THEODORE VON KÁRMÁN – HONORARY DOCTOR OF THE POLYTECHNICAL UNIVERSITY OF BUDAPEST

During October, 1962 Professor Theodore von Kármán, the world-renowned scientist visited his native country, Hungary. Apart from a short visit paid to Budapest after its liberation in 1945, to see members of his family, he has been away for more than 43 years, since leaving the country in 1919.

He came to Budapest on the invitation of the President of the Hungarian Academy of Sciences, Dr. I. Rusznyák and has spent a fortnight here rather heavily filled with programs. On October 22nd, during a special session of the Council of Budapest Technical University, a honorary doctor's title was conferred upon him by Dr. József Gruber, Rector of the University. Also, in order to commemorate the 60th anniversary of Professor von Kármán's graduation, he was presented with a diamond diploma of the University.

The festive occasion with its intimate tone — a commemorable event for those who were present — prompts us to give a concise review of Professor von Kármán's immense contribution to engineering sciences and to the science of educating engineers.

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Theodore von Kármán was born on the 11th May, 1881, in Budapest.

His father, Dr. M. Kármán was a professor of the Science University in Budapest, a nation-wide authority on education. His efforts in rendering up-to-date the secondary school system in Hungary have largely been recognized and his secondary-school reform project still provides the basis for the education curricula in Hungarian schools. His books and papers on education are still utilized in forming the secondary and high-school teachers and professors. A special demonstration secondary-school was founded by him (the so-called Mintagimnázium in Trefort street) and Theodore von Kármán received his secondary tuition in this renowned school, under the direct supervision of his father. The highly intellectual atmosphere of the Kármán family, the advices of the father, an excellent educationalist in his own home, have left a deep impression on him and have certainly influenced his activity and his view of life in later years.

While young Theodore von Kármán acquired a deep interest in mathematics, his father persuaded him to choose a profession "nearer to everyday's life", to quote his own words. Thus, after having finished secondary school with full honours, he entered the faculty of mechanical engineering at the Technical University of Budapest. At an age of 21, he received a "summa cum laude" M. Sc. degree in mechanical engineering.

The *Polytechnical University of Budapest*, a high-standard institution for the education of engineers, provided a solid foundation for later scientific research work for Th. von Kármán. Amongst his professors we find Donát *Bánki*, an interesting personality, whose theoretical work in hydraulics as well as his practical industrial activity (Bánki is the inventor of the carburetter) have largely contributed in formulating the main aim of von Kármán's engineering research work: to provide a bridge between theory and practice, so far from each other in many fields of engineering sciences. After graduation Th. von Kármán remained at the university as an assistant professor of the chair of hydraulics under Professor Bánki.

In 1906 he went to the *Göttingen University* in order to study applied mathematics and to start postgraduate research work. He became a research fellow at the chair and institute of Professor Ludwig *Prandtl*, who is the recognized founder of modern fluid dynamics. This event has been of decisive significance so far as further scientific activities of von Kármán are concerned. Prandtl himself was a genius in finding theoretical solutions useful for practical engineering purposes and his approach to solve complicated engineering problems by boiling them down to their very physical essence and looking for mathematical formulations giving relatively simple but still satisfactory engineering solution, has been very important in developing similar trends in early research work by Kármán. It may be added that Prandtl himself was deeply impressed by another famous German scientist at Göttingen University, namely Felix Klein, to whom is largely due the role played by this famous German university in the development of modern applied mathematics and mechanics. Certainly Prandtl, von Kármán and Timoshenko are among the best known representatives of the Göttingen school in this field of science so important in view of engineering applications.

Kármán's first research papers have dealt with some practical engineering problems on the theory of elasticity. His dissertation for his Dr. Ing. degree, submitted in 1908, is a typical representative of this type of problems. Here he considers the stability of short compression-loaded struts, loaded to beyond their limit of elasticity. The results thus obtained have found their way into every textbook on applied mechanics as "von Kármán's theory of stability" and are certainly very important in stressing engineering structures in the elastic-plastic domain. But this is only one part of von Kármán's contribution to modern theory of stress and strain. His interests in bending theory have prompted him to consider the stress and strain conditions in thin-walled curved hollow beams and tubes, the results herewith obtained being of fundamental importance in the proper design of machine elements.

