rather arbitrary (continuous) universe, together with a large number of explicit results for sampled universes of special types. Sam often said that his own work on the theory of nonparametric or distribution-free methods – an area in which Sam made a number of truly outstanding contributions[7] – had its origins in the general formulas given by Craig for the distributions of the "median, quartile, decile, and range."

Sam's doctoral dissertation was, likewise, a contribution to "the theory of small samples." Entitled "On the distributions of statistics in samples from a normal population of two variables with matched sampling of one variable" (WILKS 1932a), it provided the small-sample distribution theory required to answer a number of questions drawn to Sam's attention by Professor E.F. Lindquist, Professor of Education at the University of Iowa and Director of the Iowa Testing Programs, who had used the technique of "matched" groups in experimental work in educational psychology, and whose lectures Sam had attended.

Sam's thesis was preceded by a short note by Sam on "The standard error of the means of 'matched' samples" (WILKS 1931), published in the March 1931 issue of the *Journal of Educational Psychology*, where it was accompanied by an article by Lindquist (LINDQUIST 1931), describing the use and importance of "matched" groups as a statistical technique in experimental psychology and educational testing. Sam's predoctoral note and his doctoral dissertation were the first of a series of papers on multivariate analysis suggested by real-life problems in experimental psychology and educational testing, and mark the beginning of Sam's life-long association with the latter field.

Sam and Allen Craig both received their Ph.D.'s from the University of Iowa in June 1931 – Sam in Mathematics, with a minor in Education; Allen, in Mathematics alone. "Father Rietz" was mighty proud of his "twins." Theirs were the first doctoral dissertations written at the University of Iowa on aspects of "the theory of small samples," the new area of mathematical research, initiated in 1908 by "Student" (William Sealy Gosset, 1876-1937) and developed to full flower by R.A. Fisher (1890-1962) between 1915 and 1928, to which an increasing number of American mathematicians were devoting attention at that time – notably C.C. Craig (at the University of Michigan in Ann Arbor), Harold Hotelling (at Stanford University, in California), Paul R. Rider (at Washington University, St. Louis), and Rietz (at the University of Iowa, in Iowa City).[8] Rietz was doubly proud of their accomplishments; not only had each made a first-rate contribution to "the theory of small samples," but also the mathematics in their dissertations was intelligible to American mathematicians – which was a great deal more than one could say about the papers of R.A. Fisher.[9] He therefore held out two "prizes" to his deserving "twins": (1) an appointment as an Associate (a rank between Instructor and Assistant Professor) in his department, and (2) his endorsement for a National Research Council Fellowship. Allen chose the appointment in the Department of Mathematics – stayed on to become a full Professor in 1945, and retired in 1970; Sam, the NRC Fellowship, and made plans to continue research in multivariate statistical analysis under Harold Hotelling (1895-1973), a pioneer in the field, and the individual in the United States most versed in the mathematics of the Student-Fisher theory of small samples.[10]

After receiving his Ph.D., Wilks stayed on to attend the lectures given, and seminar conducted, during the first half of the summer session, 8 June-16 July, by the British mathematical statistician, Egon S. Pearson; and gave a talk in the seminar series. Pearson's two papers with Jerzy Neyman on "The use and interpretation of certain test criteria for the purposes of statistical inference" (Part I, *Biometrika*, Vol. 20A (1928), pp. 175-240; Part II, *ibid*, pp. 263-294) had been well received by mathematicians interested in statistical theory. As you will recall, it was in these papers that they introduced and explored their <u>likelihood-ratio</u> technique for more or less automatically discovering "good" tests of various statistical hypotenses.[11]

Wilks also met R.A. Fisher, who came over to Iowa City from Ames for a day during this period. By an extraordinary coincidence, R.A. Fisher was "in residence" that summer at Iowa State College, at Ames, 90 miles distant, giving a "competing" series of lectures on the material in his two books, <u>Statistical Methods for Research Workers</u> (3rd edition, 1930) and <u>The Genetical Theory of Natural Selection</u> (1930), during the first half of their summer session, 16 June-24 July. The overlap of the two programs, and the distance between the two institutions, made it physically impossible for faculty and students to take in both programs in their entirety.

<u>3. MARRIAGE AND POSTDOCTORAL STUDY</u>

Sam returned to Texas in midsummer 1931, and on September 1 married Gena Orr of Denton. The Wilks and Orr families had been friends for many years. Indeed, about one year before Chance Wilks finally won the hand of Bertha, she was being courted by Will Orr, while Chance was away from Little Elm, trying his hand at the banking business. But Chance returned in time to prevent my story from ending before it began – and in due course Gena was fathered by Will; and Sam, by Chance.

Sam and Gena had known each other from childhood. They attended the same high school in Denton; she was a student at the College of Industrial Arts, in Denton, at the same time that Sam was attending the North Texas State Teachers College there; and they both received their A.B. degrees in 1926; but they did not start "dating" until that summer. What brought them together was the wedding of Sam's cousin, James Hodge, and Jessie Hill, at which Sam was Best Man, and Gena a bridesmaid. Gena then taught school locally for a couple of years, while Sam was continuing his study of mathematics at the University of Texas, in Austin; and continued to date Sam from time to time when he was home on vacation. In due course she got herself over to the University of Texas, where she did graduate work in English, and received her Master's Degree in 1929.

As part of their honeymoon, Sam and Gena set off for New York City by boat, from Galveston, Texas. The trip took five days. They settled in an apartment on the 6th floor of the

Columbia University-owned apartment building at 401 West 118th Street. During World War II the main offices of the Statistical Research Group–Columbia (SRG-C), of which Harold Hotelling was the Principal Investigator, were located in this building, in what had been Sam and Gena's apartment; and W. Allen Wallis, the Group's Director of Research, occupied what had been their bedroom.

Among those attending Hotelling's lectures on "Statistical Inference" that first year at Columbia in addition to Sam was Acheson J. Duncan, from whom I was later to receive my first course in this subject, and W.J. Youden (1900-1971), who was later to join me at the National Bureau of Standards (1948-1965) as practitioner, expositor, and innovator of statistical methods par excellence. "Atch" Duncan was then an Instructor in Economics at Princeton University, and at my father's insistence had been sent at University expense to study modern statistical inference under Hotelling. I shall say more about this in a few moments. "Jack" Youden had received his Ph.D. in Chemistry from Columbia in 1924, was a Physical Chemist at the Boyce Thompson Institute for Plant Research in Yonkers, New York, and was commuting to New York to hear Hotelling's lectures on his own volition to gain a better grasp of Student-Fisher theory and methods.[12]

In addition to auditing Hotelling's lectures, Sam joined Jack W. Dunlap and Warren G. Findley, then Ph.D. candidates at Columbia in Psychology and Educational Psychology, respectively, in attending the lectures, at Teachers College, of the English psychologist, Charles E. Spearman (1863-1945), revered by psychologists as the father of Factor Analysis (1904) and for development of a rational basis for determining general intelligence and for validating intelligence testing.[13] I mention Jack Dunlap and Warren Findley explicitly because Sam's and their paths were to meet and join for a while at various times in later years, for example, when Dunlap was Director of Research of the National Research Council's Committee on Pilot Selection and Training (1941-42), and when Findley was Director of Test Development (1948-53), and later in charge of the Evaluation and Advisory Services (1953-56) of the Educational Testing Service in Princeton.

It was a year of exceptional productivity for Wilks: he wrote or completed four distinct papers in the area of multivariate analysis all of which saw almost immediate publication. In one (WILKS 1932b) he found the maximum likelihood estimates of the parameters of a bivariate normal distribution when some of the individuals in a sample yield observations on both variables, x and y, and some only on x, or on y, alone; in a second (WILKS 1932c), he showed that the distribution of the multiple correlation coefficient in samples from a normal population with a non-zero multiple correlation coefficient could be derived directly from Wishart's generalized product moment distribution (1928) without making use of the geometrical notions and an invariance property utilized by R.A. Fisher in his derivation (1928); in the third, his great paper on "Certain Generalizations in the Analysis of Variance" (WILKS 1932e), he defined the "generalized variance" of a sample of n individuals from a multivariate population, constructed multivariate generalizations of the correlation ratio and coefficient of multiple correlation; deduced the moments of the sampling distributions of these and other related functions in random samples from a normal multivariate population from Wishart's generalized product moment distribution (1928); constructed the likelihood ratio criterion for testing the null hypothesis that k multivariate samples of sizes $n_1, n_2, \dots, n_k$ are random samples from a common multivariate normal population, now called “Wilks’s Λ criterion,” and derived its sampling distribution under the null hypothesis; and similarly explored various other multivariate likelihood ratio criteria; and in the fourth (WILKS 1932d), an outgrowth of attending Spearman’s lectures, he obtained an exact expression for the standard error of an observed “tetrad difference”[14] in samples of size *n* from normal population (in the special case in which the intercorrelations of the four variables are all zero in the population).

I mention these details just to show to what a remarkable extent Sam was not only applying, but also <u>extending</u> the most advanced concepts and tools of Fisher, Hotelling, Neyman, E.S. Pearson, and Wishart within one year of the receipt of his Ph.D.! I often heard my father, Luther Pfahler Eisenhart (1876-1965), remark when he was Chairman of the Department of Mathematics (1928-1945) and Dean of the Graduate School (1933-1945) of Princeton University, that what determined a man’s stature in his chosen field was not the caliber of his doctoral dissertation, but rather the caliber of the papers that he wrote and published <u>after</u> receiving his Ph.D. Sam certainly passed that test in 1932 with a wide margin to spare! Furthermore, the high regard in which Sam’s papers were held immediately following their publication is attested by the fact, already mentioned, that Irwin devoted 9 out of the 14 pages on “Exact sampling distributions” in his “Recent Advances … (1932)” (IRWIN 1934) to detailed consideration of Sam’s thesis and the first three of these four postdoctoral papers. And E.S. Pearson more recently remarked that Sam’s “stature as a statistician was I think early established by his *Biometrika* paper of 1932 on ‘Certain generalizations in the analysis of variance’ [which] must have been written during the winter after he gained his Ph.D. and as such was a remarkable performance.” (PEARSON 1964, p. 597)

While at Columbia University, Sam went down to the Bell Telephone Laboratories at 463 West Street to visit Walter A. Shewhart (1891-1967), father of statistical quality control of manufacturing processes, with whose work he had become acquainted through Rietz and Hotelling.[15] Sam became very interested in Shewhart’s work, and shortly thereafter Sam and Gena paid a brief visit to Walter and Edna Shewhart at their home in Mountain Lakes, New Jersey. Several years ago, Mrs. Shewhart told me that she remembered well how, as soon as Sam and Gena had left, Walter had turned to her and said, “There is a young man who is going to be one of the top men in Statistics in this country,” or words to that effect. This was the beginning of the friendship and collaboration of these two men that continued until Sam’s death.

