Lecture Notes in Physics

Edited by J. Ehlers, München K. Hepp, Zürich
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and J. Zittartz, Köln

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Advances in Fluid Mechanics

Proceedings, Aachen 1980

Edited by E. Krause

Springer-Verlag
Berlin Heidelberg New York

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Editor

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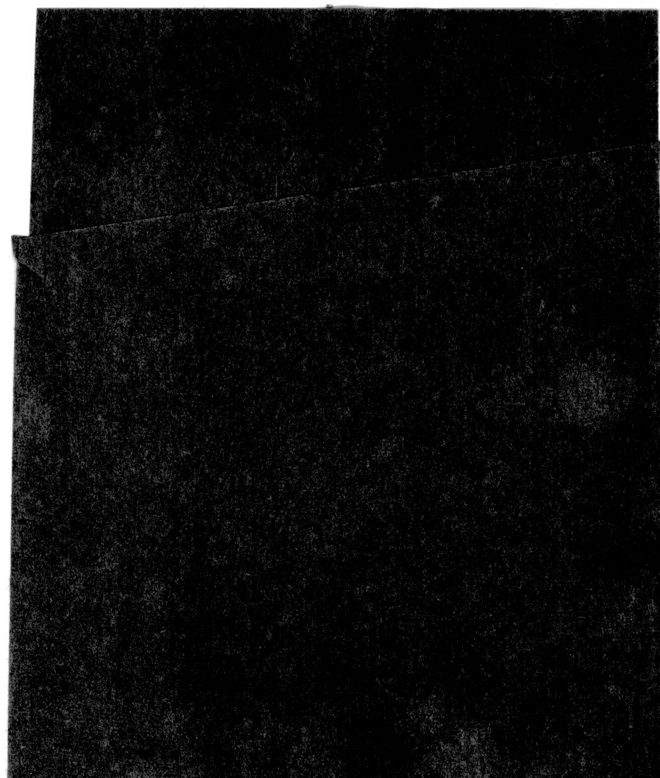
Wüllnerstr. zw. 5–7, D-5100 Aachen



ISBN 3-540-11162-X Springer-Verlag Berlin Heidelberg New York
ISBN 0-387-11162-X Springer-Verlag New York Heidelberg Berlin

Printing and binding: Beltz Offsetdruck, Hemsbach/Bergstr.
2153/3140-543210

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Editor's Preface

In 1929 the Aerodynamisches Institut of the Rheinisch-Westfälische Technische Hochschule Aachen inaugurated the first extension of its building with a scientific meeting to which the then director of the Institut, Theodore von Kármán, invited scientists from all over the world. About seventy accepted his invitation and over thirty papers were presented. The meeting, held in a rather informal manner, was one of the scientific events in aerodynamics of that time. It seems noteworthy that Dr. Julius Springer offered to print the contributions.

Almost 50 years later, the building of the Aerodynamisches Institut, bearing many scars from World War II and with parts of it close to collapse, was finally reconstructed during the period 1976 - 1980. It was felt that the new building should, like its first extension, be inaugurated with a scientific conference.

Since aerodynamics and fluid mechanics had undergone an enormous expansion in the intervening 50 years, it was clear from the very beginning of the planning of the conference that not the whole field but only those parts of fluid mechanics could be covered which relate to the work of the Institut. It was therefore decided to call on distinguished experts and ask them to describe the progress in the various branches of fluid mechanics in question. The following topics were chosen: biological flows, non-homogeneous flows, vortex motion, transition, turbulent shear flows, shock-wave boundary-layer interaction, solution of the conservation equations, wing theory, and aerodynamics of aircraft. Many approved of this concept. Approximately 300 scientists from 14 countries, among them scientists from the USA, the USSR, China, and the European countries, attended the conference, which was held March 26-28, 1980 in the Kármán Auditorium of the RWTH Aachen (completed in 1977).

The opening address, the inaugural lecture, and the papers presented are published here in full, with a minimum of editorial changes.

