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The Apollo Program: The Contributions of the NASA Langley Research Center

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The landing of humans on the Moon was a major accomplishment and seminal event in human history. The Langley Research Center, which celebrated its 100th anniversary in 2017, made many important contributions to the planning and development of the Apollo Program. Unfortunately, NASA Langley never received the recognition for its many contributions to the Apollo Program as pointed out by several space historians. The objective of this paper is to summarize some of the contributions to the Apollo Program by the women and men of the Langley Research Center.

Keywords: Apollo Program, Langley Research Center, Space Task Group, Lunar Orbit Rendezvous, Lunar Orbiter Project, "Human Computers"

1 INTRODUCTION: THE APOLLO MISSIONS TO THE MOON

In 1999, as the 20th century was ending, Pulitzer Prize-winning historian Arthur Schlesinger, Jr. was among a group asked what the most significant human achievement of the 20th century was. He picked the first Moon landing of Apollo 11 as the most significant event of the 20th century [1].

Author Charles Fishman [1] writes:

"When President John F. Kennedy declared in 1961 that the United States would go to the Moon, he was committing the nation to do something we couldn't do. We didn't have the tools, the equipment – we didn't have the rockets or the launch pads, the spacesuits or the computers or the zero-gravity food – to go to the Moon. And it isn't just that we didn't have what we would need; we didn't even know what we would need. We didn't have a list; no one in the world had a list. Indeed, our unpreparedness for the task goes a level deeper: we didn't even know how to fly to the Moon. We didn't know what course to fly to get there from here… we didn't know what we would find there."

Fishman [1] concludes: *"Every one of these challenges was tackled and mastered between May 1961 and July 1969."*

Space historian James R. Hansen, author of *Enchanted Rendezvous: John C. Houbolt and the Genesis of the Lunar-Orbit Rendezvous Concept* [2] and *Spacecraft Evolution: NASA Langley Research Center from Sputnik to Apollo* [3] wrote [4]:

"… all of NASA's research centers were involved in Apollo, but none more so than Langley: wind tunnel tests on the models of the Apollo spacecraft and the huge Saturn booster development by rocket genius Wernher von Braun, studies on the effects of sizzling re-entry speeds of 25,000 mph on heat shields, simulators to crack the puzzle of how astronauts could safely rendezvous and dock in space, landing tests of the Apollo capsule on water and on land to ensure crew safety."

Hansen continues [2]:

"By the time of Armstrong's historic mission, Langley, which had contributed so much, was largely overlooked by the public, no longer part of the 'big show'.

"It's just kind of the way it works," Hansen said recently.

"Langley was in the business – its raison d'etre *was to provide the basic, fundamental knowledge that was necessary to get these things done. And once they had done that, they weren't involved so much in the actual doing of the thing. They weren't Mission Control. They weren't Cape Canaveral. They weren't Houston. They weren't actively involved in the mission itself, so it sort became forgotten.*

But the point is … without what Langley had done prior to the actual launching of a mission, it would never have gone well. It could not have succeeded. So a place like Langley is critically important. You take that role away, you don't get things done right."

This article summarizes some of the roles of the NASA Langley Research Center in tackling and mastering some of these challenges of the first human landing on the Moon.

2 THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS, NACA (1914), THE FIELD STATION OF NACA (1917), SPUTNIK 1 AND 2 (1957) AND NASA (1958)

On March 3, 1915, the U. S. Congress created a 12-member National Advisory Committee for Aeronautics (NACA). The committee was charged to "supervise and direct the scientific study of the problem of flight with a view to their practical solution." On July 17, 1917, formal groundbreaking occurred for the nation's first civil aeronautical research laboratory, the Field Station of the NACA on a 1,650 acre tract of land near Hampton, Virginia. The NACA research laboratory, the Langley Memorial Aeronautical Laboratory (LMAL) was named in honor of Dr. Samuel Pierpoint Langley, astronomer, physicist, inventor and aviation pioneer, and secretary of the Smithsonian Institution. It was formally dedicated on June 11, 1920 (Dr. Langley died in 1906).

To commemorate and summarize the 100-year history of the NACA/NASA Langley Research Center in 2017, two books were published: Joseph R. Chambers: *A Century at Langley: The Storied Legacy and Soaring Future of NASA Langley Research Center*, NASA Special Publication SP-2017-07-100-LaRC, 2017 [5] and Tamara Dietrich, Mark St. John Erickson and Mike Holtzclaw: *The Unknown and Impossible: How a Research Facility in Virginia Mastered the Air and Conquered Space*, The Daily Press Media Group, 2017 [4].

