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Theodor Meyer—Lost pioneer of gas dynamics

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ABSTRACT

Theodor Meyer's 1908 doctoral dissertation, with Ludwig Prandtl (1875–1953) as his advisor, introduced much of what has now become basic gas dynamics: not only the Prandtl–Meyer expansion but also the oblique-shock-wave theory as well. It is arguably the most influential dissertation in all of fluid dynamics. Yet no biography or even a photograph of Meyer has been available in the intervening century. This biography provides some insight into his character and covers his education, dissertation, World War I combat service and long career as an engineer and a teacher of math and physics.

Contents

1. Introduction

A hundred years ago, the young professor Ludwig Prandtl (1875–1953) educated three early gas dynamicists in his new Institute of Applied Mechanics at Georg-August Universität in Göttingen, Germany. They were Ernst Magin, Adolf Steichen and Theodor Meyer. Though Magin and Steichen are all but forgotten, Theodor Meyer is now immortalized—along with Prandtl—because the fan-like, simple-wave supersonic-flow phenomenon that they jointly discovered has come to be known everywhere as *Prandtl–Meyer flow.*

Meyer's doctoral dissertation [1] presents the theory of this flow, as well as that of oblique-shock waves and the transonic flow at a nozzle throat, all cornerstones of gas dynamics, and all for the first time. It is arguably the most influential dissertation in the entire field of fluid dynamics. Meyer was 26 years old when he wrote it in 1908, and was only 7 years younger than Prandtl himself.

Although history is mute regarding the life of Theodor Meyer after 1908, we have learned that he lived another 64 years and died at age 90 in 1972. Our goal is to fill in what can be learned, a century later, about the life of this lost pioneer of gas dynamics.

2. Early years and education

Theodor Meyer himself tells us of his youth and education in a brief biographical sketch at the end of his dissertation. He was born on July 1, 1882, to a Lutheran family in Bevensen (now Bad Bevensen), a resort town in Lower Saxony, in the north of Germany. His father—also named Theodor Meyer—and his mother Anna Mertens Meyer ran a Bevensen hotel. A photo of the child Theodor is shown in Fig. 1. He attended the

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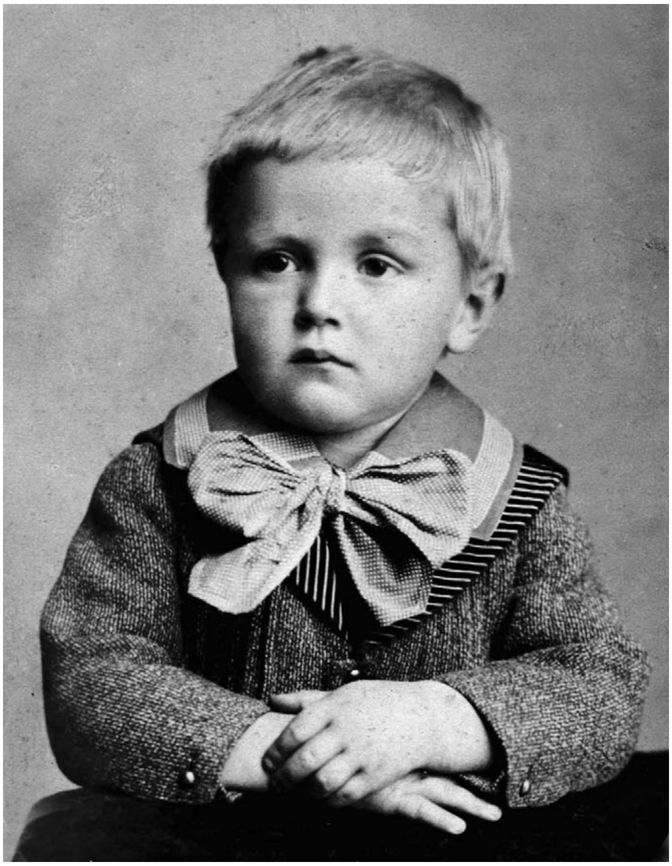

Fig. 1. Photograph of Theodor Meyer as a child, taken in the 1880s, courtesy Christoph Meyer.

famous six-century-old Johanneum Gymnasium in Lüneburg beginning in 1892, where he prepared to study mathematics and physics and passed his qualifying examination for admission to a university.

While satisfying his military obligation, Meyer attended lectures by the mathematicians Frege, Gutzmer and Thomae at the Friedrich-Schiller-Universität in Jena, Germany. In 1902 he transferred to the Friedrich-Wilhelm-Universität in Berlin and studied there for four semesters, attending the lectures of mathematicians Frobenius, Helmert, Hettner, Knoblauch, Lehmann-Filhes, E. Landau, F. Schottky and H. Schwarz, physicists Lummer and Warburg, astronomers Bauschinger and Foerster, the philosopher Lasson, and the economist von Bortkiewicz.