In the Spring of 1932, Sam obtained a renewal of his National Research Fellowship, as an International Research Fellowship. He and Gena set off in August 1932 for London, England, where Sam was to be in residence in Karl Pearson’s Department of Applied Statistics at University College (of the University of London) during the “Michaelmas Term” (September-December).[16] While there, Sam and Karl Pearson’s son, Egon S. Pearson, wrote a joint paper (PEARSON AND WILKS 1933) in which the likelihood ratio techniques of Sam’s generalized analysis-of-variance paper are developed in greater detail for samples from a bivariate normal distribution, generalizing to this bivariate case the three tests developed by Neyman and Pearson (1931) for the univariate case. To illustrate the numerical application of the procedures they had developed, they included two worked examples, one based on data on the tensile strength and Rockwell hardness of aluminum dicastings, taken from Walter A. Shewhart’s <u>Economic Control of Quality of Manufactured Product</u> (1931).[17]

While in London, Sam met a great many of the leading British statisticians, and their disciples, either at University College or at the delightful teas that preceded the monthly meetings of the Royal Statistical Society. To add to the excitement – and to the strain of a married couple's attempting to live in London on the small stipend of an International Research Fellow – Sam and Gena's son Stanley Neal Wilks was born in London, in October 1932.[18] Early in January 1933, the family of three moved to Cambridge so that Sam could work with John Wishart (1898-1956), whose work in multivariate analysis was close to Sam's main interest.[19]

When Sam arrived at Cambridge, he found that Wishart and Bartlett had just completed an "independent" derivation of Wishart's generalized product-moment distribution "by purely algebraic methods," that is, by means of moment-generating functions in combination with the matrix algebra of quadratic forms (WISHART and BARTLETT 1933). Wilks found himself right at home in their company, and promptly wrote another major paper (WILKS 1934) in which he gave a method of deriving directly from the multivariate normal distribution (i.e., without using the Wishart distribution) the moments of the sampling distributions of functions of determinants of the types considered in his two *Biometrika* papers. Also, at the suggestion of G. Udny Yule (1864-1951), he wrote a paper, "On the Independence of Sums of Squares in the Analysis of Variance," in which by means of characteristic functions in combination with elementary matrix algebra, he demonstrated the independence of various row, column, etc., "sums of squares" involved an analysis-of-variance analysis of randomized blocks, Latin square, and certain other experimental arrangements, discussed previously by R.A. Fisher. Communicated to the Royal Society – not the Royal Statistical Society – by Yule, for publication in its *Proceedings*, the paper suffered rough treatment: it was apparently sent to Fisher to referee, who seems to have felt that by its very theme it implied that he had not already given adequate and intelligible proofs; then the manuscript was lost, and Sam had to provide a second copy; and then it was rejected. The publication shortly thereafter, in a publication of the Royal Statistical Society, of a similar, but somewhat more elementary, paper on the same subject, by one of Fisher's protégés, was a sore point with Sam for many years. (I have discussed this matter with the author of the "offending" paper. He assures me that he never saw Sam's manuscript; and, until our conversation, never knew of its existence.)

In May 1933 my father offered Sam an appointment as an Instructor in Mathematics in Princeton University. I first met Sam when he turned up in Princeton in time for the fall semester 1933, imported for the express purpose of teaching me – at least, that was what I thought at the time. My budding interest in probability and statistics may have helped a tiny weeny bit, but the true explanation was quite otherwise, and has an interesting background.

4. WILKS'S PRINCETON APPOINTMENT, AND STATISTICS AT PRINCETON BEFORE WILKS

The key figure in Wilks's appointment was my father, Luther Pfahler Eisenhart (1876-1965), who, in the spring of 1933, was not only willing, but, as Chairman of the Department of Mathematics (1928-1945), Dean of the Faculty (1925-1933), and Chairman of the University Committee on Scientific Research (1930-1945), was also able to effect Wilks's appointment to an Instructorship in Mathematics on a more or less emergency basis over the opposition of almost every member of his Department.[20]

An event that was to be instrumental in bringing both mathematical economics and modern statistical theory and methodology to the Princeton campus was the arrival of Charles F. Roos (1901-1958) as a National Research Fellow in Mathematics for the academic year 1927-28. Roos had received his Ph.D. in theoretical economics at the Rice Institute in 1926 under Professor G.C. Evans (1887-1973), who at that time was developing a new mathematical theory of economic phenomena termed “economic dynamics,” and had spent 1926-27 at the University of Chicago working with Professor Henry Schultz (1893-1938) who at that time was deeply engaged in his epochal research on statistical laws of demand and supply as one facet of his life’s work on the theory and measurement of demand. Roos came to Princeton primarily to broaden and sharpen his knowledge of mathematics as a basis for making further contributions to Professor Evans’ new “economic dynamics.” While there he succeeded in convincing some members of the Department of Economics and Social Institutions that the Department could not afford to continue to neglect much longer the advances in economic theory and methods pioneered by Evans and Schultz.

In 1928 my father became the Chairman of the Mathematics Department. One of his early acts in this capacity was to arrange for the loan by the Bell Telephone Laboratories, Inc. of a member of its Technical Staff, Dr. Thornton C. Fry, author of <u>Probability and Its Engineering Uses</u> (D. Van Nostrand, 1928), to give a course at Princeton on “Methods of Mathematical Physics” as a Visiting Lecturer in Mathematics during the first semester 1929-30. I remember going with my father to Bell Labs to visit Fry during either my spring or summer vacation of 1929 – the necessary arrangements may have been broached, or perhaps firmed up on that occasion. Be that as it may, one result of Fry’s visit to Princeton was that a course in probability, taught by H.P. Robertson (1903-1964), Associate Professor of Mathematical Physics, using Fry’s book as the text, was offered by the Mathematics Department during the second semester of my sophomore year (1931-32). It was this course that first interested me in probability and mathematical statistics and started me on my career.

In 1931 steps were taken that led to a course in “modern statistical theory” being offered for the first time at Princeton by the Department of Economics and Social Institutions during the first semester of my senior year (1933-1934). What happened was this: Professor Frank D. Graham (1890-1949) of this department approached my father in his capacity as Dean of the Faculty, and suggested that one way to overcome lack of competence in his department with respect to the latest developments in mathematical and statistical methods in economics would be to send one of the young instructors in his department to study with Professor Henry Schultz at the University of Chicago. (The possibility of hiring a new staff member from the outside to this end had been considered earlier but put aside – the Depression was in full swing, and there was a freeze on new University appointments.) My father was favorable to this proposition, subject to an additional provision: that the individual concerned also study the modern theory of statistical inference with Harold Hotelling for the purpose of initiating a course in this subject on his return. The “victim” that Professor Graham had in mind was Acheson J. Duncan; and this is how it came to pass that Duncan, with financial assistance from the International Finance Section of Princeton University, spent the first half of the academic year 1931-32 studying with

Professor Henry Schultz at the University of Chicago; and the second half with Professor Hotelling at Columbia.[21]

When Duncan arrived at Columbia University early in 1932, one of the first persons he met was Wilks. Another was W.R. Pabst, then a graduate student in Economics at Columbia, who years later, was to be instrumental in Duncan's becoming active as a teacher, author, and consultant on statistical methods in standardization and quality control. Duncan returned to Princeton in the fall of 1932, and began to ready himself to teach his projected new courses, unaware – as were also Wilks and my father – that before his course in "modern statistical theory" would get under way, Wilks would have joined the Princeton University faculty.

The program worked out for Duncan on his return to Princeton was this: he would participate as an assistant in the course, "Elementary Statistics," taught by Professor James G. Smith (1897-1946) in the Department of Economics and Social Institutions, scheduled for the Spring semester in 1933, serving as instructor in charge of the "laboratory" or "workshop" sessions in which the students gained practical experience in graphical and tabular presentation, and in the computation of descriptive statistics, index numbers, moving averages, link relatives, etc. Then, as a sequel to this course, Duncan's new course on "Modern statistical theory" would be offered by the same Department during the first semester of the academic year 1933-34.

I took these two courses in the Spring and Fall of 1933, respectively. In Smith's course we used as text <u>Principles and Methods of Statistics</u> by Robert E. Chaddock (1879-1940), published by the Houghton Mifflin Company in 1925, but the scope, nature, and mode of presentation is more accurately reflected by Professor Smith's <u>Elementary Statistics, An Introduction to the Principles of Scientific Methods</u>, published the following year (New York: Henry Holt and Company, 1934). Some of R.A. Fisher's contributions to statistical methodology were alluded to, but only very briefly, as tips on recent developments that would warrant looking into, not as integral parts of the course. In Duncan's course, on the other hand, built as it was around Hotelling's lectures, and the then available mimeographed chapters of Hotelling's never published book, <u>Statistical Inference</u>, the contributions of Student and R.A. Fisher occupied the center of the stage a large part of the time.

In the spring of 1933 a crisis developed of which I was totally unaware at the time, and the particulars of which I was not to learn until some years later. Wilks was at Cambridge University working with Wishart on the last lap of his two-year fellowship program and would be needing a permanent post, or at least a new source of income, by fall. He had sent résumés of his professional career to the universities in the United States known to have programs in probability and mathematical statistics, indicating that he was in need of an instructorship or other full-time position beginning with the academic year 1933-34. The replies that he received were all negative – the United States was in the depth of the Depression, colleges and universities were having to make do with dramatically reduced income from endowment and other sources, and all, it seemed, were tightening the belt, and none were planning to take on additional personnel. With an exceptional training in mathematical statistics, with four substantial research papers and two research notes already published, one joint research paper accepted for publication, and two research papers nearly ready for publication, he was one of the most promising young men in mathematical statistics and applied mathematics generally, yet he had no prospect of a job. Wilks's situation seemed hopeless and was rapidly becoming desperate. Here he was in England with his wife and son; his fellowship funds, which were never really adequate for married people, or couples with children, were about to run out; and no prospect of employment.

