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KARL POHLHAUSEN, AS I REMEMBER HIM

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I have had the rare privilege during my lifetime to have known intimately some of the people who have made significant contributions to modern aeronautics: Harry Bateman, Gottfried Guderley, Theodore von Kármán, Harold Kaufman, Hans von Ohain, Karl Pohlhausen, G. I. Taylor, Orville Wright, and Fritz Zwicky, to name a few. Bateman and Zwicky were two of my teachers at Caltech. Kaufman was one of my Colorado State doctoral students of whom I am justifiably proud. Guderley, von Ohain, and Pohlhausen were Wright Field colleagues. Wright quite inexplicably took a young lieutenant to heart when I was assigned to Wright Field in his hometown, Dayton, Ohio; and Taylor and von Kármán were simply close personal friends.

The Herculean feats of Wright and von Ohain will be immortalized by articles, stories, novels, and films, done and redone, over and over again. Legions of pupils and associates and their intellectual heirs will perpetuate the distinct personalities and overwhelming accomplishments of Taylor and von Kármán; I even have a few original anecdotes involving G. I. and Todor that I relish in telling with eloquent gestures and approximately correct accents. Proper biographies of Bateman and Zwicky would require the talents of a Dickens, although Fritz would object with unbelievable vulgarity that the author was incompetent because of his lack of Swiss citizenship. Gottfried and Harold are reserved for another time, another place. But if the story of Karl Pohlhausen is to be told, I must tell it, for during the last three and a half decades of his life, I was his only close friend who had comparable technical training—one could add that there were precious few other friends with comparable technical backgrounds during the first five and a half decades of his life. Dr. P. was an extreme introvert and an incredibly private person; hence, although we spent, whenever we

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were living in the same town, from one to four hours every day in each other's company, 365 days a year for 34 years (the last 13 years of his life he lived in an apartment only a few blocks from my house), I am not sure that I really knew him or that he really knew me. On some days we said nothing except a greeting to each other; we simply drank coffee or tea, went to lunch together, and passed papers, articles, and books back and forth while we nodded our heads in approval or expressed marked disapproval by oscillating our heads with peak angular velocities directly proportional to the reputation of the offenders. On other days we talked at the same time in loud voices while both of us wrote furiously and simultaneously on the blackboard without respecting the other's territory, both of us correcting the errors and alleged errors of the other; and, often, we just reminisced. We shared a common interest in and similar reactions to nearly every area of human activity from philosophy and music to horticulture and diabetes mellitus with one overriding exception, economics. I have the inborn contempt of a proper Southern gentleman for all fiscal matters, while Dr. P. thought and frequently said, "The only problem in applied mathematics worth anyone's salt is the prediction of the course of the stock market," and he lectured me without beginning or end on the sins of my prodigal behavior while extolling the virtues of miserly ways. Yet, in spite of our similarities, there were great differences: his language was Saxonian German, while I am locked on a single-track linguistic facility in English; our ages differed by three decades; Kármán, Ollendorff, Rüdenberg, and Trefftz were his contemporaries and are listed among my idols; Hilbert, Prandtl, and Runge were his teachers and friends, while they are merely gigantic historical figures to me; and, most importantly, I read about and studied in finished form lifting-line theory, the analyses of the transient performance of electrical networks, and boundary-layer theory, while Karl Pohlhausen helped create them as the solutions to what he called, "good, hard and important problems." On one hand, it is quite clear that applied mathematicians and electrical and aeronautical engineers will not forget the monumental work of Karl Pohlhausen for many, many years to come; on the other hand, I shall remember him during my lifetime without thinking about his major contributions to modern technology as a close and dear friend and collaborator with whom I shared thousands of hours of pure intellectual joy.

HIS LIFE

Karl Pohlhausen was born on 17 May 1892 in Mittweida, a little village that is located a few kilometers southwest of Dresden. His mother, who died shortly after the birth of her second child, had the maiden name of Hedwiga

Eugen, and his father, August Pohlhausen, was a licensed engineer and a teacher in the Technikum. His father's family came from East Prussia. He had a younger brother, Ernst, who also became a pupil of Prandtl, and who became a celebrated lecturer on applied mechanics and an ordinary professor and rector at the University of Danzig. Sibling rivalry, a synonym for pure hatred, characterized their relationship; in later years Karl would not acknowledge his brother's existence (needless to say, this drove the security people up the wall—I know all too well), although he made frequent and generous gifts to help his brother's first wife until her death.

