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Chapter 18

AMERICAN ROCKET AIRCRAFT: PRECURSORS TO MANNED FLIGHT BEYOND THE ATMOSPHERE*

Richard P. Hallion†

Between 1946 and 1968, the United States flew a variety of supersonic and hypersonic rocket-propelled research aircraft. These aircraft included the Bell X-1 series, the Bell X-2, the Douglas D-558-2, and the North American X-15. At the beginning of this high-speed flight research program, scientists within the Federal government and private industry were concerned with "breaking" the Mach 1 "sound barrier;" in retrospect what appears to have been a modest goal, but what in fact gave aeronautical science its greatest challenge up to that time. By 1968, however, the first manned lunar flights lay just in the future, and scientists within industry and government now concerned themselves with the problems of winged reentry into the atmosphere from space at speeds on the order of Mach 20-25. A technological revolution had occurred within this twenty-odd year span in materials and the design of flight structures, in rocket engine development, in physiological research, in the state of high-speed aerodynamic and thermodynamic knowledge, and in the basic pattern of ground support, including telemetry, tracking, simulation, and research organization. In great part, the early American rocket aircraft paved the way for this revolution and helped create the technology base necessary to support manned flight beyond the atmosphere.

THE EARLY ROCKET RESEARCH AIRCRAFT

The American rocket research aircraft had their birth amid the scientific and engineering controversy surrounding the feasibility of flight faster than the speed of sound. As propeller-driven aircraft dive speeds increased beyond the 500 mph/Mach 0.7 mark, many conventionally designed aircraft encountered severe trim change and drag rise problems stemming from compressibility. In some cases, such as that of the Lockheed P-38 Lightning or the Hawker Typhoon, the rapid onset of transonic airflow over the wing led to creation of airflow-disturbing shock waves, lateral and longitudinal oscillations, tail Machbuffeting, and eventual structural breakup.

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Though some engineers and aerodynamicists dubbed the speed of sound a "sound barrier" beyond which no aircraft could safely pass, by 1944 a small body of scientists and engineers in the United States believed the "sound barrier" might really be little more than a steep hill requiring careful attention to design. This group included John Stack, Eastman Jacobs, Robert Gilruth, and George Lewis of the National Advisory Committee for Aeronautics (NACA); Maj. Ezra Kotcher of the Army Air Forces (AAF); Lt. Abraham Hyatt of the U.S. Marine Corps; Cmdr. Walter Diehl of the U.S. Navy; Robert Wolf, Robert Woods, and Robert Stanley of the Bell Aircraft Corporation; and L. Eugene Root of the Douglas Aircraft Company. All of these men recommended development of experimental manned aircraft to explore aircraft behavior and acquire aerodynamic information at speeds around Mach 1.[1]

At a series of conferences held in March and May 1944, NACA, AAF, Navy, and industry representatives agreed to sponsor development of special transonic and supersonic research airplanes. The Navy and NACA favored a conservative approach using a turbojet-powered airplane. The AAF supported a more radical rocket-propelled design capable of 800 mph performance at 35,000 feet. These desires led, respectively, to development of the turbojet-propelled D-558-1 Skystreak, and the turbojet-propelled XS-1. Douglas received a Navy contract for development of the D-558-1 on May 9, 1945. Two months earlier on March 16, 1945, Bell had received an Army contract to develop three XS-1's (later X-1) as Project MX-653.[2]

In late 1945, intrigued with the benefits promised by the sweptwing planform for high-speed flight, Bell and Douglas initiated design development of a supersonic sweptwing rocket-propelled research aircraft. The AAF sanctioned Bell's efforts on December 14, 1945, and on July 3, 1947 issued Bell a contract for two aircraft, designated XS-2 (later X-2) under project MX-743. Likewise interested in evaluating the sweptwing at supersonic speeds, the Navy turned to the Douglas Aircraft Company. Douglas engineers had studied possible turbojet-propelled sweptwing research aircraft based on the D-558-1 design as early as October 1945, but then had decided to design an entirely new airplane powered by a turbojet engine for takeoff and landing, and a rocket engine for high-speed supersonic studies. The Navy gave preliminary authorization for the project on January 19, 1946, and Douglas began developing the airplane under the designation D-558-2 Skyrocket. Both these aircraft, especially the X-2, contributed to studies of aircraft stability and control in a near-space environment. Additionally, the X-2 was the first airplane in which aerodynamic heating at supersonic speeds became a primary design consideration requiring use of special structural materials.

The Bell XS-1 design team consisted of engineers Robert Stanley, Benson Hamlin, Paul Emmons, Stanley Smith, and Roy Sandstrom. They completed detail design of the aircraft in the late summer of 1944. Bell finished the first XS-1 in December 1945. It was fabricated from 24 ST aluminum. The trim lines hid a complex internal structure that demanded the highest of design engineering. It could withstand 18g structural loads. Within the fuselage were two large propellant tanks, one for 311 gallons of liquid oxygen, the other for 293 gallons of a special 25% water and 75% ethyl alcohol fuel mixture. Since the original two XS-1's

(Figures 1 and 2) did not have turbopump fuel feed systems, they incorporated twelve separate nitrogen spheres to provide source pressure for supplying the propellants to the rocket engine. Gaseous nitrogen also provided cabin pressurization. The rocket engine was a Reaction Motors XLR-11-RM-3 (Model A6000C4) regeneratively cooled four-chamber motor capable of producing 6,000 lb. static thrust in 1,500 lb s.t. increments. The pilot could not throttle the engine, but he could fire each chamber separately or in conjunction with the others. The XLR-11 engine, America's first practical, safe, and reusable rocket aircraft engine, proved so reliable during subsequent flight research that it is still used today to power the Martin X-24B lifting body. The Bell design team selected inflight aerial launching from a converted Boeing B-29 Superfortress bomber for the XS-1, both to save propellants for high-speed flight research, and as a matter of safety. Thus, the XS-1 landed after propellant exhaustion like a high-speed glider.[3]

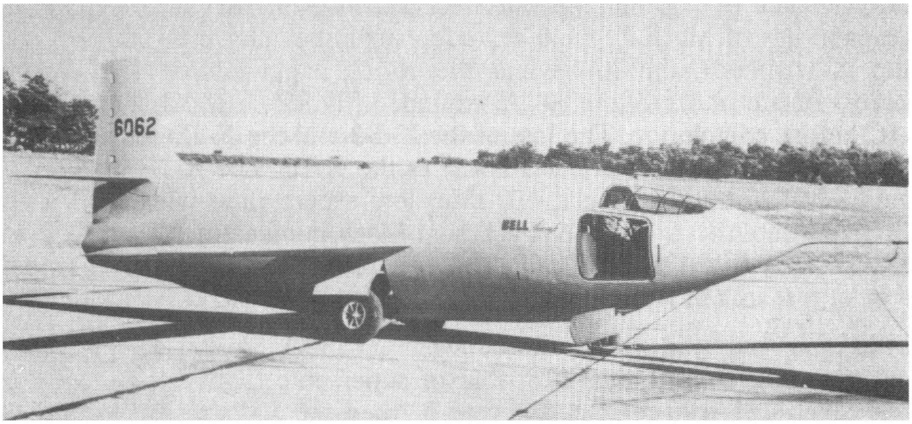

Figure 1 Bell X-1 research aircraft.

Figure 2 X-1 No. 2 (NASA photo no., Langley Facility-50).

The XS-1 design team originally planned to incorporate a turbopump low-pressure fuel feed system in the three XS-1 airplanes, but because of delays in turbopump design, this could not be done. The high-pressure nitrogen system necessitated that storage space which could have been utilized for propellants then housed nitrogen pressure bottles, with consequent penalties to engine burn time and maximum performance capability. Bell set aside the XS-1 #3 (later designated the X-1-3) for completion when a turbopump became available. This aircraft first flew in 1951. Though no different externally from the other XS-1's, its greater fuel capacity, 437 gallons of liquid oxygen and 498 gallons of water-ethyl alcohol, raised its estimated performance from Mach 1.45 to Mach 2.44. Pleased with the earlier two XS-1's, the Air Force Air Materiel Command ordered four new advanced X-1 models on April 2, 1948, under project MX-984. These aircraft, the X-1A, X-1B, X-1C, and X-1D, were longer than the original XS-1's, with revised cockpit and fuel systems. Equipped with turbopumps, the advanced X-1's could carry 500 gallons of liquid oxygen and 570 gallons of water-ethyl alcohol. This gave them maximum speed capabilities of Mach 2.5, and altitude capabilities above 90,000 feet. Two of the later X-1 aircraft, the X-1-3 and the X-1D, exploded in 1951, fortunately without loss of life. A third, the X-1A, exploded in 1955. The Air Force cancelled the X-1C before completion. The loss of the X-1-3 and the X-1D led the NACA to modify the old X-1 #2 (formerly XS-1 #2) as the X-1E. The X-1E featured a new turbopump fuel system, a special 4% thin, low aspect ratio wing, and a revised cockpit. These modifications gave it a design Mach number of 2.7, and a potential altitude capability in excess of 100,000 feet. These aircraft, the last X-1 type to fly, retired from research in April 1959.[4]

Little need be said about the Douglas D-558-1 Skystreak. This turbojet-powered low-wing aircraft was incapable of supersonic flight. It could fly in the transonic Mach 0.85-0.90 regime, and thus it freed the X-1's to explore the supersonic region more fully than they might have done otherwise. Its powerplant consisted of an Allison J-35-A-11 turbojet rated at 5,000 lb s.t., fueled by 230 gallons of kerosene. It featured an airframe structure formed largely from high-strength 75S aluminum alloy frames covered by heavy magnesium sheeting. Douglas completed three D-558-1's; one crashed due to engine failure at low altitude, killing the pilot. The other two flew in Douglas and NACA flight research programs before their retirement in 1953.

The D-558 design team consisted of Edward Heinemann, L. Eugene Root, Leo Devlin, A. M. O. Smith (one of the original pre-war members of Caltech's GALCIT rocket research group), and Kermit Van Every. Early in 1946, team members designed the D-558-2 after assimilating sweptwing design data from American and captured German sources (Figures 3 and 4). The plane featured a 35 deg sweptwing, and a design load factor of 12g. Like the D-558-1, its airframe consisted of mixed aluminum and magnesium members. As originally designed, the D-558-2 had a Westinghouse J-34-WE-40 turbojet rated at 3,000 lb. s.t., fueled with 260 gallons of gasoline (unlike the D-558-1) for sustained flight, ground takeoff, and landing. It also had a Reaction Motors XLR-8-RM-5 (Model E6000C4) rocket engine; this engine was identical to the Air Force X-1's XLR-11, for XLR-8 was simply its Navy numerical designation. A turbopump fed the engine 170 gallons of liquid oxygen and 192 gallons of water-ethyl alcohol.[5]

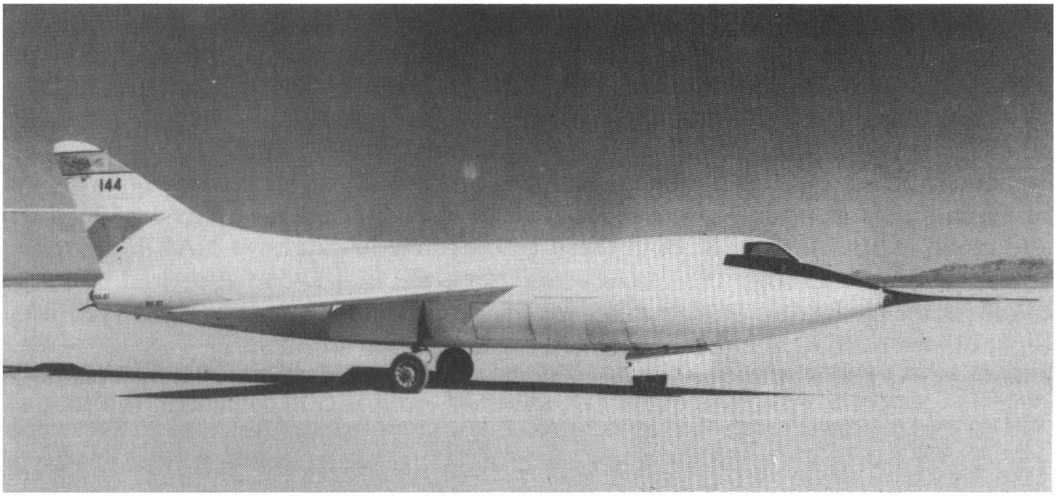

Figure 3 Douglas Skyrocket - rocket research aircraft.