Hotelling, knowing full well of my father's desire to build up a program in probability and mathematical statistics at Princeton and of the need of the College Entrance Examination Board for assistance from someone of Wilks's caliber on multivariate sampling distribution problems arising in education testing, appealed directly to my father to take Wilks on at Princeton, stressing the long-term advantages to Princeton and the at-the-moment desperateness of Wilks's situation. Thus it came to pass late in the spring of 1933 that my father, as Chairman of the Mathematics Department, offered Wilks an instructorship in the Department of Mathematics for the academic year 1933-34, and advised him of a tentative arrangement that he had made with Professor Carl C. Brigham of the Department of Psychology and Associate Secretary of the College Entrance Examination Board (the central office of which had been at Princeton for some years) to work part-time also with the Board on problems arising in the scaling of achievement tests. It was not until many years later that I learned from my father that he had brought off this coup over the opposition of almost every member of his Department. I have often wondered whether he would have been able to bring it off a year or even six months later because, although he continued as Chairman of the Mathematics Department until 1945, in mid-1933 he gave up his post as Dean of the Faculty to become Dean of the Graduate School.

I also learned in later years, after I had returned from London and had become a close personal friend of Sam and Gena Wilks, that Sam had received only one other offer: at Rothamsted Experimental Station, in response to Wishart's repeated pressuring of R.A. Fisher on Wilks's plight and need. The offer itself, however, was humiliatingly niggardly and grossly inadequate to Wilks's needs, perhaps as a result of Wilks having already incurred Fisher's wrath over his analytical (in contrast to geometrical) exposition of the independence of sums of squares in the analysis of variance.

Wilks arrived in Princeton in September 1933. As a new instructor in the Department of Mathematics, he found himself teaching the usual undergraduate courses in analytic geometry, calculus, and so forth during the academic year 1933-34. In addition to such teaching that first year, Sam continued his research, primarily in multivariate analysis; gave me helpful guidance in the preparation of my senior thesis on "The Accuracy of Computations Involving Quantities Known Only to a Given Degree of Approximation;" and spent the remainder of his "spare time" on his "second job" with Professor Brigham and the College Entrance Examination Board. The following year, 1934-35, Sam's program was much the same, except that he now guided my post-graduate reading and study in probability and statistical theory and methodology in preparation for my becoming a doctoral candidate in Statistics under J. Neyman and E.S. Pearson at University College, London, 1935-37.

Wilks taught his first statistics course at the University of Pennsylvania, in Philadelphia, during 1935-36. (Dr. George Gailey Chambers, Professor Mathematics, University of Pennsylvania, had died on 24 October 1935, shortly after his graduate course "Modern Theory of Statistical Analysis" had gotten under way. Sam was commissioned to complete the teaching of this course in his stead.) During the same period Sam gave an informal course – i.e., not listed in the official University course catalog – to three Princeton seniors, Walter W. Merrill, John O. Rohm, and William C. Shelton, on much the same material; and supervised Shelton's senior thesis on "Regression and Analysis of Variance." (Shelton continued in Statistics, rising to become Special Assistant to the Commissioner of Labor Statistics. Merrill and Rohm took up accounting and law, respectively.)

Wilks was promoted to an assistant professorship in 1936; and in 1936-37 taught his first statistics courses at Princeton: a graduate course during the Fall Term – see Wilks 1937 – and an undergraduate course during the Spring Term. A Princeton senior that year who took the graduate course, Irving E. Segal (now a Professor of Mathematics at MIT), wrote a senior thesis under Sam's supervision that was subsequently published in the *Proceedings of the Cambridge Philosophical Society* (SEGAL 1938).

The publication, in the January 1973 issue of the IMS *Bulletin*, of Professor Harry C. Carver's letter of 14 April 1972 to Professor William Jackson Hall on the "beginnings of the *Annals*" prompts me to correct a mistaken conjecture contained therein on why Sam Wilks was not permitted to teach a course in mathematical statistics during his first few years as an instructor in the Mathematics Department there. Professor Carver wrote:

> "… one day I asked [Wilks] how it was that he was not teaching a course in mathematical statistics at Princeton. He replied that he had tried to start such a course there, but his superiors turned down his request each time, – probably because mathematical statistics and probability had not yet rung a bell in the staid Eastern Colleges."

The fact of the matter is that mathematical statistics and probability already had "rung a bell" at Princeton: two years before Wilks's arrival, Acheson J. Duncan had been sent off at University expense to study with Professors Henry Schultz and Harold Hotelling for the express purpose of readying himself to initiate courses in "mathematical economics" and "modern statistical theory" on his return. It was this prior arrangement and commitment, not lack of appreciation of the importance of mathematical statistics and probability – or of Wilks's exceptional qualifications – that constituted the primary obstacle to Wilks's offering an undergraduate course in mathematical statistics during his first three years as a member of the Mathematics Department of Princeton University. Duncan's course on "modern statistical theory" had been scheduled to be offered for the first time during the Fall Term of 1933 before the possibility of Wilks's coming to Princeton had even been considered. In view of the expense that the University had incurred in underwriting Duncan's year of training in preparation for the offering of this course, and the sacrifice that Duncan had made in postponing work on his doctoral dissertation in order to acquire the requisite training at the University's request, it would have been very improper and cruel to have shelved Duncan's course and let Wilks start one instead. I am sure that Wilks recognized this; and was also cognizant of the other factors that delayed his getting a course of his own in the Mathematics Department.

The three-year delay between Sam's arrival at Princeton and his first officially recognized course in statistics under the auspices of the Mathematics Department was the result of at least four factors.

First, there was the priority that circumstances had accorded to Duncan's course in the Department of Economics and Social Institutions. Furthermore, that Department had taken the initiative in the matter, and was desirous of modernizing its outlook and course offerings with respect to mathematical economics and statistics.[22]

Second, under the circumstances, any course on "mathematical statistics," "statistical analysis," "statistical inference," or whatever, to be offered by Wilks in the Mathematics Department would have to be an additional new course, and would require the approval of the all-powerful Course of Study Committee of the Faculty. A new course at Princeton had to be described in detail by the department proposing to offer it. Faculty approval gave the department the right to teach the described subject matter. I am not sure that this was an exclusive right, but I doubt that the Course of Study Committee would have approved teaching essentially the same material in two departments. Hence a major obstacle to Sam's teaching an undergraduate course in Statistics was the historical fact that Statistics had been the province of the Department of Economics and Social Institutions.

Third, until Sam was promoted to an assistant professorship in 1936, he was only an instructor; and in a department having the stature, nationally and internationally, of Princeton's Mathematics Department it was definitely not customary for an undergraduate, much less a graduate course, to be initiated by and be the sole responsibility of an individual with the rank of instructor.

A fourth, and very inhibiting factor was the unfavorable mathematical "climate" that prevailed in Fine Hall, which housed Princeton's Mathematics Department during Sam's early years at Princeton. Geometry had occupied the center of the stage in this Department, for over a quarter of a century, with Algebra and Analysis accorded much less exalted roles. Then, in 1932, the new Institute for Advanced Study, an institution completely distinct from Princeton University, had come into being, and the members of its School of Mathematics were granted office space in the Mathematics Department's Fine Hall until the completion of their first building, Fuld Hall, in 1939. Albert Einstein (1879-1955) arrived to take up his post in the Institute during the Winter of 1933, and Hermann Weyl (1885-1955) arrived a few months earlier. John von Neumann (1903-1957) was already there (Lecturer, 1930-31, Princeton, then Professor of Mathematical Physics, 1931-33; Professor Mathematics, Institute for Advanced Study, 1933-57); as were also E.U. Condon (1903-1961; Assistant Professor of Mathematical Physics, Princeton, 1928-31; Associate Professor, 1931-39, Professor, 1938-47), and E.P. Wigner (Lecturer in Mathematical Physics, Princeton, 1930; Professor, 1930-36, 1938-1971). With this galaxy of mathematical physicists all together in one place for the first time, the mathematical theory of relativity and quantum mechanics were definitely the fashion of the day in Fine Hall – a difficult "climate" in which to initiate a program in mathematical statistics.

By 1936-37, the division of territory between the Department of Mathematics and the Department of Economics and Social Institutions had been resolved. The latter would be restricted to instruction in statistical theory and methods pertinent to the economic and social sciences; and the basic general undergraduate course(s) in statistical theory and methodology, and the graduate courses in advanced mathematical statistics would be the province of the Mathematics Department. As we have already said, Wilks taught his first statistics course at Princeton in the fall of 1936, the graduate course leading to his lithographed lecture notes on Statistical Inference (1937); and in the spring of 1937, a sophomore course with calculus as prerequisite, quite possibly the first carefully formulated college underclass course in mathematical statistics at this level. It was offered thereafter for a number of years to students in all fields in the second half of the sophomore year. The material presented in this course, extended and polished, became generally available a decade later in his "blue book," Elementary Statistical Analysis (1948b). A third course, also one semester in length, was added in 1939-40. It was an upperclass course for students who wanted to specialize in statistics, and consisted of a rather thorough mathematical treatment of statistical theory in the classroom plus a laboratory section devoted to applications and computations. This course was taken also by beginning graduate students. Wilks's first doctoral student, Joseph F. Daly received his Ph.D. in 1939. George W. Brown and Alexander M. Mood followed in 1940. World War II demolished his plans for sabbatical leave to lecture in South America and accept an offered exchange professorship for one semester at the National University in Santiago, Chile. As World War II progressed, Sam became ever more deeply involved in war research – I shall return to this in a moment – and in due course was released from academic duties entirely. Helped by two of his graduate students, T.W. Anderson and D.F. Votaw, Jr., and Henry Scheffé, he succeeded in seeing through to lithoprinted publication the graduate level text, Mathematical Statistics (1943), before becoming totally involved in war work. This was the forerunner of his polished comprehensive treatment bearing the same title published as a typeset book in 1962.

In keeping with my father's policy of promotions as soon as merited without regard to leave of absence, Sam was promoted to a full Professor of Mathematics in 1944, effective on his return to academic duties; and plans were laid for a Section of Mathematical Statistics within the Department of Mathematics. Following the war there was a steady flow of able graduate students and postdoctoral research associates, some of whom, like Robert Hooke and Henry Scheffé, were changing from mathematics to statistics. By the time of Sam's death (1964), Princeton had granted Ph.D.'s to approximately 40 men in mathematical statistics and probability, all of whom had studied to some extent with Wilks, and the dissertations of about half had been supervised by him.

