X-Planes at Edwards AFB

Introduction

Since Captain Chuck Yeager blasted through the “sound barrier” in October 1947, Edwards Air Force Base has become synonymous with the famous “X-series” of experimental flight research aircraft. These airplanes were designed to explore the unknowns of flight and solve their mysteries. Many of them, like the X-1, were rocket planes designed to probe and expand the frontiers of flight in terms of speed and altitude. Others, like the X-5, the X-13 and, most recently, the X-48A were designed to explore new concepts and technologies that might be applied to future designs. Although the “X” designation was originally limited to U.S. Air Force airplanes, other aircraft—such as the D-558-I, D-558-II, M2-F2, M2-F3, and HL-10—are considered in the same class because they met all of the same experimental flight research criteria. The following compendium provides brief summaries of each of the X-plane programs that were conducted at Edwards AFB over the past 60 years.

1. X-1:

The Bell X-1 in flight

During World War II, fighter pilots began to encounter a new and terrifying phenomenon. Rolling over into steep dives, they accelerated to speeds of 500 mph and into the unknown region of transonic flight (0.7-1.3 Mach) where they began to encounter mixed—subsonic and supersonic airflow conditions—and the effects of compressibility, loss of control and structurally devastating aerodynamic loads, began to take over with often deadly consequences. By war's end, turbojet engines promised even higher speeds—speeds passing through the transonic and even, perhaps, into the supersonic region. So little was known about transonic aerodynamics, however, that many aerodynamicists theorized that drag would reach infinity as an airplane approached the speed of sound. The possible existence of a "sound barrier" was only one of a host of unknowns constituting a very *real* barrier to flight progress. Aircraft designers could no proceed without valid data and the wind tunnels of the day, which "choked" as the airflow around models reached transonic velocities, provided few answers. Thus an experimental research airplane was designed and built to acquire the necessary data…and determine whether or not a piloted aircraft could actually penetrate the "sonic wall."

The X-1 program was a joint U.S. Air Force (USAF)/National Advisory Committee for Aeronautics (NACA, the precursor to NASA) flight research program conceived to explore the high-speed transonic flight regime and provide the answers. The first in a long series of "X-Plane" programs, it represented one of the most successful flight research efforts in aviation history, proving that manned aircraft could fly faster than the speed of sound and do so safely. Three X-1s were built by the Bell Aircraft Corporation, Buffalo, NY, with the serial numbers 46-062, 46-063, 46-064. The aircraft engine, the XLR-11-RM-3, was a four-chamber rocket engine rated at 6000 lb of static thrust. The No. 1 aircraft employed an extremely thin eight-percent thickness/chord ratio wing (with a 6-percent thickness/chord ratio horizontal stabilizer) for maximum speed, while the No. 2 aircraft employed a ten-percent thickness/chord ratio wing and an eight-percent horizontal tail. In order to insure that the airplane would not break apart during its turbulent transition from subsonic to supersonic flight, it was designed for an ultimately load factor of 18 g's—or roughly twice that of existing fighter aircraft.

The Bell Aircraft Corporation signed a contract to build three airplanes at a total cost of $4,278,537 on 16 March 1945. The first X-1 (46-062) was completed late in 1945 and rolled out of Bell's Wheatfield, N.Y., plant on 27 December 1945. The first glide flight took place at Pinecastle Field (near Orlando, FL) in January 1946, with Bell company test pilot Jack Woolams in the cockpit. There were many weather delays and landing mishaps at Pinecastle, however, and by March 1946, the decision was taken to move X-1 test program to the more remote Muroc Army Air Field (now Edwards AFB) on California's high desert. Thus, on 7 October 1946, the second X-1 (46-063) was delivered to Muroc to be used to initiate the powered portion of the flight test program.

Following several glide flights, on 9 December 1946 the first powered flight using the Reaction Motors XLR-11 engine was logged by Bell test pilot Chalmers H. "Slick" Goodlin at Muroc without major problems. Indeed, despite a small engine fire which burned some wiring and instrumentation, Bell considered the first powered flight quite successful and Goodlin judged the handling characteristics of the X-1 to be very good. Starting on 20 December, 20 or more additional powered/unpowered flights using both the No. 1 and No. 2 aircraft were undertaken by Goodlin through 5 June 1947. This officially concluded Bell's contractual obligations to demonstrate the airworthiness of the

X-1 up to Mach 0.8 and the test aircraft were turned over to the USAF for a final assault on the sound barrier.

