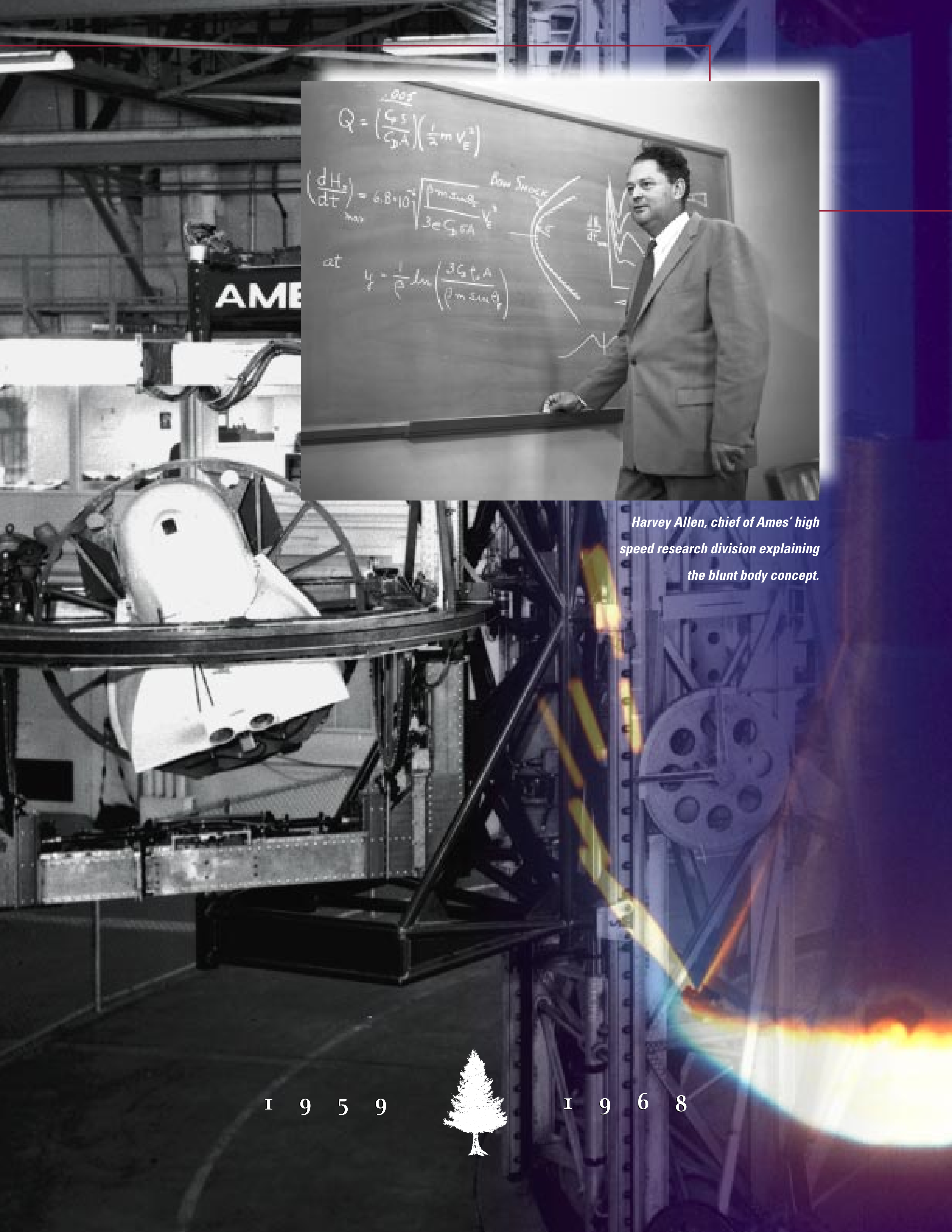


Harvey Allen, chief of Ames' high speed research division explaining the blunt body concept.

1959 – 1968

Transition into NASA

Chapter 2:

From a Laboratory to a Research Center

Ames contributed much of the technology that helped NASA succeed in the mission that most preoccupied it during the 1960s—sending an American to the Moon and returning him safely to Earth. Ames people defined the shape, aerodynamics, trajectory and ablative heat shield of the reentry capsule. They mapped out navigation systems, designed simulators for astronaut training, built magnetometers to explore the landing sites, and analyzed the lunar samples brought back. Still, compared with how it fueled growth at other NASA Centers, the rush to Apollo largely passed Ames by.

HICONTA simulator (for height control test apparatus), in February 1969, mounted to the exterior framing of the 40 by 80 foot wind tunnel. It provided extraordinary vertical motion.

Ames' slow transition out of the NACA culture and into the NASA way of doing things, in retrospect, was a blessing. Under the continuing direction of Smith DeFrance, then Harvey Allen, Ames people quietly deepened their expertise in aerodynamics, thermodynamics, and simulation, then built new deep pockets of research expertise in the space and life sciences. They sat out the bureaucratic politics, feeding the frenzy toward ever more elaborate and expensive spacecraft. The gentle refocusing of Ames' NACA culture during the 1960s meant that Ames had nothing to unlearn when NASA faced its post-Apollo years—an era of austerity, collaboration, spin-offs, and broad efforts to justify NASA's utility to the American public.

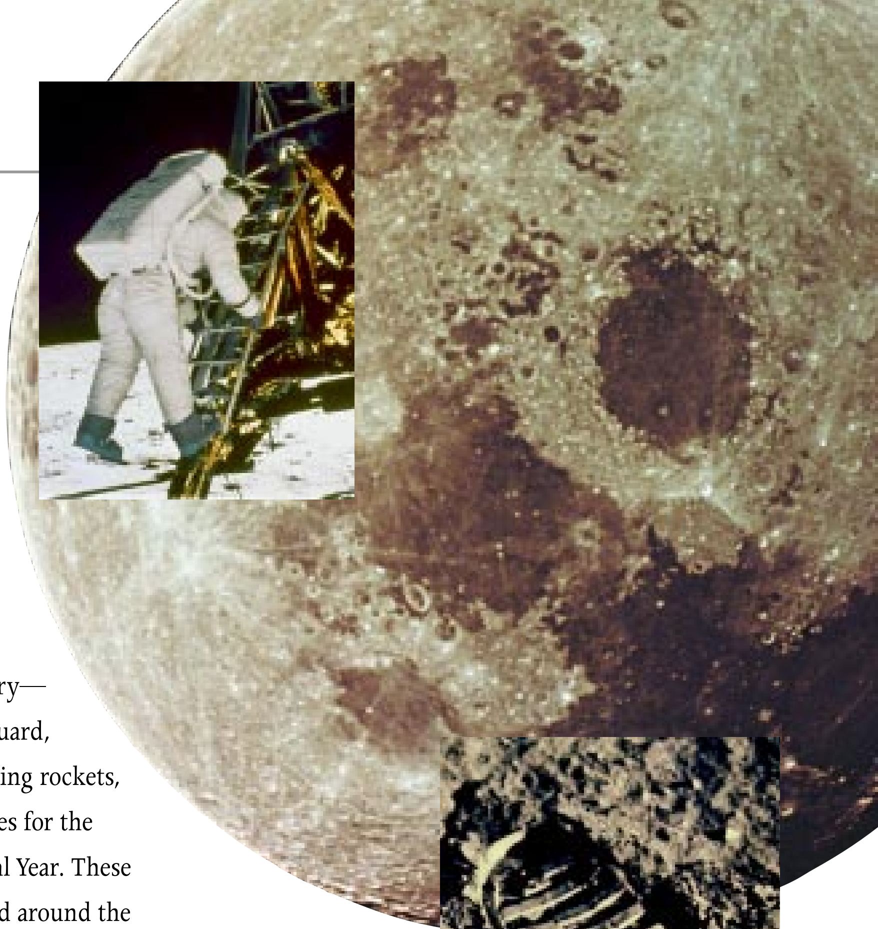
RELATIONS WITH NASA HEADQUARTERS

President Dwight Eisenhower signed the National Aeronautics and Space Act into law on 29 July 1958, and its immediate impact was felt mostly in redefining Ames' relations with its headquarters. The NACA was disbanded, and all its facilities incorporated into the new National Aeronautics and Space Administration (NASA) which formally opened for business on 1 October 1958. Eisenhower wanted someone in charge of NASA who would take bold leaps into space and he appointed as administrator T. Keith Glennan, then president of the Case Institute of Technology. Hugh Dryden, who had been NACA chairman, was appointed Glennan's deputy. Glennan first renamed the three NACA "Laboratories" as "Centers," but kept Smith DeFrance firmly in charge of the NASA Ames Research Center.

DeFrance went a year without making any organizational changes to reflect NASA's new space goals. At the end of 1959, he announced that Harvey Allen was promoted to assistant director, parallel to Russell Robinson. Robinson continued to manage most of Ames' wind tunnels, some of which were mothballed or consolidated into fewer branches to free up engineering talent to build newer tunnels. Allen's theoretical and applied research division was reconfigured so that he now managed an aerothermodynamics division and a newly established vehicle environment division. In addition, DeFrance formed an elite Ames manned satellite team, led first by Alfred Eggers and later by Alvin Seiff, that helped define the human lunar mission that would soon become NASA's organizational mission.

Perhaps the biggest cultural change at Ames came from personnel shifts. NASA

Ames Research Center, 14 December 1965.



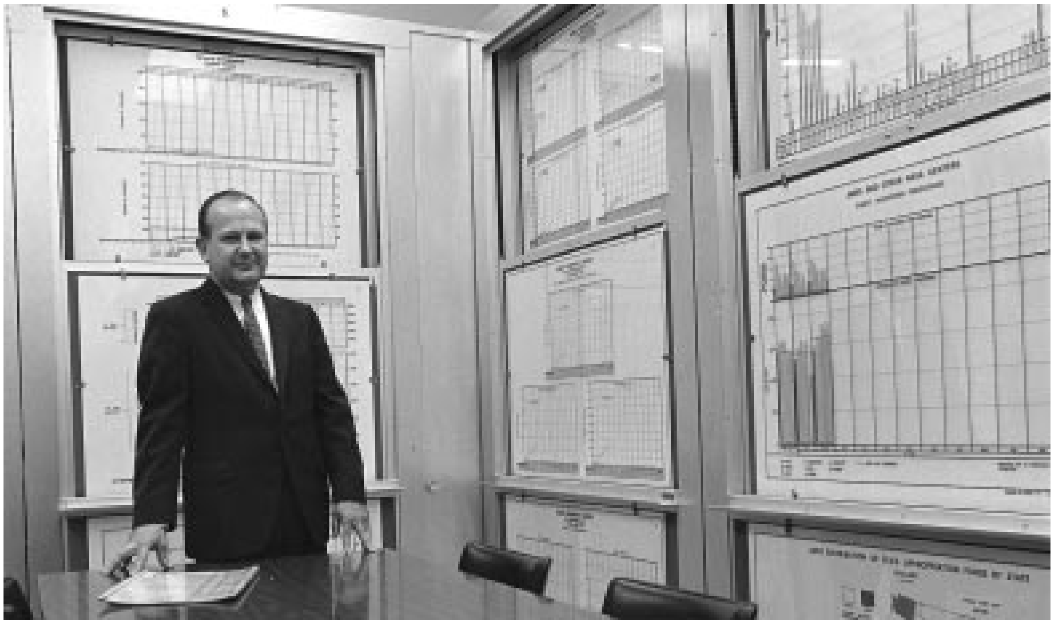
also inherited the various space project offices managed by the Naval Research Laboratory—specifically Project Vanguard, upper atmosphere sounding rockets, and the scientific satellites for the International Geophysical Year. These offices had been scattered around the Washington, D.C. area, and Glennan decided to combine them at the newly built Goddard Space Flight Center in Beltsville, Maryland. Goddard would also be responsible for building spacecraft and payloads for scientific investigations, and for building a global tracking and data acquisition network. Glennan asked Harry Goett, chief of Ames' full scale and flight research division, to direct the new Goddard Center. Goett's departure, in August 1959, was a big loss for Ames. To replace Goett, DeFrance turned to Charles W. "Bill" Harper. Fortunately, Goett resisted the temptation to cannibalize colleagues from his former division, and instead built strong collaborative ties between Ames and Goddard, especially in the burgeoning field of space sciences.

The flood of money that started flowing through NASA only slowly reached Ames. The NACA budget was $340 million in fiscal 1959. As NASA, its budget rose to $500 million in fiscal 1960, to $965 million in fiscal 1961, and earmarked as $1,100 million for fiscal 1962. Staff had essentially doubled in this period, from the 8,000 inherited from the NACA to 16,000 at the end of 1960. However, most of this increase went to the new Centers—at Cape Canaveral, Houston, Goddard and Huntsville—and to the fabrication of launch vehicles and spacecraft. Ames people had little engineering experience in building or buying vehicles for space travel, even though they had devised much of the theory underlying them. Glennan, in addition, followed a practice from his days with the Atomic Energy Commission of expanding research and development

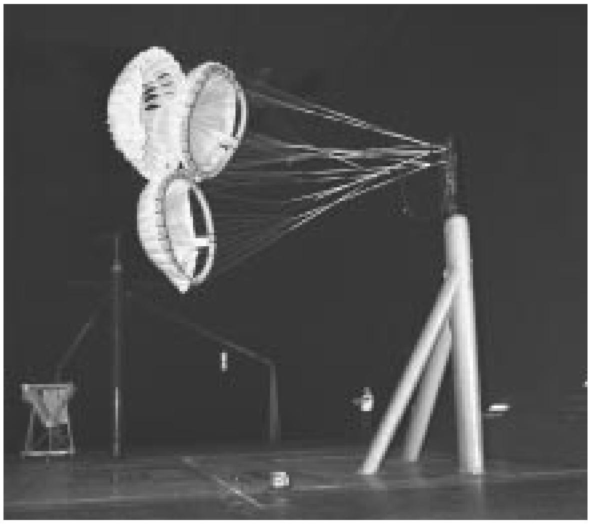
Model mounted in the 40 by 80 foot wind tunnel, for studies in 1962 on using paragliders to land space capsules.

through contracts with universities and industry rather than building expertise in-house. Thus, between 1958 and 1961, the Ames headcount dropped slightly to about 1,400, and its annual budget hovered around $20 million.

The disparity between what NASA got and what Ames received grew greater in early 1961 when President John Kennedy appointed James E. Webb to replace Glennan as administrator. Kennedy had campaigned on the issue of the missile gap and Eisenhower's willingness to let the Soviets win many "firsts" in space. So in Kennedy's second state of the union address, on 25 May 1961, he declared that by the end of the decade America would land an American on the Moon and return him safely to Earth. Ames people had already planned missions to the Moon and pioneered ways to return space travelers safely to Earth, but they had expected decades to pass before these plans were pursued. Kennedy's pronouncement dramatically accelerated their schedules. Kennedy immediately boosted NASA's fiscal 1962 budget by 60 percent to $1.8 billion and its fiscal 1963 budget to $3.5 billion. NASA's total headcount rose from 16,000 in 1960 to



Management process invaded Ames as the Center shifted from NACA to NASA oversight. Ames constructed a review room in its headquarters building where, in the graphical style that prevailed in the 1960s, Ames leadership could review progress against schedule, budget, and performance measures. Shown, in October 1965, is Merrill Mead, chief of Ames' program and resources office.



