Theodore von Kármán — His "American Period"

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IT IS indeed a great honour to participate in the appreciation of Dr. Theodore von Kármán by the Royal Aeronautical Society of which he was so devoted a member. I have been asked to consider in particular those portions of his extraordinarily varied and productive career which centred around his activities in the United States. Even within this scope his contributions were so tremendous as to have stimulated literally dozens of articles on his career and influence. I myself was privileged to prepare "appreciations" on the occasions of his sixtieth and seventy-fifth birthdays, and many other more competent writers have chosen von Kármán as the subject for articles both before and after his death on 7th May 1963. Under these circumstances I have found it impossible to avoid plagiarism and even repetition. An attempt has been made to list some of the tributes and articles which have appeared and from which material has been drawn, but this bibliography is certainly woefully incomplete.

A brief sketch of von Kármán's activities before his first coming to the United States will suggest the characteristics which were so uniquely apparent in his later career. He was born in Budapest on 11th May 1881. His father, Dr. Maurice von Kármán, professor of philosophy and education at the University of Budapest, was one of the outstanding pedagogues and philosophers of the Austro-Hungarian empire in the late nineteenth century. The intellectual capacity and tastes of the father were passed on in full measure to the son, whose interests from the first were directed towards the fields of science and technology. Graduating with highest honours as a mechanical engineer from the Budapest Royal Technical University in 1902 Theodore von Kármán, after completing his one-year military service, returned to his Alma Mater as an instructor for a year, and was then employed as research engineer by a well-known local firm engaged in the manufacture of all kinds of machinery. The feeling for practical engineering problems which he obtained during his subsequent two years in this position profoundly influenced his later life. In 1906 von Kármán decided to resume his technical studies and accordingly dropped his engineering work to enroll as an advanced student at the University of Göttingen. Until 1909 he studied intensively mathematics, physics, and mechanics at this institution as well as in Paris and London. Göttingen awarded him the Ph.D. degree in 1908 and appointed him Privatdozent in 1909, which position he held until 1912, when he was made Professor of Aeronautics and Mechanics and Director of the newly established Aeronautical Institute of the University of Aachen. The war interrupted his academic activities, necessitating his service as director of a research department in the Austro-Hungarian Aviation Corps until late 1918, when he returned to Aachen. In the decade following the war the Aachen Aeronautical Institute under von Kármán's guidance became one of the outstanding aeronautical research centres of the world, while at the same time its director engaged actively in practical engineering matters as consultant or adviser to the Junkers, Zeppelin, and other aircraft companies.

During this period he had already demonstrated the extraordinary versatility and range of accomplishments which continued to characterise the remainder of his life. He had published some fifty scientific and technical papers, many of fundamental significance, had created an outstanding technical Institute, trained dozens of young students who went on to become true disciples, contributed through his consulting activities to many practical engineering and industrial creations, and even participated in military affairs, although not at the high policy-making level at which he later played so important a role.

In 1926 von Kármán made his first visit to the United States under the auspices of the Daniel Guggenheim Fund for the Promotion of Aeronautics, lecturing at many universities and research establishments. In particular he spent several weeks at the California Institute of Technology where he laid the basic plans for the Graduate School of Aeronautics with its associated laboratory which the Guggenheim Fund had generously endowed and with which he was later so closely associated. This was followed by a trip around the world during which aeronautical developments were studied and lectures were delivered in Japan, China and India. In 1928 von Kármán became Research Associate of the California Institute of Technology and arranged to divide his time between Aachen and Pasadena, and in 1930 settled permanently in California, becoming Director of the Guggenheim Aeronautical Laboratory at the California Institute of Technology which has since become widely known under the less unwieldly acronym of GALCIT.

Thus began the phase of von Kármán's career which was centred around American activities, although even in this era his travels, lectures, and interests abroad far exceeded those of any normal man. This "American" period can be divided into two parts: the first from 1930 to 1944 had its focus in Pasadena where he lived in the gracious home presided over first by his mother and then, after her death, by his sister. Both were extraordinary women and the family life was one of remarkable warmth which made itself profoundly felt by the hundreds of colleagues, students, and friends who constantly filled the von Kármán house and basked in its hospitality.

During the first decade of this period von Kármán's primary activity was the building up of the GALCIT as an outstanding laboratory and graduate school in Aeronautics, Applied Mechanics, and related fields. He was a brilliant, if unorthodox lecturer, and an extraordinarily creative and versatile research worker, who had a unique gift for stimulating, and then working as collaborator with, the remarkable group of students who were attracted to his laboratory. In fact these two aspects of the really great teacher were in him inextricably intertwined. One of the characteristic gestures which his students will never forget frequently occurred when he was lecturing on a subject on which he was himself currently working. Such lectures were never formally prepared and he would often find himself at the blackboard attempting to resolve a problem which he had not yet completely worked out. It was an unforgettable experience to follow his original mental processes as he took out his hankerchief, chewed on it as he stepped back from the blackboard, and then proceeded to carry to completion the solution for which he was seeking.

