Harvard Lomax: His Quiet Legacy to Computational Fluid Dynamics

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Harvard Lomax: 1922-1999

Harvard Lomax one of the pioneers of Computational Fluid Dynamics passed away early Saturday morning May 1, 1999. Harvard who retired in 1994 after 50 years of government service, had just turned 77 on April 18, 1999. Harvard was beloved by everyone who came in contact with him over his many years at NASA Ames Research Center, Moffett Field, CA.

Harvard's Background (1)

- In 1940, Harvard came to California from Broken Bow, Nebraska at the invitation of his Aunt Edith Stephenson.
- He was valedictorian of his graduating class in 1940.
- His aunt encouraged him to study mathematics.
- Harvard received his BA in Mechanical Engineering from Stanford University in 1944
- Masters in Engineering Sciences from Stanford in 1947.

Harvard's Background (2)

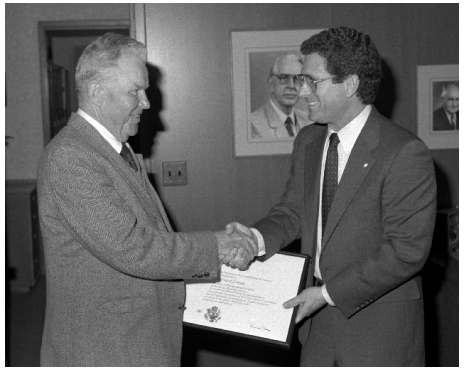
- Joined NACA at Moffett Field in 1944
  - War Time Navy Assignment.
  - Started out in the 16-Foot High Speed Wind Tunnel
  - Soon after transferred to Theoretical Aerodynamics Branch
- 1944 to 1970: Research Scientist
- 1970 to 1992: Chief of the Computational Fluid Dynamics Branch and made it the premier CFD research group in the world.
- 1992 to his retirement in 1994: Senior Staff Scientist.
- Published over 80 technical papers, reports and journal articles.

AWARDS and HONORS

- NASA Medal for Exceptional Scientific Achievement (1973)
- The AIAA Fluid and Plasma-dynamics Award (1977)
- AIAA Fellow (1978)
- Presidential Rank Award for Meritorious Executive, SES (1983)
- Ames Research Center Fellow (1986)
- Presidential Rank Award for Distinguished Executive, SES (1987)
- Member of the National Academy of Engineering (1987)
- Prandtl Ring Recipient (1996).

With Center Director Hans Mark, 1973

With Center Director Clarence Syvertson, 1983



With Center Director William Ballhaus, 1987

- It is an indication of the high esteem NASA Ames management held Harvard that one of Dean Chapman's last acts before retiring as Director of Aeronautics, was to promote Harvard to the Senior Executive Service making him the only SES Branch Chief in all of government service.

Harvard's Passions

- His Family: Wife Joan, Sons Harvard L. and James W. and Daughter Melinda Cootsona, 6 grandchildren.
- Harvard was an Avid Golfer Spending Many a Weekend at the Stanford Links

Harvard with his wife Joan, 1944

Harvard and some of his golfing buddies

Professor Lomax

- 1950 to 1994, Lecturer and Consulting Professor at Stanford
- 1970 to 1994 AA214A: "Introduction to CFD"
  - Developed a simplified, but highly insightful approach to
    - Accuracy, Stability and Convergence
    - PDE $\rightarrow$ ODE $\rightarrow$ OΔE
    - Method to design algorithms
    - Linear Theory/Algebra Approach
  - Harvard was constantly updating course with the latest methods.
  - Trained many of the world's leading CFD researchers
  - Still taught at Stanford today.

- At one time some of the more energetic students in the CFD Branch tallied the total mileage on Harvard's car and compared that with the Lomax triangle distance, i.e. the travel distance between Harvard's home, NASA Ames and Stanford. The story has it that the two numbers were in equilibrium.