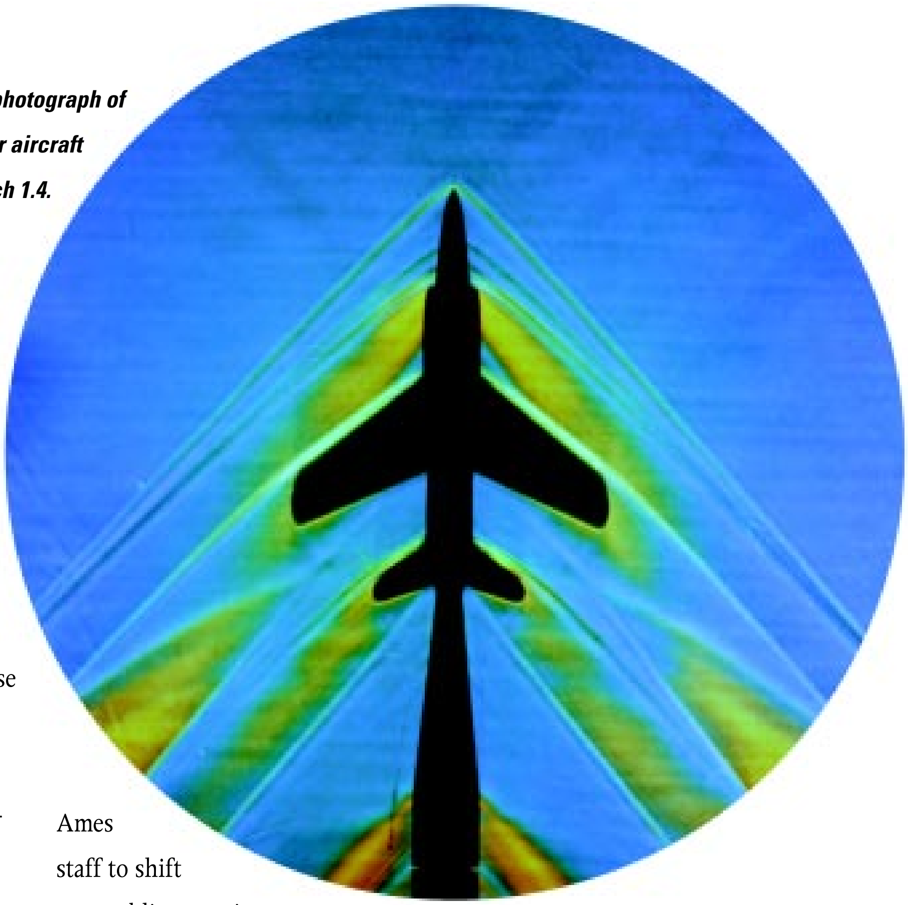
Steerable parachute for the Apollo capsule being tested in the 40 by 80 foot wind tunnel.

25,000 by 1963. More than half of this increase was spent on what Ames managers saw as the man-to-the-Moon space spectacular.

Again, Ames grew little relative to NASA, but it did grow. Ames' headcount less than doubled, from 1,400 in 1961 to 2,300 in 1965, while its budget quadrupled, from about $20 million to just over $80 million. Almost all of this budget increase, however, went to research and development contracts—thus marking the greatest change in the transition from NA¢A to NA$A. Under the NACA, budgets grew slowly enough that research efforts could be planned in advance and personnel hired or trained in time to do the work. Under NASA, however, the only way to get skilled workers fast enough was to hire the firms that already employed them. Furthermore, under the NACA, Ames researchers collaborated with industrial engineers, university scientists, and military officers as peers who respected differences of opinions on technical matters. Under NASA, however, these same Ames researchers had enormous sums to give out, so their relations were influenced by money. Gradually, Ames people found themselves spending more time managing their contractors and less time doing their own research.

Ames continued to report to what was essentially the old NACA headquarters group—guarded by Dryden, directed by Ira Abbott, and renamed the NASA Office of Advanced Research Programs. The four former NACA laboratories—Ames, Langley, Lewis, and the High Speed Flight Research Station—continued to coordinate their work through a series of technical committees. Even though the organizational commotion left in NASA's wake centered in the East, throughout the 1960s Ames found itself an increasingly smaller part of a much larger organization. Gradually the intimacy of the NACA organization faded as NASA's more impersonal style of management took over.

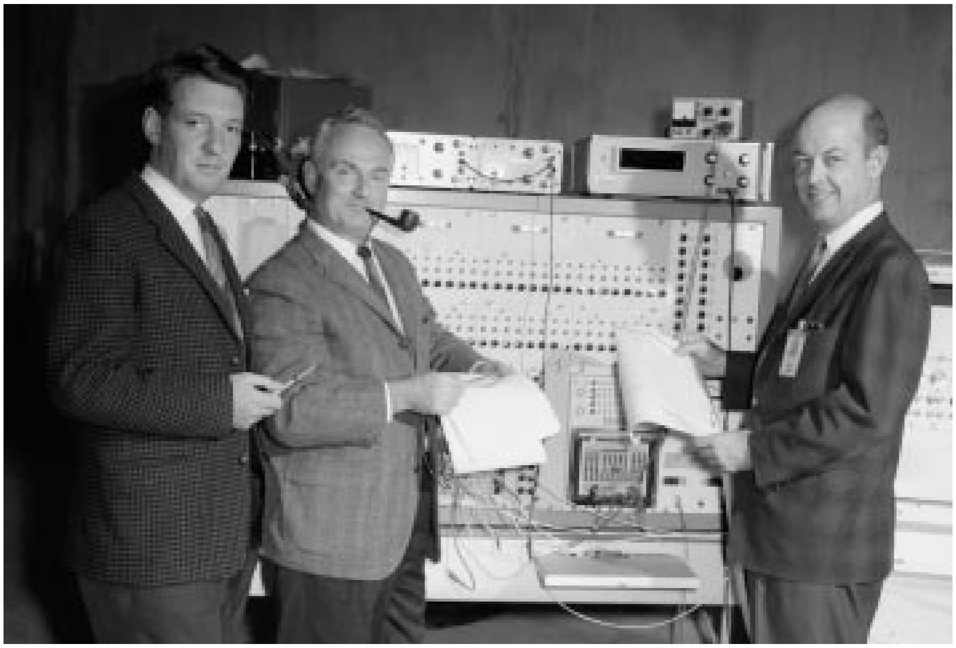
Four examples displayed the cultural chasm between Ames and the new NASA headquarters. First, in 1959 NASA headquarters told Ames to send all its aircraft south to Rogers Dry Lake—home of NASA's flight research station located at Edwards Air Force Base, California—except for those used in V/STOL research and one old F-86 used by Ames pilots to maintain their flight proficiency. Thus started decades of debate, and a series of subsequent



Schlieren photograph of a supersonic fighter aircraft model at Mach 1.4.

disagreements, over how aerodynamicists got access to aircraft for flight research. Second, NASA headquarters asserted its new right to claim for itself the 75.6 acres of Moffett Field on which Ames sat as well as 39.4 acres of adjacent privately held property. DeFrance argued that there was no need to change Ames' use permit agreement with the Navy, and he negotiated a support agreement that showed he was happy with Navy administration. Third, NASA renumbered the NACA report series but, more importantly, relaxed the restriction that research results by NASA employees first be published as NASA reports. New employees, especially in the space and life sciences, generally preferred to publish their work in disciplinary journals rather than through the peer networks so strong in the NACA days. Finally, NASA wanted Ames to leap into the limelight. DeFrance had encouraged Ames staff to shift any public attention to the sponsors of its research, and Ames' biggest outreach efforts had been the triennial inspections when industry leaders and local dignitaries—but no members of the public—could tour the laboratory. NASA headquarters encouraged DeFrance to hire a public information officer better able to engage general public audiences rather than technical or industry audiences. Bradford Evans arrived in August 1962 to lead those efforts, and soon Ames was hosting tours by local school groups.

General Dynamics F-111B aircraft, with its wings fully extended, undergoing tests in the 40 by 80 foot wind tunnel in 1969.

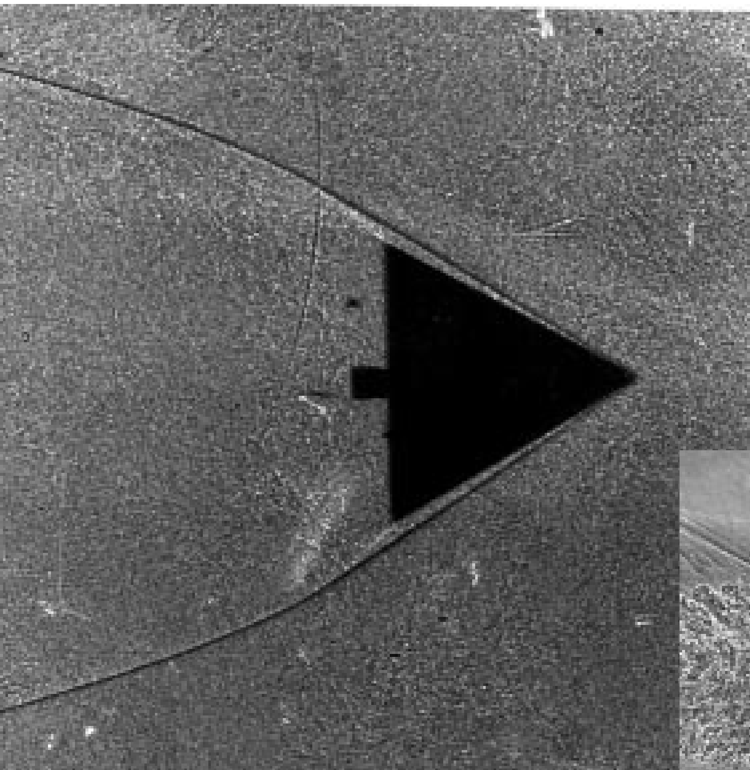


John Billingham, Melvin Sadoff, and Mark Patton of the Ames biotechnology division.

Ames moved more firmly into America's space program following three organizational changes. The first occurred in August 1962, when Harvey Allen formed a space sciences division and hired Charles P. Sonett to lead it. Sonett had worked for Space Technology Laboratories (later part of TRW, Inc.) building a variety of space probes for the Air Force, and he quickly established Ames as the leader in solar plasma studies.

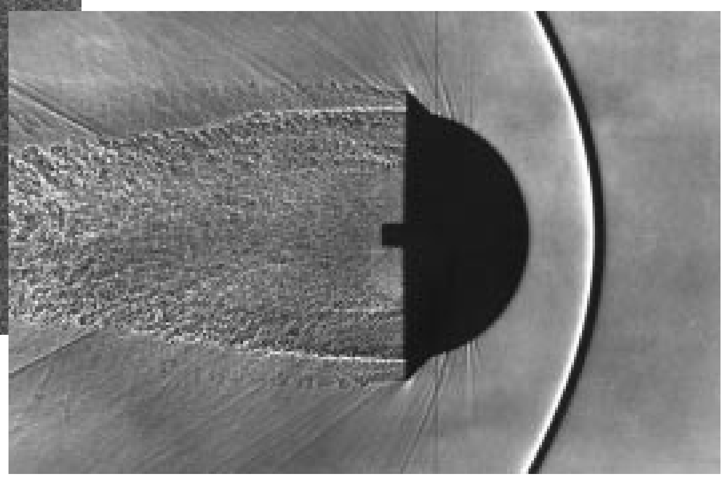
The second organizational change was the start of life science research at Ames. Clark Randt had worked at NASA headquarters dreaming up biological experiments that could be carried into space. He decided that a laboratory was needed to do some ground experimentation prior to flight, and he thought Ames was a good place to start. So Randt sent Richard S. Young and Vance Oyama to work at Ames and build a small penthouse laboratory atop the instrument research building. Both reported back enthusiastically on how they were received. In the Bay Area, they had contact with some of the world's best biologists and physicians and, at Ames, they got help from a well-established human factors group in its flight simulation branch. With encouragement from headquarters, Ames established a life sciences directorate and, in November 1961, hired world-renowned neuropathologist Webb E. Haymaker to direct its many embryonic activities.

Lockheed JF-104A Starfighter piloted in 1959 by Fred Drinkwater to demonstrate very steep landing approaches of the type ultimately used with the space shuttle.



Shadowgraph of a flow field around a sharp nose cone at Mach 17.

Shadowgraph of a finned hemispherical body in free flight at Mach 2, during a 1958 test of the blunt body concept.



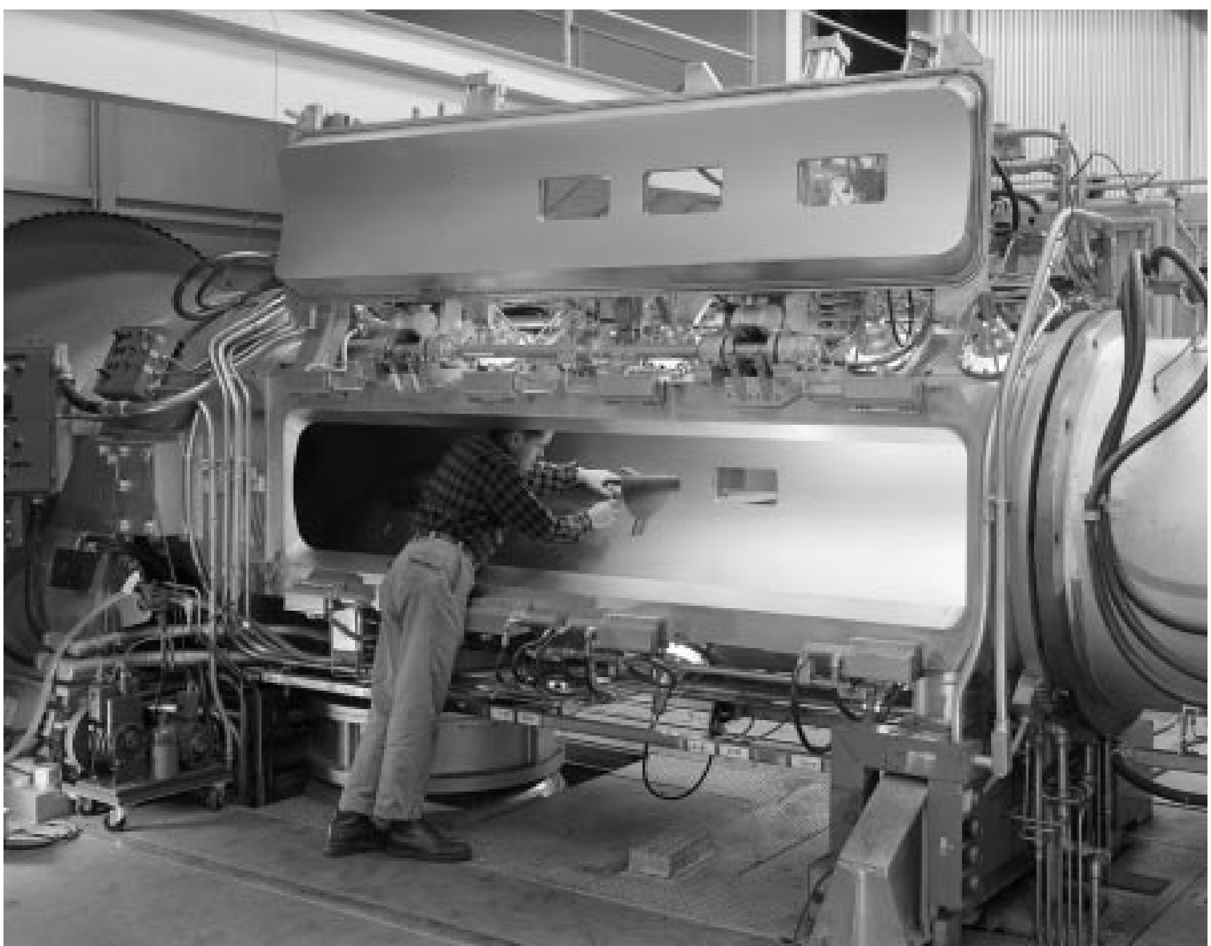
These life scientists, like the physical scientists that had long run Ames, were laboratory types who appreciated theory and its dependence upon experimentation. They, too, shunned operational ambitions. Yet these biologists still seemed grafted onto the Center. They used different disciplines, procedures and language. Many of the leading biologists were women, at a time when women were still sparse in the physical sciences. The biologists looked for success from different audiences, starting the fragmentation of the centerwide esprit de corps. Ames people had always been individualists, but all felt they were moving in the same general direction. Now, Ames served different intellectual communities and reorganized itself accordingly. Whereas Ames had always organized itself around research facilities, by 1963 it organized itself around disciplines throughout.

