Reinventing the NASA Ames Research Center: Sixty Five Years of Innovations

John W. Boyd,* Paul Kolodziej,† Glenn E. Bugos‡
NASA Ames Research Center, Moffett Field, California 94035

Over the past six decades, the NASA Ames Research Center has continually reinvented itself to make new types of contributions to NASA's aeronautical and space exploration missions. Though one of NASA's smaller field centers, NASA Ames has continually placed itself into the core of NASA's missions by: 1] routinely forging new scientific disciplines through a focus on fundamental research, and 2] allowing individuals at the Center to reinvent their own careers. This paper will explore how NASA Ames, both as an institution and through the collective efforts of those who flourished there, moved from a facility optimized for subsonic aerodynamics, into supersonic and hypersonic aerodynamics, then the life sciences, supercomputing and information technology, materials science, and nano-scale science and technology.

I. Founding Spirit of NACA Ames Aeronautical Laboratory

The first organized approach to conducting aeronautical research in the United States came in 1915 when Congress established the National Advisory Committee for Aeronautics (NACA). This was only twelve years after the Wright Brothers' first flight in 1903 and two years before the United States put its aircraft into the test of World War I. Outreach and intra-institutional cooperation was at the heart of the NACA culture. The NACA was structured as a hierarchy of nested committees with representatives from industry, academia, and the civil and defense branches of the federal government. Their job was to create a discipline of aeronautical engineering, and apply it to America's air aspirations. To conduct specific, exemplary research projects, the NACA built a laboratory and a series of wind tunnels at Langley Field, Virginia. Three other laboratories were later built as offspring of the Langley Memorial Aeronautics Laboratory: the Ames Aeronautical Laboratory (1939), the Lewis Flight Propulsion Laboratory (1940, now the Glenn Research Center), and the High Speed Flight Station (1946, now Dryden Flight Research Center). [Chart 1] Ames was named for Joseph Sweetman Ames, who chaired the NACA for twenty years, was an eminent physicist, and served as president of Johns Hopkins University. He is widely recognized as the architect of aeronautical science. Though he never set foot on the Center that bears his name, it is infused with his belief in the value of disciplined research, in the freedom of inquiry, and the immense responsibility that entails. From these four government centers came most of the technology that shaped American aircraft, and many other significant industries. And at these centers were trained the people who shaped much of the modern world.

Charles Lindbergh noted: "The most vital area for aeronautical research is the human mind, not the facilities." The NASA Ames Research Center developed both minds and facilities (incidentally, at a site selected by Lindbergh). [Chart 2] The key research facility for the first half of Ames' history was the wind tunnel, and Ames engineers built many of the most sophisticated in the world. The first wind tunnels built were the 16 foot subsonic tunnel, two 7 x 10 foot workhorse tunnels, followed by the closed loop 40 x 80 foot full-scale tunnel. The first test aircraft arrived in 1940, on loan from the defense services to the NACA, and hangars were built to house them. Those aircraft types evolved over the years into sophisticated flight test beds, especially for rotorcraft research. Later, Ames people built hypervelocity ranges for reentry studies, essentially long and sturdily constructed tubes. Other key facilities have included arc jets for thermal protection research, laboratories and simulators for life sciences research, airborne science aircraft, and supercomputers for modeling airflows, planetary climates, and nano-materials.

The wind tunnels—and the cooling towers and gas balls and electric transformers that support them—still dominate the landscape at NASA Ames. Seen from the air, the physical structure of the Center has not been

* Senior Advisor for History, NASA Ames History Office, Mail Stop 207-1, AIAA Fellow.
† Project Manager, Code AT, Mail Stop 210-15, AIAA Member
‡ Historian, NASA Ames History Office, Mail Stop 207-1.

radically reinvented. The most important work, though, has moved indoors into laboratories for bioscience and nanotechnology, into robot assembly rooms, and through computer networks—where work is done from a human scale down to a nanoscale. The Center now houses most of the tools it needs to develop the technologies to enable NASA's vision for space exploration. These tools attract the best researchers.

II. Reinventing Careers

Some of the NACA's most talented designers left Langley in the early 1940s to build and use the new facilities at Ames. At Ames, they cultivated an atmosphere of freedom, and an appreciation for the role of basic research in taking a deeper look at new technological challenges. On its sixtieth anniversary, the Center inducted into the NASA Ames Hall of Fame twelve individuals who have exemplified this spirit at Ames, which has proven remarkably resilient over the years. [Chart 3] As appropriate to a Center that has contributed to a broad spectrum of science and engineering fields, these people were active in aerodynamics, engineering, physics, chemistry, computing and biology. Many were recognized leaders in several fields of research. Many of them vigorously avoided static places in the organization chart, all the better to lead by example and to hunt new knowledge across organizational boundaries. Ames people, using the language of science, have written the poetry of our universe.

Three people in the Ames Hall of Fame, just as examples, can easily be called genius. R.T. Jones flourished in this atmosphere of freedom, taking on the most complex problems and using mathematical tools to refine flight. After his elegant explanation of the value of sweep in wings, he devised the transonic area rule, worked on fluid flows in artificial hearts, then designed an oblique wing test aircraft. Likewise, Dean Chapman moved easily from one field into another. After a brilliant career as a aerodynamicist, he created new tools and methods for thermodynamics, then helped create the field of computational fluid dynamics. James Pollack spent his entire career as a planetary scientist, though through his insight and mentoring he showed his peers how to make sense of all the data being returned from NASA spacecraft—and thus better understand all planets, especially our own.

And at each stage, Ames people were supported by Center Directors who—after themselves forging reputations for scientific and engineering excellence—managed the Center in the same spirit of integrity and essential public service that Smith DeFrance, Ames' first director, infused throughout the Center. [Chart 4] If we focus on only the first three Center Directors, whose combined tenure spanned more than half the life of the Center, then we can see the spirit of reinvention at work.

DeFrance was an aeronautical engineer first renowned for his work in building large-scale wind tunnels at the NACA Langley Laboratory. At Ames, his management style was known as "management-by-poking-your-head-in." And when he poked his head into your office, he first insisted on safety, soundness, integrity, and honesty. He exemplified the spirit of civil service. He also patrolled the borders of his Center, and so long as his staff kept his trust he protected his them from bureaucratic intrusion.

H. Julian Allen, the second Director, was a brilliant scientist and engineer who originated, then proved, the concept of bluntness as an aerodynamic technique for reducing the severe reentry heating of ballistic missiles and spacecraft. His management style was also one of walking around, though more like perambulation driven by his intense curiosity about all things scientific. He also had a show-me sort of attitude, reflected in both his own career and the physical structure of the Center. He encouraged Ames theorists to devise new methods or apparatus to test and prove their ideas, and thus make them more useful to national needs.

Hans Mark arrived at the Center from the outside, with the explicit goal of reinventing the Center. He was already an internationally-recognized leader in high energy physics, weapons technology, environmental science, and research management. During his tenure, he envisioned new ways of leveraging the brilliance of Ames people, and made frequent trips to Washington to gain support for new efforts. But apart from his trips outward, he also walked around Center, encouraging Ames people to move into new fields, often by working with unexpected collaborators. Most notably, Ames people began using advanced computers to calculate flow fields around aircraft and spacecraft, and took a more active role in spacecraft projects. He first brought clarity to the Center mantra of personal and institutional reinvention.

III. Reinventing By Intertwined Research

NASA Ames has made many distinct technological contributions, though all flow from the same basic core tenacity to apply what was known about emerging scientific fields to current challenges. [Chart 5] Looking historically at sixty-five years of innovation, Ames people have accomplished most when their work intertwined with other fields of research.