On October 4, 1957, the world was shocked with the successful launch of Sputnik 1 by the Soviet Union, the world's first artificial Earth-orbiting satellite. On November 3, 1957, the world was again shocked with the launch of Sputnik 2 with a 500 kilogram payload, carrying a dog as its passenger. At this time, the Naval Research Laboratory (NRL) was developing the first U. S. Earth-orbiting satellite, called Vanguard, with a payload of only 2 kilograms. On December 6, 1957, the Vanguard satellite failed to reach orbit. On January 31, 1958, the U. S. successfully launched its first Earth-orbiting satellite, Explorer 1.

On July 29, 1958, as a direct result of the launch of the Soviet Sputnik 1 and 2, President Dwight Eisenhower signed an act of Congress that created the National Aeronautics and Space Administration (NASA). On October 1, 1958, NASA was formed with the nucleus of the NACA research laboratories-the Langley Research Center, Lewis Research Center, Ames Research Center and the Hugh L. Dryden Flight Research Facility. Also transferred into NASA were the Army George C. Marshall Space Flight Center and the California Institute of Technology Jet Propulsion Laboratory. New NASA centers included: The Goddard Space Flight Center, commissioned by NASA on March 1, 1959; the John C. Stennis Space Center, commissioned on October 25, 1961; the Manned Space Center, created on November 1, 1961; and the John F. Kennedy Space Center, created on July 1, 1962.

3 THE SPACE TASK GROUP (1958)

The NASA Space Task Group (STG) was created at NASA Langley Research Center on November 5, 1958, shortly after the formation of NASA on October 1, 1958. Originally, the STG consisted of 37 employees – 27 from NASA Langley and 10 assigned from the NASA Lewis Research Center (later renamed the Glenn Research Center), including eight secretaries and "computers," the title for the Langley women who ran calculations on mechanical adding machines. Langley engineer Robert Gilruth was selected to head the STG. Charles Donlan was selected as Gilruth's deputy. Other key positions in the STG were: Max Faget, head of engineering and lead designer of the Mercury capsule vehicle, and Christopher Kraft in flight operations.

In early 1959, Langley formed the Langley Lunar Mission Steering Group, with Clinton E. Brown as its head, to study the problems of lunar exploration. During Project Mercury, Brown headed a team designing a lunar landing module, and taught orbital mechanics and space flight to the first seven astronauts and others at NASA. The Steering Group developed multiple concepts for landing a human on the Moon. The working group consisted of David Adamson, Paul R. Hill, John Houbolt, Samuel Katzoff, William Michael and Albert A. Schy [2]. One concept, favored by many influential individuals of the scientific community, would have first created a space station as a stepping-stone to the Moon. Brown strongly objected to this approach, believing it would significantly delay the ultimate moon landing. His influence and advocacy were significant contributors to selection of the LOR approach that enabled the successful Apollo missions. His influence during the acceptance of the LOR concept was a major contribution to the U.S. space program [2].

On May 25, 1961, in a speech before the Congress of the United States, President John F. Kennedy set the U. S. goal of landing a man on the Moon and bringing him safely back to Earth by the end of the 1960s. After the President's speech, NASA Administrator James E. Webb realized that to achieve this difficult objective, Gilruth would need a significantly larger organization and facilities – a new NASA center dedicated to human spaceflight programs. On September 19, 1961, he announced that a new NASA facility to be named the Manned Spacecraft Center (MSC, later renamed the Johnson Space Center) would be built in Houston, Texas. Gilruth began the transition of the STG to Houston in temporary leased office and test facility space on a dozen sites until the construction of the new MSC could be completed. By September 1962, the STG had moved to Houston. The MSC was completed in September 1963.

4 THE FIRST HUMANS IN SPACE: SOVIET UNION AND THE UNITED STATES (1961 AND 1962)

On April 12, 1961, Soviet Union cosmonaut Yuri Gagarin became the first human to fly in space by completing one orbit of Earth. The first U. S. suborbital Mercury Project flight, lasting 15 minutes by Alan Shepard, took place on May 5, 1961. The second U. S. suborbital flight, lasting 15 minutes by Gus Grissom, took place on July 21, 1961. The first American to orbit the Earth with a three-orbit flight was John Glenn on February 20, 1962. Subsequent orbital flights by Mercury Astronauts Carpenter (3 orbits of Earth, launched May 24, 1962), Schirra (6 orbits of Earth, launched October 3, 1962) and Cooper (22 orbits of Earth, launched May 15, 1963) completed the six crewed flights of Project Mercury.