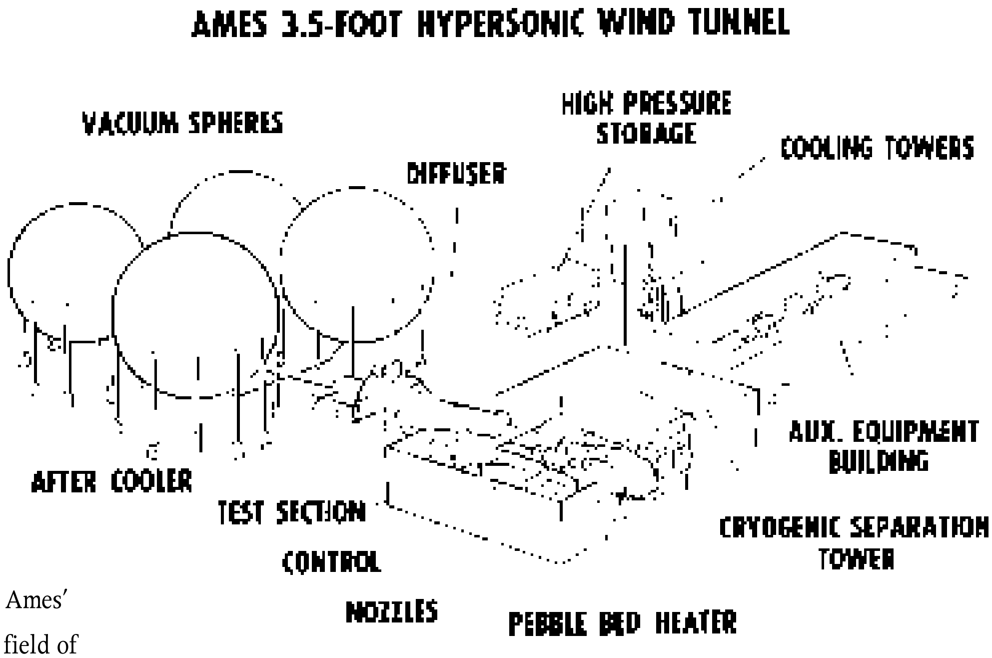
The third organizational change happened at headquarters. In November 1963, NASA headquarters reorganized itself so that Ames as a Center reported to the Office of Advanced Research and Technology (OART) while some major Ames programs reported to the other headquarters technical offices. DeFrance could no longer freely transfer money around the different programs at his Center. Headquarters staff had grown ten times since the NACA days, and from Ames perspective countless new people of uncertain position and vague authority were issuing orders. Some of these newcomers even bypassed the authority of the director and communicated directly with individual employees on budgetary and official matters. Virtually all of them wanted to know how Ames was going to help get a human on the Moon. Ames' NACA culture was under direct attack.

"…RETURNING HIM SAFELY TO EARTH"

By far the biggest contribution Ames made to NASA's human missions was solving the problem of getting astronauts safely back to Earth. Ames started working on safe reentry in 1951, when Harvey Allen had his eureka moment known as "the blunt body concept." In the early 1950s, while most attention focused on the rockets that would launch an object out of our atmosphere—an object like a nuclear-tipped ballistic missile—a few scientists started thinking about the far more difficult problem of getting it back into our atmosphere. Every known material would melt in the intense heat generated when the speeding warhead returned through ever-denser air. Most meteors burned up as they entered our atmosphere; how could humans design anything more sturdy than those? While many of the NACA's best aerodynamicists focused on aircraft to break the sound barrier, a few of its best

Model of the M-1 reentry body being mounted in the test throat of the 3.5 foot hypersonic tunnel.





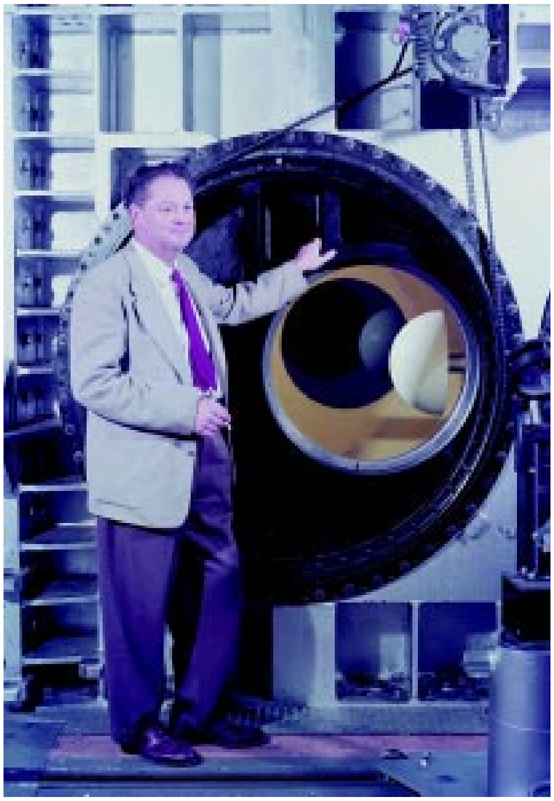
Schematic of the 3.5 foot hypersonic wind tunnel.

and brightest aerodynamicists focused instead on the thermal barrier.

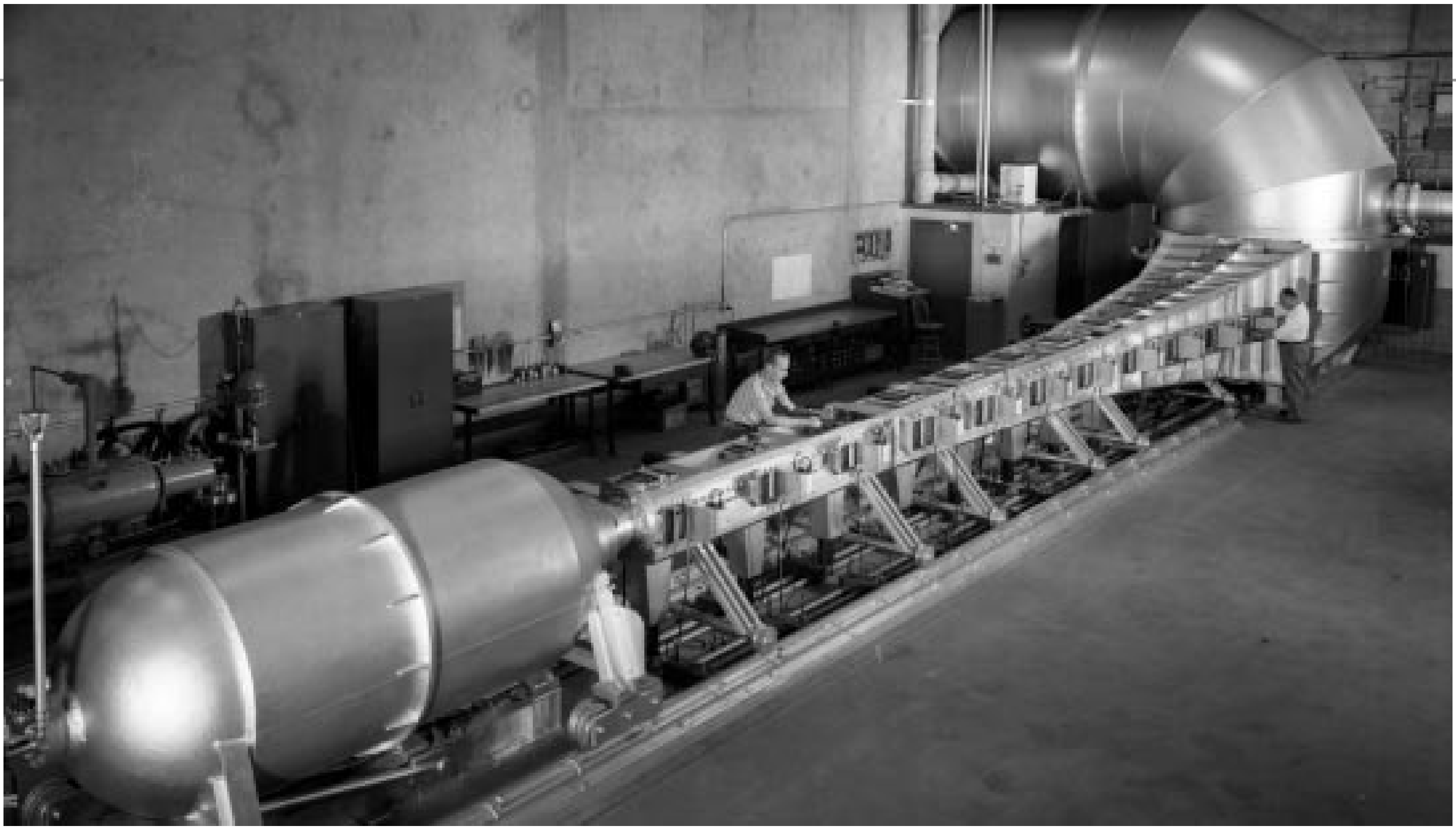
Blunt Body Concept

H. Julian Allen and Alfred Eggers—working with Dean Chapman and the staff of Ames' fastest tunnels—pioneered the field of hypersonic aerodynamics. Though there is no clean dividing line between supersonics and hypersonics, most people put it between Mach 3 and 7 where heat issues (thermodynamics) become more important than airflow issues (aerodynamics). Allen and Eggers brought discipline to hypersonic reentry by simplifying the equations of motion to make possible parametric studies; by systematically varying vehicle mass, size, entry velocity and entry angle; and by coupling the motion equations to aerodynamic heating predictions. Allen soon came to realize that the key parameter was the shape of the reentry body.

A long, pointed cone made from heat-hardened metal was the shape most scientists thought would slip most easily back through the atmosphere. Less boundary layer friction meant less heat. But this shape also focused the heat on the tip of the cone. As the tip melted, the aerodynamics skewed and the cone tumbled. Allen looked at the boundary



H. Julian Allen with a hemispheric model at the 8 by 7 foot test section of the Unitary plan tunnel.



Atmosphere entry simulator in 1958.

layer and shock wave in a completely different way. What if he devised a shape so that the bow shock wave passed heat into the atmospheric air at some distance from the reentry body? Could that same design also generate a boundary layer to carry friction heat around the body and leave it behind in a very hot wake? Allen first showed theoretically that, in almost all cases, the bow shock of a blunt body generated far less convective and friction heating than the pointy cone.

Allen had already designed a wind tunnel to prove his theory. In 1949, he had opened the first supersonic free flight facility—which fired a test model upstream into a rush of supersonic air—to test design concepts for guided missiles, intercontinental ballistic missiles and reentry vehicles. To provide ever better proof of his blunt body concept, Allen later presided over efforts by Ames researchers to develop light gas guns that would launch test models ever faster into atmospheres of different densities and chemical compositions.

Allen also showed that blunt reentry bodies—as they melted or sloughed off particles—had an important chemical interaction with their atmosphere. To explore the relation between the chemical structure and aerodynamic performance of blunt bodies, Ames hired and trained experts in material science. By the late 1950s, Ames researchers—led by Morris Rubesin, Constantine Pappas and John Howe—had pioneered theories on passive surface transpiration cooling (usually called ablation) that firmly moved blunt bodies from the theoretical to the practical. For example, Ames material scientists showed that by building blunt bodies from materials that gave off light gases under the intense heat of reentry, they could reduce both skin friction and aerodynamic heating.

Electric arc shock-tube facility, opened in 1966, was used to study the effects of radiation and ionization during outer planetary entries.

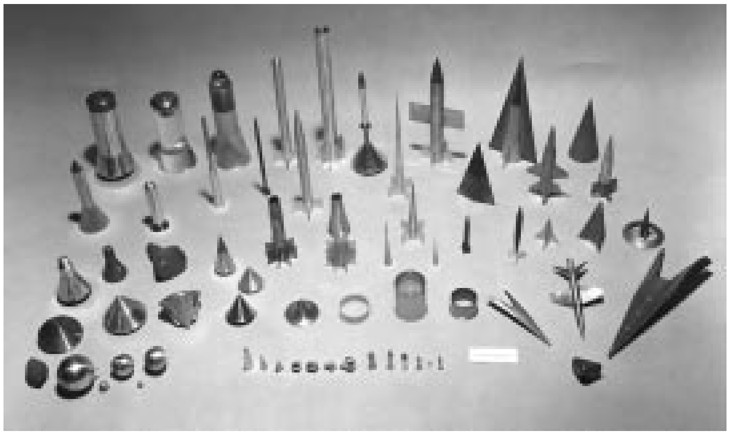
Meanwhile, Dean Chapman had developed a broad set of analytical tools to solve the problems of entry into planetary atmospheres, including calculations for the optimum trajectory to get a reentry body returning from the Moon back into Earth's atmosphere. Too steep an angle relative to the atmosphere, and the air about the body would get too dense too fast, causing the capsule to melt. Too shallow an angle, and the reentry capsule would skip off Earth's atmosphere like a flat rock on a smooth lake and continue off into space. First published in 1956, Chapman continued to refine his equations into the early 1960s. Hitting the precise trajectory angle that became known as the Chapman Corridor became the goal of navigation specialists elsewhere in NASA. At Ames, Chapman's methods were used to refine the aerodynamics of Allen's blunt body concept and define the thermodynamic envelope of the rarified atmosphere.

Ames applied its work on thermal structures, heating, and hypersonic aerodynamics to the X-15 experimental aircraft, which first flew faster than Mach 5 in June 1961 over Rogers Dry Lake. Data returned from the X-15 flight tests then supported modifications to theories about flight in near-space. But as America hurried its first plans to send humans into space and return them safely to Earth, NASA instructed Ames to make sure that every facet of this theory was right for the exact configuration of the space capsules. So in the early 1960s Ames opened several new facilities to test all facets—thermal and aerodynamic—of Allen's blunt body theory.

