National Aeronautics and Space Administration, Ames Research Center, Moffett Field, CA

October 2003

Astrogram

Communication for the Information Technology Age

For 45 years, Ames pioneers NASA science and technology

Re-interpreting Ames' history

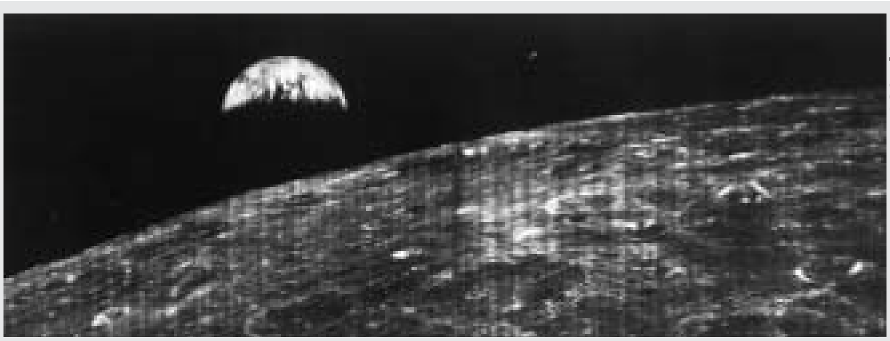
This month, NASA Ames Research Center celebrates 45 years as one of the pillars of the National Aeronautics and Space Administration. Ames stands as an extraordinary repository of high-tech equipment, research laboratories and facilities to support humankind's conquest of the atmosphere and the exploration of space. That physical infrastructure supports what Ames truly is--a growing and evolving community of researchers and managers. It is a community with a fertile, open and pan-disciplinary culture, driven by people who have contributed all they know to all that NASA has accomplished over the past 45 years.

In this anniversary year, Administrator Sean O'Keefe has asked everyone in NASA to re-engage the spirit that has made NASA so great. NASA people are being encouraged through the 'One NASA' effort to move beyond any segmented, rule-based, bureaucratic mindset. Years of wasteful "divided-pie" competition between NASA centers and the "not-invented-here" dismissal of new ideas have clouded NASA's historical spirit. Rules are the vestiges of tough times for the organization. Rules proliferate whenever organizational cultures weaken, whenever futures are uncertain, and whenever individuals cannot take personal responsibility for their work. Eventually rules can replace common sense as well as a sense of the common good and common goals.

'One NASA' is reinvigorating Ames by giving people the freedom to manage, the freedom to challenge outdated procedures, the freedom to take responsibility for the full cost of a program, and the freedom to move financial and management information across artificial organizational barriers. We will see this spirit flourish as Ames contributes its expertise to returning the space shuttle to flight following the tragic loss of the Columbia and its crew. Such tragedies display how all the people and pieces of NASA are fit so closely together. The Columbia Accident Investigation Board made good use of Ames' resources while conducting its investigation, and Ames will certainly be called upon to step up to the challenge of implementing the outlined changes.

At Ames, we have an obligation to explore our history--not only to remember the past, but also to reinterpret the past in light of current questions. To understand 'One NASA' today, and how we will return Americans to space flight, we need to look back at NASA during its Apollo years and during the early shuttle years. Doing so may help us understand how these histories serve as historical analogy for what we want NASA to once again become.

-- Jack Boyd, Ames Senior Advisor for History



NASA photos

The first view of the Earth taken from the moon in August 1966. The photo was transmitted to Earth by the U.S. Lunar Orbiter I and received at the NASA tracking station at Robledo De Chavela near Madrid, Spain. This crescent of the Earth was photographed when the spacecraft was on its 16th orbit and just about to pass behind the moon.

The Apollo encounter with our moon was one of the defining events of the last century. Apollo forever changed the way we look at the moon, at the Earth and at NASA. Anyone over the age of 30 can look up at the moon today

Chicago welcomed the Apollo 11 astronauts with a ticker tape parade in 1969.

and personally remember that 12 men once walked there. They can recall how thrilling were those late-night, black-and-white images of the small plots of lunar soil around where the lunar landers camped. For those under 30--and that includes some holding PhDs in space science, and some with star-struck kids of their own--they learned that the last man to have trod the lunar landscape did so before they were even born. When these youngsters think about the moon and wonder why we have only returned to the moon twice since then, once through a robotic probe developed by NASA researchers at Ames, perhaps they conclude that that early generation of explorers found the moon an even more barren rock than they had imagined. Apollo changed how we think about our moon.

When we think about our Earth in our post-Apollo age, by comparison with the moon, we see it as even more life-giving. Before Apollo, school kids imagined the Earth like a brown Mercator projection lined with political divisions. After Apollo, we envision the Earth--as first did the Apollo astronauts--as that fragile orb of interlaced green, blue and white suspended in the black vastness of space. Life on Earth now inspires even more wonderment.

And when we think about NASA, there may also be a generational divide.

R. T. Jones, Ames theoretical aerodynamicist, performs calculations in his NASA laboratory.

Some envision NASA as that can-do team of brainy young men and women--some wearing thick black glasses and others wearing thick white space suits--who achieved what once seemed impossible and did so before that decade was out. Perhaps others envision NASA as scientists in orange jump-suits, looking down upon Earth while floating free from gravity but simply off to their jobs.

Of course, the story of NASA then, like the story of NASA today, is vastly more complicated and interesting once we look deeper. And as Ames' life with NASA reaches its 45th anniversary, it is worth exploring how the historical analogy to the Apollo years—and to the early shuttle years--illuminates the 'One NASA' effort of today.

Ames during Apollo

Apollo was a time of sweeping cultural change within NASA. Yet Ames probably changed the least of all the centers, as the National Advisory Committee for Aeronautics was absorbed into NASA in October 1958 and as NASA became preoccupied with Apollo in 1962. Smith DeFrance kept Ames the way he had built it, as director from its founding in 1939 though his retirement as director in 1966. DeFrance was succeeded as director by H. Julian Allen, a paradigm-shifting aerodynamicist completely imbued with the NACA spirit of relevant but free research. The first 'A' in NASA stands for aeronautics, and during the Apollo years Ames did much of the work that needed to be done on aircraft so that the new NASA centers could focus on space travel.

H. Julian Allen, a paradigm-shifting aerodynamicist, served as Ames director during the Apollo years.

Apollo launch escape system being tested in the Ames unitary wind tunnel, 1963.