At the Center, the initial focus was on aeronautical research to help the war effort. Ames people built the world's greatest collection of wind tunnels, some still in service. Applying their experience from building these early tunnels, they then built supersonic wind tunnels, which in turn led into hypersonic tunnels to study reentry configurations. Ultimately, Ames devised arc jet tunnels to study reentry materials, which then required construction of material science laboratories that much later proved useful in defining the field of nanotechnology.

Ames people also forged an historical path from wind tunnels into a prominent place in space life sciences. Starting with tunnel data to study handling characteristics, Ames people modified flight test aircraft, and then built simulators. Simulators led Ames into the human factors, including fatigue measures and data display, and into basic research on adaptability to microgravity, which paved a path into exobiology and ultimately the exploration for life on Mars.

Our Center also paved a winding historic path from wind tunnels into information technology. To better mine the data from these wind tunnels, Ames moved boldly into digital data computing, which led into supercomputing, then computational fluid dynamics, then into internetworking, then air traffic safety, and artificial intelligence and robotics. At the birth of the commercial internet in the early 1990s, one-quarter of all the world's internet traffic moved through Ames servers. Meanwhile, using its expertise in handling massive amounts of data, Ames did fundamental work in infrared astronomy, earth sensing, robotics, remote visualization, and now nanotechnology.

Some specific contributions stand out along the intertwined pathways of these sixty-five years of innovation. The swept-back wing now used on all high-speed aircraft was developed by R.T. Jones, who started his career at NACA Langley then completed his work among his cohort of Ames aerodynamicists. The blunt body concept used on every spacecraft to prevent burning upon entering a planetary atmosphere was developed by Ames scientists. Center engineers managed the Pioneer series of planetary spacecraft, the first human made objects to pass through the asteroid belt, visit the giant planets, leave our solar system, and serve as the exemplar of the NASA faster-better-cheaper approach to robotic explorers. The Viking life detection experiment, which first landed on the surface of Mars to search for life, was designed by Ames scientists. Most recently the Lunar Prospector, which discovered water at the poles of the moon, was devised and controlled from NASA Ames. NASA Ames people made many contributions to the stunning and continuing success of the 2004 Mars Exploration Rovers—including tests of the parachutes in Ames wind tunnel, tests of the reentry materials in the arc jets, and all facets of the astrobiology, robotics, and information processing programs.

IV. Inventing New Disciplines

While it is historically more interesting to see all these accomplishments as intertwined developments, splayed along the temporal life of the Center, they can also be seen separately as distinct fields of innovation. After all, new science and engineering graduates see the world through the prisms of scientific disciplines, and that is why they will want to come to work at NASA Ames.

Re-entry technology and thermal protection systems has been one coherent area of research at NASA Ames, starting with the blunt body concept, leading to the arc jet complex, and into thermal protection tiles. [Chart 6] The legacy of H. Julian Allen and his blunt body concept is the safe return of all our astronauts—from Mercury through the Space Shuttle—as well as the entire package of heat transfer technologies that will enable more routine egress from space. The concept of bluntness, as well as all we have learned about gas and heat flows around blunt objects, also remains our principle tool in exploring the atmosphere of distant planets, as with the Viking, Pioneer Venus, Magellan, Galileo and Stardust probes.

NASA Ames sits on Moffett Federal Airfield, a truly great flying facility, so Ames people have grasped the opportunity to explore new areas of flight research and air operations. [Chart 7] The heritage of flight research at NASA Ames dates back to 1940, and in the early days included a wide variety of aircraft—like the Lockheed P-38F and the Douglas F5D-1—used to validate theoretical understandings of supersonic airflows around new airframes and jet engines. Lewis Rodert used a variety of aircraft to fine tune an efficient whole-aircraft deicing system, for which he won the Collier Trophy. Ames test pilots were the first to use vortex generators to control flow separation on aircraft wings. As high-speed flight research moved south to Dryden, Ames test pilots increasingly focused on the more complicated airflows around slow moving rotorcraft. The Bell XV-14 was flown primarily at Moffett Field. Ames people developed the first in-flight aircraft simulator for V/STOL research. George Cooper, for many years Ames' chief test pilot, developed the Cooper-Harper handling qualities rating scale, which in 1957 became the standard guide to aircraft handling qualities and remains in use today. Later Ames test pilots worked closely with the Federal Aviation Administration to devise certification specifications for vertical and short take-off aircraft.

Starting with the flight test research on aircraft handling qualities, Ames grew into the NASA lead center for basic research into human factors. [Chart 8] NASA Ames people have used their knowledge about pilot workloads, vision and balance, and information management, to pioneer new methods for making air transportation safer. Ames devised and maintains the Aviation Safety Reporting System, a massive database that helps make sense of any unsafe events in daily flight. The Center's continuing research into display technologies, pilot fatigue countermeasures, and human performance modeling is now being applied to make astronauts more productive during long space flights.

Enabling Ames' leadership in the discipline of human factors research has been the ingenuity of Ames' people in devising new types of flight simulators. [Chart 9] The earliest flight simulators were simple pitch and roll chairs, though very quickly Ames was building more sophisticated simulators capable of five, then six degrees of motion. In addition, Ames built simulators to practice celestial navigation for the Apollo missions, as well as NASA's only human-rated centrifuge. The Vertical Motion Simulator remains today the state-of-the-art in flight simulation research, and has been used to investigate flying characteristics of military aircraft, rotorcraft, V/STOL aircraft, and the Space Shuttle Orbiter.

Many notable innovations emerged from this combination of simulator engineering and human factors research. [Chart 10] Ames' complex of simulators has contributed to improvements in the Shuttle Orbiter landing and roll-out procedures, to designs for heads-up displays, for information management to improve pilot workload for civil transports, and to solve problems of runway incursions and operations around busy airports.

A long term collaboration between NASA Ames and the Federal Aviation Administration has infused our national aerospace system with greater safety, efficiency and timeliness. [Chart 11] Ames' contributions to air traffic management include two modern flight management systems of great value to air traffic controllers. The Center TRACON Automation System (CTAS) follows aircraft in flight, and the Surface Movement Advisor (SMA) improves the flow of aircraft on the ground around airports. In addition, NASA Ames has led the development of scheduling algorithms and computer networking that will allow further automation in air traffic control.

Befitting its place at the heart of Silicon Valley, Ames has led the development of each new generation of supercomputer. As a result, others at Ames have been able to pioneer the fields of computational fluid dynamics, climate modeling, and computational chemistry. [Chart 12] One of Ames' most important contributions to the world of aerospace was the computation of complicated airflows around vehicles. Harvard Lomax, the father of computational fluid dynamics, was a brilliant theoretician who laid the mathematical foundations of this new discipline in the 1950s. He later trained and mentored an entire generation of CFD experts. Since then, Ames CFDers continually matched new developments in aerodynamics with computing power. Ames acquired the ILLIAC IV, the world's first massively parallel computer, in 1952 and over the decades has worked with industry partners to continue to push the development of larger and more efficient supercomputers. Ames recently installed the Columbia, the largest and fastest Linux-based supercomputer, offering NASA a ten-fold boost in its computing and imaging power. With these machines, Ames people have authored tools for solving two- then three-dimensional Navier-Stokes equations, turbulence models, the complicated flows around V/STOL vehicles, and hypersonic flows—involving heat, compressibility, and turbulent flows—such as around the Space Shuttle at launch and landing. The science of weather modeling will be especially enhanced by these new machines.

In addition, these supercomputers were networked, and Ames played a key role in the development of the internet and all the information technologies enabled by it. [Chart 13] NASA Ames applies its expertise in information technology to improve air traffic management and make the skies safer for all who fly. One critical ingredient in the NASA New Exploration Initiative is the development of intelligent flight controls and human-centered computing to enable long-term space flight, with humans and intelligent machines sharing the workload. Over the past decade, Ames has developed these new robotic technologies and incorporated them into such missions as Deep Space I, Mars Pathfinder, and the Mars Exploration Rovers (MER).

