LUDWIG PRANDTL IN THE NINETEEN-THIRTIES: REMINISCENCES

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Ludwig Prandtl's name is well known to most people in the field of fluid mechanics. There are several articles describing his scientific life and work (Hoff 1935, Sommerfeld 1935, Anon. 1950, Prandtl 1961). Therefore, we shall not go here into details of his life and career, still less so since we would have to extract the data from other publications and thus might even become guilty of spreading an occasional piece of misinformation. However, one thing seems to be missing, and this is a description of the atmosphere around Prandtl's personality, of the human being who influenced so many. Both writers of this article spent many years in Göttingen (I. F.-L. nine years, W. F. seven years). Both have often talked to their friends about their life at the Göttingen research institute. Therefore they gladly accepted the invitation to give a more intimate description of what scientific life near L. Prandtl was like.

I. F.-L. arrived in Göttingen in 1929, a short time before Prandtl returned from his trip around the world. Prandtl had left Göttingen to attend an international engineering congress in Tokyo and had used the opportunity to see the world—in his own way. On the day of his return the research associates (wissenschaftliche Assistenten) and Professor A. Betz, who had been working with L. Prandtl since 1911, accompanied Mrs. Prandtl, Ludwig Föppl's[1] daughter, to Göttingen's small but modern railroad station to greet the admired scholar. Naturally, several days later, we got a fine report about the trip in one of the bi-weekly colloquia in the library of the institute. Prandtl gave a short résumé of his trip from an engineering viewpoint and then spoke of general travel experiences. As usual, his scientific curiosity had led him to observe many things. He had enjoyed watching the flight of the sea gulls following the ship, noting how different the flight of birds is from that of airplanes. On calm days he also observed the slipstream of the ship's propellers. He had visited several American universities but felt that the insistence upon small classes, which resulted in the teaching of many parallel sections, had a detrimental influence upon the quality of the academic atmosphere and the character of the faculty. He was deeply surprised to see that a professor could teach students straight from a book that someone else had written.

[1] Known for his textbooks on mechanics.

One visit, planned well in advance, had disappointed him deeply. He had wanted to meet the man who had invented the zipper, just then finding increasing acceptance in Europe. He expected to find a man full of practical, technical ideas, but what he found was a man who had created the zipper by "tinkering" and had then spent ten years improving it. This was his only outstanding work—no interest in mechanics or instruments was visible.

The Institute for Fluid Dynamics, where Prandtl did most of his work, consisted of two sem-independent parts: the Kaiser-Wilhelm-Institut (KWI) and the Aerodynamische Versuchsanstalt (AVA). In the KWI, later (much later!) renamed the Max-Planck-Institut, Prandtl was the only boss, initiating research work with salaried research associates and with doctoral candidates from the University. There he had his sanctum sanctorum, accessible only through the office of the secretary, who faithfully shielded him against intruders. The AVA had wind tunnels and other expensive research equipment and had the character of an incorporated, nonprofit organization. It needed a firm administration and, since handling a large group of divergent people was not Prandtl's strength, he had delegated command to A. Betz, without, however, losing his influence upon the scientific program.

Prandtl had started his work in Göttingen early in the century as a full professor of the University, and he held this office until his retirement. He gave his lectures, held university seminars every week, supervised his doctoral candidates, and discussed experiments and theories with his associates. He had the habit of putting notes about ideas and recent publications on the back of envelopes of letters he had received. In the first seminar meeting of the semester, the inner pockets of his jacket were well stuffed with all this material, which he then gradually produced. He offered one subject after another to the audience and when no one volunteered for a talk, he prodded his candidates and other victims into accepting the items closest to their current work. Since Prandtl worked in both fluid mechanics and solid mechanics, we had a mixed program covering both these fields. The seminar was always well attended and had very interesting discussions because Prandtl was not willing to listen to vague presentations.

The seminars took place in the Mathematics Institute, built largely with money given by the Rockefeller Foundation. It had a wonderful library, whose setup had been determined essentially by O. Neugebauer, who worked in the field of history of mathematics and later came to this country.