Simultaneously he began with an interesting series of experiments in order to prove one of the main theories in elasticity and plasticity. He had tested marble specimens under triaxial compressive loads and obtained unequivocal yield curves from a material generally known as absolutely rigid. This was one of the starting points for a new theory on the plastic yield of solids and a substantial proof of Mohr's theory of failure. These famous experiments have also proved that there is no standard, single approach to engineering problems and that material behaviour is largely dependent on actual loading conditions.

During these days, however, research fellows in Göttingen — especially in the institute of applied mechanics and mathemathics — began to concentrate their attention on a new field of problems. Aviation was in the coming and scientists — young and old — had seen tremendous possibilities in this new branch of applied science where a close cooperation between theory and practice was essential to success. Already Felix Klein during his visit to America had been greatly impressed by engineering developments leading in a logical way to heavier-than-air flight and early experiments all over the world gave the necessary impetus to theoretical investigations. Gradually Prandtl and all his fellow scientists turned their attention (and best capabilities) to problems in fluid dynamics which promised potential applications in the practice of aviation engineering.

One of the best known works done by von Kármán during these years in Göttingen concerned the vortex system forming behind a body placed into the flow. While vortex systems of this type had already been observed by others, it was Th. von Kármán who developed precise mathematical conditions for a stable arrangement of a similar vortex system. His results based on sound theoretical considerations have shown excellent agreement with observed phenomena and drag values thus obtained were near to actually measured values, — a rather new positive result in this field of fluid dynamics. This "Kármánsche Wirbelstrasse", (known as "*Kármán vortices*" in English textbooks) was named after von Kármán as a special recognition of his way of tackling difficult problems. It is interesting to note that von Kármán's paper on the vortex path was published exactly fifty years ago, a date for friendly commemoration during the professor's recent visit to Hungary.

Kármán predicted that alternate vortices separating from the body may be the source of oscillations. In engineering structures oscillations of this type may become excessively dangerous as was shown by the failure of the Tacoma bridge in 1940. It is by no means an incident, that Professor von Kármán was a member of the expert committee investigating the causes of this catastrophial event, almost unique in the history of engineering.

However, not only theory of elasticity and plasticity, nor fluid dynamics have constituted the exclusive fields of research for the keen young scientist in Göttingen. With another of the well-known physicists to whom modern science owes so much, with Max Born, he entered the field of the physics of solids. For a while the problem of specific heat was an interesting theme for his investigations. It should be noted that while the specific heat theory of Debye is generally well known and used because of its simplicity, a much more precise theory had been evolved by Born and Kármán and may still be regarded as being of fundamental importance in the physics of solids, a field of physical science attracting the interest of an ever increasing team of physicists.

Undoubtedly the most significant contributions to engineering sciences have been made by von Kármán in the field of fluid dynamics and its different branches. It is this field where for many decades he was responsible not only directly for some very significant discoveries and their sound theoretical interpretation, but also indirectly by gathering around himself a group of talentful scientists devoted to the same ideals and aims as their master. When considering the creative work of Professor von Kármán, one cannot separate von Kármán the scientist from von Kármán the teacher and educator. It might be significant in this respect to oppose von Kármán's views to those of G. B. Shaw — as quoted by von Kármán himself. Shaw says: "He who knows, does it, he who doesn't know, teaches it"; while von Kármán says: "If you really want to learn some branch of science, write a paper, a textbook or teach it." (Von Kármán's paper on magneto-fluid dynamics at the Amsterdam Astronautical Conference, 1958.)