The man selected to make that assault was a 24-year old Air Force test pilot and WWII combat ace, Captain Charles E. “Chuck” Yeager. After completing three glide flights in the X-1, he flew it to a speed of Mach 0.85 on his first powered flight on 29 August 1947. He encountered severe buffeting and sudden nose-up and –down trim changes during his next six powered flights. Then, during his eighth powered flight on 10 October, he lost pitch control altogether, as a shock wave formed along the hingeline of the X-1’s elevator. Post-flight data analysis indicated that he actually reached a top speed of Mach 0.997 that day but, without pitch control, it would have been foolhardy to proceed. Fortunately, the X-1 had been designed with a moving horizontal tail and his flight test engineer, Captain Jackie L. Ridley, convinced Yeager that, by changing its angle of incidence in extremely small increments, he could control the craft without having to rely on the elevator. This had never been attempted at extremely high speeds before but Yeager was game to give it a try on the next powered flight.

After launch from a B-29 bomber for his ninth powered flight on 14 October, he fired all four chambers of his engine in rapid sequence and exploded away from the launch aircraft. Accelerating upward, he shut down two chambers and, while still climbing, tested the moveable tail as his Machmeter registered indicated Mach numbers of 0.83, 0.88 and 0.92. Moved in small increments, it provided effective control. He reached an indicated Mach number of 0.92 as he leveled out at 42,000 feet and relit the third chamber of his engine. The X-1 accelerated to 0.98 Mach and then, at 43,000 feet, the needle on his Machmeter jumped off the scale. He attained a top speed of Mach **1.06** (700 mph) and shattered the myth of the once dreaded “sound barrier forever.” Though few could comprehend its full implications at the time, Captain Yeager had just taken the first step in a chain of events that would ultimately vault man beyond the atmosphere and into space.

The importance of this milestone flight was concisely summarized by the Collier Trophy committee for 1947 which lauded it as “an epochal achievement in the history of world aviation—the greatest since the first successful flight of the original Wright Brothers’ airplane, forty-five years ago.”

In addition to breaking the “sound barrier”—which, of course, proved to be no barrier at all—the X-1 program pioneered many noteworthy structural and aerodynamic advances. For example, it proved the practicality of the all-moving horizontal tail concept which, in turn, was applied directly to operational military aircraft designed to fly in the transonic region, among them the F-86E which performed so impressively during the Korean War. During the course of its flight test program, the X-1 reached a maximum speed of Mach 1.45 (957 mph) on 26 March 1948, with Yeager at the controls; and a maximum altitude of 71,902 feet, on 8 August 1949, piloted by Major Frank K. "Pete" Everest.

Captain Yeager completed the No. 1 airplane's final flight on 12 May 1950 and it was thereafter transported to the Smithsonian Institution in Washington, DC, for permanent display. The No. 2 aircraft with a thicker wing and horizontal elevator was assigned to the NACA contingent at Muroc to conduct a very detailed and methodical investigation of the transonic flight regime. The No. 3. aircraft, which was modified with a turbopump fuel-delivery system, only completed one unpowered glide flight on 20 July 1951. It was lost in a ground accident on 9 November 1951.

2. <u>D-558-I</u>:

Clockwise from left, the X-1A, D-558-1, XF-92A, X-5, D-558-II Skyrocket, X-4 and X-3 (center).

Like the Bell X-1, the Douglas D-558-I *Skystreak* was one of the early transonic research airplanes built in the United States. Unlike the X-1, the D-558-I was the outcome of a conservative approach to design—its jet engine slower and less "glamorous" than its rocket-powered, air-launched Bell counterpart. This design concept, however, enabled the D-558-I to fly for longer periods and to gather more data more easily than the X-1, significantly contributing to the U.S. aviation community's understanding of what happened when an aircraft approached the speed of sound (about 741 mph at sea level).

The D-558-I program was jointly operated by the National Advisory Committee for Aeronautics; the U.S. Navy; U.S. Marine Corps; and the contractor, Douglas Aircraft Company. (For an account of the second phase of D-558 testing, with the D-558-II, see below.) Three of the single-seat aircraft were built by Douglas, each about 35 feet long, 12 feet high, and 25 feet across the wingspan. The design featured a straight wing of low aspect ratio for the plane's cigar-shaped fuselage. Magnesium was employed extensively in the fuselage structure, while an aluminum alloy was used for most of the other structures. Similar to the X-1, the *Skystreak* incorporated a horizontal stabilizer that was thinner than the wing in an effort to avoid simultaneous shock wave effects on the wing and horizontal tail. Each of the planes was powered by a single Allison J-35-A-11 turbojet engine (developed originally by General Electric as the TG-180) rated at 5,000 lbs of static thrust.