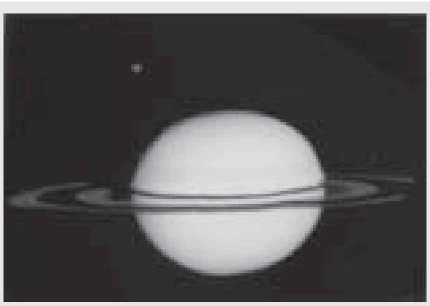
Ames still contributed much to NASA's Apollo mission--in terms of science, technology and culture. During the Apollo years, competition between centers was vigorous and heartfelt. The pie of increased funding was growing, regardless of how funding was apportioned. Every member of the new NASA felt free to contribute their best efforts to the mission, they could get support and protection from their center and new ideas were welcome throughout the administration. The culture was competitive largely because the intra-NASA peer review system, which NASA inherited from the NACA, went into overdrive. NASA people also felt free to criticize--constructively, and in scientific reports or around meeting rooms--any new idea being offered. And there was enough money available that the thrust-and-parry of new ideas encountering peer-critique could usually be ended by cutting metal and strapping sensors to it in order to prove the point. Ames representatives to NASA committees especially earned a reputation for their 'show-me' attitude.

Furthermore, DeFrance and Allen enjoyed the freedom to manage their center, because James Webb at NASA headquarters respected their judgment. Research leaders within Ames also enjoyed the freedom to manage their groups because DeFrance and Allen continued the NACA tradition that all communication to and from headquarters—or to their scientific colleagues at Langley or Lewis--go through the director's office. NASA headquarters slowly opened up direct lines of communication to researchers within Ames--notably in the way it structured Ames' life sciences efforts--but DeFrance and Allen fought hard to minimize interference from Washington.

The result was a 'One Ames' spirit that allowed DeFrance and Allen to move many new types of researchers into the center without cultural conflict. One strategic enterprise dominated most of the centers set up by NASA, or re-shaped by NASA. JPL came to focus on robotic explorers, Goddard on Earth observation, Marshall on propulsion, Kennedy on launch vehicles and Johnson on human space flight. At Ames in the 1960s, as today, most all of NASA's strategic enterprises were pursued--aerospace, information technology, human factors, space and Earth science and aeroflightdynamics. Each enterprise was weighted equally by the management of the center and each looked for fertile areas to explore along their borderlands.

Life Sciences, Information Technology and Aeronautics

Life sciences, information technology and aeronautical research were prime examples of the inclusive research tradition at Ames. Life sciences, especially, grew at Ames over the past 45 years like a river--fed by streams, splitting around rocks, merging again around a new idea, sometimes branching and pooling and accelerating as channels deepen. This perambulation into sundry research efforts frustrates attempts to write a linear history of the life sciences at Ames, though it made the ride all that more thrilling for those who lived that history. Furthermore, one might think that during the go-go years of Silicon Valley, secure government jobs might have been seen as a drain on the



Pioneer 11 image of Saturn and its moon Titan, 1979.

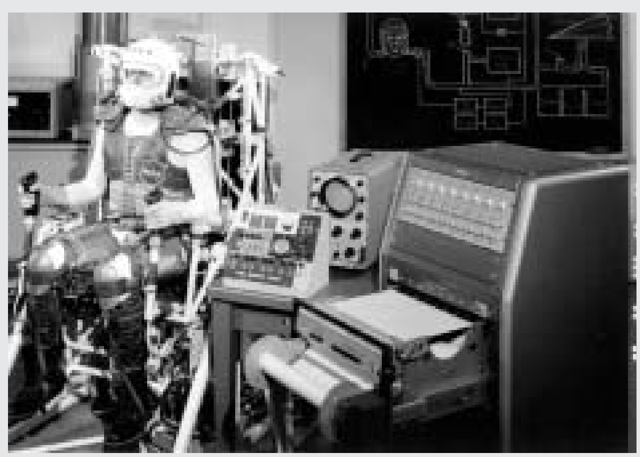
economy. Instead, Ames people, like all those who built Silicon Valley into an epicenter of biotechnology and computing, persistently figured out ways to make their work both cutting-edge and cross-pollinating. There is nothing linear about how they have collaborated.

Viking Lander soil sampler arm being tested, 1971.

Ames began research on living subjects in the early 1950s when it started building simulators to improve the analog computers behind aircraft controls. With the birth of NASA in 1958, Ames was asked to invent and build more sophisticated simulators for studying how human pilots could control the coming spacecraft. From there, Ames developed expertise in the design of space suits that could support life in space while permitting a wide range of functionality. And Ames began its work in miniature biosensors that could monitor and diagnose the health of astronauts sealed, far away, in space suits and capsules.

NASA headquarters, seeing how well biologists adapted to the research environment at Ames, asked DeFrance to take on more life sciences work. DeFrance then hired Chuck Klein to coordinate those efforts, and Klein did a masterful job of growing the life sciences within the 'One Ames' culture inherited from the NACA. Ames built for NASA a comprehensive laboratory for more fundamental studies of human adaptation to weightlessness, and built the biosatellite capsules to carry the first pure biology experiments into space. University scientists working at Ames then used all NASA was learning about the chemical composition of the universe to theorize about what sparked life on Earth. Exobiology flourished at Ames as very fundamental science, though NASA applied it very concretely to study why the moon did not support life.

NASA continued to find uses for the life sciences capabilities at Ames. Exobiologist teams built instruments for the Viking Lander in 1976 to study the prospects of life on Mars, and analyze the chemical composition of the planets passed by the Pioneer series of satellites. A series of ever more powerful infrared telescopes--like the Kuiper Airborne Ob-



Closed loop breathing system, 1963, to study life support in space.

servatory--returned new information about the chemical composition of the solar system and generated new insights on the formation of planets. Meanwhile, NASA researchers at Ames continued their work on flight simulators--for new generations of piloted spacecraft and rotorcraft and to study human adaptation to long stays in space. And they managed experiment packages sent aloft to study how other creatures adapted to microgravity--on Skylab, on the shuttle orbiter and on a series of Cosmos/Bion flights with the Soviet space agency.

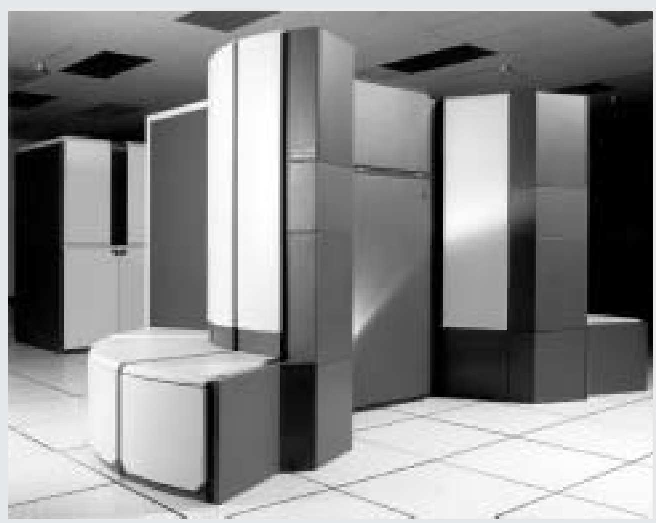
An exercise device, 1990, for studying the effect of weightlessness on astronauts.