Airborne science is another area to which Ames people have made notable contributions since the 1970s. [Chart 14]. Leveraging the Moffett Field infrastructure used to support its flight research aircraft, Ames developed a fleet of flying laboratories. This fleet included a Learjet, a Convair 990 (Galileo), a Lockheed C-130, a DC-8, a C-141, and an ER-2. On these airborne science aircraft were trained many generations of scientists—from all parts of the world, and from all types of universities, industry, and government agencies. Some airborne science platforms were optimized to look downward—to map agricultural trends or forest fires, chart the thermal structure of Earth, and explore the Earth's atmosphere. Others were optimized to look upward, notably to create the discipline of infrared astronomy, all to better understand solar eclipses, the Martian atmosphere, and the Orion Nebula. The most recent addition to Ames airborne science legacy will be the SOFIA, a Boeing SP747 with a port for an infrared telescope.

To take one final example, Ames' many experts in the life sciences and planetary sciences virtually invented the scientific discipline of astrobiology, which seeks to understand the prospects for life in the universe. [Chart 15] NASA established its life sciences effort at Ames in the early 1960s, led by Webb Haymaker and Harold Klein, an Ames Hall of Famer. Astrobiologists considered Klein the godfather of their discipline, and indeed he did a superb job in orienting all manner of NASA and university scientists toward common questions at the birth of our space age. Klein also gained fame as principal investigator on the Mars Viking Lander—the first robotic spacecraft to conduct scientific experiments on another planet.

Since the 1960s, Ames has done much fundamental research on the habitability of humans in space flight—on microgravity, radiation biology, space suits, miniature biosensors and human factors. Ames people also led the development of most major space-borne biological laboratories, including the Biosatellites, the Cosmos-Bion flights, Spacelab, and the Space Station Biological Research Project. Ames people also charted the origins of life in the universe, and breathed life into the field of exobiology. This group led, among other things, the life detection experiments flown aboard the Viking Lander on Mars, and technologies for the biological quarantine of planets. Ames also provided the first home for SETI, the scientists leading the search for extraterrestrial intelligence, as well as the home of the Kepler project to chart other places in the universe that may nurture life.

Building on this accumulated expertise in the prospects of life in the universe, Ames people created the NASA Astrobiology Institute. [Chart 16] Astrobiology is arguably the hottest new scientific discipline. Nobel laureate Baruch Blumberg was named the first director of NAI in 1999. Since then it has enrolled as members a variety of university and international partners, doing a vast array of research projects.

Perhaps the least known facet of Ames' contributions has been its innovations in program management. [Chart 17] Compared with the other NASA centers, the projects Ames has led have been small and focused. However, they have also been cheaper, timely, and prone to succeed. Notable among these have been the Pioneer series of spacecraft, and the Lunar Prospector program, which have epitomized the collaborative mentality prevalent in Silicon Valley. Ames will continue to develop innovative methods of project management, so that its fundamental expertise can be used by the human and robot explorers who will carry out our vision for space exploration.

The NASA Research Park is how Ames intends to bolster its collaboration with Silicon Valley biotechnology and information technology firms, as well as with the world-class universities to which it is often compared. [Chart 18] NASA Research Park is being developed to create a world-class, shared-use research and development campus for government, academia, non-profit and industry to support the mission of NASA. Carnegie-Mellon University has already located in the park its principal research center in robotics. And the University of California at Santa Cruz, renowned for its leadership role in planetary sciences and nanotechnology, has already forged with Ames an innovative University Affiliated Research Center.

V. Perpetual Reinvention

It is impossible to speculate how NASA Ames will reinvent itself in the future. NASA Ames now hosts the largest and most vibrant group of researchers of any federal laboratory in nanoscale science and technology. If Ames succeeds in making nanoscience relevant to NASA's missions to explore our planet and the universe, then perhaps historians six decades hence will look at the present time as the time when Ames once again reinvented itself by birthing a new field of science and a new family of significant technologies.

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12] Advanced Supercomputing
13] Information Science and Technology
14] Airborne Science Platforms
15] Life Sciences
16] Astrobiology
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Establishment of NACA Laboratories

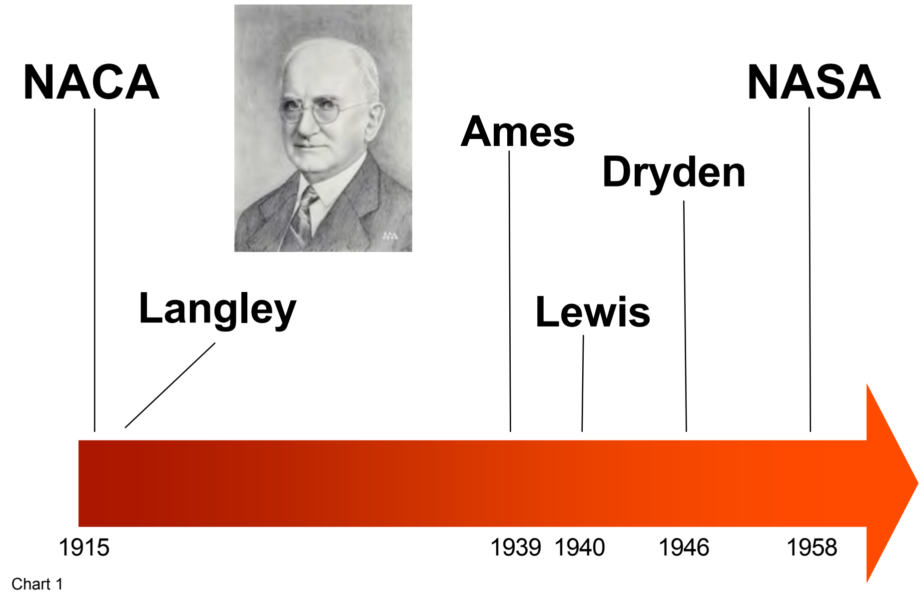
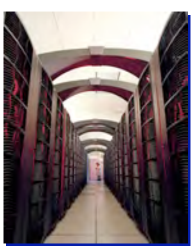