It would be a mistake to infer from the foregoing that Wilks's educational activities were limited to teaching and thesis guidance in mathematical statistics. He was deeply interested in the whole spectrum of mathematical education. In "Personnel and Training Problems in Statistics" (1947) he outlined the growing use of statistical methods, the demand for personnel, problems of training, and made recommendations that served as a guide in the rapid growth of university centers of training in statistics after World War II. Drawing on his experience at Princeton, he urged, in "Teaching Statistical Inference in Elementary Mathematics Courses" (1958), teaching the principles of statistical inference to freshman and sophomores, and further proposed revamping high school curricula in mathematics and the sciences to provide topics in probability, statistics, logic, and other modern mathematical subjects. In furtherance of his ideas in this direction he co-authored, as a member of the Commission on Mathematics of the College

Entrance Examination Board 1955-1958, the Introductory … Experimental Course (1957) that recommended major changes in the teaching of mathematics in the secondary schools and suggested inclusion of an option of Introductory Probability with statistical applications in the twelfth grade. During his last few years he worked with an experimental program in Miss Mason's School in Princeton which introduced new mathematics at the elementary level, down to kindergarden. During his final week of life, he was considering, as a member of the Advisory Board of the School Mathematics Study Group, how much time the following summer he would be able to devote to writing on probability and statistics for this group.

5. WILKS'S FURTHER CONTRIBUTIONS TO MATHEMATICAL STATISTICS

A few more words are in order on Wilks's further contributions to mathematical statistics before turning to his many services to the U.S. Government generally and to the Army in particular.

Wilks was definitely not an ivory tower researcher. A great many of his research papers in mathematical statistics were written to meet needs that he personally had encountered in his applied work; and, especially in his earlier papers, he usually included explicit worked examples of the application of the new theory concerned. Thus, his first important contribution to multivariate analysis after arriving in Princeton, "On the Independence of *k* Sets of Normally Distributed … Variables" (1935a), appears to have been written to meet a need Wilks encountered in his work with the College Entrance Examination Board in Princeton, New Jersey; as do also many of his later contributions to multivariate analysis, e.g., "Weighting Systems for Linear Functions of Correlated Variables …" (1938b) and "Sample Criteria for Testing Equality of Means, Equality of Variance, and Equality of Covariances …" (1946); and "Multivariate Statistical Outliers" (1963), the last of his total of fifteen research papers on topics in multivariate analysis, has a definitely applied flavor.

In addition to the extensive and penetrating studies of likelihood ratio tests for various hypotheses relating to multivariate normal distributions embodied in the aforementioned papers, Wilks investigated (1935b) likelihood ratio tests for various hypotheses relating to multinomial distributions and to independence in two-, three-, and higher-dimensional contingency tables, and provided (1938a) a compact proof of the basic theorem on the large-sample distribution of the likelihood ratio criterion for testing "composite" statistical hypotheses, i.e., when the "null hypothesis" tested specifies the values of, say, only m out of the h parameters of the probability distribution concerned. Jerzy Neyman's basic paper on the theory of confidence-interval estimation appeared in 1937. The following year Wilks showed (1938c) that, under fairly general conditions, confidence intervals for a parameter of a probability distribution based upon its maximum-likelihood estimator are on the average the shortest obtainable in large samples; and a year later, in a joint paper with J.F. Daly, generalized this result to the case of several parameters.

In response to a need expressed by Shewhart, Wilks, in "Determination of Sample Sizes for Setting Tolerance Limits" (1941), laid the foundations of the theory of statistical "tolerance limits," which are actually confidence limits, in the sense of Neyman's theory, not, however, for the value of some parameter of the distribution sampled as in Neyman's development, but rather for the location of a specified fraction of the distribution sampled. In this paper he showed that a suitably selected pair of ordered observations ("order statistics") in a sample of sufficient size from an arbitrary continuous distribution provide a pair of limits, statistical "tolerance limits," to which there corresponds a stated chance that at least a specified fraction of the underlying distribution is contained between these limits, thus providing the "distribution-free" solution needed when the assumption of an underlying normal distribution of industrial production is unwarranted. In the same paper he derived the corresponding parametric solution of maximum efficiency in the case of sampling from a normal distribution (based on the sample mean and standard deviation), and an expression for the relative efficiency of the distribution-free solution in this case. In "Statistical Prediction …" (1942), he found formulas for the probabilities that at least a fraction N_o/N of a second random sample of N observations from an arbitrary continuous distribution would (a) lie above the r^{th} "order statistic" (r^{th} observation in increasing order of size), $1 \leq r \leq n$, in a first random sample of size n from the same distribution; (b) be included between the r^{th} and s^{th} order statistics, $1 \leq r \leq s \leq n$, of the first sample; and illustrated the application of these results to the setting of one- and two-sided statistical tolerance limits. These papers embodied the earliest of a series of contributions made by Wilks to "nonparametric" or "distribution-free" methods of statistical inference, an area of research in which he persuaded a number of his students to write senior theses or doctoral dissertations; and of which he provided an extensive review in depth in "Order Statistics" (1948a), an expository paper that was in large part responsible for the ensuing blossoming of research activity in this area.

Wilks was one of the small group of mathematicians and statisticians who at Ann Arbor, Michigan, on September 12, 1935, founded the Institute of Mathematical Statistics, and thereafter was an active and leading member. At this meeting, Harry C. Carver, who had founded, edited, and personally financed and published the *Annals of Mathematical Statistics* (in affiliation with the American Statistical Association) from 1930, volunteered to turn over the editing and publication of *Annals* to the Institute as its official organ as soon as the Institute was able to assume these responsibilities. The Institute assumed full responsibility for the *Annals*, and Wilks took over as editor, with the June 1938 issue.[23] He served as editor through the December 1949 issue, and guided the development of the *Annals* from a marginal journal with a small subscription list, to the foremost publication in its field, with a ten-fold increase in individual, and a five-fold increase in library subscriptions; and in the process, fostered the growth of the Institute, from a once marginal society to a mature international organization, large in both size and contribution. His editorship of the *Annals* was his greatest contribution to mathematical statistics.

In 1954 Wilks joined Walter Shewhart in editing the Wiley Publications in Statistics, a major U.S. publication effort that did much to change statistics from a subordinate branch of the social sciences in the 1930's, to a respected discipline in its own right with a large and solid literature in the 1960's.

6. HIS BROAD CAREER OF GOVERNMENT SERVICE, AND AS INITIATOR OF THESE EXPERIMENT DESIGN CONFERENCES

In 1936, when my father recommended Sam for promotion to Assistant Professor of Mathematics he noted in his recommendation that Sam had just received an appointment as a

Collaborator in a United States Soil Conservation Program of the Department of Agriculture. A broad career of government service was underway that was to range widely and continue through the last twenty-eight years of his life. He served the United States Government as a member of the Applied Mathematics Panel, NDRC, OSRD, and director of its Princeton Statistical Research Group, 1942-1945; chairman, mathematics panel, Research and Development Board, DOD, 1948-50; member, scientific advisory committee, Selective Service System, 1948-1953; "charter" member, ASA advisory committee to the Bureau of the Budget, 1951-1964; member, divisional committee for the mathematical, physical and engineering sciences, NSF, 1952-1956; member, committee on battery additives, NAS, 1953; member, divisional committee for the social sciences, NSF, 1957-1962; member, scientific advisory board, NSA, 1953-1964 (chairman, 1958-1960); member, U.S. National Commission for UNESCO, 1960-1962; and academic member, Army Mathematics Advisory Panel (called "Army Mathematics Steering Committee," from 1956 on), 1954-1964. It was in this latter capacity that he initiated these Experiment Design Conferences.[24]

General Leslie E. Simon, upon becoming Chief of the Research and Development Division in the Office, Chief of Ordnance, in 1951, entered into an agreement with Duke University to establish on that campus, an Office of Ordnance Research to sponsor external basic research initiated by non-government investigators with ordnance interests. Such research had always been carried out by all Army Technical Services, but previously under vague mandate and seldom on an appreciable scale. The level of effort had been wholly dependent on the sophistication of the administrators concerned. A Statistics Branch, and other units with statistical interests, was included in the setup.

In 1954 the Army Research Office–Durham (then the Office of Ordnance Research) upon the request of the Chief of Research and Development Division, Office, Assistant Chief of Staff G-4, Department of the Army, established the Army Mathematics Advisory Panel (AMAP) as an ad hoc committee to provide advice on the mathematical needs of the Army. (The Panel was reconstituted as a permanent body, the Army Mathematics Steering Committee, on 27 February 1956.)

Soon after its formation, the AMAP conducted a comprehensive inquiry into the Army's uses of mathematics; whether these uses could be advantageously extended; what future needs might be anticipated; and what measures might then be taken to insure a future capability adequate to these needs. As an academic member, Wilks surveyed thirty Army installations with the AMAP and reported that "the most frequently mentioned needs expressed by the scientific personnel were for greater knowledge of modern statistical theory of the design and analysis of experiments" (SIMON 1965, p. 958), clearly implying that a major deficiency of Army research, development, and testing was insufficient use of modern statistical experiment design techniques. He proposed, therefore, that the Army establish a series of Army-wide conferences on design of experiments in Army research, development, and testing. Dr. Frank E. Grubbs, who had chaired an Ordnance symposium on Statistical Methods in 1953,[25] strongly endorsed Wilks' proposal for Army-wide conferences devoted primarily to design of experiments. General Simon gave the proposal a green light and his support. Upon making further inquiries it was found that a number of research workers at various facilities expressed an interest in contributing papers to such a conference. Others had unsolved or partially solved problems that they wished to present for discussion.

The AMAP decided to organize a three-day conference on the design of experiments with three kinds of sessions. The first group of sessions would consist of invited papers by well-known authorities on the philosophy and general principles of the design of experiments. The second group would consist of technical papers contributed by research workers from various Army research, development, and testing facilities. The third group would be clinical sessions consisting of presentations and discussions of partially solved and unsolved problems that had arisen in these establishments.

Wilks agreed to serve as chairman of the first Conference, which was held on October 19-21, 1955 at the Diamond Ordnance Fuze Laboratories and the National Bureau of Standards in Washington, D.C. It was attended by over 230 registrants and participants representing some 50 organizations. Speakers and other participants in the conference came from the Bell Telephone Laboratories, Johns Hopkins University, Princeton University, Virginia Polytechnic Institute, Bureau of Ships, National Bureau of Standards, and 18 Army facilities.[26]

More specifically, the principal speakers, and their topics, were:

1. W.G. Cochran, "The Philosophy Underlying the Design of Experiments."

2. Churchill Eisenhart, "The Principle of Randomization in the Design of Experiments."

3. M.E. Terry, "Finding Optimum Conditions by Experimentation."

4. Panel Discussion led by John W. Tukey on "How and Where Do Statisticians Fit In." (The others on this Panel were: Besse B. Day, Cuthbert Daniel, Churchill Eisenhart, M.E. Terry, and S.S. Wilks.)