NASA researchers at Ames then brought their space biology work back home. They turned what they learned about the atmospheric observation of other planets to look at the ecosystem of the planet Earth with new technologies and new theories. Ames hosted a fleet of NASA science aircraft, like the DC-8 and the ER-2, that served as airborne platforms available to carry interesting experiments devised by scientists at other centers, at universities or from around the world. Micro-electrical mechanical systems (MEMS), now a huge industry on Earth, grew directly out of work by John Hines in collaboration with university and government researchers to develop miniature biosensors for space. All of this work at Ames coalesced in the 1990s in a series of inclusive NASA projects--on astrobiology, air traffic systems and telemedicine.

During the NACA years, Ames had been organized by facilities. By the mid-1960s, it was organized by scientific discipline. By the mid-1990s, it was organized by tasks that could only be solved by the aligned efforts of many people.

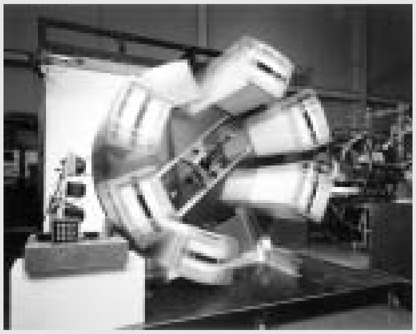
Information technology at Ames started later than the life sciences, though its history also displays the same perambulation. At first, the computers at Ames were mathemeticians, hired to work through equations and compile vast amounts of experimental data. Ames began using analog computing machines to simulate flight controls, and in the early 1960s, added a few digital computers to compile wind tunnel data and handle administration. In 1972, Ames acquired the Illiac IV supercomputer, which Harvard Lomax used to create the field of computational fluid dynamics. Over the next two decades, NASA researchers at Ames bought and debugged almost every new generation of supercomputer. They also figured out how to share them and invented protocols for distributed computing that underlay the development of the Internet. They also invented all types of CFD codes, software that graphically modelled how air flowed over an object and thus moved much of aircraft development from the wind tunnel into the computer. Ames applied its basic expertise in modelling air flows to model heat flows, chemical interactions, microorganisms, molecular structures and the thermal evolution of the galaxies. The amount of computing time it takes Ames to do a model of global climate change, for example, continues to drop. When NASA researchers at Ames matched their computing power with new telecommunication technologies, they became experts in surface rovers, robotics, virtual landscapes and, connecting back to the life sciences, in air traffic systems and telemedicine.

The dawn of the space station era in the mid 1980s shifted the emphasis of Ames work in information technology into intelligent systems, that is, computing systems that extend decision-making support into spacecraft far from Earth. NASA researchers at Ames developed systems to plan and schedule major NASA missions, systems to monitor and diagnose space vehicles and the equipment they carry, systems to analyze vast amounts of space science data, and systems to assist both ground-based scientists and astronaut-scientists in the conduct of experiments. Ames brought into use a host of specific applications arising from its basic work on intelligent systems. A laptop-based experiment assistant was used by astronaut Shannon Lucid on a vestibular biology flight experiment. The Mars Exploration Rover science teams at JPL use a number of collaborative tools developed by NASA researchers at Ames. Ames today has more people working on information technology than in any other federal laboratory, and NASA uses this capability extensively.



Ames advanced both the mathematics of computational fluid dynamics and the hardware on which it was done: the Cray Y 190A in 1990.

Aeronautics was Ames' earliest research discipline, and DeFrance allowed it to evolve in new directions during the



Space station centrifuge mockup, 1987, used to support life science experiments in space.

1960s, as has every center director since. Ames built the world's greatest collection of wind tunnels, then routinely rebuilt its tunnels and invented new test instruments to keep them relevant to all kinds of flight. Ames maintained a fleet of research and flight-test aircraft, and in the 1980s managed NASA's flight research center at Dryden, Calif. Some of the most fruitful research efforts in aircraft research blossomed on the borderlands of the traditional aeronautical disciplines. Ames' work on digital 'fly-by-wire' flight controls melded its work on information technology and human factors, as did Ames' comprehensive research program on pilot workload and safety.

One flight research program that made good use of every area of expertise at Ames was the development of tilt-rotor aircraft, like the joint NASA-Army XV-15 prototype that first flew in 1976. Tiltrotors are aircraft that ascend from the ground like a helicopter, then rotate their propellors forward to fly like an airplane. During the 1960s, while the rest of the aerospace industry focused on how to builder sleeker and faster aircraft--using research results generated earlier at Ames--aerodynamicists at Ames studied the less glamorous question of how to keep these aircraft aerodynamically stable as they slowed down to land.

From this work in slow airspeeds, Ames developed a research program in V/STOL aircraft--those that could take off vertically from an aircraft deck or land on short runways like those in Southeast Asia. Throughout the 1960s and 1970s, Ames tested all types of V/STOL aircraft, including the AV-8B Harrier. They learned that every rotor, including those on helicopters, generates very complex airflows. Ames turned its expertise in CFD to modelling these airflows and it built new wind tunnel facilities--including an 80-by-120-foot test section on its large-scale tunnel--to test rotorcraft to high Reynolds numbers and without wall interference. Ames built simulators to test new designs for digital flight controls for rotorcraft, and to train rotorcraft pilots on the many types of flight situations they would encounter. Into the 1980s, Ames continued to provide scientific support to the Army and to industry as they brought rotorcraft to the field. Then Ames aeronautical researchers turned their expertise in many aeronautical disciplines to improving helicopters. Rotorcraft research at Ames continues to display its pan-disciplinary culture.

Deciding What Ames Was Not

Historically, it also is important to remember the fields Ames did not enter. Even when money was available, DeFrance demurred from taking on projects that did not leverage the research culture at Ames. For example, throughout the 1960s there were NASA engineers at Ames eager to take on management of complete space programs. NASA headquarters encouraged them. Program management then was a creative art, advancing rapidly at the time throughout science, industry and government. Program management got most creative as it got closer to the engineers cutting metal or the scientists compiling the results, in understanding the dynamic tensions of piecing together all the people and the pieces. Ames did a great job managing its wind tunnel projects, then considered very high technology, and could have done well managing space projects.

The XV-15 prototype in a hovering test over Ames, 1976. The XV-15 was recently installed in the Udvar-Hazy Center of the National Air and Space Museum as a pioneering rotorcraft aircraft.

