Biographies

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William F. Ballhaus Jr. (b. 1945)

(NASA Ames Research Center)

William F. Ballhaus Jr. distinguished himself among the many researchers who created the field of computational fluid dynamics (CFD) at the NASA Ames Research Center at Moffett Field, California. Harvard Lomax had introduced computational aerodynamics at NASA Ames (see *Annals*, vol. 27, no. 3, pp. 98-102) and Ballhaus pushed it in new directions. For more than a decade of intense research, beginning in 1971, Ballhaus was widely recognized for his contributions to the theoretical advance of CFD by developing increasingly elegant numerical solution algorithms and computer programs on faster computers. Beginning in 1979, Ballhaus guided the progression of CFD at NASA Ames through a succession of management positions, from branch chief to director of astronautics, and as director until 1989. Notably, he oversaw completion of the Numerical Aerodynamic Simulation facility (NAS), which was optimized for numerical solutions of complex engineering physics problems, especially in fluid flows. With the NAS, Ames became a leading center for the application of supercomputing power to aerospace research.

Ballhaus as CFD researcher: 1971–1979

Ballhaus' father, who had been a senior manager at Northrop, tutored him on the growing importance of computers in aerospace and whetted his appetite for executive management. Ballhaus earned all his degrees in engineering from the University of California, Berkeley, culminating in 1971 with a PhD and a dissertation on the interaction between the ocean surface and underwater blast waves.

Ballhaus joined the US Army's Air Mobility Research Development Laboratory at NASA Ames as a research scientist, and the army assigned him to the Ames CFD branch. Ballhaus arrived at Ames less than a year after Lomax had formally organized the CFD branch, and soon after Ames and the army had begun a collaborative research program to improve the aerodynamics of helicopters. This all came two years after Ames Director Hans Mark had begun reshaping the NASA Ames Center to place more emphasis on computing and on collaboration with other agencies.

Under Lomax's tutelage, Ballhaus studied complex nonlinear airflows associated with transonic speeds (near the speed of sound, like an advancing helicopter rotor blade). IBM's 360-series machines, released in the mid-1960s, allowed scientists to model these airflows in two dimensions. Ames had acquired an IBM 360/67 just before Ballhaus arrived, and he used it to calculate these airflows over 3D shapes.

Ballhaus teamed with Frank R. "Ron" Bailey to investigate 3D transonic interference problems. Two key papers provided the 2D foundation for researchers, like Ballhaus and Bailey, to expand their solution set into three dimensions and thus to the practical design of military and civilian aircraft.[1] The transonic speed regime is so interesting because that is where the aircraft generally optimizes both its cruise and maneuver performance. Air flowing over the leading edge of a wing accelerates from subsonic to supersonic speed. Thus, within a flow that is generally subsonic, there is a region of embedded supersonic flow over the wing that is usually terminated by a shockwave, the location of which is not known a priori. However, the mathematics used to analyze transonic flows about wings were in the form of nonlinear partial differential equations, even in their simplest approximate forms. In 1971, Ballhaus and Bailey invented a finite-difference methodology that solved these problems.

As Ballhaus remembered,

> With finite-difference methods, we divided the whole flow field surrounding the wing into small cells, literally millions, and wrote equations for each cell that expressed conservation of mass, momentum, and energy in that cell. We then used relaxation techniques to solve the resulting large number of algebraic (matrix) equations to determine the flow field variables, for example, velocity and pressure. Relaxation is a technique used to solve large matrix equations by starting with an initial guess at the solution and continuously refining it until an acceptable level of accuracy is achieved.[2]

At Mach numbers near one, 3D effects can run in a spanwise direction so, for example, the fuselage can significantly affect air flow over the wing. Ballhaus and Bailey developed

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Background of William Ballhaus Jr.