Early Research (1)

- Lomax was instrumental in the development of Linearized Lifting Surface Transonic and Supersonic Wing Theory
  - Heaslet, Lomax and Jones (1947), "Volterra's solution of the wave equation as applied to three-dimensional supersonic airfoil problems"
  - Over 20 NACA Technical Papers, Notes and Memoranda on the Subject.
  - Culminating in: Heaslet and Lomax (1954), Section D:General Theory of High Speed Aerodynamics,Vol. VI of High Speed Aerodynamics and Jet Propulsion, "Supersonic and Transonic Small Perturbation Theory", Princeton University Press

Max Heaslet was Harvard's Mentor

- Worked Closely with Max Heaslet for over 20 years..

Figure 1: Left to right: Harvey Allen, Max Heaslet, Walter Vincenti, Max's wife, and Milton Van Dyke at Heaslet Retirement, 1967

Section D:General Theory of High Speed Aerodynamics

- Definitive Text For Supersonic and Transonic Wing Design
- Table of Contents
  - Chapter 1. The Wave Equation and Methods of Solution
  - Chapter 2. Two-Dimensional Supersonic Steady State Flow
  - Chapter 3. Three-Dimensional Supersonic Steady State Flow
  - Chapter 4. Axially Symmetric Supersonic Steady State Flow
  - Chapter 5. Slender Airplane Theory
  - Chapter 6. Unsteady Lift
  - Chapter 7. Reciprocity Relations and Reverse Flow Theorems in Aerodynamics
  - Chapter 8. Small Perturbation Theories of Transonic and Hypersonic Flows

Early Research (2)

- Developed a method for the **determination and minimization** of the **wave drag** of arbitrary aircraft configurations at **high subsonic and low supersonic conditions**.
- A significant **extension** of Richard **Whitcomb's area-rule** theory at transonic speeds in two ways.
  - Design of aircraft for **minimum wave drag** on the basis of **design parameters** that included both **volume and lift distributions**.
  - Evaluations and optimizations at **Mach numbers other than one**.

Transition from Theory to Computation

- **Wave-drag mathematical technique developed by Harvard** for the minimization of the wave drag of aircraft configurations at speeds from high subsonic to well into supersonic Mach numbers **involved a large amount of computations**, which were first carried out on electro-mechanical computers, which was **very tedious**.
- Harvard **recognized the possibilities** available if **theoretical aerodynamics** and **high speed computing machines** could be **utilized together**.
- Early in his studies Harvard **expanded the application** of his new theory **by adapting** his theoretical method **to the electronic computers** available at Ames, which greatly improved the usefulness of his method.
- From that time onward, **Harvard's endeavors** were more and **more closely tied** to the use of **digital electronic computers** for the solution of aerodynamic problems of wide variety.