In 1904 Meyer transferred again, this time to the Georg-August-Universität in Göttingen, where he attended the lectures of mathematicians Carathéodory, Herglotz, Hilbert, Klein, Lexis, Runge and Zermelo, physicists Abraham, Minkowski, Prandtl, Riecke, Voigt and Wiechert, astronomer Brendel, philosopher Husserl and several others.

With this imposing list of teachers, Meyer clearly had about the best education in mathematics and physics that was possible to have, anywhere in the world, at the beginning of the 20th century.

He passed the candidacy examination for mathematics at Göttingen in July 1905, and Prandtl invited him to work in the Institut für angewandte Mechanik (Institute of Applied Mechanics). Prandtl offered him the theoretical gas dynamics project that became the subject of his doctoral dissertation, and for which he will always be remembered.

3. The dissertation

The only writing of Theodor Meyer that survives, other than his correspondence with Prandtl, is his doctoral dissertation itself. We briefly examine the dissertation here, looking particularly for differences between his original work and what is now taught as about one-third of a modern course in elementary gas dynamics.

Meyer's 46-page doctoral dissertation, in three parts, was also published verbatim in a 1908 technical journal [2]. Bound copies of the dissertation can still be found in major libraries, and it was reprinted verbatim in George F. Carrier's 1951 collection of fundamental papers on high-speed flow [3]. But despite the availability of Meyer's dissertation and the hundreds of times it has been cited, Anderson [4] appears to be the only one thus far to remark upon its historical content.

In Part A of his dissertation, Meyer sets up the problem of a gas expanding to supersonic speed at a sharp corner (Fig. 2a) in polar coordinates. Conservation laws, irrotational flow and the necessary thermodynamics are cited as precedents at the outset, including the perfect-gas and isentropic-flow assumptions and the definition of the ratio of specific heats, γ. (Isothermal flow is considered as well, but found inappropriate.)

Unfortunately, Meyer did not recognize the advantage of framing this problem in terms of the ratio of gas speed to sound speed, later famously named the *Mach number*, *M*, after Ernst Mach (1838–1916), by Jacob Ackeret (1898–1981) [5]. Thus the Mach number appears only implicitly in Meyer's mathematics, in the definition of the *Mach angle* (named by Prandtl [6]), which was then readily available. Instead of the Mach number, Meyer uses

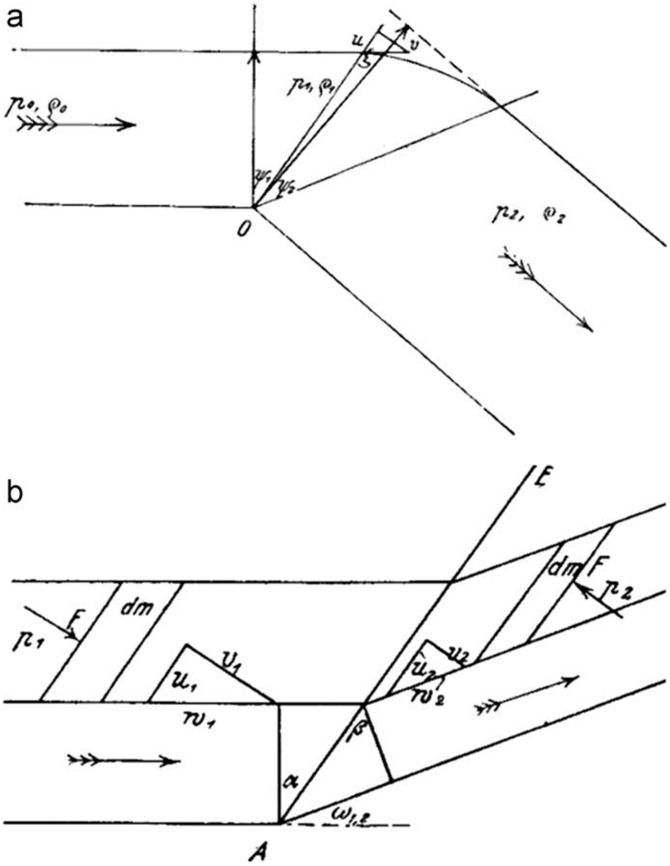

Fig. 2. Diagrams from Meyer's dissertation [1], showing his original layout and notation for the problems of (a) the supersonic expansion and (b) the oblique-shock wave.

the static-to-stagnation pressure ratio (nowadays recognized as a function of the Mach number and the ratio of specific heats: $p/p_0 \equiv f(M, \gamma)$), where p is the static pressure and p_0 is the stagnation pressure. This becomes his index of flow expansion from the sonic condition to the maximum possible velocity upon expanding to a vacuum. For a perfect diatomic gas, this range of pressure ratios is $0.528 \geq p/p_0 \geq 0$.