The Deutsche Forschungsgemeinschaft generously gave financial support to the conference which without this help could not have come to pass. My colleagues Prof. em. Dr.phil. Dr.med.h.c. A. Naumann, Prof. Dr.-Ing. H. Zeller, and Dr. rer.nat. W. Limberg helped to arrange the programme and worked to make the conference a success. Special mention is made of Mrs. H. Rehfeld and Mr. H. Thal, who undertook the laborious task of preparing the manuscript. Grateful acknowledgement is also due to Mrs. D. Steinbach, Dipl.-Ing. U. Giese, and Dipl.-Ing. H. Henke, who assisted in reading the proofs.

Finally, I am indebted to Prof. W. Beiglböck of the Springer Verlag, Editor of the Lecture Notes in Physics, for arranging the publication of these Proceedings in this series.

Egon Krause
Aerodynamisches Institut
RWTH Aachen

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Eröffnung *

F. Schultz-Grunow
Aachen

Meine Damen und Herren,

Magnifizenz hat mich gebeten, sie hier bezüglich der fachlichen Bedeutung dieser Einweihungsfeier zu vertreten.

So kann ich im Namen der Hochschule dem Aerodynamischen Institut gratulieren zur Vollendung seines Erweiterungsbaues und ihm danken, daß es ihm jede Mühe wert war, damit erweiterte Lehr- und Forschungsmöglichkeiten auf einem zentralen Gebiet der Ingenieurwissenschaften zu schaffen.

Der heutige Tag weckt Erinnerungen an die Anfänge der Aerodynamik in Aachen. Auch bei uns entwickelte sie sich aus der Mechanik heraus. Schon der zweite Lehrstuhlinhaber für Mechanik, kein geringerer als Arnold Sommerfeld (1900 - 1906), zeigte Interesse für Flüssigkeitsbewegungen. Er schuf bei uns die Theorie der Lagerreibung, deren grundlegende Differentialgleichung nach ihm benannt ist.

Ihm folgte bis 1913 Hans Reissner. Die sieben Jahre, die Hans Reissner bei uns verbrachte, haben insbesondere dadurch einen nachhaltigen Einfluß ausgeübt, als er einer derjenigen war, die an die Probleme der Flugtechnik mit wissenschaftlichen Methoden herangetreten sind. Der Anregung und Pionierarbeit Hans Reissners verdankt die Hochschule die Entstehung des Aerodynamischen Instituts, welches in Verbindung mit dem Lehrstuhl für Mechanik und Aerodynamik 1912 - 1914 erbaut wurde (zitiert nach v. Kármán).

Bereits 1909 begann Reissner mit aerodynamischen Versuchen zunächst in dem von Hugo Junkers geleiteten Maschinenlaboratorium, wo er eine Rundlaufvorrichtung und eine provisorische Luftstromanlage betrieb, welche Geräte den Grundstock des Aerodynamischen Instituts bildeten. Reissner lieferte neben dieser Versuchsarbeit grundlegende Beiträge zur Stabilität der Flugzeuge, die die vielen Abstürze der Pionierzeit allen voran das Unglück Otto Lilienthals zu klären verhalfen. Er war ein weitblickender Geist, denn er war es, der das erste Metallflugzeug, die Reissnersche Ente, baute. Es hatte bereits eine selbsttragende Flügelhaut aus Wellblech. Drei Bilder dieses Flugzeugs will ich zeigen, das letzte, weil es ein Datum trägt. Die Entwicklung wurde von Reissner nicht weitergeführt, einmal aus finanziellen Gründen, und weil es zum andern keine Flugzeugführer gab, um ein solch fortschrittliches Flugzeug steuern zu können.

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*) The English translation is given on the subsequent pages.