On May 25, 1961, only three weeks after Alan Shepard became the first American in space with his suborbital flight, President John F. Kennedy announced in a speech to Congress the U. S. goal of sending humans to the Moon and returning them safely before the end of the decade.

5 THE LANGLEY "HUMAN COMPUTERS" AND HUMAN SPACE FLIGHT

As already mentioned, when the NASA Space Task Group (STG) was formed at NASA Langley in 1958, the personnel assigned to the STG included the "human computers," the black and white women who performed difficult and complicated calculations on mechanical adding machines, such as the cumbersome and noisy Freden calculating machines, for the Langley engineers. The dozens of black "computers" were segregated from the white "computers." The "human computers," were very important contributors to the U. S. human space program. The NACA/NASA "human computers," mostly three black women, were featured in the best-selling book written by Margo Lee Shetterly and seen in the Academy Award for Best Picture-nominated film of the same name, *Hidden Figures:*

The American Dream and the Untold Story of the Black Women Who Helped Win the Space Race. Katherine Johnson, Dorothy Vaughan and Mary Jackson were the three black women featured in the book and movie.

Katherine Johnson started her Langley career in 1953. She calculated the flight window for Alan Shepard's 15-minute suborbital flight on May 5, 1961, the trajectories for Astronaut John Glenn's first orbital flight by an American on February 20, 1962, and was a key member of the mission team on both Apollo 11 and 13 human flights to the Moon. In 2015, Johnson received the Presidential Medal of Honor for her NACA/NASA work. Vaughan started at Langley 1943 and was selected as the first black supervisor at Langley in 1951 and later moved to electronic computing and programming. Vaughan's work was integral to the U. S. space program, including the development and flights of the Scout Launch Vehicle Program that started at Langley in 1961. Jackson started her career at Langley in 1951 and was one of the first black women granted the title of "engineer". She became responsible for a series of wind tunnel experiments in Langley's Theoretical Aerodynamics Branch that led her to author 12 NASA technical papers. In 2019, Johnson, Vaughan and Jackson were awarded the Congressional Gold Medal (posthumously for Vaughan and Jackson).

The importance of the Langley "computers" to the U. S. human space program was illustrated in the book and the movie. The calculations for reentry of John Glenn's historic flight were the first to be done not by hand by the woman computers, but by an early electronic computer. Prior to his flight, Glenn told NASA to get Katherine Johnson to check the electronic computer's calculations by hand before he would fly. Johnson confirmed that the electronic calculations were correct and the rest is history.

6 THE LUNAR-ORBIT RENDEZVOUS (LOR) CONCEPT

As previously noted, when President Kennedy announced in 1961 that the U. S. would send humans to the Moon and return them safely in this decade, there was no plan on how to accomplish this complicated and dangerous goal. Engineers considered three different architectures to accomplish the goal: 1. Direct Ascent; 2. Earth Orbit Rendezvous (EOR); and 3. Lunar Orbit Rendezvous (LOR). Eventually, NASA Headquarters selected the lunar orbit rendezvous developed and championed by Langley engineer, John Houbolt [2].

Lunar Orbit Rendezvous consisted of a single rocket launch with two coupled spacecraft – the command module and the lunar lander. After launch, the combined command module and lunar lander would orbit the Moon. Once in lunar orbit, the command module would keep orbiting while the lunar lander would set down on the surface of the Moon. After exploring the Moon, the astronauts would enter the ascent stage of the lunar lander and blast off from the Moon's surface and rendezvous with the orbiting command module for the return to Earth.

Houbolt also envisioned the lunar module to serve as a "lifeboat" should the command module ever be compromised. This was in fact what happened on the Apollo 13 mission to the Moon, when an oxygen tank explosion disabled the command module on the way to Moon and the crew used the lunar module to get back to Earth safely.

Houbolt's Lunar Orbit Rendezvous architecture required a new, untried and potentially dangerous maneuver – a rendezvous between the lunar module and command module at high speed in lunar orbit. This maneuver led to the two-person Gemini Program that followed the successful Mercury Program to prepare for a lunar landing in the Apollo Program. The Gemini Program rendezvous between two Gemini spacecraft in Earth orbit proved that the rendezvous concept could be done safely.