Early Day Computers At Ames

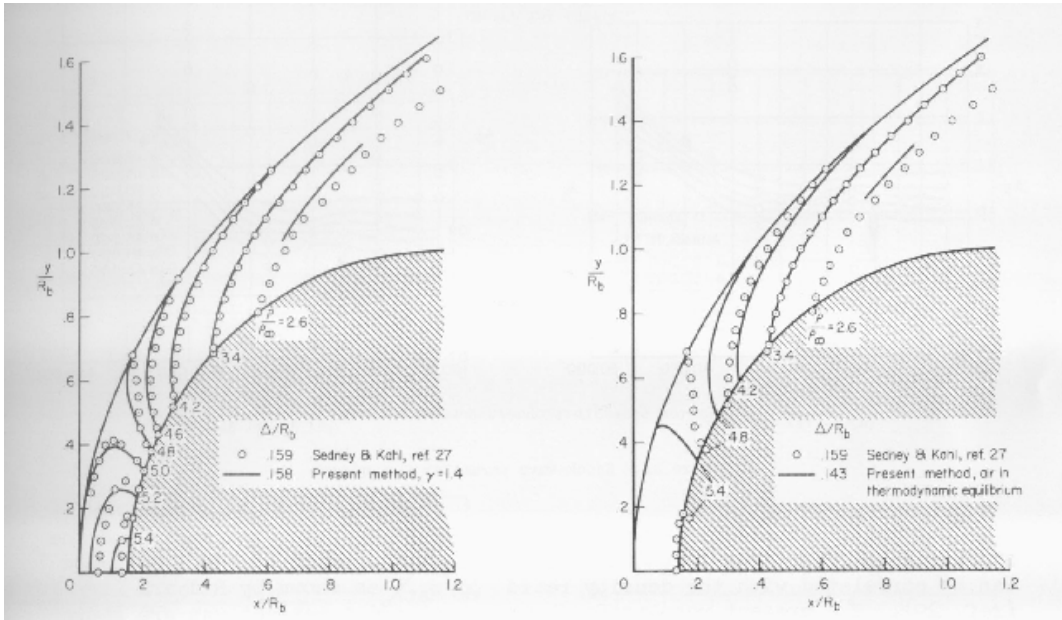
- Late 50's: IBM 650, data reduction in the Unitary WInd Tunnel
- Harvard and others wrote machine language code for theoretical analysis.
- Circa 1960: IBM 704 (the last tube computer at Ames)
- Harvard taught a class for the machine in the ABC language.
- Early 60's: high-speed electronic computer (IBM 1401) dedicated to Harvardand his co-workers.
- Late 60's: IBM 360/50, 360/67 directly connected to the IBM 1800.
- Early 70's Ames obtained a CDC 7600.
- 1972: Illiac IV
- 1980 – Present: Cray's, Supercomputers, NAS Facility

Numerical Analysis of Blunt Bodies (1)

- Lomax and Inouye (1964), "Numerical Analysis of Flow Properties About Blunt Bodies Moving at Supersonic Speeds in an Equilibrium Gas"
- Developed computer programs for inviscid supersonic flow over blunt bodies.
- Inverse method: Fix bow shock shape compute body shape.
- Finite Difference Approach
- Numerical instabilities categorized and suppressed
  - *Inherent instabilities*: due to physical or mathematical formulation.
  - *Induced instabilities*: due to numerics.
- Perfect gas and real gas computations.
- Gas table interpolation method developed.

Numerical Analysis of Blunt Bodies (2)

- Comparisons with other theories and results were presented.
- Results included:
  - Parameterized Shapes, ellipsoids, spheres, paraboloid.
  - Extensive Tables of Data.
  - A computer code disseminated to over 60 organizations.



(a) Perfect gas calculation. (b) Real-gas calculation.

Figure 20.- Constant-density lines for spheres in nitrogen; $\gamma = 1.4$, $M_\infty = 5.017$.

25 Years of CFD Research and Leadership

- CFD Branch Formed in 1970
- Outgrowth of Theoretical Branch
- Harvard as Branch Chief
- Bob MacCormack and Mamoru Inouye as Assistants
  - "Converted" aerodynamicists, graduate students and Post-Docs
  - F. Ron Bailey, Harry E. Bailey, Barrett Baldwin, William Ballhaus Jr., Timothy Barth, Richard Beam, Pieter Buning, Denny Chaussee, Bill Davy, Steve Deiwert, Terry Holst, Ching-Mao Hung, Jeanne Hyett, Dennis Jespersen, John Kim, Paul Kutler, Tony Leonard, Yen Liu, Cathy Maksymiuk, Nagi Mansour, Dale Martin, Unmeel Mehta, Marshal Merriam, Parviz Moin, Robert Moser, Nadine Omlid, Tom Pulliam, Walt Reinhardt, Marnie Ridgway, Art Rizzi, Bob Rogallo, Mike Rogers, Lew Schiff, Karim Shariff, Yvonne Sheaffer, Reese Sorenson, Philippe Spalart, Joseph Steger, Ken Stevens, Robert Warming, Velvin Watson, Alan Wray, Helen Yee

A Strong Group of Students and Post-Docs

- Work-Study with Iowa State Set up by Vernon Rossow
- Brought in a talented group of researchers.