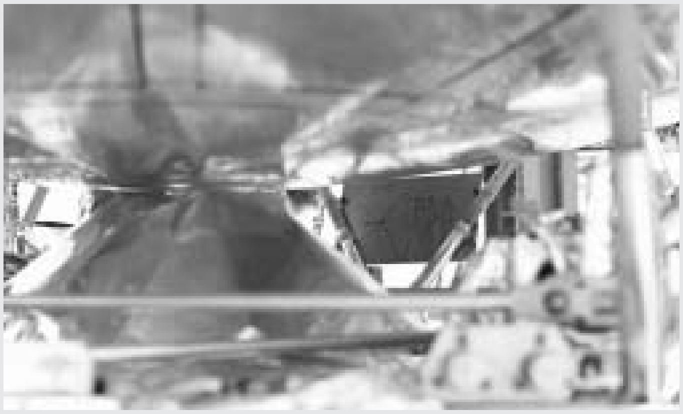
Yet DeFrance demurred. Only the biosatellite and the M2-F2 lifting body prototype emerged as completed projects during his watch and afterward Ames never managed complete projects on the scale of the other centers. However, the projects that NASA people at Ames did manage--notably the Pioneer satellite, the Galileo probe, the Lunar Prospector, a series of infrared telescopes, the space station biology laboratory, the Mars rovers--were notable for their low cost and timely performance, their collaboration with university scientists and for the brilliance of their results.

DeFrance also was cautious about developing expertise at Ames that would not complement its existing strengths. For example, because of mathematical work at Ames culminating in the Kalman-Schmidt filter, a navigation algorithm, NASA people at Ames could have lead the work in the early 1960s on defining the flight envelop for the Apollo missions. DeFrance encouraged the aerodynamicists hired during the NACA years to branch into new areas, to reinvent their careers, to seek new relevance for their work. They were, after all, all very bright people who could make an impact wherever they turned their attention. While NASA would later task Ames to use its computing power to improve air and space navigation, at that time DeFrance thought it was too far afield from what NASA more clearly needed from Ames—leadership on thermal protection systems and space science.

Apollo Technology

Ames researchers quietly contributed to the Apollo mission. Public attention focused on the spectacular—powerful rockets, massive spaceports, mission control centers and charismatic astronauts. Ames hosted none of these spectacles. Perhaps the most exciting photographs to emerge from that era, around here, were of tiny capsule models ablaze in a high-speed and high-temperature tunnel or ballistic range. Instead, behind the scenes, Ames researchers gathered knowledge about new scientific fields and tested their technologies with painstaking precision. And they did so with a style that was uniquely Ames. Researchers with many areas of expertise discussed their work persistently and freely, then cooperated to bring every tool they had to solve a very complex problem. And they were given the freedom to work quickly and to their own ideal of thoroughness.

Ames developed some key Apollo technologies, most importantly technologies to allow the astronauts to return safely to Earth. Building upon what was already two decades of research on



Ames mounted a special plaque to the Pioneer 10, the first spacecraft to exit humankind's solar system, in case it was found by others. The plaque used scientific symbols to indicate where Pioneer 10 had come from and a line drawing to depict what those who built it looked like, generally.

re-entry physics and material science--a discipline today known as aerothermodynamics--NASA researchers at Ames devised the basic shape of the Apollo capsule and its thermal protection system. Today, almost 60 years later, all spacecraft are still derived from essential insights learned at Ames.

Before Ames began its work, many thought that a spacecraft re-entering the Earth's atmosphere at meteoric speeds would, like a meteor, burn into a fireball. Those who speculated about spacecraft design suggested pointy, cone-shape tips of hardened metal to pierce the atmosphere with the least possible friction and the slowest possible melting. Harvey Allen stepped outside the conventional thought, and took an entirely fresh approach. (Appropriately, the H. Julian Allen Award is presented each year to the scientists at Ames who do the most creative and relevant basic research.) In 1948, Allen advanced the blunt-body concept, which was further developed by Al Eggers and Dean Chapman.

Lunar Prospector in an Ames clean room, mated atop the Star 37 trans lunar injection module, 1997.

They conceptualized that, with a blunt body, atmospheric air would still heat up as it crossed the bigger bow shock wave in front of the spacecraft. However, that air would be heated at a distance from the spacecraft, then pass harmlessly around it and into the wake of gas behind the body. With less heat near the spacecraft, different types of heatshield materials could be imagined. Such a radical idea met with resistance, so Ames set about to prove it.

Atmospheric entry simulator, 1959, used to determine if a specific shape can survive atmospheric re-entry.

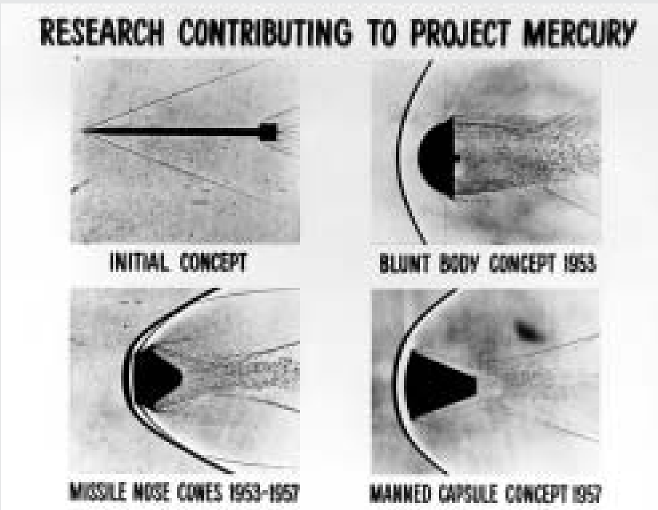
Ames then used its practical expertise in wind tunnels and its theoretical expertise in hypersonics and built free-flight tunnels to determine which precise blunt-body shape would be best during re-entry. These ballistic ranges shot tiny metal models into an onrush of air to reach the actual velocities at which they would enter the atmosphere, while delicate instruments recorded the results. These test runs led Thomas Canning to discover that the best shape for retaining a laminar boundary layer, and thus minimizing heat transfer to the capsule, was a nearly flat front face to the blunt body. They also checked these shapes for lift and drag and for aerodynamic stability—so a capsule would not start to tumble. Based on these tests, NASA selected this shape for the Mercury, Gemini and Apollo capsules.

Alfred J. Eggers in the Ames hypervelocity ballistic range.

Once Ames demonstrated which specific blunt-body shape worked best, work began on picking the best materials to protect it. Since no known materials could insulate against that kind of heat, Morris Rubesin, Constantine Pappas, John Howe and other NASA researchers at Ames developed an ablative heat shield. Ablation meant that the heat shield material was slowly consumed by burning and vaporization, but as it burned it transfered heat into the atmosphere and away from the underlying metal frame of the spacecraft. Surface transpiration also reduced skin friction, which kept the spacecraft more aerodynamically stable.