Die Wahl des Nachfolgers von Reissner war ein Glücksfall. Theodor von Kármán, ein Doktorand und Mitarbeiter Ludwig Prandtls, der bereits in jungen Jahren durch die Kármánsche Wirbelstraße hochberühmt geworden war, erhält nicht den erhofften Ruf nach München zur Nachfolge August Föppls und war dadurch für Aachen frei. Er kam 1913 mit dem mächtigen Rüstzeug der Prandtlschen Aerodynamik nach Aachen. Mit einem seltenen Schwung, einer ausgeprägten Persönlichkeit, die mit ihrem Witz und Humor ausgezeichnet in die Aachener Landschaft paßte, und mit einer phänomenalen Schöpferkraft wurde das Institut und das Lehrgebiet nach modernen Gesichtspunkten aufgebaut. 1928 konnte ein Windkanal nach Göttinger Muster mit einer Drei-Komponenten-Waage nach Wieselsberger in Betrieb genommen werden. Er hatte einen ungewöhnlichen Platz, nämlich auf dem Dach des Instituts und wurde so zum Wahrzeichen der T.H. Aachen. Ich zeige ihn im Bild. Der Efeubewuchs des Gebäudes hat aber nichts mit der Tätigkeit in dessen Innerem zu tun. Der Kanal überlebte den 2. Weltkrieg, wurde von den Alliierten abgerissen, dann nochmals aufgebaut und 1946 endgültig abgebrochen.

Es war damals in Aachen eine berühmte Zeit, denn Aachen verfügte auch über eine reiche Zahl hervorragender Mathematiker, die sich für Aerodynamik interessierten. 1911 stellte Kutta hier seine berühmte Auftriebsformel auf, nachdem er schon vorher in München durch seine Dissertation, die das heute in der Numerik nicht mehr wegzudenkende Runge-Kutta-Verfahren brachte, von sich reden gemacht hatte. Blumenthal gab erste Methoden zur Berechnung von Tragflügelströmungen. Hamel leitete zähe Strömungen ab, deren Stromlinien auch Stromlinien einer Potentialströmung sein können, es sind die Spiralströmungen. Trefftz half v. Kármán die äußerst wichtige Familie der Kármán-Trefftz-Profile theoretisch herzuleiten.

Und damit komme ich zu den Mitarbeitern. Unser Ehrendoktor und jetziger Ehrenprofessor am Courant-Institute in New-York, K. Friedrichs, den v. Kármán als Mathematiker aus Göttingen an sein Institut holte, schrieb eine bekannte Arbeit über den freitragenden Flügel als Rahmentragwerk. Unser Ehrendoktor, Professor Gabrielli, der zu unserer großen Freude heute mit seiner Gattin unter uns weilt, promovierte über die Torsionssteifigkeit freitragender Flügel in der Rekordzeit von einem Jahr. Der Amerikaner Wattendorf promovierte über den Landestoß von Wasserflugzeugen. Er war ein guter Trompetenbläser und trug dadurch zur fröhlichen Geselligkeit im Institut bei. Andere Namen sind Scheubel und Hermann, der den Großteil der Windkanäle für Peenemünde konzipierte.

Auf dem Gebiet des Unterrichts wurde neben der Kármánschen Vorlesung eine Vorlesung über Flugzeugbau eingerichtet, die dem damaligen ersten Assistenten W. Klemperer übertragen wurde. Gleichzeitig sammelte sich eine Gruppe Studenten zur Flugwissenschaftlichen Vereinigung Aachen, die in enger Zusammenarbeit mit dem Aerodynamischen Institut Segelflugzeuge baute. V. Kármán setzte sich dafür ein, daß in der Rhön Segelflug betrieben werden durfte. Dort gewann die Vereinigung 1920 den Ersten Preis und 1922 brach W. Klemperer mit 13 Minuten Flugzeit den von Orville Wright gehaltenen Weltrekord von neun Minuten Flugdauer. Heute ist es nur noch die Nacht, die die Flugzeit begrenzt.

Die sogenannten Aachener Vorträge, eine 1929 abgehaltene Konferenz über Aerodynamik und verwandte Gebiete stellt ähnlich wie die Innsbrucker Vorträge einen Merkstein in der Entwicklung der Aerodynamik dar. Was Rang und Namen hatte traf sich hier. Ich zeige ein Bild der Teilnehmer. Vorne rechts v. Kármán, links vorne seine Schwester Pepe, die über ihn mit Strenge wachte, in der Mitte natürlich Prandtl mit einem ungewöhnlich strengen Gesicht, daneben Reissner, in der näheren Umgebung v. Mises, Ackeret, Tollmien, weiter hinten Busemann mit zerwühltem Haarschopf, dann links Miss Swain, mehr in der Mitte Goldstein, Rosenhead, hinten rechts Lerbs und links Friedrichs und der lange Trefftz, um niemand zu verdecken.