Hypervelocity Free Flight Facility

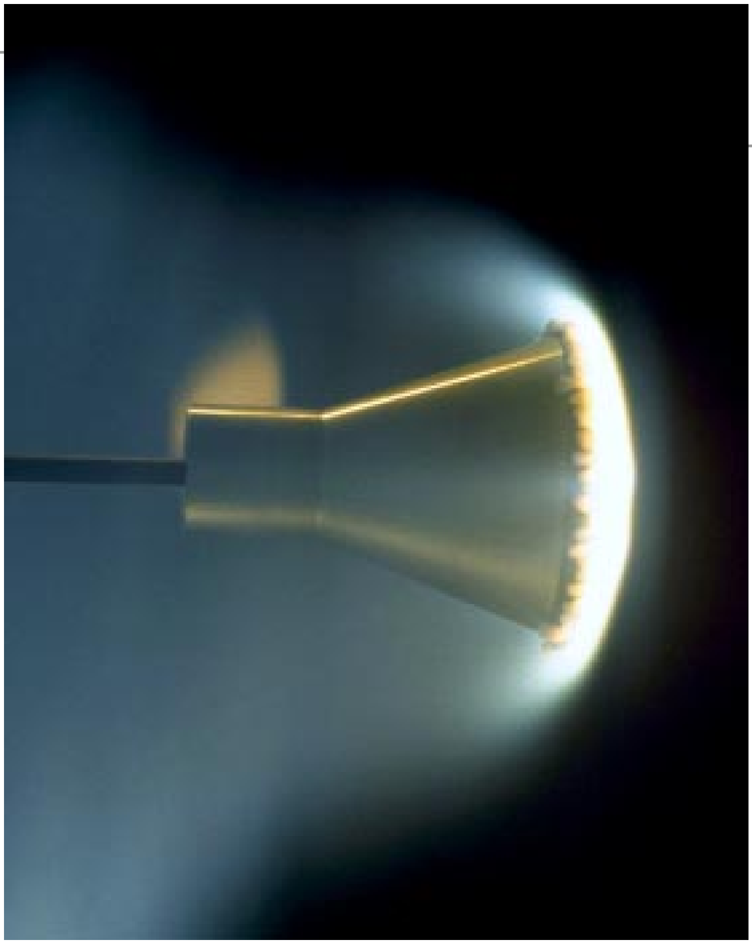
The hypervelocity research laboratory became the home of Ames' physics branch and carried out a significant body of research into ion beams and high temperature gases. Its 3.5 foot tunnel opened with interchangeable nozzles for operations at Mach 5, 7, 10 or 14. It included a pebble-bed heater which preheated the air to 3000 degrees Fahrenheit to prevent liquefaction in the test section at high Mach numbers. Ames added a 14 inch helium tunnel (at almost no cost) to the 3.5 foot tunnel building, which already had helium storage, and opened a separate 20 by 20 inch helium tunnel. These provided a very easy way of running preliminary hypervelocity tests from Mach 10 to Mach 25. Compared with air, helium allowed higher Mach numbers with the same linear velocities (feet per second). A one foot diameter hypervelocity shock tunnel, a remnant of the parabolic entry simulator, was built into an old Quonset hut. The shock tube could be filled with air of varying chemical composition, or any mixture of gases to simulate the atmosphere of Venus or Mars. It produced flows up to Mach 14, lasting as long as 100 milliseconds, with enthalpies up to 4000 Btu (British thermal units) per pound. Enthalpy indicated how much heat was transferred from the tunnel atmosphere to the tunnel model, and was thus a key measure in hypersonic research.

Models tested in the hypervelocity free flight tunnel.



The hypervelocity free flight facility (HFF), which grew out of this hypervelocity research laboratory, marked a major advance in Ames' ability to simulate the reentry of a body into an atmosphere. The idea of building a shock tunnel in counterflow with a light gas gun had been proven in 1958 with a small pilot HFF built by Thomas Canning and Alvin Seiff with spare parts. With a full-scale HFF budgeted at $5 million, Ames management wanted a bit more proof before investing so much in one facility. So in 1961, Canning and Seiff opened a 200 foot prototype HFF. Its two-stage shock compression gun hurled a projectile more than 20,000 feet per second into a shock tunnel that produced an air pulse travelling more than 15,000 feet per second. Ames had thus created a relative airspeed of 40,000 feet per second—the equivalent of reentry speed. Using this facility, Canning showed that

Hypersonic free flight gun, in June 1966, with Thomas Canning at the breech of the counterflow section.



Ablation test of a Mercury capsule model.

the best shape for a space capsule—to retain a laminar boundary flow with low heat transfer—was a nearly flat face. Seiff also used it to test the flight stability of proposed capsule designs. Ames next increased the airspeed by rebuilding the piston driver with a deformable plastic that boosted the compression ratio. By July 1965, when the HFF officially opened, Ames could test models at relative velocities of 50,000 feet per second. To vary the Reynolds numbers of a test, Ames also built a pressurized ballistic range capable of pressures from 0.1 to 10 atmospheres. Every vehicle in America's human space program was tested there.

Arc Jets

While the HFF generated an enthalpy of 30,000 Btu per pound, the peak heating lasted mere milliseconds. These tunnels worked well for studying reentry aerodynamics, but the heating time was of little use for testing ablative materials. Ablative materials could be ceramics, quartz, teflon, or graphite composites that slowly melted and vaporized to move heat into the atmosphere rather than into the metal structure of the capsule. To test ablative materials—both how well they vaporized and how the melting affected their aerodynamics—Ames began developing the technology of arc jets. This work actually began in 1956, when Ames surveyed the state of commercial arc jets. Under pressure from NASA, in the early 1960s Ames designed its own. As the Apollo era dawned, Ames had a superb set of arc jets to complement its hypervelocity test facility.

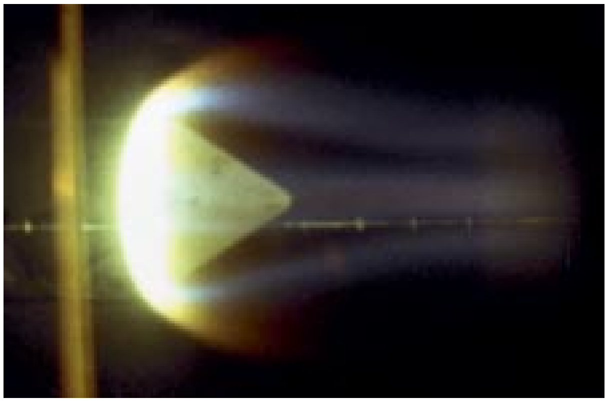
These arc jets started with a supersonic blow-down tunnel, with air going from a pressurized vessel into a vacuum vessel. On its way through the supersonic throat the air was heated with a powerful electric arc—essentially, lightning controlled as it passed between two electrodes. The idea was simple but many problems had to be solved: air

Glen Goodwin, chief of Ames' thermo and gas dynamics division, describing the workings of the broad plasma beam facility.

tends to avoid the electrical field of the arc so heating is not uniform; the intense heat melted nozzles and parts of the tunnel; and vaporized electrode materials contaminated the air.

So Ames devised electrodes of hollow, water-filled concentric rings, using a magnetic field to even out the arc. At low pressures, one of these concentric ring arc jets added to the airstream as much as 9000 Btu per pound of air. Though significant, this heating still did not represent spacecraft reentry conditions. Ames people looked for a better way of mixing the air with the arc. They devised a constricted arc that put one electrode upstream of the constricted tunnel and the other electrode downstream so that the arc passed through the narrow constriction along with the air. This produced enthalpies up to 12,000 Btu at seven atmospheres of pressure. By using the same constricted arc principle, but building a longer throat out of water-cooled washers of boron nitride, in late 1962 Ames achieved a supersonic arc plasma jet with enthalpies over 30,000 Btu per pound and heating that lasted several seconds. Expanding upon Ames' technical success in building arc jets, Glen Goodwin and Dean Chapman proposed a gas dynamics laboratory to explore how arc jets work in a comprehensive way. Opened in 1962, the $4 million facility accelerated the theoretical and empirical study of ablation.

By 1965, Ames had built a dozen arc jets to generate ever more sustained heat flows. An arc jet in the Mach 50 facility could operate with any mixture of gas, and achieved enthalpies up to 200,000 Btu per pound. As industrial firms began to design ablative materials for the Apollo heat shield, Ames researchers like John Lundell, Roy Wakefield and Nick Vojvodich could test them thoroughly and select the best.



Apollo capsule free flight ablation test.

Impact Physics and Tektites

For clues on reentry aerodynamics, Allen also suggested that Ames study meteorites, nature's entry bodies. Using their high-speed guns, Ames first explored the theory of meteor impacts by hurling spheres of various densities at flat targets. At the highest impact speeds, both the sphere and target would melt and splash, forming a crater coated with the sphere material—very much like lunar craters. Ames then turned its attention to lunar craters—specifically the radial rays of ejected materials—by shooting meteor-like stones at sand targets like those on the Moon. By concluding that an enormous volume of material was ejected from the Moon with every meteor impact, they paved the way for lunar landings by suggesting that the surface of the Moon was most likely all settled dust.

One stunning example of what results when Ames' raw scientific genius is unleashed was the work of Dean Chapman on tektites. In early 1959, Chapman used the 1 by 3 foot blowdown tunnel (as it was about to be dismantled) to melt frozen glycerin in a Mach 3 airstream. In the frozen glycerin he first photographed the flattening of a sphere into a shape similar to Allen's blunt body. The ball quickly softened, its surface melted into a viscous fluid, and a system of surface waves appeared that were concentric around the aerodynamic stagnation point. On his

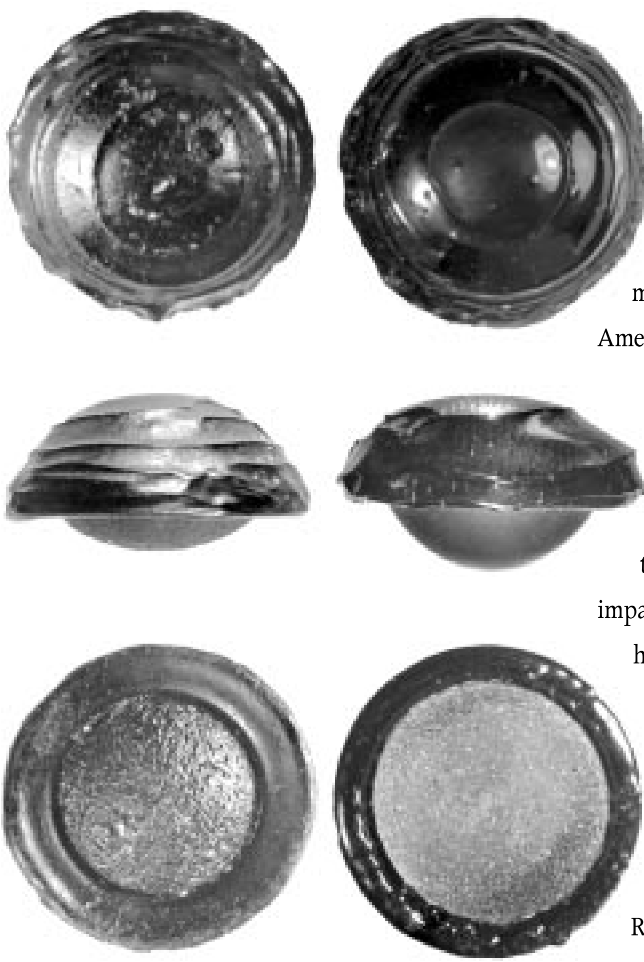
Gas dynamics facility, in 1964, and the 20 inch helium tunnel.

Impact test, simulating space debris hitting an orbiting capsule. The spark came from a blunt-nose, 20 millimeter polyethylene model hitting an aluminum target at 19,500 feet per second in a pressure simulated as 100,000 foot altitude.

Dean Chapman showing a tektite to Vice President Lyndon Johnson in October 1961.

way to England for a year of research, Chapman visited a geologist at the American Museum of Natural History, who saw some similarity in the wave patterns on the glycerin balls and the wave patterns on glassy pellets of black glass called tektites. Tektites had been unearthed for centuries, mostly around Australia, though geologists still vigorously debated their origin. When geologists asked the Australian aborigines where the tektites came from, they pointed vaguely up to the sky.

A natural tektite, at left, compared with an artifical tektite.



Chapman applied the skills he had—in aerodynamics and ablation—and learned what chemistry he needed. He cut open some tektites and found flow lines that suggested they had been melted into button shapes, after having been previously melted into spheres. From the flow lines he also calculated the speed and angle at which they entered Earth's atmosphere. He then melted tektite-type material under those reentry conditions in Ames' arc jet tunnels. By making artificial tektites, he established that they got their shape from entering Earth's atmosphere just as a space capsule would.

Chapman next offered a theory of where the tektites came from. By eliminating every other possibility, he suggested that they came from the Moon. Ejected fast enough following a meteor impact, these molten spheres escaped the Moon's gravitational field, hardened in space, then were sucked in by Earth's gravitation. Harvey Allen walked into Chapman's office one day and egged him on: "If you're any good as a scientist you could tell me exactly which crater they came from." So Chapman accepted the challenge, calculated the relative positions of Earth and Moon, and postulated that they most likely came from the Rosse Ray of the crater Tycho.

Thirty caliber vertical impact range, in 1964, with the gun in the horizontal loading position. William Quaide and Donald Gault of the Ames planetology branch used the gun range to study the formation of impact craters on the Moon.

In October 1963, Chapman won NASA's Medal for Exceptional Scientific Achievement. His bit of scientific sleuthing had accelerated curiosity about the composition of the Moon and the forces that shaped it, in the process validating some theories about ablation and aerodynamic stability of entry shapes. But the community of terrestrial geologists kept open the debate. While most geologists now accepted that tektites had entered Earth's atmosphere at melting speeds, most maintained that they were terrestrial in origin—ejected by volcanoes or a meteor crash near Antarctica. Only a single sample returned from the Moon, during Apollo 12, bears any chemical resemblance to the tektites. Thus, only the return of samples from the Rosse Ray would ultimately prove Chapman's theory of lunar origin.

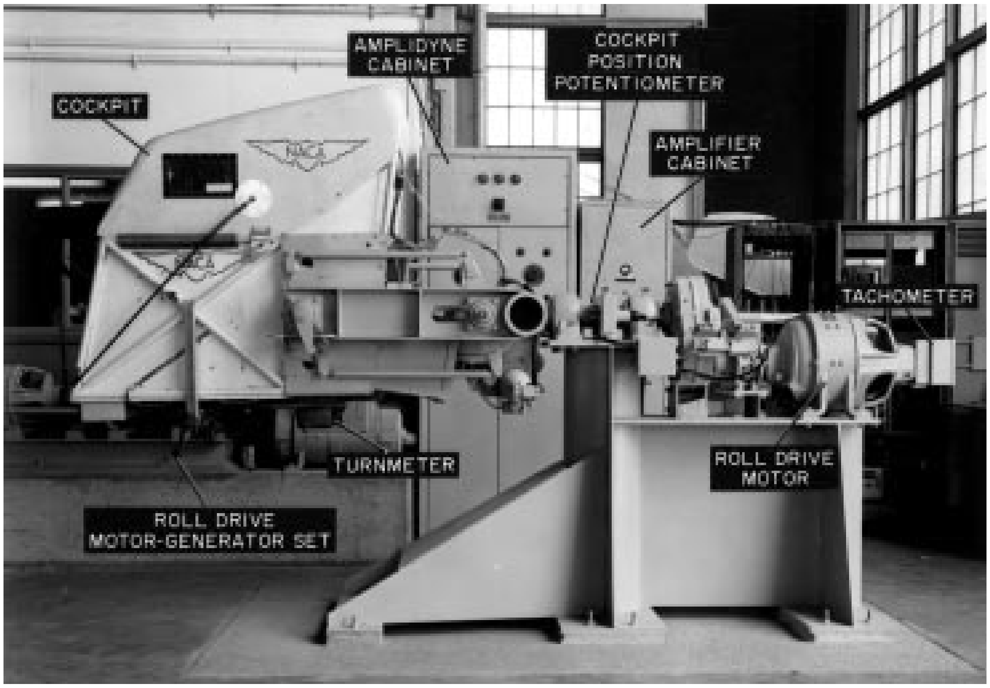
FLIGHT STUDIES

Of course, not every aerodynamicist at Ames was working on the Apollo project. Ames continued working on high-speed aerodynamics, such as boundary layer transition, efficient supersonic inlets, dynamic loads on aircraft structures, and wing-tip vortices. Ames focused its work on high-lift devices to test new approaches to vertical and short take-off and landing aircraft. Ames continued to use its wind tunnels to clean up the designs of modern commercial aircraft as air passengers took to the skies in the new jumbo jets. And Ames solved many of the seemingly intractable flight problems of military aircraft—problems often uncovered during action in Vietnam.

