AIAA JOURNAL
Vol. 42, No. 10, October 2004

Book Reviews

BOOK REVIEWS published in this section reflect the opinions of their individual authors. They are not necessarily the opinions of the Editors of this journal or of AIAA.

Hypersonic Inviscid Flow

W. D. Hayes and R. F. Probstein, Dover Publications, New York, 2004, 602 pp., $39.95

This is a Dover paperback edition of the book entitled *Hypersonic Flow Theory: Inviscid Flow*, published by Academic Press 38 years ago. This edition is dedicated to the memory of Wallace D. Hayes (1918–2001). The earlier (1966) version of this book[1] was conceived as the first of a two-volume treatise, to be followed by a monograph on the corresponding problems of viscous flows. It would have represented a fuller extension of a still earlier monograph by the same authors, *Hypersonic Flow Theory*,[2] which was the first text addressing the problem of hypersonic boundary layers and the importance of inviscid–viscous interactions, but the project was not continued, as explained in the preface to the present edition. Indeed, research and development in the high-temperature and rarefied aspects of hypersonic gasdynamics and heat transfer problems since the 1966 edition have become so huge in volume and diverse in direction that to write a quality text elucidating the entire field could be an unrewarding, if not impossible, task.

Whereas the gap in question has been filled in part by several relatively recent texts and review papers,[3–6] the present volume should be a welcome resource for analytically inclined newcomers who would like to acquire some of the fundamental concepts and ideas applicable to hypersonic-flow analyses and design and also to many seniors in the field, who (like the reviewer himself) may be happy to have his own desk copy of Hayes and Probstein once again. Undoubtedly, both the 1959 and 1966 editions were thoroughly reviewed not long after their publications; nevertheless, the book's content, read from this paperback version in today's perspective, can add a valuable historical perspective to the work that reflects the undertone of research activities during the dynamic Sputnik–Apollo era.

Of the seven book chapters, Small Disturbance Theory (Chapter 2) and Thin Shock Layer Theory (Chapter 5) represent the book's strength as a monograph on hypersonic flow theory and a work of scholarship in breadth and depth. Two other chapters are more closely associated with thin shock layer development, namely, Newtonian Theory (Chapter 3) and Constant Density Solutions (Chapter 4). Chapters 6 and 7 cover the then-current works on numerical methods for blunt-body flow and other methods for locally supersonic flows.

Efforts were made throughout the book to make clear the assumptions in the physical models and of the approximations used in mathematical analyses. Although a formal asymptotic approach to perturbation analyses was not followed throughout, the parametric requirements in distinguishing several important classes of inviscid hypersonic flows (basic hypersonic, slender body, strong shock, small density, and linearization) were emphasized. Additional assumptions, or specializations, such as the constant-density approximation and the constant stream-tube approximation, were introduced to make the analyses more amenable to applications and to help in elucidating certain intricate flowfield behaviors, to which the thin-shock layer theory cannot readily contribute. In an effort to cover more ground, analyses and results based on ad hoc assumptions were also included for comparison studies.

Many fundamental aspects of hypersonic small-disturbance theory and thin shock-layer theory were the original contributions by Wallace Hayes. Whereas excellent definitive analyses of problems in the small-disturbance and shock-layer flows can be found in Chernyi's[7] and other earlier texts for plane and axisymmetric cases, the works in Chapters 2 and 5 treat asymmetric flows, conical flows, and three-dimensional flows more generally, carrying out, in some cases, novel extensions far beyond available results. Noteworthy among these are an extended analytical treatise on self-similar solutions in gasdynamics together with their application to hypersonic slender-body flows, a comprehensive exposition of Lighthill's[8] ideal dissociating gas model and nonequilibrium shock-layer flows, the review and extension of Cole and Brainerd's shock-layer theory for a blunt-faced body,[9] the elucidation of Freeman's shock-layer detachment analysis,[10] and a detailed discussion of the vortical layer on asymmetrical pointed bodies after Ferri.[11]

Prominent among the blunt-body calculation methods and results covered in Chapter 5 are Dorodnitsyn's method of integral relations,[12] the time-dependent calculations employing equations in conservation form by Goudunov[13] and Lax and Wendroff,[14] the inverse method via complex characteristics applied to Garabedian and Lieberstein's work,[15] and the inverse approach via analytical extension by van Dyke.[16] The need for a greater computation fluid dynamics involvement in hypersonics is quite evident here.