In 1912, as the chair of mechanics at the Technical University of Aachen (Technische Hochschule Aachen) became unoccupied, von Kármán was invited to this post and also entrusted to introduce a new discipline in the curriculum of the university — aerodynamics. It was almost at the same time that in his home country he had been nominated to the chair of Theory of machines at the College of Mining Engineering in Selmecbánya, one of the traditional engineering schools of Hungary. While von Kármán has actually started his term as professor at Selmecbánya, his final choice was in favour of his professorship in Aachen, which provided him with much broader possibilities to advance a newly-developed branch of applied mechanics. Thus he left Hungary for Aachen where he also embarked upon a larger project: that of building the Aerodynamical Institute of TH Aachen.

As the first World War broke out, von Kármán, who had made his military service in a fortified artillery regiment, was called to active military service with the rank of a lieutenant. However, since the years of his first military service a significant new development took place: aviation had entered the military services. Von Kármán, already a renowned authority in aeronautical engineering, was called to the Military Aircraft Factory at Fischamend, Austria, to work as an engineering consultant there. During these years he developed — with the cooperation of Colonel I. Petróczy and an assistant named J. Zurovecz — the first stable hovering captive helicopter of the world, bound to substitute the captive observation balloon which proved to be extremely vulnerable in military operations. The development of a suitable design involved a substantial amount of theoretical work, later to be published in one of the classic papers on rotary-wing aircraft (Zeitschrift für Flugtechnik und Motorluftschiffahrt, 1921. Vol. 12. No. 24). In the summary of this paper von Kármán points out: "...the construction of a suitable helicopter certainly presents greater difficulty than most inventors and constructors believe, but is nevertheless not without prospects. In my opinion the helicopter can only compete with fixed-wing aircraft when aircraft are required for purposes... necessitating hovering at low velocity." These words are certainly valid even today. He also found that helicopters and other rotary-wing aircraft are inherently unstable dynamically and tethering — as it did in the classic P—K—Z design — there is only one way of overcoming this difficulty not found with conventional fixed-wing aircraft because they are unable to fly in a hovering condition. Thus von Kármán became one of the real pioneers of helicopter engineering.

During the last year of first World War, von Kármán returned to Budapest, lecturing in aerodynamics and theoretical physics at the Polytechnical University, his real "alma mater". He also took up a post at the University Section of the Peoples' Commissariat on Education, his task being the modernization of higher technical education. His ideas on rendering engineering education are still up-to-date retaining their validity even in these times, as stated by Professor E. Rácz, Dean of the Faculty of Mechanical Engineering in his report to the special session on von Kármán's work. Professor Rácz points out: "Von Kármán's ideas on the modernization of engineering education are not only valid in these days, but they are partially reflected by the main principles of our present educational reform. In order to illustrate this I would only like to quote one statement by von Kármán: 'Results of education in mathematics and natural sciences at the Technical University are in many respects not proportional to the time and effort given to it by professors and students. In my opinion this is partly due to improper selection of the material to be taught, i.e. in its lack of contact with engineering sciences, partly due to the fact that lectures in mathematics and natural sciences fully cease at the higher terms, exactly then when the student begins to see what kind of mathematical and physical knowledge may be necessary to him.' This statement touches according to my own opinion even to-day, after some 43 years, a living problem of our university education."

After the fall of the Hungarian soviet republic he returned to Aachen, ensuring him the possibilities of quiet and undisturbed work in theoretical and experimental aerodynamics. Under his leadership the Aerodynamical Institute of the Technische Hochschule Aachen developed into one of the most significant centres of European aeronautical research. During this time he wrote a comprehensive theory of propellers. His superb knowledge of the aerodynamical applications of conform transformations enabled him to generalize the well-known Joukowski transformation theory and — in cooperation with Trefftz — to find the theoretical foundations for an important family of wing sections having a finite included angle at the trailing edge and thus easy to be realized in actual aircraft structures.

