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REVIEWS

Vortical Solutions of the Conical Euler Equations. By K. G. POWELL. Vieweg, 1990. 285 pp. £45.20.

Most of the volumes in the series to which this book belongs contain proceedings of conferences or workshops. This one is a monograph based on the author's doctoral studies at MIT. The vortical solutions of the title are for inviscid supersonic flow over delta wings with sharp leading edges, and they display the leading-edge separations which would be expected. The conical Euler equations of the title are obtained from the equations of continuous inviscid flow. Conical similarity is exploited to eliminate one spatial variable and then the equations are discretized on a structured quadrangular mesh by the finite-volume technique in its cell-vertex form. So-called 'artificial viscosity' terms are added, actually second- and fourth-difference smoothing terms, to allow the capture of shock waves and suppress chequer-board instability. The main novelty of the method, enhancing its efficiency, is the use of embedded grids, so that two levels of subdivision of the basic grid can be used where the solution varies rapidly. The steady-state solution is obtained by integrating in time until the residual is reduced by a factor of at least 10^4. The text, including the mathematical expressions, is laid out generously and clearly. Typos are few and cause no difficulty. There are over 200 figures, mostly computer-generated, which convey the rich structure of the flow fields calculated. A listing of the main FORTRAN computer code occupies 76 pages. After a brief introduction Professor Powell derives his equations and sets out his solution procedure with care and completeness.

For me, publication of the book is justified by the results presented. The vortex cores, with up to three shocks radiating from them, take on shapes ranging between the near-circular, the flattened ellipse and the near-triangular. The flow variables displayed include cross-flow (conical) streamlines, flow angularity, static and total pressure, and cross-flow (conical) and radial Mach numbers, as contour plots and surface values. Comparison is made with vapour-screen and wing-tuft observations, and with measured static and Pitot pressures. Internal consistency is shown by comparison of results on different grids and with different levels of smoothing.

Two features of numerical solutions of the Euler equations which predict vortex flows have been controversial.These are the occurrence of separation and of losses in total pressure. Sharp edges, like those of the present configurations, appear to force separation, with the shedding of rotation, even on very fine grids; though it is not certain that this would persist if the grid were refined indefinitely. In the present study, a form of Kutta condition is introduced at the leading edge. The use of shock-capturing formulations for vortex flows involves losses of total pressure in both the vortex core and the shear layer that feeds rotation into the core from the body surface. To the mathematician, such losses are erroneous. To the engineer, on the other hand, their appearance may even be welcome, since similar losses appear in real flows and in numerical solutions of the laminar and Reynolds-averaged Navier–Stokes equations.

The agreement between the measured and computed contours of Pitot pressure at two angles of incidence above a delta wing is indeed striking, though much of the loss arises from the normal shock ahead of the Pitot tube. The independence of mesh spacing is also striking, but might arise because all the grids are coarse near the core

– they are certainly too coarse to display the structure calculated by Susan Brown (*J. Fluid Mech.* vol. 22, 1965, pp. 17–32). It might be that the independence of artificial viscosity level arises because the effect of the coarse grid dominates.

A most helpful result comes from a solution of a modified set of equations, in which the radial momentum equation is replaced by a specification of uniform total pressure. The distribution of static pressure, which most interests the aerodynamicist, is virtually the same in this loss-free solution as in the standard solution with a 38% loss in total pressure. Explanations are provided for the losses. The shear-layer loss is seen to be a simple consequence of applying a smoothing operator to the components of the momentum. For the core, a viscous model flow is proposed. This produces a total-pressure loss independent of Reynolds number and closely correlated with the ratio of the maximum of the circumferential component of velocity in the core to the axial component of velocity outside it. These features parallel features of the numerical solutions.

This long review of a short and specialized book may be justified on three grounds. CFD is now one of the leading activities in fluid mechanics, particularly in aerodynamics. Conical flows are a valuable stepping stone from planar to fully three-dimensional flows, particularly where vorticity is important. Thirdly, the need to identify effects of numerical viscosity is central, whether or not the physical viscosity is represented in the calculation. The virtues of the book are its comprehensive account of the method used, its clear presentation of the striking results obtained with the method, and the implied view of CFD as an experimental activity in which certainty is hardly to be attained. It would provide excellent illustrative, discussion and project material for a postgraduate course in CFD, and will stimulate practitioners of the art at all levels.

