NORBERT PETERS

1942–2015

Elected in 2002

"For contributions to the field of combustion modeling of turbulent flames and the development of chemical kinetic mechanisms for hydrocarbon oxidation."

BY FORMAN WILLIAMS

NORBERT PETERS, internationally recognized for his scientific and engineering contributions to advances in combustion and the fluid dynamics of reacting flows, died on July 4, 2015, at the age of 72. He was on vacation with his family in France when he experienced a sudden and severe heart attack; medical help came too late, and he died just two days later. He was seemingly in great health, lively, as sharp as ever, always full of ideas with big plans and in a good mood, and scientifically very active, not having lost any of his unbelievable energy and unstoppable scientific curiosity.

Norbert was born July 10, 1942, in Linz, Austria. He grew up in Dortmund, Germany, and finished high school there in 1962, having spent a year at a Florida high school in the United States. Before starting his university studies he worked for six months in a program of practical engineering in a German-Indian collaboration at the Rourkela steel plant in India. He studied mechanical engineering at the Technical University of Karlsruhe and received a "prediploma" in 1965. Subsequently, he continued his studies at the Technical University of Berlin and received a diploma in chemical engineering in 1968. He then studied economics in Paris (Bourse d'État Français during a year at the École Pratique des Hautes Études), where he also published a paper in 1969 on French poetry. He then returned to Berlin, where he received his PhD in 1971 for his work on chemically reacting boundary layers, completing his habilitation in 1975, on the topic of thermodynamics and the theory of chemically reacting flows. He advanced from a research assistant to an assistant professor in Berlin.

Norbert moved to RWTH Aachen University in 1976 as a professor in the Institute for Mechanics and became a full professor and director of the Institute for Applied Mechanics in 1987. Through his efforts, this institute became the Institut für Technische Verbrennung (the Institute for Combustion Technology). In 2001 he accepted a 1-year full-professor appointment at Stanford University but returned to Aachen after that. Although he retired as director of his institute in 2013 (succeeded by Heinz Pitsch), he continued his research and teaching in the institute unabated.

Norbert left a strong mark in combustion science with his seminal and foundational contributions to the theory of flames and flame asymptotics, reduced chemical kinetics and surrogate fuels, turbulent combustion, and the theory of turbulence. While his research included experiments, his focus was on theory and simulation. This research was always characterized by a deep physical understanding, engineering intuition, and the application of systematic mathematics-based analysis; his theoretical work was based on first principles and was always intended to result in practical models for simulation and analysis of real-world technical combustion systems. For example, he regularly attended meetings of the Society of Automotive Engineers and contributed discussions of technological advances.

He began his scientific career working on inert and reacting laminar and turbulent boundary layers during his PhD and habilitation. In the early 1970s he made the transition from reacting boundary layers to combustion, focusing on analysis and numerical simulations, and published an early paper on simulations of a methane-air diffusion flame with full chemistry as early as 1975. His paper on the theory of heterogeneous combustion instabilities of spherical particles at the Fifteenth International Combustion Symposium, published in 1975, forcefully demonstrated his unsurpassed abilities and preferences for extracting useful physical understanding by simplified mathematical methods, as is made clear from the comments on that paper, published in the volume. During that time, Norbert came across the work of Amable Liñán, especially the 1974 paper on the structure of diffusion flames, which deeply impressed Norbert and inspired some of his early asymptotics investigations, shaping his views on nonpremixed combustion. In 1980 he spent a sabbatical at the University of California, San Diego (UCSD), where he started a long-term collaboration with the UCSD combustion group and established important interactions with the fluid-mechanics faculty there. During that stay, he also developed the flamelet model for nonpremixed combustion, based on asymptotic analysis. Both the steady flamelet model and the representative interactive flamelet model for unsteady processes are now among the most used models for nonpremixed combustion in technological combustion systems.

