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In Memoriam

Professor Norbert Peters
(1942 - 2015)

Norbert Peters passed away on July 4, 2015 at the age of 72. His death was a shock for many of us who knew him well. He was seemingly in great health, lively, sharp as ever, and always full of ideas and big plans; he was in a good mood, scientifically very active, and he had not lost any of his unbelievable energy and unstoppable scientific curiosity. All of these attributes were in evidence to all who attended the Sheffield meeting in September 2014. However, what may have not been so evident was that Norbert was involved in significant work behind the scenes, assisting with the planning and organization of the meeting, and acting as a Guest Editor for this special issue. He volunteered to take on these roles without hesitation and provided significant help refining the scientific direction of the meeting. The paper in this special issue that Norbert co-authored with Jonas Boschung, Sylvain Laizet, and Christos Vassilicos exemplifies his collaborative approach, as well as his interests in the development of new fluid mechanics research techniques and their application in a range of flow domains.

Norbert as a scientist has greatly influenced fluid mechanics and combustion science with his seminal and foundational contributions to the theory of flames and flame asymptotics, chemical kinetics, 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 generally based on first principles, and it was always intended to result in practical models for simulation and analysis of real technical flow and 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 '80s 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 2-, 3-, and 4-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 multi-step chemistry, and it engendered many other later studies of premixed and diffusion flames based on applying similar techniques.

In the 1990's, Norbert developed 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 what he called the thin-reaction-zones regime, a previously unknown regime of premixed turbulent combustion, where reaction zones remain intact but turbulence affects the transport, a regime in which most practical applications reside. In 2000 he published his book entitled *Turbulent Combustion*, a clear, concise, and complete exposition of that subject, treating diffusion and premixed as well as partially premixed flames - a book that remains today a most authoritative source of information on the topic.

More recently, much of Norbert's original research has been in turbulence theory, where he introduced the concept of dissipation elements for the unique decomposition of scalar fields: A dissipation element consists of all points in space which are connected by gradient trajectories to the same minima and maxima. As dissipation elements are closely related to local scalar extrema, they provide a description of small-scale turbulence, including information on local gradients, which are important for dissipation. Statistics of the parameters describing the dissipation elements have been found to be partly universal and could hence be the basis for a multi-scale description of turbulence. While this work is very fundamental, it was Norbert's trademark to use this new theory in applications, for example, in predictions of mega-knock in turbo-charged spark-ignition engines. He then went on and expanded the concept of dissipation elements for the velocity field by looking at streamline segments, where the streamlines are separated into segments with positive and negative gradient of the velocity magnitude (see Norbert's contribution to this special issue for more information on this technique). Streamline segment statistics are found to be very similar for different flow types and might lead to new models in the future. Recently, Norbert was focusing on the explanation of the so called anomalous scaling of structure functions, the higher moments of the two-point velocity difference first introduced by Kolmogorov. His interest was to provide a rigorous scaling based on the Navier-Stokes equations. For this, he analyzed the transport equations both for the different order structure functions and for the source terms appearing in these equations. The resulting system of equations must contain the solutions and scaling parameters for structure functions of all orders, hence also information on anomalous scaling.

Norbert 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. He 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.

Besides being dedicated to science, 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, two young sons, and a daughter and two sons by his previous marriage.
He will be greatly missed, both as a person and as a scientist.

Heinz Pitsch
RWTH Aachen University
Email address: h.pitsch@itv.rwth-aachen.de

Chris Keylock
University of Sheffield
Email address: c.keylock@sheffield.ac.uk