Frontiers of Computational Fluid Dynamics 1998

Frontiers of Computational Fluid Dynamics 1998

Editors

D A Caughey
Cornell University

M M Hafez
University of California, Davis

World Scientific
Singapore • New Jersey • London • Hong Kong

Published by

World Scientific Publishing Co. Pte. Ltd.

P O Box 128, Farrer Road, Singapore 912805

USA office: Suite 1B, 1060 Main Street, River Edge, NJ 07661

UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

FRONTIERS OF COMPUTATIONAL FLUID DYNAMICS 1998

ISBN 981-02-3707-3

Printed in Singapore by Uto-Print

Frontiers of Computational Fluid Dynamics 1998

Dedication

This volume consists of papers presented at a symposium honoring Earll Murman and recognizing his seminal contributions to transonic aerodynamics and to computational fluid dynamics (CFD) over the past three decades.

The symposium, entitled *Thirty Years of CFD and Transonic Flow*, was held in Everett, Washington on June 24-26, 1997. The authors were selected from among internationally known researchers working in aerodynamics and CFD, where the impact of Murman's contributions have been so important. It is the pleasure of the authors and the editors to dedicate this book to Earll in recognition of the important role he has played in our technology and in our lives.

Earll Murman was born on May 12, 1942. He was raised in San Francisco, but went East to Princeton University where he received the B.S., M.A., and Ph.D. degrees in 1963, 1965, and 1967, respectively. His Ph.D. research, under the direction of Professor S. M. Bogdonoff, led to the dissertation entitled "Experimental Studies of a Laminar Hypersonic Cone Wake." He joined the Boeing Scientific Research Laboratory (BSRL) in 1967, and remained there until 1971. During this period he worked with Professor Julian Cole, who was spending a sabbatical leave from UCLA at the Boeing Laboratory. Their collaboration produced the breakthrough known as the Murman-Cole scheme, which allowed the first practical calculations of steady, transonic flow fields containing regions of supersonic flow embedded in subsonic regions.

In 1971 Earll joined the NASA Ames Research Center and, in 1973, presented his fully conservative version of the Murman-Cole scheme at the first AIAA Conference on CFD, held in Palm Springs, California. His pioneering work on wind tunnel wall interference and on design and optimization also were remarkable forerunners of current attempts to develop multi-disciplinary optimization techniques.

The paper describing the Murman-Cole scheme was published in the January 1971 issue of the *AIAA Journal*, and has been identified as a Citation Classic by *Current Contents*, Vol. 27, No. 45, November 9, 1987.

Frontiers of Computational Fluid Dynamics – 1998
Editors: David A. Caughey & Mohamed M. Hafez

Murman's collaboration with Cole continued and produced another classic, their AIAA paper on Inviscid Drag at Transonic Speeds, presented in Palo Alto in 1974. In that year, Earll joined the Flow Research Company in Kent, Washington, where he became Vice President and General Manager in 1977. He moved to MIT as Professor of Aeronautics and Astronautics in 1980, and became Department Head from 1990 to 1996.

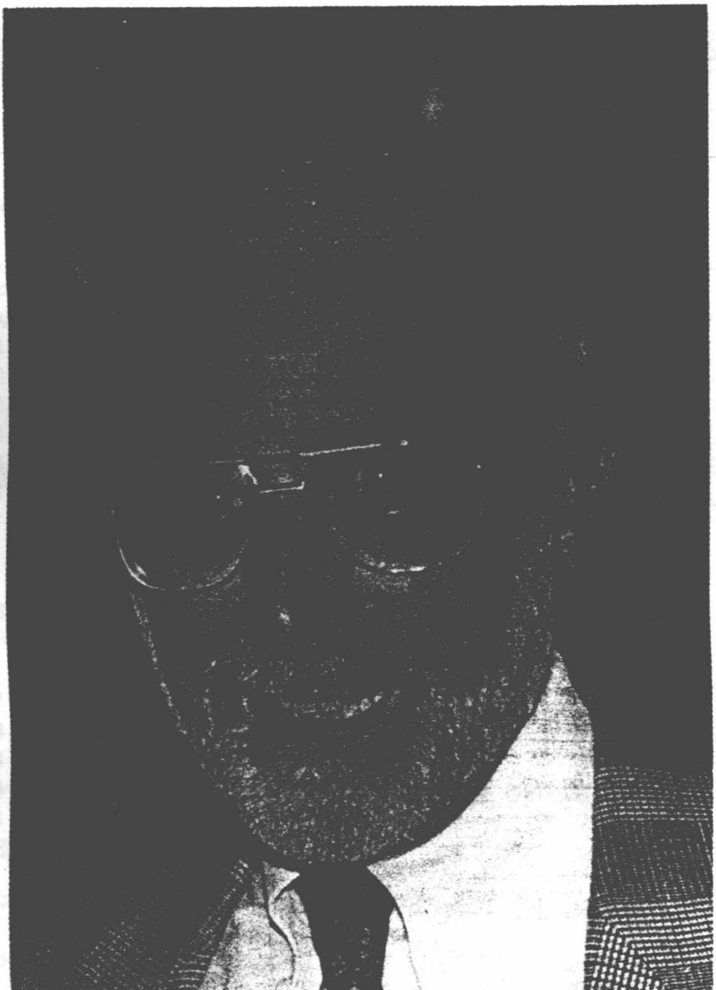
Earll has served as a consultant to Calspan, United Technologies Corporation, Pratt & Whitney, General Electric Corporation, Stellar Computer Company, Kendall Square Research, and Microcraft Technology.