Ames people then invented and built arc jet tunnels to prove which were the best specific ablative materials. Arc jets are a type of wind tunnel that generated very hot gas flows for minutes so that re-entry heat could be simulated both in terms of temperature and chemistry. Aerospace firms then designed ablative heat shields for the Apollo capsules. These then were tested again by John Lundell, Roy Wakefield, Nick Vojvodich and others in Ames' arc jet complex.

The result was superb performance from all the Apollo spacecraft during their re-entry into their home atmosphere.



Shadowgraph images, 1960, showing shockwaves around possible re-entry shapes.

Apollo Science

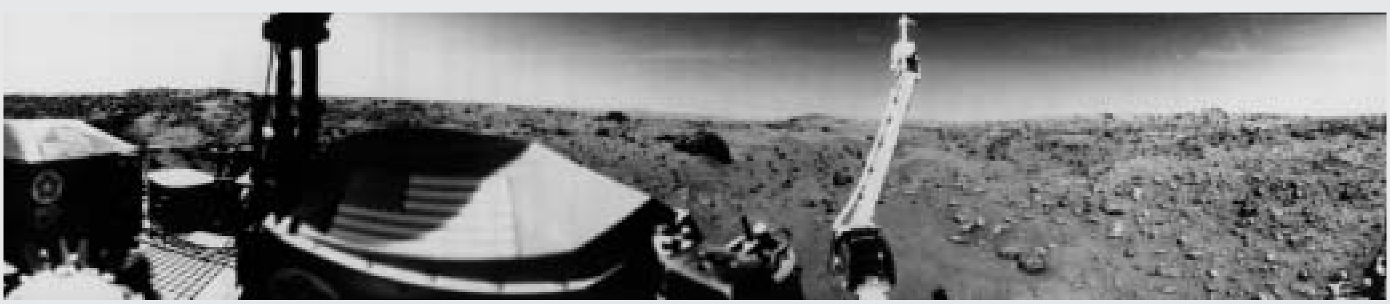
And upon their return home, the Apollo astronauts had much good information to convey. Ames had formed a space sciences division in 1962 to maximize all we learned from the Apollo mission. Ames scientists analyzed samples of rock and soil taken from the moon, studied the lunar craters and measured lunar magnetic fields.

Apollo astronauts spent a total of 340 hours on the lunar surface and carried back to Earth more than 840 pounds of lunar rock. Only at Ames and JSC did NASA build lunar receiving facilities to analyze soil samples returned from the moon. JSC would identify and isolate hazardous materials in the samples; Ames would explore the essential composition of the lunar materials. So Ames built a very clean laboratory and outfitted it with unique equipment. They observed the carbon chemistry of the samples, and concluded that they did not contain life. This led them to question what kind of carbon chemistry happens in the absence of life. They discovered that the moon was being constantly bombarded with solar wind and micrometeorites, which left the moon with a carbon chemistry dominated by the energetic interaction of the sun, the moon and cosmic debris.

Ames space scientists also devised magnetometers to study the moon's composition and its magnetic fields. Four Apollo missions flew Ames magnetometers to different sites on the surface of the moon, and two portable magnetometers carried aboard the lunar rovers measured magnetic fields while in motion. These revealed much about the moon's geophysics and geological history. For example, the moon did not have two-pole magnetism like Earth but did have a stronger field than expected. They also revealed that the moon was a solid mass, without a molten core like the Earth. Transient magnetic fields were induced by changes in the solar wind. Based on this magnetometer data, NASA developed an orbiting satellite to map the permanent lunar magnetic fields, as well as equipment to measure magnetism in other bodies throughout our solar system.

NASA scientists at Ames also devised an ingenious method for doing basic planetary science with what they learned during the re-entry testing of the Apollo spacecraft. Al Seiff, in a brilliant bit of scientific opportunism, proposed sending small spacecraft to Mars and Venus to gather the first hard data on their atmospheres. Seiff inverted the re-entry problem. Rather than developing a new vehicle to better enter Earth's known environment, he proposed dropping a blunt-body vehicle of known aerodynamic characteristics into an unknown atmosphere.

First, of course, Ames tested the concept. They started by sending various gases--of the sort that might enshroud other planets--through ballistic ranges and arc-jets to see how blunt bodies reacted to them. In 1971, Sieff managed the planetary entry experiment test into Earth's atmosphere, to demonstrate that one well-designed probe could gather data on the structure of an upper atmosphere based on aerodynamic responses during hypersonic entry, could directly measure the temperature and pressure of a lower atmosphere once slowed with a parachute, and could gather data about an atmosphere's chemical composition through mass spectroscopy analysis of the hot bow shock wave. And a probe could telemeter all this data back to NASA before smashing into the planet surface. Working closely with colleagues at JPL, Langley, Goddard and industry, Ames sent probes into the atmospheres of Mars with the Viking in 1976, of Venus with Pioneer Venus in 1978, and Jupiter with Galileo in 1995. For very little money they returned spectacular data about the composition of planetary atmospheres.



First picture of Mars, 1976, taken from the martian surface.

Space Shuttle

As with Apollo, Ames' contribution to the space shuttle included both shaping the technological choices and analyzing the scientific results to make the most of what we learned from each flight.

M2-F1 lifting body, shown in a tow test at Dryden in 1964, set design parameters for the shuttle orbiter.

In much the same way that Ames' research defined the basic shape of the Apollo capsules, Ames work on lifting bodies by Sy Syvertson and Al Eggers also defined the shape of the space shuttle orbiter. The lifting-body program represented perhaps the waning of the NACA spirit within NASA. Three former NACA centers—Ames, Langley and Dryden—each offered competitive proposals for what the design should look like. They critiqued each other's designs, collected wind tunnel data to justify their changes, then built inexpensive prototypes to test in the air. Competition was intense, but there was a common direction, and they trusted and respected each other. By collaborating they freed up funding for more research, and when the nation was ready to commit to building the space shuttle in the early 1970s, NASA had in place strong tools for teamwork.

The shuttle orbiter also is basically a blunt re-entry body, complicated with aerodynamic control surfaces. The orbiter approaches re-entry at a very high 40- degree angle of attack to present its entire blunt underside as it rushes into the increasingly dense air at 25 times the speed of sound. After a long and fiery re-entry, the orbiter dissipates speed through a series of sweeping 'S' turns. Once the orbiter goes subsonic, its angle of attack is reduced so that while landing--unpowered-- it can be piloted like an airplane. Ames people, with the same spirit of fluid cooperation, made possible each step in this complicated landing process through differing flight regimes.