A great merit in theoretical aerodynamics lies in the fruitful exploitation of parametric limits, which has led to powerful aerodynamic concepts in analyses and designs, as exemplified in the tradition of Prandtl's lifting line and boundary layer theories.[17] This mode of research is prevalent throughout Chapters 1–5. The asymptotic nature of such treatments must, however, address the problem of nonuniform validity that may arise, as is familiar to students of singular-perturbation analyses. Whereas treatments given to the breakdown issues of the blast-wave analogy, shock-layer detachment and reattachment, and vortical layer and other singularities represent the book's successful treatments of the nonuniformity problems, fundamental issues still remain and may not be considered as being satisfactorily resolved. Outstanding among these, in this writer's opinion, is the theoretical question: To what degree of approximation can one relate the nose-bluntness effect in a steady hypersonic (infinite Mach number) flow to the blast-wave analogy in the (Hayes) small-disturbance theory? This question was dealt with more directly in the analysis by Guiraud et al.[18]

An erratum on an error in Eq. (2.6.21b) of page 62 and in three equations that follow is added on page xix of the present edition. It is essential to recognize that these errors cannot invalidate the self-similar solution system on pp. 55–103, except for the unrealistic cases with cylindrical and spherical symmetry, which involve a finite impulse given at the origin.

In closing, apart from its value as a classic of high quality in theoretical aerodynamics, the present paperback version should prove to be a handy desk copy to practitioners in aerodynamics. In reading over the section headings and the list of references, senior aerodynamicists may find in Hayes and Probstein many fond memories of those exciting days four decades ago.

References

[1]Hayes, W. D., and Probstein, R. F., *Hypersonic Flow Theory: Volume I, Inviscid Flows*, Academic Press, New York, 1966.

[2]Hayes, W. D., and Probstein, R. F., *Hypersonic Flow Theory*, Academic Press, New York, 1959.

[3]Anderson, J. D., *Hypersonic and High Temperature Gas Dynamics*, McGraw–Hill, New York, 1989.

[4]Park, C., *Nonequilibrium Hypersonic Aerothermodynamics*, Wiley, New York, 1990.

[5]Cheng, H. K., "Perspectives on Hypersonic Viscous Flow Research," *Annual Review of Fluid Mechanics*, Vol. 25, 1993, pp. 455–484.

[6]Cheng, H. K., and Emanuel, G., "Perspective on Hypersonic Nonequilibrium Flow," *AIAA Journal*, Vol. 33, No. 3, 1995, pp. 385–400.

[7]Chernyi, G. G., *Introduction to Hypersonic Flow*, Fizmatgiz, Moscow, 1959, English translation by R. F. Probstein, Academic Press, New York, 1961.

[8]Lighthill, M. J., "Dynamics of a Dissociating Gas: Part I, Equilibrium Flow," *Journal of Fluid Mechanics*, Vol. 2, 1957, pp. 1–32.

[9]Cole, J. D., and Brainerd, J. J., "Slender Wings at High Angles of Attack in Hypersonic Flows," *Hypersonic Flow Research*, edited by F. R. Riddell, Academic Press, New York, 1962, pp. 321–343.

[10]Freeman, N. C., "Asymptotic Solution in Hypersonic Flow: An Approach to Second-Order Solutions of Hypersonic Small-Disturbance Theory," *Research Frontiers in Fluid Dynamics*, edited by R. J. Seeger and G. Temple, Wiley-Interscience, New York, 1965, pp. 284–307.

[11]Ferri, A., "Supersonic Flow Around Circular Cones at Angles of Attack," NACA Rept. 1045, 1951; superseding NACA Tech. Notes 2236, 1950.

[12]Dorodnitsyn, A. A., "Numerical Methods in Gas Dynamics," *Archives of Mechanics [Archiwum Mechaniki Stosowanej] of the Polish Academy of Sciences*, Vol. 12, 1960, pp. 13–27.

[13]Godunov, S. K., "A Difference Method for the Numerical Calculation of Discontinuous Solutions of Hydrodynamics," *Matematicheskii Sbornik*, Vol. 47, 1959, pp. 271–306.

[14]Lax, P. D., and Wendroff, B., "System of Conservation Law," *Communications in Pure and Applied Mathematics*, Vol. 13, 1960, pp. 217–237.

[15]Garabedian, P. R., and Lieberstein, H. M., "On Numerical Calculation of Detached Bow Shock Waves in Hypersonic Flow," *Journal of Aero/Space Sciences*, Vol. 25, 1958, pp. 109–118.

[16]van Dyke, M. D., "The Supersonic Blunt-Body Problem—Review and Extension," *Journal of Aero/Space Sciences*, Vol. 25, 1958, pp. 485–496; reprinted in *AIAA Journal*, Vol. 41, No. 7A, 2003, pp. 265–276.

[17]Prandtl, L., "Uber Flussigkeitsbewegung bei sehr kleiner Reibung," Proc. 3rd International Congress of Mathematicians, Heidelberg, Germany, 1904, pp. 484–491.

[18]Guiraud, J. P., Vallee, D., and Zolver, R., "Bluntness Effects in Hypersonic Small Disturbance Theory," *Basic Developments in Fluid Dynamics*, Vol. 1, edited by M. Holt, Academic Press, New York, 1965, pp. 127–247.

H. K. Cheng
University of Southern California and HKC Research