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QUEST

THE HISTORY OF SPACEFLIGHT QUARTERLY

Mercury

Apollo VIII Launch Control Operations

Gemini

Development of the X-15 at NACA Langley Aeronautical Laboratory

My Life as a NASA Flight Controller

John Tribe: Tales of a Rocket Engineer

Super Dyna-Soar: The USAF Dyna-Soar System Program Office In-House Proposal

Space Shuttle

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Mission control from the Mercury, Gemini, Apollo, and Space Shuttle programs. Credit: NASA

Chasing Theory to the Edge of Space:

The Development of the X-15 at NACA Langley Aeronautical Laboratory

By Robert C. Moyer and Mary E. Gainer

Most aerospace enthusiasts, if asked to identify the "home" of the X-15 research airplane on a map, would point to the high desert of California, where the operational phase of the X-15 program took place. Images of the sleek black rocket-plane thundering toward the edge of the atmosphere at hypersonic speeds above the Joshua trees and dry lake runways of Edwards Air Force Base are visually striking, and they tend to leave a lasting impression. Edwards AFB and the National Aeronautics and Space Administration's (NASA) Dryden Flight Research Center, then known as the National Advisory Committee for Aeronautics (NACA) High-Speed Flight Station (HSFS), are rightfully proud of their role in the setting of speed and altitude records during the X-15 program. Nevertheless, the design concept that became the X-15 was envisioned and refined, not at Edwards and the HSFS, but at another NACA facility over 2,000 miles to the east.

In the late 1940s and early 1950s, Langley Aeronautical Laboratory, known as the Langley Memorial Aeronautical Laboratory prior to 1948, in Hampton, Virginia, was the only U.S. aeronautical research facility capable of wind-tunnel tests at hypersonic speeds ("hypersonic" is defined as greater than Mach 5). Among Langley's facilities, the crown jewel was the 11-Inch Hypersonic Tunnel, designed and built by Langley personnel to test scale models at speeds in excess of Mach 6. After using their unique facility to determine that hypersonic flight was feasible from an aerodynamic standpoint, the Langley engineers who designed, built, and operated the 11-Inch Tunnel then developed a preliminary design for a hypersonic aircraft, refined the concept, and worked with the Department of Defense and industry on a rocket-powered flight test vehicle that would be known as the X-15. Although the project would ultimately require the efforts of every NACA/NASA aeronautical facility, Langley was the birthplace of the X-15, a vehicle that established design and operational precedents that were applied to subsequent NASA vehicles, including the Space Shuttle.

Langley Research Center's official involvement in what would be known as the X-15 program began on 10 July 1952, in the form of a memorandum from NACA Headquarters to Langley titled "Research on Space Flight and Associated Problems." The memo informed the Langley director of a 24 June 1952 resolution by the Committee on Aerodynamics to "increase its program dealing with problems of unmanned and manned flight…at altitudes between 12 and 50 miles, and at Mach numbers between 4 and 10" and to "devote a modest effort" to flight above 50 miles and greater than Mach 10. The developments leading to this resolution were also mentioned, including a recommendation from Robert J. Woods of Bell Aircraft on 30 January 1952 and a letter from the Air Force in June 1952 suggesting that hypersonic flight research be explored. The memorandum concluded with a request by author Milton B. Ames that Langley Aeronautical Laboratory "consider the research problems related to outer atmosphere and space flight in light of the foregoing information and resolution."[1]

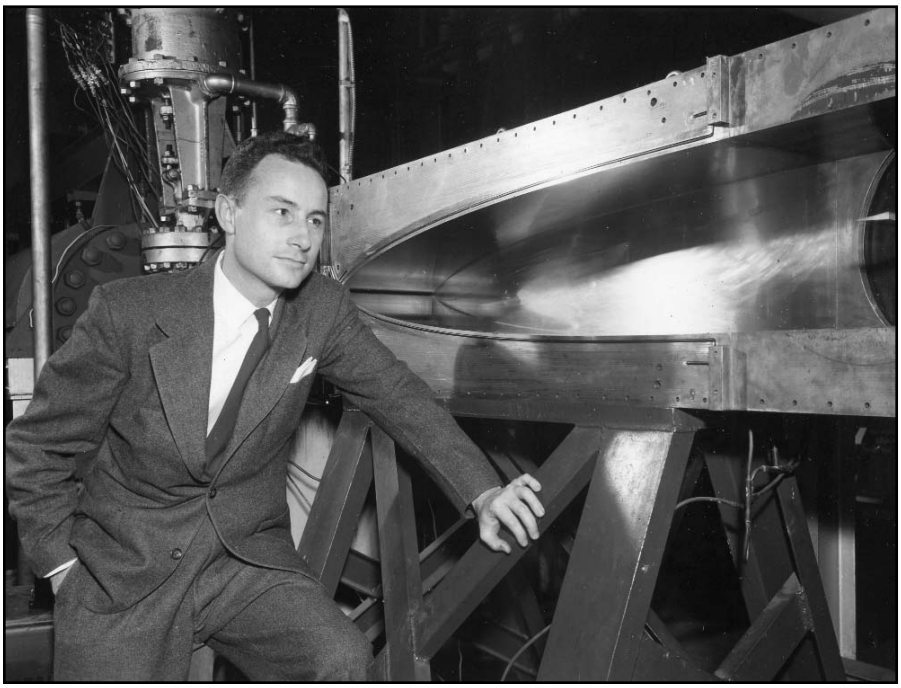
The interest in high-altitude hypersonic flight being shown by Woods and other employees at Bell Aircraft had already stimulated informal research at Langley before the NACA resolution of 1952, although the research in question focused more on issues of extreme altitude than hypersonic speeds. Under the direction of David G. Stone, members of the Stability and Control Branch of Langley's Pilotless Aircraft Research Division (PARD) began a preliminary study of the feasibility of a manned aircraft capable of traveling into space. In a report dated 21 May 1952, the study group established a practical definition of "space" for research purposes (namely, the altitude at which there were "no aerodynamic effects" on the vehicle) and determined that "an altitude near 300,000 feet (approximately 57 miles) may be considered equivalent to space as far as any aerodynamic effects are concerned." Based on this altitude, Stone's group felt that a Bell X-2 research aircraft would be "entirely feasible" if it were launched from a carrier aircraft and equipped with two JPL-4 "Sargeant" solid-fuel rocket boosters. The report did caution, however, that extrapolation of available flight data indicated that "X-2 static directional stability will be poor and the aerodynamic controls will be weak at Mach numbers greater than 2.0," and recommended that wind tunnel tests at speeds between Mach 2 and Mach 4 be conducted to examine the problem more fully.[2]

The PARD study group addressed the problem of controlling an aircraft in a region of flight where conventional aerodynamic control surfaces were useless and determined that low-thrust rockets mounted at the tail and wingtips could be used to control aircraft attitude above 300,000 feet. The group examined configurations involving both swiveling and fixed thrusters before determining that the fixed-thruster configuration was more fuel-efficient. Although the study's findings did acknowledge that atmospheric re-entry velocities would be "large," the group

was not expecting velocities above 4,000 feet per second (around Mach 4). As a result, the group calculated that aerodynamic heating would only cause an increase in aircraft surface temperature around 300 degrees F and decided that excessive structural loading due to acceleration during the recovery portion of re-entry was the most significant design challenge.[3]

In response to the July 1952 NACA memo, Langley Director Henry J. E. Reid commissioned an additional study group composed of three engineers from different divisions at Langley: Charles H. Zimmerman from Stability and Control, William J. O'Sullivan Jr. from PARD, and Clinton E. Brown from the Compressibility Research Division, who served as chairman for the group. Since hypersonic flight was identified as a goal in addition to flight outside the atmosphere, the group found that structural heating rather than acceleration-induced structural loads was the primary engineering problem. The Brown group accepted the idea of using a modified X-2 as a hypersonic research vehicle, but recommended several changes from Stone's report. The most noticeable of these changes was the elimination of strap-on boosters in favor of an internal rocket engine powerful enough to propel the vehicle at Mach 3.7. Due to the perceived difficulties of solving the thermal heating problem at higher velocities, the Brown group recommended that exploration of speeds in excess of Mach 4.5 should be conducted by unmanned missiles.[4]

The decision by Langley management to intentionally avoid specialists in thermodynamics or hypersonic flight when choosing members for the Brown study group has puzzled historians, especially in light of the fact that such specialists were readily available at Langley. Director Henry J. E. Reid and Assistant Director Floyd L. Thompson had taken this seemingly unorthodox approach in the hope that the group members would offer innovative long-term suggestions without being constrained by the current state of the art in hypersonic research.