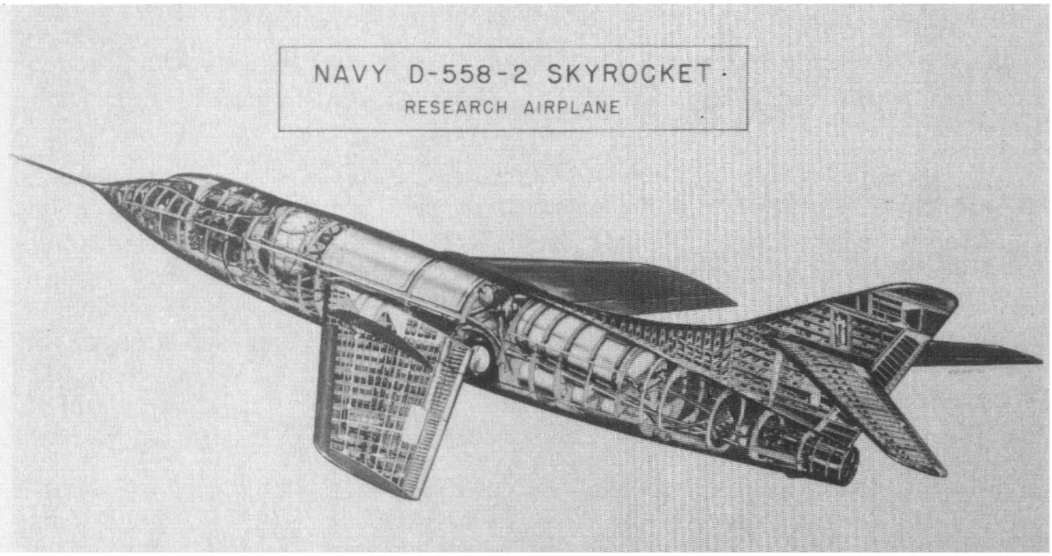

Figure 4 Drawing of interior of Douglas D-558-2 Skyrocket aircraft, 10 October 1951; also titled Douglas Skyrocket, phantom view (Douglas Aircraft Co. photo ES 84358).

From the outset, Douglas designed the D-558-2 for conventional ground takeoffs. However, during actual flight operations from the ground, the heavy fuel-laden Skyrockets exhibited potentially dangerous low-speed characteristics, especially if the turbojet engine should fail. Additionally, the pilot usually fired two of the chambers of the XLR-8 engine, thus reducing the rocket engine burn time for high-altitude high-Mach tests. Since air launching appeared a safer method of operation, especially after the loss of one of the D-558-1's after a ground takeoff, and since it guaranteed higher maximum performance, Douglas modified the second and third D-558-2's for air-launch operations from a Navy Boeing P2B-1S Superfortress (Figure 5). The company removed the J-34 turbojet from the D-558-2 #2, and converted this particular aircraft to all-rocket air-launch operation, approximately doubling its propellant capacity. The all-rocket D-558-2 #2 could carry 345 gallons of liquid oxygen and 378 gallons of water-ethyl alcohol, giving it a potential maximum performance of Mach 2, and altitude capabilities in excess of 80,000 feet. On November 20, 1953, this aircraft attained Mach 2.005, the first manned flight past Mach 2. Like the Bell X-1's, the D-558-2 #2 landed following its research flights as a high-speed glider. The third D-558-2 retained its J-34 engine, and could attain Mach 1.08. Both these aircraft flew in extensive NACA flight research programs through 1956. NACA modified the first D-558-2, retired in 1951, to all-rocket air-launch configuration in 1955, but this aircraft only completed one flight before NACA canceled its planned flight research schedule.[6]

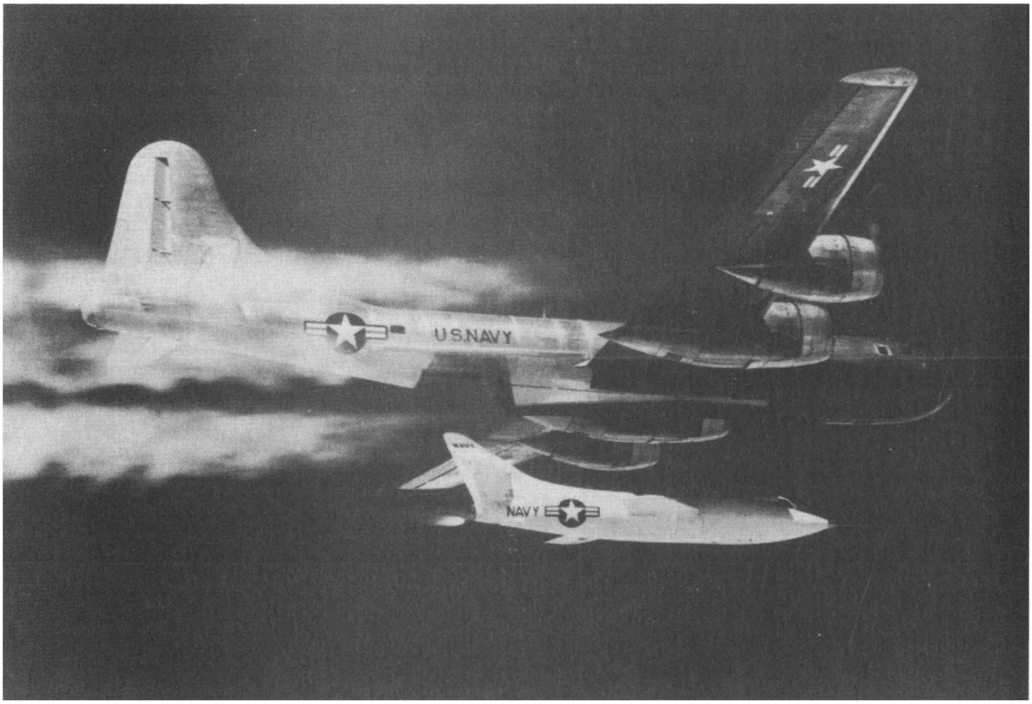

Figure 5 Launch of the Douglas Skyrocket aircraft.

The Bell X-2 design team, consisting of Robert Stanley, Paul Emmons, Stanley Smith, and Robert Lapp, developed the X-2 specifically as a rocket-propelled air-launch research airplane from the outset. In an attempt to gain every possible bit of performance from the plane, Bell designed the X-2 without a conventional landing gear. The X-1's and the D-558's all had retractable tricycle landing gears with wheels. The X-2, on the other hand, had simply a retractable nosewheel, a fuselage landing skid, and two wingtip "whisker" skids. The plane had a two-chamber Curtiss-Wright XLR-25-CW-1 regeneratively cooled rocket engine, fueled by liquid oxygen and water-ethyl alcohol. This engine is historically significant to manned space flight, for it was the first throttleable rocket engine installed on an American rocket research airplane. The engine consisted of two thrust chambers, each of which could be throttled from 50% to 100% of its thrust capability. One large chamber furnished 10,000 lb s.t., and the other, smaller engine produced 5,000 lb s.t. This engine was a direct descendant of a throttleable rocket engine design produced by Robert H. Goddard; shortly before his death in August 1945, Goddard had made arrangements to join Curtiss-Wright and continue this research program.[7]

Bell's advanced thinking on this program is very evident. The X-2 design team configured the airplane for Mach 3 flight speeds at altitudes of 70,000 to 80,000 feet, with a maximum high-altitude powered climb capability of 206,000 feet. Both the speed and altitude capability represented roughly a 300% increase over existing aircraft performance at that time. With the X-2, some problems of high-speed high-altitude flight assumed major importance. There was the problem of pilot safety. Bell's design team developed a special jettisonable nose capsule whereby the pilot could jettison the X-2's nose at high speed in the event of an emergency. A drogue parachute would slow the capsule down, and at lower altitudes and subsonic speeds, the pilot could then execute a normal bailout, descending on his personal parachute while the capsule fell to destruction. The Air Force went so far as to fire a V-2 with a specially instrumented full-scale X-2 nose capsule, the "Blossom III" test. Interestingly, this idea of a two-state bailout cropped up briefly during early Project Mercury reentry and recovery discussions.[8]

An 1,800 psi tank pressurized the cabin of the X-2 with an air atmosphere. In contrast, the earlier X-1 series used a nitrogen cabin atmosphere, and the pilot breathed oxygen during the entire flight. In one case this nitrogen system almost led to loss of the aircraft when a pilot of the X-1 #1 inadvertently plugged his oxygen mask system into a nitrogen outlet while in flight. Theoretically, the X-2 pilot could breathe the cabin atmosphere; in practice he breathed pure oxygen from the moment he entered the research airplanes from the launch aircraft, until he landed after completing his research mission. If it became necessary for the pilot to abandon the airplane via the emergency capsule at high altitudes, he depended for survival on his T-1 partial-pressure suit.[9]

Because of its speed capabilities, the X-2 (Figure 6) was the first rocket airplane for which the designers had to face the problem of aerodynamic heating. During its Mach 3 excursions, Bell engineers estimated that the X-2 could encounter temperatures up to 750 deg Fahrenheit. It thus became the first airplane designed to penetrate the so-called "Thermal Thicket." Bell engineers selected a copper-nickel alloy for the structure, K-Monel, to withstand the effects of aerodynamic heating. Elsewhere, the plane made extensive use of stainless steel. Strangely, considering the potential altitude capability of the X-2, Bell did not foresee the need to incorporate some sort of reaction control system to maintain aircraft attitude while the aircraft operated at high altitudes in regions of low dynamic pressure. This could have had extremely serious implications during the

X-2's record altitude flight to 126,200 feet in September 1956. At one point NACA considered installing a reaction control system on board the X-2, and did, in fact, install such a prototype system on the Bell X-1B.[10]

