Paving the way: The influence of early research and development programs on Apollo, Saturn, and legacy system development.

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Introduction

As we celebrate the 50th anniversary of the first successful human landings on the surface of the Moon in 1969, it is insightful to review the many historic accomplishments that contributed to this astounding human achievement. While the Apollo Program officially began following the charge by United States President John F. Kennedy in 1961, much of the foundation for Apollo was already underway with early research and development that began as early as the close of the second World War. Innovations and key decisions prior to the formal initiation of the Apollo Program, and even prior to the formation of the National Aeronautics and Space Administration (NASA), enabled the relatively rapid development of the Saturn V rocket, the Apollo capsule, and the Lunar Lander systems needed to achieve the goal of landing humans on the Moon and returning them safely to Earth by the close of the 1960s.

The history of aerospace research and development in the United States of America (USA) begins with the establishment of the National Advisory Committee for Aeronautics (NACA) in 1915. At the dawn of World War I, prominent scientists and engineers in the United States became concerned about the lack of advancement in aviation just a few short years following the historic flights of the Wright brothers. Research and Development in the USA was not as centralized and organized as many European nations at the time. In response, the United States Congress authorized the creation of the NACA in 1915 to conduct the fundamental research necessary to advance aviation in the United States.[1] The NACA mission was described "to supervise and direct the scientific study of the problems of flight with a view to their practical solution."[2]

Upon its establishment, the NACA conducted research through technical committees, staffed by other agencies and organizations, which limited significant advancement. In 1917, again with authorization by the United States Congress, NACA established the first research facility, the Langley Memorial Aeronautical Laboratory (LMAL). Created on a site in Hampton, Virginia, on the shores of the Chesapeake Bay about 150 miles southeast of Washington, D.C., the LMAL began with administrative offices and a wind tunnel on rural land that the United States Air Service, also located in Hampton, was not using. For several decades, NACA and the LMAL

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conducted research that led to significant advancements in atmospheric flight and aviation. Through systematic aerodynamic testing, NACA researchers found practical ways to improve the performance of many different varieties of aircraft.[3]

Figure 1. *Aerial view of the NACA large wind tunnels, tank and hanger in the foreground, from 1932.*

Following World War II, NACA and the LMAL began to conduct fundamental research that would lead to advancements in hypersonic flight, rocket development, re-entry systems, and mission operations. This work accelerated in 1958 when the United States recognized the need to transition and expand the fundamental research capabilities of NACA into an aerospace research and development agency that would lead the USA to becoming a spacefaring nation. The National Aeronautics and Space Administration (NASA) was created and became operational on October 1, 1958. The LMAL became the NASA Langley Research Center. Many of the early advancements at NASA Langley were crucial to the foundation for the Apollo program, the lunar landings, and safe return of the crews to Earth. Moreover, the legacy of these advancements, and the culture of research and innovation that led to them, continues to have an impact on space technology and exploration programs today.

An historical account of a few of these important endeavors underscores the importance of early research and development in enabling the success of complex system development programs and missions.

Fundamental Research and Development

Pilotless Aircraft Research Division (PARD)

Following the Second World War, it became evident that a transition from aviation to aerospace research was needed to push the speed of powered flight higher and eventually reach space. NACA researchers turned their attention to the high-speed frontier and solved many of the basic problems that were inhibiting the flight of aircraft at supersonic speeds. This research led to development of several experimental high-speed research airplanes including Bell's X-1, the first plane to break the sound barrier, and the North American's X-15, the first winged aircraft to fly into space.[4]

The leaders of NACA went even further beyond supersonic flight to explore the possibilities of high-speed guided missiles and spaceflight. To provide a focus for this important work, the LMAL established the Pilotless Aircraft Research Division (PARD) around 1945.[5] Leadership of PARD was entrusted to LMAL engineer Robert Gilruth, who would later become a key figure in Project Mercury and the establishment of NASA's early human spaceflight programs. The mission of the PARD was to solve the fundamental challenges of aerodynamics, materials, guidance, navigation, control, and flight testing for high-speed aerospace vehicles.