1934 nahm die große Epoche v. Kármán ihr Ende. Nach kurzer Zwischenzeit folgte C. Wieselsberger. Er führte die Hochgeschwindigkeits-Aerodynamik ein, verstarb aber leider viel zu früh. Sein Nachfolger Seewald richtete einen heute viel in Anspruch genommenen Ventilprüfstand ein, sein Nachfolger, Herr Naumann, baute das Institut in seiner jetzigen Form mit Windkanälen aus und errichtete ein von den Medizinern viel gefragtes biomedizinisches Labor. Sein Nachfolger, der jetzige Leiter, Professor Krause, führt die numerische Behandlung von Strömungen ein, welche Tätigkeit kürzlich mit der Berechnung der Taylor-Wirbel im Kugelspalt einen beachtenswerten Erfolg erzielt hat. Die neuere Zeit kommt kurz, weil sie sich im Institut manifestiert, das man nachher besichtigen kann.

Alle Anstrengungen in Lehre und Forschung bleiben erfolglos, wenn wie jetzt, die Vorbildung von der Schule her völlig unzureichend ist. Die Studienreformen sind ein Schlag ins Wasser, das Päppeln der Jugend hat sich nicht bewährt. Ähnlich wie früher für Medizin und Philologie das große Latinum Vorbedingung war, müssen wir auf ein fachbezogenes Abitur pochen, wenn schon das bewährte alte Abitur heute durch eine Vielfalt von verschiedenen Fach-Abiturs ersetzt worden ist. Es geht nicht, daß wir in mühevoller Paukarbeit in zwei Semestern nachzuholen versuchen müssen, was auf der Schule von Anfang an versäumt wird. Nicht nur soll es dabei auf das Wissen ankommen, sondern auf das Training des Denkapparates. Wie ein Vater eines Aachener Freundes von mir zu seinem Sohn sagte: Die Hauptsache ist, daß das Gehirn turnen lernt. Ich will hier nur auf Tatsachen den Finger legen und keineswegs in Belehrungen ausufern. Ich muß es Ihnen überlassen, sehr ernst darüber nachzudenken, wie das geändert werden kann und, wo es auch sei, an einer Besserung kräftig mitzuarbeiten.

Ich schließe, indem ich dem Aerodynamischen Institut eine erfolgreiche Zukunft wünsche, eingebettet in seine große Vergangenheit.

Opening Address

Ladies and Gentlemen,

Our vice-chancellor asked me to speak here on his behalf about the scientific meaning of this inaugural ceremony.

First of all I congratulate the Aerodynamisches Institut in the name of the Hochschule on the completion of its reconstruction and thank the institute for making every effort to create additional teaching and research facilities in a central field of the engineering sciences.

This day wakens rememberances of the beginnings of Aerodynamics in Aachen. As at other universities also here it evolved out of Mechanics.The second holder of the professorial chair for Mechanics, no one less than Arnold Sommerfeld (1900 - 1906), showed interest in fluid motion. Here in Aachen he proposed the theory of lubrication, the fundamental differential equation which is named after him.

He was followed by Hans Reissner until 1913. The seven years which Hans Reissner worked here brought lasting influence, since he was one of those, who approached the problems of aviation with scientific methods. The Hochschule owes the foundation of the Aerodynamisches Institut to Hans Reissner's initiative and pioneering work. It was built in conjunction with the chair for Mechanics and Aerodynamics 1912 to 1914.