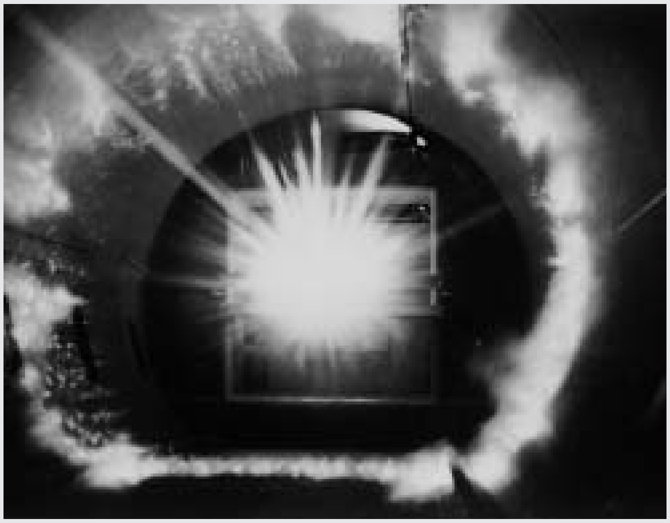
As with the Apollo spacecraft, Ames started by anticipating the airflow environment around the shuttle during reentry. Hot gases that envelop the orbiter reach temperatures as high as 25,000 degrees Fahrenheit and heat the underside tiles of the orbiter to as much as 2,500 degrees Fahrenheit. Before, Ames researchers devised the three-dimensional, real-gas, computational fluid dynamic codes to make such calculations more precise for each part of the orbiter, they painstakingly estimated the rates and intensity of heating over the entire surface of the shuttle. Though the specifications for constructing the orbiter thermal protection systems simplified the definition of the expected heating, Ames researchers demonstrated that the tiles must work better than specification. These calculations were followed by tunnel tests to verify the shape of the bow shock wave and suggest modifications to the orbiter shape.

Its mission defined the space shuttle as reusable, which meant it could not have an ablative heat shield that burned away. Yet Ames' work on ablation had led into work on glassy meteorites called tektites, which led into work on ceramic tiles that deflected heat from the shuttle orbiters. Using their arc jets, researchers from Ames and JSC evaluated all likely candidate materials for use as shuttle tiles. One of these was the LI-900 silica tile developed by Lockheed Missiles and Space Company nearby in Sunnyvale. NASA selected this as the baseline material for a vigorous tile improvement program to come, led by Howard Goldstein. In 1973, Ames showed how the purity of the silica fibers in the tiles affected their shape and thus their performance. Ames invented a black borosilicate glass coating called 'reaction cured glass' that radiated heat back into the shockwave and was adopted by the shuttle program managers in 1977. These improved tiles could be glowing on their surface at 2,300 degrees Fahrenheit while the back face, only a few inches below the surface, would never exceed 250 degrees Fahrenheit. The orbiter, which is essentially an aluminum airplane, could now fly at hypersonic speeds.

To support NASA's shuttle work, Ames upgraded its arc jet facilities so that they could simulate reentry heating for tens of minutes. In the mid-1970s, the Ames facilities group brought online the 60-megawatt Interaction Heating Facility, which produced heating three times hotter and on larger models than any other arc jet. Compressed air passed through a constriction arc heater, invented by Ames, which was essentially a standing lightning bolt. Half of its energy was deposited as heat into the flowing gas, which then expanded through a nozzle--either a cone-shaped nozzle for tests at stagnation

Space shuttle Atlantis (STS-27) in 1988 showing the parts of the ascent stack.

points or at wing-leading edges. Using a semi-elliptical nozzle, Ames could test a 2-by-2-foot section of tiles. By varying the composition of the heated gas, and using special instrumentation, Ames could also study the rapidly shifting reaction chemistry between the tile and the superheated gas.



Energy flash from a projectile during an impact study, 1963.

Through the intensity and comprehensiveness of its effort, Ames became a world leader in thermal protection materials. When the first orbiter, the Columbia, encountered a tile strength problem in 1978, Ames had already invented a stronger version of the silicon carbide tile, called the LI-2200. Ames then invented a new class of tiles, called Fibrous Refractory Composite Insulation (FRCI 12) that provided greater durability and a 500 pound overall weight savings. As hot gas flows between the tiles became recognized as a serious problem, Ames developed a gap filler. The gap filler was essentially a ceramic cloth impregnated with silicon polymer, and was applied to all the orbiters. The upper side of an orbiter also needs insulation, though it stays much cooler during re-entry. Ames worked with Johns Manville to develop a flexible silica blanket insulation. When the shuttle first flew in 1981 it was covered by a patchwork of thermal protection materials, each type optimized to the particular stress re-entry placed on it.

Shuttle Flight Simulation

Hans Mark served as Ames' center director from 1969 through 1977, the formative years of the shuttle program. Mark came from outside Ames, and led the center to more directly engage work on the shuttle program. Ames formed the Shuttle Project Office, led by Victor Stevens and Bob Nysmith, which coordinated all its work on the shuttle. JSC served as the lead center for the shuttle program, and tasked to Ames more than half of all wind tunnel testing of designs leading to the shuttle. Ames accomplished more than 10,000 hours of testing, using every wind tunnel it had, even before construction began on the first shuttle in 1972. More than 25,000 hours of testing came after. Almost half of all testing was done in the 3.5-foot hypersonic wind tunnel, which could simulate flight at Mach 5, 7 and 10. During the entire development of the shuttle, NASA conducted tests in more than 50 different wind tunnels, run by the government, universities and by industry. The shuttle program both proved the value of a coordinated wind tunnel infrastructure, while also exposing the limits of tunnel testing and justifying Ames' investment in CFD.

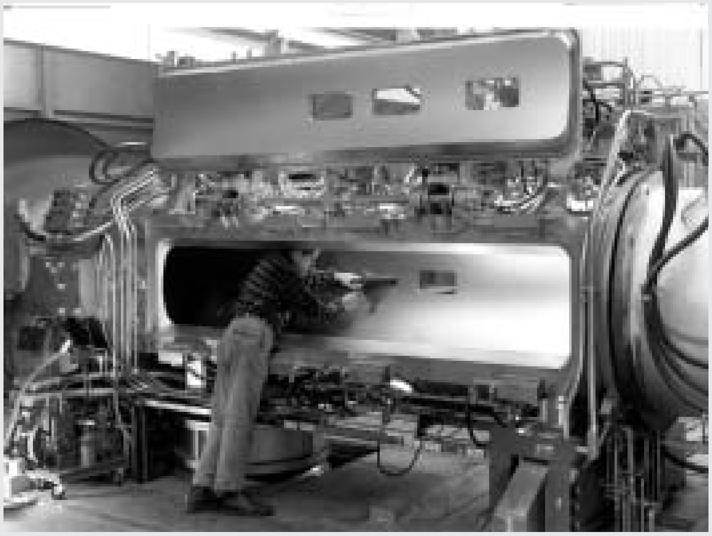
The ascent stack--that is, the shuttle mated with the external tank and solid rocket boosters as it stood on the launch pad--created enormously complex aerodynamics, followed by shock-shock interactions as it all hurtled faster into space. Ames did much to improve the ascent stack configuration. Ames also used its 14-foot wind tunnel to study the airflow interference around the Boeing 747 as it was mated with the orbiter. The 747 was used to launch the Enterprise--a full-scale model of the orbiter--to test its glide-landing performance. Later, NASA used the 747 to ferry the orbiter from its landing spot at Dryden back to the Kennedy Space Center for relaunch. NASA also built a 36 percent scale model of the orbiter, reaching 44 feet long, for tests in Ames' 40-by-80-foot wind tunnel. This model was tested primarily to study the scheduling of speed brakes and the affect of thermal protection systems on the orbiter's low-speed aerodynamics. Almost every facet of shuttle flight was analyzed and honed at Ames.