By early 1958, when the United States was preoccupied with responding to the first Sputnik flights, historical records show that approximately 55 percent of all NACA activity was already applicable to space flight. According to another set of NACA statistics, the PARD was conducting 90 percent of its efforts on space and missile research by this time. Research advancements by the PARD continued during the transition from NACA to NASA in July 1958 when U.S. President Dwight D. Eisenhower signed the Space Act that authorized the creation of NASA. On October 1, 1958, the authorization went into effect and most of the NACA employees working at the LMAL transitioned to NASA where the work largely continued under the banner of the new agency.[6]

<u>Establishment of Wallops Island Facility</u>

A significant lasting legacy of the PARD came from the establishment of the Pilotless Aircraft Research Station on Wallops Island, located on the Eastern Shore of Virginia. PARD Chief Robert Gilruth established the Wallops Facility (today known as the Wallops Flight Facility) as a launch test facility under Langley management to compliment the ground test work of the PARD.[5] The Wallops station was a convenient rural location to conduct flight tests that would advance the use of rockets to understand high-speed flight. In particular, flight testing at Wallops advanced critical knowledge in rocket design and flight operations. The knowledge acquired from this work also played a key role in the development of the Mercury space capsule.

In 1945, the first test vehicle was launched as a two-stage rocket.[2] Between 1947 and 1949, at least 386 rockets were launched from Wallops, leading to the publication of the NACA's first technical report on rocketry, "Aerodynamic Problems of Guided Missiles". As historian James R. Hansen wrote, "The early years of the rocket-model program at Wallops (1945-1951) showed that Langley was able to tackle an enormously difficult new field of research with innovation and imagination."[5]

In 1952, PARD started the development of multistage hypersonic solid-fuel rockets. These vehicles were used primarily in aerodynamic heating tests at first and were then oriented towards a reentry physics research program. The latter was important to developing orbital satellites and re-entry systems to return from space.

On October 14, 1954, the first American four-stage rocket was launched by the PARD, and in August 1956 it launched a five-stage, solid-fuel rocket test vehicle, the world's first, that reached a speed of Mach 15.[5] Over the years the PARD specialists had perfected their techniques of launch, guidance, automatic control, and telemetry on small rockets, and had steadily added to the mountain of experimental data on hypersonic flight performance and aerodynamic heating.[6]

The four-stage and five-stage solid rocket systems later developed into the Scout program. These rockets were the first systems that could fire stages sequentially to place a small satellite into orbit.[6] The Scout Project Office opened in March 1960 and the first launch of Scout was in July 1960.[2] The Scout Project actually continued through the 1960s and beyond, and on Jan. 1, 1991, management of the Scout Project was transferred to NASA's Goddard Space Flight Center.[7] The focus of the Pilotless Aircraft Research Station expanded to include studies of airplane designs at supersonic flight and gathering information on flight at hypersonic speeds. These tests included aircraft and missile designs from a variety of organizations and corporations.

Figure 2. *Scout launch vehicle lift off on Wallops Island in 1965.*

Hypersonics Research

In parallel to the work of the PARD, a key focus area at the LMAL by the early 1950s was research in hypersonic flight (approximately Mach 5 and greater). Vehicles in this speed regime are characterized by special challenges in aerothermodynamics (a combination of aerodynamics and heating), materials, and control systems.

In keeping with the practice of ground testing as the foundation for fundamental research, noted Langley engineer John Becker proposed an 11-inch pilot tunnel in August 1945 which was intended to achieve Mach 7 test conditions. In November 1947, Becker's vision became reality when the 11-inch pilot tunnel operated at Mach 6.9. This marked the first operation of a hypersonic tunnel in the United States.[2] Langley engineer John Stack later proposed the Gas Dynamics Laboratory for a range of speed regimes from Mach 1.5 to 8.0 which was in operation by 1951. These facilities would form the nucleus of the early ground test capability needed to develop a working understanding of hypersonic flight that would later lead to the development of rockets and atmospheric re-entry systems needed to travel to space and return to Earth.