NASA Administrator James Webb approved LOR as the architecture for the Apollo missions in July 1962 and it was announced at a press conference on July 11, 1962 [2].

7 THE RENDEZVOUS DOCKING SIMULATOR (COMPLETED IN 1963)

The Lunar Orbit Rendezvous architecture for sending humans to and from the Moon developed by John Houbolt required a lunar docking rendezvous between the lunar module leaving the surface of the Moon and the command module orbiting the Moon after the human landing and lunar exploration phase. The objective of the Gemini Program initiated after the successful Mercury Program was to train astronauts for the rendezvous docking in lunar orbit that was critical for a successful return to Earth after the lunar landing. To this end, the Rendezvous Docking Simulator was constructed in the Langley Research Aircraft Hangar and became operational in June 1963. The simulator consisted of a gantry frame, with an overhead carriage from which the test craft were suspended by cables. Both Gemini and Apollo astronauts trained in the simulator.

The Rendezvous Docking Simulator was declared a National Historic Landmark in 1985.

8 PROJECT FIRE (FLIGHT INVESTIGATION REENTRY ENVIRONMENT) (1964-1965)

Project FIRE (1964-1965) was a Langley Research Center research program to determine the effects of atmospheric reentry heating on spacecraft materials, such as the Apollo command module returning to Earth after its lunar voyage. Project FIRE wind tunnel testing took place in the Langley's 4-foot Unitary Wind Tunnel, the High Temperature Tunnel and the 9 × 6 foot Thermal Structures Tunnel. Two flight tests with an Atlas D launch vehicle carried the instrument probe to an altitude of more than 800 km with atmospheric entry speeds of greater than 40,000 km/h creating a spacecraft exterior temperature in excess of 11,000 K. The FIRE 1 flight test occurred on April 14, 1964 and the FIRE 2 flight test occurred on May 22, 1965 [3].

9 THE LUNAR LANDING RESEARCH FACILITY (COMPLETED IN 1965)

Langley engineer Hewitt Phillips developed a suspension system for a Lunar Landing Research Facility (LLRF) that would simulate the effects of the Moon's reduced gravity on a human lunar landing. The facility's lunar module simulator was suspended beneath a large gantry (300 ft long, 250 ft high, and 100 ft wide), while small rockets and servo mechanisms reproduced the motions that the pilot would experience upon landing in the 1/6 lunar gravity.

Completed in 1965, the LLRF was used by 24 Apollo astronauts including Neil Armstrong and Buzz Aldrin, to practice solving the piloting problems they would encounter in the last 150 feet of descent to the surface of the Moon. The last 150 feet above the surface of the Moon were difficult to navigate due to the obscuration of the lunar surface due to the blowing up of surface lunar dust into the thin lunar atmosphere (which was not anticipated prior to the landing of Apollo 11), the widely varying terrain and topography of the planned landing site covered with hills, large boulders, numerous impact craters and the problem of running out of lunar module fuel for the landing due to the dust obscuration of the surface and last minute navigation changes resulting from changes in surface topography.

After his historic first human landing on the Moon in 1969, Neil Armstrong was asked: "What was it like to land on the Moon?" Armstrong replied, "Like Langley" [5].

The "Reduced Gravity Walking Simulator" on the Lunar Landing Research Facility allowed astronauts to practice how to walk and perform tasks on the Moon's surface in 1/6 gravity. In one nationally-televised segment in 1968, CBS-TV anchorman Walter Cronkite tried Moon walking in an astronaut suit [5].

The Langley Lunar Landing Research Facility was designated a National Historic Landmark in 1985 for its important role in the Apollo lunar landing.

In 1974, the Lunar Landing Research Facility was re-designated the Impact Dynamics Research Facility (IDRF). In 2005, the facility was re-opened and renamed the Landing and Impact Research Facility (LandIRF) to conduct landing tests associated with the development of the Crew Exploration Vehicle (CEV) Orion.

10 WIND TUNNEL TESTING OF THE AERODYNAMIC CHARACTERISTICS OF THE APOLLO-SATURN LAUNCH VEHICLE

Many other things were done at Langley to support Apollo. Through hundreds of hours of wind tunnel testing, researchers helped to determine the aerodynamic characteristics of the Apollo-Saturn launch configuration. In order to evaluate Apollo's ablative heat-shield materials, an electric arc heater was used at Langley that could duplicate the intense heat generated by friction during reentry. In numerous facilities, including the 8-foot High-Temperature Tunnel, Langley engineers conducted critical investigations into the structural integrity of Apollo [3].