5. W.J. Youden, "Design of Experiments in Industrial Research and Development."

It was such a success that the Army has continued these conferences annually in October or November since 1955, following the same format. (See the Appendix for places and dates of the first nineteen Conferences, and names and topics of the invited speakers at these Conferences.) Wilks chaired the first nine of these Conferences (1955-1963), and wrote the Foreword to the *Proceedings* of the first eight. At the tenth Conference, held in 1964 and dedicated to Wilks's memory, establishment of the Samuel S. Wilks Memorial Award and Medal was announced, to be administered by the American Statistical Association, and to be awarded annually "to a statistician … based primarily on his contributions … to the advancement of scientific or technical knowledge in Army statistics, ingenious application of such knowledge, or successful activity in the fostering of cooperative matters which coincidentally benefit the Army, the DOD and the Government, as did Samuel S. Wilks himself;" and the initial award presented to Dr. Frank E. Grubbs, Ballistic Research Laboratories, Aberdeen Proving Ground. In 1947, Wilks was awarded the Presidential Certificate of Merit for his contributions toward antisubmarine warfare and the solution of convoy problems; and the same year, the Centennial Alumni Award of the University of Iowa.

7. HIS DEATH, AND CONCLUDING REMARKS

Sam became "my teacher" and guiding spirit at once in 1933; and in later years, he proved "a friend indeed," on a number of "difficult" occasions. He died most unexpectedly in his sleep, on March 7, 1964, at his home in Princeton, New Jersey. At that instant Statistics lost one of its greatest champions; government agencies, professional societies, and the field of education a devoted work mate, helping hand, and guide; and I, "my teacher" and "a friend indeed."

As W.G. Cochran has said: "He will be long remembered with affection and gratitude: no man of his generation did as much to ensure that the rapid growth of statistical theory, applications, and education in the United States took place along sound and healthy lines." (COCHRAN 1964, p. 191); and Egon S. Pearson: " … it is hard to think of any mathematical statistician of the past 30 years who combined to a greater extent an excellence in the field of theory with a power of inspiring confidence in government agencies, national research institutions, and educational authorities, as a wise counselor in practical affairs." (PEARSON 1964, p. 597)

He is survived by his widow, Gena Orr Wilks, his son, Stanley N. Wilks; a brother, William Weldon Wilks, three granddaughters, one grandson; and a host of friends.

8. POSTSCRIPT AND ACKNOWLEDGMENTS

At the Tenth Conference (1964) dedicated to the memory of Professor Wilks, I spoke from notes on "Sam Wilks as I Remember Him." The material presented was for the most part subsequently written up and a typescript prepared, but unfortunately not in time for publication in the *Proceedings* of that Conference – nor in the *Proceedings of the Eleventh Conference*, as was suggested. Portions of the typescript were submitted to, and comments received in writing from Alva E. Brandt, Acheson J. Duncan, the late Frederick F. Stephan (1903-1971), and the late George W. Snedecor (1881-1974). Large portions of that previous manuscript have been taken over bodily and incorporated in the present text, with revisions in the light of the comments received from the foregoing, for which I am very grateful. Use has also been made of comments received from Frederick Mosteller on the penultimate draft of a biography of Wilks prepared for publication in a forthcoming volume of Dictionary of Scientific Biography (New York: Charles Scribner's Sons, Publishers, 1970-), likewise gratefully acknowledged. In addition, I have taken advantage of, and have very probably incorporated more than I realize, from the obituaries and other memorial articles on Wilks that have appeared during the past decade, especially: ANDERSON (1965), COCHRAN (1964), DIXON (1965), HANSEN (1965a, 1965b), MOOD (1965), MOSTELLER (1964, 1968), PEARSON (1964), SIMON (1965), STEPHAN AND TUKEY (1965), and TUKEY (1965). My thanks to these for what I have "borrowed" explicitly or otherwise. For whatever faults of commission or omission still afflict this memorial to Sam Wilks, I must assume full responsibility.

NOTES

1. Alexander McFarlane Mood was the second of Sam's graduate students to receive a Ph.D. (1940) in mathematical statistics from Princeton University. After teaching at the University of Texas, and serving as a statistician in the Bureau of Labor Statistics, Mood returned to Princeton during World War II as a research associate in the Statistical Research Group-Princeton, engaged in war research under Wilks's direction as an arm of the Applied Mathematics Panel (AMP) of the National Defense Research Committee (NDRC) of the Office of Scientific Research and Development (OSRD), under a contract between Princeton University and the OSRD. It was as a member of this group that he and Wilfrid J. Dixon wrote their famous memorandum, later published as an article in the *Journal of the American Statistical Association* (Vol. 43, No. __ (March 1948), 109-126), on the statistical theory of the "up-and-down" or "Bruceton" method of obtaining and analyzing sensitivity data, with which they had become acquainted in 1943 at the NDRC's Explosives Research Laboratory (now a unit of the Bureau of Mines, U.S. Department of the Interior), at Bruceton, Pennsylvania. Subsequently Mood became a professor of mathematical statistics at Iowa State College; deputy chief, mathematics division, RAND Corporation; president, General Analysis Corporation; a vice president of CEIR, Inc.; and at the time of writing his tribute to Wilks, was Assistant Commissioner of Education, U.S. Office of Education.

2. Dodd had joined the staff of the University of Texas in 1907 as Instructor in Pure Mathematics. He seems to have been silent publication-wise until 1912 when two papers by him appeared, one on plane and skew curves, and the other on the method of least squares and orthogonal transformations. These were followed immediately in 1913 by four papers on statistical properties of the arithmetic mean, the median, and "other functions of measurements." One of these latter, entitled "The probability of the arithmetic mean compared with that of certain other functions of the measurements," was published in the *Annals of Mathematics* (Vol. 14, pp. 186-198, June 1913), of which my father (Luther Pfahler Eisenhart, 1876-1965) was then an editor. My father seems to have corresponded with Professor Dodd with regard to this paper. Thereafter Professor Dodd sent my father reprints of many of his subsequent papers on functional and statistical properties of various types of "means." These reprints proved to be very helpful to me when I became interested in such matters in the early '30's. I had the good fortune to meet Professor Dodd, when I went with Sam to the Joint Meeting of the American Mathematical Society and Institute of Mathematical Statistics in Indianapolis in December 1937. (For additional information on Dodd, see footnote 4; J.C. Poggendorff, <u>Biographisch-Literarisches Handwörterbuch für Mathematik ---</u>, Vol. 5 (1904-1922), Leipzig and Berlin, 1926, p. 299; and C.D. Simmons, "Edward Lewis Dodd, 1875-1943," *Journal of the American Statistical Association* Vol. 38, No. 222 (June 1943), 247-248).

3. The University of Iowa in Iowa City (now known at the "State University of Iowa") was, in the 1920's, the leading center in the United States for research and training in mathematical statistics. It should not be confused with Iowa State College at Ames (renamed "Iowa State University" on the occasion of its centenary in 1958), which, during the same period, was the leading center for application of, and teaching the application of, modern statistical

methods in the experimental sciences, especially in agricultural research and closely related fields.

4. Professor Dodd after receiving his Ph.D. in mathematics from Yale in 1904, had served as an Instructor in mathematics for two years (1904-06) at the University of Iowa, and one year (1906-07) at the University of Illinois, in Urbana. At the University of Illinois, Dodd had become acquainted with Rietz, who at that time was dividing his time about equally between his position of Assistant Professor of Mathematics in the Department of Mathematics, and his position of Statistician in the Experiment Station of the College of Agriculture. Rietz was teaching a course in the Mathematics Department entitled "Averages and Mathematics of Investment," which he had been induced to develop two years before, when a demand had arisen for a course in statistics which none of the members of the Mathematics Department were particularly prepared to give. Also, at the time Rietz was very busy working on his first publication in statistics, a 32 page appendix ("Statistical Methods. Appendix to Principles of Breeding") to A Treatise on Thremmatology by Eugene Davenport, Dean of the College of Agriculture and Director of the Agricultural Experiment Station (Boston: Ginn and Co., 1907, pp. 681-713); and also on his bulletin (with Dean Davenport) on *Statistical Methods Applied to the Study of Type and Variability in Corn* (Illinois Agriculture Experiment Station Bulletin No. 119, 1907). From then until he was called to the University of Iowa in 1918 as Head of the Department of Mathematics, Rietz published a long list of papers on statistical topics, some purely theoretical, some expositional, some arising out of his connection with the College of Agriculture. I mention these details to emphasize the fact that the development of statistical theory and methodology in the United States owes far more to the needs and support of workers in agriculture than many people realize today.

5. Under Reitz's leadership the University of Iowa rapidly became one of the leading centers of actuarial mathematics in the United States, and the leading center for research in mathematical statistics. (Other notable centers of actuarial mathematics and mathematical statistics were the University of Michigan, in Ann Arbor, under the leadership of James W. Glover (1868-1941) and Harry C. Carver, who in 1930 founded, and for five years personally financed the *Annals of Mathematical Statistics*; and Harvard University, under the leadership of Edward V. Huntington (1874-1952), Truman L. Kelley (1884-1961), and Warren M. Persons (1878-1937).) Two of Rietz's publications helped to firm up the University of Iowa's standing: (1) the Handbook of Mathematical Statistics (Boston: Houghton Mifflin Company, 1924) prepared by the "Members of the Committee on the Mathematical Analysis of Statistics of the Division of Physical Sciences of the National Research Council" (H.C. Carver, A.R. Crathorne, W.L. Crum, James W. Glover, E.V. Huntingon, Truman L. Kelley, Warren M. Persons, H.L. Rietz, and Allyn A. Young) with Rietz serving as Editor-in-Chief; and (2) Rietz's own Carus Mathematical Monograph (No. 3) entitled Mathematical Statistics, published for the Mathematical Association of America by the Open Court Publishing Company in 1927, which served as the basis for courses in mathematical statistics given in Departments of Mathematics of many universities and colleges for years afterward. The jointly written Handbook was doomed, however, to become obsolete almost upon publication: the future of mathematical statistics was being shaped in the 1920's by the papers of R.A. Fisher; and the future of statistical methodology, by his Statistical Methods for Research Workers (1925), which rapidly became "the Bible"

of statistical methodology at Iowa State College, Ames, under the guidance of Professors George W. Snedecor (1881-1974) and A.E. Brandt. (For additional information on Rietz, see A.R. Crathorne, “Henry Lewis Rietz – In Memoriam,” *Annals of Mathematical Statistics*, Vol. 15, No. 1 (March 1944), 102-108, which contains lists of selected publications of Rietz, of his books, and of doctorate dissertations written under his supervision; and Frank Mark Weida, “Henry Lewis Rietz, 1875-1943,” *Journal of the American Statistical Association*, Vol. 39, No. 226 (June 1944), 249-250.)