The Langley 11-Inch Hypersonic Tunnel and its founder, John V. Becker. Both Becker and the 11-Inch Tunnel were instrumental in the development of the X-15. Credit: NASA

Unfortunately, this experiment in "thinking outside of the box" did not bear fruit. The Brown group's conclusions, which were conservative and offered little in the way of innovation, were particularly disappointing to Assistant Director Thompson, and would prove to be of little use to the engineers and scientists who designed the X-15.[5]

In February 1954, the NACA Interlaboratory Research Airplane Panel took another look at the hypersonic flight issue. As Langley engineer John Becker would later note, NACA "reached a definite conclusion: the exciting potentialities of rocket-boosted aircraft could not be realized without major advances in technology in all areas of aircraft design."[6] The Panel suggested that instead of using a modified X-2, NACA should "look into the possibility of obtaining a new research airplane having higher speed and altitude capabilities than present types." On 9 March 1954, NACA headquarters in Washington requested that the three NACA laboratories nationwide (Ames in California, Lewis in Ohio, and Langley in Virginia) as well as the High-Speed Flight Research Station at Edwards Air Force Base consider the research objectives and design requirements of such an airplane.[7] All four NACA research facilities established *ad-hoc* committees in response to this request.[8]

The engineers at Langley Aeronautical Laboratory had a significant advantage over the other NACA laboratories in the area of hypersonic research equipment. The 11-Inch Hypersonic Tunnel, attributed to John V. Becker and his hypersonic research program launched in 1945, was originally so secret it was identified only by the nondescript designator "Project 506" until 1950, when technical reports revealed the nature of the wind-tunnel research taking place at Langley.[9] The tunnel allowed research to be conducted at velocities up to Mach 6.86 through a square aperture with sides that were 11 inches in length.[10] Researchers at Langley began using the 11-Inch Hypersonic Tunnel in 1947 to verify recently developed hypersonic theories and to discover previously unknown hypersonic airflow phenomena such as shock-boundary layer inter-

action.[11] The tunnel equipped Langley engineers with the working knowledge and experience necessary to address the 1954 design request, and later served as the primary aerodynamic research tool during the development of the X-15.[12]

The Langley ad-hoc committee was composed of four engineers from different areas of specialization: Max A. Faget (propulsion), Thomas A. Toll (configuration, stability, and control), Norris F. Dow (structures and materials), and James B. Whitten (piloting). The group was chaired by John V. Becker, who had launched the hypersonic research program.[13] The group's primary objectives, which were established by Langley Associate Director Floyd L. Thompson with the assistance of John Stack, Robert Gilruth, and Hartley A. Soulé, directed the group to explore the feasibility of a research aircraft capable of at least Mach 5 velocities and maximum altitudes "above the sensible atmosphere" in order to explore alternate methods of attitude control in flight regimes where conventional aerodynamic control surfaces such as ailerons and rudders had virtually no airflow to deflect.[14] In a retrospective lecture about the X-15 program, Becker explained that although the idea of exploring hypersonic flight was met with approval throughout the aeronautical research community, the idea of flying to the fringes of space "was viewed in 1954 with what can best be described as cautious tolerance" by those outside of Langley who were familiar with the program.[15]

In addition to the formal objectives established for the Becker group, Floyd L. Thompson "provided a bit of philosophy" during a series of informal office chats with Becker that "strongly influenced" the direction taken by the study group. Thompson pointed out that "aero-thermal-structural considerations" created by air friction at hypersonic speeds would be the largest problem to be overcome by the new design, and that Becker's aim should be to "penetrate as deeply as possible into the region of high-aerodynamic heating and to seek fresh design approaches" instead of "makeshift modifications to conventional designs." At the same time, however, Thompson cautioned that the group should not "overreach the advanced state of the art in materials, propulsion, launch techniques, etc."[16] There was a good reason for this seeming contradiction. Thompson wanted the new aircraft to have "a procurement time on the order of 3 years," and suggested that Becker present his group's findings after an "intensive study" that would last only four weeks.[17]

Floyd L. Thompson's suggestion of haste, both in the development of the initial design concept and the production of the actual aircraft, was grounded in experience gained during his NACA tenure. The Bell X-2, predecessor to the X-15 and the fastest experimental aircraft at the time of Becker's 1954 study, had taken *ten years* to produce, which led some to complain that the X-2 was out of date before it began generating flight test data.[18] One of the most outspoken critics of the entire X-planes program was Clarence L. "Kelly" Johnson, the legendary designer of the Lockheed U-2 reconnaissance aircraft and founder of the "Skunk Works" division at Lockheed. Never a man to mince words, Johnson declared that military aircraft with superior performance had reached operational status and provided flight data before similar X-planes had made their first flight.[19] Later, when the NACA Committee on Aerodynamics formally considered the question of whether to proceed with development of the X-15, Johnson would cast the only dissenting vote.[20] Given the checkered past of the X-2 and the resistance of Kelly Johnson, any new X-plane would have to be built quickly and correctly if it were going to be built at all.

The Becker group took Floyd L. Thompson's advice to heart. The feasibility study was divided into five major areas, with each group member tackling the area that matched their specialization: Faget examined launch and propulsion; Dow worked on weights, materials and structures; Toll took configuration, stability, and control; and Whitten examined piloting issues. Becker assigned trajectories and aerodynamic heating, the most daunting engineering problem, to himself.[21] The group took aircraft heating limitations as the starting point from which the rest of the design concept was developed. A maximum skin temperature of 1,200 degrees F could be sustained by manufacturing the skin panels out of a high-temperature nickel-chromium alloy known as Inconel X, which would endure with only a slight loss in strength and stiffness. With a maximum sustainable skin temperature of 1,200 degrees, the Becker group determined that the aircraft could reach Mach 6.3 if it were dropped from a B-52 carrier aircraft at 35,000 feet.[22]

Skin panels made of Inconel X would not solve all of the heating issues that would be encountered by the new design. Becker's team determined that the lower surface of the aircraft would experience considerably higher skin temperatures than the upper surface, and the resulting temperature differential would change the camber (curvature) of the wing while at the same time causing the wings to flex upward by as much as 12 to 14 inches. The internal stresses created by in-flight wing deformation would be relieved by an internal structure of shear webs and trusses that would allow heat-related expansion while still providing structural support.[23]

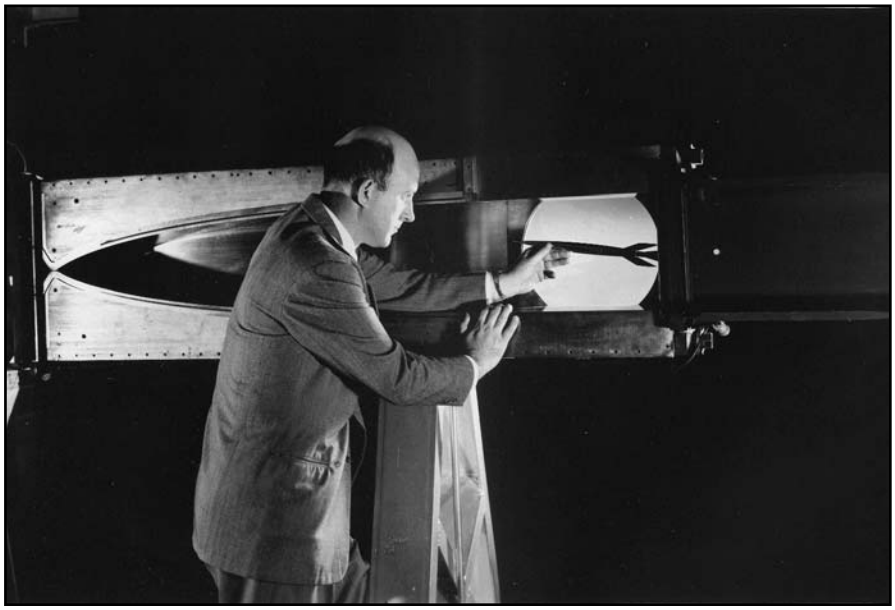
Although heating was the primary engineering problem, it was by no means the only serious issue that the Becker group had to examine. Thomas Toll's examination of configuration, stability, and control for the new aircraft was driven by an incident that had taken place just a few months earlier. On 14 December 1953, as Air Force test pilot Chuck Yeager flew the Bell X-1A to a maximum speed of Mach 2.44, the aircraft developed a series of lateral oscillations that steadily increased in severity under powered flight and became much worse when power was cut. Yeager lost control of the aircraft for a little over one minute, losing over 50,000 feet of altitude and finally recovering control only after the X-1A had slowed to below Mach 1 and

entered a spin from which a normal recovery could be executed. This phenomenon of high-speed oscillations would be encountered again in 1956 by the X-2, killing pilot Milburn Apt during a flight that reached Mach 3.196 and tragically validating the concerns expressed by the Stone research group at Langley in 1952.[24]