11 THE LUNAR ORBITER PROJECT (1966-1967)

Five Lunar Orbiter missions were launched between 1966 and 1967 with the purpose of mapping out the surface of the Moon for the landing and exploration of the Moon by the first humans. All five missions were successful and photographed 99% of the surface of the Moon with a resolution of 60 m or better. The first three Lunar Orbiter missions were dedicated to photographing 20 potential Apollo landing sites, each selected based on observations from Earth. These missions were flown at low inclination orbits. The fourth and fifth missions were devoted to broader scientific objectives and were flown in high altitude polar orbits. Lunar Orbiter 4 photographed the entire near side of the Moon and 95% of the Moon's far side. Lunar Orbiter 5 completed the far side coverage and obtained medium (20 m) and high (2 m) resolution images of 36 pre-selected lunar areas. One of the most important scientific discoveries of the Lunar Orbiter missions, and Lunar Orbiter 5 in particular, was the discovery of lunar mass concentrations or "mascons" under the lunar ringed maria.

The Lunar Orbiter program was conceived, developed and managed by the NASA Langley Research Center. The photographs of the surface of the Moon obtained by the Lunar Orbiter Program were critical for a safe landing of the six Apollo human missions. The success of the NASA Langley Lunar Orbiter team in obtaining five out of five successful missions between 1966 and 1967 was an important factor in the selection of the Langley Research Center by NASA Headquarters to conceive, develop and managed the twin Viking Orbiter/Landers missions to Mars launched in 1975. The Viking Landers achieved the world's first successful soft landings of an operational spacecraft on another planet on July 20, 1976 and again on September 3, 1976. Many of the Langley Lunar Orbiter personnel went on to form the nucleus of the Viking Project team.

The Langley Lunar Orbiter Team consisted of Clifford Nelson, Project Manager, James V. Martin, Assistant Project Manager, Israel Taback, Bill Boyer and Norman Crabill, Head of the Lunar Orbit Project Office Mission Design Team.

Lunar Orbiter 1 Launched August 10, 1966; entered lunar orbit-August 14, 1966; spacecraft deliberately crashed on the Moon: October 29, 1966.
Lunar orbit: 118 × 1,160 miles
Scientific instruments: Imaging system, micrometeoroid detectors and radiation dosimeters.
Mission Firsts: First U. S. spacecraft to orbit the Moon. Obtained first pictures of Earth from the vicinity of the Moon.
Primary Mission: To photograph nine potential Apollo landing sites, seven secondary areas, and the Surveyor 1 landing site.

On August 23, 1966, on its 16th orbit, just before it passed behind the Moon, Lunar Orbiter 1 obtained what was referred to at the time as the "picture of the century" – the first view of the Earth from space. The photo also provided a spectacular dimensional view of the lunar surface.

Lunar Orbiter 2 Launched November 6, 1966; entered lunar orbit November 10, 1966; spacecraft deliberately crashed on the Moon October 11, 1967.
Lunar orbit: 122 × 1,150 miles; after 32 orbits moved to its photographic orbit with a perilune of 31 miles.
Scientific instruments: Imaging system, micrometeoroid detectors and radiation dosimeters.
Primary Mission: To photograph 13 primary and 17 secondary Apollo landing sites

Lunar Orbiter 3 Launched February 5, 1967; entered lunar orbit February 8, 1967; spacecraft deliberately crashed on the Moon: October 9, 1967.
Lunar orbit: Initial orbit of 131 × 1,120 miles, later changed to 34 × 1,148 miles.
Scientific instruments: Imaging system, micrometeoroid detectors and radiation dosimeters.
Primary Mission: Final mission to photograph potential Apollo landing sites. One of its images showed the Surveyor 2 lander on the lunar surface.

Lunar Orbiter 4 Launched May 4, 1967; entered lunar orbit May 8, 1967; spacecraft crashed onto the Moon on October 6, 1967 having lost radio contact with the Earth on July 17, 1967.
Lunar orbit: Initial polar orbit of 1,681 × 3,797 miles at an inclination of 85.5 degrees.
Scientific instruments: Imaging system, micrometeoroid detectors and radiation dosimeters.
Mission Firsts: First spacecraft to go into polar orbit around

the Moon. Obtained first photographs of the Moon's south pole.
Primary Mission: Scientific survey of the Moon. Obtained photographs of 99% of the near side and 75% of the far side of the Moon.