Chart 1

NASA Ames Facilities

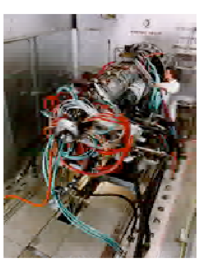


Super Computer

National Full Scale Aerodynamic Complex, 80x120 Wind Tunnel

Research Aircraft

9 x 7 Supersonic Wind Tunnel



Arc Jet

Hypervelocity Free Flight

Vertical Motion Simulator

Chart 2

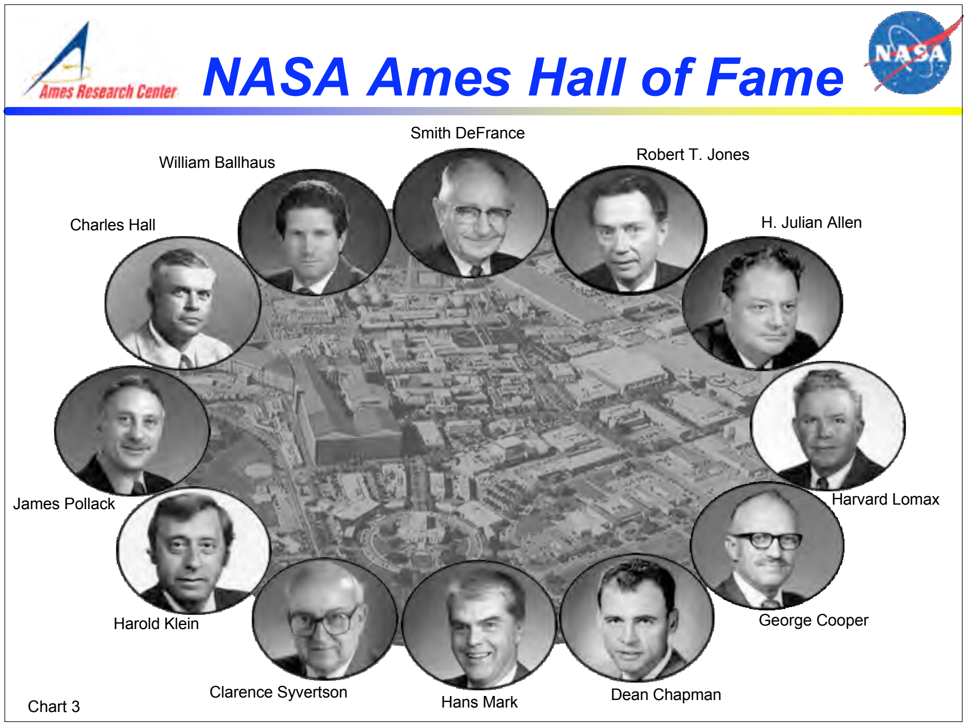


Chart 3