The lack of the Mach number complicated Meyer's dissertation throughout, at least in hindsight. His resulting differential equation for the expansion flow is

$$d\varphi = \frac{du}{\sqrt{\frac{2(\gamma-1)}{\gamma+1}C - \frac{\gamma-1}{\gamma+1}u^2}} \tag{1}$$

where φ is the angle of the radius vector in the x–y plane, u is the radial velocity component and C is a constant. This has some resemblance to the equation that we solve

$$dv = \frac{\sqrt{M^2-1}}{1+\frac{\gamma-1}{2}M^2}\frac{dM}{M} \tag{2}$$

and ultimately yields the same result. These equations are integrable analytically, a major mathematical advantage in 1908, when computerized numerical integration was still many decades away and integration by hand was a nightmare. From the solution, Meyer arrived at a function that he called v, the convex angle through which the gas flow must turn, beginning at the speed of sound, in order to expand to a desired supersonic speed. His expression is equivalent to the one we use for the *Prandtl–Meyer turning angle*, which still has the same symbol v. Its values in air, for example, are exactly those of Meyer's original working curves and tables for solving expansion problems in supersonic flow. He may not have taken the simplest path, but he got the right answer on the first try.

In Part B of his dissertation, Meyer addresses the problem of the oblique-shock wave. Normal-shock theory was already available from W.J.M. Rankine (1820–1872) [7] and P.-H. Hugoniot (1851–1887) [8], but experiments reported in 1907 by Prandtl [9] had demonstrated clearly that oblique shocks also occur in nature at various angles of inclination to a supersonic gas stream.

Meyer sets up the problem as shown in Fig. 2b. A standing normal-shock wave has a tangential velocity imposed upon it, thus rendering it oblique to the oncoming flow. He recognizes that the isentropic assumption is no longer valid here, and uses instead a momentum balance across the inclined shock wave, which emanates from a concave corner and deflects the entire flow through an angle that Meyer calls ω. Assuming that the tangential velocity component is invariant across the shock, he applies the normal-shock theory in the normal direction. This approach eventually yields an expression for α, the complement of the shock-wave angle, and for the flow-turning angle ω in terms of γ and the upstream and downstream pressure ratios, p_1/p_0 and p_2/p_0, which Meyer tabulates and plots in these coordinates (Fig. 3).

This is the world's first shock-wave polar diagram. If simply replotted in terms of p_2/p_1 vs. M, it would serve as one of our modern family of oblique-shock charts [10]. The numerical accuracy is good, considering that Meyer worked out the 70 solutions required to draw Fig. 3 longhand with substantial effort.

Meyer restricted his calculations to an initial Mach number range between 1.0 and 2.6, which was adequate for the low-supersonic nozzles and free-jet flows that he and his colleagues were investigating. The world was not yet ready for hypersonic flow in 1908.

In analyzing these results, Meyer observed for the first time that oblique-shock waves are possible between the limits of the Mach wave and the normal shock. He further noted that the ω-curves in Fig. 3 form loops, i.e. that the turning angle ω is double-valued for a given initial flow condition. These are now called the weak and strong oblique-shock solutions. The maximum flow deflection angle, Mach reflection and detached shocks are left for future investigators.

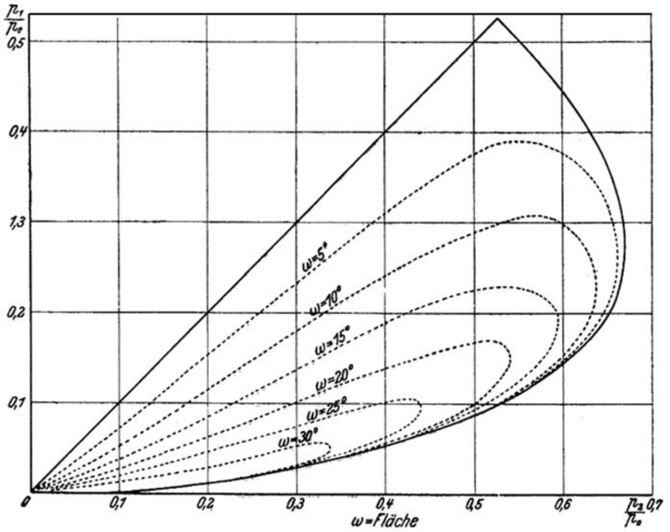

Fig. 3. Meyer's original oblique-shock polar diagram, in which the pressure ratio p_1/p_0 before the shock wave is plotted vs. p_2/p_0 after the shock, with the flow-turning angle ω as a parameter, here solved for $\gamma = 1.4$. (The recognized introduction of the shock polar diagram was by Busemann in 1929 [11].)

