Preface to the First Edition

The aims of this book are to bring together the most recent results on the behavior of turbulent boundary layers at supersonic speed and to present some conclusions regarding our present understanding of these flows. By doing so, we hope to give the reader a general introduction to the field, whether they be students or practicing research engineers and scientists, and to help provide a basis for future work in this area. Most textbooks on turbulence or boundary layers contain some background on turbulent boundary layers in supersonic flow, but the information is usually rather cursory, or it is out of date. Only one, by Kutateladze and Leont'ev (1964), addresses the specific issue of turbulent boundary layers in compressible gases, but it focuses largely on solutions of the integral equations of motion, and it is not much concerned with the turbulence itself. Some aspects of turbulence are addressed by Cousteix (1989), but only one chapter is devoted to this topic, and his review, although very useful, is not exhaustive. The scope of the present book is considerably wider in that we are concerned with physical descriptions of turbulent shear-layer behavior, and the response of the mean flow and turbulence to a wide variety of perturbations. For example, in addition to turbulent mixing layers, we will consider boundary layers on flat plates, with and without pressure gradient, on curved walls, and the interaction of boundary layers with shock waves, in two and three dimensions.

Considerable progress has recently been made in developing our understanding of such flows. This progress has largely been driven by experimental work, although numerical simulations of compressible flows have also made significant contributions. Except for the most recent work, the data are readily available from the compilations edited by Fernholz and Finley (1976, 1980, 1981), Fernholz et al. (1989) and Settles and Dodson (1991), and the quantity of relatively new experimental information presented there is impressive. The recent focus on hypersonic flight has also stimulated extensive computational work, and the reviews by Délery and Marvin (1986) and Lele (1994) give a good impression of what is currently possible. Despite these efforts, the full matrix of possibilities defined by Mach number, Reynolds number, pressure gradient, heat transfer, surface condition, and flow geometry is still very sparsely populated and a great deal of further work needs to be done. One clear message from the failure of the most recent hypersonic flight initiative is that to make substantial progress in improving the understanding of high-speed turbulent flows we need a concerted, broadly based effort in experimental and computational research.

Presently, we are beginning to form a reasonably coherent picture of high-speed boundary layer behavior, particularly in terms of the structure of turbulence, and its response to pressure gradients and its interaction with shock waves. It seemed to us that this was an opportune time to try to bring together the efforts of different research groups, and to present the sum of our present knowledge as a unified picture. We recognize that the details of the picture may change as new insights become available, and we hope that this volume may serve to stimulate such insights.

Our primary focus is on how the effects of compressibility influence turbulent shear-layer behavior, with a particular emphasis on boundary layers. We have restricted ourselves to boundary layers where the freestream is supersonic, and transonic and hypersonic flows are not considered in detail. Without being too precise, we are generally dealing with boundary layers where the freestream Mach number is greater than 1.5, and less than 6. The low Mach number limit is set to reduce the complexities introduced by having large regions of mixed subsonic and supersonic flow, and the high Mach number limit is set to avoid the presence of real gas and low density effects. Moreover, we will restrict ourselves to fully turbulent flows and the problems of stability and transition at high speed will not be discussed. These problems are numerous and important, and they deserve a separate treatment.

Even within these bounds, there exists a rich field of experience, and in Chapter 1 we have tried to give an overview of the complexities that occur in compressible turbulent flows. The equations of motion are discussed in Chapter 2, and the mean equations for turbulent flow are given in Chapter 3, primarily to develop some useful scaling and order-of-magnitude arguments. As further background, a number of concepts important to the understanding of compressible turbulence are introduced in Chapter 4, with a particular emphasis on the development of rapid distortion approximations. Morkovin's hypothesis and Reynolds Analogies are discussed in Chapter 5. Chapter 6 is concerned with the behavior of mixing layers, and Chapters 7 and 8, respectively, deal with the mean flow and turbulence structure of zero pressure gradient boundary layers. The behavior of more complex flows, with pressure gradients and surface curvature, is considered in Chapter 9, where we also illustrate how rapid distortion approximations can give some useful insight into the behavior of these flows. When the flow is compressed rapidly, shock waves appear, and shock boundary layer interactions in two- and three-dimensional flows are the subject of Chapter 10, where we discuss the role of shock wave unsteadiness and the consequences of separation. Throughout the book, we have tried to emphasize some of the possibilities for future development, including guidelines for future experiments, the prospects for computational work, turbulence modeling, and rapid distortion approaches. Chapters 2 and 3, and to some extent Chapters 4, 5, and 7, treat some basic elements in the description of compressible turbulent flows. Although much of this work is available elsewhere, we felt it would be useful to address the elementary properties of these flows in a systematic manner, especially for newcomers to the field. The other chapters are more specialized, and are probably more suitable for readers who have some previous expertise.

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