The KWI had a small research library but was rich in reprints, which Prandtl had received from authors all over the world. When I. F.-L. came to Göttingen, she had to agree to spend at the beginning of her career some hours of each day on building up a system for cataloging these treasures, which could not be used efficiently when just shelved alphabetically by author. Miss L. v. Seebach, Prandtl's long-time secretary, was at hand to take notes (in Germany every secretary had to know shorthand) and to type the necessary file cards.

German professors have often been compared with kings, each of them a supreme and independent ruler in his domain. Prandtl was a double king, ruling two kingdoms side by side. One of them was the institute for fluid flow just

described. The second kingdom was an institute of the University, the Institute for Applied Mechanics. It was located in the old town, with a view of the canal that carried water to several mills. This was the place where Prandtl started his work when he joined the Göttingen faculty as a young professor. During our time, the day-to-day operations had long been delegated to an assistant, and Prandtl came once a week to exercise his prerogative as director. Several well-known men have started their career from this Assistant position. One of them was A. Nádai (later in Pittsburgh), an authority on plasticity. In a glass box on a wall, the institute preserved his famous marble cylinders, which, when tested in compression in the presence of a high hydrostatic pressure, had not suffered a brittle fracture but showed the barrelshaped plastic deformation known from metal specimens. There had been other interesting test pieces, made of a mixture of wax and soot, but they were melted down by a disrespectful doctoral candidate, who wanted a cheap supply for his own work.

In the early nineteen-thirties the assistantship was held by W. Prager, who had gathered a lively group of young people around him. Vibrations, plasticity, and photoelasticity were the principal interests of this group. Prandtl, although mostly interested in fluid mechanics, nevertheless wrote in those years his second paper on the "Gedankenmodell," a fictitious model that simulated and—to some extent—explained nonelastic phenomena in solids in terms of more familiar concepts.

The assistant was not the only viceroy of the place. The university provided the full-time services of two skillful mechanics, who built test objects and instrumentation. The older one lived upstairs in the house and had evidently weathered several assistants. He took care of the physical well-being of the house and represented the law-and-order principle. There were stories going around about his attempts to "keep the students in their place" and how the students occasionally got the better of him.

The students of this group participated in the mechanics seminar on Wednesdays. They all knew, of course, that Göttingen was a place of high reputation, but one of them was particularly proud. At the beginning of his doctoral work, he put a few big books on a table and posed beside them to have his picture taken. At the end of his work, when he presented it in the seminar, he threw his head so far back with pride that he stumbled and almost fell over backwards.

The AVA was a financially independent institution. This meant not only freedom in decisions of spending, but also the obligation first to find the money. The members of the staff had to make themselves useful through consulting and by executing wind-tunnel experiments for industry, and they applied also for grants from scientific foundations (of which there were not many in Germany). Naturally, the financial situation was mostly precarious, and Prandtl could never have had such a wonderful, relaxed atmosphere for his work had he not had A. Betz, with his combination of administrative skill and scientific knowledge.

Each of the big wind tunnels had one research associate as the immediate supervisor of work and crew. These supervisors had to deal with all sorts of problems. Some aircraft corporations felt that they had money enough to order

almost endless series of experiments on a detailed question—of airplane-tail forms, for instance—and then to make a design decision on the basis of the charts received. The Göttingen scientists, however, knew that thinking ahead often could shorten the time for experimental work, which would allow them to do some more advanced work of their own. Thus, some companies had to learn that money doesn't buy everything. On the other hand, a wind-tunnel crew had technicians trained in technical schools, where they had learned routine methods but were not adjusted to accepting the fast progress of aerodynamic thinking at its source. Thus, one day Professor Betz was told by one of them that the formulas he wanted used for evaluating propeller tests were not correct, and the technician showed him what he had learned in school. He did not realize that he was working here for the man who had just established a new propeller theory, one that would go into the text books of the next decade.

The wind tunnels used in the nineteen-thirties were of the "Göttingen" type, with an open test section and an orderly return flow in a closed circuit. Guide vanes in the corners, a honeycomb, and then a contraction of the flow provided a very uniform velocity distribution at the test site. Downstream from the edge of the nozzle, a mixing zone developed between the airflow and the surrounding laboratory air, but since it started from zero thickness, it did not much interfere with the measurements. Because of the uniform flow and the easy access to the test object, wind tunnels of this type have been built in many countries and are still much in use for the study of incompressible flow.