Ames also continued to do airplane configuration studies, most notably for

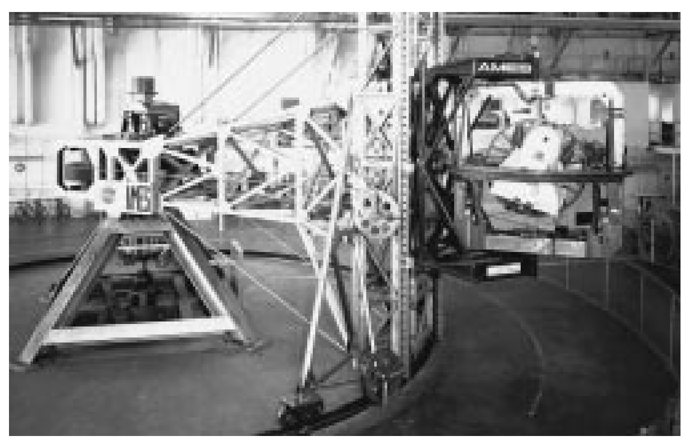
Double-delta planform on a supersonic transport model, mounted in the 40 by 80 foot wind tunnel.

A simple pitch-roll chair, a 2-degree-of-freedom simulator built in 1958.



the supersonic transport. NASA decided it would outline the general configuration from which an aircraft firm would build a commercial supersonic transport (SST). Because of Ames' long interest in delta wings and canards—going back to tests of the North American B-70 supersonic bomber—Victor Peterson and Loren Bright of Ames helped develop a delta-canard configuration. The Ames vehicle aerodynamics branch also suggested a double-delta configuration that Lockheed used for its SST proposal. Then Ames used its wind tunnels to help the Federal Aviation Administration (FAA) to evaluate the efficiency and environmental impact of the designs. And Ames used its flight simulators to coordinate handling qualities research by NASA, pilot groups, industrial engineers, and airworthiness authorities from the United States, the United Kingdom, and France. Ames thus led development of criteria used to certify civil supersonic transports; the European-built Concorde was certified to these criteria in both Europe and the United States.

Ames people are famous for reinventing themselves to apply the skills they have to problems that are just being defined. One example of personal reinvention, in the



The Ames 5-degree-of-freedom simulator, 1962.

The 5-degree-of-freedom flight simulator, in 1962, with time-lapsed exposure to show its wide range of motion.

The 5-degree-of-freedom piloted flight simulator.

1960s, is Ames' emergence as a leader in flight simulators. Ames had begun building simulators in the early 1950s, when the Center acquired its first analog computers to solve dynamics, and as part of Ames' work in aircraft handling qualities. Harry Goett had pushed Ames to get further into simulator design, and George Rathert had led the effort. Ames' analog computing staff recognized that they could program the computer with an aircraft's aerodynamics and equations of motion, that a mockup of the pilot stick and pedals could provide computer inputs, and that computer output could drive mockups of aircraft instrumentation. Thus, the entire loop of flight control could be tested safely on the ground. Simulators for entry-level training were already widely used, but by building their system around a general, reprogrammable computer, Ames pioneered development of the flight research simulator.

By the late 1950s, using parts scrounged from other efforts, Ames had constructed a crude roll-pitch chair. Goett championed construction of another simulator, proudly displayed at the Ames 1958 inspection, to test design concepts for the X-15 hypersonic

The 6-degree-of-freedom motion simulator, opened in 1964, was used to investigate aircraft handling qualities, especially for takeoff and landing studies. The cab is normally covered, with visuals provided by a TV monitor.

experimental aircraft. Ames was ready to move when NASA asked for simulators to help plan for spacecraft to be piloted in the unfamiliar territory of microgravity. Fortunately, Ames had on staff a superb group of test pilots and mechanics who wanted to stay at Ames even after NASA headquarters sent away most of its aircraft. Led by John Dusterberry, this analog and flight simulator branch pioneered construction of sophisticated simulators to suit the research needs of other groups at Ames and around the world.

In 1959, Ames embarked on an ambitious effort to build a five-degree-of-freedom motion simulator. This was a simulated cockpit built on the end of a 30 foot long centrifuge arm, which provided curvilinear and vertical motion. The cockpit had electrical motors to move it about pitch, roll and yaw. It was a crude effort, built of borrowed parts by Ames' engineering services division. But the simulator proved the design principle, pilots thought it did a great job representing airplane flight, and it was put to immediate use on stability augmentors for supersonic transports.

In 1963, Ames opened a six-degree-of-freedom simulator for rotorcraft research, a moving cab simulator for transport aircraft, and a midcourse navigation simulator for use in training Apollo astronauts. Ames combined its various simulators into a spaceflight guidance research laboratory, opened in 1966 at a cost of $13 million. One of the most important additions was a centrifuge spaceflight

Apollo navigation simulator, used to test concepts for midcourse correction on the voyage to and from the Moon.

simulator at the end of a centrifuge arm, capable of accelerating at a rate of 7.5 g forces per second. Another was a satellite attitude control facility, built inside a 22 foot diameter sphere to teach ground controllers how to stabilize robotic spacecraft.

Ames had become the best in the world at adding motion generators to flight simulators, and soon pioneered out-the-window scenes to make the simulation seem even more realistic for the pilot. Ames also emphasized the modular design of components, so that various computers, visual projectors, and motion systems could be easily interconnected to simulate some proposed aircraft design.

Ames also made key contributions to flight navigation. Stanley Schmidt had joined Ames in 1946, working in instrumentation, analog computing and linear perturbation theory. In 1959, when NASA first tasked its Centers to explore the problems of navigating to the Moon, Schmidt saw the potential for making major theoretical extensions to the Kalman linear

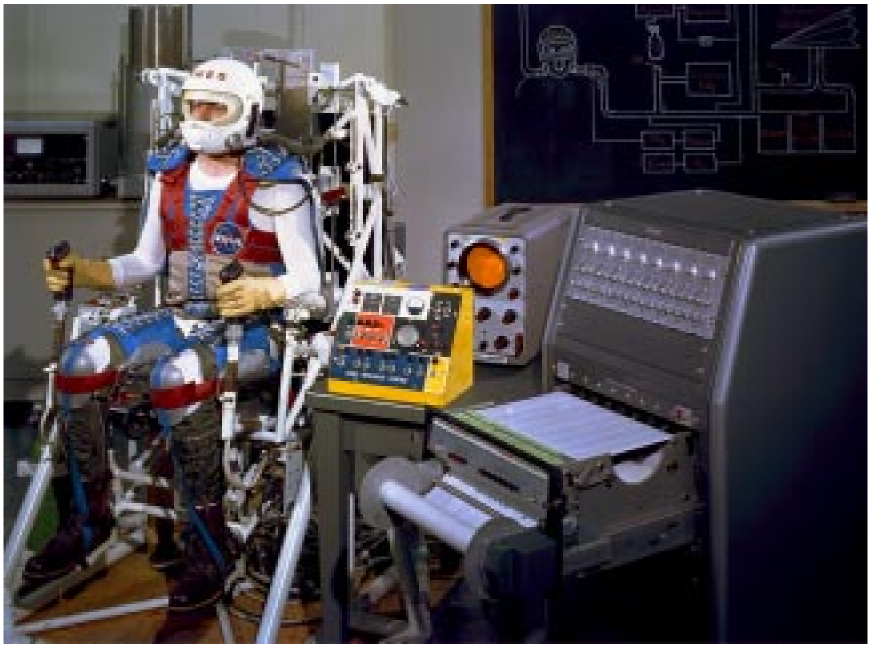
Brent Creer, chief of the Ames manned spacecraft simulation branch, developed the Apollo midcourse navigation and guidance simulator. Here he is shown with sextants designed to be carried aboard the capsule.

This human-carrying rotation device opened in 1966. It was used in studies of motion sickness, pilot response to microgravity, and in studies of pilot sensing of rotation.

filter. The result was a state-estimation algorithm called the Kalman-Schmidt filter. By early 1961, Schmidt and John White had demonstrated that a computer built with this filter, combined with optical measurements of the stars and data about the motion of the spacecraft, could provide the accuracy needed for a successful insertion into orbit around the Moon. Meanwhile Gerald Smith, also of the Ames theoretical guidance and control branch, demonstrated the value of ground-based guidance as a backup to guidance on board the Apollo capsules. The Kalman-Schmidt filter was embedded in the Apollo navigation computer and ultimately into all air navigation systems, and laid the foundation for Ames' future leadership in flight and air traffic research.

In the mid-1960s, Ames also participated in the design of suits for astronauts to wear for extravehicular activity. Though none of the concepts demonstrated by Ames were included in the Apollo spacesuits, many were incorporated in the next-generation of suits designed for Space Shuttle astronauts. Hubert "Vic" Vykukal led Ames' space human factors staff in designing the AX-1 and AX-2 suits for extended lunar operations, and in validating the concepts of the single-axis waist and rotary bearing joints. The AX-3 spacesuit was the first high pressure suit—able to operate at normal Earth atmospheric pressures—and demonstrated a low-leakage, low-torque bearing. Ames continued to advance spacesuit concepts well beyond the Apollo years, and some concepts were applied only two decades later. The AX-5 suit, designed for the International Space Station, was built entirely of aluminum with only fifteen major parts. It has stainless steel rotary

Vic Vykukal modeling the AX-1 spacesuit in 1966.



bearings and no fabric or soft parts. The AX-5 size can be quickly changed, it is easy to maintain, and it has excellent protection against meteorites and other hazards. Because it has a constant volume, it operates at a constant internal pressure, so it is easy for the astronaut to move. Ames also developed a liquid cooled garment, a network of fine tubes worn against the skin to maintain the astronaut's temperature. To expedite Ames' efforts in spacesuit design, in September 1987 Ames would open a neutral buoyancy test facility, only the third human-rated underwater test facility in the country. In building these suits, as in building the simulators for aircraft and spaceflight, Ames came to rely upon experts in human physiology joining the Center's burgeoning work in the life sciences.

A 1962 study of breathing problems encountered during reentry, with pilot Robert St. John strapped into a respiratory restraint suit and a closed-loop breathing system.

START OF LIFE SCIENCES RESEARCH

In the early 1960s, as in the early 1940s, Ames looked like a construction zone. Not only were new arc jet and hypervelocity tunnels being built at top speed, but the life sciences division had to

Flight and guidance centrifuge in 1971 was used for spacecraft mission simulations and research on human response to motion stress.

Artwork of an astronaut training for the Gemini missions using a simulator chair based on an Ames design.

build numerous facilities from scratch. The first biologists to move out of their temporary trailers, in 1964, moved into the biosciences laboratory. Much of this laboratory was an animal shelter, where Ames housed a well-constructed colony of several hundred pig-tail macaques from southeastern Asia for use in ground-based control experiments prior to the Biosatellite missions. In December 1965, Ames dedicated its life sciences research laboratory. It was architecturally significant within the Ames compound of square, two story, concrete-faced buildings, because it stood three stories tall and had a concrete surfacing dimple like the Moon. It cost more than $4 million to build and equip its state-of-the-art exobiology and enzyme laboratories.

These new facilities were designed to help Ames biologists understand the physiological stress that spaceflight and microgravity imposed on humans. While the Manned Spacecraft Center near Houston screened individual astronauts for adaptability and led their training, Ames developed the fundamental science underlying this tactical work. Mark Patton in the Ames biotechnology division studied the performance of humans under physiological and psychological stress to measure, for example, their ability to see and process visual signals. Other studies focused on how well humans adapted to

Vic Vykukal models the AX-3 hard spacesuit.

long-term confinement, what bed rest studies showed about muscle atrophy, and what sort of atmosphere was best for astronauts to breathe. Ames' growing collection of flight simulators also was used for fundamental studies of human adaptability to the gravitational stress of lift-off, microgravity in spaceflight, and the vibration and noise of reentry. All these data helped define the shape and function of the Gemini and Apollo capsules.

Ames' environmental biology division studied the effect of spaceflight on specific organs, mostly through animal models. Jiro Oyama pioneered the use of centrifuges to alter the gravitational environment of rats, plants, bacteria and other living organisms, and thus pioneered the field of gravitational biology. In conjunction with the University of California Radiation Laboratory, Ames used animal models to determine if the brain would be damaged by exposure to high-energy solar rays that are usually filtered out by Earth's atmosphere. To support all this life sciences research, Ames asked its instrumentation group to use the expertise it had earned in building sensors for aircraft to build bio-instrumentation. Under the guidance of John Dimeff, the Ames instrumentation branch built sophisticated sensors and clever telemetry devices to measure and record all sorts of physiological data.

Flight Simulator for Advanced Aircraft (FSAA), opened in 1969, was used to investigate the landing, takeoff and handling qualities of large aircraft. The control room is on the right.

Building Blocks of Life

Exobiology, however, generated the most headlines during Ames' early work in the life sciences. As the task was first given to Ames, exobiology focused on how to identify any life encountered in outer space. Harold P. "Chuck" Klein had worked for eight years at Brandeis University defining what nonterrestrial life might look like in its chemical traces. He arrived at Ames in 1963 to head the exobiology branch and guided construction of Ames' superb collection of gas chromatographs, mass spectrometers, and quarantine facilities. A year later DeFrance asked Klein, who had served as chairman of Brandeis' biology department, to become director of Ames' life sciences directorate. Klein brought intellectual coherence to Ames' efforts, fought for both support and distance from Washington, and did a superb job recruiting scientists from academia.

Cyril Ponnamperuma of the Ames chemical evolution branch with the electrical-discharge apparatus used in his experiments on the chemical orgins of life.

Cyril Ponnamperuma arrived at Ames in the summer of 1961 in the first class of postdoctoral fellows under a joint program between NASA and the National Research Council. What he saw at Ames led him to join the permanent staff, and for the next decade he infused Ames' exobiology efforts with a flourish of intellectual energy. Using all that NASA scientists were learning about the chemical composition of the universe, Ponnamperuma brought a fresh outlook to the question of how life began at all.

Geologists had already discovered much about the chemical composition of primordial Earth. Scientists at Ames used their chromatographs and spectroscopes to detect the minute amounts of organic compounds in extraterrestrial bodies, like meteorites. From this, Ponnamperuma's colleagues in Ames' chemical evolution branch elucidated the inanimate building blocks and natural origins of life. Like many biochemists, they

suspected that life was simply a property of matter in a certain state of organization, and if they could duplicate that organization in a test tube then they could make life appear. If they did, they would learn more about how to look for life elsewhere in the universe.