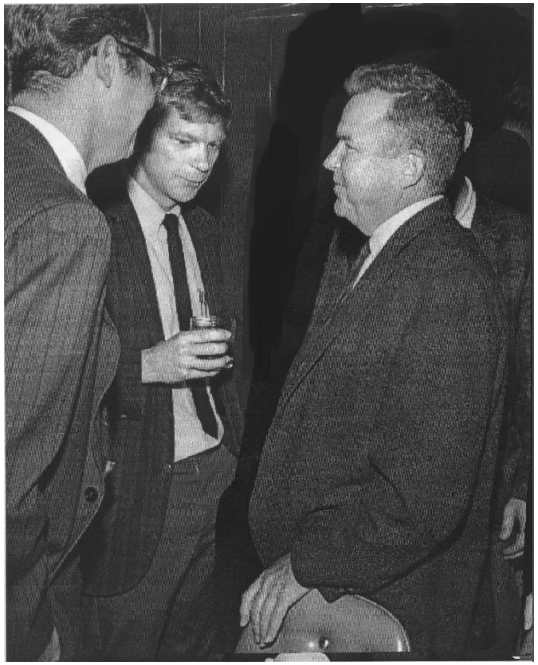


Figure 2: Left to right: Joe Steger, Ron Bailey and Harvard at Frank Fullers Retirement, 1970

When Harvard was asked on numerous occasions
what the qualifications were for
being a Branch Chief, he would respond:

"Only someone who doesn't want the job should get it."

Series of Invited Papers.

- Beginning in 1969 through 1991:
  - October 1969, Symposium for Analytic Methods in Aircraft Aerodynamics, held at NASA Ames
  - 1975 AIAA 2^{nd} CFD meeting in Hartford, Conn.
  - 1981 AIAA 5^{th} CFD Conference, Palo Alto, CA
  - 1991 AIAA 10^{th} CFD Conference, Honolulu, HI

- *Harvard set the standards and ignited the imagination of those of us who were inspired to perform research in CFD.*

1969: Analytic Methods in Aircraft Aerodynamics

- "Analysis of Finite-Difference Techniques Applied to Equations Governing Convective Transfer"
  - Introduced the concepts of dispersion and diffusion of numerical methods to the theoretical aerodynamicists.
  - Lax-Wendroff and MacCormack's methods illustrated and analyzed.
  - Artificial Dissipation discussed.
  - A consistent development from PDE to ODE to OΔE (Ordinary Difference equation) is employed.
  - Formed the basis for Harvard's course in CFD at Stanford

Stirred Up the Numerical Wind Tunnel Controversy

- In response to Harvard's Opening Remarks
- "A survey of the presentations at this conference points clearly to the fact that the development of numerical wind tunnels for practical airplane shapes is emerging as a reality."
- Caused a stir in the discussion session.
- Raymond Sedney of the Martin Co, starts out his comments by saying:
  - "I hate to in any sense detract from the interesting material you presented, but I have to raise a strong objection to the rather provocative opening statement about numerical wind tunnels being on the verge of appearing."
- Harvard's response:
  - "That's too loaded of a question, but I think that each year I can see significant progress in this area, ... we can cut back on wind-tunnels ... rely more and more heavily ... on the methods being developed, ... "

The Numerical Wind Tunnel Controversy (1)