Figure 3. *Langley's Gas Dynamics Laboratory with multiple hypersonics test facilities.*

While ground testing was crucial to advance the fundamental understanding of flow physics, this approach is limited for hypersonic flight and must be combined with flight testing. The combination is key to developing a more complete understanding of design conditions and performance. Early recognition of this importance led to discussions on a hypersonic research airplane, which were underway by the early 1950s as a possible joint project between NASA and the U.S. Department of Defense (DoD). Eventually, the X-15 program was initiated as a joint NASA/DoD effort. By 1957, design of the X-15 was well underway and this historic research aircraft flew for the first time on June 8, 1958.[2] Overall, the X-15 flew a total of 169 total missions between 1959 and 1968.

It is notable that the 11-inch hypersonic testing at Langley was critical to fully realizing the goals of the X-15 flight test program. The legacy of the X-15 program included fundamental advancements in aerothermodynamics, structures, materials, trajectory, simulation, instrumentation, and control systems for hypersonic vehicles. By the summer of 1958, Langley was doing research to study transition from hypersonic flight to orbit which was necessary to developing an orbital satellite.[8]

Ballistic Entry Capsule Design

The fundamental work in hypersonics provided the foundation for one of the key early decisions in the quest to establish a human spaceflight program, specifically the selection of a re-entry vehicle concept. Early work by the PARD to understand re-entry flow physics laid the foundation for studies on different concepts which led to an early crucial decision that made the Apollo program possible. The choice was between a winged lifting-body vehicle and a non-lifting ballistic-type capsule.

PARD Chief Robert Gilruth favored the ballistic capsule approach. He wrote that, "Because of its great simplicity, the non-lifting, ballistic-type of vehicle was the front runner of all proposed manned satellites, in my judgment. The choice involved considerations of weight, launch vehicle, reentry body design, and to be honest, gut feelings."[5,6] While initially criticized as an inelegant, impractical solution to the challenge of human spaceflight, the ballistic concept gained momentum as NACA engineers, led by Gilruth and noted Langley figure Maxime Faget, studied the concept and obtained test data in LMAL facilities. At a meeting on human spaceflight held at Ames on March 18, 1958, the ballistic approach gained official support after reviewing the data from these early studies. This work led to NACA publishing a set of preliminary specifications for a ballistic capsule design in August 1958.[6]

In September 1958, a joint panel by NASA and the Advanced Research Projects Agency (an early United States Department of Defense organization) formally provided recommendations on design requirements to achieve the earliest practicable date for orbital flight and successful recovery of a manned satellite.[6] These recommendations specified that:

- The vehicle must be a ballistic capsule with high aerodynamic drag.
- Descent from orbit must be initiated by the application of retro-rocket thrust, parachutes would be deployed after the vehicle has been initially slowed by aerodynamic drag, and recovery would be on land or water.
- Structurally, the capsule must be designed to withstand any combination of acceleration, heat loads, and aerodynamic forces that might occur during boost and reentry of successful or aborted missions.

A launch abort system was added later to increase safety and reliability.

These preliminary specifications were eventually used to guide the industrial development for a ballistic capsule that would fly during project Mercury from 1961-1963. The basic capsule design was adopted by the Gemini and Apollo programs to return astronauts safely to Earth after the lunar missions.