Construction of the first *Skystreak* got underway in early 1946. Despite almost daily problems the project remained, for the most part, on schedule. Completed in January 1947, the first D-558-I—painted scarlet and polished to a "mirror like finish"—was rolled out of the contractor's El Segundo, CA, plant on 4 February and unveiled to the public the next day. Among those present were six admirals, three Marine generals and an Army Air Force (AAF) general. Attended by scores of news media, the unveiling received world-wide coverage in daily newspapers and radio.

In April 1947, the aircraft (U.S. Navy Bureau No. 37970) was trucked out to the Muroc Army Air Field (now Edwards AFB) to begin flight testing. Simply stated, the goal of the testing was to explore operation of a straight-wing configuration in the lower half of the transonic speed range and to garner data about flight in that range that could not be obtained from existing wind tunnels. (Note: The lower third of the transonic speed range extended from about 0.7 to 1.0 Mach; the *Skystreak* was designed to get *up to* Mach 1 but not much beyond it. In fact, it never did officially reach Mach 1; see below.) The Douglas test team, responsible for the initial, contractor-led portion of the test program, included company test pilot Eugene F. "Gene" May and members of the company's Experimental Flight Test Division.

On 15 April, May took the D-558-I aloft on its first flight. The flight was a brief one, however, terminated by the pilot shortly after takeoff due to a partial loss of power. As May landed the left brake disintegrated, fortunately with no damage to the aircraft. A week later the airplane was back flying, yet similar power-loss problems resulted in it being grounded for a month of extensive engine repairs. By late May 1947, the plane had returned to the air and, in successive flights over the next two months, additional bugs—among them, landing gear trouble—were ironed out. By the 20th flight in early August 1947, the aircraft had attained Mach 0.85.

In August 1947, the second D-558-I (BuNo. 37971) arrived at Muroc, while U.S. Navy and Marine Corps pilots joined in the test flying. After gaining familiarity with the *Skystreak's* handling qualities and performance, the Navy decided to make an attempt at a new world airspeed record. On 20 August at the Roger's Dry Lake Speed Course, U.S. Navy pilot Cdr. Turner F. Caldwell, Jr., flying the first D-558-I, made four passes over the measured course at an average speed of 640.7 mph, shattering the current record of 623.738 mph (set on 19 June 1947 by USAF Colonel Albert Boyd in a P-80R). On the blistering hot morning of 25 August, the record was broken again—this time by Marine Major and World War II ace Marion E. Carl, who piloted the tiny scarlet jet (in this case, the second D-558-I) over the course at an average of speed of 650.7 mph. The speed records marked the first time in aviation history that the same aircraft had set two such records in the same year.

After the record flights, the first D-558-I was returned to the flight test program, accomplishing a total of 101 flights before being delivered to NACA's Muroc facility on 21 April 1948. This plane, however, would never be flown by NACA, being used instead for spare parts to support the second and third *Skystreaks*. Earlier, on 23 October 1947, the second D-558-I had been delivered to NACA, following 27 flights by Navy, Marine and contractor pilots. NACA pilot Howard C. Lilly managed to conduct two flights with this aircraft in November, before rains flooded the Edwards AFB runway and the requirement for engine maintenance grounded it for some 11 weeks.

Flight testing by NACA resumed in the spring of 1948, with Lilly flying several research missions to gather data on directional stability. On 29 April, he attained a speed of Mach 0.88 at 36,000 feet (about 580 mph). Yet on Lilly's next flight, on 3 May 1948, disaster struck. Shortly after taking off from Muroc and becoming airborne, the compression section of his J-35 engine disintegrated, severing the elevator and rudder cables and leading to his loss of control over the airplane at a relatively low speed and altitude. The NACA test pilot perished in the subsequent crash.

The third, and final, D-558-I (BuNo 37972) was grounded for almost a year as the accident was investigated. Based on recommendations from the accident board, the contractor added duplicate control cables, armor plating around the emergency fuel pump and fuel lines, and wire-wound fuel hoses. The aircraft was also repainted white.