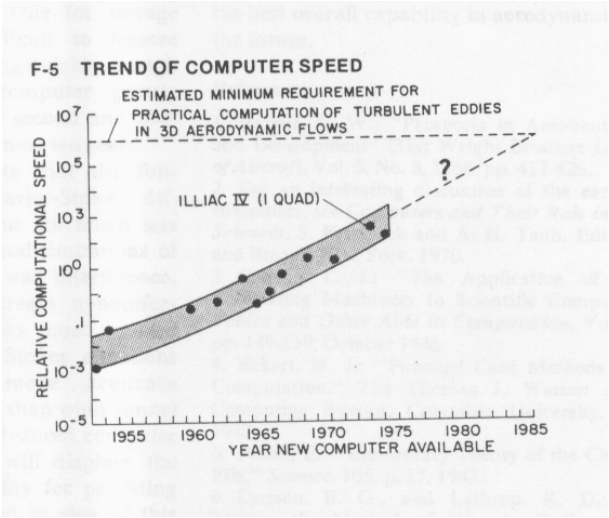
- An Outgrowth of the Success of CFD Under Harvard's Leadership, was the Concept of the "Numerical Wind Tunnel"
- Management at Ames Pushed This Philosophy to the Point of Controversy.
- In Fact one can trace the "Numerical Wind Tunnel" concept dates back to the Original NACA Charter.

The Numerical Wind Tunnel Controversy (2)

- First Annual Report, Page 13, NACA 1915 identified:
  - Of the many problems now engaging general attention, the following are considered of immediate importance ...
  - A. *Stability as determined by mathematical investigations.* The reduction to practical form of the analytical methods of determining the stability of aeroplanes from design data, without necessarily requiring wind tunnel tests or full sized tests of the same.

The Numerical Wind Tunnel Controversy (3)

- In 1975, Chapman, Mark, and Pirtle create an uproar when they stated:
  - "Because within a decade computers should begin to supplant wind tunnels in the aerodynamic design and testing process, the nation needs integrated planning of both to acquire the most effective overall capability for the 1980's and beyond."



- Lomax and the newly formed CFD Branch were tasked with the job of making this happen!.

The Illiac IV (1)

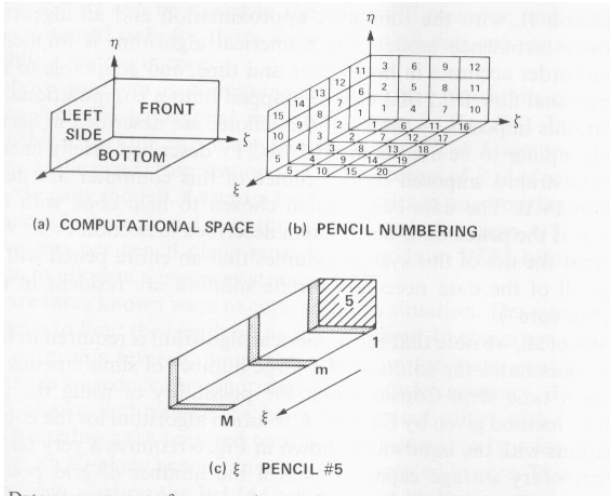
- The Illiac IV Computer arrives at Ames, 1972
  - 64 (CDC 6600 Speed) Processors
  - Local Memory: 2048 Floating Point 64-bit Words
  - SIMD or MIMD Capable (Mainly used in SIMD Mode)
  - Logical Drum Disk: 7 Million 64-Bit Words
  - FORTRAN Like Parallel Language: Called CFD
    - Developed at Ames in CFD Branch
    - Employed Parallel Constructs: $C(*) = A(*) + B(*)$
- Illiac IV becomes functionally operational in 1976.