Part B of the dissertation concludes with an experimental section in which Meyer uses the flow channel and optical apparatus described by Prandtl [9] and featured in Magin's dissertation [12] to take schlieren photographs of over- and under-expanded nozzle-exit flows. These are then compared with Meyer's theory of the expansion and the oblique-shock wave. p_0, p_1 and p_2 are measured, from which the expected angles of shock waves and expansion fans are determined from Meyer's working charts described earlier. The flowfields are then drawn on tracing paper and overlaid upon the schlieren photos to check the theoretical accuracy. Meyer states that his new theory is "confirmed perfectly," and several schlieren photos are shown along with calculated wave angles to support this claim. This is one of many historical examples in which the schlieren optical technique plays a key role in new discoveries [13], and it may be the earliest case where quantitative data are extracted from schlieren photographs.

Part C has the least historical importance of the three sections of Meyer's dissertation, but is nonetheless an elegant mathematical treatment of the challenging 2-D transonic nozzle throat problem, examined by Meyer for the first time. He sets this up in a coordinate frame expertly chosen for simplicity, then assumes that the nozzle flow accelerates linearly through the sonic point along its centerline while satisfying continuity. A Taylor-series expansion is written for the velocity-potential function and, once again with substantial longhand mathematical effort, the equations of motion are solved up to coefficients of the 6th order.

The result, plotted in Fig. 4a, reveals that the sonic line in a 2-D Laval[1] nozzle throat is not the straight line expected from 1-D theory, but is instead parabolic. This discovery has provided ever since the initial condition for Laval nozzle design based on the method of characteristics. Several noted fluid dynamicists have improved and extended Meyer's original solution in the

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[1] The converging–diverging nozzle that accelerates a gas to supersonic speed was invented by C.G.P. de Laval (1845–1913) in 1888 to drive a steam turbine.

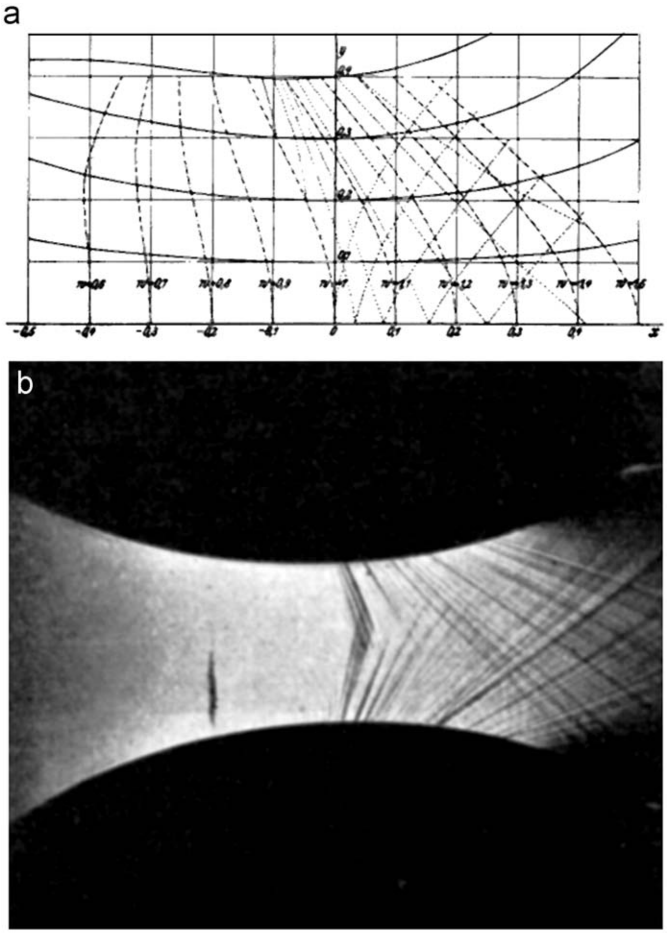

Fig. 4. (a) Meyer's plot of his solution for streamlines and constant-velocity lines in transonic flow at a Laval-nozzle throat and (b) schlieren image of Mach lines in the corresponding experiment [1].

intervening century, and the topic is now textbook material [4,14]. Once again Meyer was not content to simply give the equation, he also ran a nozzle experiment and measured Mach angles downstream of the throat in a schlieren image to verify his solution (Fig. 4b).

Two decades later, Ackeret christened and summarized the new field of gas dynamics (compressible fluid flow) in a handbook chapter [15] that was an early prototype of modern textbooks on the subject. All three parts of Meyer's dissertation are duly represented, but now with the addition of $M \equiv u/a$, the Mach number, to Meyer's table of the expansion function, ν. Ackeret wrote that the supersonic expansion flow was first described by Prandtl in 1907 [9], then theoretically derived by Meyer in 1908 [1]; hence, he called it the *Prandtl–Meyer expansion*.[2] So did Taylor and Maccoll in 1935 [16]. By the arrival of the first real textbooks on gas dynamics in the 1950s [17–19], *Prandtl–Meyer flow* was universally accepted terminology. Today this term yields many thousands of "hits" in a search of the Internet.