When Dr. P. was a very young boy, his father, after his mother's death, transferred to a Technikum in Dresden where Dr. P. went to the famous Dreikönigschule. He never tired of relating six things from his boyhood: stories about his French governess, the long walks to school in winter after washing in cold water, the debut of "Der Rosenkavalier," the camellias of Dresden (Dresden single red and Frau Minna Seidel, which we know as Pink Perfection), a proper recipe for potato pancakes, and Christmas stollen.

In 1911 after completing the gymnasium in Dresden, he went to the University of Jena, where he intended to study optics with the lesser Wien, who proved to be far less than Dr. P. could stomach. In 1913 he moved to Göttingen to study under Carl Runge, who had just returned from Columbia in New York City; however, once in Göttingen, Dr. P. was attracted to Ludwig Prandtl, who quickly became and remained his hero and idol. As a result of innumerable conversations with him I arrived at the conclusion that Dr. P. classified scientists and engineers into three categories: virtuosos, first-chair men, and good section men. Dr. P. had Toscanini's standards in that his first-chair men were von Kármán, von Mises, Runge, Sommerfeld, and even Hilbert, although he thought that they all might occasionally give a virtuoso performance, but the only certain virtuoso was Ludwig Prandtl.

Among Pohlhausen's talents was his ability as a draftsman and cartoonist; some old gold-process photographs of his cartoons from the pre-WWI Göttingen days survive. I have had two of these enhanced by computer techniques in the Applied Optics Laboratory of the Department of Engineering Sciences of the University of Florida (Figure 1). One of these is an academic procession showing Klein, Prandtl, Hilbert, and others; the other is of Hilbert on a bicycle and Kuhn collecting biological specimens. Dr. P. denicd that he was the artist, but Kármán and Paula Kyropoulos were certain of the artist's identity.

Many interesting stories have been recalled by people who lived in Göttingen in the Early Teens, and I shall retell two of these. It was alleged by the local citizenry of Göttingen that the Pohlhausen brothers knew

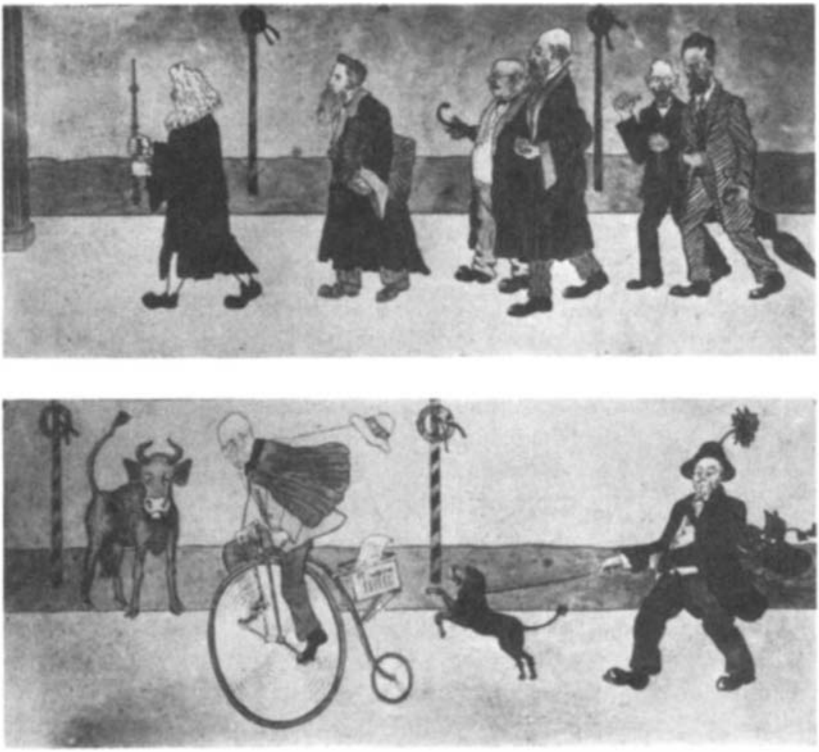

Figure 1 Some examples of Pohlhausen's ability as a cartoonist. See text for a description of the frames.

