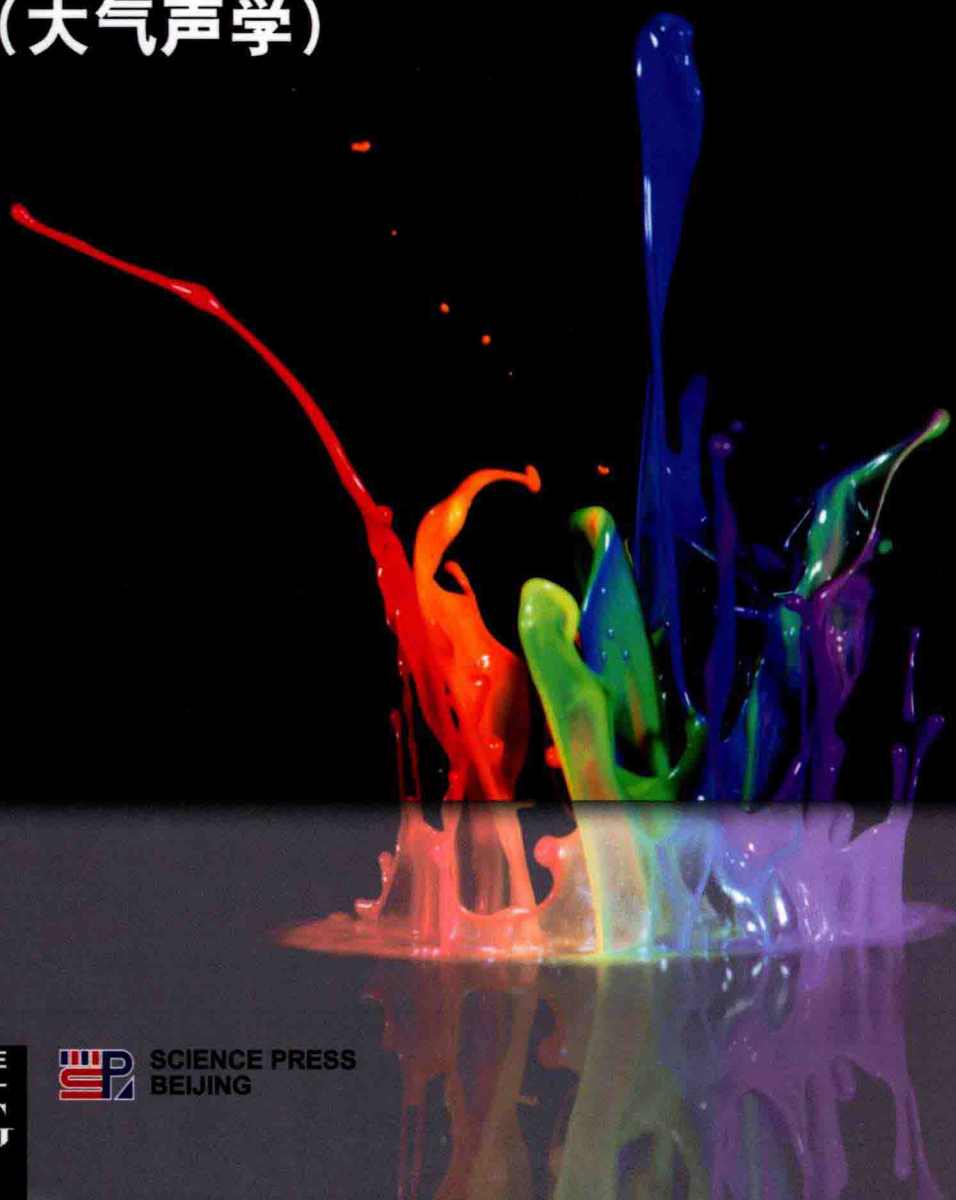


Xunren Yang (Hsun Jen Yang)

ATMOSPHERIC ACOUSTICS

(大气声学)



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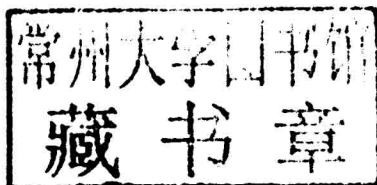


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Atmospheric Acoustics

(大气声学)

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In Memory of My Mother
Via this book I seemed to hear her voice from the
Heaven

Preface

It is an inconceivable phenomenon that atmospheric acoustics, a discipline with such importance and long history had no monograph contributed to the field. This situation was not changed until 1997, when the first Chinese edition of Atmospheric Acoustics was published by Science Press. Hereafter, quite a few publishers expressed their interests in publishing its English version. Some “sample chapters” were reviewed and approved by expert-group and earned favourable comments. However, all projects miscarried purely due to the duty-derelection of some staff members there.