Flight testing resumed in April 1949, with NACA pilots Robert A. Champine and John H. Griffith accumulating data about handling qualities, aileron effectiveness and pressure distribution. On 13 June 1950, Griffith flew it to a speed of Mach **0.99**, the highest official speed ever attained by any of the *Skystreak* airplanes. On 29 November 1950, NACA pilot A. Scott Crossfield began a series of buffeting, tail loads and longitudinal stability tests which continued until October 1951. NACA pilots Walter P. Jones and Joseph A. Walker also participated in these tests. Beginning in June 1952, Crossfield and NACA pilots Stanley P. Butchart and John B. McKay began a series of flights to gather data on lateral and dynamic stability. These were followed by an investigation of the effects of tip tanks on the aircraft's buffet characteristics. On 10 June 1953, the airplane flew for the final time, with Crossfield at the controls.

Over the course of their six year test program, the three *Skystreaks* had flown a total of 225 times. During this period, a voluminous amount of data was accumulated, enabling NACA and the U.S. military to learn much about high subsonic flight. As Air Force historian, Dr Richard P. Hallion has noted, "Some have denigrated the Skystreak as having been unnecessary in light of the success of the X-1 family…Undeniably, the Skystreak did not have the revolutionary impact on aviation that the X-1 did. Like the X-1 and the D-558-II, however, during 1948-50 the Skystreak provided virtually the only means of acquiring data on transonic flight conditions pending the development of improved ground-research techniques such as the slotted throat wind tunnel." Equally significant, the D-558-I freed the X-1 to "explore supersonic flight conditions during its short rocket flights without necessity to cruise at transonic speeds where its rocket potential would have been wasted." Finally, it paved the way for its "undeniably significant stablemate: the sweptwing D-558-II which was, in many ways, the workhorse of NACA high-speed flight testing, bridging the era from the subsonic aeroplane almost to the era of the hypersonic X-15."

Of the three D-558-Is, the first and the third still exist. Number one can be found at the Naval Aviation Museum, Pensacola, FL; while number three is on display at the Marine Corps Air Ground Museum, Quantico, VA.

3. D-558-II: *(For photo, see page 5)*

The D-558-II *Skyrocket* was the phase two version of the D-558 program, and like its predecessor, the D-558-I, was also one of the early transonic research airplanes. Three of the single-seat, swept-wing aircraft were built by the Douglas Aircraft Company, and flew from 1948 to 1956 in a joint program involving the contractor, the NACA, the U.S. Navy and the U.S. Marine Corps. In the course of its flight research program, the D-558-II would become the first aircraft to reach Mach 2.0.

All three of the aircraft were 12 feet 8 inches high, 42 feet in length and outfitted with 35-degree swept wings with a span of 25 feet. Similar to the D-558-I, the *Skyrocket* featured a horizontal stabilizer set high on the vertical tail to avoid the wake from the wing. As with the D-558-I and the X-1, the *Skyrocket*'s horizontal stabilizer was thinner than the wing and movable in flight to avoid the simultaneous effect of shock waves on the wing and horizontal tail and to provide pitch control when shock waves rendered the elevators ineffective. Instrumentation for the D-558-II was basically the same as on the D-558-I, with the exception that more strain gauges were installed on the *Skyrocket* for the collection of stress information.

The D-558-II, however, differed significantly in design detail from its predecessor, and there was little commonality between them. For example, the needle-nosed fuselage of the D-558-II was larger in diameter and longer to accommodate both jet and rocket engines, the landing gear and fuel for both engines. Each of the *Skyrockets* began their test programs powered by a 3000-lb Westinghouse J34-WE-40 turbojet engine for low-speed flight; for high-speed research, they were equipped with the Reaction Motors XLR-8RM (Navy designation for the USAF XLR-11 rocket engine used in the X-1) four-chamber rocket engine rated at 6,000-lbs of thrust at sea level.

The first D-558-II (BuNo 37973) was completed in November 1947. It was then trucked to Muroc on 10 December, where it underwent nearly two months of intensive preparation, including installation of the J34 turbojet engine. On 4 February 1948, Douglas chief test pilot John F. Martin rolled down the runway and climbed into the air for the maiden flight. The flight lasted less than an hour and was less than fully successful, as performance was sluggish with jet power only (the rocket engine had yet to be installed), especially on takeoff, and directional stability was poor. The latter concern was resolved by increasing the vertical tail from 11 feet 6 inches to 12 feet 8 inches. However, the rocket engine was needed to solve the problem with sluggish performance.