Lunar Orbiter 5 Launched August 1, 1967; entered lunar orbit August 3, 1967; spacecraft deliberately crashed on the Moon: January 31, 1968.
Lunar orbit: Initial polar orbit of 121 × 3,743 miles moved to an orbit of 62 × 3,743 miles at an inclination of 85.01 degrees.
Scientific instruments: Imaging system, micrometeoroid detectors and radiation dosimeters.
Primary Mission: Photographed five potential Apollo landing sites, 36 science sites, and 23 previously unphotographed areas of the Moon's far side.

12 THE NACA/NASA LANGLEY HALL OF HONOR (HOH)

In 2015, to commemorate its 100th anniversary in 2017, the Langley Research Center established the NACA/NASA Langley Hall of Honor (HOH) to honor scientists, engineers, technologists and project/program managers that had made significant contributions to aeronautics and space development. The Hall of Honor was conceived and planned by Langley researcher Duncan McIver, former president of the Langley Alumni Association. Nominations of candidates for the HOH are open to the entire aeronautics and space community, including past and present Langley staff members. The HOH Selection Panel consists of about a dozen past and present Langley employees, including former Center Directors. After voting by the Selection Panel, the HOH candidates are reviewed and approved by NASA Langley Research Center senior management.

The Hall of Honor formally recognizes those persons whose contributions have had the most sustained and far-reaching influence on the leadership, direction, mission and capabilities of the NACA Langley Memorial Aeronautical Laboratory and NASA Langley Research Center and/or whose work at Langley enabled unprecedented and fundamental advancements in either a scientific or engineering field and made significant contributions to the United States' aerospace industry for commercial and military aircraft and/or spacecraft. The nomination and selection of the current 37 inductees into the HOH occurred in 2015 (19 inductees) and 2017 (18 inductees).

It is interesting to note that more than a third of the Langley HOH membership (13 out of 37 members) played a role in the Apollo human landing on the Moon. Those named in this paper, in order of their appearance, are Robert R. Gilruth, Charles J. Donlan, Maxime A. Faget, Christopher C. Kraft, Jr., Clinton E. Brown, John C. Houbolt, Samuel Katzoff, Katherine G. Johnson, Dorothy J. Vaughan, Mary W. Jackson, W. Hewitt Phillips, James S. Martin, Jr., and Norman L. Crabill.

A full list of Hall of Honor inductees follows. Note that the names are followed by two sets of dates: the first giving their year of birth and death; the second giving their NACA/NASA career span. The official citation on the HOH member plaque and the year of induction (either 2015 or 2017) are also given. The inductees are listed in order of their year of birth [6].

Dr. Max. M. Munk (born 1890, died 1986; NACA/NASA Career: 1920-1927). In recognition of the development of thin airfoil theory and the revolutionary Variable Density Wind Tunnel (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/max-m-munk

Dr. Henry J. E. Reid (1895-1968; 1921-1961). In recognition of development of the NACA V-G Recorder, and his exemplary leadership during a storied career as the "Engineer-in-Charge" of the NACA Langley Memorial Aeronautical Laboratory and Director of the NASA Langley Research Center (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/henry-j-e-reid

Pearl I. Young (1895-1968; 1922-1961). In recognition of enduring contributions to the NACA and NASA resulting from her personal establishment of systems that ensured the accuracy, thoroughness and quality of technical publications (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/pearl-i-young

Dr. Smith J. DeFrance (1896-1985; 1922-1965). In recognition of leadership of the design, construction, and early operations of iconic Langley test facilities- the Full-Scale Tunnel, 19-Foot Pressure Tunnel, Propeller Research Tunnel, and 8-Foot High-Speed Tunnel (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/smith-j-defrance

Dr. Theodore Theodorsen (1897-1978; 1929-1946). In recognition of groundbreaking research on the phenomenon of aircraft flutter and development of the use of Freon in wind tunnels to enable aeroelastic testing in simulated flight-like environments (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/theodore-theodorsen

Dr. Floyd L. Thompson (1898-1976; 1926-1973). In recognition of exemplary leadership of Langley research programs spanning both the NACA and NASA eras, and especially as Langley Center Director during the formative years of NASA's manned spaceflight program (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/floyd-l-thompson