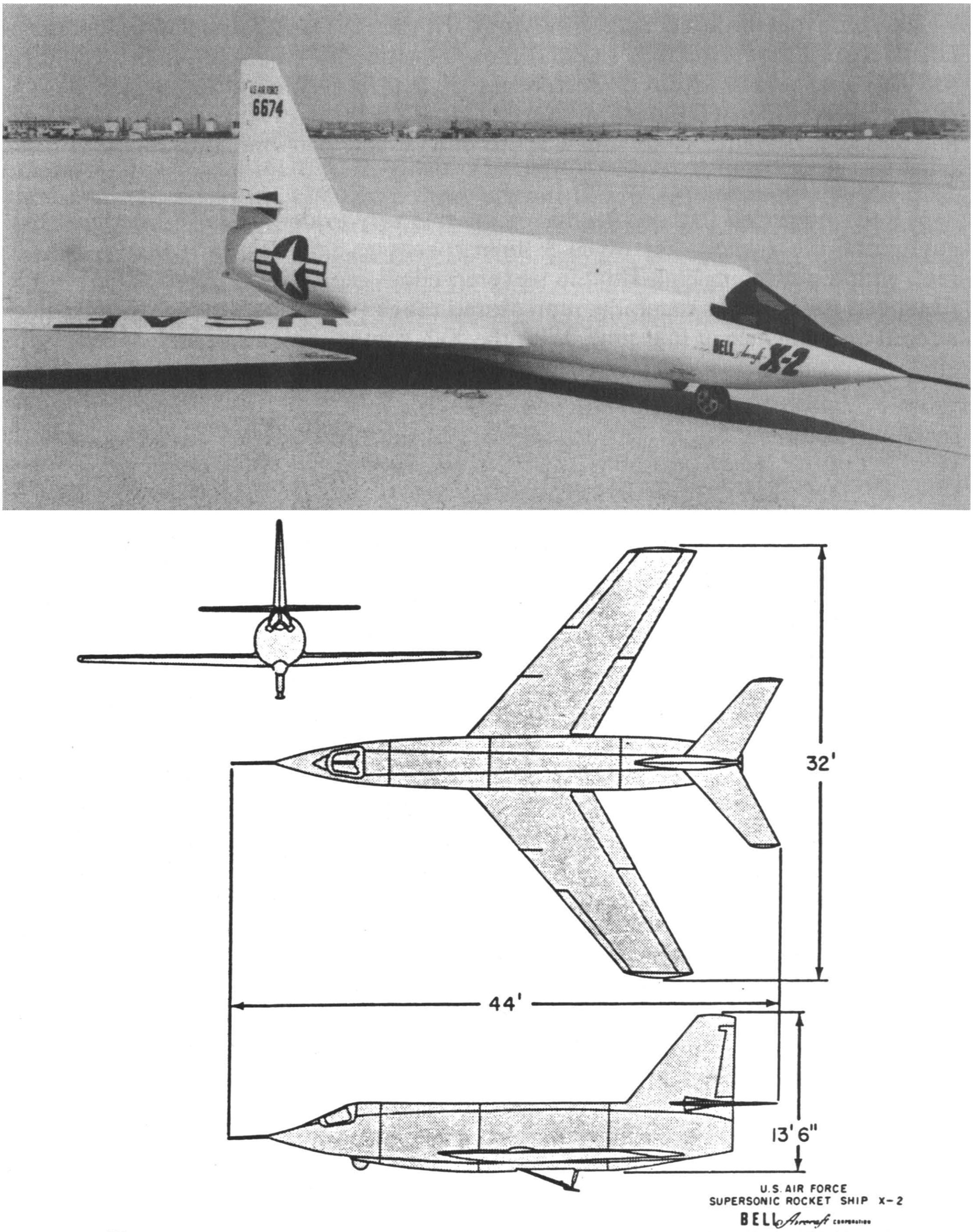

Figure 6 Bell X-2 rocket research aircraft.

TOWARD HIGH-ALTITUDE HYPERSONIC FLIGHT: 1947-1956

On October 14, 1947, the Bell XS-1 #1 fulfilled its research mission. That morning, at an altitude of 43,000 feet above California's Mojave Desert, Capt. Charles E. Yeager, USAF, became the first pilot to exceed the speed of sound, attaining Mach 1.06, approximately 700 mph. The XS-1 #1 ultimately attained a maximum speed of Mach 1.45 (957 mph) at 40,000 feet during flight tests in March 1948. Before its retirement in May 1950, it also made several altitude flights, in unsuccessful attempts to exceed the record altitude of 72,395 feet set by Capts. Orvil Anderson and A. W. Stevens in the balloon *Explorer II* on November 11, 1935. During these flights, the T-1 partial pressure suit proved its worth. The T-1 suit, based on the research of aeromedical pioneer Dr. James P. Henry, was an important forerunner of the modern full-pressure space suit. It consisted of a helmet with a neck seal and removable faceplate joined to a close-fitting nylon-cotton twill garment with inflatable capstans running down the sides, arms, and legs. It was an emergency "get me down" suit offering six minutes protection. On August 25, 1949, during a flight by Maj. Frank K. Everest, USAF, the X-1 #1's canopy ruptured at 69,000 feet, depressurizing the cockpit. The T-1 suit inflated automatically, enabling Everest to return safely to Earth, and save the airplane. This was the first emergency validation of the pressure suit concept, under development in the United States since 1934.[11]

During 1953 and 1954 the advanced X-1A made a number of high-Mach, high-altitude flight attempts (Figure 7). One of these flights, on December 12, 1953, nearly ended in disaster for the pilot, Maj. Charles Yeager. During a flight to Mach 2.44 (1,612 mph) at 74,200 feet, the X-1A experienced severe longitudinal and lateral coupled motions; its vertical and horizontal tail surfaces did not have sufficient area to ensure adequate stability for flights beyond Mach 2.3. After a 50,000 foot uncontrolled drop, Yeager managed to recover and land safely. Although NACA subsequently installed ventral fins on the X-1B and X-1E in an attempt to improve stability and control above Mach 2, neither airplane exceeded Mach 2.3 because of the stability and control difficulties experienced by the X-1A. On May 28, 1954, Maj. Arthur Murray, USAF, flew the X-1A to 87,094 feet. He later extended this to 89,750 feet, and, on August 26, 1954, attained 90,440 feet, a new unofficial record for manned flight. These three flights pointed up the need for reaction controls to maintain aircraft attitude at high altitudes, where the plane essentially flew a ballistic arc. A minor engine thrust misalignment caused the X-1A to roll and tumble out of control at the apex of its flight on June 4, 1954 to 89,750 feet. Murray finally regained control at 65,000 feet. By this time the need for reaction controls was self-evident, although many engineers disagreed as to the type or method of their operation.[12]

One of the few disappointments of the early rocket research aircraft program was the failure of the Bell X-2 to acquire information on aerodynamic heating and aircraft stability and control characteristics at Mach 3+ speeds. Several factors combined to bring about this deficiency: the unusually long and explosion-prone development cycle of the Curtiss-Wright XLR-25 engine, difficulties with fabricating the stainless steel and K-monel alloy, and problems with the skid landing gear.

But the greatest blow came on May 12, 1953, when Bell lost the second X-2 in an inflight explosion and fire during captive flight tests over Lake Ontario. The X-2 was the third Bell rocket research plane to mysteriously explode; the others were the X-1-3 and the X-1D, both in 1951. The actual cause of these explosions did not come to light until after the similar loss in 1955 of the Bell X-1A. Then, a NACA-Air Force-Bell accident board concluded that the use of ulmer leather gaskets in the planes' fuel systems caused a series of progressive events in which the gaskets decomposed and exuded tricresyl phosphate. Given proper conditions, the tricresyl phosphate would then freeze in the presence of liquid oxygen-cooled piping, and as the pilot pressurized the fuel system, the jolt of pressurization would detonate the frozen tricresyl phosphate/ulmer leather gaskets, leading to catastrophic propellant tank explosions. Altogether, these accidents had killed one pilot, one aircrewman, injured another pilot, and destroyed four rocket planes and two B-50 launch aircraft. They pointed the need for extensive safety precautions and fail-safe systems in future rocket engines, as well as greater attention to careful design, a philosophy that assumed critical importance in the American manned spacecraft program, particularly after the disastrous Apollo 204 fire at Cape Kennedy drove the lesson home once again with tragic emphasis.[13]

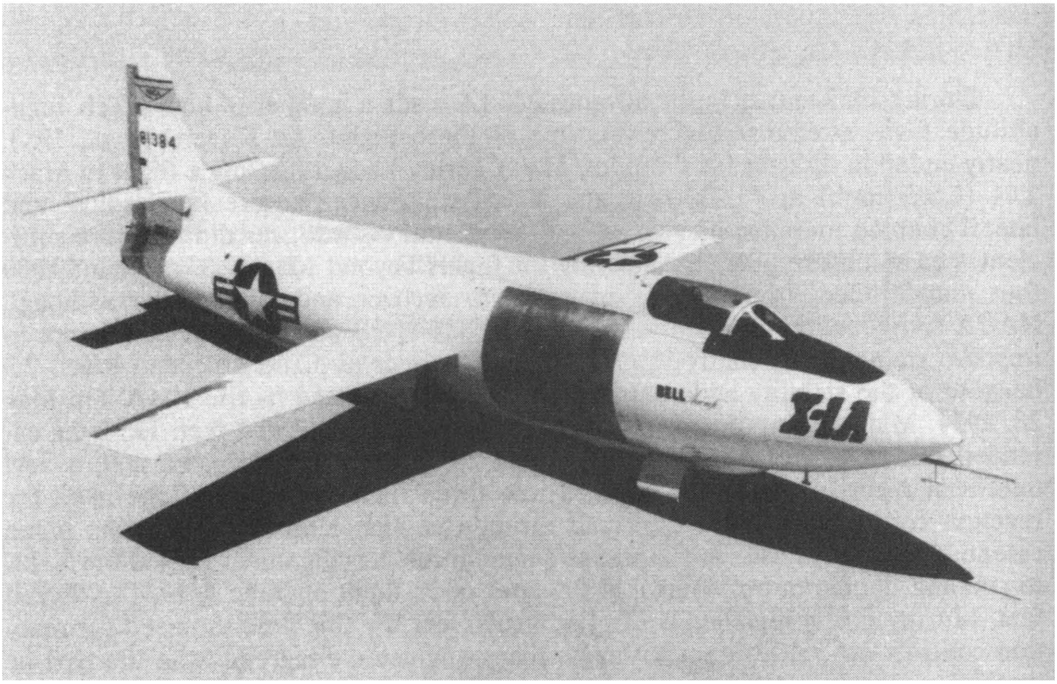

Figure 7 Bell X-1A research aircraft at the NACA's Langley Facility, Virginia., 21 February 1953, following the first flight (NASA photo no., Langley Facility-51).