Norbert was one of the few combustion scientists with substantial contributions in both turbulent combustion and chemical kinetics. After addressing, for example, NO formation in turbulent diffusion flames, in the 1980s he developed reduced mechanisms based on steady-state assumptions. While this technique had been known for a long time, it had never been applied to complex reaction systems, and Norbert developed a formalism for systematic reduction. This was an important, seminal step, since only these reduced mechanisms allowed for a systematic analysis of the structure of flames. The combination of the reduction techniques and asymptotic analysis led to one of Norbert's most influential contributions in combustion science, the analysis of the structure of laminar premixed methane-air flames. This work includes the two-, three-, and four-step reduced mechanisms for methane flames, which clearly reveal the layered flame structure and represent the first application of rate-ratio asymptotics, a new and innovative asymptotic approach having much greater versatility than the previously existing activation-energy asymptotics. For the first time, this led to a quantitative understanding of the structure of premixed flames based on multistep chemistry, and it engendered many later studies of premixed and diffusion flames based on similar techniques.

In the 1990s Norbert shifted his focus to premixed turbulent combustion, developing the theory for turbulence-flame interactions, models for the turbulent burning velocities, and numerical simulation techniques based on level sets, resulting in the so-called *G* equation, which he clarified and extended for use in turbulent-combustion modeling. One of his major findings was that flamelet-related behavior extends beyond the Klimov-Williams boundary into what he called the thin-reaction-zones regime, where reaction zones remain intact but turbulence affects the transport in preheat zones. Without his identification of this new regime, in which most practical applications reside, resulting now in continuing work, investigations of regime diagrams would have been severely restricted. In 2000 he published his book entitled *Turbulent Combustion*, the clearest and most complete existing exposition of that subject, treating diffusion and premixed as well as partially premixed flames—the book remains today the most authoritative source of information available on the topic. More recently, much of Norbert's original research was in turbulence theory, where he introduced the concept of dissipation elements that leads to a description of small-scale turbulence, and which again has been strongly influential for many researchers. While this work is very fundamental, it was his trademark to use this new theory in applications, for example, in predictions of mega-knock in turbocharged spark-ignition engines.

Norbert's scientific productivity was always on an upward swing. In total he generated on the order of 500 publications, and in 2010 alone he produced 26—an average of one every 2 weeks, which may be hard to comprehend. And he was in the midst of making further landmark advances, which his collaborators should be able to bring to fruition. He had an incredible excitement for science and was always ready to share his latest ideas, to a point where it was nearly impossible to talk with him and not know everything about his most recent theories. Norbert leaves us with many questions in turbulence and combustion science, for a number of which he would have provided unique answers characterized by his inimitable special way of thinking and tackling outstanding scientific challenges.

Norbert was a member of the North Rhine-Westphalian Academy of Sciences, and he received the Gottfried Wilhelm Leibniz Prize in 1990, a very prestigious research award in Germany, the Harry L. Hornig Memorial Award and the Arch T. Colwell Merit Award of the Society of Automotive Engineers, and the Zeldovich Gold Medal from the Combustion Institute in 2002. He also was awarded honorary doctoral degrees from the Université Libre de Bruxelles, the Technical University of Darmstadt, and ETH Zurich. He was a deputy editor of *Combustion and Flame* from 1982 to 1998, one of the founding editors for *Flow, Turbulence and Combustion* from 1998 to 2002, and an associate editor of the *Journal of Fluid Mechanics* from 2002 to 2007. He also served as a member of the board of directors of the Combustion Institute and organized several combustion summer schools in Aachen, and participated more recently in Princeton and European combustion summer schools. Earlier he had organized a series of International Workshops on Mathematics in Combustion, hosting the first in Aachen in 1979; he recognized the need to bring international mathematically oriented researchers together for exchanges of ideas to advance the science, which was notably effective through the eleventh workshop, held in 1991, after which international communications had progressed to a point at which these workshops were no longer needed and so were discontinued.

Besides being dedicated to science and engineering, for which he had marvelous abilities, Norbert was a very decent and considerate individual who was always fun to be with. He is survived by his wife, Cordula, their two young sons, and a daughter and two sons by his previous marriage. He will be greatly missed, both as a person and as an engineering scientist.