In all tests the object is to study forces and velocity fields for a body immersed in an infinitely extended air stream, and the results of wind-tunnel experiments require a correction to eliminate the influence of the finite dimensions of the test section. The theory of this correction leads to a partial differential equation with a mixed boundary condition, whose solution presents some difficulties.

In those precomputer times the application of the wind-tunnel correction to the test data was done in a special computing office, staffed by young girls who had finished their high-school education with good grades in mathematics and physics. There was never any shortage of applicants for these positions because the dignified Göttingen families considered them far preferable to other jobs a girl could find. The social atmosphere of the AVA was definitely appreciated.

As soon as the compressibility of the air stream had to be taken into account, tunnels with a closed test section became necessary. Tests for transonic flow were still another matter. They presented new design problems, which were recognized in the thirties but did not find a good solution until, much later, various groups in the United States constructed working transonic wind tunnels.

The turbulent mixing zone of the free-stream wind tunnel occasionally found an amusing application. One of the research associates connected with the tunnels was rather allergic to visitors who had too much pomade in their hair. When one of these turned up and had to be shown around, he tried to place him as close as possible to that mixing zone, which carried the cosmetic fragrance away and recirculated it in a diluted form.

A specialty of Göttingen was the rotating laboratory, built by A. Busemann. A

big drum with vertical axis could spin at different speeds; in it experiments were set up to study the flow in turbines and pumps. The observer was placed inside the laboratory and had to take much care not to get hurt, because the Coriolis forces interfered highly with the relation between his muscular effort and the resulting motion of his limbs. No one could work more than two hours in this drum, and after that he usually rested for the day. The drum was one of the attractions shown to visitors. Once a German airforce group wanted to see it, but only some lieutenants got the experience of a ride; the colonel preferred to become very involved in a discussion outside, on solid ground. Today, when thinking back, one wonders about the rather primitive precautions taken for the safety of the observer in the drum—flight medicine was still a thing of the future.

One aspect of life in the institute is seldom mentioned: the strange objects and proposals occasionally received at the world-famous institute. There were in the hallway near the old big wind tunnel some wonderful fishes carefully preserved in alcohol. They had been sent by someone who believed that their study in the wind tunnel would yield important results of technical applicability, but they had, in fact, never left their jars.

Prandtl gave his personal advice freely to industry and submitted rather moderate bills. Once he was on a trip and F. Schultz-Grunow (now professor in Aachen) had to close out some consulting in railroad affairs. He wrote a bill that took into account the savings the company would realize from following the advice given. When Prandtl returned, he was stunned at seeing the sum that had been asked (and paid!), but agreed that this method of billing was perhaps better since the Institute badly needed money for some new and expensive instruments.

Once a group of visitors had to be entertained with refreshments. At that time, one did not call a caterer—the institute had to dig into its modest means for the raw materials, and then a secretary would spread butter on rolls and make some tea. At one time, A. Busemann was responsible for the finances. On this occasion, instead of asking his wife, he took to mathematics, assumed the cross section of a roll to be an ellipse and the layer of butter to be half-a-millimeter thick. Given the number of visitors and the specific weight of the butter, he could calculate the amount needed. But he did not know feminine logic. The secretary was in tears, claiming the rolls had pores and that she needed much more butter.

Before the Nazi years, the Institutes had a steady flow of foreign scientists visiting, mostly for a year. This was a wonderful help for spreading Göttingen's reputation and, for Prandtl's associates, a marvelous chance for getting to know people of many countries. Among many others, Clark Millikan spent a year at Göttingen. Only two Russians appeared, unfortunately chosen more for their political merits than for their involvement in modern fluid mechanics. They were designers in hydraulics, and Prandtl did not feel obliged to hide his disappointment.