everything, and upon an occasion when Karl couldn't answer a question, he retorted, "Ask my brother." The other story is more serious. A young privatdocent named Todor von Kármán was given the elementary course on applied mechanics to teach, a very thoughtful thing for Prandtl to have done since large numbers of students took the course at so much per student, all of which went to the young, needy Hungarian. A slight difficulty arose in that all of the students signed a petition to Prandtl asking for Kármán's removal on the grounds that (*a*) Todor spoke German with such an intolerable Hungarian accent that effective communication was impossible; and (*b*), in any case Kármán did not understand and/or know elementary mechanics. Prandtl reacted with his characteristic intellectual honesty by saying, "(*a*) is probably true, but (*b*) is false"; he assigned young Karl to write Todor's lectures "in good German." Pohlhausen liked this story; Kármán did not. Incidentally, by 1925 all of the signers of the petition had vanished from the face of the Earth. Nevertheless, the story is true, for Kármán's papers contain Pohlhausen's notes on his 1913 lectures on elementary mechanics.

In August of 1914, young reserve Lt. Karl Pohlhausen was sent with his reserve regiment to serve Fatherland and Kaiser in their attack on France. He later said, "My patriotism was eroded by every kilometer we walked into Belgium and France, and it evaporated at the Marne." Although he was awarded two Iron Crosses (two of the second class or one each of the first and second class—the records are not clear on this matter), he never forgot the carnage of trench warfare in WWI; he still had terrifying nightmares from his military experiences during his final illness nearly six decades later.

By early 1916 the airplane had assumed considerable importance as an observation device, and Prandtl was assigned the role of principal German investigator for this American invention. Prandtl was extended the courtesy of selecting a military officer to be the uniformed head of his laboratory, and to everyone's surprise he selected Lt. Karl Pohlhausen, who returned from the Western front to assume his duty. It is no wonder that Pohlhausen loved Prandtl so much, for Dr. P. was the only officer of his regiment to survive World War I, a fact that he freely acknowledged with the observation, "Prandtl saved my life." The group that Lt. Pohlhausen bossed included Prandtl, Betz, Grammel, Munk, Wieselsberger, Walter Baade (the astronomer), and Peter Debye (the physical chemist)—to name a few. The outstanding accomplishments of their efforts were the formulation of lifting-line theory and the development of the Göttingen profiles. Although history has disagreed with him, Pohlhausen always thought that lifting-line theory, not boundary-layer theory, was Prandtl's masterpiece. Max Munk, an old and dear friend of mine, who will surely forgive me for recording the facts, was Pohlhausen's administrative cross to carry. Once, Major R. von Mises and Capt. L. Hopf, whom Lt. P. reported to in Berlin, complained that some of Munk's data were inconsistent; when Lt. P. relayed the complaint to Munk, he retorted, "I know it, and never again shall I put enough data in a report to permit a cross-check." Years later both Munk and Pohlhausen worked for me at Wright Field, and by then they had forgiven one another for their wrangling during World War I. At least, when a group of Prandtl's former students celebrated in Gainesville on 4 February 1975 the one-hundredth anniversary of the Master's birth, they drank champagne toasts together.

At the end of World War I, Pohlhausen returned to Göttingen and received his doctorate in 1919 from Prandtl. His dissertation on experimental verification of boundary-layer theory contained as little as possible, since he could not afford the printing costs for a voluminous document.

When Kármán went to Aachen in 1920 as the ordinary professor of applied mechanics because of the very active participation of Felix Klein, he took with him his old amanuensis, Karl Pohlhausen, a student of Prandtl; two of Sommerfeld's brilliant students, C. Wieselsberger and L. Hopf; and von Mises' entry, E. Trefftz. While in Aachen, Kármán and Pohlhausen worked closely together and produced their two famous papers on boundary-layer theory that complement each other so beautifully; they were permitted to work, under the terms of the Versailles Treaty, on boundary-layer theory by the French occupation troops, since everyone knew that boundary-layer theory had nothing to do with military aeronautics. Trefftz and Pohlhausen became close personal friends, and Trefftz's early death was felt very deeply by Dr. P.