6. After one year of graduate work in actuarial mathematics at Iowa, Curtiss decided against a career as an actuary, and went on to earn his Ph.D. in pure mathematics (analysis) at Harvard in 1935. However, five years later, as instructor in mathematics at Cornell University, and the most junior member of the Mathematics Department, he was assigned the responsibility of a course in mathematical statistics. To prepare for this course, to answer the teasing query of his senior colleagues, “What is there to statistics anyway?”, he dug into the first ten volumes of the *Annals of Mathematical Statistics*, the first six volumes of the *Supplement to the Journal of the Royal Statistical Society* (borrowed from the late Frederick F. Stephan (1903-1971), and J.O. Irwin’s series of reviews of “Recent Advances in Mathematical Statistics” in the *Journal of the Royal Statistical Society*, and other sources. In the third of these reviews (for 1932), he no doubt noticed nine of the fourteen pages of the section on “Exact sampling distributions” were devoted to discussion of four papers of his friend Sam Wilks. During World War II, Curtiss, as a Lt. Commander, USNR, applied modern statistical theory and methodology to problems of naval engineering with considerable success in the Bureau of Ships of the U.S. Navy Department. (For discussion of some of these applications, see J.H. Curtiss “Statistical Inference Applied to Naval Engineering,” *Journal of the American Society of Naval Engineers*, Vol. 58, No. 3 (August 1946), 335-398.) In April 1946, he was brought to the National Bureau of Standards by its new Director, Dr. E.U. Condon (1902-1974), and appointed statistical assistant to the Director for the express purpose of introducing modern statistical theory and methodology into the scientific and technical programs of the Bureau. However, before Curtiss could get such a program under way, Dr. Condon was obliged to turn over to him the day-to-day administration of the Bureau’s new responsibilities in the development of large-scale automatic digital computers, and of an associated program of developing the mathematics of numerical analysis. John’s original assignment at the Bureau was therefore placed on my shoulders, when I arrived at the Bureau to receive it on October 1, 1946 – and the rest of that story you know.

7. See Wilks 1941, 1942, 1948; pp. 18-19 of ANDERSON 1965; and items (40), (41), and (45) in the list of “The Publications of S.S. Wilks” appended thereto.

8. Rietz gave a paper, “Comments on Applications of Recently Developed Theory of Small Samples,” at the 92nd Annual Meeting of the American Statistical Association, Cleveland, Ohio, 30 December 1930, which saw publication in the *Journal of the American Statistical Association*, Vol. 26, No. 175 (June 1931), 150-158.

9. Thus Paul Rider, in a valuable review article, "A Survey of the Theory of Small Samples" (*Annals of Mathematics*, 2nd Series, Vol. 31, No. 4, (October 1930), pp. 577-628), which was later to "save my neck" on a number of occasions, wrote (p. 578):

> "Undoubtedly the leading writer in the theory of small samples is R.A. Fisher, whose work in this field has revolutionized modern sampling theory. Much of it is to be found in his book, Statistical Methods of Research Workers, but this book is extremely unsatisfying to a mathematician, as it merely states results without proofs and usually without even indicating how a given result may be derived. It discusses such things as the distribution of *t* without telling what the distribution is. His original papers are much more enlightening, but from the references as given in the book it is sometimes difficult to tell which paper treats of a given topic. Even these papers suffer in places from the same defects as those of the book, and they are often troublesome to follow."

I don't know whether Paul later retracted these remarks, or Fisher was forgiving, because, when I got to University College, London, in 1935, to study under J. Neyman and E.S. Pearson, there was Paul sitting at a desk up in "Fisher territory" (the Galton Laboratory and Department of Eugenics), working on moment functions for Fisher's *k*-statistics in samples from a finite population.

10. Hotelling's paper on 'The distribution of correlation ratios calculated from random data," in *Processing of the National Academy of Sciences*, 11, No. 10 (October 1925), 657-662, made him the first person in the United States to respond in kind to R.A. Fisher's signal contributions to the theory of small samples – his derivation employed the same kind of geometrical reasoning in terms of Euclidean N-dimensional space that Fisher had used so effectively. This paper carries a footnote that I've always considered to be very significant. I believe it affords an explanation of why so many American mathematicians had difficulty following Fisher's geometrical proofs. Anyone who attempts to duplicate Fisher's geometrical reasoning soon discovers that a crucial step is the correct evaluation of the relevant element of volume. Hotelling, at this juncture in his paper, gives a general expressing for the relevant element of volume, which he numbers "(17)," and then remarks in a footnote:

> "This important expression for the volume element has been used in lectures by [at Princeton University] by Professors O. Veblen and L.P. Eisenhart. I do not find it in any of the treatises on Calculus, Analysis, or Differential Geometry, save for the special case in which the manifold of integration is a surface. It may readily be proved by showing first that (17) is a relative invariant under arbitrary transformations of the parameters; and second, that if the parameters of the hypersurface are orthogonal at a point, (17) becomes at this point the simple expression for the volume element in cartesian coordinates."

Hotelling had gone to Princeton University as a J.S.K. Fellow in mathematics, 1921-1922, after receiving his A.B. (1919) and an M.S. (1921) from the University of Washington, in Seattle. His interests in statistics predated his going to Princeton in the Fall of 1921. He had hoped to find some work in probability theory and the mathematics of statistics going on there in the Mathematics Department. Finding none, he undertook instead a program of study and research in topology (then called "analysis situs") and differential geometry, under the direction of Professor Oswald Veblen (1880-1960) and my father, Luther Pfahler Eisenhart (1876-1965). He stayed on at Princeton, 1922-1924, as an Instructor in Mathematics and received his Ph.D. from Princeton University in June 1924, his doctoral dissertation being on "Three-dimensional manifolds of states in motion." In 1927 he published a paper "An application of analysis situs to statistics" (*Bulletin of the American Mathematical Society*, Vol. 33, (1927), pp. 467-476), which had to do with topological aspects of serial and multiple correlations.

Following receipt of his Ph.D., Hotelling returned to the West Coast, to Stanford University, where he was a Junior Research Associate (1924-25), and then Research Associate (1925-27), in the Food Research Institute; and finally, as Associate Professor of Mathematics (1927-31), in the Department of Mathematics. Hotelling visited Fisher in England, in 1929, hoping to persuade Fisher to join with him in the preparation of an up-to-date textbook on the mathematics of <u>Statistical Inference</u>. Fisher was not interested in the proposition. In 1931, Hotelling was called to Columbia University, in New York City, as Professor of Economics to develop further the existing work there in Mathematical Economics, and to initiate a program in Mathematical Statistics.

11. These papers had been followed by their more elegantly written "On the problem of two samples" (*Bulletin de l'Académie Polonaise et des Lettres*, Series A, 1930, 471-494), and "On the problem of *k* samples" (*idem*, 1931, 460-481), in which the likelihood-ratio technique had led directly to the now famous test for the homogeneity of variance involving the ratio of the weighted arithmetic mean of the sample variances (with weights subsequently modified by Bartlett). This great discovery was discussed by Pearson in one of his lectures, and no doubt contributed to Sam's enthusiasm for likelihood-ratio tests.

    It was too early to claim that the tests thus found were "best" in some sense inasmuch as the Neyman-Pearson Lemma was yet to come in J. Neyman and E.S. Pearson, "On the problem of the most efficient tests of statistical hypothesis," communicated to the Royal Society of London in August 1932, "read" to the Society on November 10, 1932, and published on February 16, 1933 in the Society's *Philosophical Transactions*, Series A, Vol. 231, pp. 289-337; which, incidentally was refereed by Fisher who, at the time, considered it an important step forward.

12. Time and again during his years at the Bureau I would hear him tell a consultee, or an audience, that he was "a chemist," implying that he was <u>not</u> a statistician. Well, Jack may have been <u>all</u> chemist at one time, but by 1931 he was already on his way to becoming an exponent and practitioner of Fisherian methods too. He had come upon a Student's *t* test "by accident … in 1925" (W.J. Youden, <u>Risk, Choice and Prediction: An Introduction to Experimentation</u>, Duxbury Press, North Scituate, Massachusetts, 1974, p. 5). By the

"summer of 1931 [he] had obtained one of the 1050 copies printed of the first edition" of Fisher's Statistical Methods for Research Workers (1925). And when Fisher "visited Cornell" to attend the 6th International Congress of Genetics, 24-31 August 1931, Youden "drove there … to show him an experimental arrangement." (Quotations are from p. 727 of W.J. Youden, "Memorial to Sir Ronald Aylmer Fisher," *Journal of the American Statistical Association*, Vol. 57, No. 300 (Dec. 1962), 727-728.) From Hotelling's lectures Youden "first got some hint that [Fisher's Statistical Methods …] also held a message for mathematicians … He told the young men listening to him not to be misled by the large print, the wide margins, and a text almost devoid of mathematical symbols, that in this book were concepts as new to the theorists as to the researchers." (Quoted from p. 47 of W.J. Youden, "The Fisherian Revolution in Methods of Experimentation," *Journal of the American Statistical Association*, Vol. 46, No. 253 (March 1951), 47-50.) During the next few years he published a variety of papers expounding and demonstrating the application of known statistical techniques to various problems arising in studies of apples, seeds, soils, leaves, tomatoes, trees, and viruses. He had clearly "crossed the Rubicon;" was on his way to becoming an expert expositor and practitioner of statistical methods in experimentation; and from then on he became more and more of a statistician – or shall we say, "experimentrician" – and less and less "chemist."

13. Spearman devoted over 40 years of his life to the development of a psychological theory of mental ability built around a General Factor, g , that characterizes an individual's "general mind power" – see his The Abilities of Man (New York: The Macmillan Company, 1972); but is most widely known among statisticians today for a comparatively minor contribution, his coefficient of rank-order correlation (1904).

14. Whether the population tetrad differences, $\tau_{1234} = \rho_{12}\rho_{34} - \rho_{13}\rho_{24}$ and $\tau_{1324} = \rho_{13}\rho_{24} - \rho_{14}\rho_{23}$, where both zero, both non-zero, or one zero and the other non-zero, where ρ_{ij} is the coefficient of correlation between the i^{th} and j^{th} traits, was of decisive importance in Spearman's theory of mental abilities of man.