Strictly speaking, oblique-shock waves are also a Prandtl–Meyer flow of a different kind, but here a curious historical lapse has occurred. Ackeret [15] and other early gas dynamics authors cited Meyer's dissertation [1] for the oblique-shock theory, but around the middle of the 20th century this attribution was inexplicably dropped, along with any credit to Prandtl [9] as well. The last gas dynamics textbooks to get it right were Sauer [20] and von Mises [21], and nowadays no modern textbook except Anderson [4] credits anyone at all for the discovery and the theory of oblique shock waves. In a field full of named phenomena and equations, this is a glaring omission.

We can further comment on the relative contributions of Meyer and Prandtl to the content of Meyer's dissertation. The mathematical rigor is certainly Meyer's, while Prandtl provided the inspiration and probably much of the physical insight, based on his interpretation of schlieren images revealing oblique shocks and expansion fans. Werner Heisenberg (1901–1976) once remarked that Prandtl could examine differential equations and predict their solutions without calculation. Prandtl had to admit that he lacked that ability, but instead claimed that he solved fluid-dynamic problems by other means and then sought mathematical descriptions of them after the fact [22]. Nonetheless, Prof. Naumann, formerly of the Aerodynamics Institute at RWTH Aachen, believed that Prandtl predicted the Prandtl–Meyer equation (Eq. (1)) before Meyer actually worked it out.

Further evidence of Prandtl's deep involvement in the work of his early gas dynamics students is found in nozzle design. Some of the Laval nozzles used by Magin and Meyer diverged linearly downstream of the throat, but both mentioned [1,12] another nozzle with parallel exit flow designed by Prandtl. Schlieren images of the flow through this nozzle are shown by Prandtl [9] without an explanation of its design, but Adolf Busemann (1901–1986) [23] relates that Prandtl used a primitive form of the *method of characteristics* to design it in 1906.

4. World War I and the Gas Pioneers

Shortly after finishing his dissertation, Meyer was called to military duty and served from the beginning of World War I as a captain in the German infantry [24] (Fig. 5). He fought in the early battles of Liège and Antwerp on the Western Front, then in the infamous trench warfare near Ypres, Belgium, where he was wounded.

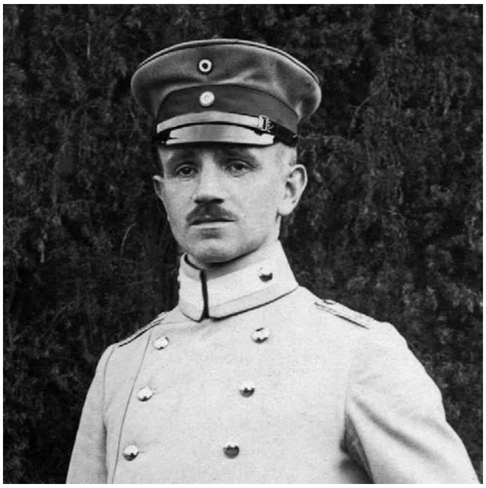

Fig. 5. Photograph of Theodor Meyer at the Munsterlager troop encampment in Germany during World War I, courtesy Christoph Meyer.

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[2] Prandtl's 1907 journal article [9] is actually a summary of a lecture he gave in Stuttgart at the 78th Meeting of the Gesellschaft Deutscher Naturforscher und Ärzte (GDNÄ) in 1906. He showed over 40 schlieren images of supersonic nozzle and free-jet flows, only a subset of which was included in the published version. No theory of expansion fans or oblique shocks was given, but he did mention that theoretical efforts were under way. Contrary to present practice, Prandtl did not acknowledge in print his three students who were working on these gas-dynamic problems, nor did he include them as co-authors.

Returning to the trenches after recovery, probably in early 1915, he received a transcribed field-telephone message stating that "Mythologists and experimental theologians are needed for the development of a new method of attack," and ordering him to report for this duty. This bewildered him and his superiors, but he reported as ordered and learned that the poorly transcribed message should have read "Meteorologists and experimental physicists…" This turn of events got Meyer out of the trenches and brought him into contact with the well-known but controversial Fritz Haber (1868–1934), whereupon he became a member of the Gas Pioneers, the German regiment that first employed chlorine gas in the trenches.

However, Meyer's stay in the Gas Pioneers was brief. He was not a gas chemist, even though the word "gas" appears in the title of his dissertation. It may be that his training in fluid dynamics got him selected for this duty on the expectation that he knew something about meteorology. In any case he became just another of many junior military officers in the Pioneers regiment. None of the accounts we consulted on gas warfare in World War I mentions his name. Meyer wrote to Prandtl [24] that his only distinction was to be the first of the Gas Pioneers injured in battle. He suffered a bullet wound to the knee that was serious enough to end his combat service for the remainder of the war, and he was driven to the military hospital by Haber himself.