Although Kármán tried to dissuade him, Dr. P. felt that academic aeronautics had no future, and, although he seriously considered an offer from Count Zeppelin to become his chief engineer, Reinhold Rüdenberg persuaded Pohlhausen to join Siemens-Schukert in Berlin on 18 May 1922 at a salary of 500 marks per month as a replacement for Fritz Nöther, although their employment by Siemens overlapped. Hc knew Nöther's sister, Emma, and he rephrased Weyl's observation that the Graces did not preside at her cradle with his own, "Genius she was, but the X and Y chromosomes were mixed $X^{n+1}Y^n$, where n is an arbitrarily large number." After Rüdenberg went to England in 1935 because of Nazi pressure, Dr. P. became the Chief Electrician at a salary of 55,000 RM per year; he remained with Siemens until he left Germany in 1946. He was a complete recluse because of his dislike of the Nazis, and this was the only way to live in Germany if you didn't agree with Der Fuehrer. Some idea of the quality of the research staff at Siemens may be inferred by recalling that some Nobel Laureates—G. Hertz, D. Gabor, and G. von Békésy—were scientific members and that Rüdenberg, Ollendorff, and Duffing were engineering members. Siemens hosted Pohlhausen's Jubilarium on 18 May 1947 in Dayton, Ohio, and tried to persuade him to return to Germany; he refused with the simple statement, "You can't go home again; it's never the same."

In 1946 Karl Pohlhausen came to the United States as a participant in Operation Paperclip in order "to start a new life in a free country"; he became a citizen in 1952. He worked in the Armament Laboratory, the Office of Air Research, the Flight Research Laboratory, and the Aeronautical Research Laboratory at Wright Field from 1946 until 1965 (staying until 1967 under a contract with Ohio State University); he was one of the PL-313 scientists of the US Air Force. In early 1948 Dr. P. and I began an almost exclusive collaboration that lasted until his death, although he wrote two reports, one with T. Butler and the other with L. Blichter, that had their bases in our joint work. Most of our joint work dealt with heat transfer to fluids, although we did a few extraneous things. On 17 Nov. 1967 he retired to Gainesville, Florida, at my suggestion, and thereafter he rarely missed a daily coffee, lunch, tea, or dinner at my home—sometimes taking in all four. He was a familiar figure on the streets of Gainesville, where he took daily five- to ten-mile hikes as long as he was able. In 1978 he discovered he had cancer, which led to his death on 18 Nov. 1980. No funeral service was held, in accordance with his will, but a memorial seminar was convened at the University of Florida on 25 Feb. 1981 with Raymond L. Bisplinghoff as Moderator and with two talks (Ray Dandl on "Uncle Elmo's Bumpy Torus" and M. S. Longuet-Higgins on "Vortex Ripples in Sand") in honor of Pohlhausen's life work in electrodynamics and fluid mechanics.

Physically, Dr. Pohlhausen was an average man, 68 inches tall and 150 pounds in weight. His eyes and hair were brown, and he had a birthmark on his right cheekbone and temple that was removed by surgery in the early sixties. He was quite active and strong, and enjoyed mountain climbing for a hobby. He was left-handed, although he wrote right-handed. (His draftsmanship was superb and unbelievably precise.) He admired and collected Persian rugs, although most of his collection was destroyed in the Berlin air raids, and he also liked German nineteenth-century landscapes, of which three fine examples were part of his estate.

Personally, one quickly recalls two ambivalent attributes: his acerbity and associated sentimentality, and his miserly acts and associated generous charity. For example, he once asked a colleague at Wright Field what aircraft companies he had previously worked for, adding, "I want to buy some of their stock, for it is bound to go up now that you are no longer employed by those companies." He also once told a colleague, "Yes, it's good, and Legendre thought so too when he first discovered it." I once asked him what the doctor had told him during a physical examination and without hestiation he replied, "He told me that he's gone up on his prices." He once noticed that my family tipped a waitress too much, and he reduced the tip by putting some change in his pocket. "Separate checks" was a well-known instruction. The other side of the coin was that he refused to go back to Göttingen after his wife's burial there after the Berlin flu epidemic of 1929 and that he gave more to charity drives than the rest of the office put together. He made contributions in the hundreds of thousands of dollars to worthy causes; yet, he gave up a favorite soup because of a two-cent increase in price. Finally, he left two thirds of his estate to a religious charity while insisting that he was a freethinker.

As for his scientific ability, I can only echo Todor von Kármán, who once told his sister Pippa quite emphatically in my presence, "Karl Pohlhausen is the most talented German that I have ever known"; it even stopped Pippa.

HIS WORK

Pohlhausen's list of publications in the open literature is surprisingly small for such a well-known man, although one must bear in mind that he stayed with Siemens for a quarter of a century, where a major portion of his duties was the direction of the work of others.