1909 Reissner had already began with aerodynamic experiments, first in the Mechanical Laboratory, directed by Hugo Junkers, where he urged on a whirling arm and on a provisional air stream apparatus. These devices constituted the experimental foundation of the Aerodynamisches Institut. In addition to the experimental work, Reissner wrote fundamental papers on the stability of airplanes, whereby he helped to clarify the numerous crashes of the pioneering time in particular the crash of O. Lilienthal. He was a man of farsightedness and imagination and it was he who built the first all-metal plane, the Reissner Canard. It already had a self-supporting wing fabric out of corrugated metal. I will show three pictures of this airplane, the last as it bears a date. The development was not continued by Reissner, mainly for financial reasons, but also, because no airplane pilot existed, who was able to pilot such a sophisticated airplane.

The choice of Reissner's successor was a stroke of luck. Theodore von Kármán, a doctoral candidate and Ludwig Prandtl's assistant, who had already become famous at a young age through the Kármán vortex street, was not offered the chair at Munich he had hoped for as successor of August Föppl, and therefore, was free to come to Aachen. He arrived in Aachen 1913 equipped with an immense knowledge of Prandtl's aerodynamics. The Institut and the curriculum were built up in accordance with modern viewpoints with the rare enthusiasm of a strong personality, whose wit and humor fit excellently into the Aachen landscape, and by a phenomenal creative power. In 1928 a windtunnel of the Göttingen type with a three-component balance as developed by Wieselsberger could be set in operation. The tunnel had an unusual place, namely on the roof of the Institut and thereby it became a distinctive mark of the T.H. Aachen. Here is a picture of it. The tunnel survived World War II, was turn down by the Allies , then reconstructed , and was turn down completely in 1946.

Aachen was in its golden age since at that time it had an impressive number of excellent mathematicians who were interested in aerodynamics. Here in 1911 Kutta developed his famous formula for the lift, after he had already previously caused a great stir in Munich through his dissertation, in which he derived the Runge-Kutta-method, an indispensible part of modern numerics. Blumenthal proposed some of the earliest methods for calculating flows about wings. Hamel derived a solution for viscous flows, the streamlines of which can also be identified with the streamlines of potential flows; they are the spiral flows. Trefftz helped v. Kármán to derive theoretically the extremely important family of the Kármán-Trefftz-Profiles.

And with this I come to the assistants. Our honorary doctor and present honorary professor at the Courant-Institute in New York, K. Friedrichs, whom v. Kármán engaged as a mathematician for his institute from Göttingen, wrote a renowned work about the cantilever wing as a frame system. Our honorary doctor, Professor Gabrielli, who together with his wife give us the great honour of their presence, wrote his doctoral dissertation about the torsional strength of cantilever wings in the record time of less than one year. The American Wattendorf wrote a dissertation about the impact of landing of seaplanes. He was a good trumpet player and contributed to the spirited social life of the Institut. Other names are Scheubel and Hermann, who drew up, the major plans for the windtunnels in Peenemünde.

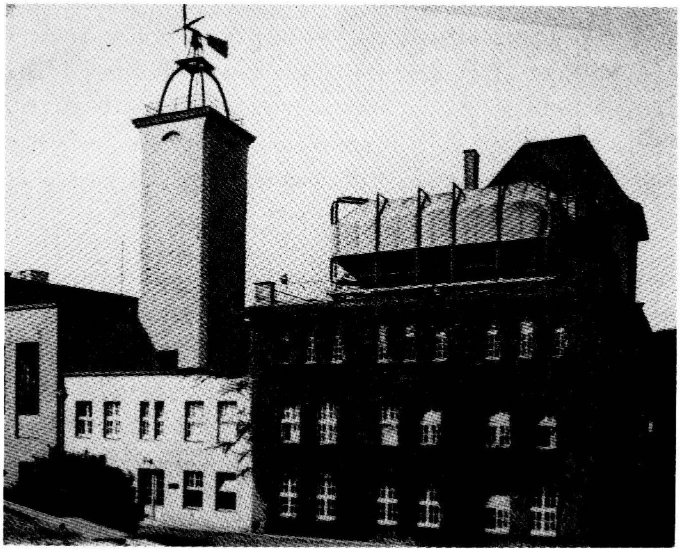
In the teaching field, in addition to Kármán's course, a course in airplane design was initiated, which was given by the first assistant at that time, W. Klemperer. At the same time a group of students founded the student aeronautics society Aachen (FVA) which in close cooperation with the Aerodynamisches Institut built gliders. V. Kármán used all his influence in seeing to it that the group could participate in the gliding contests in the Rhön hills. There the society won the first price in 1920 and in 1922 W. Klemperer broke the world record of 9 minutes flight time, held by Orville Wright, with a flight time of 13 minutes. Today it is only the night which limits the flying time.