By the end of 1965, in apparatus designed to simulate primitive Earth conditions, Ponnamperuma and his group succeeded in synthesizing some of the components of the genetic chain—bases (adenine and guanine), sugars (ribose and deoxyribose), sugar-based combinations (adenosine and deoxyadenosine), nucleotides (like adenosine triphosphate), and some of the amino acids. A breakthrough came when the Murchison carbonaceous meteorite fell on Australia in September 1969. In the Murchison meteorite, Ames exobiologists unambiguously detected complex organic molecules—amino acids—which proved prebiotic chemical evolution. These amino acids were achiral (lacking handedness), thus unlike the chiral amino acids (with left handedness) produced by any living system. The carbon in these organic compounds had an isotope ratio that fell far outside the range of organic matter on Earth. The organic compounds in the Murchison meteorite arose in the parent body of the meteorite, which was subject to volcanic outgassing, weathering and clay production as occurred on prebiotic Earth.

The evolution of life on Earth, depicted from its chemical origins on the left to mammalian life on the right.

Lunar Sample Analysis

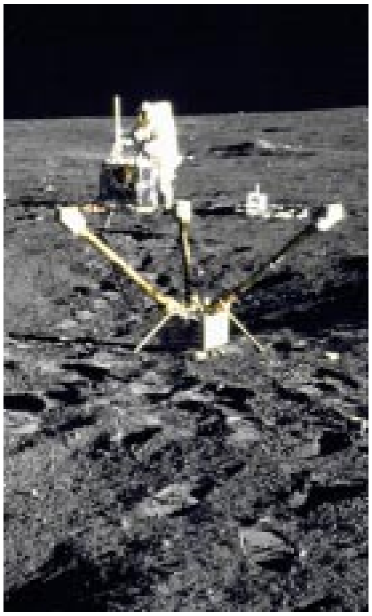
Because of the expertise Ames people had developed in the chemical composition of nonterrestrial environments and in the

Apollo 12 lunar module over the lunar surface. Apollo 12 left an Ames magnetometer on the Moon as part of a package of scientific instruments.

life sciences, headquarters asked Ames to build one of two lunar sample receiving facilities. To prevent any contamination of the samples, this facility had to be very clean, even beyond the best of the Silicon Valley clean rooms. Whereas the facility at the Manned Spacecraft Center in Houston focused on identifying any harmful elements in the lunar samples, Ames scientists looked at the overall composition of the lunar regolith (the term for its rocky soil).

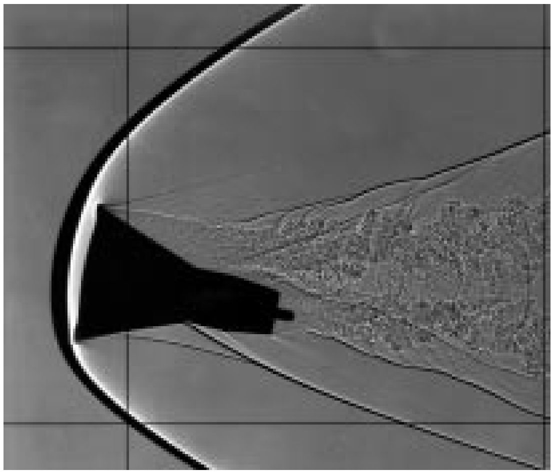
Ames researchers—led by Cyril Ponnamperuma, Vance Oyama and William Quaide—examined the carbon chemistry of the lunar soils, and concluded that it contained no life. But this conclusion opened new questions. Why was there no life? What kind of carbon chemistry occurs in the absence of life? Continuing their efforts, Ames researchers discovered that the lunar regolith was constantly bombarded by micrometeorites and the solar wind, and that interaction with the cosmic debris and solar atomic particles defined the chemical evolution of the surface of the Moon.

Ames also provided tools for investigating the chemistry of the Moon beneath its surface. Apollos 12, 14, 15, and 16 each carried a magnetometer—designed by Charles Sonnet, refined by Palmer Dyal, and built at Ames around an advanced ring core fluxgate sensor. These were left at the Apollo lunar landing sites to radio back data on the magnetic shape of the Moon. Paced by a stored program, these magnetometers first measured the permanent magnetic field generated by fossil magnetic materials. They then measured



Thr tri-axis magnetometer, developed at Ames, and used to measure magnetic fields on the Moon.

Shadowgraph of the Gemini capsule model in a test of flight stability.



the electrical conductivity and temperature profile of the lunar interior, from which scientists deduced the Moon's magnetic permeability and its iron content. And they measured the interactions of the lunar fields with the solar wind. For Apollos 15 and 16, Ames also developed handheld magnetometers to be carried aboard the lunar rover.

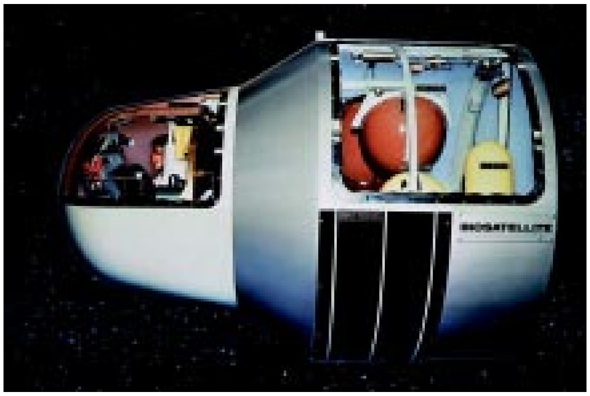
The magnetometer left on the Moon by Apollo 12 showed that the Moon does not have a two-pole magnetism as does Earth. It also suggested that the Moon is a solid, cold mass, without a hot core like that of Earth. But it also unveiled a magnetic anomaly 100 times stronger than the average magnetic field on the Moon. The series of magnetometers showed that the Moon's transient magnetic fields were induced by the solar wind and that they varied from place to place on the surface. Most important, these data allowed NASA to develop plans for a satellite to map in detail the permanent lunar magnetic fields in support of future missions to the Moon. These efforts in the space and life sciences displayed Ames' strengths in basic research and experimentation, but they were not at the heart of NASA's early missions.

SPACE PROGRAM MANAGEMENT

Smith DeFrance and Harvey Allen both insisted that Ames stick to research—either basic or applied—and stay out of what NASA called project management. Russ Robinson agreed, and so did Ira Abbott at NASA headquarters. Jack Parsons, though, encouraged the many young Ames researchers who wanted to try their hand at project management, and so did Harry Goett. Early in 1958, Goett and Robert Crane prepared specifications for a precise attitude stabilization system needed for the orbiting astronomical observatory (OAO), as well as the Nimbus meteorological satellite. Encouraged by how well NASA headquarters received their ideas, Goett convinced DeFrance to submit a proposal for Ames to assume total technical responsibility for the OAO project. Abbott, with Dryden's concurrence, told Ames to stick to its research.

Al Eggers, backed by the expertise pulled together in his new vehicle environment division, was the next to try to get Ames involved in project management. Eggers' assistant division chief, Charles Hall, wanted to build a solar probe. By late 1961, Hall had succeeded in getting two audiences with headquarters staff, who discouraged him by suggesting he redesign it as an interplanetary probe. Space Technology Laboratories (STL) heard of Ames' interest, and Hall was able to raise enough money to hire STL for a feasibility study of an interplanetary probe. Armed with the study, DeFrance and Parsons both went to headquarters and, in November 1963, won the right for Ames to manage the PIQSY probe (for Pioneer international quiet sun year), a name soon shortened to Pioneer.

DeFrance also reluctantly supported the Biosatellite program. Biosatellite started when headquarters asked Ames what science might come from sending monkeys into space in leftover Mercury capsules. When Carlton Bioletti submitted Ames' report to headquarters early in 1962, an intense jurisdictional dispute erupted with the Air Force over which agency should control aerospace human factors research. Because the United States was already well behind the Soviet Union in space life sciences, NASA won this battle and immediately established the life sciences directorate at Ames. In the meantime, biologists had started submitting unsolicited proposals to Ames. Bioletti and his small group of ten visited each of these biologists to sketch out the specifications for a series of biological satellites. Impressed with these efforts, in October 1962 Ames was tasked to manage Project Biosatellite.



Biosatellite model with monkey shown in the front of the capsule and the life-support package in the rear.

Ames' work in lifting bodies also took it, slowly, into project management. Eggers and his group in the 10 by 14 inch tunnel in 1957 had conceived of a spacecraft that could safely reenter Earth's atmosphere, gain aerodynamic control and land like an airplane. They called these "lifting bodies" because the lift came from the fuselage rather than from wings, which were too vulnerable to melting during reentry. Using every tunnel available to them, Ames aerodynamicists formalized the design, tunnel tested it, and procured a

flying prototype called the M2-F2 from Northrop for flight tests at NASA's High Speed Flight Station beginning in 1965. These tests, in conjunction with flight tests of the SV-5D and HL-10 lifting bodies, gave NASA the confidence it needed to choose a lifting body design for the Space Shuttle.

By 1963, even DeFrance had to recognize that without some experience in how projects were managed, Ames would be left behind NASA's growth curve. The NACA culture indicated that any scientist interested in a project should execute it. That had been possible even on the larger wind tunnels because a scientist only needed the help of Jack Parsons to marshal resources within the laboratory. When projects were launched into space, however, executing projects got substantially more complex. First, most of the support came from outside the Center—from aerospace contractors or from the NASA Centers that built launch vehicles, spacecraft, or data acquisition networks. Second, nothing could be allowed to go wrong when the spacecraft or experimental payload was so distant in space, so technical integration and reliability had to be very well-conceived and executed. Finally, the larger costs evoked greater suspicion from headquarters, and thus warranted more preliminary reporting on how things would go right. Scientists were increasingly willing to have a project

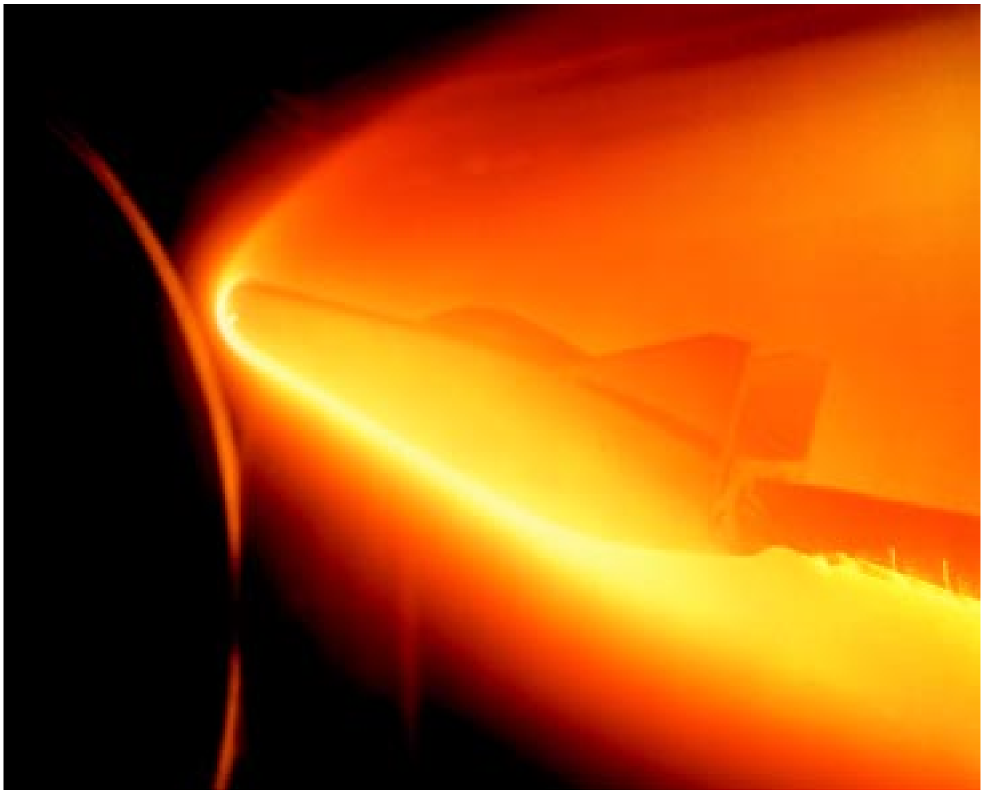
M2-F2 lifting body mounted in the 40 by 80 foot wind tunnel in July 1965 prior to flight tests.

The M2-F2 lifting body returns from a test flight at the Dryden Flight Research Center with an F-104 flying chase. On its first flight on 12 July 1966 the M2-F2 was piloted by Milt Thompson. The M2-F2 was dropped from a wing mount on NASA's B-52 at an altitude of 45,000 feet. The M2-F2 weighed 4,620 pounds, was 22 feet long, and was 10 feet wide.

management specialist handle these more burdensome support arrangements.

Project management was the sort of integrative, multidisciplinary work that engineers excelled in, but spare engineers were hard to find at Ames. So Ames management began to cultivate some project managers attuned to the scientists they would serve. Bob Crane was named to the new position of assistant director for development and he, in turn, named John V. Foster to head his systems engineering division. Charlie Hall then managed the Pioneer project, and Charlie Wilson managed the Biosatellite. Both Hall and Wilson worked with lean staffs, who oversaw more extensive contracting than was usual at Ames. They studied NASA protocols for network scheduling and systems engineering. Significantly, both reported to headquarters through the Office of Space Science and Applications (OSSA), whereas the Center as a whole reported to the Office of Advanced Research and Technology (OART). The result was that Ames scientists in the life and planetary sciences had little to gain by participating directly in those project efforts, and thus did not compete very hard to get their experiments on either the Pioneers or the Biosatellites. Project management at Ames remained segregated from the laboratory culture of the Center even as it gradually absorbed that culture.

Alfred Eggers, in 1958, at the 10 by 14 inch supersonic wind tunnel.



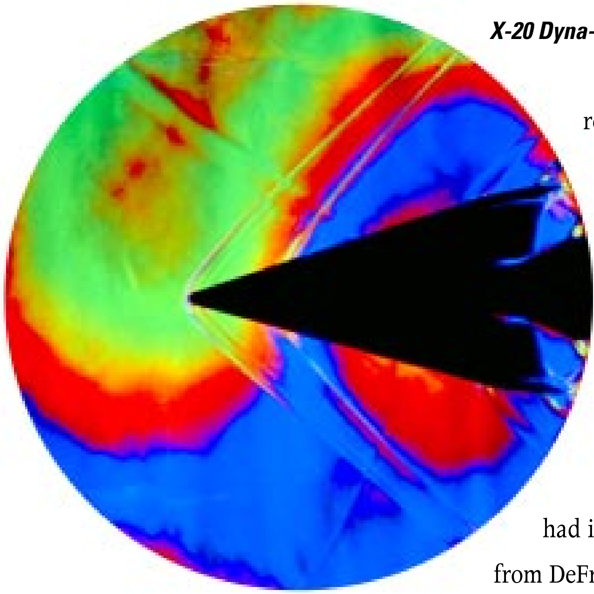
Model of the M-2 lifting body, in 1962, being tested in Ames' atmospheric entry simulator to determine the areas of most intense heat.