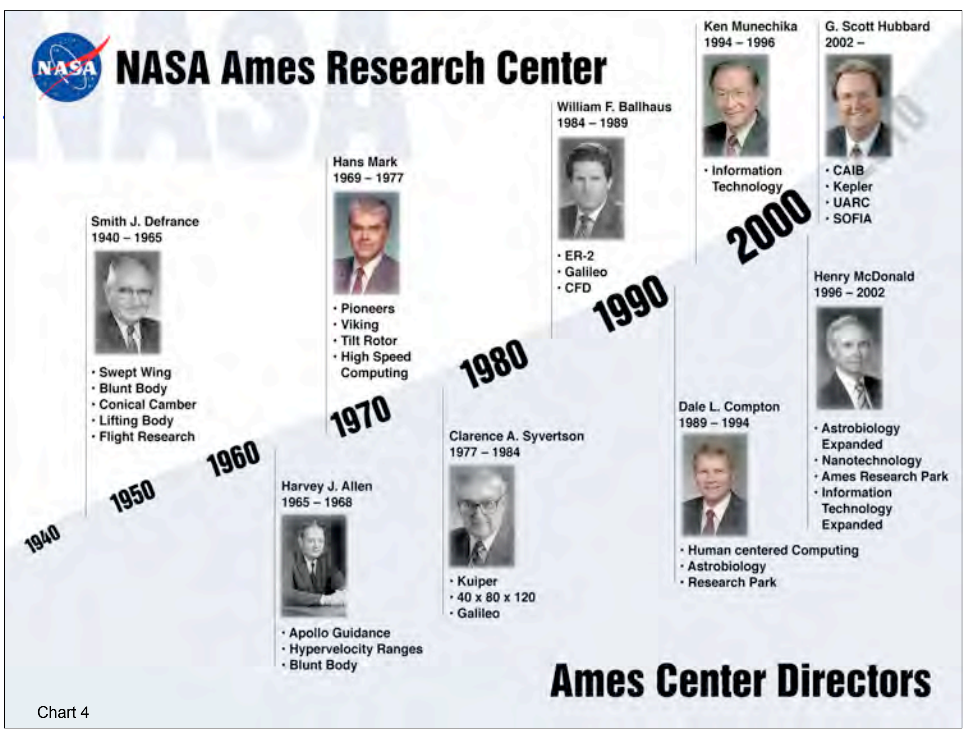


Chart 4

65 Years of Innovation

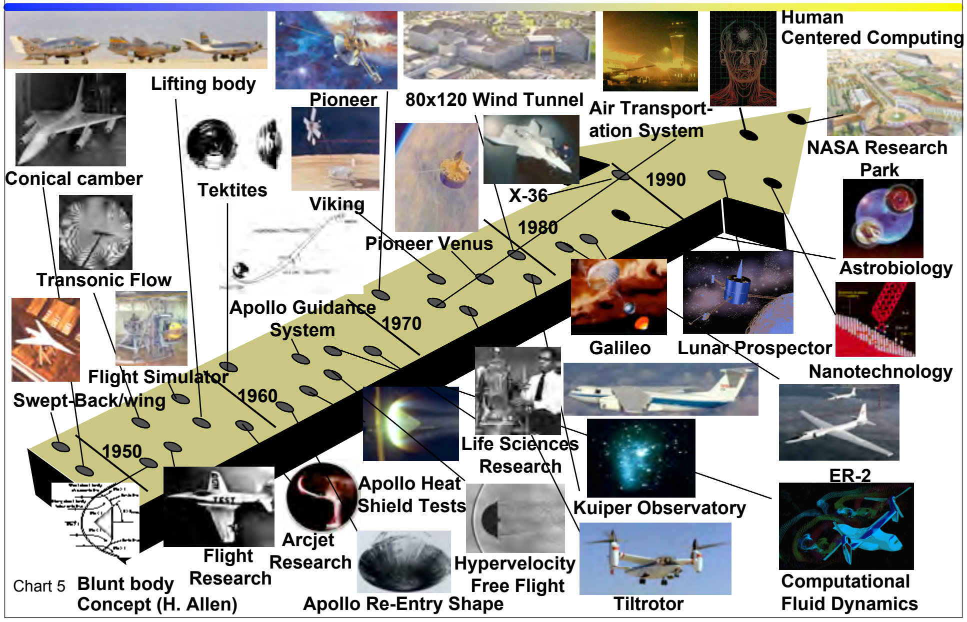


Chart 5

Thermal Protection Systems

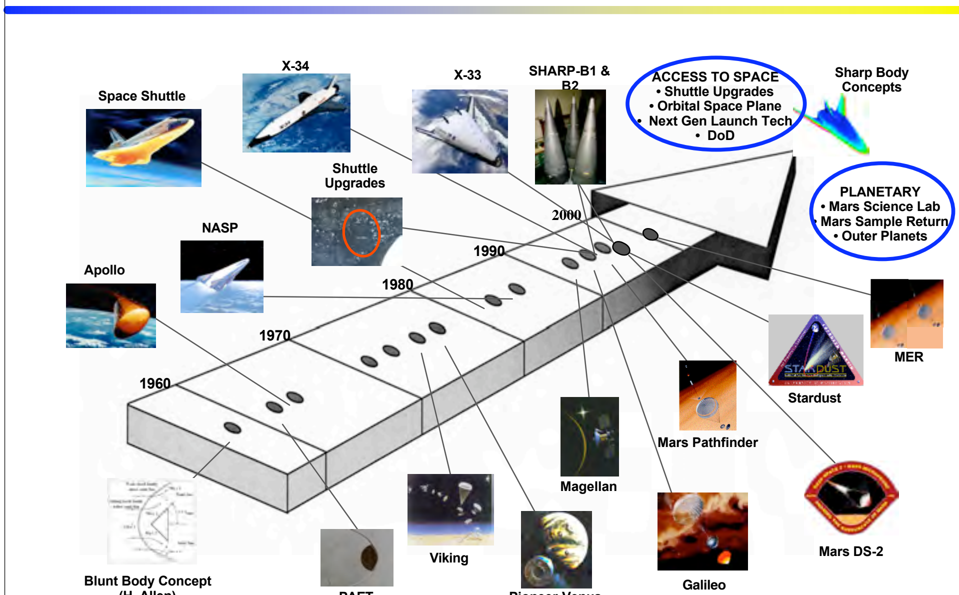
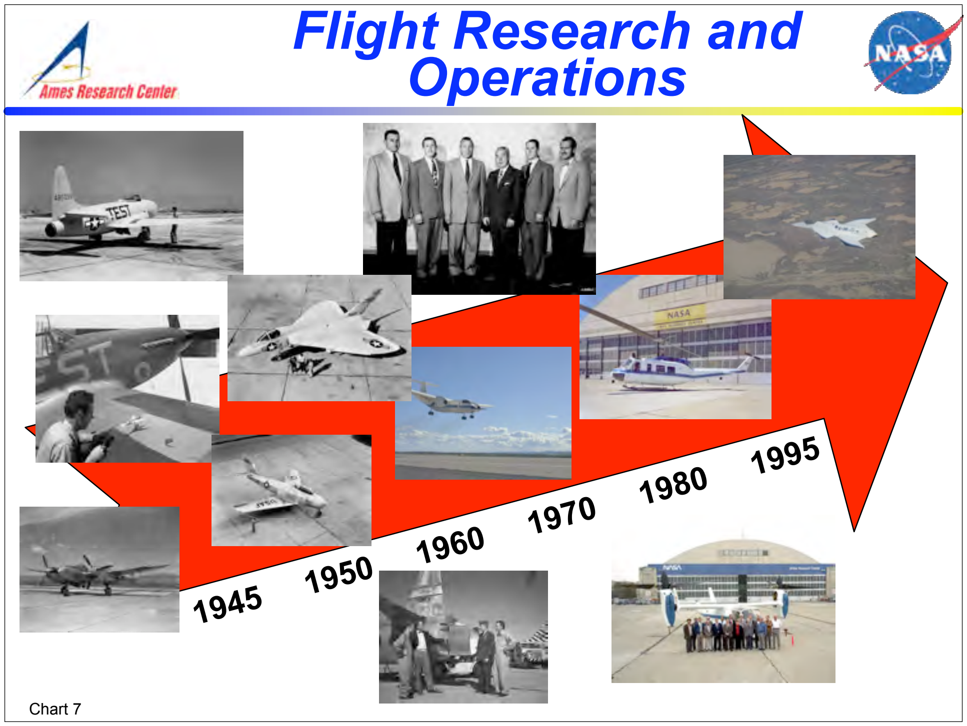
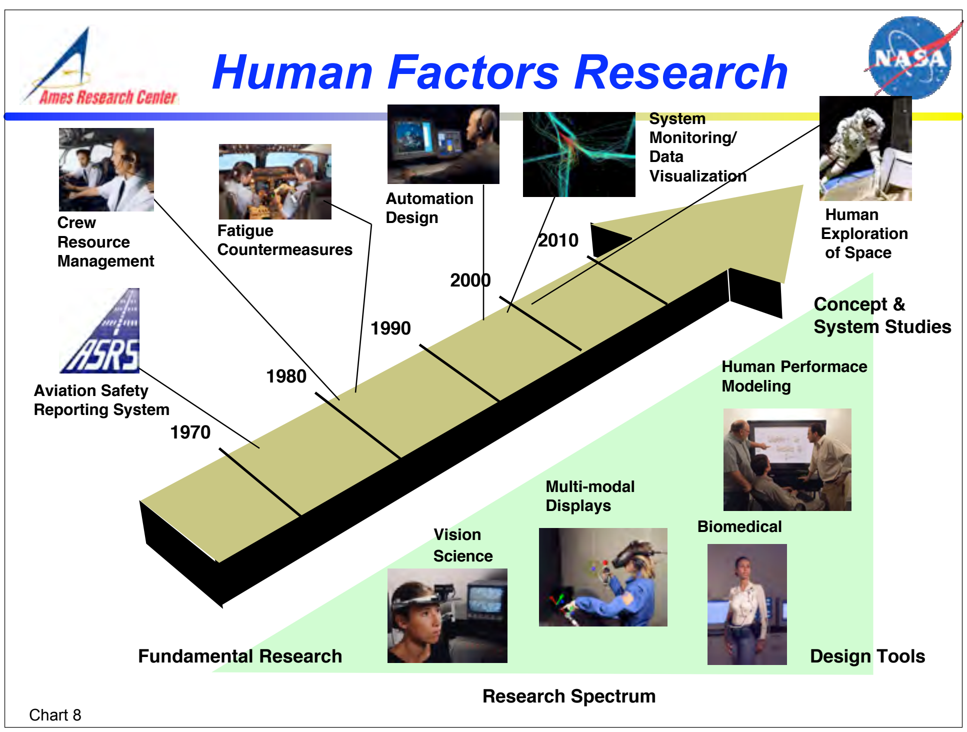
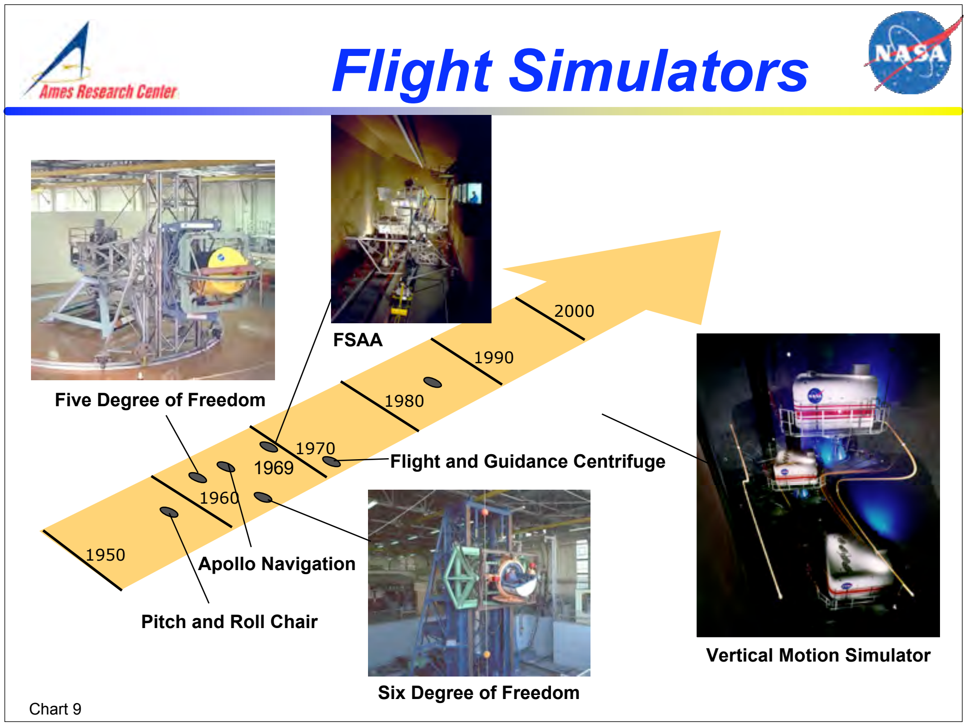
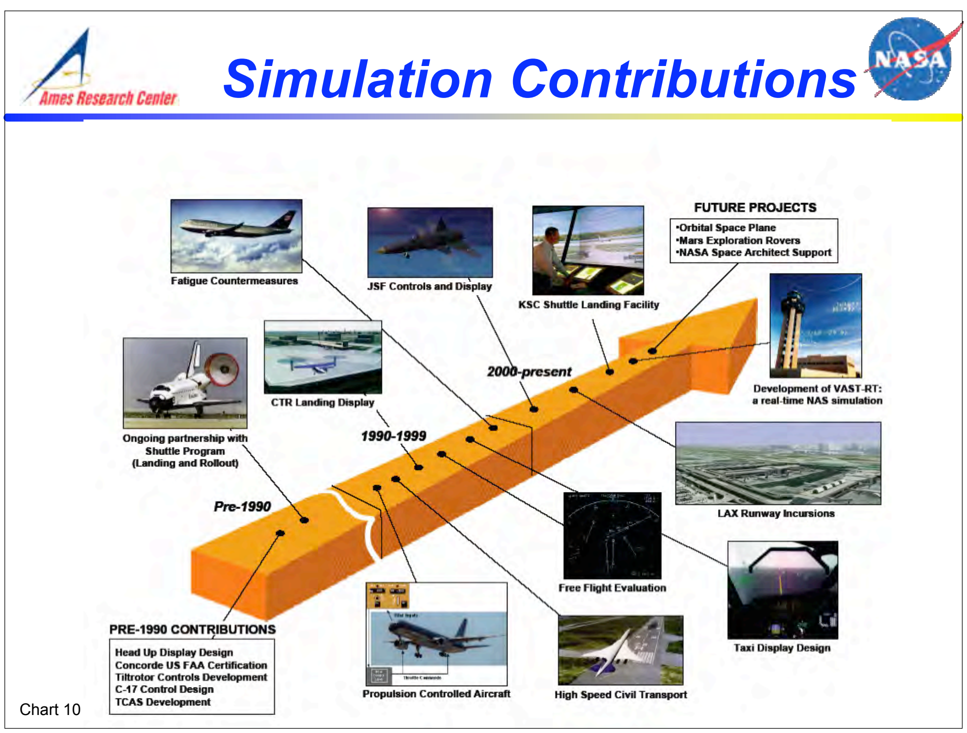