Examination of wind-tunnel data from the X-1A program revealed that the loss of stability at high speeds was caused by a decrease in the effectiveness of the aircraft's vertical stabilizer (tail) as airspeed increased during supersonic flight. The standard method of increasing stabilizer effectiveness was simple and direct—build a larger stabilizer. Toll's research revealed that if thin stabilizers such as those on the X-1A and X-2 were used, however, the stabilizer would have to be roughly the same size as one of the aircraft's wings in order to be effective. Obviously, a different solution was needed. The Becker study group approached several different research groups at Langley with the problem and asked for their suggestions.[25]

A Langley aeronautical engineer in Becker's line organization, named Charles McLellan, provided a novel solution. McLellan suggested discarding the thin stabilizer in favor of one with a wedge-shaped cross section, with the point of the wedge directed toward the nose of the aircraft. Testing in the 11-Inch Hypersonic Tunnel at Langley revealed that not only did a wedge-shaped stabilizer not lose effectiveness at high Mach numbers like a thin stabilizer, the effectiveness actually *increased* with higher airspeeds. McLellan's innovative solution ultimately resulted in a stable design and created one of the most visually distinctive features of the X-15 (McLellan would also be awarded a $1,000 bonus for his efforts.) In the Becker group's report, the suggested means of obtaining a wedge-shaped stabilizer was to start with a thin stabilizer and add a split-flap to the rear portion in order to create a variable wedge angle.[26]

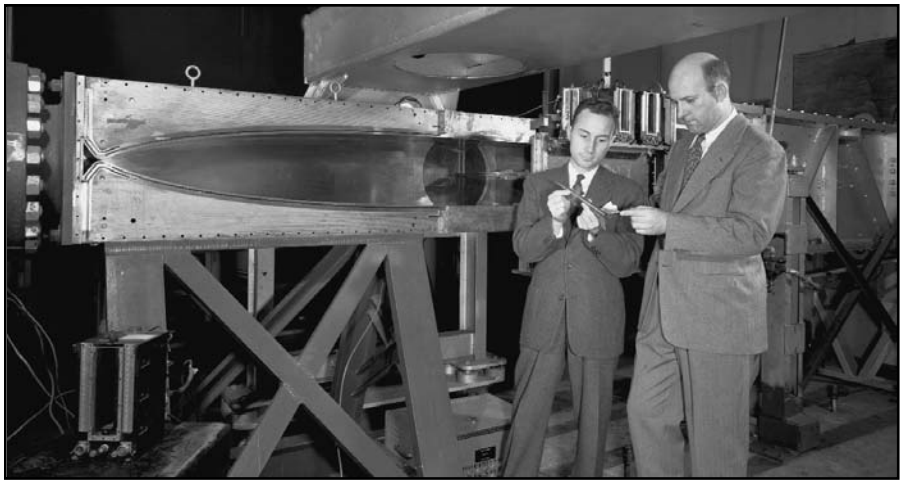
With a solution for the stabilizers in hand, Toll then examined the configuration of the tail itself. A conventional airplane tail, with horizontal stabilizers behind the wings and a single vertical stabilizer extending above the fuselage, would create serious stability and control issues. At high angles of attack, a single vertical stabilizer would become much less effective due to its position in the hypersonic wing-wake. Similarly, horizontal stabilizers in the same geometric plane as the wings could result in "undesirably large downwash gradients" during level flight at high speeds. The proposed solution was a distinctive "X-tail" with four stabilizers, each of which was oriented halfway between vertical and horizontal. Finally, Toll's examination of stability and control explored the problem of controlling the aircraft outside the atmosphere. As the Stone research group at PARD had suggested previously, the Becker group's report recommended the use of fixed hydrogen peroxide thrusters at the wingtips and tail.[27]



Langley engineer Charles McLellan at the Langley 11-Inch Hypersonic Tunnel. McLellan's wedge stabilizer for the X-15 solved the problem of "intertia coupling" that previous X-planes had encountered at high velocities. Credit: NASA

The Becker study group presented their "research airplane study" to Floyd L. Thompson on 22 April 1954, just a little over a month after the original request for input from NACA Headquarters. As John Becker later explained, "at this stage in the study, the vehicle concept itself was little more than an object of about the right general proportions and the right propulsive characteristics to achieve hypersonic performance." Although the vehicle concept proposed by Becker's team was based on sound engineering principles and the best available data, the only way to refine the concept into a design that could actually be built and flown would be to answer "questions of feasibility…firmly on the basis of research and analysis." In 1954, there was only one facility in existence that could conduct such research—the 11-Inch Hypersonic Tunnel at Langley.[28]

A team of aeronautical engineers consisting of David Fetterman, Jim A. Penland, and Herbert Ridyard immediately began working under the supervision of Charles McLellan at the 11-Inch Hypersonic Tunnel to refine the Becker group's concept.[29] The team worked with two scale models: a model of the airfoil (wing) design proposed by the Becker group and a model of the entire airplane that could test different tail and stabilizer configurations. Flow visualization tests of the airfoil model at Mach 6.86 revealed that the airflow behind



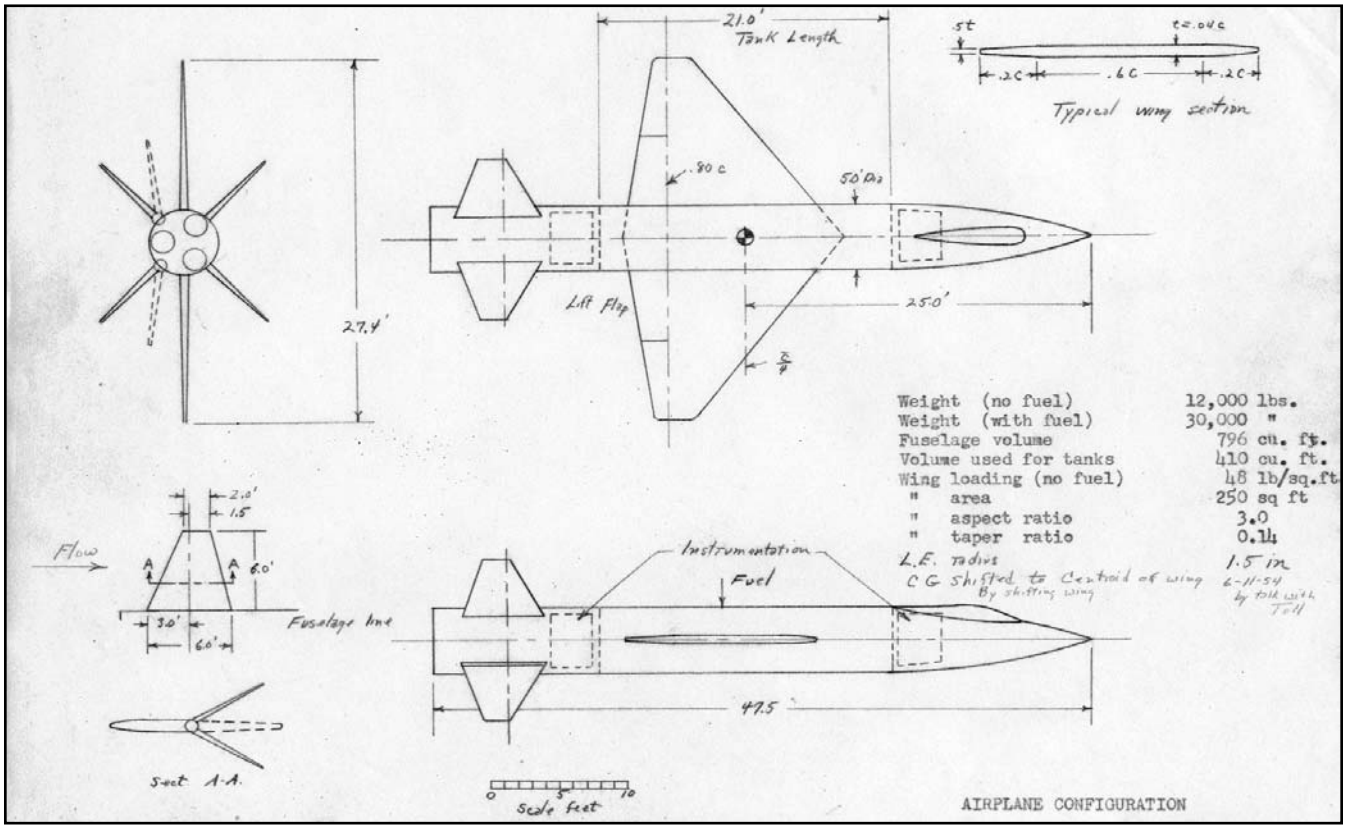
John Becker and Charles McLellan at the Langley 11-Inch Hypersonic Tunnel. Becker (left) developed the 11-Inch Tunnel and led the team that created the preliminary design for the X-15. Credit: NASA