The second Chinese edition was published in 2007, with many new material been added. Some supplements, mainly in Chapter 10, were completed by Prof. Chen Yu at Tsinghua University. Couple of years later Dr. Bao Ming and my other young colleagues at The Institute of Acoustics, Chinese Academy of Sciences, suggested to restart the plan to publish an English version. Subsequently a publishing agreement was reached between the German publishing house De Gruyter and the Science Press.

This English version is based on the translation from the 2nd Chinese edition. Thanks to Zhao Nan, Ao Lin and Lin Jianheng for their translating drafts of the corresponding parts of this book.

Though there is no other book subjected to atmospheric acoustics till now, several similar publications existed indeed. Some related contents from these publications were utilized in writing this book, which are indicated at the right places separately.

The foundation for writing this book is basing on the author’s thirty-year experiences of researching atmospheric acoustics. The main aim of this book is to give the readers fundamental understandings concerning this very field. Though both theoretical and experimental materials have been presented, the former is dominant.

Xunren Yang
June 1st, 2015, Beijing

Foreword

Acoustics is a branch of physics with distinctive features. Firstly, it is one of the earliest developed branches in the physical sciences. In ancient times, whether in China, the Orient, Greece or in the occident, people understood the basic concepts of “sound” without diversions—to this point, acoustics is much more fortunate as compared to its companion discipline, optics. As a systematic sub-branch, its fundamental theory was developed to a quite perfect level by the middle of the 19th century, the “golden age” of classical physics. Secondly, acoustics is also the most active branch of physics today. Owing to the interlocking connections with so many fields, involving not only almost all of the main fundamental natural sciences (including life sciences) but also some humanities studies, many corresponding frontiers have been formed. Presently the number of sub-branches exceeds twenty, and additional sub-branches continuously grow with each passing year. Such a position is very rare in other branches of physics, and indeed even in the whole scope of natural sciences.

Among the sub-branches of acoustics, atmospheric acoustics turns out to be one of the most ancient and most important ones. As early as the beginning of the 18th century, acoustics was preliminarily formed as a discipline, and in the 19th century a lot of important fundamental phenomena had been studied, with the corresponding theories reaching a quite mature level. Thereafter, research work in this field proceeded uninterrupted, and great developments have been achieved in recent years. As the material on which humanity relies for its existence, and as one of the three vast media (along with the oceans and the earth’s crust) through which sound waves can propagate through, the atmosphere embodies numerous and varied wave phenomena. Humanity would do well to develop a thorough understanding of the basic nature of wave phenomena, which are closely related to many other natural phenomena and human activities. Thus it is argued that atmospheric acoustics is not only an important fundamental discipline, but also an important applied one.

However, what puzzles people is the fact that there was not a monograph or book devoted to such an important and peculiar discipline in the worldwide literature until now. There are two books of a similar nature, i.e., T. Beer’s *Atmospheric Waves* and E. E. Gossard & W. H. Hooke’s *Waves in the Atmosphere* (references [32] and [208] in this book). As shown by their names, however, they do not belong solely to the category of atmospheric acoustics. Needless to say any monograph, or

even general texts regarding acoustics with contents concerning atmospheric acoustics, are scarcely found. A. D. Pierce's *Acoustics: An Introduction to Its Physical Principles and Applications* (reference [60]) is perhaps the only exception. Besides, there are merely a couple of reviews, such as the paper *Advances in Atmospheric Acoustics* written by E. H. Brown & F. F. Hall, Jr. (reference [2]) plus items in some encyclopedias of science and technology, such as those written by H. E. Bass (reference [180]) and by E. H. Brown, respectively. All the above-mentioned material have been of great instructive help in the writing of this book, and the content in several sections and/or chapters are quoted directly from them.