At MIT, Earll served as Director of the Computational Fluid Dynamics Laboratory from 1980 to 1990. He chaired the Project Athena Resource Committee and, more recently, was the motive force behind Todor, a software package designed to enhance fluid mechanics curricula using computers.

Earll has taught courses on Transonic Aerodynamics, Computational Fluid Mechanics, Viscous Fluids, Heat and Mass Transfer, Fluid Dynamics of Flight and Re-entry Vehicles, and has supervised numerical and experimental projects for undergraduate students. He has advised 26 undergraduates, 20 Masters level students, and 8 Ph.D. students. His research at MIT has been directed at solution of the Euler equations, including the simulation of vortical flows. He also has worked on boundary layers and their coupling with Euler calculations. chemically reacting flows, Navier-Stokes equations, and viscous hypersonic flows, as well as flow visualization techniques. He is genuinely interested in engineering education, as is clear from his publications.

He has been an active participant in many committees of the American Institute of Aeronautics and Astronautics, the National Aeronautics and Space Administration, the Department of Defense, and the aerospace industry, and has served as Director of the Lean Aircraft Initiative since 1995. He is a Fellow of the AIAA and a member of the National Academy of Engineering.

In the first chapter of this book, Murman's technical contributions will be discussed in more detail, particularly their impact on transonic aerodynamics and CFD in general. Earll's contributions are not restricted to his technical ideas, his leadership, the courses he has taught, or his supervision of many talented students at MIT. Our community has been blessed to have a person like Earll, who has affected not only the people with whom he has worked directly over the years, but many others who have never had the pleasure of meeting him personally. It has been said that Murman opened the door for the flood of activity that followed his original contributions. Because of his vision, his personality, and his generous nature, he is highly respected throughout the aerospace community. It is our hope that there will be a second conference in the future, dedicated to his continued contributions during the next 30 years.



Earll M. Murman

Frontiers of Computational Fluid Dynamics 1998

Contents

1

A Review of the Contributions of Earll Murman to Transonic Flow and Computational Fluid Dynamics

Mohamed M. Hafez[1] & David A. Caughey[2]

1.1 Introduction

In this chapter, the work of Earll Murman over the past thirty years will be discussed, and some of his main ideas will be examined in detail. A complete list of his publications, up to 1996, together with titles of his students' theses are included as well. (It is of interest to note that Earll's Ph.D. thesis was on experimental studies of laminar, hypersonic wakes.)

One can divide Murman's papers, after his graduation from Princeton, into two groups; the first belongs to the period from 1967 to 1980 when he was at Boeing, the NASA Ames Research Center, and Flow Research, Inc. Almost all of these papers were based on the transonic, small-disturbance equation for potential flow. The papers in the second group were written from 1980 on, after he joined MIT, and they concern many topics, including solutions of the Euler and Navier-Stokes equations.

The significance of Murman's contributions to transonic flow is evident if one, for example, compares the contents of the proceedings of the *Symposium Transsonicum* in 1962 with those of the successor conferences in 1975 and

[1] Department of Mechanical and Aeronautical Engineering, University of California at Davis, Davis, California 95616.
[2] Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca, New York 14853-7501.

Frontiers of Computational Fluid Dynamics – 1998
Editors: David A. Caughey & Mohamed M. Hafez

1988. The impact of Murman's work is manifested through the quality and the quantity of the papers dealing with transonic flow simulations in the latter two conferences. His paper on vortical flows over delta wings in the proceedings of the third Symposium (in 1988) reflects his emphasis on both the physics and the numerics of the associated phenomena.