The Illiac IV (2)

- Ames management depended on Lomax and his group to get useful results from the Illiac IV
  - Rogallo and Wray developed effective FFT algorithms.
    - Moin and Kim: 1^{st} detailed LES of turbulent flow in a channel at a $Re = 13800$
    - Channel Simulation: landmark turbulent physics result.
    - Stimulated the development of FS and LES.
    - Center for Turbulence Research at Stanford.
  - Chapman tasked Lomax to develop RANS code on Illiac IV
    - Data Base Management (DBM) was Critical
    - Mapped Large Grid System To Small Processor Memory (PEM).
    - Mapped Implicit Algorithm to Data Base.
    - Innovative Concepts of Transpose and Pencil DBM

Pencil Data Base

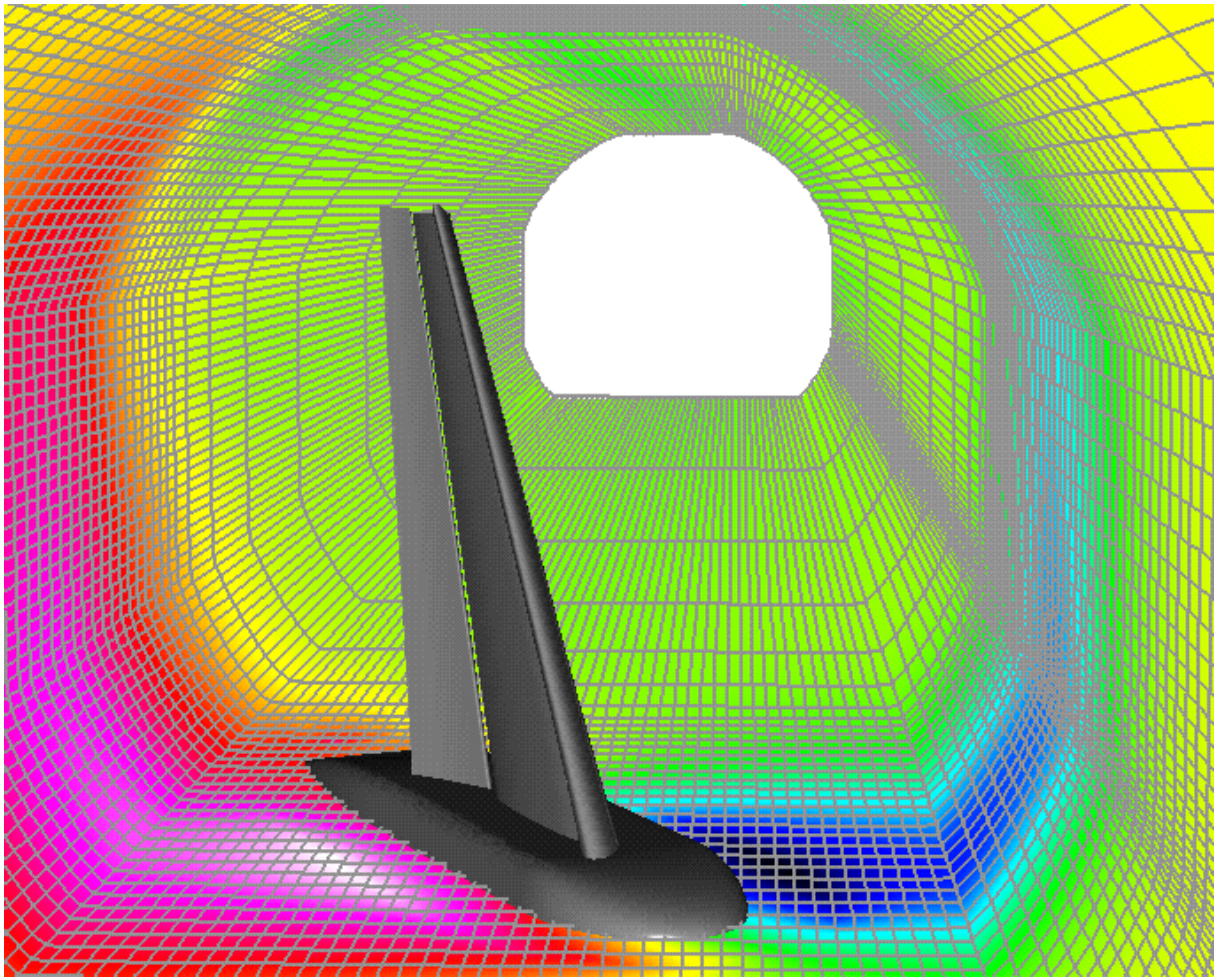
- Hierarchal Memory Mapping
- Vector Length 64, Mapped Across Processors
- Pencil Database: $8 \times 8 \times max(JMAX, KMAX, LMAX)$