Much has been written about Haber: Nobel laureate, inventor of the Haber–Bosch nitrogen-fixation process that feeds millions, and father of chemical warfare in World War I [25,26]. Theodor Meyer respected him greatly, and especially admired the nerve with which he strove against all odds [24].

Upon being discharged from the hospital, Meyer was employed by Haber to teach gas courses to officers at the Kaiser Wilhelm Institute (KWI) for Physical Chemistry and Electrochemistry at Berlin–Dahlem. Then in March 1916 he was assigned to the Armee-Oberkommando B, a regional command of the German army, where he served as a chemical-warfare specialist for the remainder of World War I.

5. At the War's end

Meyer wrote to Prandtl near the war's end in 1918, asking for scientific work to relieve his boredom since he no longer had much to do in the army. He admitted that it had taken him the entire time to learn not to lose his temper, but rather to take in stride what he could not change. Concerning the poison-gas warfare, Meyer wrote: "…what a vast effort was required to foist this enormous thing upon the world. But now it is done" [24].

Meyer's correspondence with Prandtl reveals the high regard and personal warmth he felt for his former advisor, as well as for his favorite professors Carathéodory, Hilbert, Klein, Runge, Voigt and others. Meyer wrote familiarly rather than stiffly to Prandtl, and even teased him for not advising any female students. He also reminisced about the good old days in Göttingen, gleefully recalling the awful expression on Magin's face when the fickle electric spark jumped at the wrong moment and ruined the photograph of an experiment[3] [24].

But Meyer's more serious reason for writing to Prandtl was to secure employment in Göttingen after the war and work on "something that makes sense." Prandtl was not averse to this, and encouraged Meyer to do some pre-proposal work on the design of a supersonic wind tunnel for testing the drag of projectiles [27]. This new wind tunnel was in Prandtl's plan for post-war facility development in Göttingen, but politically it ran afoul of a similar plan by German ballistics expert Carl Cranz (1858–1945), who also wanted such a wind tunnel in his domain at the Militärtechnische Akademie in Berlin-Charlottenburg. This led to friction between Prandtl and Cranz, but for the time being Prandtl appealed successfully to the military authorities for permission to proceed [28].

The new wind tunnel was to be of the "indraft" type, with atmospheric stagnation conditions, an air dryer upstream of the nozzle, a 20×20 cm test section, and flow into a vacuum reservoir. The heart of this effort once again lay in designing wave-free supersonic Laval nozzles. Prandtl suggested that this should be done graphically by the *hodograph* method of Steichen's[4] doctoral dissertation [29], which provided a way to calculate the non-simple-wave flow due to the crossing of left- and right-running expansion fans in a supersonic nozzle.

Meyer knew the method, and he improved upon it further in order to design a wave-free Mach 1.47 nozzle for Prandtl [30]. Six weeks later, though, Germany lost the war and Prandtl's plan for a new high-speed wind tunnel was thwarted, since such a facility was no longer regarded appropriate in peacetime. Worse, it developed that no one would pay Goldmarks for an aeronautics institute whose *raison d'etre* was now mostly forbidden by the Treaty of Versailles. Prandtl and his assistant director Albert Betz (1885–1968) found themselves in a desperate struggle to preserve the Aerodynamische Versuchsanstalt, AVA, in a time of runaway inflation [28]. Despite their attempts to diversify into non-aeronautical fields, most AVA employees still had to be laid off. Thus Meyer's appeal for a job, coming at the worst possible time, had no chance of success.

Meyer's contribution to what eventually became the method of characteristics for supersonic nozzle design was never published. Originally proposed by the French mathematician Monge in the 1770s as a way to solve differential equations geometrically [31], the practical application of the method of characteristics in gas dynamics is now attributed to a 1929 paper by Prandtl and Busemann [4,32].

Prandtl's supersonic wind tunnel was completely designed and ready for construction in October 1918 [33]. It was eventually built by Ackeret, who worked with Prandtl from 1921 to 1927. The plans Ackeret used to build the first supersonic wind tunnel in Germany included Meyer's Mach 1.47 method-of-characteristics nozzle.

6. After World War I

Thus the end of World War I also marked the unfortunate conclusion of Theodor Meyer's known contributions to the field of gas dynamics. Recognizing that his requests for post-war employment with Prandtl in 1918 and 1919 were futile, Meyer reconsidered his options. One of these, upon his discharge from the army, was to take additional training to become a high school teacher. He did this, and in April 1919 he was employed as a student-teacher at the Werner Siemens Realgymnasium in Berlin.

Another option Meyer pursued was a career as an engineer. In November 1920 he succeeded in finding employment with the Allgemeine Electrizitäts-Gesellschaft (AEG), the German General Electric Company, at their turbine plant in Berlin [34]. Although

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[3] The spark-schlieren apparatus, invented by Toepler [13] and later used in Mach's and Prandtl's laboratories [9,12], was flawed: its illuminating air-spark jumped around unpredictably from one exposure to the next. Since the knife-edge cutoff was fixed, this was a hit-or-miss frustration for the experimenter trying to get properly exposed photographs. With the advent of modern flashlamps, arc-lamps and now LEDs, dangerous and unpredictable open-air electrical sparks are essentially never used for schlieren illumination today.