In 1926, Th. von Kármán was invited to the USA. He went there as a visiting professor on the invitation of the Daniel and Florence Guggenheim Foundation, one of the major financial sources for the development of aeronautical sciences in America. The success of his visit has largely contributed to his willingness to move later to the USA. Since 1928 he held alternate lectures at Aachen and in Pasadena, at the California Institute of Technology. Then gradually the balance shifted in favour of Pasadena and in 1930 he finally decided to leave Germany and settle down in the USA. Quite certainly political events in Germany influenced him in taking this decision, but also the fact, that the Guggenheim Foundation provided substantial funds to establish a well-equipped modern aerodynamical research institute in Pasadena, to be known under the abbreviation GALCIT, i.e. Guggenheim Aeronautical Laboratory of the California Institute of Technology. While proceeding along similar lines which won him a tremendous reputation in the field of scientists, here in Pasadena he had incomparably better financial possibilities to build a university research establishment almost unparallelled in the world. His ideas in selecting his research fellows and in organizing scientific research remained the same and soon a new "von Kármán school" of aerodynamicists grew up, constituting a substantial factor of American success in aeronautical science and aviation technology.

While actual aircraft struggled their way towards half of the speed of sound, von Kármán and his pupils looked into the future of aviation. They began investigating high-speed aerodynamical phenomena, until then seen only by interested ballisticians; they also envisaged colossal increases in flight speeds. It is extremely interesting, that in his classical paper at the Volta Conference in 1935 (The problem of resistance in compressible fluids, Roma, 1935) he could not only foresee the possibility of flight speeds exceeding the speed of sound, but also tells us that the supersonic domain shall be divided into two sectors and Newton's classical statements on resistance will regain validity in a region, which he calls "ultrasupersonic". This is what we call "hypersonic" today.

High-speed flight with all its implications provided a new field for von Kármán and his collaborators. An ever increasing amount of papers and reports on transsonic and supersonic aerodynamics came from his institute during the last years of the second World War. A clear-cut elucidation of all problematics of high-speed aerodynamics can be found in another classic paper by von Kármán: his Tenth Wright Brothers Lecture, presented in 1947 before the Institute of Aeronautical Sciences. This paper, translated into many languages, gives concise, comprehensible but invariably exact information on all phenomena which are the distinctive features of this new chapter in aerodynamics. While some of his earlier papers during wartime deal with specific problems of transsonic and supersonic aerodynamics, this can be considered as the standard syllabus of supersonic aerodynamics. (Journal of the Aeronautical Sciences, 1947. Vol. 14. No. 7.)

Another related field where his contribution is of fundamental importance is the theory of turbulence and boundary layer. Statistical theory of turbulence largely owes its existence to von Kármán and its development in the Western states can be attributed to his pupils and research fellows. It should be noted, that applications of this theory are not only valuable for aeronautical engineering purposes, but also for the development of so-called internal aerodynamics, where flow conditions inside of pipelines, ducts, flow machines etc. are being considered.

Before he began his research into the problems of turbulence, for many decades "theory was directed toward finding semi-empirical laws for the mean motion by methods loaned from the kinetic theory of gases. Prandtl's ideas on momentum transfer and Taylor's suggestions concerning vorticity transfer belonged to the most important contributions of this period." (Progress in the Statistical Theory of Turbulence, Proc. of the National Academy of Sciences, 1948. Vol. 34. No. 11.) Undoubtedly, von Kármán's formulation of the problem by the application of the similarity principle has the merit of being more general and independent of the methods of the kinetic theory of gases. Among others, this theory resulted in the discovery of the logarithmic law of velocity distribution in shear motion for the case of homologous turbulence. After this — together with Taylor and Howarth — he developed the theory of isotropic turbulence, generally recognized as the hitherto most perfected theoretical approach to turbulence, its significance extending well beyond the field of aerodynamics.

To show von Kármán's ideas not only on highspeed flight but also on the evolution of an engineer's knowledge, let me quote from the already mentioned classical 1947 paper: "I believe we have now arrived at the stage where knowledge of supersonic aerodynamics should be considered by the aeronautical engineer as a necessary prerequisite to his art. This branch of aerodynamics should cease to be a collection of mathematical formulas and half-digested, isolated, experimental results. The aeronautical engineer should start to get the same feeling for the facts of supersonic flight as he acquired in the domain of subsonic velocities by a long process of theoretical study, experimental research and flight experience." In another classic paper by him (Journal of the Aerospace Sciences, 1959. Vol. 26. No. 3.), reviewing the main achievements of aerodynamics since 1946, he quotes the same text and adds that in the meantime this has been generally attained. Supersonic and hypersonic aerodynamics have developed under his leadership into a well-arranged, logical domain of science, where an ever improving agreement is being obtained between theory and experiment.