The so-called Aachen Lectures, a conference on aerodynamics and related subjects, held in 1929, was, like the "Innsbruck Lectures" a milestone in the development of aerodynamics. It was the gathering of the most prominent of the scientific elite. I would like to show a picture of the participants. In front on the right von Kármán, on the left his sister Pepe, who kept a stern eye on him, in the middle, of course, Prandtl with an unusual serious expression, next to him Reissner, in his immediate vicinity v. Mises, Ackeret, Tollmien, farther back Busemann with dishevelled hair, then on the left side Miss Swain, more to the center Goldstein, Rosenhead, in the back to the right Lerbs and to the left Friedrichs, and the tall Trefftzs, in the back in order not to stand in front of anybody.

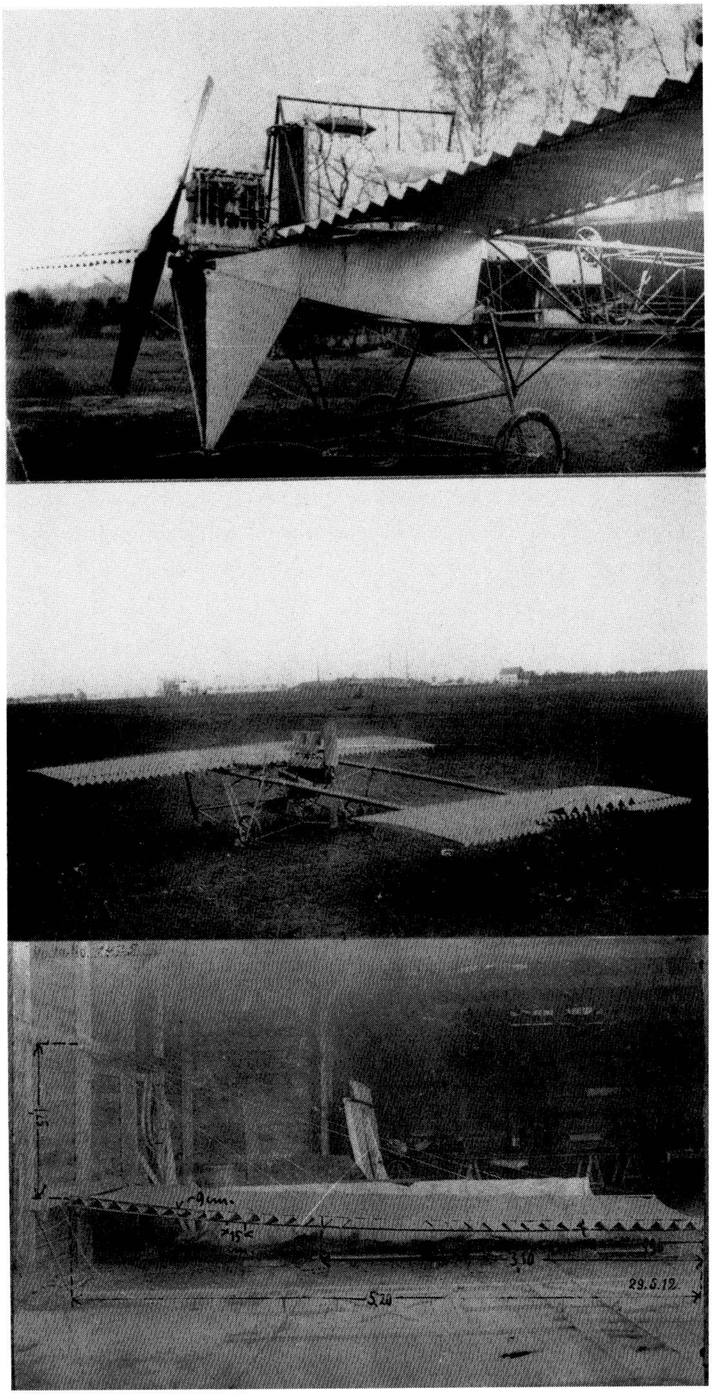
In 1934 the great epoch of v. Kármán came to an end. A short time thereafter C. Wieselsberger became his successor. He introduced high-speed aerodynamics, but most unfortunately, passed away much too early. His successor Seewald set up a test stand for safety valves which is in great demand today and his successor, Mr. Naumann, equipped the Institut with windtunnels and gave it its present form. His successor, the present director, Professor Krause, is introducing numerical analysis of flows; not long ago this activity achieved noteworthy success with the calculation of Taylor vortices in the spherical gap. The more recent developments will not be dealt with in depth at this time in as much they can be seen later on in the Institut.