15. Rietz had chaired the session of Statistical Methodology on the first day of the 92nd Annual Meeting of the American Statistical Association in Cleveland, Ohio, December 29-31, 1930, at which Shewhart had presented his paper on "Statistical Method from an Engineering Viewpoint" (published in the Proceedings of the Meeting as "Applications of Statistical Method in Engineering," *Journal of the American Statistical Association*, Vol. 26, March 1931 *Supplement*, pp. 214-221); and the following day Shewhart had been the invited discussant of Hotelling's paper on "Recent Improvements in Statistical Inference" (same *Supplement*, pp. 79-87, discussion, pp. 87-89).

16. This was Karl Pearson's last year as the first Galton Professor of National Eugenics (1911-1933), as Editor of the *Annals of Eugenics*, which he had founded and edited since 1925, and as Head of the Department of Applied Statistics (1911-1933), which included the Biometric Laboratory (which Pearson had originated in 1895, as a center for postgraduate study in this new branch of applied mathematics when Goldsmid Professor of Applied Mathematics and Mechanics (1884-1911) and the Francis Galton Laboratory of National Eugenics (which had been formed, and placed under Pearson's direction, in 1906 at Galton's

request, as successor to Galton's own Eugenics Records Office established at University College in 1904 by a gift from Galton to the University of London for this purpose). He continued, however, to edit *Biometrika*, of which he was one of the three founders, always the principal editor (vols. 1-28, 1901-1936), and for many years the sole editor; and had almost seen the final proofs for the first half of volume 28 through the press when he died on 27 April 1936.

When I arrived at University College in October 1935 as a Ph.D. candidate in statistics, we were told that Karl Pearson's strength was rapidly failing, that he was still driving himself to shut out his grief over the thwarting of his ideal of an Applied Statistics Institute (with Readers in Genetics, Medicine, Psychology, Mathematical Statistics, etc.) by the break up of his Department into separate Departments of Eugenics and Applied Statistics; and that he was very reluctant to see visitors. The end came before Paul Rider and I and many of our fellow students were granted opportunities to meet him. I have never quite recovered from that lost opportunity.

17. E.S. Pearson had spent some time with Shewhart and his colleagues at the Bell Telephone Laboratories during his 1931 visit to the United States. He was one of the early exponents in England of Shewhart's control-chart techniques, and at the time of Sam's visit was engaged in the preparation of a paper on "Satistical Method in the Control and Standardization of the Quality of Manufactured Products," presented at the December 1932 meeting of the Royal Statistical Society, and later published in the Society's *Journal*, (Vol. 96 (1933), pp. 21-60). This paper was largely responsible for the formation of the Industrial and Agricultural Research Section of the Royal Statistical Society on November 23, 1933, and the subsequent publication of the now-famous *Supplement to the Journal of the Royal Statistical Society* to provide a medium for publication of papers of this Section. (For further details, see E.S. Pearson, "Some Historical Reflections on the Introduction of Statistical Methods in Industry," *The Statistician*, Vol. 22, No. 3 (September 1973), 165-179).

18. Stanley, like his father, received an A.B. – but in mathematics, not architecture – from North Texas State College ("Teacher's" having been dropped from the name) in 1955. He studied at Cambridge University 1955-1956; married Jocelyn Wilkins, daughter of a classmate of Sam's at North Texas State, in 1958; received an M.S. in applied mathematics from Columbia University in 1961; has three daughters and a son; and works for the Department of Defense as a mathematician.

19. John Wishart had gained First Class Honors Degree in Mathematics and Natural Philosophy at the University of Edinburgh, in Scotland, in 1922. At Edinburgh he had attended the lectures of E.T. Whittaker (1873-1956), on "The Calculus of Observations" which were later to appear in book form (T. WHITTAKER AND ROBINSON, <u>The Calculus of Observations</u>, London and Glasgow: Blackie and Son, Ltd., 1924), and had learned numerical mathematics "the hard way," i.e., without the benefit of a desk calculator, in Whittaker's Mathematical Laboratory. In the autumn of 1924, Wishart had joined Karl Pearson at University College, as a Research Assistant. One of Wishart's main tasks on arriving there was to get work on Pearson's <u>Tables of the Incomplete Beta-Function</u> underway.

Wishart stayed with Pearson for three years and then in the autumn of 1927 accepted a teaching position at the Imperial College of Science and Technology (of the University of London), inasmuch as he was a teacher by training and temperament. While still with Pearson he had collaborated with R.A. Fisher on a joint paper "On the distribution of the error of an interpolated value and on the construction of tables" (*Proceedings of the Cambridge Philosophical Society*, Vol. 23, Part 8 (October 1927), pp. 917-921). He was barely settled in his new post at Imperial College, when, at the beginning of 1928, he was offered and accepted an appointment as Statistical Assistant to R.A. Fisher at Rothamsted Experiment Station. With Fisher's encouragement, he derived "The generalized product moment distribution in samples from a normal multivariate population" (*Biometrika*, Vol. 22A, Parts 1&2 (July 1928), pp. 31-52), by a geometrical argument analogous to those used previously by Fisher, the simultaneous distribution of the sample estimates of the variances and covariances of a multivariate normal population corresponding to a sample of N items from such a population, and prepared an extensive tabulation of the moments and product moments of this distribution, which is now known as "Wishart's distribution." Wishart, during his three years at Rothamsted (1928-1931) participated fully not only in the mathematical research on sampling distributions and their properties, but also in the advisory and service activities of Rothamsted Statistical Department during that period, as reflected by the twenty publications of which he was the single or joint author during this period.

In October 1931, a few months after G.U. Yule's retirement from full-time teaching as Reader in Statistics in the University of Cambridge, Wishart was appointed to a newly created post of Reader in Statistics in the Faculty of Agriculture, with responsibilities also for some teaching in the Faculty of Mathematics. This was an exceptionally fine appointment: at Cambridge, as at other English universities, a Readership is only one step below a Professorship, and until the late 1950's Professorships were very few and far between, there ordinarily being only one per established discipline (e.g., Mathematics), which Statistics certainly was not at that time. (Thus Yule himself had been merely a University lecturer in Statistics from 1912 until only a few months before his premature retirement owing to ill health). Wishart saw in his Cambridge appointment an opportunity to introduce statistics to mathematical undergraduates, and began at once to offer not only a general course on statistical methods in the Faculty of Agriculture, but also a course on mathematical statistics which undergraduate students in the Faculty of Mathematics could offer for Schedule B of the Mathematical Tripos. Among his early students in this program were M.S. Bartlett (B.A., Queens' College, 1932) and W.G. Cochran (B.A., St. John's College, 1933). (For additional information on Wishart, see E.S. Pearson, "John Wishart, 1898-1956," *Biometrika*, Vol. 44, Pts. 1&2 (June 1957), 1-8, which includes a bibliography of his published work; and M.S. Bartlett, "John Wishart, D.Sc., F.R.S.E.," *Journal of the Royal Statistical Association*, Series A, Vol. 119, Pt. 4 (1956), 492-493.)

20. A few words are in order on how my father became interested in, and partial to statistics.

My father's primary mathematical interest was differential geometry, and his research was exclusively in that area. Exactly when he began to take an "outside" interest in mathematical statistics I do not know. It may have been as early as 1913, when as noted earlier, he corresponded with Edward L. Dodd on various aspects of the latter's paper entitled "The probability of the arithmetic mean compared with that of certain other functions of measurements," which was published in the *Annals of Mathematics* (Vol. 14, pp. 186-198, June 1913), of which my father was then an editor. At any rate, thereafter Dodd sent my father reprints of many of his subsequent papers on functional and statistical properties of various types of "means," which my father kept and ultimately turned over to me when I became interested in such matters in the early '30's.

Early in 1924, "at the request of the Commission on New Types of Examination of the College Entrance Examination Board," my father "formed a committee of mathematicians to examine critically certain statistical methods used in the investigations of the Commission" (*American Mathematical Monthly,* Vol. 31, No. 4 (April 1924), p. 209). The "mathematicians" of the Committee included the economic statisticians W. Randolph Burgess and W.L. Crum (1894-1967) of the Federal Reserve System and Economics Department, Harvard, respectively; the mathematicians E.V. Huntington (1874-1952) and J.H.M. Wedderburn (1882-1948), of Harvard and Princeton, respectively; and the mathematical statistician, H.L. Rietz.

The findings of this Committee, my father's continued advisory relations with the higher-ups of the College Entrance Examination Board (CEEB), and Wilks's contributions at Iowa (and under Hotelling at Columbia) to the solution of statistical problems arising in educational testing made it possible for my father to arrange a part-time appointment with the CEEB concurrent with his initial University appointment – a relationship with the Board, and its successor, the Educational Testing Service, that continued until Wilks's death.

As mentioned earlier, Hotelling, after receiving his Ph.D. in mathematics from Princeton in 1924, went to Stanford University, first to a position in the Stanford Food Research Institute, later in the Mathematics Department, Stanford University. During these years at Stanford (1924-1931) he wrote and published a stream of important original contributions to statistical theory and mathematical economics; reviews of American and English books on statistical methods, (e.g., of Statistical Analysis by Edmund E. Day (New York: The Macmillan Company, 1925), in *Journal of the American Statistical Association*, Vol. 21, No. 155 (September 1926), 360-363), in which he deplored the obsoleteness of teaching and research in statistics in the United States and placed the blame squarely on the doorsteps of Departments of Mathematics; and expository articles on "British statistics and statisticians today" (*Journal of the American Statistical Association,* Vol. 25, No. 170 (June 1930), 186-190), "Recent improvements in statistical inference" (cited fully in footnote 15), etc., in which he did his very best to acquaint American readers with the "new look" in statistics. He regularly sent reprints of all of these to my father. When my father gave them to me in the Fall of 1932, as I was reading up on "Student-Fisher statistics," it was quite clear that my father had more than a superficial knowledge of the papers on statistical theory, and had "got the message" of Hotelling's book reviews and expository articles.

21. This assignment was very disruptive to Duncan at this time. When asked to undertake it he was already at work on his doctoral dissertation on "South African gold and international

trade;" and his acceptance of it delayed until 1936 his completion of the requirements for his Ph.D. in Economics. He also lost out on one of the features that "sweetened" the proposition, an opportunity to visit the West Coast – when the plans were made, Hotelling was at Stanford University, but had moved on to Columbia University before the time arrived for Duncan to study under him. This assignment was to be instrumental in changing the direction of Duncan's subsequent career.

22. The aim of the Department of Economics and Social Institutions was to improve its own offerings in statistics for economics students by integrating and updating the Smith-Duncan sequence of courses within that department. The extent to which this aim was achieved in evidence by the two volumes <u>Fundamentals of the Theory of Statistics: Vol. 1, Elementary Statistics and Applications; Vol. 2, Sampling Statistics and Applications</u>, authored jointly by Professors Smith and Duncan and published by the McGraw-Hill Book Company, Inc., in 1944, 1945, respectively.)