HARVEY ALLEN AS DIRECTOR

On 15 October 1965, DeFrance retired after 45 years of public service, with elaborate ceremonies in Washington and in San Jose so his many friends could thank him for all he had done. DeFrance had planned well for his retirement and had cultivated several younger men on his staff to step into his role. Harvey Allen was the best known of the Ames staff, and had the most management experience. The director's job was his to refuse which, initially, he did.

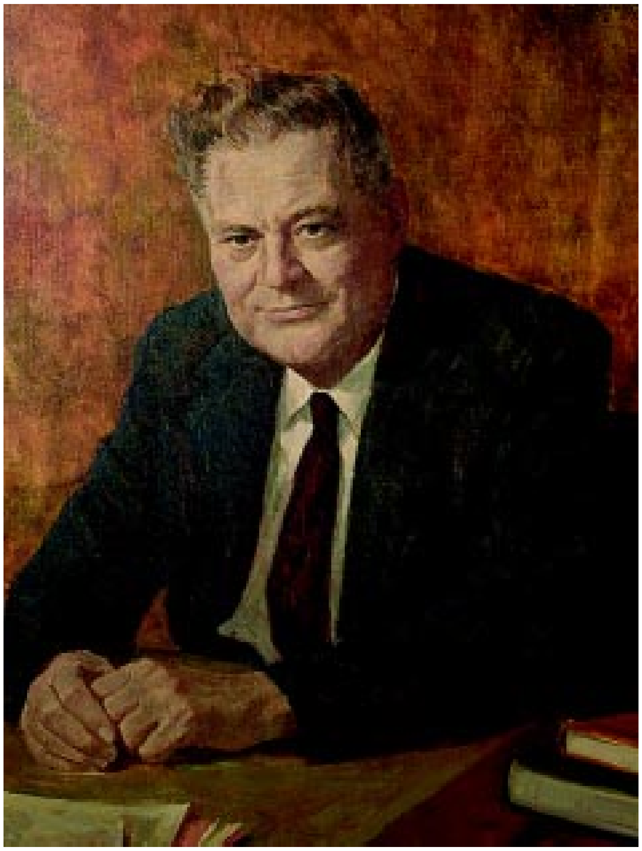
Eggers then loomed as the front runner. Eggers and Allen were both friends and competitors. Whereas Allen was seen as jovial and encouraging, Eggers was seen as abrasive and challenging. The two had collaborated in the early 1950s on the pathbreaking work on the blunt body concept, but Allen made his work more theoretical whereas Eggers explored practical applications like the lifting bodies. In January 1963, Eggers won for himself the newly created post of assistant director for research and development analysis and planning, where he could pursue his expertise in mission planning. A year later he went to headquarters as deputy associate administrator in OART. He persuaded his boss, Ray Bisplinghoff, to create an OART-dedicated mission analysis group based at Ames. It would report directly to headquarters, be located at Ames, and staffed by scientists on loan from all NASA Centers. But this OART mission analysis division, established in January 1965, never got support from the other Centers. Each Center thought it should bear responsibility for planning the best use of its research and resources. Within a year, the OART abandoned plans for assigning a complement of fifty scientists to the Ames-based OART mission analysis division. But the disarray began to spread to the Ames directorate for R&D planning and analysis that was originally created for Eggers. Clarence Syvertson

Schlieren image of the X-20 Dyna-Soar.



remained in charge of a much smaller, though very active, mission analysis division. A new programs and resources office was created under Merrill Mead to plan and fight for Ames' budget, which left Eggers as the headquarters choice to become director. To prevent that from happening and to keep Ames as it was—distant from Washington, with a nurturing and collaborative spirit, and focused on research rather than projects—in October 1965 Allen took the directorship himself.

Allen did not especially distinguish himself as director as he had in his other promotions. As a person, Allen differed dramatically from DeFrance. He was warm, benevolent, close to the research, inspirational in his actions and words. But Allen, like DeFrance, kept Ames as a research organization and worked hard to insulate his staff from the daily false urgencies of Washington. Allen asked Jack Parsons, who remained as associate director, to handle much of the internal administration and asked Loren Bright and John Boyd to fill the newly created positions of executive assistant to the director and research assistant to the director. Allen often sent Ames' ambitious young stars in his place to the countless meetings at headquarters. And every afternoon at two o'clock, when headquarters staff on Washington time left their telephones for the day, Allen would



H. Julian Allen, Director of Ames Research Center from 1965 to 1969.

Basic design of Pioneer spacecraft 6 through 9.

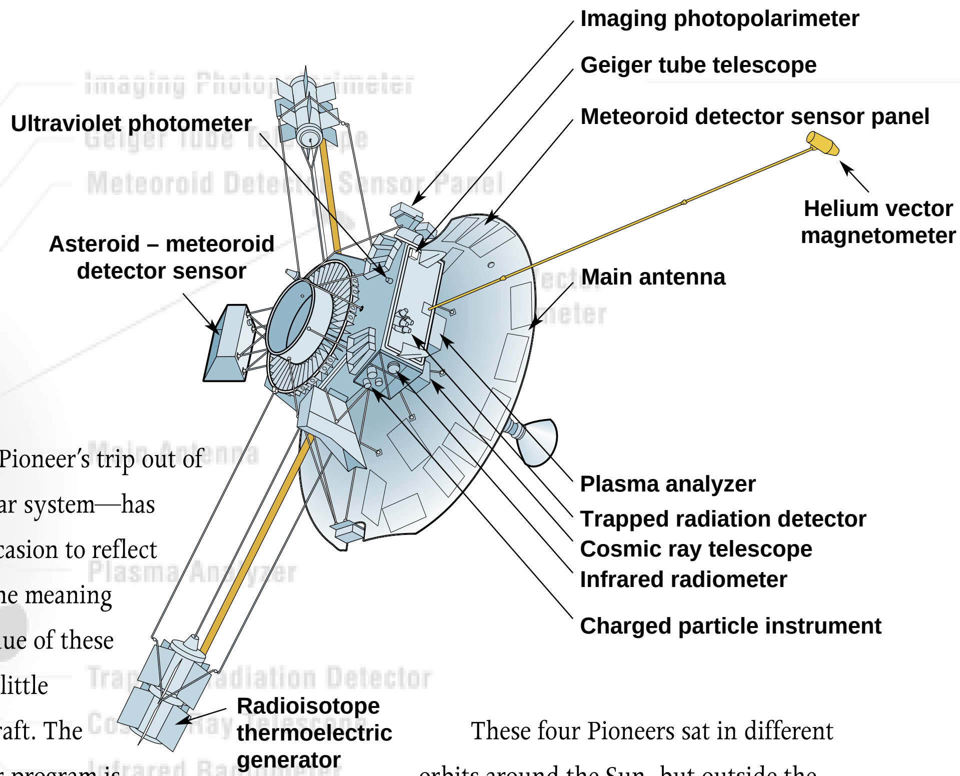
leave his director's office and wander around Ames. He would poke his head into people's offices and gently inquire about what was puzzling them. "Are you winning?" he would ask.[1] Eventually he would settle into his old office and continue his research into hypersonics.

Ames suffered a bit during Allen's four years as director. Ames' personnel peaked in 1965 at just over 2,200 and dropped to just under 2,000 by 1969. Its budget stagnated at about $90 million. For the first time a support contractor was hired to manage wind tunnel operations—in the 12 foot pressurized tunnel—and there was a drop off in transonic testing and aircraft design research. But tunnel usage actually increased to support the Apollo program, and there was dramatic growth in Ames' work in airborne and space sciences, especially from the Pioneer program.

Pioneers 6 to 9

The Pioneers span the entire recent history of Ames, transcending efforts to periodize them neatly. The first Pioneers—the Pioneer 6 to 9 solar observatories—were conceived under DeFrance and executed under Allen. Allen asked the same group to plan Pioneers 10 and 11, and Hans Mark, Allen's successor as director, presided over the execution of the Pioneers as simple, elegant, science-focused and pathbreaking projects. Every subsequent Ames director—upon the occasion of data returned from some encounter

John Wolfe, Richard Silva and Clifford Burrous in September 1962, with a model of the OGO-1 orbiting geophysical observatory and the solar plasma measuring instrument that they built for it.



Schematic of Pioneer 10.

on the Pioneer's trip out of our solar system—has had occasion to reflect upon the meaning and value of these sturdy little spacecraft. The Pioneer program is discussed as part of NASA's formative years because, in addition to all the valuable data they produced, in the late 1960s the Ames space projects division devised the Pioneer program as a shot across the bow of the NASA way of doing things.

In 1963, Ames was given a block of four Pioneer flights, and a budget of $40 million to build and launch the spacecraft. The bulk of this funding went to contractors—to Douglas and Aerojet-General to build the Thor-Delta rockets and to Space Technology Laboratories to build the spacecraft. Charlie Hall was the Pioneer project manager at Ames. On 15 December 1965, Pioneer 6 achieved its orbit around the Sun just inside the orbit of Earth. It immediately began sending back data on magnetic fields, cosmic rays, high-energy particles, electron density, electric fields and cosmic dust. It was soon followed by Pioneers 7, 8, and finally Pioneer 9 launched on 8 November 1968.

These four Pioneers sat in different orbits around the Sun, but outside the influence of Earth, and returned data on the solar environment. Until 1972, they were NASA's primary sentinals to warn of the solar storms that disrupt communications and electricity distribution on Earth. When positioned behind the Sun, the Pioneers collected data to predict solar storms since they could track changes on the solar surface two weeks before they were seen on Earth. During the Apollo lunar landings, the Pioneers returned data hourly to mission control, to warn of the intense showers of solar protons which could be dangerous to astronauts on the surface of the Moon.

In addition to building spacecraft and sensors to collect the data, Ames also designed the telemetry to gather the data and the computers to process them. Pioneer 6 first gave accurate measurements of the Sun's corona where the solar winds boil off into space. The plasma wave experiment on the Pioneer 8 provided a

Principal investigators take center stage to explain the results of the Pioneer missions.

full picture of Earth's magnetic tail. For the Pioneer 9 spacecraft, Ames established the convolution coders used for most deep space planetary missions. Since the Sun is typical of many stars, Ames astrophysicists learned much about stellar evolution. Before the Pioneers, the solar wind was thought to be a steady, gentle flow of ionized gases. Instead, the Pioneers found an interplanetary region of great turbulence, with twisted magnetic streams bursting among other solar streams.

As the group that designed and built the early Pioneers then turned their attention to the next space horizon, these simple satellites continued to send back data. Pioneer 9 was the first to expire, in May 1983, well beyond its design lifetime of six months. It had circled the Sun 22 times, in a 297-day orbit. Pioneers 6 and 7 continued to work well into the 1980s, though they were tracked less frequently as newer missions required time on the antennas of NASA's Deep Space Network. By then, these Pioneers had had their days in the Sun.

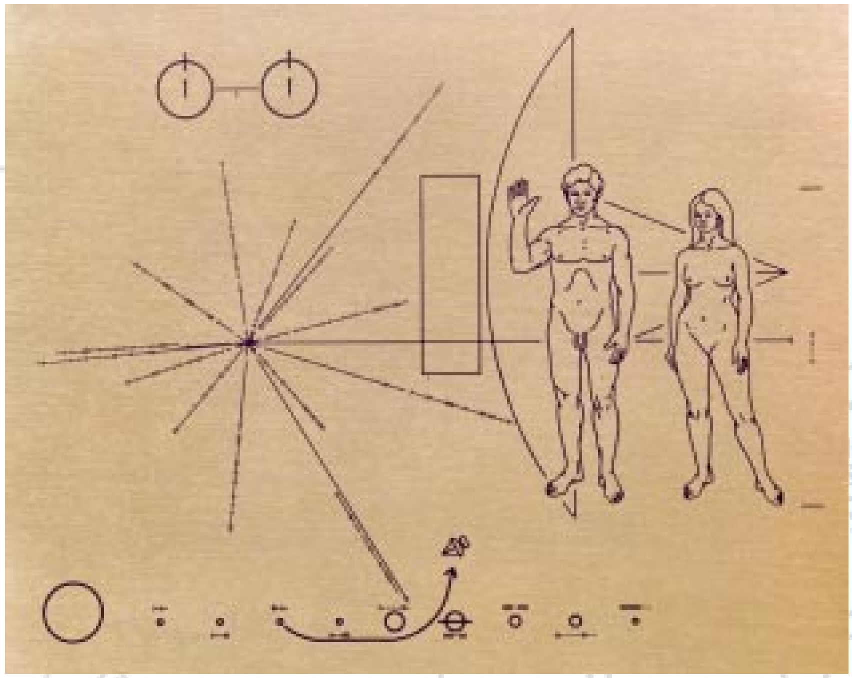
Pioneers 10 and 11

During the 1960s, astronomers grew excited about the prospects of a grand tour—of sending a space probe to survey the outer planets of the solar system when they would align during the late 1970s. The known hazards to a grand tour—the asteroid belt and the radiation around Jupiter—were extreme. The hazards yet unknown could be worse. So Ames drafted a plan to build NASA a spacecraft to pioneer this trail.

In 1968, the Space Science Board of the National Academy of Sciences endorsed the plan. NASA headquarters funded the project in February 1969, following intensive lobbying by Ames' incoming director, Hans Mark, and Ames' director of development, John Foster. Charles Hall, manager of the Pioneer plasma probe spacecraft, led the project, and asked Joseph Lepetich to manage the experiment packages and Ralph Holtzclaw to design the spacecraft. Chief scientist John Wolfe, who had joined Ames in 1960, did gamma-ray spectroscopy and measurements of the interplanetary solar wind, and later became chief of Ames' space physics branch. Originally called the Pioneer Jupiter-Saturn

Pioneer 10, being tested prior to launch.

A pre-launch view of Pioneer 10 spacecraft, encapsulated and mated with an Atlas-Centaur launch vehicle on 26 February 1972. Pioneers 10 and 11 were ejected from Earth's atmosphere at a greater speed than any previous vehicle.



Pioneer 10, the first spacecraft to leave our solar system, carries a message to other worlds. The plaque was designed by Carl Sagan and Frank Drake. The artwork was prepared by Linda Salzman Sagan.

program, upon successful launch the name was changed to Pioneers 10 and 11.

Spacecraft able to explore the giants of our solar system—Jupiter and Saturn—had to be much different from the many spacecraft that had already explored Mars and Venus. First, Jupiter is 400 million miles away at its closest approach to Earth, whereas Mars is only 50 million miles away. Thus, the spacecraft had to be more reliable for the longer trip. Second, since solar panels could not produce enough energy, the spacecraft needed an internal power supply. Finally, the greater distance demanded a larger, dish-shaped high gain antenna.

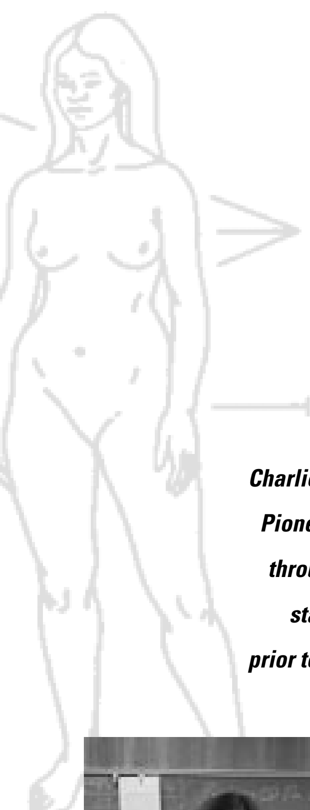
Added to these more natural design constraints were two early engineering decisions Hall made to keep the project within its budget. Both derived from Ames' experience with the earlier Pioneer plasma probes. First, rather than being stabilized on three axes by rockets, Pioneers 10 and 11 were spin-stabilized by rotating about their axes. The spin axis was in the plane of the ecliptic, so the nine foot diameter communications dish antenna always pointed toward Earth.