the wing (the "wing-wake") consisted of distinct regions where dynamic pressure was either several times higher or lower than the dynamic pressure from the surrounding airflow. The 11-Inch Tunnel team learned from the airfoil tests that the lower two stabilizers of the "X-tail" should be located in a high-pressure region of the wing-wake while the upper two stabilizers should be in a low-pressure region, which resulted in a significant difference in effectiveness between the upper and lower stabilizers that increased as the aircraft's speed increased.[30] Testing of the aircraft scale-model confirmed that the X-tail would be unsuitable, and also confirmed that the Becker group's rejection of a conventional tail configuration with three stabilizers (two horizontal and one vertical) was correct. A "plus" tail configuration was also tested, but the team discovered that at high angles of attack the lower stabilizer penetrated into an area of high pressure (making it more effective) while the upper stabilizer did not. Consequently, a "stub-tail" configuration, with two horizontal stabilizers and a lower vertical stabilizer that was much shorter than the upper, was tested in the 11-Inch Tunnel and found to be the best solution.[31] The Fetterman/Penland/Ridyard team co-authored four NACA Research Memoranda (RM) with their conclusions and supporting data from the 11-Inch Tunnel tests, while their supervisor Charles McLellan published an additional NACA RM describing his wedge-tail stabilizer concept.[32]

While McLellan's team worked to refine the Becker study group's concept in the 11-Inch Hypersonic Tunnel, the Becker group's 22 April 1954 findings were received favorably at NACA Headquarters. The contents of the "Research Airplane Study" were incorporated into a report titled "NACA Views Concerning a New Research Airplane," which was presented at NACA Headquarters on 9 July 1954. Representatives from the Air Force and the Navy were in attendance, as Hartley Soulé and Walt Williams discussed the history of the NACA research airplane program to date, followed by a briefing by John Becker and John Duberg (who stood in for Norris Dow) on the Becker group's work at Langley. NACA's proposal was largely given a favorable reception by the attendees. The Navy representative, however, expressed a desire that operational military objectives be added to the purely research-related goals of the Becker study, a position that was opposed by USAF representative Clark Millikan. A NACA memorandum the following month lent support to Millikan's position by asserting that the limited availability of strategic elements that were used to manufacture Inconel X meant that the alloy was "obviously out of the question for airframe production in any quantity." The conference participants reached an agreement that the Air Force and Navy would review NACA's proposal for a new research airplane, while Hugh Dryden worked on getting approval from the Department of Defense.[33]

In the weeks following the July 9 conference, members of the U.S. aeronautical research community became aware of the Langley concept for a hypersonic research airplane. Several aircraft manufacturers sent representatives to Langley to learn more about the concept, such as R. J. Woods of Bell Aircraft. Woods, whose 1952 recommendation to NACA had been the impetus for the Becker study group's work, became a firm supporter of the project. NACA research advisory groups including the Subcommittee on High Speed Aerodynamics, the Committee on Aerodynamics, and the Committee on Aircraft Construction, added their endorsements to the proposal.[34]

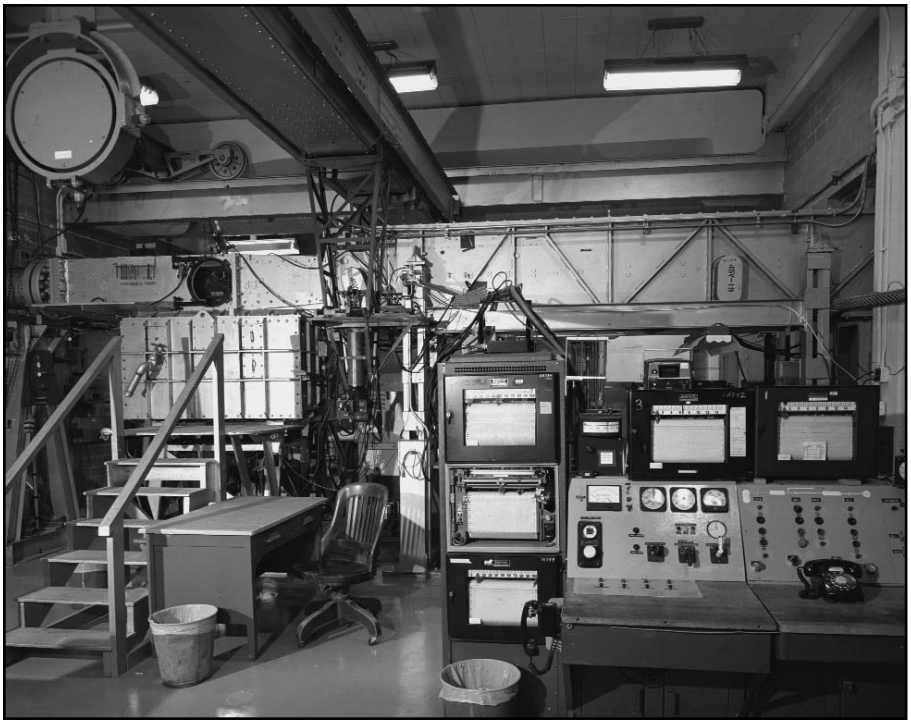
NACA representatives held meetings with USAF and Navy representatives on 31 August 1954 and again on 8 October, during which the three parties agreed to conduct a joint program to develop the new research airplane. Specifications suitable for presentation to contractors for the manufacture of the aircraft were also discussed. On 15 October, a preliminary outline specification for a high-altitude, high-speed research airplane was adopted. The outline called for general specifications, including only two major performance requirements—maximum speed of at least 6,600 feet per second and maximum altitude of at least 250,000 feet—in order to encourage innovation by manufacturers while remaining true to the Becker study. At the same time, the outline stipulated the availability of NACA facilities for "high Mach number wind tunnel and structural development work" that would be "essential to establish the final design of such a research airplane." The outline also included a six-page appendix titled "Suggested Means of Meeting General



The Becker study group's preliminary design for a hypersonic research aircraft. Note the "X-tail" (left) and the split-flap trailing edge that was used to create McLellan's wedge stabilizer (bottom left). This drawing was completed by Jim A. Penland, an aeronautical engineer at the 11-Inch Hypersonic Tunnel. Credit: NASA

Requirements" that was essentially a synopsis of the Becker study, including engineering drawings of details, such as the internal shear web and truss structure developed by the Becker team.[35]

During this same period, interest on the part of NACA, the Air Force, and the Navy was codified by two important legal documents that marked the official beginning of the X-15 project. The first of these documents was a resolution adopted by the NACA Committee on Aerodynamics on 5 October 1954 endorsing "the proposal of the immediate initiation of a project to design and construct a research airplane capable of achieving speeds of the order of Mach Number 7 and altitudes of several hundred thousand feet."[36] A few weeks later on 9 November 1954, the relationship between the Air Force, the Navy, and NACA was formalized through a Memorandum of Understanding (MoU) that originated with the Air Force and was circulated among all three parties for signatures. The MoU was a concise document, slightly over one page in length, whose stated purpose was to implement the recommendations stated



The Langley 11-Inch Hypersonic Tunnel, originally referred to only as "Project 506," generated laminar airflow at Mach 6.86 and was the cornerstone of the X-15 program. The test section and other observation window are at the top of the steps. Credit: NASA

in the 5 October 1954 NACA resolution. Technical direction for the research airplane project was assigned to the NACA director, who would be advised by a "research airplane committee" composed of one member from each of the three parties. Financing of the design and construction of the aircraft would be shared by the Navy and the Air Force, with the design and construction phase administered by the Air Force. Once the construction phase was complete, NACA would conduct flight tests and report the results. The manufacturer of the aircraft would be determined through a competitive bidding process, the basis of which would be "the characteristics determined by the configuration on which the NACA has already done much preliminary design work." The MoU was signed by all three parties between 9 November and 23 December 1954.[37]