Education: University of California, Berkeley: BS (mechanical engineering), 1967; MS (mechanical engineering), 1968; PhD (engineering), 1971. **Professional experience:** NASA Ames Research Center: research scientist, 1971–1979; chief, Applied Computational Aerodynamics Branch, 1979–1980; director of astronautics, 1980–1984; director, 1984–1989; AIAA, president, 1988–1989; Martin Marietta: vice president, Space Launch Systems, 1989–1990; president, Civil Space and Communications, 1990–1993; president, Aero and Naval Systems, 1993–1994; Lockheed Martin, corporate vice president, Engineering and Technology, 1994–2000; The Aerospace Corporation, president and CEO, 2000–present. **Honors and awards:** H. Julian Allen Award, NASA Ames, 1977; Lawrence Sperry Award, AIAA, 1980; Arthur S. Flemming Award, Washington D.C. Jaycees, 1980; Fellow, AIAA, 1982; Fellow, Royal Aeronautical Society, 1985; Presidential Rank of Meritorious Executive, 1985; Member, International Academy of Astronautics, 1986; Eminent Engineer Award, Tau Beta Pi, University of California, Berkeley, 1986; Member, National Academy of Engineering, 1988; Presidential Rank of Distinguished Executive, 1988; NASA Distinguished Service Medal, 1989; Distinguished Executive Service Award, Senior Executives Association, 1989; Distinguished Engineering Alumnus, University of California, Berkeley, 1989; Fellow, American Astronomical Society, 2002; Honorary Fellow, AIAA, 2005; Von Karman Lectureship, AIAA, 2005.

a transonic wing code that extended the pathbreaking Murman-Cole algorithm to three dimensions.[1] To do so, they mapped the planform shape of the wing in the physical plane into a rectangle in the computational plane. As Ballhaus noted in a 1976 lecture, the assumptions that led to the derivation of classical small-disturbance equations are violated near-blunt leading edges and high angles of attack. This is because computed airfoil surface pressures depend on the spacing of the grid, or arrays constructed for the numerical experiment, near the airfoil's leading edge and the location of the leading edge relative to the grid points. For nonrectangular shapes, maintaining a sufficiently fine mesh, or set of grid points, along leading edges in a Cartesian coordinate system was impractical, given available computing power, because of the number of points required. The Bailey-Ballhaus code allowed a more efficient distribution of grid points and handled the complicating effect of geometry in their governing equation.[3]

Together with Lomax, Ballhaus and Bailey improved and tested their finite-difference code against wind tunnel data on aircraft wings. As a result, their code grew more reliable and more useful to aerospace designers. Their work in simulating 3D transonic flows about a C-141 wing directly demonstrated CFD's practical benefits.[4]

Ballhaus directed use of finite-difference codes to design the Highly Maneuverable Aircraft Technology (HiMAT) aircraft. The HiMAT was an experimental drone specifically designed to test flight concepts for high-maneuverability aircraft. After the wing design was refined using the Bailey-Ballhaus code, the HiMAT achieved a 20 percent reduction in transonic drag at maneuvering lift. The HiMAT and a videotaped interview with Ballhaus are both on display in the aerospace-computing gallery of the National Air and Space Museum.

The code was subsequently applied to the redesign of the wing of the North American Sabre 60 business jet. Designers of the Sabreliner wing modification increased the range of the aircraft by at least 27 percent and reduced fuel consumption by about 10 percent. Others used the code to design the Lear Allegro and the B-2 stealth bomber. Ballhaus grew convinced that computer simulation might soon have practical benefits by

> substantially reduc[ing] the time and cost involved in detecting design errors in much the same fashion that word processing reduces the time and cost involved in correcting errors in office correspondence.[5]

Ballhaus then leveraged the surging speed of computers to develop algorithms that calculated unsteady transonic air flows more efficiently. Together with Lomax, Ballhaus used so-called semi-implicit difference operators to solve the transonic, small-disturbance equation and its low-frequency approximation.[6] At the time, CFD researchers were focusing on low-frequency oscillatory flows because of their relevance to practical engineering applications. As Ballhaus noted, so-called explicit finite difference methods were "notoriously inefficient" when applied to low-frequency transonic flows because they had "an integration time step restriction for stability that is much more severe than the one required to adequately resolve the unsteady flow field."[7] Explicit methods solve the governing partial differential equations by integrating forward in time using flow-field variable information (like pressure and velocity) from the previous step. Semi-implicit and fully implicit methods require solving a coupled set of algebraic equations in terms of flow variables at the new time step. The use of semi-implicit operators resulted in a "considerable increase in efficiency," usually by more than one order of magnitude. For example, the Ballhaus-Lomax code took 6 minutes of runtime per cycle on a CDC 7600 to analyze the pitching oscillations of the NACA 64A410 airfoil; by contrast Magnus and Yoshihara's explicit, "time-accurate" procedure[2] required 210 minutes.[7]

