Biographies

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Harvard Lomax (1922–1999)

NASA Ames Research Center

Harvard Lomax was a pioneer in the field of computational fluid dynamics (CFD), accelerating its development by applying finite-difference techniques to massively parallel computing. His research, spanning a 50-year career from 1944 to 1994, secured the leadership role of NASA's Ames Research Center in this area. Recognizing the theoretical and practical potential of his work, top management established CFD as a strategic direction for the laboratory. They brought to Ames many computer-savvy aerodynamicists who worked under Lomax's tutelage. During the 1970s and 1980s, CFD advanced at Ames in step with the increasing computer power that management made available to researchers, enabling the numeric wind tunnel to displace the real thing as the principal method for evaluating airflows.

Lomax's principal contribution to CFD was his calculations of unsteady airflows around aircraft just as they reach the speed of sound. Lomax did not invent CFD. Credit for founding the field should go to John von Neumann, who worked on finite-difference techniques after World War II at the Los Alamos National Laboratory.[1] Moreover, computational work on fluid flows of other theoreticians at Ames, including Milton Van Dyke, Frank Fuller, and Bill Mersmann, predated that of Lomax. Yet even as others were calculating the effects of flows at subsonic and supersonic speeds, Lomax solved equations for the most complex flows, which provided the most critical data for the design of air- and spacecraft.

Lomax recognized the potential benefits of digital computing when other researchers continued to rely on mechanical calculating machines. Further, while most of the computer time at Ames was used to reduce wind tunnel data, Lomax recognized that improvements in digital computers would permit his use of them in studying the physics of fluid flows. At the same time, he urged CFD researchers to use computers to conduct purely numeric scientific experiments. Once advances in computer speed and memory made it realistic to think in terms of adapting theory to complex 3D geometric shapes, Lomax sought to use CFD to learn more about fluid dynamics. As he put it, "It's the physics that we're ultimately interested in, not the wind tunnel or the computer."[2]

Early investigations: 1945–1958

Born in Broken Bow, Nebraska, Lomax attended Stanford University. He studied mechanical engineering, receiving a BA in 1944. Upon his graduation, Ames hired Lomax as a research scientist. He continued his education, earning an MS in engineering science in 1947 at Stanford. Three years later, he began more than four decades of teaching aeronautics and astronautics at his alma mater.

Lomax joined Ames as part of a team that conducted tests on military aircraft in a 16-foot wind tunnel. Soon thereafter he moved into the theoretical aerodynamics branch of the laboratory's Theoretical and Applied Research division and began working on problems associated with supersonic and transonic flight. Aircraft designers had just begun to design wing planforms that could go supersonic, Ames had just begun designing wind tunnels to test the new shapes, and both efforts were proceeding with the benefit of guidance only from theories based on highly simplified fluid-flow equations. Lomax and his colleagues began to close the gap between theory and design by developing mathematical approximations of idealized airflows with no fluid friction, heating, compression, or turbulence—which proved useful in understanding the effects of subsonic and supersonic flows on 3D shapes.

Lomax often collaborated with Max A. Heaslet, who headed the branch, and John R. Spreiter, who initiated the study of transonic theory at Ames.[3] Lomax's pioneering study investigated 2D and 3D unsteady lift problems at transonic speeds using the so-called indicial approach. This research proved valuable to CFD researchers two decades later, when they studied unsteady transonic flows with the benefit of large-scale computers. The approach solved schedules of arbitrary changes in motion once the indicial response for an instantaneous change in that motion was known. Because unsteady aerodynamic coefficients for a wide range of frequencies could be calculated from a single flow-field computation, the computer cost of analyzing many frequencies was only slightly greater than the cost of considering one.[4]

Lomax's theoretical work proved useful to the aerospace industry during the coming of the jet age.[5]

Harnessing the digital computer: 1958–1970

The large number of calculations involved in his early work interested Lomax in using digital electronic computers to develop and test aerodynamic theory. Lomax

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became a true believer in digital computing one afternoon in 1959 on his way home.

For 17 years, Lomax shared a carpool with Marcie Chartz Smith, who was a machine-programming mathematician in Ames's electronic computing machines division and was responsible for operating an IBM 704. During the ride home, Lomax complained about staff having to redo a hand calculation that had taken days to complete because he had supplied the wrong integral in the equation he had submitted. Smith pointed out that his turnaround time would be much shorter if he relied on an electronic computer.