During this period he produced another fifty-odd papers, alone and in collaboration with his students and colleagues,

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many of which have become classics, and in addition found time to engage in extensive consulting activities both for industry and the government. A study of the bibliography of his 100 publications up to the mid-1940's reveals the remarkable number of different fields to which von Kármán had already made original contributions: Applied Mathematics, Physics, Strength of Materials, Stress Analysis, Theory of Elasticity, especially Elastic Stability, Monocoque Structures, Vibrations, Mechanics of Ideal, Viscous, and Compressible Fluids, Turbulence, Aerodynamics of Aircraft and Airships, Hydrodynamics of Planning Surfaces, Heat Transfer, and Rocket Propulsion. In all of his work in these varied fields as well as in his engineering activities, which are not evidenced by publications, one or more of three distinctive and characteristic elements appear:

(*a*) The discovery and presentation of a new conception of some phenomenon which had hitherto remained quite unexplained and mysterious, in other words creative scientific conception at its highest level.

(*b*) The clarifying and reducing to clear and transparent form of material which had before been confused and hence only imperfectly comprehended. This was often associated with the finding of a mathematically elegant and thus essentially simple framework with reference to which very complex phenomena could be understood.

(*c*) The finding of the essential physical elements in complicated engineering problems so that rational and simple approximate solutions could be obtained, which solutions might then be improved by methods of successive approximation.

The presence of any of these elements is evidence of quality of the highest order; the repeated occurrence of all three in the publications of one man is almost unique.

In the late 1930's von Kármán's insatiable scientific and technical curiosity led him to explore a then highly exotic and essentially unknown field, rocket and jet propulsion, in which he was to be deeply involved and to which he was to make extraordinary contributions for the rest of his life. With a few graduate students he undertook theoretical studies of the potentialities of rocket propulsion and encouraged the students to undertake some small scale rocket tests adjacent to and in the basement of the Guggenheim Laboratory. The stench, noise, and potential hazard of even these limited tests made it quickly apparent that a small and compact college campus was not the most appropriate environment for rocket testing. Accordingly funds were found to purchase a few acres of land in the, then, uninhabited Arroyo Seco in the foothills of the San Gabriel mountains a few miles north of the Cal Tech campus where such experiments could be carried out with fewer inhibitions. In 1939 von Kármán obtained the first substantial support for the rocket programme from the National Academy of Sciences, and two years later the Army Air Corps took over sponsorship of the work with the primary objective of developing rockets to provide Jet Assisted Take Off (JATO) of aircraft. For some years this effort was called GALCIT Project Number 1, and in September 1944 the first successful JATO flight in the United States was accomplished at the Air Corps' nearby March Field, using a little civilian aircraft. In this first experiment employing small solid propellant rockets the normal take-off run was reduced by some 50 per cent. Liquid propellant rockets were also developed and the military soon decided that JATO units should be produced in quantity for operational use.

It was clear that this was a job for industry rather than for an academic institution and von Kármán accordingly tried to interest a number of large companies to enter the rocket business. However, the project seemed too visionary for any of them to be interested, so von Kármán with a few colleagues and friends in 1942 organised the Aerojet Engineering Company to undertake the production of JATO rockets for the Army and Navy. Two years later the General Tire and Rubber Company agreed to furnish the financial backing to make it possible for the fledgling venture to undertake operations of the scope the government required, and shortly thereafter purchased control. The Aerojet-General Corporation, which von Kármán's little venture developed into, was in 1962 one of the 100 largest industrial companies in the United States. von Kármán always retained a great intellectual interest in Aerojet-General and served until his death as chairman of its Technical Advisory Board.

As for the little rocket laboratory in the Arroyo Seco which had originally developed the JATO systems, its and von Kármán's interests expanded into the use of rockets as vehicles *per se* rather than merely as adjuncts to aircraft performance. Early in 1944 the Army Ordnance Corps arranged to take over the sponsorship of the Laboratory which was then established as the Jet Propulsion Laboratory (JPL) with the mission of conducting a research and development programme on long range missiles, with von Kármán as its director. At the JPL were developed the Army's tactical rocket missiles Corporal and Sergeant, as well as the experimental Wac Corporal which, mounted as a second stage on top of a reconstructed German V-2, reached an altitude of 250 miles in 1949. This, for many years, remained the record height reached by a man-made device. During the 1950's, although the development of rocket missiles for the Army was the Laboratory's primary responsibility, the interests of many of its staff turned increasingly to research and development problems associated with the possible exploration of outer space above the earth's atmosphere. On 31st January 1958, with the Army Ballistic Missile Agency furnishing the booster and JPL the upper stages, was launched America's first earth satellite, Explorer I.