Ames also helped the shuttle designers reach a compromise between a simple blunt shape for better thermodynamics and protruding aerodynamic surfaces for better landing. Ames researchers devised new ways to improve handling characteristics without changing the basic configuration of the orbiter. In the 2-foot transonic tunnel, Ames worked through a potentially troublesome panel flutter problem. Ames used its 12-foot tunnel to demonstrate that unpowered landings could be made at speeds of at least 200 knots, and collaborated with Dryden on flight tests. Ames modified a Gulfstream 2 business jet by adding direct-lift flaps and side force generators to test orbiter handling qualities and to train the pilot astronauts. Ames' Convair CV990 was used to prove that the shuttle did not need a back-up jet engine to power a fly-around in case it missed its landing. All

Ceramic tiles being mounted on a shuttle orbiter, 1980.

of this reflected well on Ames' traditional expertise in aeronautics.

Ames also reached back to its experience with flight simulation for Apollo. Maneuvering the Apollo lunar module to a soft landing on the moon was crucial to the success of the Apollo mission.



A lifting-body model being installed in Ames' 3.5-foot hypersonic wind tunnel.

Yet there was no way to train astronauts for the maneuver with existing machines. So Ames devised a piloted, free-flight simulator called the Lunar-Launching Research Vehicle (LLRV). All primary and backup Apollo astronauts trained on the LLRV for piloting the module onto the moon.

Simulating the shuttle landing on Earth was bit easier in that it would glide in like an airplane, but the margin of error was small and many more pilots needed to be trained. Ames began landing simulations in the early 1970s using its Flight Simulator for Advanced Aircraft. The large motion envelope of the FSAA provided realistic cockpit accelerations so that pilot astronauts could experience the feel of g-forces while landing the shuttle. Prior to their first flights, all pilot astronauts spent many hours training in the FSAA, which in turn helped NASA engineers identify handling qualities that needed improving. Using the FSAA, NASA identified the need for a heads-up display, and for its alpha-numeric symbology, which became the primary guidance system for orbiter landings. Ames further tested this pilot workspace in the space shuttle vehicle simulation cockpit.

During the first landing test flight, in July 1977, the Enterprise experienced a pilot-induced oscillation—that is, a longitudinal porpoising, caused by a control system problem, that worsened due to pilot overcontrol. During this flight, pilot Fred Haise had enough confidence and simulator training to simply let go of the control and let the oscillations naturally dampen out. Ames and JSC engineers then launched a major investigation into orbiter control systems using the FSAA.

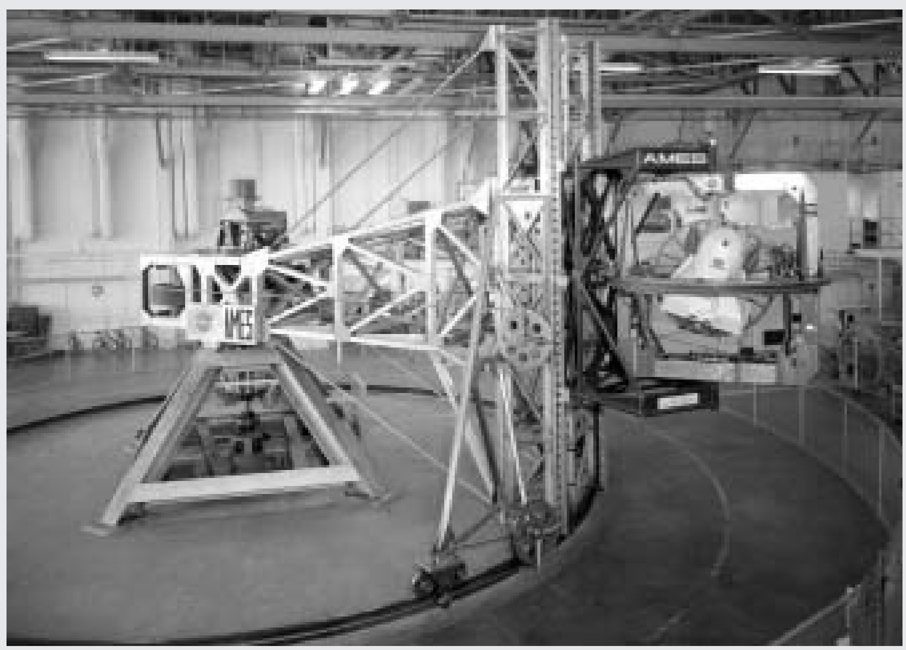
Ames opened its Vertical Motion Simulator in 1980, and it quickly became the best simulator for shuttle design and pilot training. JSC engineers and astronaut flight crews used the VMS intensively to improve landing procedures and flight rules. During these piloted flight simulations, a close working relationship developed between the engineers from JSC, the astronaut crews, and Ames' VMS researchers. Every day, from early morning to late at night, sometimes four of the T-38 aircraft assigned to the pilot astronauts would be parked on the ramp outside the VMS building. In addition to looking at future design improvements under investigation by Ames and JSC engineers, these pilots would encounter every conceivable failure mode. When they were done, they were prepared for a wide array of possible landing failures. The VMS also supported redesign of the orbiter brakes, nose wheel steering, display system, drag parachute, flight control automation for extended duration orbit, and return-to-flight studies following the Challenger accident.

Once the shuttle was flying, it was regularly overhauled and updated. The emerging science of computational fluid dynamics especially contributed to shuttle improvements. Some of the earliest CFD codes established numerical benchmarks for the aerodynamics and shock wave profiles of shuttle lift-off and re-entry, and CFD directed the redesign of the shuttle main engine and the ascent stack. A second generation of thermal protection tile, called Toughened Unipiece Fibrous Insulation (TUFI) was added to the aft heat shield and body flaps that were struck by debris kicked up during landings, thus minimizing maintenance in the Orbiter Processing Facility.