Pioneer 10 at TRW in the final stages of assembly.

Oil painting depicting the storms of Jupiter, the satellite Io, and the Great Red Spot.

Inertia came from the four heavy nuclear power units—RTGs or radioisotope thermoelectric generators—mounted fifteen feet from the axis on two long beams. Spin stabilization was cheap and reliable, but made high resolution photographs impossible.

The second engineering decision Hall made was to send all data back to Earth in real time at a relatively slow stream of one kilobit per second. Storing data on board was expensive and heavy. This again lowered the resolution of the photographs and the precision of some measurements. It also meant that Pioneer would have to be flown from the ground. Onboard memory could store only five commands, of 22 bits each, needed for very precise maneuvers such as those to move the photopolarimeter telescope quickly during the planetary encounter. Each command had to be carefully planned, since signals from Earth took 46 minutes to reach the spacecraft at Jupiter. Hall convinced the scientists designing Pioneer payloads to accept these limits. They had much to gain, Hall argued, by getting their payloads there on a reliable platform and getting there first.



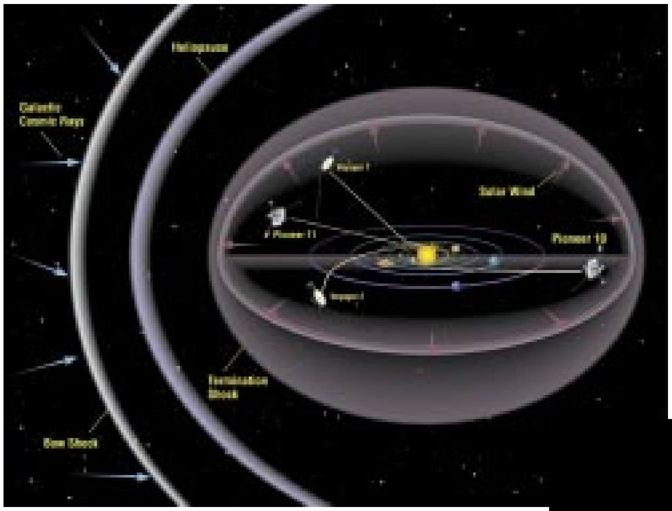
Charlie Hall leads the Pioneer project staff through an efficient stand-up meeting prior to the encounter with Jupiter.

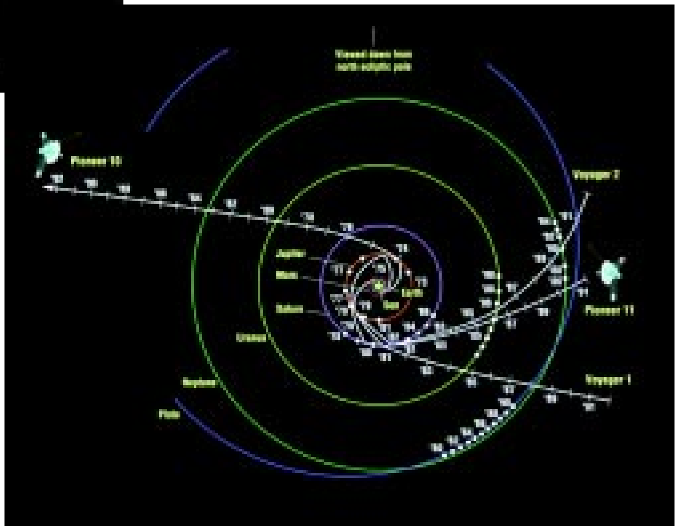
Eleven experiment packages were hung on the Pioneers, which measured magnetic fields, solar wind, high energy cosmic rays, cosmic and asteroidal dust, and ultraviolet and infrared radiation. (The two spacecraft were identical except that Pioneer 11 also carried a fluxgate magnetometer like the one carried on Apollo 12.) Each spacecraft weighed just 570 pounds, and the entire spacecraft consumed less power

Jupiters Red Spot and a shadow of the moon Io, as seen from Pioneer 10.

than a 100 watt light bulb. One of the most significant engineering achievements was in electromagnetic control—the spacecraft was made entirely free of magnetic fields to allow greater sensitivity in planetary measurements.

Ames indeed kept the Pioneers within a very tight budget and schedule. The entire program for the two Pioneer 10 and 11 spacecraft, excluding launch costs, cost no more than $100 million in 1970 dollars. (That compares with $1 billion for the Viking at about the same time.) To build the spacecraft, Ames hired TRW Systems Group of Redondo Beach, California, the company that built the earlier Pioneers. TRW named Bernard O'Brien as its program manager. Hall devised a clear set of management guidelines. First, mission objectives would be clear, simple, scientific and unchangeable. The Pioneers would explore the hazards of the asteroid belt and the environment of Jupiter, and no other plans could interfere with those





Trajectories of Pioneer 10, Pioneer 11 and Voyager.

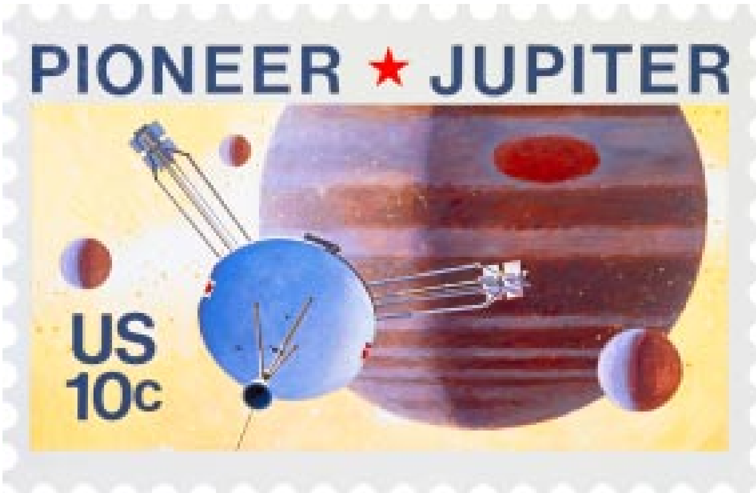
Pioneer 10 encounter with Jupiter.

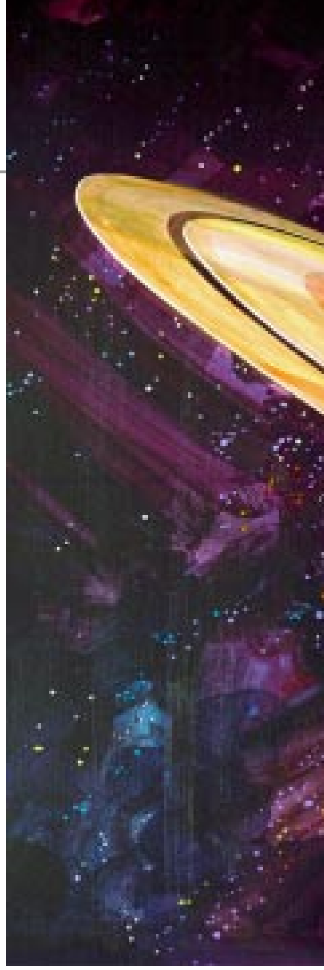
goals. Second, the prime contractor was delegated broad technical authority. Third, existing technology would be used as much as possible. Fourth, the management team at Ames could comprise no more than twenty people. Fifth, their job was to prevent escalation of requirements.

One other decision ensured that the Pioneers would have an extraordinary scientific impact. In the 1960s, NASA scientists began to explore ways of flying by gravitational fields to alter spacecraft trajectories or give them an energy boost. Gravitational boost was proved out on the Mariner 10, which flew around Venus on its way to Mercury. Ames proposed two equally bold maneuvers. Pioneer 10 would fly by Jupiter so that it was accelerated on its way out of the solar system, to reconnoiter as far as possible into deep space. Pioneer 11 would fly by Jupiter to alter its trajectory toward an encounter with Saturn five years later. Without diminishing their encounter with Jupiter, the Pioneers could return better scientific data and years earlier than Voyager for the small cost of keeping open the mission control room. No good idea goes unchallenged, and Mark and Hall found themselves lobbying NASA headquarters to fend off JPL's insistence that their Voyager spacecraft achieve these space firsts.

Jack Dyer and Richard Fimmel in the Pioneer mission control center in May 1983.

Three months before project launch, Mark got a call from Carl Sagan, the astronomer at Cornell University, a friend of Mark's from time spent at the University of California at Berkeley, and close follower of efforts at Ames to discover other life in the universe. Sagan called to make sure that Mark appreciated "the





cosmic significance of sending the first human-made object out of our solar system."[2] Sagan wanted the Pioneer spacecraft to carry a message, in case they were ever found, that described who built the Pioneers and where they were from. So Sagan and his wife, Linda, designed a gold-anodized aluminum plate on which was inscribed an interstellar cave painting with graphic depictions of a man, a woman, and the location of Earth in our solar system.

Thirty months after project approval, on 2 March 1972, NASA launched Pioneer 10. Since the spacecraft needed the highest velocity ever given a human-made object—32,000 miles per hour—a solid-propellant third stage was added atop the Atlas Centaur rocket. Pioneer 10 passed the orbit of the Moon eleven hours after liftoff; it took the Apollo spacecraft three days to travel that distance. A small group of five specialists staffed the Ames Pioneer mission operations center around the clock, monitoring activity reported back through the huge and highly sensitive antennas of NASA's Deep Space Network. Very quickly, Pioneer 10 started returning significant data, starting with images of the zodiacal light. On 15 July 1972, Pioneer 10 first encountered the asteroid belt. Most likely the scattered debris of a planet that once sat in that orbit between Mars and Jupiter, the asteroid belt contains hundreds of thousands of rocky fragments ranging in size from a few miles in diameter to microscopic size. From Earth, it was impossible to know how dense this belt would be. An asteroid/meteoroid detector showed that the debris was less

Pioneer 11 pre-encounter with Saturn, as painted by Wilson Hurley.

Jupiter, and probed the chemical composition of Jupiter's outer atmosphere. Its trajectory flew it behind the satellite Io and, by observing the alteration of the telemetry signal carrier wave, Pioneer 10 provided direct evidence of the very tenuous atmosphere around Io. Signals from the imaging photopolarimeter were converted into video images in real time, winning the Pioneer project an Emmy award for contributions to television. Most important, Pioneer 10 proved that a spacecraft could fly close enough to Jupiter to get a slingshot trajectory without being damaged.

Artist concept of Pioneer 11 as it encounters Saturn and its rings.

dangerous than feared. Next, in August 1972, a series of huge solar flares gave Ames scientists the opportunity to calibrate data from both Pioneer 10, now deep in the asteroid belt, and the earlier Pioneers in orbit around the Sun. The results helped explain the complex interactions between the solar winds and interplanetary magnetic fields. Ames prepared Pioneer 11 for launch on 5 April 1973, when Earth and Jupiter were again in the best relative positions.

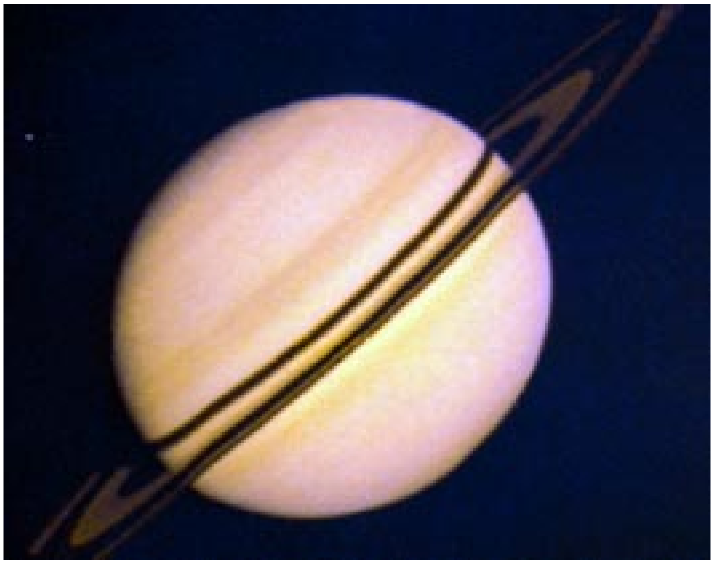
Pioneer 10 flew by Jupiter nineteen months after launch, on 4 December 1973. Over 16,000 commands were meticulously executed on a tight encounter schedule. The most intriguing results concerned the nature of the strong magnetic field around Jupiter, which traps charged particles and thus creates intense radiation fields. Pioneer 10 created a thermal map of

Pioneer 11 flew by Jupiter a year after Pioneer 10. In November 1974, its encounter brought it three times closer to the giant gas ball than Pioneer 10. Ames mission directors successfully attempted a somewhat riskier approach, a clockwise trajectory by the south polar region and then straight back up through the intense inner radiation belt by the equator and back out over Jupiter's north pole. Thus, Pioneer 11 sent back the first polar images of the planet. Pioneer 11 reached its closest point with Jupiter on December 3, coming

John Wolfe describes the transit of Pioneer 10 around Jupiter.

within 26,000 miles of the surface. This mission gathered even better data on the planet's magnetic field, measured distributions of high-energy electrons and protons in the radiation belts, measured planetary geophysical characteristics, and studied the Jovian gravity and atmosphere. Pioneer 11 then continued on to its encounter with Saturn on 1 September 1979. There it discovered a new ring and new satellites, took spectacular pictures of the rings around Saturn, and returned plenty of data about Saturn's mass and geological structure.

Pioneer 10, meanwhile, continued on its journey out of the solar system. On 13 June 1983 it passed the orbit of Pluto. The Pioneer project team, now led by Richard Fimmel, eagerly looked for any motion in its spin stabilized platform that would indicate the gravitational pull of a tenth planet, but found none. On its 25th anniversary in 1997, Pioneer 10 was six billion miles from Earth, still the most distant of human-made objects, and still returning good scientific data. By 1998, it had still not detected the plasma discontinuity that defines the edge of the heliopause, where the solar winds stop and our Sun no longer exerts any force. Pioneer was so far from Earth that its eight watt radio signal, equivalent to the power of a night light, took nine hours to reach Earth. The closest approach to any star will be in about 30,000 years, as Pioneer flies by the red dwarf star Ross 248.



A global mosaic of Saturn during the Pioneer 11 encounter. The irregular edge of the ring is caused by stepping anomalies of the imaging photopolarimeter.

The engineering model for the Pioneers hangs in the Hall of Firsts at the National Air and Space Museum since the actual Pioneers were, in fact, the first human-made objects to leave our solar system. They are also honored as the spacecraft that paved the way for exploration beyond Mars. NASA eventually did fund the grand tour, with spacecraft much different from the Pioneers. Voyagers I and II, designed and managed at JPL, were sophisticated and stable platforms that weighed more than 2,000 pounds, cost $600 million to develop, and carried better cameras to return more spectacular photographs. Ames people will always remember the Pioneers, by contrast, as spacecraft that flew much the same mission, but faster, better, and cheaper. These spacecraft—simple in concept, elegant in design, competently executed and able to return so much for so little—served as models for the spirit Ames would infuse into all of its work.