

Preface

Many significant developments in fire science have emanated from New Jersey. Howard Emmons, the father of US fire research, was born in Morristown and went to school at Stevens Institute of Technology in Jersey City; Dick Magee (flame spread measurements) also taught at Stevens; John deRis (opposed flow flame spread) lived in Englewood; Gerry Faeth (turbulent flames) was raised in Teaneck; Frank Steward (porous media flame spread) and Forman Williams (modeling) hailed from New Brunswick; Bob Altenkirch (microgravity flame spread) is President of New Jersey Institute of Technology (formerly NCE); the FAA has their key fire laboratory for aircraft safety in Atlantic City (Gus Sarkos, Dick Hill and Rich Lyon); Yogesh Jaluria (natural convection in fires) teaches at Rutgers; Glenn Corbett lives in Waldwick and teaches fire science at John Jay College; Jim Milke (fire protection) was raised in Cherry Hill; Irv Glassman (liquid flames spread) taught at Princeton University, inspiring many to enter fire research; Fred Dryer (kinetics), Thor Eklund (aircraft), Carlos Fernandez-Pello (flame spread), Takashi Kashiwagi (material flammability), Tom Ohlemiller (smoldering), Kozo Saito (liquid flame spread), Bill Sirignano (numerical modeling) and more; even Chiang L. Tien (radiation in fire), the former Chancellor of the University of California (Berkeley), graduated from Princeton and almost proceeded to join NYU Mechanical Engineering before being attracted to Berkeley.

I was born in Passaic, New Jersey, studied at NCE and graduated with a PhD in Mechanical Engineering from NYU. I guess something in the water made me want to write this book.

The motivation and style of this text has been shaped by my education. My training at NYU was focused on the theoretical thermal sciences with no emphasis on combustion. My mentor, W. K. Mueller, fostered careful analysis and a rigor in derivations that is needed to reveal a true understanding of the subject. That understanding is necessary to permit a proper application of the subject. Without that understanding, a subject is only utilized by using formulas or, today, computer programs. I have tried to bring that careful and complete approach to this text. It will emphasize the basics of the subject of fire, and the presentation is not intended to be a comprehensive handbook on the subject. Theory at the level of partial differential equations is avoided in favor of a treatment based on control volumes having uniform properties. Therefore, at most, only ordinary differential equations are formulated. However, a theoretical approach to fire is not sufficient for the solution of problems. Theory cannot allow solutions to phenomena in this complex field, but it does establish a basis for experimental correlations. Indeed, the term *fire modeling*

applies more to the formulas that have developed from experimental correlations than from theoretical principles alone. It will be seen, throughout this text, and particularly in Chapter 12 on scaling, that theory strengthens and generalizes experimental correlations. Until computers are powerful enough to solve the basic known equations that apply to fire with appropriate data, we will have to rely on this empirical approach. However, as in other complex fields, correlations refined and built upon with theoretical understanding are invaluable engineering problem-solving tools.

I honed my knowledge of fire by having the opportunity to be part of the National Bureau of Standards, NBS (now the National Institute of Standards and Technology, NIST), in an era of discovery for fire that began in the early 1970s. In 1974 the Center for Fire Research (CFR) was established under John Lyons at NBS, joining three programs and establishing a model for a nation's investment in fire research. That combined program, influenced by the attention to standards from Alex Robertson and Irwin Benjamin, innovations such as oxygen consumption calorimetry (Bill Parker, C. Huggett and V. Babauskas) and others, brought a change in the way fire was looked at. Many had thought that science did not apply; fire was too complex, or rules were essential enough. At that same time, the NSF RANN program for fire research at \$2 million was led by Ralph Long who had joined the CFR. Professors Hoyt Hottel and Howard Emmons had long championed the need for fire research in the US and now in the 1970s it was coming to fruition. In addition, the Factory Mutual Research Corporation (FMRC), influenced by Emmons, formed a basic research group, first under John Rockett, nearly by Philip Thomas and mostly carried out by Ray Friedman. The FM fire program became a model of engineering science for fire, bringing such stalwarts as G. Heskestad, J. deRis, A. Tewarson and more to the field.