Göttingen was a small town, and the University dominated the atmosphere. At noon one made a break of one or two hours. During this time everybody went home for a warm meal (dinner), while at supper time one had only open sandwiches and tea or coffee. Often Prandtl, Betz, and I. Flügge-Lotz went together

at noon for the first half of their way home. The topics discussed were always scientific, started mostly by some remark of Prandtl's. He could stop walking and stand for several minutes watching the collected rain water in the gutter vanishing in a wide slot leading to the sewer. The forming of vortices where the water approached the edges of the slot fascinated him. Turbulence was one of his favorite topics. Years were spent finding out whether one could produce certain types of turbulence in a water channel, which had walls with small movable parts. It was not a big experimental setup, but it always seemed to draw Prandtl's attention. It stood in the large laboratory room in which H. Reichardt investigated turbulence in a bigger air channel with rectangular cross section. The base of this channel could be heated. The air flow through it was very slow, and the velocity distribution was measured with fine wire anemometers. The wires were so thin that one of the computing girls caused great trouble by just slamming a door and thus breaking them all.

At the same time, turbulent flow in cylindrical pipes with rough walls was carefully measured, and a definition of roughness was developed to facilitate the comparison of the Göttingen results with those of others.

During our time at Göttingen and later, Prandtl was much interested in the motion of air in the atmosphere. Since good weather forecasts were of public interest, meteorology had found its place among the research fields of the institute. The only thing Prandtl did not appreciate in his association with the weather people (and he often complained about it) was their habit of rediscovering already known facts of fluid dynamics and dubbing them with new names.

In connection with Prandtl's interest in meteorology, one of his candidates measured boundary-layer profiles in the natural wind over different ground. The leaves of some crops (for example, turnips) gave interesting deviations from others, and the term "turnip-leaf roughness" circulated for some time.

Göttingen had a social stratification as did all German towns, and the University had its share of it. Full professors would meet socially with full professors, associate professors with their kind, etc. However, there were some occasions when mixing took place. Mrs. Prandtl had established the habit that groups of married scientific associates would be invited once a year to her home for dinner. For the unmarried associates and the doctoral candidates the Prandtls organized the annual trip to Mariaspring, a coffee-garden restaurant in the hills near town. One would meet there for an early afternoon picnic and then dance. Most people who compared considered the trip to Mariaspring much nicer than the evening dinners, which were rather stiff and formal.

After the Nazi takeover in 1933, great changes took place all over Germany, and Göttingen could not avoid the maelstrom. Most tragic was the almost complete destruction of the mathematics faculty. Under pressure or driven by personal disgust, one after another of a famous group packed and left. They went in all directions but ultimately converged on the USA to find here a second home and to do the second half of their life's work. In the Applied Mechanics Institute, Prandtl was politely squeezed out by a group of flag-waving people, but the Fluid Mechanics Institute started to grow and to enjoy prosperity under the

golden rain of government support. A. Betz, while never submitting to party rule, used the interest of the new German airforce to buy expensive equipment and to expand the staff. Among this staff—scientific, technical, and administrative—there was a wide variety of attitudes. Many went with flying colors into the camp of the new masters, and from them the precinct wardens were chosen who had to watch our thoughts and actions and to denounce us if they caught us in a word of doubt or criticism. They were the known enemies, and in their presence people fell silent. For those who did not approve of the regime, there was only the choice between martyrdom and compromise. We do not remember anyone who became a martyr, but the compromise was a walk on a tightrope. No one really knew where the other stood, whether he was a member of the muffled opposition, a spy, or, perhaps, at times the one and then the other. This uncertainty, even with regard to former friends, fell like a blight upon the social life.

Prandtl had little understanding for politics and was at times as helpless as a child. He knew that some of the people were like mad dogs, but he could not understand how results of clear logical argument could be rejected furiously if they went against the new doctrine. Standing at the top of the pyramid, he could not avoid giving once in a while a public address, and this was always a nervous strain for the scientific community of the institute. Usually someone had had an advance look at Prandtl's draft of the speech, but who could be sure that he would not be carried away and make some extempore remark that could lead us all into trouble?

After the years described here, World War II swept over all of us. At its end some of the research equipment was dismantled, and most of the research staff was scattered with the winds. Many are now in this country and in England, some have returned. The seeds sown by Prandtl have sprouted in many places, and there are now many "second-growth" Göttingers who do not even know that they are.

The authors of this article were part of the general exodus of the late forties. They still cherish the memory of those years in the old Göttingen, and wherever they meet one of their old friends, they like to talk with him of the olden times.

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