Fred E. Weick (1899-1993; 1925-1936). In recognition of pioneering full-scale propeller research, development of the low-drag NACA engine cowling and spin-resistant aircraft design (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/fred-e-weick

Eastman N. "Jake" Jacobs (1902-1987; 1925-1944). In recognition of pioneering development of the NACA-series of airfoils - especially the laminar flow series - and design of important Langley wind tunnel facilities (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/eastman-n-jacobs

Ira H. "S" Abbott (1906-1988; 1929-1962). Served from 1929 to 1962. In recognition of outstanding contributions to the development of the NACA-series of airfoils, and exemplary leadership of NACA and NASA programs of critical National importance (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/ira-h-s-abbott

John Stack (1906-1972; 1928-1962). In recognition of pioneering research and leadership related to the challenges of supersonic flight, including leadership of the X-1 Program, and contributions to the development of the slotted-wall wind tunnel (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/john-stack

Charles H. Zimmerman (1908-1996; 1929-1967). In recognition of a career of extraordinary innovation-- design of unique facilities and radical aircraft configurations, stimulation of NACA research into the challenges of spaceflight, and leadership of

NASA's aeronautics research program (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/charles-h-zimmerman

Dr. Samuel Katzoff (1909-2010; 1936-1974). In recognition of pioneering contributions to the theoretical understanding of fundamental aerodynamic phenomena and leadership to ensure the quality of NACA and NASA research publications (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/samuel-katzoff

Robert T. Jones (1910-1999; 1934-1981). In recognition of extraordinary contributions to the fundamental understanding of aerodynamic principles and development of the swept-back wing enabling efficient supersonic flight (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/robert-t-jones

Dorothy J. Vaughan (1910-2008; 1943-1971). In recognition of exemplary leadership as the NACA's first female African-American supervisor, demonstrated expertise as a programmer of earliest digital computers, and myriad contributions to the success of the Nation's aeronautics and space programs (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/dorothy-j-vaughan

John V. Becker (1913-2020; 1935-1974). In recognition of contributed critical concepts and leadership in high-speed aerodynamics programs for the NACA and NASA, including hypersonic efforts that resulted in the highly successful X-15 research aircraft program (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/john-v-becker

Dr. Robert R. Gilruth (1913-2000; 1937-1973). In recognition of pioneering contributions to the quantitative understanding of aircraft handling qualities, concepts for flight testing in lieu of wind tunnel testing and leadership of America's manned spaceflight program (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/robert-r-gilruth

Charles J. Donlan (1916-2011; 1938-1976). In recognition of early research into the challenges of high-speed flight, leadership within the Space Task Group – including selection and training of Mercury astronauts – and consummate service as Langley Deputy Center Director, and Manager of the fledging Space Shuttle Program (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/charles-j-donlan

John P. "Jack" Reeder ((1916-1999; 1938-1980). In recognition of an exemplary career as NACA and NASA's preeminent test pilot and his critical role in the development and implementation of the Terminal Configured Vehicle Program (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/john-p-reeder

Katherine G. Johnson (1918-2020; 1953-1986). In recognition of critical contributions, achieved in spite of the cultural barriers of race and gender, to the success of the nation's human spaceflight program -- Projects Mercury and Apollo, and the Space Shuttle Program (Inducted: 2017).
https://www.nasa.gov/feature/katherine-g-johnson

W. Hewitt Phillips (1918-2009; 1940-1979). In recognition of pioneering research in aircraft flight dynamics; and development of multiple unique simulation technologies at Langley - specifically the Lunar Landing and Differential Maneuvering Simulator Facilities (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/w-hewitt-phillips

John C. Houbolt (1919-2014; 1942-1985). In recognition of single-handed, unwavering advocacy of the lunar-orbit rendezvous concept that enabled accomplishment of President Kennedy's objective of a manned mission to the moon and back during the decade of the 1960's (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/john-c-houbolt

Clinton E. Brown (1920-2008; 1942-1964). A brilliant experimentalist and theoretician who contributed legendary advancements to the aeronautics and space programs of the NACA and NASA (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/clinton-e-brown

Eugene S. "Gene" Love (1920-2001; 1947-1975). In recognition of pioneering contributions to the technology of lifting bodies for controlled entry from space – especially the HL-10 – and leadership of Langley's critical roles in development of the Space Shuttle (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/eugene-s-love