As the shuttle prepares to undergo a major overhaul following the loss of the Columbia, NASA people at Ames are prepared to help with better tools and more complete knowledge of thermodynamics and computer modeling.

The Inclusive Spirit Today

Because of its tradition of collaboration among diverse groups of intelligent and dedicated people, Ames stands today as a multi-disciplinary research and development center. Nearly half its funding supports basic research, and the other half supports advanced development of key components of software,



Ames' 5-degree-of-motion simulator, 1962, used to study pilot response to aircraft-like accelerations.

Ames' virtual airport, FutureFlight Central, 1995, is used to study improvements to air traffic control.

aircraft and spacecraft. And because NASA scientists at Ames are passionate about their own pursuit of knowledge, much of Ames' funding and organization supports a wide array of education programs to teach and inspire the next generation of explorers. Ames people, using the language of science, have written the poetry of the planets.

Astrobiology stands as a prime example of how NASA managers at Ames re-integrated almost all of NASA's strategic enterprises. Exobiology as a discipline had become more routine in its institutional structure--with individual scientists applying for limited grants and banded together mostly by the equipment and overhead they shared. NASA scientists at Ames, like David Morrison and Scott Hubbard, when faced with a budgetary setback in the early 1990s, responded with a plan to create a discipline of astrobiology through an inclusive institute. They decided to build a discipline, just as others in NASA built rockets and spacecraft. What they included as 'astrobiology' was work done in many places, from many unique perspectives and all of it aligned by the Astrobiology Institute into something relevant and usable. When NASA engineers needed help identifying landing sites for the Mars rover, astrobiologists could respond. Throughout, the institute kept the diverse band of researchers focused on the biggest questions about life in the universe.

Shuttle Atlantis returns to KSC after a complete refurbishment.

Nanotechnology has a similar integrative feel. Former center director Harry McDonald foresaw the importance of nanotechnology throughout NASA, and asked Meyya Meyyapan to develop what is today the largest nanotechnology group at work in any federal laboratory. Nanotechnology creates new materials, sensors and devices from the bottom up, taking advantage of the unique properties of matter at the molecular scale. NASA called upon Ames management to coordinate efforts at defining the state-of-the-art in nanotechnology, then pushing it forward. As always, NASA researchers at Ames will do so through close and open collaboration with researchers at other federal and university laboratories. Nanotechnology is a prime example of a 'One NASA' culture hard at work. Soon other engineers in NASA may need this technology urgently--as it has in the past needed technologies for thermal protection, flight simulation, computer modeling and air traffic control. Then NASA nanotechnologists at Ames will collaborate in whole new ways.

"Nanotechnology and astrobiology are the latest evidence that Ames people share a collaborative spirit with their colleagues at the center and with scientists and engineers in universities and in industry,"-- G. Scott Hubbard, Ames Center Director.

"Nanotechnology and astrobiology are the latest evidence that Ames people share a collaborative spirit with their colleagues at the center and with scientists and engineers in universities and in industry," said G. Scott Hubbard, Ames center director. "This collaborative tradition has served Ames people well whenever the nation called upon them to work closely and quickly with their colleagues throughout the other NASA centers."

Editor's Note:
Glenn Bugos, author of Ames' 60th anniversary historical anthology, 'Atmosphere of Freedom,' prepared this article for the Ames History and Public Affairs offices.

NASA Ames History Office

Jack Boyd, an Ames employee since 1947 who most recently served as executive assistant to the director is now serving as Ames' senior advisor for history. He is overseeing efforts to make Ames' history and traditional culture relevant to its work today and in the future. This includes setting up an archive of important Ames documents, conducting oral histories of central figures in Ames' success, and writing monographs on key Ames programs. All those at Ames doing historical work, or with collections of materials in need of preservation, are invited to contact him at ext. 4-5222 or at John.W.Boyd@nasa.gov

NASA photo by Dominic Hart

Jack Boyd, Ames' senior advisor for history.

Ames' Hall of Fame members

As Ames celebrated its 60th anniversary, a committee of Ames scientists inducted these 12 people into the Ames Hall of Fame. This class of inductees represents almost every scientific endeavor for which Ames is famous. In addition to being brilliant scientists or engineers in their own right, most served as part of the formal leadership structure at Ames, and all were natural leaders of scientific talent.

H. Julian Allen: Famous for a general theory of subsonic airfoils, then for his concept of bluntness to reduce heating during re-entry. He established Ames as a leader in hypersonic aerothermodynamics and served as center director from 1965 to 1969.

Robert T. Jones: A brilliant theoretical aerodynamicist, credited with co-inventing sweptback wings, developing the theory of low-aspect ratio wings, and demonstrating the value of oblique wings in supersonic aircraft.

Smith DeFrance: Ames director from its founding in 1940 through 1965, continuing an eminent career in wind tunnel design, construction and management. Embodied a reputation for honesty, simplicity, quality and relevance that remains Ames' guiding spirit today.

Hans Mark: As center director from 1969 to 1977, he accelerated Ames' leadership in computing and information technology, tilt-rotor aircraft, and scientific support for the space shuttle program.

George Cooper: As chief test pilot from 1958 to 1973, he led Ames' exploration of aircraft performance in the transonic regime. His Cooper-Harper Handling Qualities Rating Scale remains the standard of aircraft flight qualities throughout the world.

Dean Chapman: As a scientist exploring the relationship between chemistry and aerodynamics at re-entry velocities, he pioneered new technologies for atmospheric re-entry, including thermal protection systems, ablation analysis, and arc-jet systems.

James Pollack: A pre-eminent and wide-ranging planetary scientist, he shaped theories of planetary atmospheres and surfaces, the origin of the solar system, climatic change, and ozone depletion on Earth.

Charles Hall: Legenedary for his management of the Pioneer series of probes to the outer planets and the edge of our solar system. The Pioneer spacescraft exemplify Ames ability to deliver high-impact science at low cost.

William Ballhaus: As a world-class researcher in computational fluid dynamics, he spearheaded development of Ames' Numerical Aerodynamic Simulation facility. As center director from 1984 to 1989, he positioned Ames for its future growth.

Harvard Lomax: A leader in aerodynamic theory—of supersonic flow, sonic boom and wave drag—became the leader in the use of computers to model air flows, and thus created the discipline of computational fluid dyamics.

Harold Klein: From 1963 to 1984 he led the steady growth in the life sciences at Ames, to include exobiology, gravitational biology, and space human factors and biomedicine. Under his supervision, the Viking lander first assessed whether the Mars environment could support life.

Clarence Syvertson: He pushed aerodynamics and the wind tunnels at Ames into the supersonic and hypersonic regimes, and served as center director from 1978 to 1984.

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