

Modeling and Computation of Boundary-Layer Flows – Solutions Manual and Computer Programs

by T. Cebeci and J. Cousteix (Springer-Verlag, Berlin, Germany, 2001, 288 pp.) Euro 94,95 hardcover, ISBN 3-540-41227-1

Almost a century is lying between Prandtl's introduction of the boundary layer in 1904 and the publication of the book at hand. Actually, this book is the solutions manual belonging to a textbook on the modeling and calculation of boundary-layer flows by the same authors [1]; the latter book has been reviewed in this journal some time ago [2]. The subject has been developed in a European tradition, with focal points in Germany, the UK, France and the Netherlands. One of the authors, Jean Cousteix, is an exponent of the European school, with his main roots at ONERA in France. The other author, Old-World-born Tuncer Cebeci, has been an advocate of the boundary-layer methodology in the New World through his employment at McDonnell Douglas aircraft company.

In the USA, Cebeci was an exception within the number-crunching Navier–Stokes community that was stimulated by the presence of more powerful computers than available in Europe. With less 'computational intelligence' within reach, the European engineers had to rely more on their 'human intelligence'.

The boundary-layer concept divides the flow field in interacting viscous and inviscid regions, where in each region a flow model is applied that is as simple as possible. As a result, the interacting boundary-layer approach is about two orders of magnitude cheaper than a brute-force Navier–Stokes approach. Even today, with so powerful computers available, in three-dimensional aerodynamic design studies the viscous-inviscid interaction methods act as 'working horse', with Navier–Stokes calculations being used mainly for analysis purposes. To be fair, the thin boundary-layer concept cannot always be applied: thick extended areas of separated flow do require Navier–Stokes modeling, with an adequate description of turbulence (the ultimate challenge for CFD).

The accompanying textbook [1] gives an extensive treatment of the modeling and calculation of incompressible boundary-layer flows. Subjects covered include laminar, transitional and turbulent boundary layers for steady and unsteady two- and three-dimensional incompressible flows. Maybe unexpected, there is ample attention to boundary-layer modeling in the pre-computer era. For instance, a reader will encounter a lengthy description of Pohlhausen's method to compute boundary layers, a subject that was deleted from the latest (revised) version of Schlichting's 'Boundary Layer Theory' [3].

Of course, most attention is devoted to modern boundary-layer modeling, be it in integral form (e.g., traditionals like Thwaites' method for laminar flow and Head's entrainment method for turbulent flow) or in differential form (including an elaborate discussion of turbulence models). Also, a number of chapters are devoted to the prediction of laminar-turbulent transition. Here the long-year collaboration with the late Keith Stewartson (University College London) is highly visible. The final chapter addresses the viscous-inviscid coupling between boundary layer and inviscid flow, and the algorithms that have been designed to prevent the numerical problems at a point of flow separation (Goldstein's singularity).

Many details are presented on the numerical algorithms for solving the equations of motion, mostly based on Keller's box scheme. The solutions manual contains programs (implemented in Fortran) to calculate inviscid as well as viscous flow along 2D airfoils and 3D wings and spheroids. Output examples (useful for verification purpose) are included. Most of these programs are available on an accompanying diskette: the instructions are easy to follow and I found all programs to be working fine.

There is an abundance of exercises that can be used as classroom material; the solutions to these exercises can be found in the solutions manual. Both authors have used this material in their university lectures, and this is clearly visible in the presentation. The exercises are worked out in full detail: derivations of equations are given with 'classroom patience' and when useful additional theoretical background is provided.

The textbook [1] contains all ingredients required to tackle real-life viscous aerodynamic flow problems. As such, it is unique in its kind, and mandatory reading for users of 'poor men's Navier–Stokes' as interactive boundary-layer theory is sometimes called. The only other single source of information with a large scope on simulating boundary layers that I know of is an extensive review paper by Lock and Williams [4]. But one should not really compare the two, since the latter paper concentrates on boundary-layer modeling, and in particular includes compressible flow, whereas the subject of the current review is much more numerical in nature. For scientists and engineers interested in further reading on boundary-layer CFD, Cebeci has published a follow-up book that begins where the book at hand ends [5].