23. For further details on the founding and early years of the *Annals of Mathematical Statistics* see the letter from Harry C. Carver, dated 14 April 1972, to Professor [W.J.] Hall, reproduced in the Institute of Mathematical Statistics *Bulletin*, 2, No. 1 (January 1973), 11-14; and Allen T. Craig, "Our Silver Anniversary in *Annals of Mathematical Statistics*, 31, no. 4 (December 1960), 835-837.

24. The material of the five following paragraphs is taken for the most part from MALONEY 1962 and SIMON 1965, where further details can be found on the history of statistical methodology in Army research, development, and testing.

25. See *Proceedings of the First Symposium on Statistical Methods: Sampling Techniques* (4-5 November 1953), Ballistic Research Laboratories Report No. 897, Aberdeen Proving Ground, Maryland, January 1954.

26. *Proceedings of the First Conference on the Design of Experiments in Army Research, Development and Testing,* Office of Ordnance Research Report No. 57-1, Office of Ordnance Research, Durham, North Carolina, June 1957.

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APPENDIX

Places, Dates, and Hosts of Conferences on the Design of Experiments in Army Research, Development and Testing, with Names and Topics of Invited Speakers

1st: Washington, DC, 19-21 October 1955.
Diamond Ordnance Fuze Laboratory and the National Bureau of Standards.

William G. Cochran, "The Philosophy Underlying the Design of Experiments"

W.J. Youden, "Design of Experiments in Industrial Research and Development"

Churchill Eisenhart, "The Principle of Randomization in the Design of Experiments"

M.E Terry, "Finding Optimum Conditions by Experimentation"

Panel Discussion on "How and Where Do Statisticians Fit In," John Tukey (Chairman), Cuthbert Daniel, Besse Day, Churchill Eisenhart, M.E. Terry, and S.S. Wilks

2nd: Washington, DC, 17-19 October 1956.
Diamond Ordnance Fuze Laboratory and the National Bureau of Standards.

George E. Nicholson, Jr., "The Planning of Experiments in the Presence of Variation"

Carl A. Bennett, "The Predesign Phase of Large Sample Experiments"

Ralph A. Bradley, "Recent Research in Statistical Problems in Subjective Testing"

Bernard G. Greenberg, "Application of Order Statistics in Medical Experiments"

M.B. Wilk, "Derived Linear Models in the Analysis of Variance"

Jerome Cornfield, "Choice of Error in the Design of Experiments"

3rd: Washington, DC, 16-18 October 1957.
Diamond Ordnance Fuze Laboratory and the National Bureau of Standards.

R.A. Fisher, "Practical Problems in Experimental Design"

A.W. Marshall, "Experimentation by Simulation and Monte Carlo"

Benjamin Epstein, "Life Testing"

H.O. Hartley, "Changes in the Outlook of Statistics Brought About by Modern Computers"

4th: Natick, Massachusetts, 22-24 October 1958.
The Quartermaster Research and Engineering Center.

C.I. Bliss, "Some Statistical Aspects of Preference Studies"

A.C. Cohen, "Simplified Computational Procedures for Estimating Parameters of a Normal Distribution from Restricted Samples"

A.W. Kimball, "Errors of the Third Kind in Statistical Consulting"

C.F. Kossak, "The AASHO Road Test as an Example of Large Scale Tests"

L.H.C. Tippet, "Statistical Methods Applied to the Textile Industry"

5th: Fort Detrick, Maryland, 4-6 November 1959.
US Army Biological Warfare Laboratories.

H.A. David, “The Method of Paired Comparisons”

Joseph Berkson, “The Measure of Death”

Richard Weiss, “The Army Research and Development Program as It Relates to the Civil Economy”

Nicholas E. Golovin, “Prediction of the Reliability of Complex Systems”

Wilford J. Dixon, “Medical Health Statistics”

D.B. DeLury, “Sampling in Biological Populations”

6th: Aberdeen Proving Ground, Maryland, 19-21 October 1960.
Ballistic Research Laboratories.

James R. Duffett, “Reliability”

Francis J. Anscombe, “Examination of Residuals”

W.S. Connor, “Developments in the Design of Experiments: Group Screening Designs”

J. Edward Jackson, “Multivariate Analysis Illustrated by Nike-Hercules: I. Separation of Product and Measurement Variability, II. Acceptance Sampling”

W.J. Youden, “The Enduring Values”

7th: Fort Monmouth, New Jersey, 18-20 October 1961.
US Signal Research and Development Laboratory.

G.A. Watterson, “Time Series and Spectral Analysis”

Jonh M. Hammersley, “Monte Carlo Methods”

R.L. Anderson, “Designs for Estimating Variance Components”

G.S. Watson, “Hazard Analysis”

8th: Washington, DC, 24-26 October 1962.
Walter Reed Army Institute of Research.

Egon S. Pearson, “A Statistician’s Place in Assessing the Likely Operational Performance of Army Weapon and Equipment”

Marvin A. Schneiderman, “A General Survey of Screening Theory”

Herman Chernoff, “Optimal Design Experiments”

Robert P. Abelson, “An Experimental Design for Decisions under Uncertainty”

Herbert C. Batson, “Bio-Assay”

9th: Redstone Arsenal, Alabama, 23-25 October 1963.
US Army Missile Command.

Solomon Kullback, "Communication Theory"

Frank Proschan, "The Concept of Monotone Hazard Rate in Systems Reliability"

Churchill Eisenhart, "Realistic Evaluation of the Precision and Accuracy of Instrument Calibration Systems"

H.O. Hartley, "Nonlinear Estimation"

David B. Duncan, "On the Simultaneous Estimation of a Missile Trajectory and the Error Variance Components Including the Error Power Spectra of Several Tracking Systems"

10th: Washington, DC, 4-6 November 1964.
Army Research Office.

MAJ GEN Leslie E. Simon (Ret'd), "The Stimulus of S.S. Wilks to Army Statistics"

Oscar Kempthorne, "Development of the Design of Experiments over the Past Ten Years"

H.O. Hartley and A.W. Wortham, "Assessment and Correction of Deficiencies in PERT Analysis"

Churchill Eisenhart, "Sam Wilks as I Remember Him"

W.J. Youden, "An Operations Research Yarn and Other Comments"

John W. Tukey, "The Future of Processes of Data Analysis"

M.G. Kendall, "Statistics and Management"

11th: Dover, NJ, 20-22 October 1965.
US Army Munition Command.

Joan R. Rosenblatt, "Confidence Limits for the Reliability of Complex Systems"

J. Stuart Hunter, "Non-linear Models: Estimation and Design"

William C. Guenther, "Target Coverage Problems"

H.O. Hartley, "Maximum Likelihood Estimates for the General Mixed Analysis of Variance Model"

12th: Gaithersburg, Maryland, 19-21 October 1966.
Harry Diamond Laboratories and the National Bureau of Standards.

Brian W. Conolly, "Operations Research"

John Mandel, "Statistics as a Diagnostic Tool in Data Analysis"

W.G. Cochran, "Planning and Analysis of Observational Studies"

Norman L. Johnson, "Sample Censoring"

13th: Fort Belvoir, Virginia, 1-3 November 1967.
US Army Mobility Equipment Development Center and US Army Engineer Topographic Laboratories.

Francis J. Anscombe, “Regression Analysis”

K.A. Brownlee, “Some Comments on Matching”

I.J. Good, “Some Statistical Methods in Machine Intelligence Research”

Frank Proschan, “Maximum Likelihood Estimation of Reliability”

M.B. Wilk, “Data Analysis”

14th: Edgewood Arsenal, Maryland, 23-25 October 1968.
US Army Edgewood Arsenal.

LT GEN William B. Bunker, “Broadening the Horizons of Experimental Design”

Rolf E. Bargman, “The Structure and Classification of Patterns”

Acheson J. Duncan, “Bulking Sampling”

Emanuel Parzen, “Time Series”

15th: Redstone Arsenal, Alabama, 22-24 October 1969.
US Army Missile Command.

John E. Condon, “Reliability Applied to Space Flight”

Nancy R. Mann, “Systems Reliability”

Clifford J. Maloney, “A Probability Approach to Catastrophic Threat”

Richard G. Krutchkoff, “The Empirical Bayes Approach to the Design and Analysis of Experiments”

Sam C. Saunders, “On Confidence Limits for the Performance of a System When Few Failures Are Encountered”

16th: Fort Lee, Virginia, 21-23 October 1970.
US Army Logistics Management Center.

Solomon Kullback, “Minimum Discrimination Information Estimation and Application”

Richard J. Kaplan, “Field Testing”

Gary G. Koch, “The Analysis of Complex Contingency Table Data from General Experimental Designs and Sample Surveys”

A. Clifford Cohen, “Estimation in Truncated Poisson Distributions with Concomitant Intervals and Truncation Points”

Dana Quade, “Nonparametric Analysis of Covariance”

17th: Washington, DC, 27-29 October 1971.
Walter Reed Army Institute of Research.

Marvin Zelen, “The Role of Mathematical Sciences in Biomedical Research”

Bernard G. Greenberg, “Randomized Response: A New Survey Tool to Collect Data of a Personal Nature”

Geoffrey H. Ball, “Classification and Clustering Techniques in Data Analysis”

K.S. Banerjee, “Hotelling’s Weighing Designs”

John J. Gart, “The Comparison of Proportions: A Review of Significance Tests, Confidence Intervals, and Adjustments for Stratification”

18th: Aberdeen Proving Ground, Maryland, 25-29 October 1972.
US Army Test and Evaluation Command.

John Tukey, “Exploratory Data Analysis”

G.S. Watson, “Orientation Analysis”

J. Stuart Hunter, “Sequential Factorial Estimation”

George E.P. Box, “Forecasting and Control”

Raymond H. Myers, “Dual Response Surface Analysis”

19th: Rock Island, Illinois, 24-26 October 1973.
US Army Armament Command and US Army Management Engineering Training Agency.

Jerome Cornfield, “Bayesian Statistics”

Shanti Gupta, “Ranking and Selection Procedures for Multivariate Normal Populations”

J. Sethuraman, “A Strong Justification for the Use of Rank Tests in the Case of Non-Normality”

H.L. Gray, “Generalized Jackknife Techniques”

Frank Proschan, “Reliability Growth”

Sam C. Saunders, “Accelerated Life Testing”

William A. Thompson, Jr., “Reliability of Multiple Component Systems”