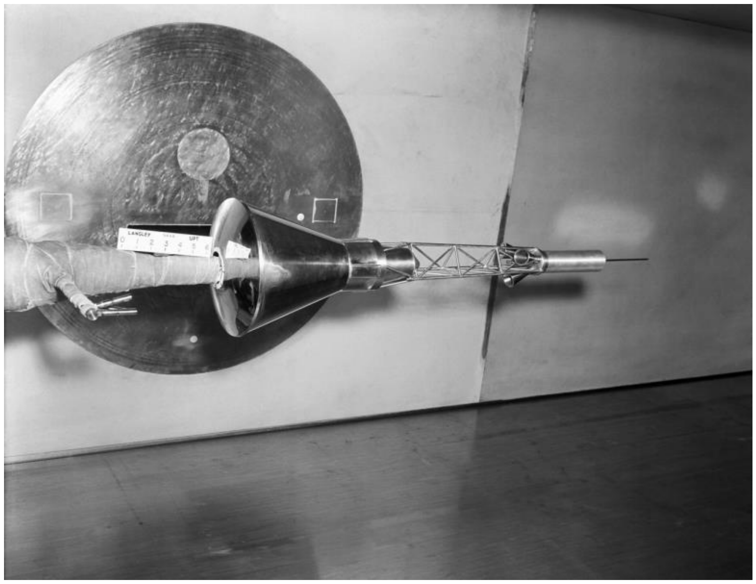

Figure 4. *A one-sixth scale model of the Mercury capsule being tested in the 7 x 10-foot wind tunnel.*

West Area Computing Group (The "*Hidden Figures*") [9]

Historical accounts of early space research and development would not be complete without mentioning some of the key people who made significa nt contributions. The Langley West Area Computing group deserves special mention not only for their technical accomplishments, but also for the significant social and cultural advancement they represented at the time in the United States.

Before the development of electronic computers, the term "computer" was an official NASA job title that referred to people who developed mathematical equations and performed calculations by hand. This role was crucial to ensuring the accuracy of complex analysis necessary to make early space missions successful. While the specific tasks varied, the majority of computing work involved three components: reading film, running calculations, and plotting data. All this work was done by hand, using slide rules, curves, magnifying glasses and basic calculating machines like the Marchant or the more popular Friedan, which could multiply and calculate square roots.

Langley first started hiring women as computers in 1935 and during the 1940s, NASA specifically began recruiting African-American women with college degrees to work as computers. During this time, racial segregation was the norm in the American southern states and in the United States military. Accordingly, the first African-American computers were grouped into a segregated section even though they did the same work as their white counterparts. This group of African-American computers was initially known as the West Area Computing Group, named after their geographic location in an area where the LMAL was expanding its facilities. One of the key figures was Katherine Johnson, who joined the West Computers in 1953 and went on to join the Space Task Group in 1958 where she calculated trajectories for Alan Shepherd and John Glenn's space flights.

A tremendous variety of research was done at Langley during the era of human computing, with computers playing a role in major projects ranging from World War II aircraft testing, to transonic and supersonic flight research and the early space program. This work required specialized knowledge, and Langley's computers devised computing methods and techniques specific to aeronautics and aerospace research.

Transition to NASA, the Space Task Group, and Project Mercury

NASA began operations on October 1, 1958. Just after this formal transition, NASA established the Space Task Group (STG) at the newly named NASA Langley Research Center. The initial nucleus of the STG consisted of 33 Langley staff members from the PARD.[6] While the STG was located at Langley, it operated as an autonomous group that reported to NASA Headquarters in Washington, DC. By July 1959, the STG had grown to 350 people.[1]

The legacy of the STG was to establish the Manned Spacecraft Center – later renamed the Lyndon B. Johnson Space Center – in Houston in 1961. The STG would be moved from Langley before mid-1962, however the technical work supporting the manned spaceflight program that was being done by others at Langley continued after the move.

Project Mercury

In December 1958, NASA officially announced the initiation of the first national manned space-flight project, Project Mercury. The goal of the project was to place a manned spacecraft in orbit around the Earth.[10] All of the PARD early research in high-speed flight, ballistic capsule design, and rocket launch, guidance, control, and telemetry transitioned to Project Mercury.[10] Langley was the initial home to Project Mercury, which was managed by the STG. By the summer of 1959, the more than 400 people assigned to the STG were conducting mission concept studies and beginning advanced engineering work that would eventually result in a successful human orbital flight.

In April 1959, selection of the first astronauts was announced and they became known as the "Mercury Seven." The astronauts were considered full working members of the STG at Langley and began their initial training there.[10] Langley engineers conducted graduate-level courses in re-entry physics, orbital mechanics, navigation, and other subjects. On a more practical level, the astronauts used several spaceflight simulation systems to familiarize themselves with the operation of the Mercury capsule.

