Preface

This book deals with solving mathematically the unsteady flame propagation equations. New original mathematical methods for solving complex nonlinear equations and investigating their properties are presented. Pole solutions for flame front propagation are developed. Premixed flames and filtration combustion have remarkable properties: the complex nonlinear integro-differential equations for these problems have exact analytical solutions described by the motion of poles in a complex plane. Instead of complex equations, a finite set of ordinary differential equations is applied. These solutions help to investigate analytically and numerically properties of the flame front propagation equations.

The author solves mathematically unsteady flame propagation equations, describes new original methods for solving complex nonlinear equations and investigating their properties, and addresses open problems existing in the field of flame front propagation.

The theories (Laplacian growth, filtration combustion, premixed flame propagation) described in the book have many engineering and scientific applications, for example: investigation of burning in Ia supernovae; designing root modules and control of transport processes in space greenhouses; NASA Announces Microgravity Combustion Science Research Grants in Filtration Combustion for Microgravity Applications in 2002; Microgravity Fluids and Combustion Research was carried out at NASA Glenn Research Center; Microgravity smolder spread over a thin cellulosic fuel was studied with Radiative Ignition and Transition to Spread Investigation (RITSI) apparatus in the Glovebox Facility on the STS-75 USMP-3 space shuttle mission.

In Chap. 1 we describe basic concepts and problems in flame front propagation; give a review of many relevant papers and books in this field.

In Chap. 2 we investigate the problem of flame propagation. This problem is studied as an example of unstable fronts that wrinkle on many scales. The analytic tool of pole expansion in the complex plane is employed to address the interaction of the unstable growth process with random initial conditions and perturbations. We argue that the effect of random noise is immense and that it can never be neglected in sufficiently large systems. We present simulations that lead to scaling laws for the velocity and acceleration of the front as a function of the system size and the level of noise, and analytic arguments that explain these results in terms of the noisy pole dynamics. We give a detailed description of excess number of poles in system, number of poles that appear in the system in unit of time, lifetime of pole. It allows us to understand dependence of the system parameters on noise.

In Chap. 3 we consider flame front propagation in channel geometries. The steady-state solution in this problem is space dependent, and therefore the linear stability analysis is described by a partial integro-differential equation with a space-dependent coefficient. Accordingly, it involves complicated eigenfunctions. We show that the analysis can be performed to required detail using a finite order dynamical system in terms of the dynamics of singularities in the complex plane, yielding detailed understanding of the physics of the eigenfunctions and eigenvalues.

In Chap. 4 flame propagation is used as a prototypical example of expanding fronts that wrinkle without limit in radial geometries, but reach a simple shape in channel geometry. We show that the relevant scaling laws that govern the radial growth can be inferred once the simpler channel geometry is understood in detail. In radial geometries (in contrast to channel geometries) the effect of external noise is crucial in accelerating and wrinkling the fronts. Nevertheless, once the interrelations between system size, velocity of propagation and noise level are understood in channel geometry, the scaling laws for radial growth follow.

In Chap. 5 Filtration Combustion is described by Laplacian growth without surface tension. These equations have elegant analytical solutions that replace the complex integro-differential motion equations by simple differential equations of pole motion in a complex plane. The main problem with such a solution is the existence of finite time singularities. To prevent such singularities, nonzero surface tension is usually used. However, nonzero surface tension does not exist in filtration combustion, and this destroys the analytical solutions. However, a more elegant approach exists for solving the problem. First, we can introduce a small amount of pole noise to the system. Second, for regularization of the problem, we throw out all new poles that can produce a finite time singularity. It can be strictly proved that the asymptotic solution for such a system is a single finger. Moreover, the qualitative consideration demonstrates that a finger with 1/2 of the channel width is statistically stable. Therefore, all properties of such a solution are exactly the same as those of the solution with nonzero surface tension under numerical noise. The solution of the Saffman-Taylor problem without surface tension is similar to the solution for the equation of cellular flames in the case of the combustion of gas mixtures.

In Chap. 6 we give a short summary of the book ideas.

Moscow Oleg Kupervasser

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