On November 18, 1955, the X-2 completed its initial powered flight. All through the spring and summer of 1956, the X-2 flew a succession of increasingly faster flights beyond Mach 2. On July 23, 1956, Lt. Col. Frank K. Everest set a new unofficial world air speed record of Mach 2.87 (1,900 mph) at 68,205 feet. The Air

Force now turned its attention to examining the X-2's altitude capabilities (Figure 8). On the X-2's twelfth powered flight, September 7, 1956, Capt. Iven C. Kincheloe attained an altitude of 126,200 feet. This particular flight is especially noteworthy. It was the first manned flight above 100,000 feet. At 126,200 feet Kincheloe was, for all practical purposes, in space. He was totally dependent on his cabin and pressure suit for survival. His aerodynamic controls, the ailerons, elevator, movable stabilizer, and rudder, were useless. His view was that of the later astronauts and cosmonauts. As he recalled the flight:

> Up-sun, the sky was blue-black in color and the sun appeared to me to be a very white spot. The sky conditions down-sun were even darker in color. This dark gray band appeared very abruptly. This gray band became lighter until eventually its appearance resembled that of a typical haze condition. The ground within a 60° cone directly beneath the aircraft could be seen very clearly.[14]

During the flight the X-2 experienced conditions of less than 0.05g for approximately 50 seconds. Its flight was a ballistic arc beyond 90,000 feet. Once again, its behavior in the rarefied atmosphere above 100,000 feet pointed to the necessity of reaction controls. Due to engine misalignment, the X-2 entered a left bank. Realizing that the plane had very poor control response and extremely low stability margins at high altitudes and high Mach numbers, Kincheloe permitted the X-2 to reenter in a left-bank position, rather than attempt to restore a wings-level attitude. He flew the entire reentry "hands off." Popular science reporters, noting the unique high-altitude and near "zero g" characteristics of the flight, promptly dubbed Kincheloe "First of the Spacemen."[15]

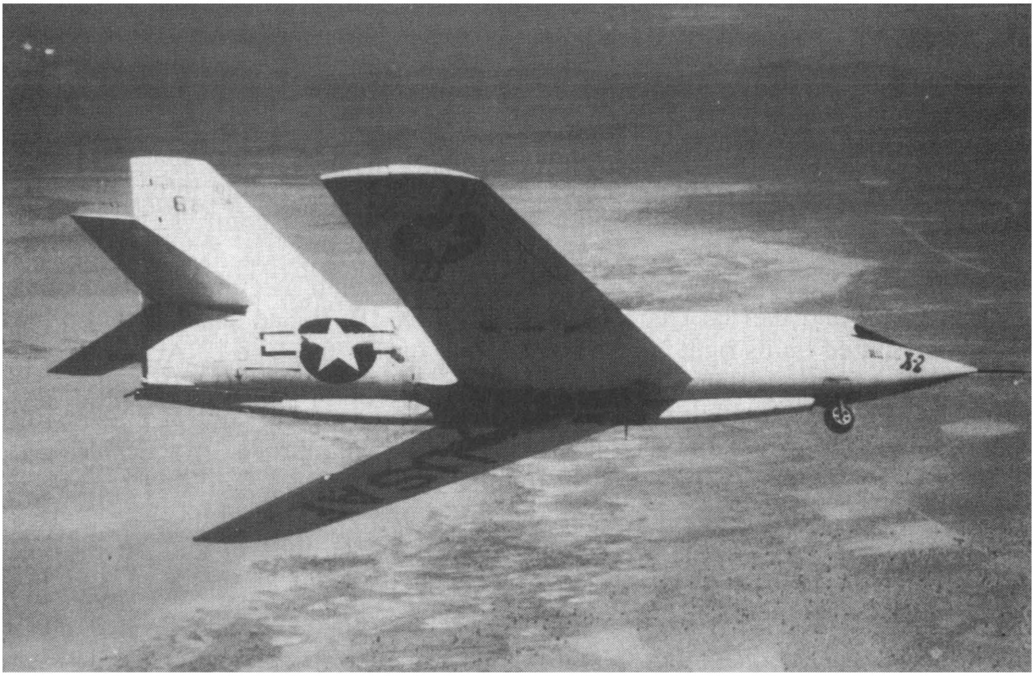

Figure 8 Bell X-2 research aircraft in flight.

On its very next flight, September 27, 1956, the X-2 went out of control at Mach 3.196 (2,094 mph) at 65,000 feet, the first manned Mach 3 flight. The pilot, Capt. Milburn G. Apt, attempted to escape using the emergency capsule, but he did not have the necessary altitude or time to bail out from the capsule before it smashed into the California desert. The accident dispelled forever the idea of capsule bailouts; from the X-2 on, all escape capsule designs provided for the pilot to remain within the capsule during the entire jettison, descent, and landing procedure.[16]

More importantly, Apt's accident illustrated the acute need for reliable instrumentation for high-speed exo-atmospheric flight research. Both the X-2's Machmeter and altimeter lagged at their upper speed and altitude levels; Kincheloe had noted this on his 126,200-foot flight. X-2 accident investigators suspected that the plane went out of control because Apt initiated a high-speed turn back to base at a speed much higher than he believed the plane to be traveling. As Paul Bikle, then Technical Director of the Air Force Flight Test Center and later director of the NASA Flight Research Center, noted, the X-2 accident demonstrated the necessity of providing the pilot with all the information he required to do his job. This led to development of a special gyro-stabilized inertial guidance system for the X-15 to furnish precise and reliable flight path data, including speed, altitude, climb angle, and geographic position. Subsequently, this concern carried over into Project Mercury, where the astronaut had full flight and display instrumentation enabling him, if necessary, to exercise control of a capsule during reentry, rather than passively riding as a passenger relying totally on automatic systems.[17]

So the X-2 program came to an end without having furnished any information on aerodynamic heating, aside from some limited data from samples of temperature-sensitive paint. NACA, which would have soon received the X-2 from the Air Force for aerodynamic heating studies, utilized the X-1B as a substitute (Figure 9). To see if reaction controls could be successfully utilized on a near-space research aircraft, and to develop techniques governing their use, including information on how a pilot could adapt to using both aerodynamic and jet controls, NACA engineers installed small thruster reaction controls on the X-1B. NACA scientists built a special ground simulator, the "Iron Cross," a beam assembly that matched the dimensions and inertial characteristics of the X-1B. It had small nitrogen gas thrusters mounted on its right "wing" and the rear of the "fuselage." NACA research pilot Neil A. Armstrong, later the NASA command pilot on *Gemini VIII* and *Apollo XI*, practiced on the simulator, and then flew several reaction control missions in the X-1B over the winter of 1957 and 1958. The controls proved practicable, and NASA later continued reaction control training flights using a modified Lockheed F-104A Starfighter, in preparation for the upcoming X-15 program. The X-1B's reaction controls were hydrogen peroxide "cold rocket" units developed by Bell Aerosystems Company, and similar to those Bell installed in the X-15 and the Project Mercury capsule.[18]

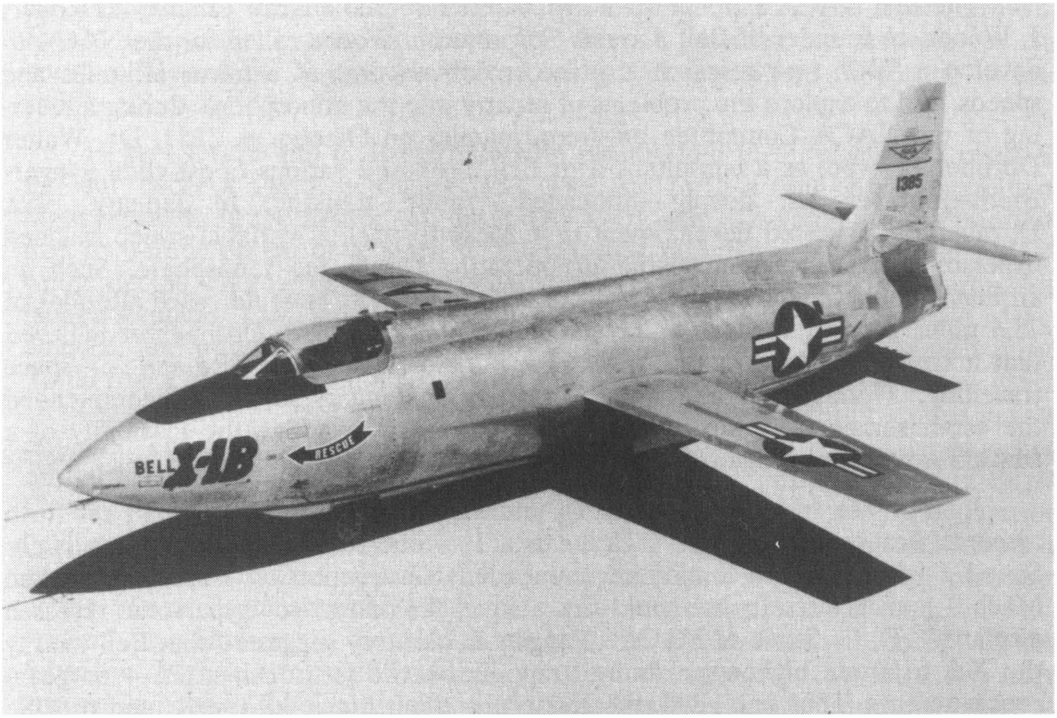

Figure 9 Bell X-1B research aircraft at NACA's Langley Facility, Virginia, 8 October 1954, following its first flight. (NASA photo no., Langley Facility-52).

THE ORIGINS AND RESULTS OF THE X-15 PROGRAM: 1950-1968

Even before Bell's ill-fated X-2 completed its first powered flight, the Air Force, Navy, and the National Advisory Committee for Aeronautics were looking beyond it toward a Mach 6 or 7 rocket research aircraft capable of operating at extreme altitudes. These deliberations led to the North American X-15. In part, the wartime research activities of two German scientists, Eugen Sänger and Irene Bredt, stimulated the interests of American scientists in winged hypersonic flight. Sänger and Bredt, while working at the *Deutsche Forschungsanstalt für Segelflug*, set forth a theoretical study for a rocket-propelled hypersonic ground-launched boost-glide antipodal aircraft in August 1944.[19] After the war, Allied technical intelligence teams sent copies of this secret report to various Allied governments. The Sänger-Bredt proposal influenced American hypersonic research by focusing attention on the potential of winged long-range hypersonic cruise aircraft, and awakened realization that the hypersonic speed range might not, after all, be limited only to unmanned missiles.[20] Such realization lay dormant until about 1950, when Dr. Hsue-shen Tsien, Robert H. Goddard Professor at the Daniel and Florence Guggenheim Jet Propulsion Center, Pasadena, California, proposed a "transcontinental rocket liner" powered by liquid oxygen and liquid hydrogen, and capable of Mach 12 speeds. He concluded that "the requirements of a transcontinental rocket liner [are] not at all beyond the grasp of present-day technology."[21]

The first NACA support for a hypersonic research aircraft came from Robert J. Woods, co-founder of Bell Aircraft Corporation. Woods called for the NACA to develop a "V-2" type research airplane to "obtain data at extreme altitudes and speeds, and to explore the problems of reentry into the atmosphere" during a meeting of the NACA Committee on Aerodynamics on October 4, 1951. Dr. Walter Dornberger, who, as a consultant with Bell, proposed various boost-glide Sänger-Bredt-type vehicles, deeply influenced Woods' thinking. In January 1952, Dornberger suggested development of a rocket-propelled variable-sweep manned hypersonic test airplane capable of operating within the ionosphere. Such an airplane should have a launch weight of about 57,000 lb. It could reach altitudes of 78.6 miles if ground-launched, or 107 miles if air-launched. Dornberger believed that it could help lead to the "goals of a piloted artificial satellite and . . . space travelling." Woods, at another NACA meeting on January 30, 1952, recommended the establishment of a small NACA study group to examine the feasibility of a Mach 5+ manned, winged "V-2" research airplane.[22]

