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DYNAMICS OF EXOTHERMICITY

In Honor of Antoni Kazimierz Oppenheim

J. Ray Bowen

Combustion Science & Technology Book Series

Volume 2

DYNAMICS OF EXOTHERMICITY

In Honor of Antoni Kazimierz Oppenheim

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Antoni Kazimierz Oppenheim

Biography

Poland

Antoni Kazimierz "Tony" Oppenheim was born in Warsaw, Poland, during World War I on August 10, 1915. His father Tadeusz, an industrialist and ceramic engineer, built and managed a dozen brick and tile factories in various parts of Poland. His mother also came from an industrial family; her father founded and owned manufacturing plants for machine tools, weighing scales, and spring mattresses. Tony's elementary education was completed at home under the guidance of a French governess, as was then fashionable. Thus, the first language he learned was French. When he went to school at the age of nine, he was advised to forget French because his command of Polish might become impaired.

In 1924 he was admitted to the Gymnazjum of Wojciech Górski, graduating as valedictorian with a national "matura" certificate in January 1933. His ambition was to become an engineer like his father, who died in 1929 at the age of forty-nine. On the basis of his high grades, he could have gone directly to the University of Warsaw; instead, he took and passed a highly competitive entrance examination to the Technical University of Warsaw (Politechnika Warszawska).

England

With the collapse of Polish resistance after the outbreak of World War II, Tony began his odyssey from Poland to England. He traveled through Romania, Greece, France, Spain, and Portugal and arrived in

England in June 1940 after many adventures. He had served on a Polish ship, the S. S. Pulawski, as fourth engineer and on an English ship, the S. S. Hillary, as a steward—quite an achievement considering the fact that he did not know a word of English. He taught himself the language when he became a private in the artillery of the Polish army in Scotland.

In April 1942, on leave from the Polish army, Tony enrolled as a student at the City and Guilds College, the engineering branch of the then Imperial College of Science and Technology (today, Technology and Medicine) to complete requirements for his degree from Warsaw Technical University. A few months later he passed the final examination for the degree of Dipl. Inz. (equivalent to the German Dipl. Ing.) before an Anglo-Polish committee appointed by the Ministry of Education of the Polish government in exile. He did not receive a formal diploma until 1945; a decree had to be passed making it legal. Meanwhile he completed his studies for a Ph.D. at the University of London, in association with a D.I.C. (Diploma of Imperial College). Six months earlier, he had fallen in love with Lavinia "Min" Stephens of Overstone, Northampton, and they were married on July 18, 1945. During a momentous time in his life, Tony received four certificates within one year. He became a lecturer at Imperial College, teaching heat transfer and gas dynamics and, with his postgraduate students, built the first supersonic wind tunnel at the City and Guilds College. A D.Sc. degree was later conferred on him in 1976.

Research

Tony's career as a scientist was launched by Sir Owen Saunders, who—as a reader in the Mechanical Engineering Department at the City and Guilds College—was given responsibility for directing the studies of the five Polish servicemen who entered the college in April 1942. Saunders was co-author with Margaret Fishenden of the first textbook on heat transfer.

Saunders received a proposal from the Napier Engine Company to investigate the possibility of improving the performance of its piston engine used in Spitfires and Hurricanes, the famous British fighter planes. He assigned the proposal to Tony; and a few weeks later, Tony gave Saunders a manuscript with an analytical solution and computed results demonstrating how the total thrust—propeller plus exhaust jet—could be augmented with an estimate of the gain thereby obtainable.

Soon afterwards, Saunders called Tony to his office and confided that Napier proposed to make arrangements for single-cylinder tests to be run at the Royal Aircraft facilities in Farnborough, together with theoretical analyses to be carried out at the college under Saunders' direction. Saunders had agreed to accept the proposal contingent on Tony's performing the theoretical work. This task required that Tony be granted an indefinite leave of absence from the Polish army and be employed by Power Jets Limited, a government company formed under the directorship of Sir Roxby Cox to develop the gas turbine jet propulsion engine of Frank Whittle.

Immediately, arrangements were made by the British Liaison Office with the Polish army for his leave and appointment by Power Jets as a scientist with a salary equivalent to that of a captain in the English army, plus a bonus for service in the war zone—which London was at that time. He was working with George Hudson, an Australian engineer at Napier who became coordinator of the project, when he noticed an application form Hudson was completing for post-graduate study leading to a Ph.D. degree. Tony followed suit as did his Polish colleagues, who were employed as research assistants on various government-financed research projects. Thus, they became the first group of government-sponsored foreign research assistants in the United Kingdom.

Progress made on the thrust augmentation project was swift. In a few months, all the exhaust manifolds of fighter engines were replaced by individual nozzles, and the valve timing, adjusted for maximum total thrust. Top aircraft speed was thereby increased, giving British pilots an advantage over their German enemies. Modifications similar to those of the Napier Saber sleeve-valve were made for the Rolls Royce Merlin poppet-valve engine, affecting all the Spitfires and Hurricanes employed during World War II by the Royal Air Force.