In view of the above-mentioned situations, to publish a high-level monograph of atmospheric acoustics thus becomes a task of top priority for filling in the gaps in this very field. This book is nothing but an attempt for "casting a brick to attract jade"¹⁾. The aim is to provide readers with a systematic and rigorous "general picture" that reflects the highest academic level in this field, and is as up-to-date and as is fully possible. Consideration has been given to both theory and practice, though particular emphasis has been placed on the former. Special attention was paid to the discussion of fundamental concepts and the treatment of physical processes. As for mathematical derivations, we did not want to go too far, as the crux of the matter is pointing out the "origin and development" rather than rigidly adhering to "rigorousness".

In this book, essential descriptions of structural properties and acoustical behaviors of the atmosphere as a propagation medium of sound waves will be given first. Then, based on fundamental equations of fluid dynamics, combined with the practice of the medium atmosphere, a series of acoustic wave processes such as reflection, refraction, scattering, diffraction and absorption are discussed. Therein, alternative methods of wave acoustics and geometric acoustics are used in accordance with different situations. Regarding the discussion of influences from the earth's gravity field and rotation, we transit from "classical atmospheric acoustics" to "modern atmospheric acoustics". In order to make the discussion more coherent and more comprehensive, some fundamental acoustic relations were derived in detail. Just through the description of these processes, an understanding of atmospheric acoustics is established. In the chapter on "computational atmospheric acoustics", some further treatment of basic problems in atmospheric acoustics are supplemented by extending several traditional computational methods to this field. Finally, in the chapter on "remote sensing for the atmosphere", the application aspects of atmo-

1) This is a "word-for-word" translation of a famous Chinese idiom (usually a self-deprecating remark), whose actual implication is "to issue some opinion, suggestion or writings of lower level in order to inspire the corresponding ones of higher level". Thus, the author expects that a book of much higher level will be contributed to this field in the near future.

spheric acoustics were discussed from the angle of the “inverse problem”.

The references directly related to the text are arranged in serial numbers listed at the end of the book, while those only involving secondary problems (e.g., the derivation of a less important equation) are indicated in the corresponding footnotes.

The non-linear phenomena are inevitable in atmospheric acoustics, the fundamental problems in this aspects has been discussed comprehensively in Chapter 9. The problems concerning sound sources in atmospheric acoustics are also arousing general concern and some related advances are given in last chapter.

Xunren Yang
Jan, 2007

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Chapter 1

Introduction

1.1 Scope of the discipline and historical review

The earth's atmosphere, on which humanity relies for its existence, is ubiquitously flooded with acoustic waves of various hues. These waves include both audible sound and infrasound, where the latter embodies a series stretching from "true" infrasonic waves to "acoustic gravity waves", "internal gravity waves" down to "planetary waves" and "atmospheric tides", whose behaviors becoming increasingly different to acoustic waves under ordinary concepts. As for ultrasonic waves, they occupy very less important position in atmospheric acoustics due to their rapid attenuation in the air. Atmospheric acoustics is a discipline that studies the generation, propagation (including the processes of reflection, refraction, diffraction, scattering and attenuation), reception and the various effects and applications of these waves. It is one of the most ancient and most important sub-branches in acoustics.

Obviously, the behavior of acoustic waves in the atmosphere depend strongly on the properties of the atmosphere itself. The variations of atmospheric properties in both space and time present very complicated relationships. The interaction of acoustic waves with this complex atmosphere, as well as with the variety of ground surfaces, requires a wide spectrum of physical phenomena be understood in order to completely describe a specific sound field.

Although the atmosphere consists of air, there exists qualitative differences between acoustic phenomena in the atmosphere and the "airborne-acoustic" phenomena at small scales, especially in closed spaces. This difference represents two distinct features of atmospheric acoustics. At first, it is a fundamental discipline involving the influences on acoustic waves from the variations and non-homogeneity of the earth's atmosphere, which are difficult to forecast; secondly, it is an application of acoustic waves to probe the atmosphere. The second feature can be considered as the "inverse problem" of the first one, and in a certain sense this also expresses the notion that atmospheric acoustics can also be regarded as a sub-branch of atmospheric physics. Of course, due to the difference between the main disciplines subordinated to, the focus of attention and the set-up system for these two sub-branches are quite