It would be very difficult to review all fields of engineering sciences where von Kármán and his pupils have achieved significant results. However, a few examples may be given. One of his closest friends and best pupils is Dr. Hsue-Shen Tsien, who is at present director of one of the largest institutes of Academia Sinica, the Academy of Sciences of the Chinese Peoples' Republic. During his long stay in Pasadena, Dr. Tsien wrote several papers in common with his master and has also contributed to a surprisingly large number of fields, including nuclear engineering and finding a new domain of activity for the physicist and engineer, what he calls engineering mechanics (a special branch of technical physics, in fact). Together with Professor von Kármán, they wrote several papers on the buckling of thin shells, on different phenomena in high-speed aviation, and also on the aerodynamics of rarefied gases, usually called molecular aerodynamics or superaerodynamics. Recently Dr. Tsien has turned his attention also to cybernetics.

The advent of jet propulsion has also influenced research carried out at his institute. (It would be more proper to say that his institute had a substantial share in the success of jet propulsion.) Here a new chapter in the history of GALCIT began, as the Jet Propulsion Laboratory, now a major factor in US space effort, has been added to it. At present the JPL is the largest purely scientific institution working in the aero/space field, still retaining close links with its founder and master.

Von Kármán and his pupils became interested in rocketry almost 20 years ago. First they tried to persuade military circles to finance the development of jet-assisted take-off (Jato) power units. Their success has later led to some of the first US military rockets and also to the first American aerophysical research rockets, Aerobee and WAC-Corporal. H. S. Seifert, F. J. Malina, M. Summerfield should be named among the real rocket engineering pioneers of the USA starting their work under the direct leadership of von Kármán. Since then they and another generation of scientists have grown up working in a rapidly developing field now termed space technology. Von Kármán's contribution in this field may be simply characterized by stating the fact that he has been unanimously elected to become Director of the International Academy of Astronautics and that a large aerodynamical institute engaged in hypersonic research was named after him (Von Kármán Hypersonic Test Facility in Tullahoma).

During the last decade or so, partially stimulated by research in jet propulsion, von Kármán's interest has centered around complex phenomena in air during combustion processes. He recognized the fact that gasdynamical, thermal and chemical processes cannot be separated and must be integrated into a new complex discipline, called aerothermochemistry. With the growing importance of ramjet power units, aerothermochemistry is also becoming a field of increasing theoretical and experimental studies.

While it is practically impossible to present a full review of the scientific activities of Professor Th. von Kármán and to give a full appraisal of his permanent contributions to modern engineering science, we would like to conclude these lines by trying to find out what may be the secret of the tremendous value as created by his work. Apart from the already mentioned duality of scientist and teacher — not always found simultaneously in university professors — it is certainly due to the fact that he has found and properly used the most powerful tool of the engineer, namely mathematics. One of his most excellent works — written together with one of his pupils, M. Biot — is "Mathematical methods in engineering" to be published soon in its Hungarian translation. His own view about mathematics and engineering may be quoted from one of his short articles (Mechanical Engineering, April, 1940): ". . . it seems to me that we witness a certain revival of the spirit of the heroic age with a better mutual understanding between the mathematician and the engineer. The practical engineer appreciated the advantage of replacing mere empirism by scientific analysis expressed in mathematical language. At the same time even the most abstract mathematician considers the usefulness of his science at least as a gracious by-product of his brain work."

Hungary has contributed many fine brains to the advancement of science in general and especially to the advancement of engineering sciences. We are convinced that Professor Theodore von Kármán, who on the 60th anniversary of his graduation accepted a honorary doctor's degree of our University belongs to the foremost group of these fellow countrymen of ours.

E. NAGY