On 30 December 1954, exactly one week after Hugh Dryden provided the final signature for the MoU on behalf of NACA, the Air Force sent letters to Bell, Boeing, Chance-Vought, Convair, Douglas, Grumman, Lockheed, Martin, McDonnell, North American, Northrop, and Republic, inviting them to submit bids. The letter informed the companies that a bidders' conference would be held on 18 January 1955 at Wright Field in Ohio, and asked that interested companies send a representative after notifying the procurement officer by 10 January. (NACA representatives were informed at the same conference that the project had been assigned the unclassified designator of "Air Force Project 1226" and the aircraft designation was X-15.) Of the twelve companies that were invited, nine chose to attend, and only four—Bell, Douglas, North American, and Republic—submitted proposals by the 9 May deadline. The attendees at the bidders' conference had been provided with refined specifications that retained the basic 6,600 fps velocity and 250,000 foot altitude requirements along with additional requirements including the allocation of 800 pounds, 40 cubic feet, and 2.25 kilowatts for research instruments, and a 30-month deadline for aircraft development and production. The attendees were also provided with prerelease copies of the NACA reports detailing the research that had been conducted at Langley based on the Becker study group's concept, including the work done by the Fetterman/Penland/Ridyard team in the 11-Inch Hypersonic Tunnel. Evaluation groups for NACA, the Air Force, and the Navy were given copies of the proposals and instructed to submit their results by 22 June.[38]

As chairman of the NACA evaluation group, Hartley Soulé decided to divide technical evaluation duties among the four major NACA laboratories, with some areas being assigned to more than one facility: Ames and Langley shared all of the four evaluation criteria listed under "basic aerodynamic design" with the High-Speed Flight Station at Edwards also sharing the fourth ("loads criteria"). Ames, Langley, and HSFS also shared evaluation responsibilities for stability and control. HSFS and Lewis shared responsibility for propulsion and miscellaneous systems. Only HSFS and Langley assumed sole responsibility, respectively, for any sections of the design evaluation criteria, with HSFS evaluating crew provisions, handling and launching, and Langley evaluating structures.[39] At the conclusion of the evaluation period, Langley engineers considered the North American proposal to be the best design, followed by Douglas, with the Bell and Republic designs "about equal."[40] After the input from the other NACA facilities was taken into account, the final NACA ranking was (1) North American, (2) Douglas, (3) Bell, and (4) Republic.[41] NACA, Air Force, and Navy evaluation teams met on 26-28 July 1955 at Wright Field to discuss their findings, ultimately selecting North American Aviation's proposal as the winning design.[42]

There was one minor hitch in this decision—North American had developed cold feet toward the X-15 project. On 23 August 1955, before the evaluation results were made known to the bidders, North American verbally informed the Air Force that the company wanted to withdraw from the competition. Although the Air Force asked North American to reconsider, the company sent a letter to the Air Force on 30 August formally withdrawing from the X-15 program. The vice president of North American later explained that this decision was made because the company had evaluated its position after winning two new military aircraft studies and increasing activity on the YF-107 fighter project and had concluded that North American could no longer meet a 30-month production deadline for the X-15. Unbeknownst to North American, the Research Airplane Committee had already recommended an extension of the production schedule of up to 18 months on 12 August. North American felt that an 8-month extension would be sufficient and retracted its letter of withdrawal after being notified on 30 September 1955 that the company's design had won the competition.[43]

Although the North American design closely resembled the concept that was proposed by the Becker team and refined by Charles McLellan's engineers in the 11-Inch Hypersonic Tunnel at Langley, the design team at North American added innovations of their own. The original X-15 design proposal from North American included "all moving" horizontal stabilizers based on earlier Langley flight research by Bob Gilruth, rather than the conventional arrangement of fixed stabilizers with moving control surfaces attached. The X-15's horizontal stabilizers could also rotate in either the same or opposite directions, controlling both pitch and roll. This "rolling tail" design allowed engineers to design the X-15's wings without ailerons, simplifying the structural design of the wing. A wing without ailerons eliminated the need for aileron hinges that would protrude below the lower surface of the wing and create potentially disastrous multiple hypersonic shock waves. Another feature of the North American design was a "full-monocoque" fuselage in which the aircraft skin also served as the side walls of the fuel and oxidizer tanks for the XLR-99 rocket engine that would

power the aircraft. This design required side fairings for the fuel and oxidizer lines that ran from the tanks to the engine, creating flared fuselage sides that are a visually distinctive aspect of the X-15.[44]

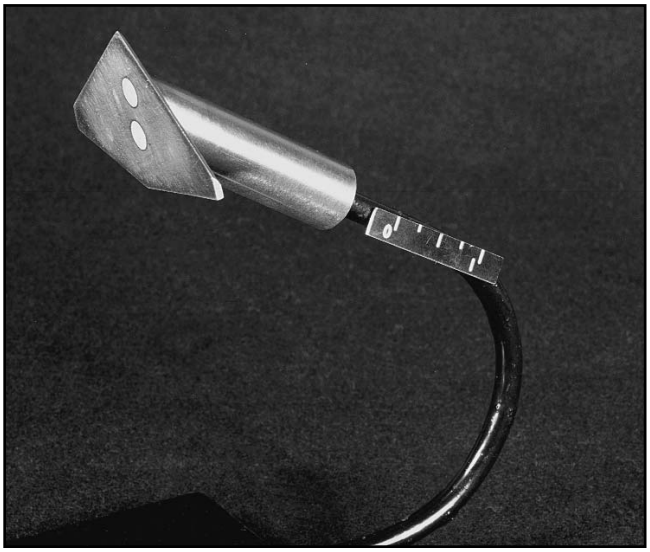
Once the manufacturer's preliminary design was approved, North American immediately accepted the offer to use NACA facilities that had been included in the original bidding specifications. North American designed several different X-15 models for testing at Ames and Langley, as well as their own facilities. Before the first X-15 was rolled out of the North American assembly plant in California, North American engineers and technicians built at least six different scale models, some with the direct assistance of Langley personnel. Additionally, NACA engineers and fabricators built several scale models in-house, including a free-flight model used in the Full Scale Tunnel. Langley facilities tested X-15 models at speeds ranging from the subsonic through Mach 1.15, 1.43, 3.0, 4.0, up to a maximum, hypersonic velocity of Mach 6.86. [45]

One aspect of the North American design that caused concern from the outset among engineers at Langley was the fuselage side-fairings, which extended forward to a point roughly four feet from the nose of the X-15. Testing in the 11-Inch Hypersonic Tunnel in March, 1956 revealed that extending the side-fairings so far forward altered the aircraft's center of pressure (the aerodynamic equivalent of center of gravity), causing "rather severe pitch-up tendencies." North American sent a "dummy" fuselage to Langley for further testing in the 11-Inch Tunnel, which indicated that moving the starting point of the side-fairings farther aft solved the problem. North American modified the X-15 design by moving the starting point of the fairings about eight feet rearward from the nose.[46]

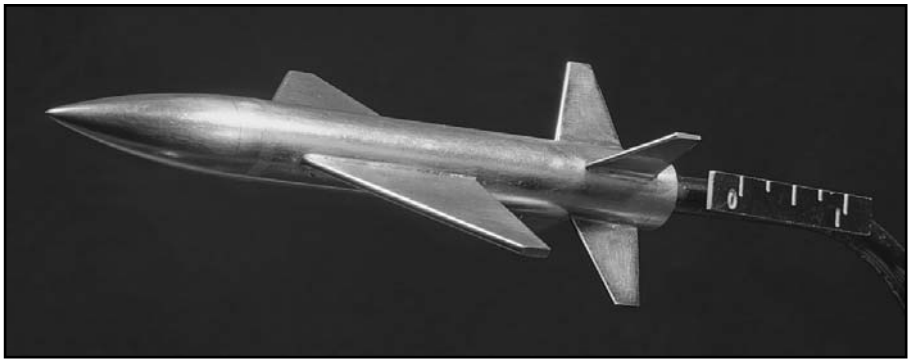
The tail of the North American design also was the focus of testing and modification. The Becker team's use of split flaps to create Charles McLellan's wedge stabilizer for control at hypersonic speeds was noted and utilized by the designers at North American, who discovered that the weight of the flap actuators changed the aircraft's center of gravity beyond design limits.[47] North American's response to this setback was to design a solid 10-degree wedge for the upper and lower vertical stabilizers, with speed brakes that opened vertically, clamshell-style, from the side-fairings on the fuselage. Testing at Langley revealed that the new tail design "still did not provide directional stability at maximum Mach number and…the speed brakes on the side fairings were very ineffective in addition to producing adverse effects on longitudinal stability."[48]