In response to industry's growing interest, various NACA scientists set forth research proposals. Hubert M. Drake and L. Robert Carman of NACA's High-Speed Flight Research Station recommended construction of a rocket-propelled Mach 3 launch aircraft that could fire a small "second stage" hypersonic research airplane.[23] D. G. Stone of NACA's Langley Laboratory suggested that Bell modify the X-2 to attain higher speeds by strapping on two jettisonable JPL-4 Sergeant rocket motors. Thus equipped, the X-2 could attain Mach 4.5 speeds and provide data on aerodynamic heating during reentry into the atmosphere. Floyd Thompson, Langley Laboratory's Chief of Research, recommended that NACA consider the X-2 as a potential space flight test vehicle, possibly with the addition of reaction controls. After study, however, NACA scientists and Bell engineers believed the X-2 was too small for their needs. What was needed was a completely new airplane.[24]

During the June 24, 1952 meeting of the NACA Committee on Aerodynamics at Wallops Island, Virginia, committee members passed a resolution that NACA increase its research aircraft program to examine the following:

> Problems of unmanned and manned flight in the upper stratosphere at altitudes between 12 and 50 miles, and at Mach numbers between 4 and 10, and [that] the NACA devote a modest effort to problems associated with unmanned and manned flights at altitudes from 50 miles to infinity and at speeds from Mach number 10 to the velocity of escape from the Earth's gravity.[25]

This meeting marked the inception of the X-15 project. The NACA Executive Committee reaffirmed this recommendation at its July 14, 1952 meeting, and a month later appointed a hypersonic study group consisting of C. E. Brown, W. J. O'Sullivan, and C. H. Zimmerman.[26] This group, which submitted its report in June 1953, endorsed modifying the X-2 for potential hypersonic research, identified aerodynamic heating upon reentry as the critical research area, and recommended that NACA conduct further hypersonic research using unmanned recoverable rocket-propelled models. The Brown committee looked beyond flight at Mach 4 to 10 and, as one NACA scientist recalled, their conclusions "had a definite orbital-flight flavor."[27] The suggested development of boost-glide passenger aircraft that could, for example, cut New York to Buenos Aires flying time to one hour. Growing NACA interest in hypersonic boost-glide aircraft provided the impetus for the abortive "Round III" NACA-Air Force-Boeing X-20 Dyna-Soar project of the late 1950's and early 1960's.[28]

Hubert Drake and L. Robert Carman resubmitted their "piggyback" research airplane concept again in August 1953. They set forth a four-phase program of flight research. In the first phase, the X-1A, X-1B, and X-2 would acquire information to permit design of a Mach 4, 250,000-foot research airplane. Then NACA would decide whether or not to proceed with construction of the rocket-propelled launch airplane. The launch plane Drake and Carman envisioned had five rocket engines, and weighed about 100,000 lb. During Phase III tests this launch plane would fire a manned Mach 8 research plane. Phase IV would develop a new Mach 18 research airplane for air-launching at Mach 3 from the rocket-propelled launch airplane. The final phase, Phase V, would see NACA flight-test an air-launched orbital boost-glide aircraft. Drake and Carman drew one possible Mach 18 Phase IV configuration (Figure 10). The launch aircraft was a straightwing configuration having a butterfly tail and powered by five rocket engines. The research airplane had lines generally similar to a blend of early X-15 studies plus the wing planform of the Sänger-Bredt aircraft. It had five rocket engines, plus an exceptionally tall vertical fin. Once again the NACA shelved the Drake-Carman concept as too futuristic. Its historical significance lies in its ambitious advocacy of a two-stage ground-launched orbital vehicle, one of the earliest "piggyback" concepts predating the later space shuttle.[29]

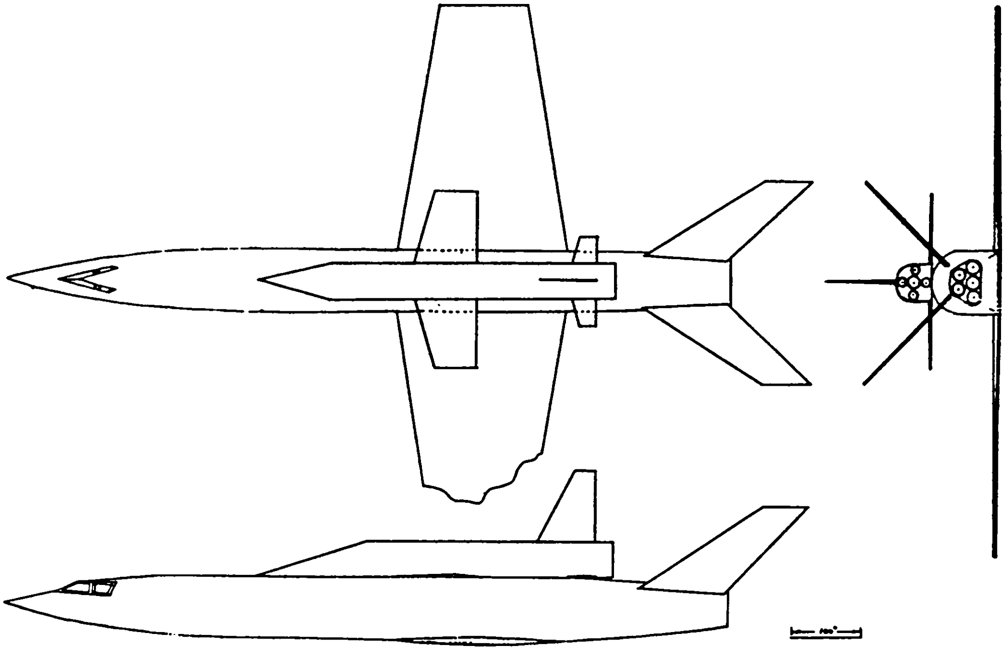

Figure 10

In October 1953, the Air Force's Scientific Advisory Board's Aircraft Panel, under the chairmanship of Dr. Clark B. Millikan, concluded that the Air Force, Navy, and NACA should investigate the feasibility of developing an advanced hypersonic research aircraft; later the committee recommended, largely on the basis of a prepared statement for NACA scientist Robert R. Gilruth, that the government develop a Mach 5-7 research airplane for the study of the problems of space flight and exo-atmospheric reentry. At this same time, the Douglas Aircraft Company had a special contract from the Office of Naval Research to study development of a 5,000- knot aircraft powered by a liquid oxygen and ammonia-fueled Reaction Motors XLR-30-RM-2 50,000 lb s.t. rocket engine, equipped with reaction controls, capable of attaining 700,000-foot altitudes, and with a potential zero g span of over 7 minutes (Figure 11). The Navy and Douglas had tentatively designated this aircraft as the D-558-3, the successor to the D-558-1 and -2. For protection against reentry heating, the D-558-3 aircraft had a titanium alloy skin with a water-cooled stainless steel wing leading edge.[30]

Figure 11 Artist's concept of the Douglas D-558-3 hypersonic aircraft which remained a paper study. Douglas Aircraft Co. photo.

At the February 4-5, 1954 meeting of the NACA Inter-laboratory Research Airplane Projects Panel, chaired by Hartley A. Soulé, RAPP members concluded that "provision of an entirely new research airplane is desirable."[31] Langley Laboratory created a hypersonic research airplane study group on March 15, 1954, chaired by John V. Becker, and consisting of Maxime Faget, Thomas Toll, N. F. Dow, and J. B. Whitten. The design study they produced closely resembled the ultimate X-15 configuration, and featured many aspects of the later design, notably International Nickel Corporation Inconel X chrome-nickel alloy heat sink construction, as well as similar estimated weights and specifications. It had a cruciform tail configuration, and a "wedge" vertical fin, since the wedge tail offered significantly better stability characteristics at high Mach numbers.[32] On July 9, 1954, during a joint NACA-Air Force-Navy meeting in Washington, D.C., John Becker presented the panel's report, and the concept of a joint development program received endorsement from Air Force, Navy and NACA representatives, including Ezra Kotcher of the Air Force, and Hugh Dryden, NACA's Director of Aeronautical Research.[33] On October 18, 1954, during another joint meeting, representatives appointed a three-man hypersonic aircraft committee to derive aircraft specifications. This committee consisted of Hartley A. Soulé, NACA; Abraham Hyatt, Navy Bureau of Aeronautics; and Colonel R. M. Wray, Air Force Headquarters.[34] On December 23, 1954, the NACA, Air Force, and Navy issued a joint "Memorandum of Understanding" which gave NACA responsibility for technical direction, and placed responsibility for funding in the hands of the Air Force and Navy.[35] A three-man Air Force-NACA-Navy steering committee would supervise the entire project. By December 30, 1954, Soulé, Hyatt, and Wray had drawn up the basic specification for the airplane, using Becker's study as a guide. It provided for an aircraft capable of attaining 250,000 feet, a velocity of 6,600 feet per second, and withstanding reentry temperatures of 1,200 deg F. The Air Force informed NACA that the aircraft would be developed as Project 1226, and be designated X-15. The Air Force transmitted the specifications, together with bid invitations, to potential contractors.[36]

Four companies entered the X-15/Project 1226 competition. These were Douglas and North American, Bell, and Republic. Actually, only Douglas and North American were favored to win; Republic lacked the background to produce a viable design, and Bell submitted a very controversial entry that stood no chance of acceptance. The Bell study reflected company interest in Mach 20 boost-glide vehicles. At this time, the company had Air Force contracts for the proposed Brass Bell (later Hi-Fi and BOMI) boost-glide vehicles. Its X-15 design had double-wall construction for its external skin consisting of an inner aluminum alloy load-bearing structure, and an outer wall of Inconel X panels, the type structure Bell engineers planned for Brass Bell. These outer panels, measuring 8 in. by 4 in., were welded to a corrugated sheet of the same material, and the whole assembly was then held by retaining strips 3/8 in. above the inner wall aluminum structure, allowing a sufficient gap for air insulation. However, NACA wanted the X-15 as a research tool and not as a structures test-bed. Further, NACA engineers believed that if one of the Inconel X panels tore loose, the entire airplane would be lost. Thus NACA turned down the Bell proposal.[37] Douglas produced an excellent design using an external surface of magnesium, but in a series of conferences during July 1955, NACA concluded that Inconel X heat sink construction was the only favorable type, making North American the only possible winner.[38] In other respects the North American and Douglas designs ranked very close. The final evaluation report, submitted on August 5, 1955, rated North American with regard to overall technical design at 81.5 out of a possible 100, and Douglas at 80.1.[39] On September 30, 1955, the Air Force formally notified North American that it had won the X-15 design competition. North American's X-15 design team began work under the direction of Harrison Storms and Charles Feltz. The company received a formal contract for three X-15 aircraft in June 1956.[40]