When they arrived at work the next morning, Lomax followed Smith to her office, where she wrote the 704 code for the equation in which Lomax was interested, ran her program, and delivered the results to Lomax 15 minutes later. Instantly a believer in the possibilities of digital computing, Lomax took a Fortran manual with him to his office and, as someone who "could learn anything from a book," mastered the language in short order.[6]

Lomax's discovery coincided with organizational changes that occurred at Ames in 1958 as a result of the creation of NASA. Lomax considered new directions in his research. In designing his theoretical investigations so that they might benefit from the exploitation of the increasing capability of digital computers, Lomax played a pivotal role in keeping Ames on the leading edge of theoretical aerodynamic research for the next three decades.

Previously, Lomax wrote programs in machine language on the IBM 650, generating numerical data for theoretical analyses of wind tunnel tests. Subsequently, Lomax demonstrated the importance of computers for solving theoretical problems on other digital machines, even as wind tunnel data reduction remained the primary activity of the Ames central computer facility (CCF). With the assistance of mathematician Mamorou Inouye, Lomax wrote a computer program for an IBM 7094, which the CCF had made available to aerodynamic theorists, to predict flows past blunt-nosed objects during atmospheric reentry—a topic of paramount interest to NASA at the time. Described in a widely disseminated 1964 paper, this blunt-body code was crucial for developing manned space capsules.[7]

In 1968 Lomax showed how graphical displays could be deployed to monitor aerodynamic simulations during their numerical computation on the IBM 7094. By writing the system software to link the 7094 processor to the display capability of an IBM 2250 cathode ray tube, Lomax demonstrated to senior management the benefits of creating digital databases that computers processed as wind tunnel experiments proceeded.[8]

Background of Harvard Lomax

Education: Stanford University: BA (mechanical engineering), 1944; MS (engineering science), 1947. **Professional experience**: NASA Ames Research Center: research scientist, 1944–1970; chief, Computational Fluid Dynamics Branch, 1970–1992; senior staff scientist, Fluid Dynamics Division, 1992–1994; Stanford University: lecturer, 1950–1994. **Honors and awards**: Medal for Exceptional Scientific Achievement, NASA, 1973; Fluid and Plasmadynamics Award, AIAA, 1977; Fellow, AIAA, 1978; Presidential Rank Award of Meritorious Executive, Senior Executive Service, 1983; Fellow, NASA Ames Research Center, 1986; Fellow, National Academy of Engineering, 1987; Presidential Rank Award of Distinguished Executive, Senior Executive Service, 1994; Ludwig Prandtl Ring, Deutschen Gesellschaft für Lüft- und Raumfahrt (German Society for Air and Space Flight), 1996.

Creating a numeric wind tunnel: 1970–1978

Lomax's work convinced Hans Mark, director of Ames from 1969–1977, and Dean R. Chapman, director of astronautics during the 1970s, that CFD should constitute a strategic direction for the laboratory. Mark had come to Ames from Lawrence Livermore National Laboratory. Chapman was a world-class theoretician who had worked at Ames since 1947. Mainframe computers were enabling CFD researchers to model the Navier-Stokes equations for nonlinear airflows—those with compression—over the transonic range of speed. With even more computing power, researchers would be able to model viscous flows—those with turbulence. Eventually, Mark and Chapman reasoned, computers would become powerful enough to constitute a principal tool in aircraft design. To implement their plan, they renamed the theoretical branch of the Thermo- and Gas-Dynamics division the CFD branch and made Lomax its chief. They brought in researchers whom Lomax mentored. As of 1977, Lomax was directing the research activities of 22 research scientists and 7 National Research Council postdoctoral associates.[9]

Mark and Chapman also acquired the most powerful computers available so that Ames might remain on the leading edge of CFD research. Their acquisition of an IBM 360/67 was a boon to both wind tunnel experiments and aerodynamic theory at Ames. The acquisition of a CDC 7600—some 15 to 20 times faster than the IBM 360/67—made possible additional theoretical advances and their prac-

Lomax played a leading role in realizing the vision of a numeric wind tunnel that researchers could use to study fluid flows and develop tools with practical applications.

tical application to aircraft design.

During the 1970s, Lomax researched a wide range of topics relevant to CFD. He also simplified the mathematical approach to CFD, enabling others to write codes to model the velocity, density, and pressure of transonic air flows over increasingly realistic designs. In addition, he helped develop specialized languages that computed unsteady transonic flows more efficiently on the IBM 360/67 and the CDC 7600. For this work, Lomax received NASA's Medal for Exceptional Scientific Achievement in 1973 and the Fluid and Plasmadynamics Award of the American Institute of Aeronautics and Astronautics (AIAA) in 1977. In 1978 the AIAA elected him a fellow.[10]

By the mid-1970s, Lomax could argue that the numeric wind tunnel for realistic aircraft design was becoming a reality, given "the confidence now being placed in the simulations" and assumptions about the increasing power and decreasing costs of computers.[11] In 1978 he observed that CFD was reaching maturity, in that nobody was questioning the accuracy of numerical calculations of transonic flows. The question now was: "Is my method as good as your method and can I get there faster?"[2]