The CFR staff numbered close to 120 at its peak and administered then over \$4 million in grants to external programs. The President's National Commission on Fire Prevention and Control published its report of findings, *America Burning* (1973), which gave a mandate for fire research and improved technology for the fire service. This time of plenty in the 1970s gave us the foundation and legacy to allow me to write this book. My association at CFR with H. Baum, T. Kashiwagi, M. Harkleroad, B. McCaffrey, H. Nelson, W. Parker, J. Raines, W. Rinkinen and K. Steckler all importantly added to my learning experience. The interaction with distinguished academics in the country from some of the leading institutions, and the pleasure to engage visiting scientists – X. Bodart, M. Curtat, Y. Hasemi, M. Kokkala, T. Tanaka, H. Takeda and K. Saito – all brought something to me. This was the climate at CFR and it was not unique to me; it was the way it was for those who were there.

In the beginning, we at CFR reached out to learn and set an appropriate course. Understanding fire was 'in', and consumer safety was 'politically correct'. Interactions with those that knew more were encouraged. John Lyons arranged contact with the Japanese through the auspices of the US–Japan Panel on Natural Resources (UJNR). Visits with the distinguished program at the Fire Research Station (FRS) in the UK were made. The FRS was established after World War II and at its peak in the 1960s under Dennis Lawson had Philip H. Thomas (modeling) and David Rasbash (suppression) leading its two divisions. Their collective works were an example and an essential starting point to us all. Japan had long been involved in the science of fire. One only had to experience the devastation to its people and economy from the 1923 Tokyo earthquake

to have a sensitivity to fire safety. That program gave us S. Yokoi (plumes), K. Kawagoe (vent flows), T. Hirano (flame spread) and many more. The UJNR program of exchange in fire that continued for about the next 25 years became a stimulus for researchers in both countries. The decade of 1975 to about 1985 produced a renaissance in fire science.

An intersection of people, government support and international exchange brought fire research to a level of productive understanding and practical use. This book was inspired and influenced by that experience and the collective accomplishments of those that took part. For that experience I am grateful and indebted. I hope my style of presentation will properly represent those that made this development possible.

This book is intended as a senior level or graduate text following introductory courses in thermodynamics, fluid mechanics, and heat and mass transfer. Students need general calculus with a working knowledge of elementary ordinary differential equations. I believe the presentation in this text is unique in that it is the first fire text to emphasize combustion aspects and to demonstrate the continuity of the subject matter for fire as a discipline. It builds from chemical thermodynamics and the control volume approach to establish the connection between premixed and diffusion flames in the fire growth sequence. It culminates in the system dynamics of compartment fires without embracing the full details of zone models. Those details can be found in the text *Enclosure Fire Dynamics* by B. Karlsson and J. G. Quintiere. The current text was influenced by the pioneering work of Dougal Drysdale, *An Introduction to Fire Dynamics*, as that framed the structure of my course in that subject over the last 20 years. It is intended as a pedagogical exposition designed to give the student the ability to look beneath the engineering formulas. In arriving at the key engineering results, sometimes an extensive equation development is used. Hopefully some students may find this development useful, while others might find it distracting. Also the text is not a comprehensive representation of the literature, but will cite key contributions as illustrative or essential for the course development.

I am indebted to many for inspiration and support in the preparation of this text, but the tangible support came from a few. Professor Kristian Hertz was kind enough to offer me sabbatical support for three months in 1999 when I began to formally write the chapters of this text at the Denmark Technical University (DTU). That time also marked the initiation of the MS degree program in fire engineering at the DTU to provide the needed technical infrastructure to support Denmark's legislation on performance codes for fire safety. Hopefully, this book will help to support educational programs such as that at the DTU, although other engineering disciplines might also benefit by adding a fire safety element to their curriculum. The typing of this text was made tedious by the addition of equation series designed to give the student the process of theoretical developments. For that effort, I am grateful to Stephanie Smith for sacrificing her personal time to type this manuscript. Also, Kate Stewart stepped in at the last minute to add help to the typing, especially with the problems and many illustrations. Finally, the Foundation of the Society of Fire Protection Engineering provided some needed financial support to complete the process. Hopefully this text will benefit their members. I would be remiss if I did not acknowledge the students who suffered through early incomplete versions, and tedious renditions on the blackboard. I thank those students offering corrections and encouragement; and a special appreciation to my graduate students who augmented my thinking and gave me

illustrative results for the text. Lastly, I am especially indebted to John L. Bryan for believing in me enough to give me an opportunity to teach and to join a special Department in 1990.

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