Ballhaus and colleagues then developed fully implicit approximate-factorization (AF) schemes that were more computationally efficient than the Ballhaus-Lomax semi-implicit algorithms. Ballhaus and Joseph L. Steger used AF algorithms to overcome the time step limitation imposed by the Ballhaus-Lomax code near singular points, where small-disturbance assumptions are violated, such as an airfoil's leading and trailing edges.[8]

Ballhaus researched more efficient computational methods for predicting unsteady loads on aerodynamic bodies with Peter Goorjian, a research scientist with Informatics Corporation, located in nearby Palo Alto. They demonstrated the relative efficiency of the so-called indicial approach in computing unsteady transonic flows, which calculated unsteady aerodynamic coefficients for a wide range of frequencies from a single flow-field computation. In doing so, they applied the theoretical work of Lomax, who had developed the approach during the early 1950s in his investigation of 2D and 3D unsteady lift problems at transonic speeds.[9]

Ballhaus and Goorjian also developed LTRAN2, a computer code designed to calculate unsteady transonic flows more efficiently than explicit algorithms. The code used an implicit-difference algorithm that integrated the nonlinear, low-frequency transonic small-disturbance equation on a so-called time-accurate basis. Ballhaus and Goorjian designed LTRAN2 to treat arbitrary combinations of airfoil pitch, plunge, and flap deflections so that it would prove valuable to aerodynamic engineers who sought to increase their understanding of transonic flows' physics. They showed that computed solutions compared favorably with linear theory results, for which there were closed-form mathematical solutions. They also demonstrated good agreement with wind tunnel measurements for different types of irregular shock wave motion induced by the unsteady motion of airfoils.[10] At the same time, Ballhaus developed AF schemes to accelerate convergence rates for steady-state solutions. This allowed solutions to be obtained in an order of magnitude less computer time.[11]

Ballhaus's research advanced in step with Ames's acquisition of increasingly powerful computers and he applied his findings to practical aircraft designs. For example, the code that Lomax, Bailey, and Ballhaus used to analyze transonic flows about the C-141 wing required about 12 hours per solution and several days in turnaround time on the IBM 360/67. The CDC 7600 allowed two turnarounds per day, increasing the number of improvements that researchers could make in their codes. It allowed researchers to write code that was reliable and robust enough to interest the aerospace industry.[12]

The Illiac IV, which Ames acquired in 1970, was powerful enough for researchers to handle complete aircraft shapes for nonlinear airflows and model viscosity for simple shapes. As the world's first parallel processing supercomputer, the Illiac IV was powerful enough to complement wind tunnels in the aerodynamic design and testing process. More computing power was required, however, if the computer were "to displace the wind tunnel as the principal facility for providing aerodynamic flow simulations," as Dean R. Chapman, Ames's director of astronautics during the 1970s, and Hans Mark, Ames's director from 1969–77, forecast provocatively in a 1975 article.[13]

Ballhaus distinguished himself as a researcher, publishing more than 40 papers on computational aerodynamics, and fueling the reputation of the Ames CFD group as a world-leading organization. In 1977, Ames management honored him and Bailey with the H. Julian Allen Award for best paper published by a member of the Ames staff. Mark noted that the paper reflected favorably on the arrangement between the army and Ames, which enabled researchers to "do their best work."[14] Subsequently, Ballhaus received recognition for his work from others, including the American Institute of Aeronautics and Astronautics (AIAA) and the National Academy of Engineering.

Ballhaus as NASA Ames Manager: 1979–1989

Like Lomax, Ballhaus was a natural mentor. Aerodynamicists from universities and companies around the world spent time at Ames to learn the state of the art in CFD, and when they returned home they remained networked into the computers and research groups at Ames. In 1979, Ballhaus first moved into the Ames' formal organization when he was named chief of Ames' new applied computational aerodynamics branch. A year later, Ballhaus succeeded Chapman, upon his retirement, as director of astronautics. Ballhaus held that post until he became Ames's fifth director in 1984.