He wrote in its entirety one book on the methods of applied mathematics (Pohlhausen 1960), based on a series of lectures given in Cloudcroft, New Mexico. He also translated into German the standard book on transforms by Carson (1929), and he contributed sections to two other books: a chapter on long transmission lines in a work on high-tension wires edited by Rüdenberg (Pohlhausen 1932), and, most importantly, a chapter on aerodynamical applications in the classic work by Rothe, Ollendorff & Pohlhausen on the uses of complex variables in engineering (Rothe et al. 1931), still, far and away, the best book on the subject ever published.

The most frequently quoted work by Pohlhausen in the literature of electrical engineering is his article on ground effects on transmission lines (Pohlhausen 1927).

It is rather curious that two of his research papers on aerodynamics are only known throughout the world because of secondary references to them by Prandtl (1918, 1919), and in these days of extensive publication of pure trash it is even more curious that these papers have not been republished. When he was the uniformed head of Prandtl's laboratory during World War I, Pohlhausen used his facility with elliptic functions to show that an elliptical loading was the optimal one in terms of form drag for wings with a finite span and elliptic planform. The result was generalized by Max Munk in his dissertation, and Munk's simple proof of the general result may explain the obscurity of Pohlhausen's suggestive and first limited result. Pohlhausen was also the first to extend Prandtl's lifting-line theory to biplanes and triplanes, since the Fokker triplane was in field use by the German army.

When Pohlhausen first came to the United States as one of the Paperclip scientists, he worked on inertial guidance and wrote with F. Wazelt and W. Kerris an important report on error accumulation in inertial guidance systems. Somewhat later, in 1948, Pohlhausen and I began a close collaboration that lasted until his death, and, although we wandered from time to time into other fields [e.g. the metabolism of glucose (Pohlhausen & Millsaps 1975), the rail gun (Pohlhausen & Millsaps 1960), and turbulence, a phenomenon that we never tired of discussing and cussing], our principal area of investigation was forced and free heat convection to fluids. In the course of our collaboration in this area we produced articles on heat transfer to rotating plates, in converging and diverging channels, in circular pipes, and from vertical cylinders (Pohlhausen & Millsaps 1952, 1953, 1956, 1958).

Nevertheless, the aforementioned work amounts to little when it is compared with one article (Pohlhausen 1921) published in the first volume of *Zeitschrift für angewandte Mathematik und Mechanik*, with von Kármán, von Mises, and Prandtl as editors. Pohlhausen's reputation as a legendary figure in fluid mechanics is firmly based on this article, for this one paper contains so many important results that it is virtually impossible to write a book on fluid mechanics, either at the most elementary level or at the height of sophistication, without the use of its results. Let me list some of the topics contained in this paper:

1. The first clear mathematical proof that the Prandtl boundary-layer equations are asymptotic forms of the Navier-Stokes equation for large Reynolds numbers.
2. The demonstration that the Kármán momentum equation can be derived from the boundary-layer equation by a simple integration.
3. The usefulness of the Kármán momentum theory, shown by approximating the velocity profiles by a quartic and by deriving simple numerical results for the pertinent physical quantities. The current reader must remember that until Pohlhausen's paper boundary-layer theory treated only two cases, the flat plate (very well) and the circular cylinder (very poorly).
4. The smoothing conditions at the outer edge of the boundary layer. Kármán thought this to be particularly important.
5. The concept of weighing various sublayers within the boundary layer, and the concept of inner and outer boundary layers.
6. The possible simplifications in boundary-layer theory when the external velocity profiles vary as a power of x. The flow in a converging channel ($U = a/x$) is solved in closed form as an example.

Although the first two topics are now standard parts of all books on fluids, widespread use of the third item as the Kármán-Pohlhausen method has overwhelmed the recognition of the importance of the other items; however, the fourth and fifth items will yield even more results in the future as their implications are explored. The sixth topic led to the Falkner-Skan profiles and the enormous literature associated with them.

Now, it is a widely held belief among aerodynamicists and other good fellows that St. Peter gives regularly scheduled lectures on turbulence. Incidentally, in addition to his role as keeper of the keys, St. Peter, a simple fisherman, is the ideal lecturer on turbulence since the idea behind turbulence is undoubtedly very elementary, although it is still elusive to us, and since a commercial fisherman would have to be interested in turbulent flows. I only hope that the good saint also includes plenty of "good, hard and important problems" for his angelic audience. But, fantasies aside, Pohlhausen's earthly memorial is his paper on the approximate integration of the boundary-layer equations; it is an impressive and enduring monument, one of the true milestones placed by a legendary figure on the ascent to the summit of human intellectual activity, fluid mechanics.

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