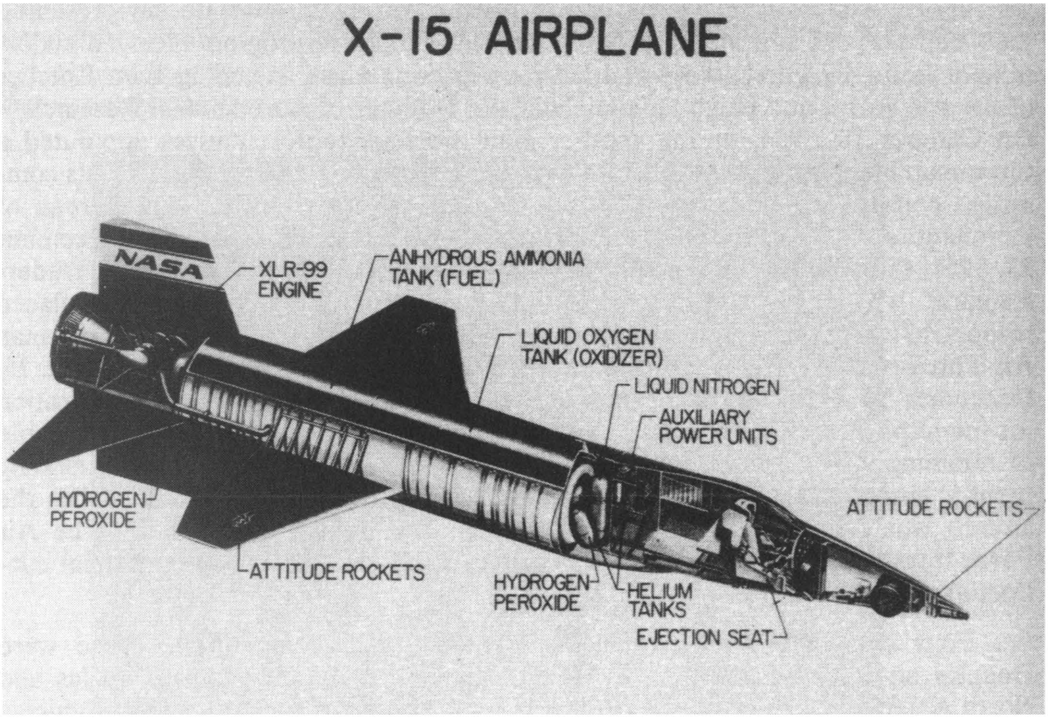

Figure 12

The actual design development of the North American X-15 advanced the state-of-the-art in several areas (Figure 12). One of these was pilot protection. Whereas previous rocket pilots had used variations of the T-1 partial pressure suit, the development of the X-15 required a completely new full-pressure suit design. Previous full-pressure suits had been cumbersome and awkward devices that severely hindered the pilot's mobility. Now, for the X-15, the David M. Clark Company developed a unique "link-net" method of fabric construction that permitted much greater flexibility. Their suit, the Clark MC-2, became the first standard X-15 full-pressure suit (Figure 13). For Project Mercury, the Clark company entered an advanced model based on the MC-2, but it lost in competition to the B.F. Goodrich Company's Navy-sponsored Mark IV full-pressure suit.[41]

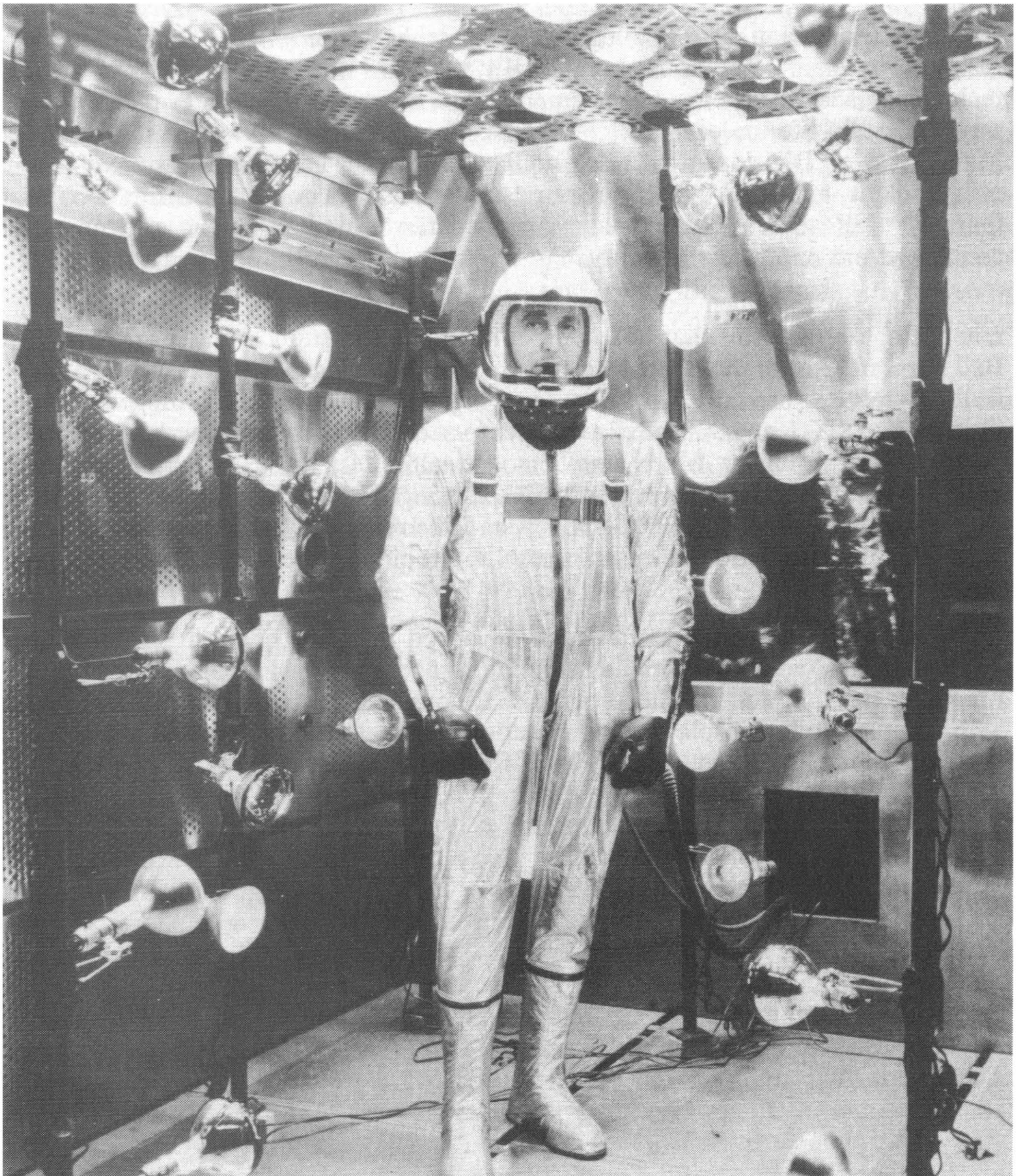

Figure 13 Pilot Scott Crossfield in X-15 flight suit in heat test with heat lamps, ca. 1960.

During the early rocket research aircraft program, aeromedical researchers concerned themselves only with providing pressure suit protection for the pilot. Now, on the X-15, they planned real-time flight monitoring of the pilot's activities for acquisition of inflight physiological data. The pilot's pressure suit contained 24 pick-up points to transmit electrocardiographic readings, body temperature, and helmet and suit pressures and blood pressure. Thus the X-15 pioneered inflight real-time acquisition of physiological data, highly important for future American manned spacecraft ventures.[42] Additionally, the X-15 was the first aircraft for which technicians had to develop environmental control and life support systems necessary to sustain life under space conditions. The Garrett Corporation's AiResearch Manufacturing Division provided a liquid nitrogen air-conditioning system to furnish cockpit and MC-2 suit pressurization and to cool instrumentation bays. Garrett's AiResearch Division later assumed responsibility for the environmental control system on Project Mercury.[43]

One area in which the early rocket research aircraft contributed to future manned spaceflight was that of computer simulation to support flight research. The Bell Aircraft Corporation constructed two special analog computers, the BAPA's--Bell Aircraft Performance Analyzers--on which engineers could "fly" entire research flights of the X-1 and X-2. Bell engineers used the computers to predict aircraft performance at higher Mach numbers and altitudes, using extrapolations from known data acquired during previous flight testing. The Air Force, in support of the X-2 program, used the GEDA--Goodyear Electronic Digital Analyzer--both as a pilot X-2 simulator, and as a research tool to predict X-2 behavior characteristics at higher speeds.

The X-15 simulator was far more advanced than any of these earlier efforts, and it foreshadowed the complex simulators and training aids developed for the Mercury, Gemini, and Apollo programs. It consisted of a full-scale X-15 cockpit, with complete pilot display instrumentation, connected to high-speed analog computing equipment and had 6 degrees of freedom. On the average, during the X-15 flight research program, pilots spent 8 to 10 hours in the simulator before each 10- to 12-minute research flight. Scientists also used the simulator to study pilot reaction to various control system changes, and as a planning tool.[44] Since the first 85 seconds of any X-15 flight spelled whether or not the plane could attain its research goals for that flight, the simulator proved invaluable for assuring mission success by honing pilot skills. During flight operations, the X-15 attained its research mission on 92% of its flights, a remarkable success rate. In preparation for the X-15 program, project pilots "flew" X-15 reentry patterns in the centrifuge at the Navy's Aviation Medical Acceleration Laboratory at the Naval Air Development Center. These centrifuge studies aided North American in developing the X-15's side stick controller and instrument display, as well as showing that a pilot-astronaut could safely control an aerospace vehicle during reentry at loads up to 15 g.

Finally, one must consider the actual flight simulation done on the X-15 program, where X-15 pilots used F-100A and F-104A to gain practice in the use of reaction controls. Simulators played an extremely important role in Project Mercury, where astronauts used the centrifuge and a special Mercury capsule procedures trainer. It has been estimated that the Mercury astronauts spent more than 4,000 hours in simulator training. Much of the technology used on these later simulators derived from simulator technology developed during the rocket research aircraft program.[45]

The development of the X-15 rocket engine was clearly a milestone on the road to reusable and restartable rocket engines for manned space flight. The Reaction Motors Division of the Thiokol Chemical Corporation had responsibility for development of this engine, a far more complex rocket engine for manned flight than any developed previously. The engine Thiokol developed, the XLR-99-RM-1, could produce 57,000 lb s.t. It burned 1,003 gallons of liquid oxygen and 1,445 gallons of anhydrous ammonia. The pilot could throttle the engine from 40% to 100% thrust, and a special "idle" feature enabled him to complete roughly 85% of the engine start procedures before launching from a Boeing B-52 Stratofortress launch plane. He could restart the engine in flight, and it featured a special sensor system that monitored engine performance and shut down the engine whenever it detected component malfunction.