North American designers responded by rotating the speed brakes 90 degrees, placing them on the upper and lower vertical stabilizers and making them open horizontally instead of vertically, but Langley engineers felt that more improvements to the design were needed. A "NACA tail" was developed as an alternative to the "North American tail." The NACA tail had roughly 55 square feet of surface area compared to about 75 square feet for the North American tail. Although both designs still had upper and lower vertical stabilizers, the NACA ratio was roughly 60/40 between the length of the

Although the Langley 11-Inch Hypersonic tTnnel was displayed to visitors in later years, its existence was originally disguised by the non-designator "Project 506." When technical reports revealed that Langley engineers were conducting aeronautical testing at the unprecedented velocity of Mach 6.86, the existence of the tunnel was acknowledged by NACA. Credit: NASA



Two models based on the Becker group's design were tested—a scale model of the airfoil only (shown above) and a model of the entire airplane with interchangeable tail and stabilizer configurations. Credit: NASA



Along with the scale model of the airfoil alone, this scale model of the Becker group's design was tested in the Langley 11-Inch Hypersonic Tunnel. The model had an interchangeable tail and stabilizer sections that could be used to test a wide variety of configurations. Credit: NASA

upper and lower stabilizers versus about 55/45 for the North American design. As a result, the NACA design did not extend so far below the fuselage that it could strike the ground during landing (the North American solution to this problem was to jettison a portion of the stabilizer just before landing.) An informal design competition of sorts developed, as both designs were tested on a 1/50-scale model in the 11-Inch Hypersonic Tunnel at Mach 6.86 and in the 9-Inch Supersonic Tunnel at Mach 3. The Langley Stability Research Division also analyzed both designs. North American and Langley engineers met at Langley in early 1957 to review the results, ultimately agreeing that the data revealed the North American tail to be the better design.[49]

X-15 models were tested in Langley wind tunnels of various sizes and speeds including the Full-Scale Tunnel, 8-Foot Transonic Tunnel, 4 x 4-Foot Supersonic Pressure Tunnel, Unitary Tunnel, 20-Foot Spin Tunnel, 9-Inch Supersonic Tunnel, and the 11-Inch Hypersonic Tunnel, where the Becker team's concept had originally been tested and refined. Although the 11-Inch Hypersonic Tunnel may have been the heart of the X-15 program, Langley's other wind-tunnel facilities conducted design tests at lower speeds, making their own vital contributions to the program.

Free-flight tests in the Full-Scale Tunnel demonstrated that the low-speed stability and maneuvering characteristics of the rolling-tail were satisfactory, which gave North American confidence to proceed with the design.[50] Outdoor drop models were used by Don Hewes and Jim Hassell to gain an understanding in stability and control.[51] The aerodynamic characteristics of the X-15 at the critical moment of separation from the B-52 "mothership" were also investigated by Langley engineers. Research led by Joe Alford and Wayne McKinley working in both the High-Speed and Low-Speed 7 x 10-Foot Tunnels was critical to launching the X-15 from the B-52 safely.[52]

There were several other Langley research divisions that contributed to the development of the X-15. North American sent a wing assembly to the Langley Structures Research Division to test the structure under transient heating conditions.[53] PARD developed a plan to mount three full-size X-15 vertical stabilizers to a "Sargeant" rocket with three Nike boosters as a way to investigate the stabilizer design's susceptibility to skin-panel flutter at hypersonic speeds (the test was cancelled due to changes in the tail design.)[54] Langley's IBM 650 computer was used to generate trajectory calculations that were then used by the Stability Research Division to conduct control-motion studies for hypersonic speeds and altitudes beyond the atmosphere, along with atmospheric re-entry conditions.[55]

The Langley Flight Research Division built a longitudinal oscillations simulator "to determine how the pilot can function under the fluctuating accelerations likely to be encountered at burnout or during re-entry," and also built a five-degree-of-freedom analog simulator with programmed velocity, Mach number, and dynamic pressure. The five-degree-of-freedom simulator was "flown" through the burnout phase of high-altitude mission profiles to simulated altitudes of 180,000 feet by pilots including Joe Walker of HSFS and Scott Crossfield of North American, both of whom later flew the X-15. Pilots in the five-degree-of-freedom simulator dealt with thrust misalignment and changing trim, aerodynamic coefficients, and dynamic pressure, with and without control damping and with various speed-brake settings. The Langley Flight Research Division also used a "pitch chair" to study operation of the sidearm controller that was used to operate the reaction-control system thrusters that controlled aircraft attitude outside of the atmosphere.[56]

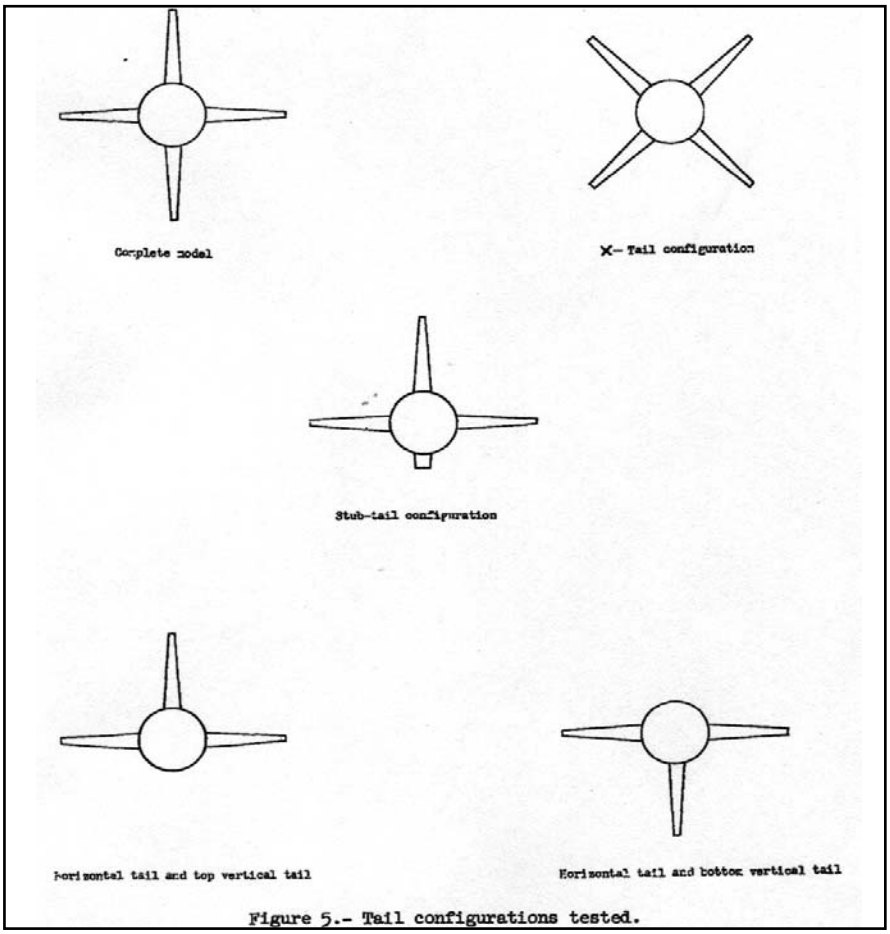
The Instrumentation Research Division (IRD) at Langley also contributed to X-15 development. When researchers and engineers expressed concern about the corrosive effects of ammonia (used as fuel for the XLR-99 rocket engine), IRD engineers tested thermocouple wires, an airspeed recorder, and other research instrumentation by subjecting them to a 50/50 mixture of room air and ammonia, at 50 percent humidity, for 360 hours to prove that the instrumentation could withstand ammonia exposure onboard the X-15.[57] The IRD also developed the specifications for the X-15's "stable platform" inertial system.[58]

If any component of the X-15 best represented Langley Aeronautical Laboratories as a whole, it was the pitot-pressure and flow-direction sensor, better known as the "ball nose" or "Q ball." The ball nose was designed to replace the conventional aircraft pitot-tube system that provided information about airflow speed and direction for the flight instruments, but which was not adequate for hypersonic airflow. The heart of the ball nose was a sphere of Inconel X with four orifices that

were placed at equal distances from the center point of the nose. Servos kept the sphere oriented so that pressures from all orifices were equal, providing a way to sense both the pressure and direction of the airflow. IRD developed the instrumentation system, and the design was tested in the 11-Inch Hypersonic Tunnel. Later, the Flight Research Center (formerly HSFS) at Edwards Air Force Base, California, developed a simple and direct method to test the ability of the ball nose to withstand the heat and pressure of hypersonic flight—the instrument was placed directly behind the engine of an F-100 Super Sabre with the afterburner lit.[59]