- Lomax Recognized The Key To Parallel programming: DBM
  - Learned early on to shoehorn problems onto low memory computers.
  - Lomax wasn't spoiled by the present day "FAT memory" computers.

Legacy of the Numerical Wind Tunnel

- Harvard was Instrumental In Defining, Demonstrating And Ensuring The Success Of The Numerical Wind Tunnel



AIAA 2^{nd} CFD Conf., Hartford, CT., 1975

- "Recent Progress in Numerical Techniques for Flow Simulation"
- *The author believes that the use and understanding of sophisticated numerical algorithms should become as natural to the physicist as are the use and understanding of calculus.*
- Introduces to the aerodynamic community a number of emerging techniques
  - Higher order methods (e.g. Pade schemes)
  - Direct solution methods
  - Splitting schemes (e.g. Beam-Warming approximate factorization)
  - Pseudo-spectral methods.
- Also introduces the concept of alternative (to FORTRAN) programming languages and formats.
- The best computer code ... gives reliable answers ... in the shortest time. ... the basic charter of CFD is to advance the knowledge of fluid dynamics, not to develop elegant algorithms per se.

Baldwin-Lomax Turbulence Model: 1978

- "Thin Layer Approximation and Algebraic Model for Separated Turbulent Flows"
- Thin Layer Assumption Introduced and Defined.
- Turbulence Model Developed by Barrett Baldwin:
  - Mixing length model
  - Patterned after the Cebeci Model
  - Length scales proportioned to the vorticity layer
  - Easy to implement and understand
  - Well documented and widely available
- Became the standard model for CFD development and application.
- Comparison between methods and codes could use the standard Baldwin-Lomax model and eliminate that uncertainty.

AIAA 5^{th} CFD Conf., Palo Alto, CA, 1981

- "Some Prospects for the Future of Computational Fluid Dynamics"
- Clearly and prophetically identifies new and promising directions for CFD:
  - Characteristic flux-splitting methods
  - Multigrid techniques
  - Zonal methods
- Characterizes the requirements for High Reynolds Number Simulations
  - Delineates the role of high-frequency dissipation and turbulence modeling.
  - Discusses the need for de-aliasing and subgrid scale modeling.

AIAA 10^{th} CFD Conf., Honolulu, HI., 1991

- "CFD in the 1980's From One Point Of View"
- Traces the advances in algorithms and turbulence over the past decade.
- Highlights
  - The Upwind-Differencing Techniques: FVS, FDS, TVD, ENO
  - Multigrid Methods for the Euler Equations
  - Unstructured Grid Methods
  - The Development and Contributions In Turbulence Physics.
  - "When the results (Moin and Kim) ... in the form of moving pictures ... of particles in a turbulent flow, ... experimentalists could immediately identify with their own experimental observations and lost their skepticism ... ".
- Future Possibilities
  - Unsteady Flows
  - LES and turbulence effects.
  - Unstructured Grid generation and solvers
  - Advanced computer architectures

Chief of the CFD Branch

- MacCormack says of Lomax: "As Chief of the CFD Branch at Ames for more than two decades, he led a star studded group of scientific talent and was an excellent mentor to new employees by giving them their initial directions in research. The key was that he gave his employees room to maneuver in the creative environment he provided and did not subject them to our own limitations on how to proceed."

Harvard Lomax

- He has left us the legacy of "The Numerical Wind Tunnel".

- **He will be sorely missed and widely remembered.**