Interactive boundary-layer theory can be considered the pioneering example of what is nowadays called partitioned modeling (current applications include, e.g., multi-body systems and fluid-structure interaction); Goldstein's singularity makes it even an extremely tough example. Throughout the years I have experienced that the coupling algorithms developed for interactive boundary layers can be readily translated into other applications. Therefore, I would advise anyone working in an area of partitioned modeling to have a look at viscous-inviscid interaction methods.

References

- [1] T. Cebeci, J. Cousteix, *Modeling and Computation of Boundary-Layer Flows*, Springer-Verlag, Berlin, 1999.
- [2] H.H. Fernholz, Review of ‘Modeling and Computation of Boundary-Layer Flows’, *Eur. J. Mech. B* 18 (1999) 1103–1104.
- [3] H. Schlichting, K. Gersten, *Boundary Layer Theory*, 8th revised edition, Springer-Verlag, Berlin, 2000.
- [4] R.C. Lock, B.R. Williams, Viscous-inviscid interaction in external aerodynamics, *Prog. Aerospace Sci.* 24 (1987) 51–171.
- [5] T. Cebeci, *An Engineering Approach to the Calculation of Aerodynamic Flows*, Springer-Verlag, Berlin, 1999.

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Kinetic Theory and Fluid Dynamics

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Foundation of Fluid Dynamics on Kinetic Theory has been a classical and challenging problem in a recent past. This book gives an impressive overview of the formidable amount of work done by the author on such a fundamental subject, emphasizing the need of kinetic theory for taking the molecular structure of matter into account, for explaining phenomena occurring in the continuum limit, and, in one word, for understanding fluid dynamics itself. An essential role in the deduction of fluid dynamic equations is played by asymptotic expansions with respect to the Knudsen number, a small parameter representing the ratio of the microscopic to the macroscopic scale, inasmuch as the fluid dynamic limit corresponds exactly to the limit when the Knudsen number tends to zero. The book deals mainly with time-independent boundary value problems in a general domain, where boundary conditions include both cases of a regular solid boundary and of a boundary made by the condensed phase of the gas (evaporation–condensation problems). Emphasis of the book, and one of its most interesting features, is on inadequacy of classical fluid dynamics in correctly describing the continuum limit, due to the occurrence of what are named nowadays “ghost effects”, as the author himself has been calling them in the past few years. Indeed, Prof. Sone has been one of the main contributors to the discovery and analysis of such effects. Methodology is generally an asymptotic approach based on Hilbert-type expansions in power series of the Knudsen number, with proper corrections and different recipes according to the physical nature of the specific problems. Of course the limiting equations cannot satisfy kinetic boundary conditions, so that one must perform the analysis of the Knudsen layer, which provides both the boundary conditions for the fluid-dynamic-type equations and the Knudsen layer corrections.

After Chapter 1, which presents Introduction, background, and state of the art, and Chapter 2, which reviews basic results from kinetic theory, Chapter 3 applies the asymptotic algorithm to the linearized Boltzmann equation for very slight deviations from an uniform equilibrium state at rest. In Chapter 4, Mach and Knudsen numbers are both small, to mean deviation from an uniform equilibrium state at rest of the same order of the Knudsen number, and the full Boltzmann equation is required. This is a good transition to the following chapter, where removing the assumption that the variation of gas temperature is limited to a small quantity, of the order of the Knudsen number, shows appearance of a ghost effect. The asymptotic procedure of Chapter 5 exhibits in fact the new feature that the leading term of the temperature field is determined together with the next order term of the velocity, which has an important bearing on detecting the incompleteness of classical gas dynamics. In other words, the leading order Maxwellian is characterized by a temperature parameter not determined by Euler equations. Thus, when the Knudsen number goes to zero, the behavior of the gas in the continuum limit cannot be studied solely with the quantities of the continuum world. Effects of this kind do appear in real world, as shown for instance by the so called thermal-stress flow. So, the temperature field of a gas at rest in the continuum limit is not described correctly by the classical heat conduction equation for wide and important classes of problems. From a different point of view, an error of the order of the Knudsen number in the boundary velocity introduces errors of order unity in the temperature. Several concrete examples with comparison to accurate numerical solutions from the kinetic level are provided. In Chapter 6 the analysis is extended to the case of a flow around a simple material boundary when the Mach number is not small, and then the Reynolds number becomes very large, giving rise to a viscous boundary layer outside the Knudsen layer, which requires an “ad hoc” asymptotic expansion. Chapter 7 deals with the same situation as before, but for a flow of a gas around its condensed phase, with different types of boundary conditions.