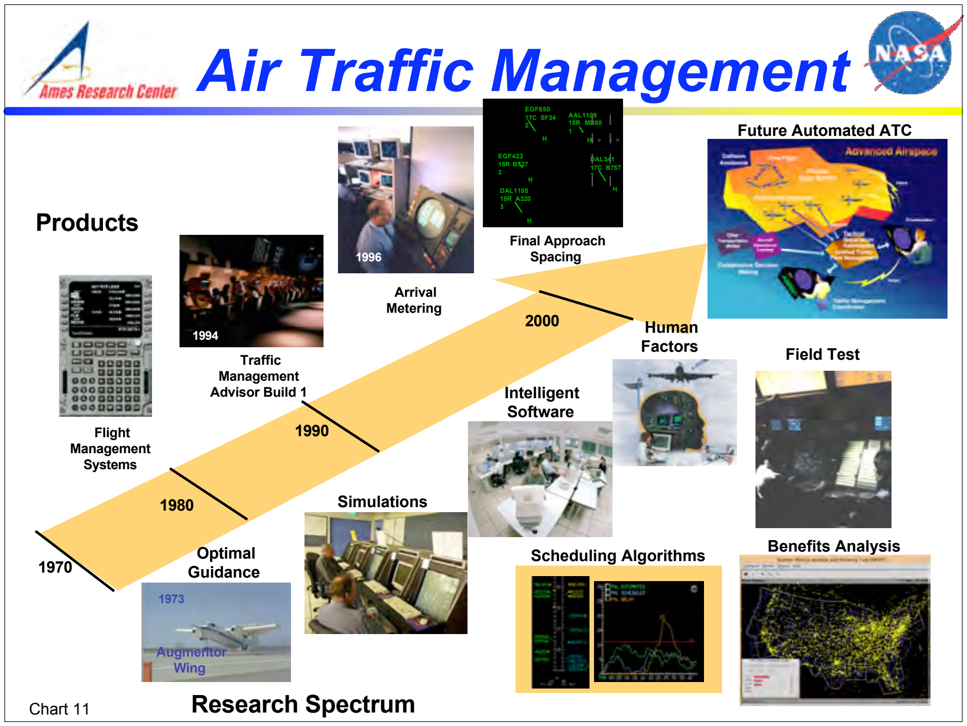
Chart 6

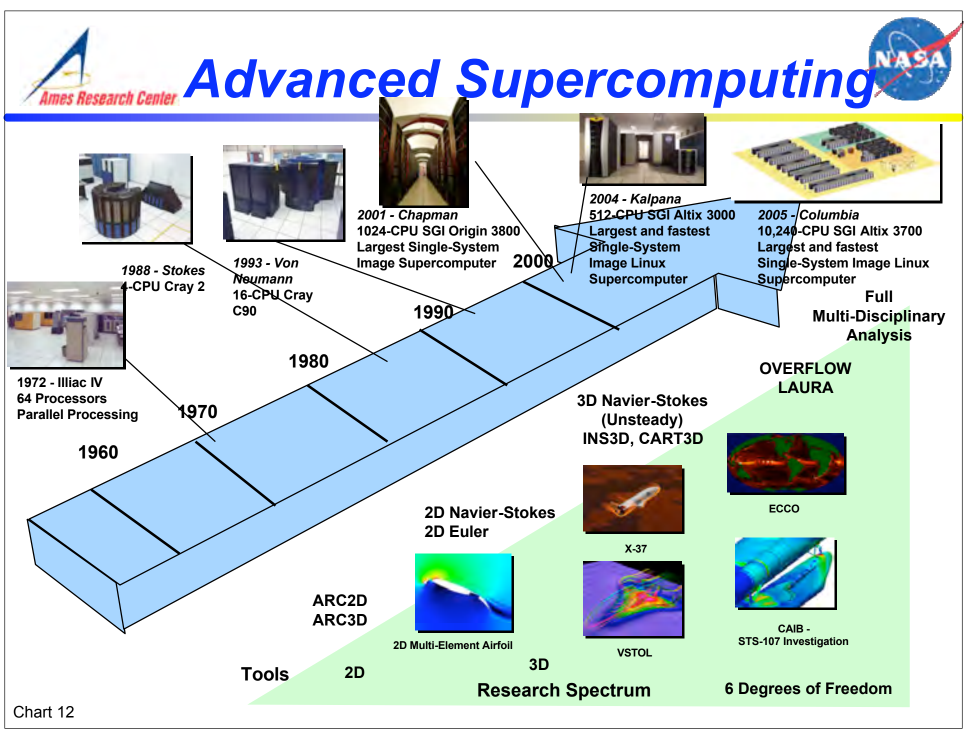

Ames Research Center
Flight Research and Operations
1945
1950
1960
1970
1980
1995
Chart 7


Ames Research Center
Human Factors Research
Crew Resource Management
Fatigue Countermeasures
Automation Design
System Monitoring/ Data Visualization
Human Exploration of Space
Aviation Safety Reporting System
ASRS
1970
1980
1990
2000
2010
Concept & System Studies
Human Performace Modeling
Multi-modal Displays
Vision Science
Biomedical
Fundamental Research
Design Tools
Research Spectrum
Chart 8


Ames Research Center
Flight Simulators
NASA
FSAA
2000
1990
1980
1970
1969
1960
1950
Five Degree of Freedom
Flight and Guidance Centrifuge
Apollo Navigation
Pitch and Roll Chair
Vertical Motion Simulator
Six Degree of Freedom
Chart 9


Ames Research Center
Simulation Contributions
NASA
FUTURE PROJECTS
•Orbital Space Plane
•Mars Exploration Rovers
•NASA Space Architect Support
Fatigue Countermeasures
JSF Controls and Display
KSC Shuttle Landing Facility
Development of VAST-RT: a real-time NAS simulation
CTR Landing Display
2000-present
Ongoing partnership with Shuttle Program (Landing and Rollout)
1990-1999
LAX Runway Incursions
Pre-1990
Free Flight Evaluation
Taxi Display Design
PRE-1990 CONTRIBUTIONS
Head Up Display Design
Concorde US FAA Certification
Tiltrotor Controls Development
C-17 Control Design
TCAS Development
Propulsion Controlled Aircraft
High Speed Civil Transport
Chart 10


Ames Research Center
Air Traffic Management
Products
Flight Management Systems
1994
Traffic Management Advisor Build 1
1996
Arrival Metering
Final Approach Spacing
Future Automated ATC
Advanced Airspace
1970
1980
1990
2000
Human Factors
Field Test
Intelligent Software
Simulations
Optimal Guidance
1973
Augmentor Wing
Scheduling Algorithms
Benefits Analysis
Chart 11
Research Spectrum