On the other hand, Murman's contributions to CFD are even more impressive. Introducing the concept of type-dependent differencing, the relation between upwind schemes and artificial viscosity, proper linearization, and viewing relaxation as an artificial time-dependent process, followed by the importance of conservation – not only at the differential level, but at the discrete level, as well – and the construction of proper switches to capture shock waves correctly; these were some of the newly born concepts put together for the first time to produce, using computers of the early 1970s, two- and three-dimensional solutions for the transonic flow over aerodynamic configurations with reasonable predictions, not only of lift, but of inviscid drag, in the transonic regime.

His work can be said to have provided the first convincing evidence that led the aerospace industry to consider CFD seriously as an analysis tool that complemented the wind tunnel.

1.2 Contributions to Transonic Flow

Theoretical work on transonic flow dates from the beginning of the twentieth century and the work by Chaplygin on gas jets. By the late 1940s the nonlinear, transonic, small-disturbance equation for planar flows

$$\left(K\phi_x - \phi_x^2/2\right)_x + \phi_{yy} = 0$$

was derived independently by Oswatitsch, Guderley, Busemann, and von Karman. In this equation, ϕ is the scaled perturbation velocity potential, x and y are Cartesian coordinates parallel and perpendicular to the direction of the free stream, respectively, and K is the transonic similarity parameter.[3] In 1947 the above form of the equation, identifying the transonic similarity parameter and establishing the transonic similitude, was derived by von Karman, and at the same time the Mach number freeze principle was discovered. The transonic area rule was discovered, based on slender-body theory, by Oswatitsch & Keune, and was verified experimentally by Whitcomb.

Guderley wrote the first book on **Theory of Transonic Flow** in 1957, and Ferrari & Tricomi's **Transonic Aerodynamics** appeared in 1962. Landahl's

[3] For planar flows the scalings are such that $K \propto (1 - M^2)/\tau^{2/3}$; for the axisymmetric version of the transonic small-disturbance theory, the similarity parameter is $K \propto (1 - M^2)/\tau^2$.

Unsteady Transonic Flow was published in 1960, and Ashley & Landahl's **Aerodynamics of Wings and Bodies** was published in 1965. Both von Mises' **Mathematical Theory of Compressible Fluid Flow** and Bers' **Mathematical Aspects of Subsonic and Transonic Gas Dynamics** were published in 1958. Bitzadze's **Equations of the Mixed Type** and Manwell's **Hodograph Equations** appeared in 1964 and 1971, respectively. In this regard Germain's review article in 1964 must also be mentioned. The most comprehensive treatment to date of the transonic, small-disturbance theory was published in **Transonic Aerodynamics** by Cole & Cook in 1986.

Most of the early work on transonic flow was based on the hodograph method, in which the dependent and independent variables are interchanged with the result that the equations of planar flow become linear, allowing solutions to be constructed by superposition. This method is restricted to isentropic, irrotational, steady flows in two dimensions, and the treatment of shocks is complicated. The simple geometry of a finite wedge was treated by Guderley & Yoshihara and by Cole in the early 1950s. Vincenti & Waggoner calculated flow over a double-wedge profile and an inclined flat plate at a free stream Mach number of unity. The boundary condition at a solid surface for a general airfoil shape is extremely difficult to handle in the hodograph plane. Nieuland & Boerstoel designed shock-free airfoils in the 1960s by extending the earlier work of Lighthill & Cherry. In the early 1970s Garabedian & Korn successfully applied the method of complex characteristics to handle the mixed type equation, and were able to design supercritical (shock-free) wing sections, including the widely-studied Korn Airfoil. (See the related work by Garabedian and Chen in this volume.) These contributions were particularly important in light of the common misinterpretation of the earlier work of Morawetz and others to imply the nonexistence of continuous, transonic flow past profiles.[4] In fact, that work did not rule out the existence of shock-free singular solutions having no neighboring shock-free solutions. Pearcey, and later Whitcomb, succeeded in demonstrating experimentally that essentially shock-free airfoils can be realized and used. From an engineering point of view, the presence of very weak shocks is allowed, as they do not destroy the efficiency of the design below the drag-rise Mach number.

Another formulation, which is restricted to steady, two dimensional (including axisymmetric) flows, is based on the use of a stream function. In the early 1940s Emmons calculated transonic flows past airfoils using this formulation. His finite-difference solutions were calculated by hand using a relaxation procedure with shock fitting. Also in the 1940s Macoll solved

[4] Recently, computer simulations have been used to study existence and uniqueness issues. Steinhoff & Jameson, and later Salas *et al.*, demonstrated the non-uniqueness of potential flow solutions. In 1991 Jameson showed similar problems for steady solutions to the Euler equations. The problem persists even for high Reynolds number, attached flow solutions of the Navier-Stokes equations, as demonstrated by Hafez & Guo.