James S. Martin, Jr. (1920-2002; 1964-1976). In recognition of extraordinary leadership as Assistant Manager of the highly-successful Lunar Orbiter Project, and as Manager of the Viking Project that successfully placed the first two landers on the surface of Mars (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/james-s-martin-jr

Robert A. Champine (1921-2003; 1947-1979). In recognition of an extraordinary career as an NACA and NASA test pilot- pioneering flight evaluation of research aircraft ranging from supersonic (X-1) to helicopters; development of simulators critical to the training of Mercury, Gemini, and Apollo astronauts; and leadership of astronaut training (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/robert-a-champine

Maxime A. Faget (1921-2004; 1946-1981). In recognition for the development of many of the innovative ideas and design concepts that have been incorporated into all of the manned spacecraft flown by the United States (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/maxime-a-faget

Harvey H. Hubbard (1921-2012; 1945-1992). In recognition of pioneering contributions to the understanding of aircraft noise generation and suppression mechanisms, leading to dramatic reductions in aircraft noise; and conception and establishment of the Langley Aircraft Noise Reduction Laboratory (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/harvey-hubbard

Mary W. Jackson (1921-2005; 1951-1985). In honor and recognition of the ambition and motivation that enabled her career progression from "human computer" to NASA's first African-American female engineer, and subsequent career supporting the hiring and promotion of other deserving female and minority employees (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/mary-jackson

Dr. Richard T. Whitcomb (1921-2009; 1943-1980). In recognition of revolutionary contributions to the science of aerospace – the area rule, supercritical wing and winglets – that enabled supersonic flight of military aircraft and energy-efficient flight of commercial aircraft (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/richard-t-whitcomb

Edward C. Polhamus (1923-2001; 1944-1981). In recognition of extraordinary aerodynamic insights which enabled practical variable sweep wings and vortex flow control for high-perfor-

mance military aircraft; and vision, advocacy, and leadership which led to realization of the National Transonic Facility (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/edward-c-polhamus

Christopher C. Kraft, Jr. (1924-2019; 1945-1982) In recognition of early research in aircraft handling qualities; and subsequent creation of the concepts and processes for the planning, execution and control of manned spaceflight missions (Inducted: 2015).
https://www.nasa.gov/langley/hall-of-honor/christopher-c-kraft-jr

Cornelius Driver (1925-2009; 1951-1986). In recognition of sustained advocacy for, and engineering leadership of, NASA programs to provide the technological foundation for civil commercial supersonic transports and other revolutionary aerospace concepts and configurations (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/cornelius-driver

Norman L. Crabill (1926-; 1949-1986). In recognition of contributions to critical Langley programs including rocket-boosted supersonic model research, satellite launches, lunar observations, missions to Mars, and characterization of phenomena in severe storms (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/norman-l-crabill

Roy V. Harris (1935-2021; 1958-1998). In recognition of extraordinary technical contributions and leadership of NASA research on supersonic civil and advanced military aircraft, and service to programs of critical National security interest (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/roy-v-harris

Dr. James H. Starnes, Jr. (1939-2003; 1970-2003). In recognition of personal contributions, and leadership of pioneering research in advanced metallic and composite structures, that heralded their use in aircraft, spacecraft, and launch vehicles (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/james-h-starnes-jr

Dr. M. Patrick McCormick (1940-; 1967-1996). In recognition of pioneering development of remote sensing capabilities (both space-based and ground-based), and research analyses that have significantly contributed to scientific understanding of the Earth's atmospheric processes (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/m-patrick-mccormick

Dr. Joel S. Levine (1942-; 1970-2011). In recognition of a career of unparalleled contributions to the scientific understanding of the atmospheres of Mars and the Earth, and a sustained leadership role in defining the scientific objectives of future Mars exploration activities (Inducted: 2017).
https://www.nasa.gov/langley/hall-of-honor/joel-s-levine

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3. J. R. Hansen, *Spaceflight Revolution: NASA Langley Research Center from Sputnik to Apollo*, The NASA History Series, NASA Special Publication 4308, 1995.
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5. J. R. Chambers, *A Century at Langley: The Storied Legacy and Soaring Future of NASA Langley Research Center*, NASA Special Publication 2017-07-101-LaRC, U. S. Government Printing Office, Washington, DC, 2017.
6. https://www.nasa.gov/feature/langley/naca-and-nasa-langley-hall-of-honor-class-of-2015 and https://www.nasa.gov/feature/langley/naca-and-nasa-langley-hall-of-honor-class-of-2017

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