Ames Research Center
Advanced Supercomputing
1972 - Illiac IV
64 Processors
Parallel Processing
1988 - Stokes
4-CPU Cray 2
1993 - Von Neumann
16-CPU Cray C90
2001 - Chapman
1024-CPU SGI Origin 3800
Largest Single-System Image Supercomputer
2004 - Kalpana
512-CPU SGI Altix 3000
Largest and fastest Single-System Image Linux Supercomputer
2005 - Columbia
10,240-CPU SGI Altix 3700
Largest and fastest Single-System Image Linux Supercomputer
1960
1970
1980
1990
2000
Full Multi-Disciplinary Analysis
OVERFLOW
LAURA
3D Navier-Stokes (Unsteady)
INS3D, CART3D
ECCO
X-37
2D Navier-Stokes
2D Euler
ARC2D
ARC3D
2D Multi-Element Airfoil
VSTOL
CAIB - STS-107 Investigation
Tools
2D
3D
Research Spectrum
6 Degrees of Freedom
Chart 12

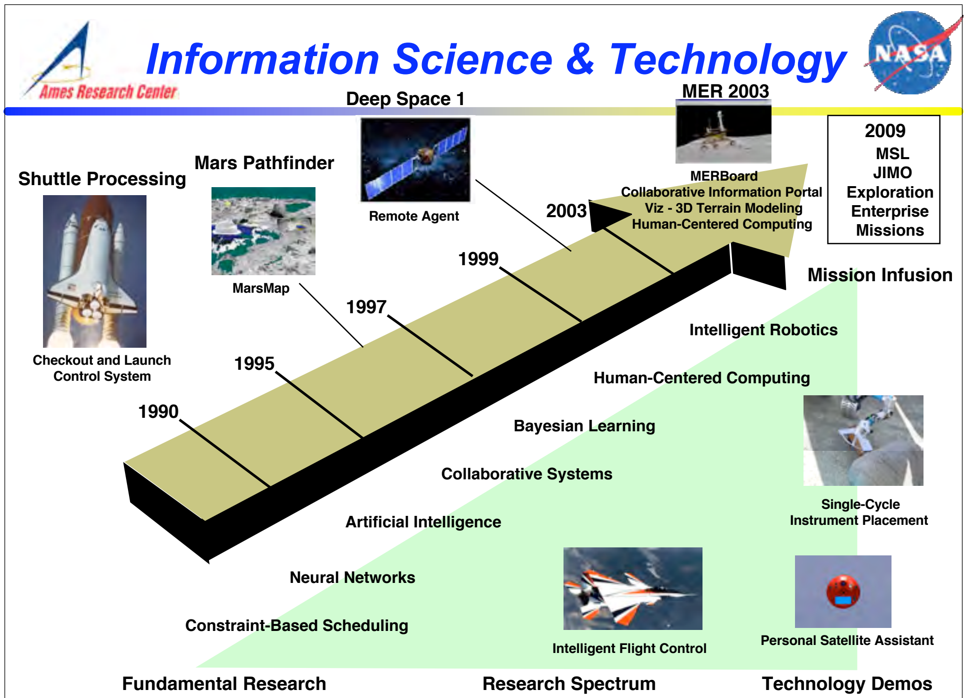


Chart 13

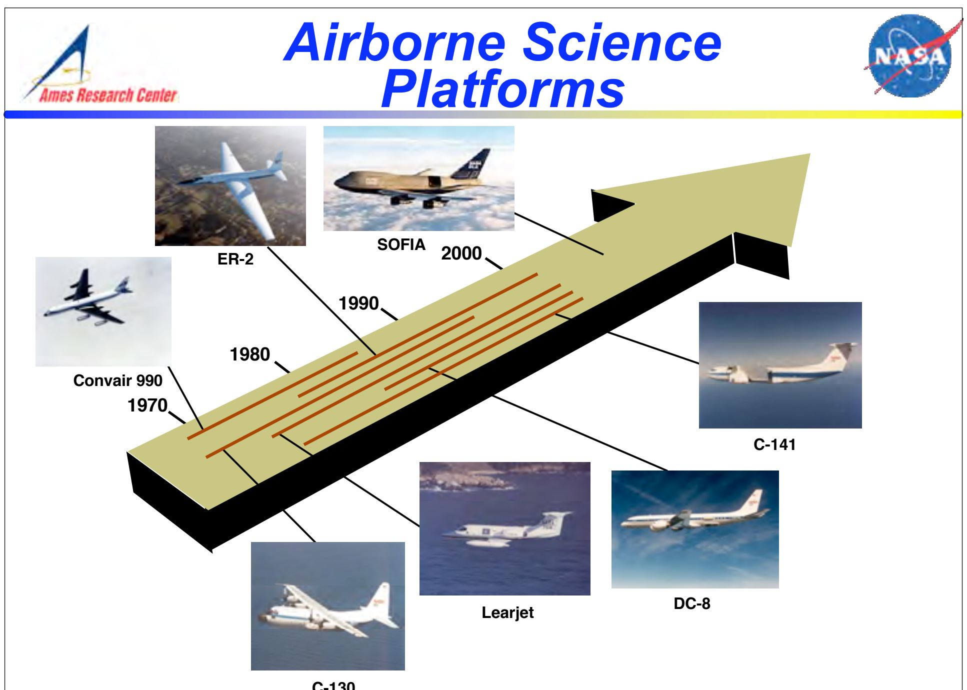
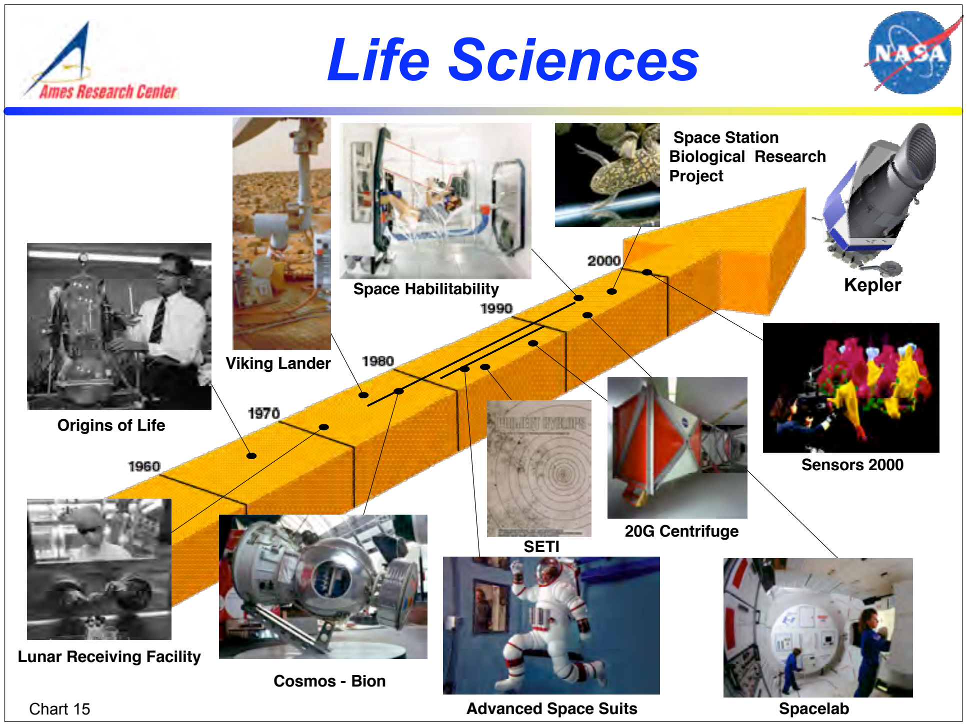
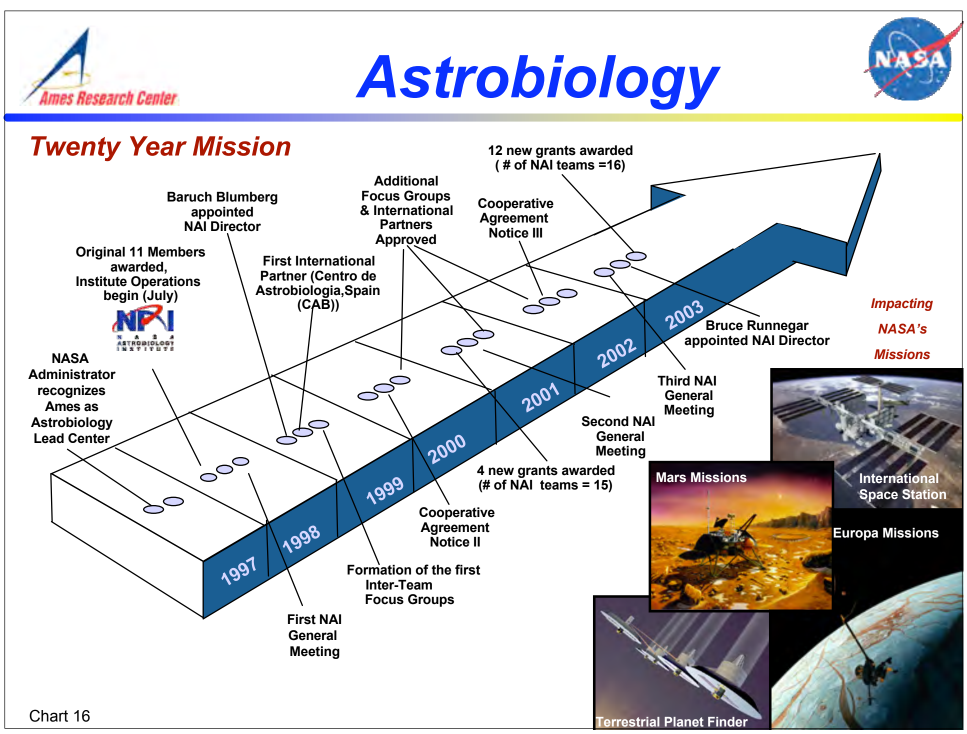