The engine, like its XLR-11 (Figure 14) and XLR-25 predecessors, had to be reusable, and not a "throwaway" item for once-only use such as a ballistic missile engine. Indeed, existing missile engines could not come close to meeting the safety standards required for the X-15 engine. This greater concern over reliability and safety increased the XLR-99's development time. Reaction Motors won the X-15 engine contract in February 1956, but X-15 airframe development outstripped that of the XLR-99 engine. When the X-15 #2 completed the type's first powered flight on September 17, 1959, it did so with two interim XLR-11 engines. The first X-15 flight with the XLR-99 came over a year later, on November 15, 1960. In subsequent X-15 flight operations, the XLR-99, proved flight-reliable 96% of the time.[46]

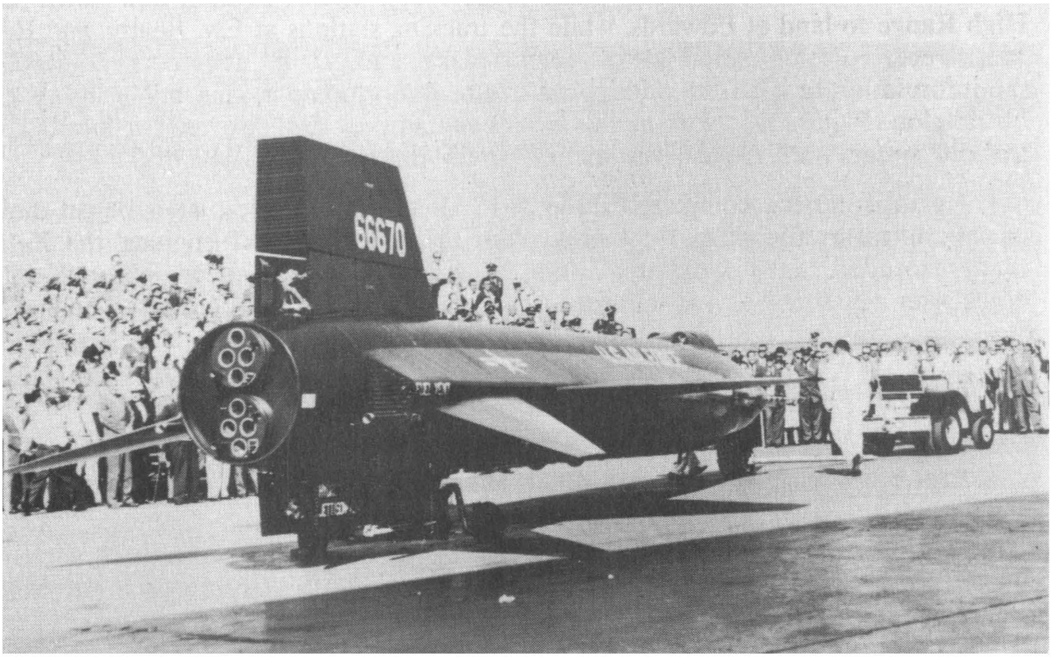

Figure 14 Unveiling the X-15 rocket aircraft, showing its two interim XLR-11 rocket engines since the XLR-99 Pioneer engine was not yet ready; left 3/4 view.

Largely because of the complexity of the new aircraft, and the necessity for comprehensive flight instrumentation displays shown by the loss of the X-2 in 1956, the X-15 contained a very precise inertial reference system developed by the Sperry Gyroscope Company in conjunction with Lear, Inc. This system sensed changes in attitude, velocity, distance, and altitude, and fed the data to a computer which then displayed the information on the pilot's instruments. Early in the X-15 program, NASA installed a special "Q-ball" spherical sensor developed by the Nortronics Division of the Northrop Corporation in the nose of the X-15 to measure dynamic pressure and indicate angles of attack and sideslip upon reentry. The X-15 also featured no less than three control sticks. The pilot used a central floor-mounted stick for his approach and landing. During launch, acceleration, and reentry, the pilot moved a special side-stick-right hand controller, so that his arm could remain fixed with minimal tendencies to move under high g loads. On the left side of the cockpit was a special reaction control stick to activate the reaction control units. Project Mercury used variations of these controls, based on X-15 experience.[47]

NASA and Air France engineers contracted with the Electronic Engineering Company to construct a network of three tracking stations at Ely, Nevada; Beatty, Nevada; and Edwards Air Force Base, California (Figure 15). This foreshadowed the later worldwide tracking network established for Project Mercury and succeeding manned space ventures. This test corridor, the "High Range," measured 485 miles long and 50 miles wide, from Wendover Air Force Base near the Bonneville Salt Flats to Edwards. In between were numerous dry lakes that could serve as emergency landing areas. The B-52 with the X-15 flew from Edwards to Wendover, where it air-launched the rocket plane (Figure 16). The X-15 then flew down the High Range to land at Edwards, while the tracking stations at Ely, Beatty, and Edwards received telemetered data from the plane, and ground engineers monitored the information to keep the pilot abreast of any developments that might influence his mission (Figure 17). Nothing this extensive had previously existed for the rocket tracking system until the establishment of the Mercury tracking network.[48]

North American completed three X-15 aircraft, and these planes began their initial contractor flights in 1959. Even with the older XLR-11 engines, the X-15 really exceeded Mach 3. After addition of the XLR-99 engine, the three X-15's quickly set new speed and altitude records for winged aircraft, as indicated below:[49]

First Mach 4 flight:	03/07/61, Mach 4.43 (2,905 mph) at 77,450 feet.
First Mach 5 flight:	06/23/61, Mach 5.27 (3,603 mph) at 107,700 feet.
First Mach 6 flight:	11/09/61, Mach 6.04 (4,093 mph) at 101,600 feet.
Fastest X-15 flight:	10/03/67, Mach 6.70 (4,520 mph) at 102,100 feet.
Highest X-15 flight:	08/22/63, 354,200 feet. (Figure 18)

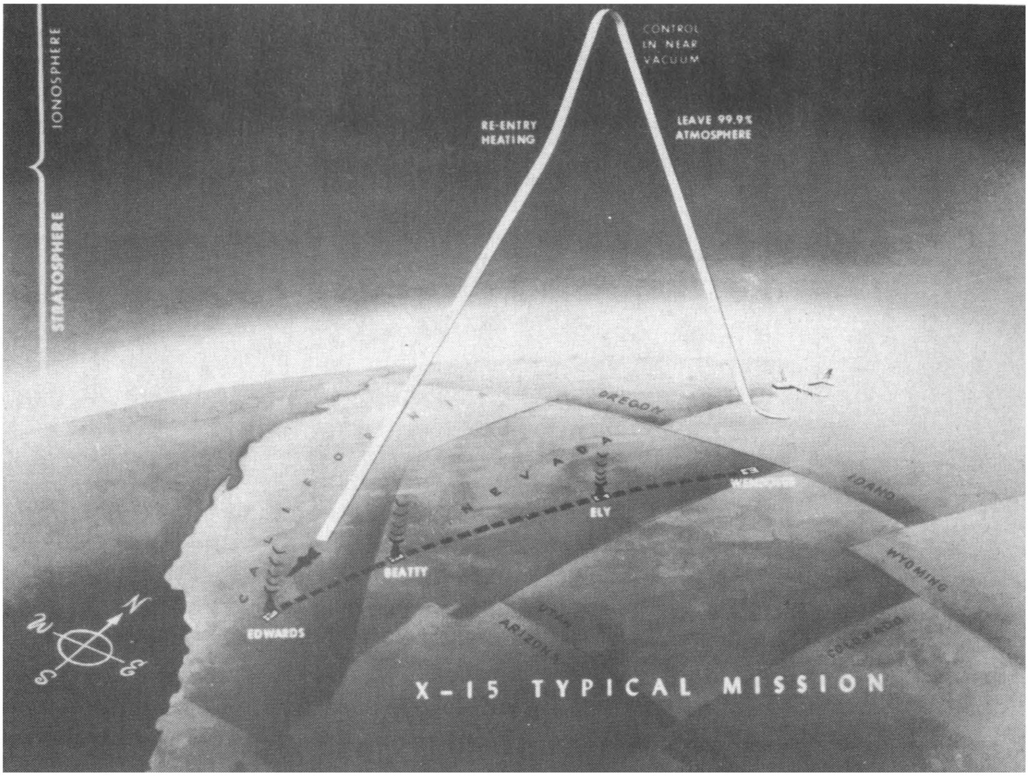

Figure 15 Flight path of a typical X-15 rocket research aircraft mission. USAF photo, Air Photographic and Charting Service (MATS) (photo 160373, ca. 1960).

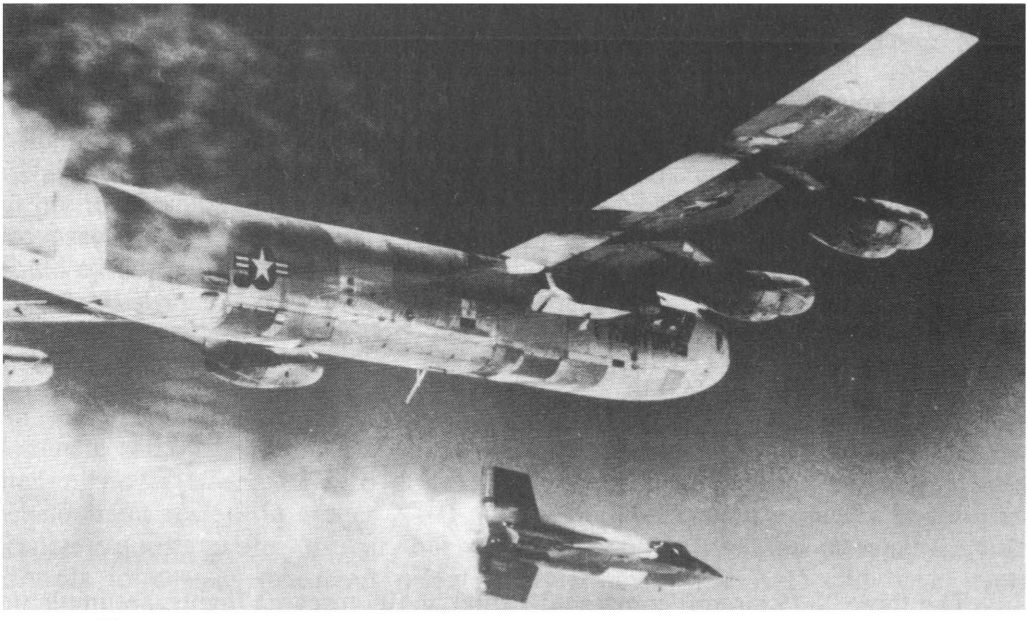

Figure 16 X-15 rocket research aircraft shown just after its release from a Boeing B-52 aircraft. The X-15 shown is one of the early models, fitted with interim XLR-11 rocket engines (ca. 1960, NASA photo 60-X-38).