Following this auspicious start, Tony conducted a study of secondary air mixing in the gas turbine combustion chamber that led to the development of the canister type that became the universally accepted standard. He demonstrated that nozzles are redundant for this purpose; holes are quite sufficient. Tony analyzed the operational mechanism of the pulsed jet engine that powered the German V1 flying bomb, and developed a systematic approach to one-dimensional gas dynamics that led to a paper with Joseph Kestin on the generalized entropy chart. Published by the Institution of Mechanical Engineers (IMechE), the paper won a prize for best technical article presented in 1948; it was the first refereed paper for the two men.

As a result of his work with the pulsed jet engine, Tony became the prime expert of this system in England. After the war, he was sent to Germany as a British intelligence objectives sub-committee officer, with a rank of wing commander, to solicit reports from the principal scientists and engineers involved in the development of the engine. He made two trips to Germany, visiting Volkenrode, the Herman Göring research facilities in the forest near Braunschweig, as well as Berlin, Munich, and Hamburg.

To obtain a value for the speed of the exothermic front that was required for the gas dynamic wave interaction analysis of the pulsed jet engine, Tony became involved in detonation phenomena—an effort that led him to the development of the theory of a double discontinuity system and its Q-curve, and the locus of states immediately behind it, for which he became well known at the Soviet Academy of Sciences in Russia. Although this concept was conceived in London, his first paper about it was presented at the Heat Transfer Institute when he was at Stanford University in California. His research also resulted in papers co-authored with Professor Lou London on the thermodynamic–dynamic analysis of free piston engines.

United States

In 1948 Tony applied to almost fifty universities in the United States for an assistant professor position. His first choice was Stanford because Stefan Timoshenko was there at that time. Stanford offered him an appointment as assistant professor, a position that entitled him to a non-quota visa. The university was then a "school on the farm" —long before the industrial park. This left him professionally somewhat stranded.

In 1950, upon the recommendation of Professor London with whom he was closely associated, he was appointed assistant professor at the University of California–Berkeley where he has been in residence for forty-five years. He also became a staff consultant at Shell Development Company, then in Emeryville, where he worked for a decade, one day a week and full time in the summer. Through his consultancy he gained an impressive amount of knowledge in physical chemistry. In 1954 he was promoted to associate professor and in 1958 to professor.

The studies Tony carried out at Berkeley included the development of the radiation network method; theory of heat transfer in free molecular flow; the vector polar methods for the analysis of interactions and intersections between gas dynamic wave fronts; the development

and structure of detonation fronts; blast wave theory; turbulent combustion; plasma jets; turbulent jet plumes; and controlled combustion in engines—a subject he finds particularly attractive today. The common denominator of all the studies conducted throughout his scientific career is his fascination with the dynamics of exothermic systems. Thus, he is finishing with what he started—a particular concern over the exothermic process of combustion and its immediate consequences in a piston engine. This time, however, it is with the addition of electronic, microprocessor, control of its execution and modeling of its intrinsic properties—the essential object of the control system—in terms of the fundamental components: 1. thermodynamics, 2. thermochemistry, and 3. aerodynamics.

ICDERS

Tony's scientific interests led him to organize the International Colloquium on Dynamics of Explosions and Reactive Systems (ICDERS). He had been an active participant in the International Symposium on Combustion since 1952. The 1966 symposium was held in Berkeley, with Ernie Starkman, later vice-president of General Motors, serving as the chairman of the organizing committee and Tony as vice-chairman.

The program committee of the symposium decided to emphasize the problem of air pollution which at the time, on the eve of the Muskie committee's introduction of anti-pollution legislation in the U.S. Congress, was fully warranted. To Tony's chagrin, however, the committee announced that to maintain this focus, full attention would be given to the thermochemical aspects of combustion rather than the fluid mechanical aspects. Tony expressed his regret, in view of the great excitement then prevailing over the breakthrough in understanding of the multi-front, cellular, structure of detonation fronts.

In response, Bernard Lewis, founder and chairman of the Combustion Symposia, met with Tony. Pointing out his concern over the problem of air pollution, Lewis suggested that fluid mechanic aspects of combustion and air pollution should be discussed at separate meetings. "Do us a favor," he added, "if you organize such meetings, hold them as far away as possible from the Combustion Symposium, so they will not be competitive."

A group of about twenty people stayed in Berkeley several days after the symposium for an impromptu get-together at the Richmond Field Station of the University, the site of Tony's detonation laboratory. There was no agenda, no formal papers; the participants simply shared

their enthusiasm over novel views of the detonation wave structure and development. Among the participants were: Numa Manson of the University of Poitiers; Rem Ivanovich Soloukhin of Akademgorodok-Novosibirsk; Heinz Wagner of Göttingen; and Louis Deffet, the head of the Belgian Detonics Laboratory near Brussels. When Tony recounted his conversation with Lewis, Deffet volunteered to organize what became known as the First International Colloquium on Dynamics of Explosions and Reactive Systems in Brussels that year. It is held biennially, alternating with the Combustion Symposium. For its first twenty years, Tony was executive co-chairman of the colloquia along with Numa Manson and Rem Soloukhin—a team that became known as the "troika." In 1975, Tony inaugurated the Manson Medal for outstanding contributions to the subject of the Colloquium; and in 1989, the Institute for Dynamics of Explosions and Reactive Systems introduced the Oppenheim Prize to be awarded for a significant theoretical contribution, and the Soloukhin Award as its experimental equivalent. In 1995, the fifteenth colloquium was held in Boulder, Colorado.