In view of these interests and activities of JPL it was natural that with the establishment of the National Aeronautics and Space Administration (NASA) the sponsorship of the Laboratory be transferred from the Army to the new Space Administration. This was accomplished in 1959 and the Laboratory was assigned by NASA the responsibility for unmanned exploration of the moon and planets. Its most spectacular accomplishment to date in support of this mission has been the Mariner II flight in which a highly instrumented spacecraft, on 14th December 1962, after a 109 day journey from the earth, passed within about 21 000 miles of the planet Venus and transmitted scientific data back to earth from all of its various sensors. Fortunately von Kármán was alive and well on that date and was able to share in the pride of achievement of the group which he had founded, and indeed created, nearly a quarter of a century earlier.

In 1944 began the second phase of what I have called von Kármán's "American" period. In that year General H. H. Arnold, Commanding General of the Army Air Forces, sensing the tremendous aeronautical developments on the horizon, asked von Kármán, who had become a United States citizen in 1936, to set up a programme which would ensure that the Air Force received the best possible scientific advice and direction. von Kármán promptly assembled an outstanding group from the leading scientists and engineers of the country, and thus the Scientific Advisory Group of the Army Air Force was created. With the establishment of the Department of the Air Force, this became the Air Force Scientific Advisory Board (SAB), of which von Kármán remained active chairman until 1954, when his title was changed to Chairman Emeritus.

The undertaking of this new responsibility required that von Kármán centre his activities in Washington rather than Pasadena, and he was accordingly granted a leave of absence from Caltech in the fall of 1944, becoming Professor Emeritus in 1949. For the next five or six years, although his scientific productivity remained as great as ever, and the number of his internationally famous lectures did not diminish, the major focus of his activities was the Air Force Scientific Advisory Group and Board. During 1945, von Kármán led teams of scientists from this group in on-the-spot studies of the German and Japanese aeronautical developments and advances during the war period. The immediate result of these studies was a small volume, "Where We Stand," comparing the American and foreign positions in a number of critical technical areas. This was followed by a collection of some thirty volumes under the general title "Towards New Horizons," which looked in detail into all the major scientific and technological fields which might have impacts on the future development of air power, and suggested procedures by which the Air Force might stimulate and utilise them most effectively. A few years later, another SAB study, the famous Ridenour-Doolittle Report, resulted in basic changes in the Air Force organisational structure which raised the research and development function to the highest levels of command and staff in the Air Force. This in turn made possible the effective implementation of many of the earlier recommendations stimulated by von Kármán. The establishment of the Air Force Institute of Technology for the training of technical officers and the construction of the tremendous laboratories of the Arnold Engineering Development Center at Tullahoma were also direct consequences of studies and recommendations by von Kármán and his group.

In 1951 he undertook the organisation of the NATO Advisory Group for Aeronautical Research and Development (AGARD) of which he was chairman until his death. Although he maintained his Pasadena home and his interest in domestic academic affairs, in the Air Force, and in Aerojet-General and his other industrial connections, the Paris headquarters of AGARD and the European activities associated with it were probably the dominent elements in his remaining years. Since these are being treated elsewhere no attempt will here be made to discuss them.

In reviewing and summarising the accomplishments and charactistics of this remarkable man, I am sure that he himself would have placed as most satisfying and significant his original and creative contributions to science and the fundamentals of technology. These I have not discussed in any detail since this has been done with great authority and discrimination by others*, and also because the record stands for all to witness and study in his "Collected Works" published on the occasion of his seventieth birthday in 1951.

Another unique characteristic which has been much in my mind during my struggles with this "labour of love", and which is illustrated by some of the examples of his activities which have been discussed, was his extraordinary power to create or profoundly influence an entire environment or area of activity by sensing in an uncanny way fields or projects which had a tremendous growth potential not apparent to others. The extraordinary change in engineering education in the United States over the past thirty years, particularly at the graduate level, certainly owes much to his influence. The modern technological U.S. Air Force stems from his concepts enunciated nearly twenty years ago. Great organisations like the Jet Propulsion Laboratory and the Aerojet-General Corporation exist largely because of his vision in creating the modest institutions from which they have developed. And, although not discussed here, I am sure that the present state of many fields of science and technology in the European community is largely the result of his post-war international activities. Thus his influence has been pervasive and profound on areas of a variety which is truly extraordinary for a man who was basically and primarily a creatively working scientist and engineer.

Finally, a word as to von Kármán's human characteristics. As I wrote on the occasion of his sixtieth birthday: "Those of us who have had the privilege of knowing and working with him intimately will always cherish the memory of the evenings in his home, when, surrounded by cultural objects collected on his travels over the world, the conversation turned to art, philosophy, politics, and other human affairs, and all were given a fresher and more profound significance." I was then thinking primarily of his colleagues, friends, and students in the Pasadena environment. However, hundreds, probably thousands of persons under other circumstances all over the world have experienced the same wit, charm, breadth, and depth which he brought to those who had the good fortune to be associated with him. Von Kármán was a truly universal man, whose like we shall not soon see again.

*In particular the articles by Hugh L. Dryden and G. I. Taylor listed in the partial bibliography of von Kármán tributes.

A Partial List of Tributes to Theodore von Kármán

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