Preface

Over the past several years, there has been an explosion of interest in analyzing flow barriers in fluids. This has been driven by a variety of reasons. One is a concern for our environment: the spreading of pollutants (such as the Deepwater Horizon oil spill in the Gulf of Mexico in 2010) is known to be greatly influenced by the location and movement of such flow barriers, which impede the transport of pollutants. Another is an increasingly urgent desire to understand geophysical processes in an era of rapid climate change. For example, the transport of ozone across the Antarctic Circumpolar Vortex boundary, or of heat across oceanic or atmospheric vortex boundaries, has a profound influence on our planet. How these boundaries (i.e., barriers) evolve with time, and the amount of transport which occurs across such evolving boundaries, has impact on the earth's weather systems. A third reason for flow barriers to become important recently is the ongoing biotechnological revolution, in which fluidic devices at the micro- and nanoscales are being developed for a variety of applications, including DNA synthesis, drug delivery and monitoring, lab-on-a-chip technology, and biofluidic cells. The tiny dimensions of these devices ensure that turbulent mixing is suppressed, and in cases in which the efficient mixing of fluids is required—to expedite a chemical reaction between a sample and a reagent, for example—improving transport across a fluid interface (i.e., a barrier once again) is needed.

Flow barriers and the transport associated with them are currently being studied in many ways, including observationally at the geophysical scale, experimentally at the laboratory scale, computationally from either numerically generated velocity fields or from observational data, or theoretically through the development of analytical methods to define, understand, and quantify flow barriers. This book is a contribution to the last of these approaches, based on insights I have built up over many years of working in this area. While much of the development is theoretical in nature, the inspiration for the relevant theory arises directly from applied questions, which I have made an effort to motivate throughout. With this in mind, I have chosen to begin the book with an introductory chapter which positions the material within the large research area of fluid barriers, associated with oceanography, atmospheric science, engineering, physics, and of course mathematics. Chapters 2 and 3, which respectively develop the Melnikov approach to characterizing flow barriers as stable/unstable manifolds for nonautonomous flows and assess the transport across such flow barriers, are at the heart of the book. In the next chapters, these methods are modified and applied toward optimizing transport across barriers (Chapter 4) and controlling the barriers (Chapter 5), inspired primarily by applications in microfluidics.

Parts of this book are fairly technical, and it is not necessary for a reader to digest every section to be able to proceed to the next. I provide a brief picture of the chapter dependencies in Figure 1 to enable a reader to choose a pathway through the book. For example, a reader seeking to access the optimization chapter needs only Sections

3.1–3.4 from Chapter 3. To assist the reader, I have identified sections which I call "fundamental" as being Sections 1.1–1.6, 2.1–2.4, and 3.1–3.4. The "later" sections in each chapter are often self-contained in the sense that while they do depend on the fundamental earlier sections, they are independent of the (nonfundamental) other sections. Readers interested in microfluids may find Chapters 4 and 5 as the main goals to reach, while those interested in geophysics might be interested in the transport determinations in Sections 3.4 and 3.8. Optimizing and controlling geophysical flows is of course highly challenging, but perhaps aspects of Chapters 4 and 5 will be useful to geophysics in the future.

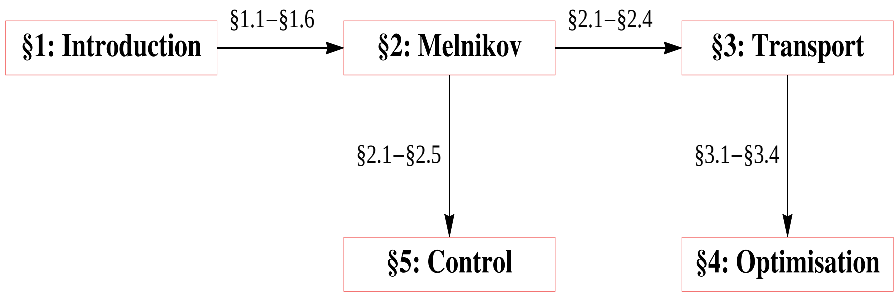

Figure 1. *Chapter and section dependencies. The "fundamental" sections are Sections 1.1–1.6, 2.1–2.4, and 3.1–3.4, which are needed to access the remaining sections of the book.*

The many theoretical and applied areas which are touched on by the material in this book necessitate my providing an extensive and current bibliography, which I hope will benefit the reader wishing to track down more information on a particular aspect of interest. While dealing comprehensively with the details of the theory, I have also strived to provide geometric intuition for the results in all situations. The theory I discuss is motivated by applied problems primarily in fluid mechanics, and many standard examples, such as the double-gyre, the Duffing oscillator, the Taylor-Green flow, the Kelvin-Stuart cat's-eyes flow, and the Hadamard-Rybczynski droplet flow, are used in a recurring fashion to illustrate the theory developed, with many other examples also provided. As such, I trust that this book will provide an applications-inspired theoretical approach to dynamical systems methods applied to fluid dynamics in which the geometrical intuition is emphasized throughout. The connections I provide to many branches of research will I hope inspire additional extensions in the future.

SIAM's publications staff and several anonymous reviewers of the original manuscript provided invaluable advice in expanding the book's scope, detecting errors, and improving readability. Finally, I wish to thank my wife, Rasika, for her unending support, critical perusal of the manuscript, and good humor while I was writing this book, which, inevitably, turned out to take much more time than anticipated. This book is dedicated to her.

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