Ultimately Lomax was interested in using computers to study the physics of fluid flows. For this to happen, however, CFD code had to become more reliable through testing across dissimilar experiments. Even as CFD was reaching maturity as a field, Lomax lamented the fact that CFDers were typically "wind tunnel builders" rather than students of fluid flows. As he put it,

> What has happened over and over again is that somebody has developed a method to solve something and they've put that method together in a code. They have solved some problem with it and they've published it in a journal and they've thrown their code away, they've destroyed their wind tunnel, and they've gone on and built another code and on and on and on.[2]

The problem, as Lomax saw it, was that CFD researchers did not trust one another's work. Solving the problem required researchers leaving their code unmodified while others tested it. Once researchers gained confidence in the reliability of CFD code generally, they could design numerical experiments in unexplored areas and "discover something new" about the physics of fluid flows. As of 1978 researchers "were a long way off from doing that."[2]

Supercomputing and the Numerical Aerodynamic Simulation Facility: 1975–1994

More computing power than the CDC7600 was required if CFD researchers were to consider separated flows and viscous effects. At a time when the cost of wind tunnel experimentation was increasing by orders of magnitude, owing to the complexity of the aircraft models being tested, the costs of speed and memory were plummeting in like order. Creating numeric wind tunnels on computers promised to overcome the fundamental limitations of wind tunnels, which, for instance, could not simulate flowfield temperatures around atmosphere entry vehicles or propulsive-external flow interaction in flight. Thus both senior management and CFD researchers had an interest in working with more powerful computers.[12]

Mark's strategy of devoting significant resources to CFD began to pay off in terms of the practical application of theory with the implementation of supercomputing power at Ames during the last half of the 1970s, when researchers could depend on the operation of the Illiac IV, which Ames had acquired in 1970. The Illiac IV was the world's first parallel computer and 300 times faster than the IBM 7094. It was only with the Illiac IV that researchers could begin to simulate separated flows, airfoil buffeting and buzz, aerodynamic noise, surface pressure fluctuations, and boundary-layer transition—all requisite components of a fully robust numeric wind tunnel.[13]

Lomax made important contributions to CFD theory at this level of complexity, most significantly the Baldwin–Lomax turbulence model.[15] Into the 1990s, the model remained the leader in terms of so-called code validation, "insofar as its good points and its bad points are known for more types of flow applications in a wider variety of situation than any other," as Lomax put it.[14]

To ensure Ames's ongoing leadership in aerodynamic research, Mark and Chapman advocated and obtained resources for a Numerical Aerodynamic Simulation (NAS) facility. Conceived in 1975, the NAS program aimed to develop a large-scale, distributed resource computer network at Ames that might be upgraded seamlessly from the user's point of view with a minimum impact on existing applications, ensuring that the facility would retain its leading-edge computational capability. After eight years of study and refinement of requirements, during which NAS designers greatly increased the initial operating capacity, a finalized plan was approved in February 1983. The US Congress approved the NAS program as a "new start" (to receive ongoing funding) for fiscal year 1984.[16]

Lomax strongly supported the NAS because it let him think in terms of the numerical experiments in which he was interested. It would provide the requisite computing power and facilitate the sharing of information and testing of codes that would permit researchers to investigate the physics of fluid flows.

Dedicated in March 1987, the NAS constituted "an evolving capability," with several orders of magnitude more speed than the Illiac IV computer, linking researchers via a national communications network to the processing of a Cray-2 supercomputer and an array of systems housed within a 90,000-square-foot building on the Ames campus. NASA now had the requisite computing capacity "to displace the wind tunnel as the principal facility for providing aerodynamic flow simulations," as Chapman and Mark had hoped, as well as the capacity to apply computing power to other fields, such as chemistry and astrobiology.[17]

The NAS enabled CFD researchers to push the limits of theoretical approximation of the full Navier-Stokes equations. The researchers packaged their codes into routine programs for application by industry. For instance, the Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics (CAMRAD) and ROT22 modeled the aerodynamics of helicopters. The Incompressible Navier-Stokes Solver in General 3D Coordinates (INS3D) depicted flows within space shuttle engines. Thus, in a little more than a decade, CFD as a field made many of the theoretical advances that Lomax hoped for in the late 1970s. At the same time, it demonstrated the extent to which fundamental research might underpin the development of engineering applications of interest to industry and government.[15]

Lomax retired in 1994, having played a leading role in realizing the vision of a numeric wind tunnel that researchers could use to study fluid flows and develop tools with practical applications. His research yielded more than 80 technical papers and reports, which constituted

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For more information on Harvard Lomax and the research he conducted, refer to the following resources.

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