The Mercury space capsule was extensively tested at Langley, including: wind tunnel testing from subsonic to supersonic speeds; rocket-launched models tested from Wallops Station; drop tests of the capsule; impact testing; instrumentation of flight test models; and piloted simulation.[1]

Figure 5. *A Mercury capsule in the Full Scale Tunnel in 1959 undergoing testing to assess low-speed performance and stability.*

Project Mercury successfully conducted the first suborbital flight on May 5, 1961, and the first orbital flight on February 20, 1962.

Little Joe Rocket Test Program

Among the most successful and crucial early contributors to the success of Project Mercury were the rocket test programs known as “Little Joe” and “Big Joe”. Early in the program, STG engineers conducted drop tests on boilerplate capsule test articles to assess the aerodynamics and dynamic stability of the capsule design in free fall. While these data were valuable, the need for comparable data in the powered phase became apparent and engineers needed to devise a flight test program. These experimental flight test programs were critical to gaining a thorough understanding of the performance of the Mercury crew module during launch and atmospheric re-entry.

Little Joe was a solid-fueled rocket, one of the earliest U.S. rocket systems based on the principle of clustered rocket systems. STG engineers developed a small booster that could allow for numerous test flights to qualify the range of various solutions to the many challenges associated with human space flight development. These included orbital insertion, capsule aerodynamics under re-entry conditions, and escape from a failure during launch or ascent. In order to allow for extensive flights, the booster system needed to be simple in concept and cost effective. The selection of solid-fueled rockets and systems that required no electronic guidance and control were critical to meeting this criterion.[6]

The first Little Joe test on March 21, 1959 was a failure but was followed by successful flights between October 1959 and January 1960. Little Joe rockets carried instrumented payloads to various altitudes to test the Mercury capsule and recovery systems. Little Joe was also used to carry Rhesus monkeys into space, one in December 1959 and another in January 1960, to provide data on how Mercury astronauts might react physically during subsequent flights.[6]

In order to gain a complete understanding of atmospheric re-entry performance, it was necessary to get to space and test the performance during a representative re-entry profile. The "Big Joe" test, launched on an Atlas D booster from Cape Canaveral, was conducted as a full-scale mockup of the proposed Mercury spacecraft design.[10] "Big Joe" was designed to conduct ballistic re-entry tests, including the aerodynamics of the capsule design as well as the performance of the ablative heat shield. Big Joe was successfully launched on September 9, 1959, the first launch of a spacecraft under Project Mercury. The flight data from Big Joe ultimately validated the Langley wind-tunnel tests and analytical predictions leading to the eventual suborbital and orbital Mercury flights.

Figure 6. *Little Joe test rocket on the launch pad at Wallops in 1960.*

<u>Mission Control Concept</u>

One of the largest, and most logistically challenging, efforts undertaken during Project Mercury was the task of establishing integrated spacecraft tracking and communications. The efforts at Langley during the initial phases of Mercury laid the foundation for the modern-day concept of "mission control."

The vision for the development of mission control was provided by Langley's Christopher C. Kraft, Jr. Kraft was one of the core team members of the STG, and as work began on the Mercury Program he was asked to investigate the challenges associated with supporting an astronaut orbiting the Earth, including the need to communicate with teams on the ground.[10] Project Mangers needed a global network of linked stations capable of receiving, processing, and reacting to voice, radar, and telemetry data while maintaining constant radio communications.

These mission control concepts were tested during the early suborbital test flights of Mercury capsules in the late 1960s, including Alan Shepard's Freedom 7 May 5, 1961, flight. They continued to evolve during the following orbital flights, including the November 1961 flight of Enos, the first chimpanzee to orbit the Earth. Enos' flight concluded the testing for human orbital flight which was achieved by John Glenn on February 20, 1962. During Glenn's flight the full tracking network was exercised for the first time, and they dealt with real-time technical issues with the spacecraft.[11]

Even as the STG began relocating from Hampton, Virginia, to the Manned Space Center in Houston as part of NASA's massive Apollo expansion, Kraft continued as flight director on every Mercury mission and helped design the new Mission Control Center. Kraft personally invented the mission planning and control processes required for crewed space missions, in areas as diverse as go/no-go decisions, space-to-ground communications, space tracking, real-time problem solving and crew recovery. As spaceflight missions continued to advance, and became longer in duration, he made key subordinates into flight directors on other shifts.

