Book Review

Nonequilibrium Hypersonic Aerothermodynamics

Chul Park, Wiley, New York, 1990, 358 pp., $59.95.

This book is written to be both a graduate textbook and a reference book for an active research and development engineer working in the field of aerothermodynamics. The author assumes that the student would have at least a semester of Vincenti and Kruger[1] before a course from this text, and the rapid coverage of the fundamentals of the physical and chemical problem areas is consistent with this assumption. However, the book supplies an excellent review of these fundamentals, and the explanations are very clear. The first five of the nine chapters each contain an appropriate set of problems for review. In addition the book includes the tables, graphs, and references so valuable to the researcher, along with reviews of the relevant results of several flight programs. The book draws heavily on the published work of the author and his colleagues at NASA Ames Research Center, which provides an important updating of calculated results now available for nonequilibrium problems.

The first chapter provides a very brief review of the fundamentals of atomic and molecular energy states, and some previous background in these matters would be expected of the student using this as a text. The chapter concludes with tables of energy levels, partition functions, and parameters for curve fits to equilibrium constants, all for air species. The usual spectroscopic values are augmented by the extensive ab initio calculations that have been performed at NASA Ames Research Center, providing values for high-lying levels that are important at high temperatures ($>$ 10,000 K). Inclusion of these high-lying levels yields appreciably larger partition functions at very high temperatures for low-density calculations, but does not have an appreciable effect on the equilibrium constants at orbital re-entry temperatures ($<$8000 K).

The second chapter provides a succinct review of the state of knowledge of internal atomic and molecular transitions, and again constitutes very rapid coverage for a student without appreciable background. However, the presentation is clear and concise, and is well referenced. Theory and experimental results on the ionization and electronic excitation of hydrogen, oxygen, and nitrogen atoms by electrons are reviewed, and a table at the end of the chapter provides rates between states of oxygen and nitrogen atoms, taken from Park's NEQAIR program.[2] Vibrational and rotational relaxation, experiments, and theory, are reviewed, along with the recent use by NASA Ames Research Center of extensive classical-trajectory calculations for collisions of atoms and molecules, and the resultant excitation. A brief discussion of the calculation of vibrational relaxation[3] for a rotationless nitrogen molecule, using all possible vibrational transitions, is compared with earlier harmonic-oscillator calculations. This problem is discussed in much greater detail in Chapter 3, where it is pointed out that the restriction of no rotation could critically affect the results. The electron excitation of atomic and molecular electronic states is also covered in Chapter 3, in which the master equation for relaxation is derived.

In Chapter 4, simplified equations for the internal energy of atoms and molecules are developed, and specific expressions are written for all the species one can expect to encounter in high-temperature air. Results calculated with these equations are then compared with recent computer calculations made by Jaffe[4] without approximations, so that the range of validity of the simplified equations is demonstrated. This chapter also provides a derivation of the conservation equations (including diffusion), the chemical rate equations, and the wall boundary conditions for a dissociated flow. These relations are then used in Chapter 5 to obtain the flow equations, and the remainder of that chapter is devoted to a discussion of numerical techniques for solution of the aerochemical flow equations. A broad overview of different techniques is given without much detail. The chapter ends with some warnings of bad things that can happen in nonequilibrium numerical calculations.

In Chapter 6, all manner of equilibrium and nonequilibrium gasdynamic phenomena are reviewed: normal shock waves, radiation, expanding flows, and base flows and wakes, including effects of wall catalysis. The magnitude of the nonequilibrium effects is displayed for each case. Because of the broadness of the scope, little detail is presented. A table identifies the major molecular radiation transitions. Chapter 7 provides an overview of the various experimental devices used to study high-temperature nonequilibrium effects.

Chapter 8 attempts to review and compare the nonequilibrium experimental work that has been performed over the past 30 years, including shock-tube and shock-tunnel data, ballistic-range data, flight data, and data obtained from various techniques for studying charge-exchange (116 references). Such a critical review, of course, reflects the author's preferences, and not everyone will agree with his interpretations or with his conclusions. However, it is a very helpful review for the beginner, and a useful summary for the serious researcher. The chapter concludes with a table of recommended chemical reaction rates for air reactions, most of which utilize the geometric mean temperature introduced by Park.[5] The last chapter provides a primer on the subject of gas-solid interactions in recognition of the aerothermodynamic problems associated with evaporation, surface catalysis, and oxidation.

In summary, this text will be of great use to students and researchers of nonequilibrium aerothermodynamics because of the broad range of information that is covered, as well as for the detail that is presented in some portions. There are an above-average number of typographical errors in this first edition, but few that will cause confusion for the reader.

[1]Vincenti, W. G., and Kruger, C. H., *Introduction to Physical Gas Dynamics*, Wiley, New York, 1965.

[2]Park, C., "Nonequilibrium Air Radiation (NEQAIR) Program: User's Manual," NASA TM-86707, July 1985.

[3]Sharma, S. P., Huo, W., and Park, C., "The Rate Parameters for Coupled Vibration-Dissociation in Generalized SSH Theory," AIAA Paper 88-2714, 1988.

[4]Jaffe, R. L., "The Calculation of High-Temperature Equilibrium and Nonequilibrium Specific Heat Data for N_2, O_2, and NO," AIAA Paper 87-1633, June 1987.

[5]Park, C., "Assessment of Two-Temperature Kinetic Model for Dissociation and Weakly Ionizing Nitrogen," *Journal of Thermophysics and Heat Transfer*, Vol. 3, No. 3, 1989, pp. 233-244.

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