The first flight of the X-15 took place on 8 June 1959, 44 months after North American Aviation was informed that they had been awarded the contract to build the aircraft. Floyd L. Thompson's goal of a three-year procurement period had been missed by only eight months, a vast improvement over the X-2. The X-15 exceeded nearly every expectation envisioned in the Becker group's original concept. Three X-15 aircraft were flown by 12 pilots for a combined total of 199 missions over a 10-year period. At the end of that period, 11 pilots and two aircraft survived, an attrition rate that was unfortunate but quite good for an experimental flight-test program nevertheless. Flight milestones included a maximum altitude of 354,200 feet during a flight by NACA/NASA pilot Joseph A. Walker on 22 August 1963 (over 100,000 feet higher than the contract specifications established by the NACA), and a maximum airspeed of Mach 6.70 (4,520 mph) established by Major William J. "Pete" Knight, USAF, on 3 October 1967.[60]

Although the program did experience a handful of less serious mishaps, the only X-15 fatality took place on 15 November 1967, during the seventh X-15 flight of Major Michael J. Adams, USAF. As the aircraft approached a maximum altitude of 266,000 feet, it drifted slightly off the correct heading, a condition that worsened when Adams attempted a correction using the RCS thrusters. As the aircraft traveled through a ballistic arc and began to reenter the atmosphere, neither Adams nor his ground support team at Edwards realized that an initial yaw angle of 15 degrees had increased to 90 degrees, and his aircraft was literally coming back into the atmosphere sideways. At an altitude of 230,000 feet and a speed of Mach 5, Adams and X-15-3 entered the only hypersonic spin in the history of human flight. Although the aircraft did recover from the spin, the resulting aircraft gyrations created severe positive and negative g-loads that incapacitated Adams and destroyed the aircraft at an altitude somewhere above 60,000 feet.[61]



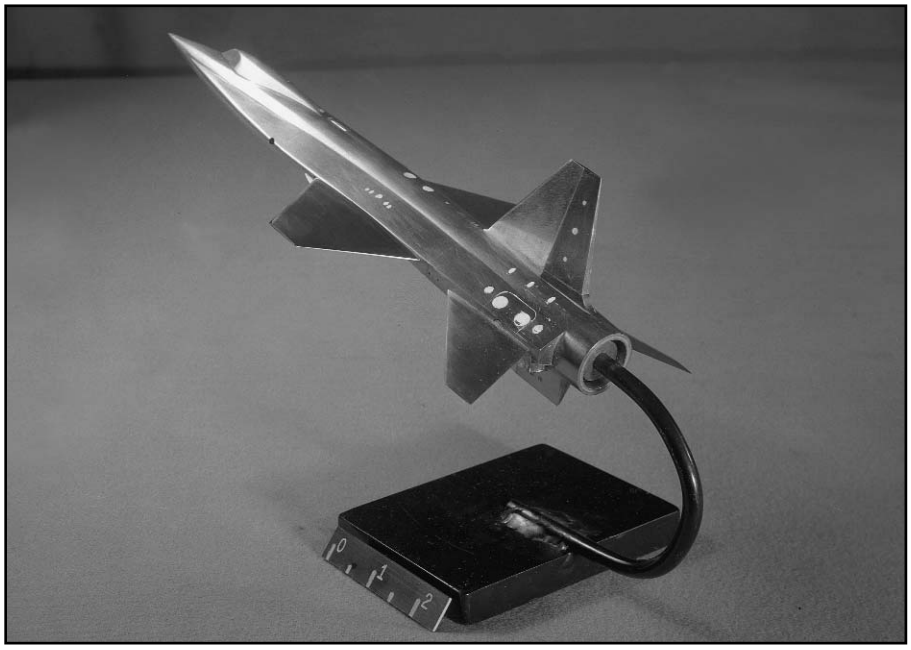
Under the direction of Charles McLellan, 11-Inch Hypersonic Tunnel engineers Jim Penland, Dave Fetterman, and Herbert Ridyard refined the Becker group's design, evaluating several different tail configurations. The original "X-tail" (top right) was abandoned in favor of the "stub tail" configuration (center). Credit: NASA

The accident review board found several factors that contributed to the crash including prior complaints of vertigo by Adams (not an uncommon condition among pilots during X-15 flights), a minor electrical disturbance in the adaptive flight-control system caused by one of the onboard scientific experiments, and the inability of the support team at Edwards to monitor the aircraft attitude via telemetry. The board made five recommendations, the last of which was perhaps the most telling: "X-15 aircraft when under ballistic conditions should have adequate and redundant means of permitting the pilot to maintain the proper heading, and the primary attitude indicators *should not be changed from their conventional functions* [italics mine]." The X-15 primary attitude indicator included vertical and horizontal deviation needles, identical in appearance to instrument landing system (ILS) approach deviation needles in conventional aircraft. In the X-15, the function of these needles could be changed by

pressing one of four switches, causing the same set of indicator needles to direct a pilot to fly the precise attitudes required by an onboard experiment package, or fly the equally precise but very different attitudes required to safely reenter the atmosphere. In Adams's case, the positions of four rather innocuous switches apparently caused his attitude indicator to direct him to fly an incorrect re-entry attitude that resulted in his death and the loss of his aircraft.[62]

The case could be made that the Mike Adams X-15 crash represented the first in a series of "failures of imagination" on the part of NASA, a phrase used by flight director Gene Kranz to describe the circumstances that led to the 1967 *Apollo 1* fire that claimed the lives of astronauts "Gus" Grissom, Ed White, and Roger Chaffee. The X-15 program was instrumental in the beginning of many institutional traditions for the fledgling National Aeronautics and Space Administration, which absorbed NACA before the end of the X-15 program. Despite the Adams crash, most of the traditions that resulted from the X-15 were not only positive but essential to the lofty goals that NASA would pursue in the years to come. Many key X-15 personnel form a "who's who" in America's human spaceflight program. Walt Williams, Max Faget, and Gerald Truszynski played key roles in the development of the X-15 program and later made significant contributions as managers in the Mercury, Gemini, and Apollo programs.[63] Two X-15 pilots blazed their own trails in the Astronaut Corps—Neil Armstrong, who left one of the most famous footprints in history, and Joe H. Engle, the only astronaut in the history of the Space Shuttle program to fly an orbiter *manually* through re-entry all the way from Mach 25 to touchdown.[64]

Many operational solutions and procedures that were pioneered and developed by NACA and NASA during the X-15 flight test program were readily adopted by Project Mercury and became part of NASA human spaceflight operations. The "High Range" tracking and telemetry network that stretched across California and Nevada to support X-15 missions served as the progenitor of similar networks that supported spaceflight operations in the 1960s and 1970s. The practice of using astronaut Capsule Communicators (CAPCOMs) to maintain voice communication with fellow astronauts during space operations can be directly traced to the use of X-15 pilots at the "NASA-1" console at Edwards to communicate with other X-15 pilots during flight operations. The extensive use of ground-based simulators to build pilot proficiency before and between X-15 flights can also be seen as a direct influence on astronaut training, as is evidenced by the many spaceflight simulators at NASA facilities across the country.[65]



This scale-model of North American's initial design was tested in North American and NACA wind tunnels—note the conventional tail and fuselage side-tunnels that extend far toward the aircraft nose. North American engineers would determine that the variable wedge-angle stabilizer created a weight issue and aeronautical testing by Langley engineers confirmed that the side-tunnels made the design less stable. Credit: NASA

Although plagued by cost overruns and delays in the development of the XLR-99 engine, the X-15 program was a phenomenal success. Among members of the public who know of the program, the general impression of the X-15 is that of a truly "cosmic" aircraft, a technological wonder that was decades ahead of its time. The X-15 was portrayed as a marvel of technological wizardry to an enamored American public in the early 1960s, a literal movie star with top billing over contemporary actors including Charles Bronson, Mary Tyler Moore, and Jimmy Stewart.[66]

As is often the case, those who designed and built the X-15 had a slightly different perspective. John Becker observed that because of the emphasis on keeping the X-15's design and procurement period as short as possible, "it was obviously impossible that the proposed aircraft be in any sense an optimum hypersonic configuration."[67] Becker asserted that instead the X-15 was designed "as a general tool for manned hypersonic flight research, able to penetrate the new regime briefly, safely, and without the burdens… imposed by operational requirements other than research."[68] The X-15 was a hypersonic workhorse whose brief forays into the realm of Mach 5+ velocities and extra-atmospheric flight pushed the aircraft to its operational limits. For an aircraft whose original development constraints included a short three-year procurement period and confinement to state-of-the-art materials and construction techniques, the

results were impressive. Those who designed and flew the X-15, whose knowledge went far beyond the superficial, understood the triumph of the design in light of its limitations. For many X-15 project members, that understanding was the basis of a love affair with the aircraft that lasts to this day. As was often the case with glamorous celebrities, the public's perception of the X-15 had little to do with reality. The aircraft's true beauty lay, not in "effortless" performance, but rather in the ability to reliably do the job for which it was designed, a job that could be done by no other aircraft in the world.