<u>Lunar-Orbit Rendezvous (LOR) Concept</u>[10]

One of the most significant decisions that enabled a successful lunar landing in 1969 was the decision to use the Lunar Orbit Rendezvous (LOR) concept for the Apollo missions. Although the decision to use LOR was made in 1962 after the Apollo program was underway, early studies enabled a thorough evaluation and comparison of LOR with other concepts.

Langley first established a Lunar Exploration Working Group in early 1959 to begin studying possible lunar mission concepts. In February 1959, NASA HQ established a "Working Group on Lunar and Planetary Studies Exploration." Many early studies recognized that flying a rocket – directly from the Earth to the Moon and back – might be impractical due to the need to carry all of the payload mass for Earth ascent, lunar landing and ascent, and Earth return on one massive rocket. To alleviate this challenge, some researchers and engineers began to study rendezvous of spacecraft in space as an alternative method. John Houbolt was a Langley engineer who began studying spacecraft rendezvous requirements in 1959. By the summer of 1959, Langley had established two space rendezvous study committees.

Many documented committees, studies, and reviews on space rendezvous, and the competing "direct ascent" method, took place throughout 1959 - 1961. An early study in 1959 began to look at the idea of a spacecraft in a "parking orbit" around the Moon during a landing mission. This became the basis of the lunar orbit rendezvous (LOR) concept. In 1960, Houbolt began to publish papers and provide briefings to various committees and senior officials on the LOR concept, thus becoming the most well-known champion of the LOR concept. The first documented briefing on LOR to NASA senior leadership took place in December 1960.

The basic concept of LOR was to launch the three required elements, the crew module (CM), the service module (SM), and the Lunar Excursion Module (LEM) into space with one rocket launch. The LEM is designed to descend and land on the lunar surface with the CM remaining in Lunar orbit. Following surface operations, an ascent module launches from the Moon and re-docks with the CM in Lunar orbit for Earth return.

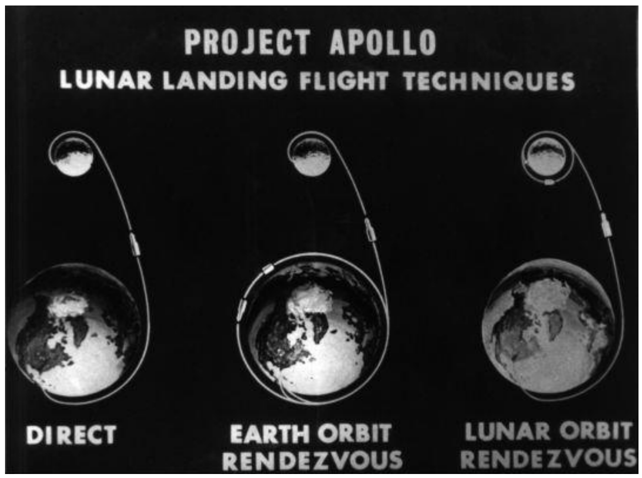

Figure 7. *Three principal lunar landing techniques which were proposed for the Apollo program.*

The idea of spacecraft rendezvous was thought by many to be an unacceptable risk. If the rendezvous failed, there was no chance for a rescue and the crew would be lost. A competing concept, known as Earth Orbit Rendezvous (EOR), was seen as a less risky option since the rendezvous would take place in Earth orbit. However, EOR would still require more payload mass than LOR, possibly requiring more than one launch.