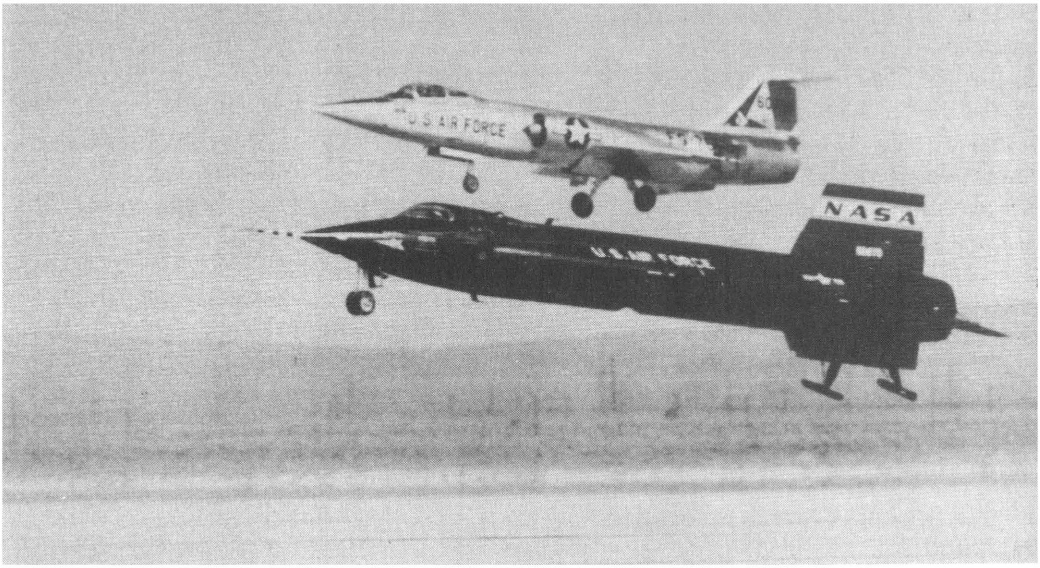

Figure 17 The X-15 aircraft about to land at Air Force Flight Test Center, Edwards Air Force Base, California with an F-104 chase plane flying alongside it (U.S. Air Force photo No. 103.69).

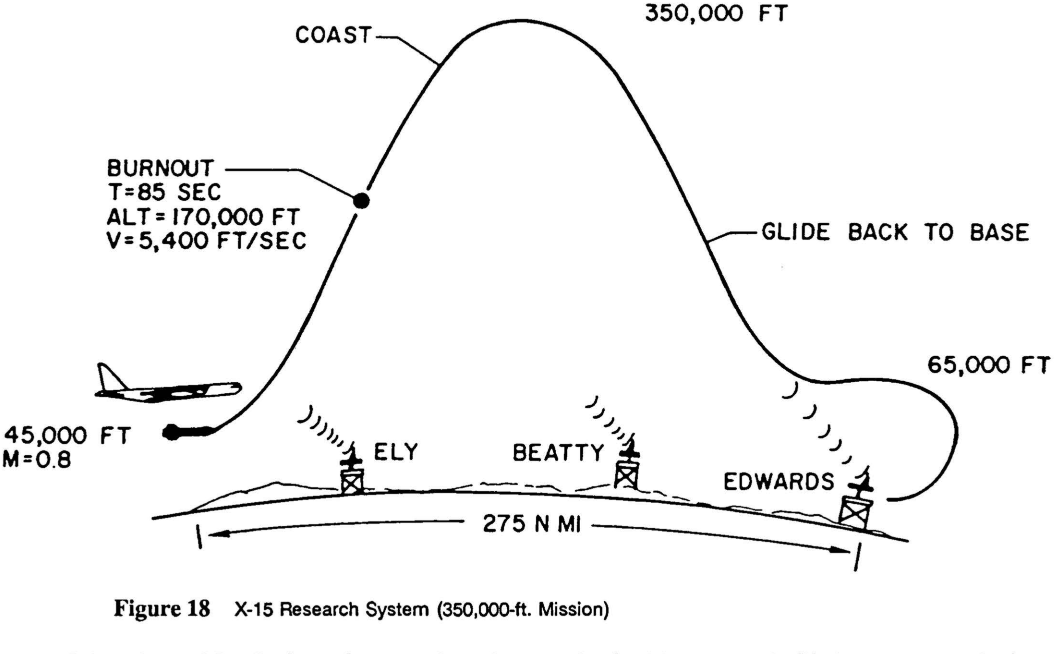

Figure 18 X-15 Research System (350,000-ft. Mission)

The three X-15 aircraft completed a total of 199 research flights, accumulating over 82 minutes of flight time at speeds above Mach 5. One aircraft, the X-15 #3, was lost on November 15, 1967 with its pilot, Maj. Michael Adams, USAF, as a result of pilot disorientation (possibly induced by vertigo) combined with a control failure of the airplane's Honeywell MH-96 adaptive control system.[50] Another X-15, the X-15 #2, crashed during an emergency landing on November 9, 1962, injuring the pilot. The Air Force and NASA rebuilt and modified this aircraft as the X-15A-2, with Mach 8 capability. During 1967, NASA coated the X-15A-2 with a Martin-developed ablative material, M-25S, consisting of a resin base, a catalyst, and a glass bead powder. Researchers hoped that future winged spacecraft could utilize a sprayed-on ablative coating for Mach 20 reentry ablation cooling; at lower speeds, the craft's metal heat sink construction could suffice. The X-15A-2 completed one flight with the M-25S coating, and showed that this approach was highly impractical. Applying and refurbishing the coating took too long (up to 2,000 man-hours over 5 weeks) and technicians had great difficulty in ensuring adequate depth coverage. The X-15A-2 was the fastest X-15 built. It flew to Mach 6.7 while covered with the ablation coating and with a mockup of a ramjet engine mounted on its ventral fin.[51]

NASA ended the X-15 program, initiated in June 1952, in October 1968, after the 199th X-15 flight. Paul Bikle, Director of NASA's Flight Research Center, saw the X-15 and Project Mercury as a parallel two-pronged approach to solving some of the problems of manned space flight. While Mercury was demonstrating man's capability to function effectively in space, the X-15 was demonstrating man's ability to control a high-performance vehicle in a near-space environment; considerable new knowledge was obtained on the techniques and problems associated with lifting reentry.[52]

Actually, the X-15 enabled researchers to examine winged flight in the corridor between the satellite operating in space, and the lower atmosphere used by conventional aircraft. What is little known is that, on several occasions, North American considered developing a "growth" version of the X-15 with orbital capability. This new vehicle, the "X-15B", would have utilized two Navaho boosters for launch, and possibly have had a two-man crew. North American initiated X-15B design studies even before Sputnik, but it lacked official support. After Sputnik and during the germinating days of Project Mercury, North American engineers again proposed the X-15, this time as an expandable spacecraft. After reentry, the pilot would eject from the rocket plane while the X-15, its mission accomplished, would crash to destruction. This proposal, one of many to put a man in space, gave way before the advocates of blunt-body reentry. Project Mercury continued, but with the McDonnell-designed capsule.[53]

Project Mercury quickly eclipsed the X-15 in glamour, and Mercury did dominate some of the areas scientists had wanted the X-15 to study, such as the then-unknown effects of zero g. Likewise, the use of reaction controls, whose development rested on earlier X-1B and X-15 developments, quickly became an academic question after Mercury operations proved the feasibility of using reaction controls to change spacecraft orientation. However, the X-15 did have many notable achievements that influenced future space systems. As John Becker, NASA's director of hypersonic aircraft studies at Langley Research Center, has noted, the X-15 clearly demonstrated that pilots could fly rocket-propelled aircraft out of the atmosphere and then return them to selected landing areas with great precision and accuracy. The importance of this to such future vehicles as the space shuttle, which may be used as a logistics vehicle to support space station operations, cannot be overemphasized.[54] For example, the X-15 completed reentry flights at speeds up to Mach 6, flight path angles of -38 deg, and aircraft angles of attack of +26 deg, which, in the words of one NASA scientist, "presented a more difficult piloting problem than the shallow entries of lifting manned vehicles returning from orbital or lunar missions."

The X-15 experience also reaffirmed the importance of man in space as a director and monitor of machine and systems operation. Without the pilot and system redundancy, the X-15 would have crashed on 13 of its first 44 flights.[55] On the 184th X-15 flight, the plane lost engine operation and both Auxiliary Power Units (APU) during the atmospheric exit portion of its flight. The pilot, Maj. William Knight, thus had a complete loss of computed flight information and aircraft guidance. During reentry, he restarted one APU, and by using minimal instrument indications and pilot visibility from the cockpit, was able to successfully complete reentry and an emergency landing at Mud Lake.[56] Scientists added new cockpit instrumentation to record airflow temperatures and air pressures, especially important for high-altitude high Mach flights, thus upgrading the system's usefulness to the pilot. Aeromedical researchers discovered that X-15 pilots experienced heart rates of between 145 and 185 beats per minute. At first gravely worried, the researchers soon concluded that the rates reflected prelaunch psychological stress rather than postlaunch physical stress, and what were thought excessive heart rates were reclassified as probable normal baselines for predicting future pilot-astronaut physiological behavior.[57]

The X-15 operated as a research tool in a space-equivalent region previously open only to unmanned rocket probes. In this function, it carried numerous experiment packages on space-related research. The X-15 tested insulation used on the Saturn booster in order to duplicate heating conditions that Saturn would encounter on actual flights. It conducted experiments to measure, with what accuracy instrumentation could determine, the horizon of the Earth, in order to aid development of navigation equipment for the Apollo spacecraft. Other X-15 research dealt with Earth resources photography, micrometeorite collection, and measurements of sky brightness and atmospheric density. Unlike a satellite, these experiment packages could be returned to Earth, examined and analyzed, and then repeated.[58] In 1961-62, NASA concluded that the X-15 could itself fire Scout rockets carrying satellite payloads, the entire B-52/X-15 Scout vehicle in effect becoming a multistage satellite booster. However, NASA subsequently determined that this was not a desirable program, inasmuch as proximity to urban areas such as Los Angeles placed restrictions on the upper-stage launch path, the satellite payloads would be small, and the B-52/X-15/Scout launch method would not be cheaper than conventional launch techniques unless NASA planned to fire more than 20 such satellites.[59]

Other scientists used the X-15 as a theoretical baseline vehicle for manned winged voyages to Venus and Mars, computing the predicted characteristics of the two planets' atmospheres upon the reentry and landing profile of the X-15. They concluded that winged spacecraft could land on Venus and Mars in similar fashion to X-15 landings here on Earth. The Martian landing conditions, involving a 60,000-foot landing slide for an X-15 type vehicle seemed particularly feasible, using American dry lakebed experience as a guide.[60]

Finally, one must not neglect the impact of the organization behind the American manned rocket aircraft program as it influenced American manned space flight. Beginning with the "sound barrier" mission of the X-1 in 1946-47, and continuing through the planning of the X-15 High Range, ground support for rocket research aircraft operations continuously expanded. The X-15 required a greater degree of cooperation between the Air Force, NASA, the Navy, and private industry than had been known in any aerospace research and development program up to that time. This unity of purpose formed a partnership of strong ties that became invaluable and necessary for Project Mercury and subsequent manned space ventures. The same individuals who managed the NACA X-1, D-558-2, X-2, and X-15 programs assumed positions of key leadership in operations, tracking, and management when the focus of NASA turned to space. As the complexity of American aerospace systems advanced and the requirements for strong leadership and direction increased, these leaders were ready to step in and take charge. When *Apollo 11* reached the Moon, Command Pilot Neil A. Armstrong, fittingly enough, was a research aircraft program veteran who had flown the Bell X-1B on its pioneer reaction control studies, and had made numerous flights in the X-15. Clearly, the American rocket aircraft were precursors to manned flight beyond the atmosphere. The impact of their accomplishments will continue to be felt as man continues his quest beyond the Earth.

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