About the Authors

Robert C. Moyer received his B.A. in history from the University of Maryland University College in December 2011 and is preparing to begin work in Fall 2012 on a PhD in the history of science and technology. He is currently working as an intern in the Cultural Resources offices at NASA Langley Research Center. When he is not working on graduate school applications, Robert enjoys kayaking on the Chesapeake Bay and geocaching, a hobby that he describes as "the use of multimillion-dollar military satellite technology to find Tupperware hidden in the woods."

Mary E. Gainer has worked at the NASA Langley Research Center since May 1998 and is currently the Historic Preservation Officer for the Center. Prior to NASA, she taught geography and geology at Valdosta State University in Georgia and worked for the Environmental Office at Moody AFB. Ms. Gainer's degrees in biology and geography are from Valdosta State University and the University of South Florida where her emphasis was in GIS and wetlands development. When not working to preserve the history of NASA Langley, Ms. Gainer enjoys farming and restoring old houses.

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1 Milton B. Ames, Jr., Acting Assistant Director for Research, Headquarters, National Advisory Committee for Aerodynamics [henceforth: NACA], to Henry J. E. Reid, Director, Langley Aeronautical Laboratory [henceforth: LAL], 10 July 1952, Box 176, X-15 Project Correspondence, May 1955—October 1954, Entry 1—Project Correspondence Files, 1918-1978, Records of the National Aeronautics and Space Administration, Record Group 255 (RG 255), National Archives and Records Administration—Mid-Atlantic Region (Philadelphia) [henceforth: Box 176, Entry 1, RG 255, NARA—Mid-Atlantic (PHL)].

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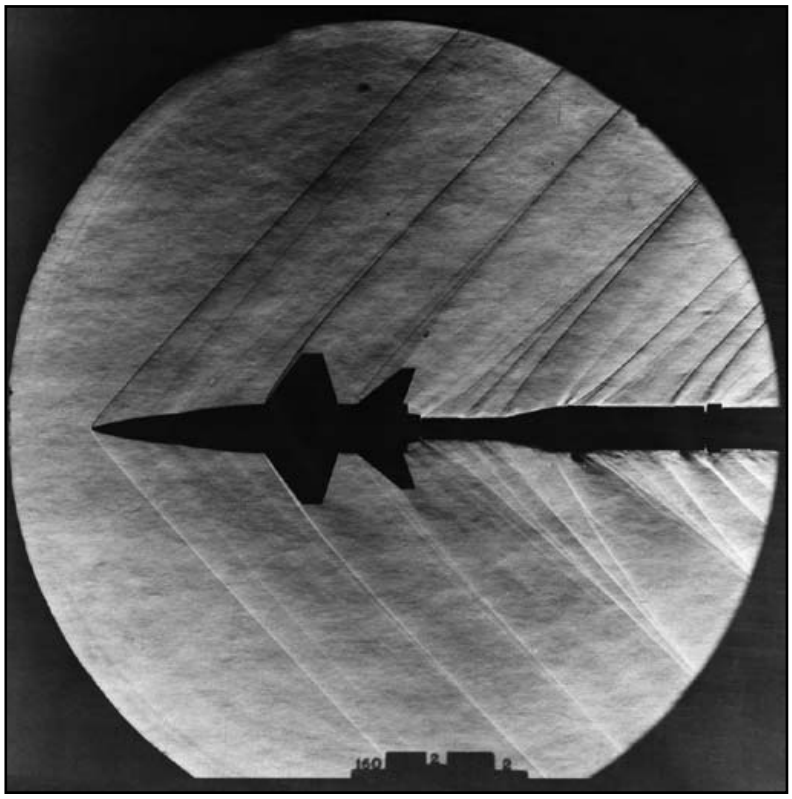
Scale model of the final X-15 configuration, mounted for testing in the Langley 11-Inch Hypersonic Tunnel. Project 506 would be used in every phase of the X-15's development. Credit: NASA



Although the 11-Inch Hypersonic Tunnel was the cornerstone of the X-15's development, numerous other Langley wind tunnels were also involved. This Schlieren image is from the Langley 4x4 Foot Supersonic Pressure Tunnel. Credit: NASA

NASA Langley Research Center, 8 [henceforth: Langley Staff, "Conception"].

15 Becker, "Retrospect."

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38 Jenkins, Extending, 59-60, 63; Henry J. E. Reid, Director, LAL, to E. M. Scholes, North American Aviation, 24 March 1955, Box 176, Entry 1, RG 255, NARA—Mid-Atlantic (PHL).

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X-15-2 is carried aloft by a B-52 in preparation for launch. After an air launch from 45,000 feet, the X-15 typically flew either an "altitude" mission that carried the aircraft outside the atmosphere on a ballistic arc or a "speed" mission at lower altitudes. Credit: NASA

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51 Donald E. Hewes and James L. Hassell Jr., "Subsonic Flight Tests of a 1/7-Scale Radio-Controlled Model of the North American X-15 Airplane With Particular Reference to High Angle-of-Attack Conditions" (NASA TM X-283, NASA Langley Research Center, June 1960), 1.

The X-15 first flew in 1959, beginning an operational career that spanned ten years and 199 flights. The aircraft set several speed and altitude records, some of which still stand today. Credit: Air Force

52 William J. Alford Jr. and Robert T. Taylor, "Aerodynamic Characteristics of the X-15/B-52 Combination," a paper in "Research Airplane Committee Report on Conference on the Progress of the X-15 Project" (Los Angeles, CA, 28-30 July 1958) 69-82.

53 Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for months of September and October 1956," 15 November 1956, Box 174, Entry 1, RG 255, NARA—Mid-Atlantic (PHL).

54 Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for month of March 1956," 10 April 1956, Box 175, Entry 1, RG 255, NARA—Mid-Atlantic (PHL); Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for months of November and December 1956," 17 January 1957, Box 174, Entry 1, RG 255, NARA—Mid-Atlantic (PHL); Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for months of January and February 1957," 19 March 1957, Box 174, Entry 1, RG 255, NARA—Mid-Atlantic (PHL).

55 Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for March 1956," 10 April 1956, Box 175, Entry 1, RG 255, NARA—Mid-Atlantic (PHL); Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for month of April 1956," 17 May 1956, Box 175, Entry 1, RG 255, NARA—Mid-Atlantic (PHL).

After earning astronaut wings in the X-15, Joe H. Engle (pictured here in front of X-15-2) joined the "conventional" astronaut corps. As commander of STS-2, Engle became the only astronaut in history to manually fly a Shuttle re-entry from start to finish. Credit: NASA

56 Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for month of May 1956," 7 June 1956, Box 175, Entry 1, RG 255, NARA—Mid-Atlantic (PHL); Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for month of August 1956," 18 September 1956, Box 174, Entry 1, RG 255, NARA—Mid-Atlantic (PHL); Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for months of September and October 1956," 15 November 1956, Box 174, Entry 1, RG 255, NARA—Mid-Atlantic (PHL).

57 Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report for month of February 1956," 13 March 1956, Box 175, Entry 1, RG 255, NARA—Mid-Atlantic (PHL).

58 Soulé to members of NACA Research Airplane Projects Panel, "Project 1226—Progress report from 1 June 1956 to 9 July 1956," 18 July 1956, Box 175, Entry 1, RG 255, NARA—Mid-Atlantic (PHL).

59 Soulé to members of NACA Research Airplane Projects Panel, "Project 1226 – Progress report for months of September and October 1956," 15 November 1956, Box 174, Entry 1, RG 255, NARA—Mid-Atlantic (PHL); Jenkins, *Extending*, 161-163.

60 Jenkins, *Extending*, 603-658.

61 Donald R. Bellman et al., "Investigation of the Crash of the X-15-3 Aircraft on November 15, 1967" (NASA/USAF report, Edwards Air Force Base, California, January 1968), 1.

62 Ibid., 2-3, 11-12, 16.

63 Jenkins, *Hypersonics*, 73-74.

64 NASA Johnson Space Center, "Astronaut Bio: Joe Henry Engle (06/2009)" http://www.jsc.nasa.gov/Bios/htmlbios/engle-jh.html (accessed 29 September 2011).

65 Jenkins, *Hypersonics*, 72-73.

66 See the 1961 movie *X-15*, http://www.imdb.com/title/tt0055627/.

67 Jenkins, *Extending*, 35.

68 Becker, "Retrospect."