Chart 14

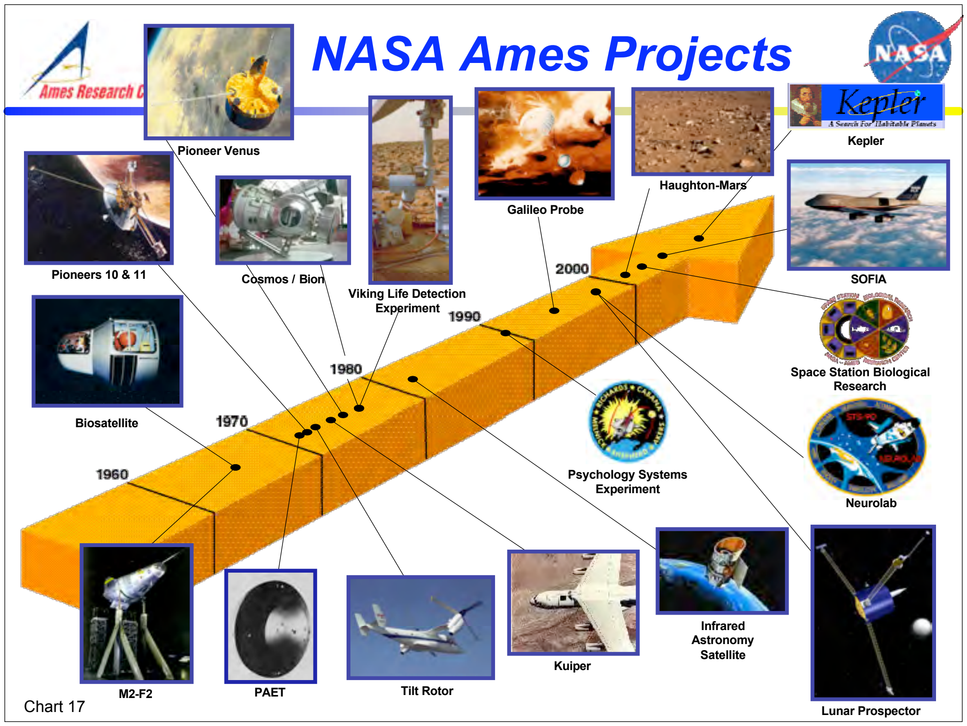


Ames Research Center
Life Sciences
NASA
Space Station Biological Research Project
Kepler
Space Habilitability
2000
1990
Viking Lander
1980
Origins of Life
1970
1960
Sensors 2000
20G Centrifuge
SETI
Lunar Receiving Facility
Cosmos - Bion
Advanced Space Suits
Spacelab
Chart 15

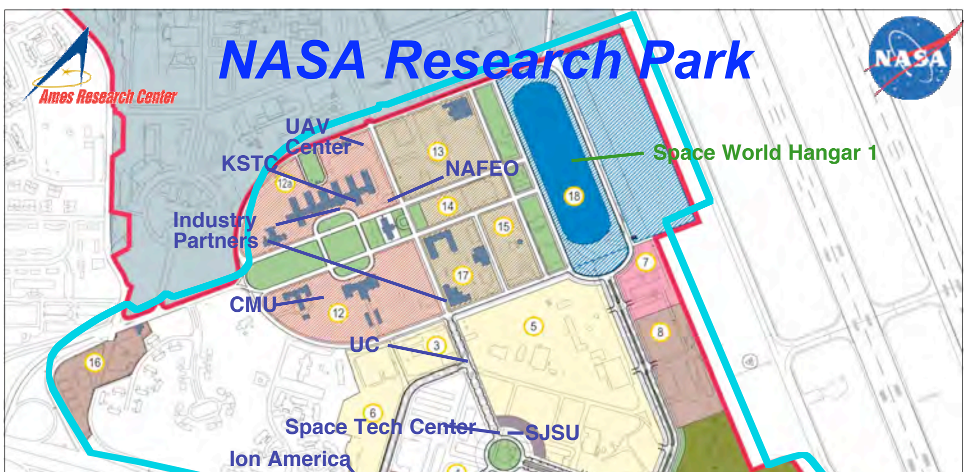


Ames Research Center
Astrobiology
NASA
Twenty Year Mission
12 new grants awarded (# of NAI teams =16)
Additional Focus Groups & International Partners Approved
Cooperative Agreement Notice III
Baruch Blumberg appointed NAI Director
Original 11 Members awarded, Institute Operations begin (July)
First International Partner (Centro de Astrobiologia,Spain (CAB))
NAI NASA ASTROBIOLOGY INSTITUTE
NASA Administrator recognizes Ames as Astrobiology Lead Center
Bruce Runnegar appointed NAI Director
Third NAI General Meeting
Second NAI General Meeting
4 new grants awarded (# of NAI teams = 15)
Cooperative Agreement Notice II
Formation of the first Inter-Team Focus Groups
First NAI General Meeting
1997
1998
1999
2000
2001
2002
2003
Impacting NASA's Missions
International Space Station
Mars Missions
Europa Missions
Terrestrial Planet Finder
Chart 16

NASA Ames Projects



NASA Research Park



Partners Today:
University of California- Building 555
Carnegie Mellon University-Building 23
San Jose State University-Metropolitan Technology Center in Building 583C
Space Technology Center-San Jose State, Stanford, Santa Clara University, Utah State University / Starting 1st Micro Satellite Classes
National Association for Equal Opportunity in Higher Education (NAFEO)-In its second year
Kentucky Science & Technology Corporation-Building 19
Ion America-Building 543 (Fuel Cell Research)
Industry Partners-Building 566 & 19
UAV Center-Building 18
Foothill-De Anza Community College-Newly signed agreement
Space World Hangar 1-Non-profit Foundation, raising funds
Women in STEM-Formulating Plans