The debate involving direct ascent, EOR, and LOR continued into 1961. LOR was dismissed by a NASA committee in 1961 as too risky. However, in late 1961, another NASA committee requested a study on LOR. Houbolt published an extensive two-volume report in October 1961 which was the culmination of his extensive studies, analyses, and risk mitigation options. Houbolt even famously appealed directly to the NASA associate administrator in November 1961 to argue for LOR, presenting the data he thought would address the concerns around risk, and show that LOR was the best practical solution for meeting the objectives of the Apollo program.

In February 1962, the STG endorsed LOR as the preferred concept. Werner von Braun, director of NASA's Marshall Space Flight Center, endorsed the concept in the Spring of 1962 even though many engineers at Marshall were proponents of EOR. The LOR decision was finalized by NASA in June 1962 and proved a critical decision in achieving the goal of human lunar landings by the end of the 1960s.

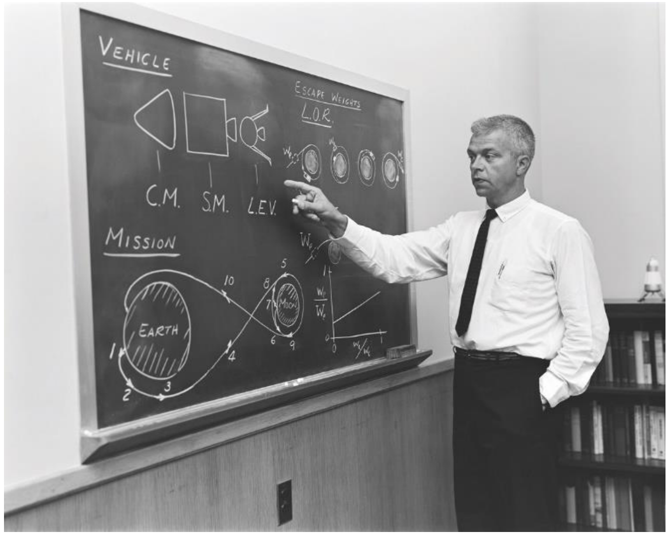

Figure 8. *Langley researcher Dr. John Houbolt describing the Lunar Orbit Rendezvous (LOR) concept.*

Lasting Legacies

The strongest legacies from early space research and development include the application of aerosciences, hypersonic, re-entry aerothermodynamics, systems analysis, ground and flight testing, and innovative concept development to NASA missions in the decades following Apollo.

Langley's expertise in wind-tunnel testing and aerodynamic performance was applied to the development of the Space Shuttle and, in the present era, to development of the Space Launch System (SLS) and the Orion crew module. Langley's expertise in atmospheric entry, descent, and landing (EDL) has been applied to many aerospace vehicles, including the Viking landings on Mars in 1976, the Space Shuttle, Orion, and current commercial concepts under development in the United States. Following the STS-107 Columbia accident in 2003, Langley's extensive capabilities in aerothermodynamic testing and analysis contributed to determining the cause of the accident and to establishing end-to-end debris analysis protocols crucial to a safe return-to-flight of the space shuttle and eventual completion of the International Space Station (ISS).

Langley's robust systems analysis capabilities have been applied to complex mission architectures, including the decisions necessary to meet the challenges of returning humans to surface of the Moon by 2024. Langley's systems engineering, ground testing, and flight test experience is being applied to develop the launch abort system (LAS) for the Orion crew module. The legacy of complex analysis and computations applied to space missions is captured in the recently dedicated Katherine G. Johnson Computational Research Facility.

The Lunar Lander Test Facility, used extensively in the Apollo era for crew training and simulations of lunar landings, was re-purposed in later years as the Landing and Impact Research (LandIR) Test Facility, providing the capability to test the crashworthiness of many different aircraft configurations. More recently, the LandIR has returned to use as a landing test facility for NASA's

Orion and American companies' commercial crew concepts, undergoing land and water impact testing to evaluate structural design models and impact loads.

Early research and development, including concept development, analysis, ground testing, and flight testing remain critical to future missions that will eventually extend a human presence beyond Earth orbit, create a sustainable human presence on the surface of the Moon and further enable the robotic and human exploration of Mars.

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