As a manager, Ballhaus's goal was to give shape to the numeric wind tunnel. He wanted Ames to be solving more complete aircraft configurations, like a full aircraft shape instead of just a wing. He wanted simulations to include viscosity, turbulent flows, and separation. He also wanted Ames to solve the complex aerodynamic problems, notably of the Space Shuttle launch stack and of the F-16 at high angles of attack. The Ames budget saw dramatic increases

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William Ballhaus Jr. considers the following works on CFD to be his most significant:

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H. Lomax, F.R. Bailey, and W.F. Ballhaus, *On the Numerical Simulation of Three-Dimensional Transonic Flow with Application to the C-141 Wing*, NASA TN-6933, 1973.

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W.F. Ballhaus, "Computational Aerodynamics and Supercomputers," *Proc. 28th Int'l Conf. IEEE Computer Society*, IEEE CS Press, 1984.

in the late 1980s, during Ballhaus' tenure as director, and some of this funding breathed life into the NAS, housed in building 258 on the Ames campus.

Initially conceived in 1975, the architects of the NAS, led by Bailey, who led the original task team and became the project's manager, sought to develop a distributed computer network that might be easily and continuously upgraded as newer supercomputers came online. The NAS would have the speed and memory to "estimate the performance of relatively complete aircraft configurations, but also to serve as an effective tool to study the physics of turbulent flows, a subject eluding researchers for more than 80 years." After eight years of study, during which the initial operating capacity was increased significantly, NASA approved a finalized plan for the NAS in February 1983.[15]

As Ames director, Ballhaus continued to secure resources for the NAS and helped bring it online. First, Ames built a 90,000-square-foot building on an empty corner of the campus, and connected it to massive electrical and data cables. A Cray-2 supercomputer—installed in late 1985—supported the evolving testbed network. In July 1986, Ames unveiled the system at its Interim Initial Operating Configuration conference. After several months of additional testing by more than 200 users at Ames and 20 remote sites, the NAS's initial capability became operational. Dedicated in March 1987, the NAS constituted the evolving capability that NASA hoped would bring supercomputing and visualization to many other areas of aerospace research.

The NAS housed a networked collection of supercomputers, which together had 200-to-300 times more processing capability and 10 times more memory than the Illiac IV. At the time, NASA Ames housed the world's greatest collection of wind tunnels, which were growing increasingly expensive to operate. A simple model could cost $1 million to build. Ballhaus advanced CFD to enhance the work of the wind tunnel. Parametric variation could be done cheaply on the computer and then the refined design would be validated in the wind tunnel.

Over the two decades since it opened, the NAS has proved its value as a flexible, pathfinding facility. There, NASA pioneered new technologies. The routers and networks supporting the NAS eventually served as the backbone of the commercial Internet as well as most of NASA's information technology. Likewise, the supercomputers installed at the NAS several times over the years were benchmarked among the fastest in the world. And the NAS helped NASA pioneer new computation and visualization-intensive scientific disciplines, such as computational chemistry and nanotechnology, as well as continuing advances in CFD.

Ballhaus after NASA: Post 1989

Ballhaus's career at Ames ended abruptly in the summer of 1989. In February 1988, NASA headquarters tapped Ballhaus as acting associate administrator for aeronautics and space technology. For a year, he managed NASA's three research centers: Ames, Langley, and Lewis. During this time, he also served as president of the AIAA. In March 1989, he returned to Ames as director. Then, in July 1989, he resigned, citing inadequate compensation for senior federal executives and vague new post-government employment regulations. The situation at the time resulted in "the premature loss of many talented executives in NASA."[16]

Ballhaus moved into the private sector, joining the Martin Marietta Astronautics Group in Denver as vice president and program director of the Titan IV Centaur program. From 1990 to 1994, he served as president of two Martin Marietta businesses, Civil Space and Communications in Denver and Aero and Naval Systems in Baltimore. Following the merger of Martin and Lockheed, in 1995 he became vice president of science and engineering at Lockheed Martin headquarters in Washington, D.C. There he authored improvements to Lockheed's engineering process and participated in Lockheed Martin's merger transition activities during the defense industry consolidation of the late 1990s.

In September 2000, he became president, and soon after chief executive officer, of The Aerospace Corporation, a California-based nonprofit corporation focused on strategy and systems research into America's space security issues. "We're the repository," Ballhaus said, characterizing the work of Aerospace, "for lessons learned in the space business and we understand all of the systems that make up the national security space infrastructure."[3]

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