Travel

During the years he was on the faculty at the University of California, Tony took four sabbatical leaves in France. The first three were spent with Numa Manson at the Ecole National de Méchanique et Aérotechnique (ENSMA) in Poitiers. The fourth sabbatical, in 1985, was at the University of Marseilles, at the end of which Tony went to Göttingen, Germany, for several months and worked with Heinz Wagner, director of the Max Planck Institute for Physical Chemistry.

Scientific activities have occasioned numerous trips to France and Germany, as well as England, Italy, Belgium, Holland, Denmark, Switzerland, Austria and Spain. He has taken half a dozen trips to Poland and Russia as a guest of the Academy of Sciences; and he has visited Japan twice as a guest of the automotive industry, attending conferences at the research laboratories of many automobile manufacturers.

Honors

Dr. Oppenheim's awards include:

- Water Arbitration Prize of the Institution of Mechanical Engineers (GB) for "The Calculation of Compressible Fluid Flow," an outstanding technical paper, 1949;

- Fellow of the American Rocket Society (currently American Institute of Aeronautics and Astronautics), 1958;
- Member of the International Academy of Astronautics, 1963;
- Pendray Award of the American Institute of Aeronautics and Astronautics, "for outstanding contributions into the literature of the flight sciences," 1966;
- Member of the U. S. National Academy of Engineering, 1978;
- Numa Manson Medal of the International Colloquium on Dynamics of Explosions and Reactive Systems "for outstanding contributions to gasdynamics of explosions and reactive systems," 1981;
- Doctor *honoris causa* of the University of Poitiers, 1981;
- Dionizy Smolenski Medal of the Polish Academy of Sciences "for outstanding contributions towards advances in the knowledge of combustion and especially to dynamics of explosions and reactive systems," 1987;
- Berkeley Citation of the University of California, "the highest honor the campus bestows," 1988;
- Alfred C. Egerton Medal of The Combustion Institute "for distinguished, continuing, and encouraging contributions to the field of combustion," 1988;
- Doctor *honoris causa* of the Technical University of Warsaw, 1989;
- Honorary member of the American Society of Mechanical Engineers, 1989;
- Fellow of the Society of Automotive Engineers, 1991;
- Fellowship of Imperial College, 1995.

Societies, Government, Academic

His activities in professional and honorary societies and his work for the government include: membership in the American Society of Mechanical Engineers, American Institute of Aeronautics and Astronautics, Society for Automotive Engineers, Pi Tau Sigma, Tau Beta Pi, Sigma Xi, and the Athenaeum. He organized the Northern California Section of the American Rocket Society (ARS), served as its president in 1957 and was elected a member of the ARS National Board of Directors. The ARS merged with the American Institute of Aeronautics (AIA) to form the American Institute of Aeronautics and Astronautics (AIAA). From 1963 to 1968 he served on the NASA Research Advisory Committee on Fluid Mechanics. In 1972 and 1973 he was deputy editor of *Combustion and Flame*, the journal of the International Combustion Institute. In

1973 he was an associate editor of *Astronautica Acta*, the archival journal of the International Academy of Astronautics, and in 1974 he became editor-in-chief of *Acta Astronautica*, the continuation of this journal—a position he held until 1978. Between 1966 and 1983 he was the executive co-chairman of the International Committee on Dynamics of Explosions and Reactive Systems.

During his tenure as a professor of engineering at the University of California–Berkeley, he was also a visiting professor at the Sorbonne in the Senior Postgraduate Fellowship of the National Science Foundation, 1960–1961; a Miller Professor at the University of California–Berkeley, 1961–1962; and a Professor Associé at the University of Poitiers in 1973 and 1980.

In Conclusion

Tony has had the opportunity to become personally acquainted with great men of science—some of whom became his good friends. Included among them are first, his professors at the Technical University in Warsaw, Witold Pogorzelski, Maximilian Huber, Boghdan Stefanowski, and Stefan Neumark; then, in Scotland, Lord Ritchie Calder; and, at Imperial College, Sir Owen Saunders, Sir Alfred Egerton, and Sir Richard Southwell.

Completing this list are: Sir Harry Ricardo, Sir Geoffrey Taylor, Ludwig Prandtl, Adolf Busemann, Ernst Schmidt, Stefan Timoshenko, Frederick Terman, W. Frederick Durand, Alfred Tarski, Jerzy Neyman, Bernard Lewis, Theodore von Karman, Charles F. Kettering, Jakob Ackeret, Antonio Ferri, Luigi Crocco, Waclaw Olszak, Numa Manson, Rem Ivanovich Soloukhin, Wilhelm Jost, Klaus Oswatitsch, Yakov Borisovich Zel'dovich, Nikolai Nikolaevich Semenov, and Robert Maxwell. All of them are dead.

Among the living are many friends, in particular the editor and contributors to this volume.

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