COMBUSTION WAVES AND FRONTS IN FLOWS

Combustion is a fascinating phenomenon coupling complex chemistry to transport mechanisms and nonlinear fluid dynamics. This book provides an up-to-date and comprehensive presentation of the nonlinear dynamics of combustion waves and other non-equilibrium energetic systems. The major advances in this field have resulted from analytical studies of simplified models performed in close relation with carefully controlled laboratory experiments. The key to understanding the complex phenomena is a systematic reduction of the complexity of the basic equations.

Focusing on this fundamental approach, the book is split into three parts. Part I provides physical insights for physics-oriented readers, Part II presents detailed technical analysis using perturbation methods for theoreticians and Part III recalls the necessary background knowledge in physics, chemistry and fluid dynamics. This structure makes the content accessible to newcomers to the physics of unstable fronts in flows, whilst also offering advanced material for scientists who wish to improve their knowledge.

PAUL CLAVIN is Professor Emeritus at Aix-Marseille Université and is an honorary member of the Institut Universitaire de France (Chair of Mécanique Physique 1993–2004). In 1995 he founded a renowned research institute, the Institut de Recherche sur les Phénomènes Hors Équilibre (IRPHE), and has received major awards from the Société Française de Physique (Plumey 1988), French Academy of Sciences (Grand Prix 1995) and the Combustion Institute (Zeldovich Gold Medal, San Francisco, August 2014).

GEOFF SEARBY is retired Director of Research at the Institut de Recherche sur les Phénomènes Hors Équilibre (IRPHE). He is a renowned specialist of the physics of thermo-acoustic instabilities in combustion chambers and rocket motors, and his experiments have made major contributions to the understanding of the dynamics of flame fronts. In 2004 he obtained a major award from the French Academy of Sciences.

COMBUSTION WAVES AND FRONTS IN FLOWS

Flames, shocks, detonations, ablation fronts and explosion of stars

PAUL CLAVIN
Aix Marseille Université, France

GEOFF SEARBY
Formerly of the Centre National de la Recherche Scientifique (CNRS), Marseille, France

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

Shaftesbury Road, Cambridge CB2 8EA, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of Cambridge University Press & Assessment,
a department of the University of Cambridge.

We share the University's mission to contribute to society through the pursuit of
education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107098688

First published 2016

A catalogue record for this publication is available from the British Library

Library of Congress Cataloging-in-Publication data
Names: Clavin, Paul, author. | Searby, Geoff, 1945– author.
Title: Combustion waves and fronts in flows : flames, shocks, detonations,
ablation fronts and explosion of stars / Paul Clavin (Aix Marseille
Université, France), Geoff Searby (Formerly Centre National de la
Recherche Scientifique (CNRS), Marseille, France).
Description: Cambridge, United Kingdom ; New York, NY : Cambridge University
Press, 2016. | ©2016 | Includes bibliographical references and index.
Identifiers: LCCN 2016011752| ISBN 9781107098688 (hardback ; alk. paper) |
ISBN 1107098688 (hardback ; alk. paper)
Subjects: LCSH: Combustion. | Waves. | Chemical reactions. | Dynamics. |
Nonlinear theories. | Fluid mechanics.
Classification: LCC QD516 .C57 2016 | DDC 541/.361–dc23 LC record available at
http://lccn.loc.gov/2016011752

ISBN 978-1-107-09868-8 Hardback

Contents

Cambridge University Press & Assessment
978-1-107-09868-8 — Combustion Waves and Fronts in Flows
Flames, Shocks, Detonations, Ablation Fronts and Explosion of Stars
Paul Clavin , Geoff Searby
Frontmatter
More Information

Preface

Combustion is a fascinating phenomenon coupling complex chemistry to transport mechanisms and nonlinear fluid dynamics. The combustion of reactive mixtures, frozen far from chemical equilibrium, is an irreversible process in which the approach to equilibrium proceeds through the propagation of nonlinear waves in the form of sharp fronts exhibiting complex geometrical forms. These waves were discovered in the nineteenth century, but the understanding of their structure and dynamics is quite recent. In gaseous mixtures, the rate of chemical heat release is small compared with the rate of elastic collisions, so that combustion is described by the macroscopic equations for the conservation of mass, species, momentum and energy, assuming local equilibrium (except for the inner structure of shock waves). The full system of equations is complicated and is not useful to describe each of the elementary phenomena, separate from the others. Even the coupling of two phenomena, as for example a quasi-isobaric flame and acoustic waves, is represented by simplified equations. The major advances have resulted from analytical studies of simplified models performed in close relation to carefully controlled laboratory experiments. A systematic reduction of the complexity of the basic equations, validated by the confrontation with experiments, is the key to understanding. It is also the most difficult step. The analytical and numerical solutions of simplified equations of relevant models can be completed in a second step by direct numerical simulations of a more detailed system of equations.

The book is written along this line and attention is focused on fundamental aspects. It is meant to be a survey of the nonlinear dynamics of combustion waves, which now constitute a mature scientific field. A similar approach is used to improve the understanding of other types of waves such as ablation fonts in inertial confinement fusion. The approach is also tentatively extended to the explosion of stars at the end of their lifetime, the famous supernovae. A large variety of phenomena is presented. The purpose is to provide a wide view of the physical problems involved in different domains that can benefit from cross-fertilisation. The most important scientific results are reported, ranging from the pioneering works of the last century to the advanced research of the last decade.

The book is aimed at both newcomers to the physics of unstable fronts in flows and scientists who wish to improve their knowledge. It is self-contained and can also be used as a textbook by students. The background in physics, chemistry and fluid mechanics is given in the last part as complements. Physical insights into the phenomena occupy half of the book and are presented first. Detailed analytical studies are developed in the second part and no prerequisites in applied mathematics are required concerning the perturbation methods that are used (multiple-scale and asymptotic analyses).

This book would never have been written without 40 years of activity in our research group, interacting closely with our friends and colleagues, Louis Boyer, Bruno Denet, Alain Pocheau, Joel Quinard and Emmanuel Villermaux. We are also grateful to our close friends and outstanding theoretical physicists for fruitful collaboration and enlightening discussions of great help to improve our understanding of nonlinear problems related to combustion, particularly Guy Joulin, Amable Liñan, Yves Pomeau, Grisha Sivashinsky and Forman A. Williams.