J. H. B. SMITH

Wing Theory. By R. T. JONES. Princeton University Press, 1990. 216 pp. $35.

This slender volume is written by an aerodynamicist who has been one of the dominant figures in the development of wing theory during a substantial part of the twentieth century. It is not intended as a detailed text for a lecture course, along the lines for example of the volume of the same title by Robinson and Laurmann (Cambridge University Press, 1956). The author's aim is, rather, to draw attention to, and emphasize, the elements of his subject and physical basis for its various components. In this he is highly successful. The role of the computer in present-day aerodynamics is acknowledged, but developments based on it are not addressed. Just as *Aerofoil and Airscrew Theory* by H. Glauert (Cambridge University Press, 1948) summarized the state of the art for the quarter-century following the first powered flight at the beginning of this century, Jones' volume includes the exciting developments of the next 50 years to give us a perspective of the subject from the end of the century.

Following a brief chapter on fundamentals there is one which discusses the aerodynamically interesting flows past ellipsoids. The next two chapters deal with two-dimensional wing theory for incompressible flow. The first of these is dominated by the Joukowsky aerofoils, with sections on viscous effects, including boundary-layer transition, and special-purpose aerofoils, whilst the second is devoted to thin aerofoils. The notion that thickness and lift may be represented by source and vortex distributions is introduced, but not developed in detail. The points to be illustrated are so done via a table of thin-aerofoil functions. This chapter also includes a careful discussion of the development of lift starting from rest. By the 1930s the fundamental problems associated with flight at supersonic speeds were understood, and Busemann in 1935 showed how the effect of sweep could reduce wave drag; all this of course before supersonic flight had been achieved. But almost a decade elapsed before it was realized that wave drag could be eliminated if the angle of sweep was such that the wing panels were enveloped by the Mach cone.

Chapter 5 discusses compressible flow phenomena, largely on the basis of the Prandtl–Glauert transformation, although a section on the hodograph method and supercritical aerofoils is included, and chapter 6 discusses the effects of sweep. Wings of high aspect ratio, with their known efficiency at small Mach number, are the subject of chapter 7. The early developments due to Prandtl and Munk are traced through to the wing-tip 'winglets' that are now a common enough sight. Chapter 8 is devoted to lifting-surface theory, beginning with Prandtl's acceleration potential; an extensive discussion of the elliptic wing is followed by sections on slender wings and supersonic conical flow. A disappointing feature of this chapter is the scant attention given to the leading-edge vortex phenomenon, which is an important feature of the flow over slender wings.

The penultimate, and longest, chapter is devoted to a discussion of the minimum drag of thin wings. For subsonic flow, minimum drag consistent with a given span occurs when the downwash is constant across the width of the wake and the spanwise loading is elliptical. At supersonic speeds the elliptical wing of high aspect ratio again plays a central role, and indeed the simplest example which satisfies the requirements for minimum wave drag is the oblique, elliptically loaded, lifting line. This leads to a discussion of the merits of oblique wings. Experiment shows that these can yield higher lift-to-drag ratios than those obtained in comparable tests of conventional swept or triangular wings, particularly in the transonic range. A final short chapter on the drag of wings and bodies in combination concludes with the supersonic area rule for speeds close to Mach 1.

Graduate and senior undergraduate students should have this book at hand for illumination and insight. They need to be reminded of fundamentals, whether it be that a circular cylinder whose diameter is less than 1% of the chord of an aerofoil section can experience the same drag or that 'the laws of aerodynamics are distinctly favourable to flight in the subsonic range' in the sense that 'the high efficiency of the wing at subsonic speeds results from the ability to influence a large volume of air, thereby creating the downward momentum needed to produce lift with a small expenditure of kinetic energy'.

In 25 years' time the author of a book comparable with those of Jones and Glauert will inevitably focus upon the achievements of large-scale computation. Whilst these are considerable even now, the present author's account of wing theory does not embrace them. This is not because he undervalues them but because he has taken the opportunity, at the end of an era, to present his own point of view of the subject, and *inter alia* to point out the dangers that the computational aerodynamicist faces if he is not conversant with the underlying principles of the subject.

N. Riley