All efforts in teaching and research are fruitless, if as at the present time the basic secondary education is completely inadequate. All reforms of our educational system have been in vain, the coddling of the youth has proven to be a failure. Similar to earlier times when the Matriculation Latin was a prerequisite for medicine and philology we must insist on a subject-orientated school-leaving examination, even if the old time-tested school-leaving examination has nowadays to be replaced by a variety of different specialized school-leaving examinations. It is impossible for us to try to make up in two terms through irksome cramming what was neglected in school from the very beginning. We are not only concerned about factual knowledge but even more about training of the brain muscles. As a father of one of my Aachen friends said to his son: "The main thing is that the brain learns how to turn a somersault." I only want to point out facts and by no means do I want to become pedantic. I must leave it up to you to think very seriously about how this could be changed and, wherever it may be, to vigorously help to improve things.

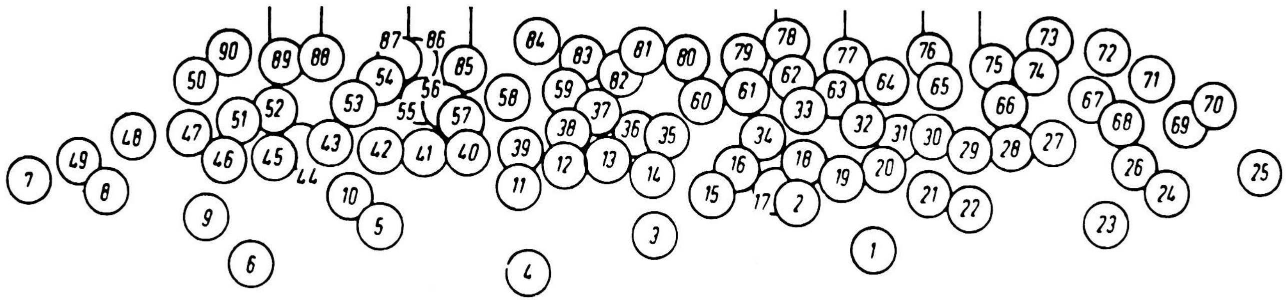
I close by wishing the Aerodynamisches Institut a successful future, rooted in its great past.



The first windtunnel of the Göttingen type located on the roof of the Aerodynamisches Institute; completed under v. Kármán in 1928.



The Reissner Canard. First all-metal airplane with cantilever wing built around 1912.



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Participants of the conference on aerodynamics held at the Aerodynamisches Institut in 1929 on the occasion of the inauguration of the first extension building of the Institut.

Education, Training, and Research in the Engineering Sciences

H. W. Liepmann
Pasadena

After struggling with the wording for a lecture in German - only my third in the last forty years - I have now the unenviable task of writing a reasonable facsimile of the address in English. It is not easy to translate the three words used in the German title into equally concise English while keeping the same meaning. The word "Bildung" is closely akin to the term "liberal arts education" "Ausbildung" to "vocational training". But neither conveys quite the same ideas as the corresponding German, at least not to me. "Forschung" into "research" is fortunately a conformal translation. Worse than that, ideas which are easily discussed in a talk, in the presence of an audience with feedback, tend to sound stuffy and pompous when written down. I lose somehow the ease of presentation and feel that I might sound like Nolte in Wilhelm Busch: "Drum soll ein Kind die weisen Lehren der alten Leute hoch verehren, die haben alles hinter sich und sind, gottlob, recht tugendlich!"