[4] Referring to Steichen, Prandtl wrote to Meyer: "You probably still know that clerical gentleman" [27]. Steichen was an older student who may have had a previous theological education.

Fig. 6. Post-World War II photo of the Meyer residence at 48 Medinger Strasse, Bad Bevensen, courtesy Christoph Meyer. The tall figure at the gate is Dr. Theodor Meyer.

the Meyer family believes that he advanced to become a director there, we are unable to learn anything definite about his AEG employment because personnel records of that era are lost [35]. Thus we can only speculate that Meyer's world-class expertise in supersonic nozzle design may have been put to use in the improvement of AEG's steam turbines. If so, though, the details were probably proprietary.

Apparently Meyer continued to teach while employed at AEG. We have not discovered when these employments ended, but the Nazis closed the Werner Siemens Realgymnasium in 1935.

During this time Theodor Meyer also married Frieda Büscher Koopmann. Their daughter Hannelore was born on March 30, 1924. Between the world wars the Meyer family lived at 1 Meranerplatz in the Schöneberg suburb of Berlin.

Meyer was 57 years old at the outbreak of World War II and played no role in it, but it nonetheless brought him personal tragedy: Hannelore Meyer worked for the Reichsarbeitsdienst (RAD), a civilian workforce that became an armed forces auxiliary during World War II. She died on August 25, 1942, probably as a war casualty, though no details are known. On the family gravestone in Bad Bevensen there is inscribed beneath her name: "We are thankful for 18 happy years".

The Meyer residence was destroyed during the 1943–1945 allied bombing of Berlin, and Theodor and Frieda returned to the family home in Bad Bevensen (Fig. 6). There he again taught mathematics and physics, first at a new local secondary school, then at the Johanneum in Lüneburg where he had once been a student. Sadly, Theodor Meyer made it clear to his family that he did not find teaching secondary school challenging or fulfilling as a career.

7. Family recollections

Almost everything we know about the last 50 years of Theodor Meyer's life comes from his family, as related by his grandnephew Christoph Meyer of Langwedel in northern Germany. "Thedsch," as they called him, was regarded as the family genius, one of a kind, somewhat of an oddball and a recluse but nonetheless a calm and amiable character. His mathematical ability astonished everyone, and it was all done in his head. He decried slide rules and the like as "unreasonable things." He was tall and slim, a health addict and nature lover. He neither stood on ceremony nor valued appearances, as evidenced by a certain untidiness of house and garden. Family issues and controversies particularly disinterested him.

According to the family saga, Theodor Meyer, while working at AEG, was instrumental in solving a fluid dynamics problem in the pressure pipes of the famous Walchensee hydroelectric plant in Bavaria, which began operation in 1924. However, our inquiry into the early history of the plant reveals that this story is unlikely, since the pressure pipes were not under the purview of the AEG [36]. Similarly the family story that he patented a new type of air filter at AEG cannot be verified: A patent search turned up numerous patents by inventors named Meyer during the period, none of them clearly attributable to the Theodor Meyer of present interest.

Meyer's active imagination and highly original sense of humor is revealed in several of these family stories. For example, although von Kármán found Göttingen austere and stand-offish [37], Meyer told his family that he rather liked the place. He recalled the graduate students going drinking at a local pub of an