Any university has to contribute to the culture of the time through research and pass on to younger minds the heritage of the past and the challenge of the future. The selection of the proper mix of general education, professional training, and research is an eternal problem for which no general solution can be found. Schools of technology in particular face an often self-contradictory criticism. They are accused of being too theoretical or too applied, too far from industry or governed by industry. Technology has become the whipping boy of modern times, so much so that an unhealthy and unproductive bad conscience pervades the technical professions. Natural sciences and technology are sometimes portrayed as anti-culture or anti-humanity. These attacks are to me ridiculous expressions of frustration. I consider natural sciences and technology as much a part of the general culture as, say, the arts. I admit that one can do more damage by mishandling an engineering project than by mishandling a symphony but to quote from one of may favorite aphorisms: Never mistake impotence for virtue!

The dictionary defines the culture of a group as its shared customs, ideas, and attitudes. This definition leaves me somewhat cold since it does not emphasize the heritage of accomplishments from which the ideas and attitudes have grown. A true education should make it at least possible to appreciate this past heritage and to contribute to the future. It is commonly expected that an educated human will appreciate music, literature, and the arts and that he will be aware of the social and political ideas of his time and their historical roots. Appreciation of the natural sciences, let alone engineering, is seldom if ever expected and these fields of human endeavor are hardly considered today as part of the culture of our times.

This lack of appreciation is indeed a strange regression from former times. The inscription above the entrance of Plato's academy reads: "Let no one ignorant of geometry enter". The cultural elite in ancient Athens or during the height of Islamic splendor in Damascus, Cordova or Samarkand would have ostrasized anybody lacking in appreciation of mathematics and astronomy. In the quadrivium of the middle ages, mathematics and music were combined in the masters' curriculum.

Our century will probably be less remembered for its contributions to the arts than for its revolutionary ideas in physics and biology, the rise of the computer, and the creative engineering which allowed man to leave the ground to travel the air and finally outer space. This feat, together with the subsequent burst of new understanding of the universe, extends the horizon of mankind more than even the terrestrial discoveries of the fifteenth century and the realization that the earth is round and finite. These contributions of science and technology to an understanding of the world we live in and our own makeup will rank as a permanent part of our culture.

The loud and persistent clamor for increased education of technologists in the social sciences and humanities can be and should be answered by a demand for increased appreciation of the natural sciences and technology by social scientists and humanists, and indeed by anybody who subscribes to a true liberal education. There are more technologists today who appreciate Shakespeare, Mozart, and van Gogh than humanists who appreciate the beauty of Maxwell's equations, the lines of an aircraft, or the marvelous intricacy of an integrated circuit.

The lack of real understanding of contemporary technology among social scientists and lawyers who, after all, make decisions on questions ranging from the uses of atomic energy to problems of pollution is, I think, far more dangerous than any lack of appreciation of social sciences among engineers. To educate an electorate, or at least a legislature, capable of making decisions on the basis of understanding of technology rather than fear and mystique is probably the most important task of education today, and very likely the crucial test for the survival of a democratic society.

The term "engineering education" implies exposure to subjects beyond purely professional techniques. Part of such exposure is, in fact, mandatory from a purely professional point of view: In a time of rapidly changing technology, the professional techniques of the day are rapidly outmoded, new fields of engineering endeavor appear suddenly, and the background in fundamentals must be sufficiently broad to make respecialization possible. Beyond this strictly professional point of view, intellectual pleasure and curiosity plus the possiblity of fruitful interaction with a greater part of the human society are the driving forces for extended education. Obiously, only part of such an extension can be provided by a formal study program, but the foundation can be laid and interest stimulated by an early opportunity to sample other fields. In spite of pressure for more courses in a narrow engineering discipline, enough time must be left for options in cultural subjects, where culture is interpreted in a broad sense and where much is left to individual taste. Subjects such as economics and psychology, music and