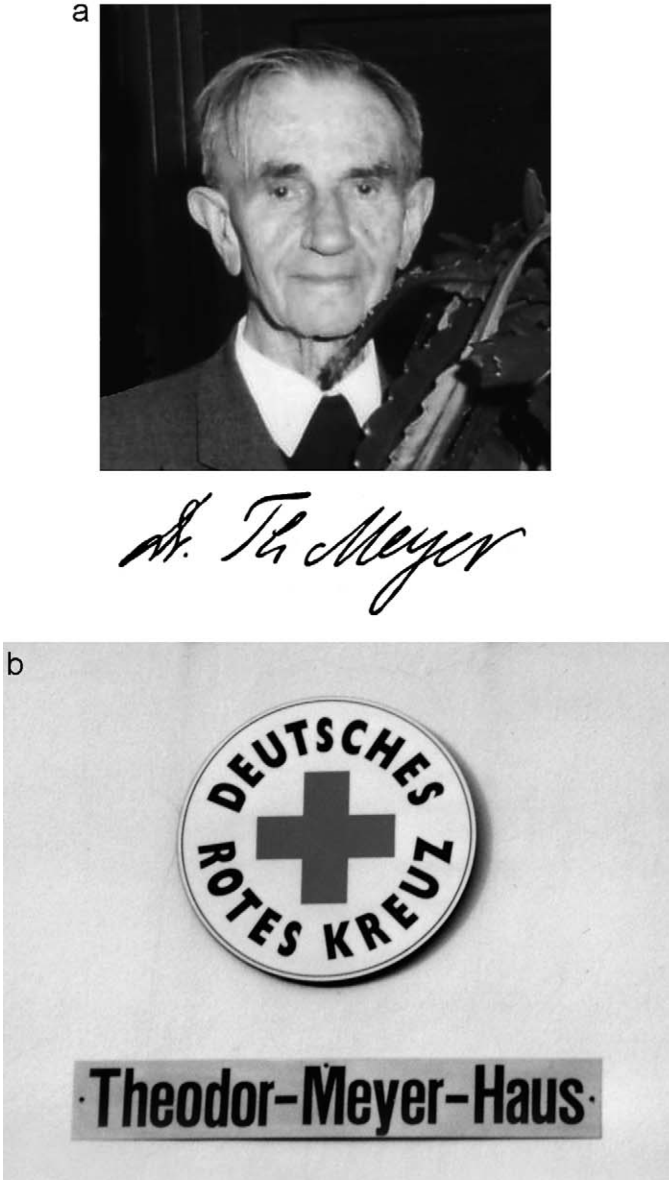

Fig. 7. (a) Photograph of Theodor Meyer in old age (November 1969), courtesy Christoph Meyer, with the signature "Dr. Th. Meyer" from [24]. (b) The Red Cross insignia on the Meyer house at 48 Medinger Strasse, Bad Bevensen, with a placard proclaiming its name; photo courtesy H. Bergel.

evening, much as they still do now. One student, too inebriated to stand, was rolled up in a carpet and propped outside the door of the pub as sentry. Meyer also told a story of getting stuck behind a column at a cello concert, whereupon his lively imagination saw the cellist performing music on the column rather than on the cello itself.

Late in life, Meyer sent his family a postcard relating that he had suffered a stroke, but otherwise things were fine. After the stroke he took the daily train 11 km to Uelzen, walked home, and re-learned his multiplication tables along the way.

A photo of the aged Theodor Meyer is shown in Fig. 7a. Frieda Meyer died in 1959, and Theodor spent his last years in the company of Frau Erika Rubarth. He died at almost age 90 on March 8, 1972, and is buried in the cemetery of Bad Bevensen. He deliberately did not leave the Meyer House at 48 Medinger Strasse in the family, in order to avoid envy and controversy. Instead he bequeathed it to the German Red Cross, and it is now their local headquarters (Fig. 7b).

8. Epilogue

Theodor Meyer was curiously reticent to tell his neighbors and family that he had done anything more than teach secondary school, let alone to claim that his doctoral dissertation was the cornerstone of a modern scientific discipline. Before he died gas dynamics blossomed, humans flew faster than sound, and even rocketed to the moon trailing a magnificent Prandtl–Meyer expansion. Textbooks such as [17–19] were already available for decades with chapters on Prandtl–Meyer flow and oblique-shock waves. Theodor Meyer was certainly aware of all this, yet both the Meyer family and the historians of Bad Bevensen were surprised when they learned of his historical importance from us. His death certificate lists him merely as a schoolteacher.

We refer to him as a "lost pioneer" for two reasons: First, despite the best education available and his prodigious mathematical talent, Meyer was unable to attain the career that he sought in gas dynamics and had to settle for a lesser one that disappointed him. The research he had hoped to do was eventually done instead by Ackeret and Busemann in collaboration with Prandtl. This was not a result of ill will between Prandtl and Meyer, just bad timing. Post-World War I Germany offered scant prospects for a peaceful and prosperous scientific career, especially not in gas dynamics, which was still several decades ahead of its time. The high academic career path in old Germany was long, arduous and impoverished, but one could alternatively earn a living as a gymnasium teacher, and also support a family.

Second, though Meyer's name remains irrevocably linked with the foundation of gas dynamics, over most of his life this burgeoning field somehow overlooked the man himself. There was no known invitation to write a review paper, no festschrift, no listing in *Who's Who*, no obituary in the journals, and until now no biography. Yet when we searched for information about him after a century had passed, the trail was not so difficult to find. Even the ubiquity of the Meyer name in Germany was not a major obstacle.

Theodor Meyer visited Göttingen again in 1937 and sent his condolences upon Prandtl's death in 1953. Thereafter, even though the distance between Göttingen and Bad Bevensen is only about 200 km, there is no record of any fluid dynamicist ever visiting him at home. Somehow, this founding father of modern gas dynamics did not receive the recognition that he deserved while still alive, and even today he is only credited for a fraction of his essential contribution to the field.

In the oppressive days just before Germany surrendered in World War I, Meyer wrote to Prandtl [24]: "It would be difficult to create the right mood under the present circumstances, but perhaps by accident another beautiful differential equation will come along again, as it once did when I worked with you." But that differential equation eluded him.

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