Following the tail modification and other changes, the initial D-558-II was used by the contractor for subsonic flight testing. Maximum speed reached by this aircraft with jet power alone was Mach **0.825** at 20,000 feet. In the summer of 1949, the first Reaction Motors XLR-8-RM-5 rocket engine—delayed by developmental problems—was finally delivered and installed in *Skyrocket* No. 1. With both jet and rocket engines now in place, the aircraft was test flown by Douglas test pilots from October 1949 to August 1951. After conducting a total of 122 flights, it was turned over to NACA on 31 August 1951 and put in storage until 1954.

The second D-558-II (BuNo 37974) was also built and delivered without its rocket engine installed. In early November 1948, Douglas test pilot Gene May flew two contract demonstration flights using jet power only. The plane was then handed to the NACA, whose pilots had conducted 21 jet-powered flights by 6 January 1950. This *Skyrocket* was then returned to the factory, to be modified for *air launched* high-speed flights. Over a 10-month period extensive changes were made to the aircraft; most importantly, the original jet engine was removed and a 6,000-lb XLR-8-RM-6 rocket engine installed along with additional rocket fuel tanks. A USAF B-29 was transferred to the Navy and delivered to the contractor's factory in El Segundo to be modified to support air-launch of the second D-588-II.

After completion of modifications, the number two aircraft was ferried back to Edwards, slung under the belly of the specially adapted P2B-1 (Navy designation for the B-29). Following several unsuccessful air launch attempts in December 1950, a fourth attempt was made on 26 January 1951. At the controls of the *Skyrocket* was contractor test pilot William B. "Bill" Bridgeman, who was inadvertently launched when his abort signal failed to reach the crew of the P2B-1. He managed to start the rocket engine and soared to a height of 40,000 feet. Before diving back to Edwards, he attained Mach 1.28 at 38,900 feet—the highest *Skyrocket* speed to date.

In the flights that followed, Bridgeman gradually advanced the speed all the way up to Mach 1.88 on 7 August 1951, while reaching a maximum altitude of 74,494 feet on 15 August 1951. On 31 August, after more contractor modifications and flight testing, Ship No. 2 was returned to NACA, where the agency's engineers examined the behavior of the aircraft before beginning their own flight research in September 1951. Over the next two years, NACA pilot A. Scott Crossfield flew the *Skyrocket* 20 times, gathering data on longitudinal stability and control, wing and tail loads, and lift, drag and buffeting characteristics at speeds up to Mach 1.878. At this point in the test program, Marine Lt Col Marion Carl piloted the D-558-II to a new (albeit unofficial) altitude record of 83,235 feet on 21 August 1953.

Following Carl's flights, NACA technicians equipped the second *Skyrocket's* rocket engine cylinders with nozzle extensions to prevent exhaust gas from affecting the rudders at supersonic speeds—a modification which also enhanced the engine's thrust by 6.5 percent at Mach 1.7 and 70,000 feet. The NACA flight team also chilled the propellants so more could be forced into the tanks and waxed the fuselage to reduce drag. With these changes in place, Crossfield made aviation history on the morning of 20 November 1953, when he became the first pilot to reach Mach 2. Aerospace historian Richard P. Hallion described the flight:

> After climbing for over an hour, the launch plane reached 32,000 feet. [NACA pilot Stanley] Butchart positioned the rocket plane for launch and, finally, the Skyrocket dropped clear of the bomber. As it fell away, Crossfield ignited the LR-8 rocket engine and began his climb, carefully watching the flight instruments so that the plane would not stray from its pre-selected flight path, wasting energy and fuel. The Skyrocket accelerated up into to the stratosphere streaming a broad white contrail. At 72,000 feet, Crossfield initiated his pushover, and the Skyrocket arced over into a shallow dive. During the dive the plane picked up speed rapidly, edging closer to Mach 2 as the engine continued to fire, the cold soaking having added vital seconds to the engine burn. At 62,000 feet, the D-558-II attained Mach 2.005, 1291 mph: A. Scott Crossfield had become the first man to travel at twice the speed of sound.

During the remainder of its test program, the D-558-II never again approached Mach 2, for the one successful attempt had demanded extensive and unusual flight preparations that could not be repeated for every high-Mach research sortie. Moreover, NACA soon anticipated receiving two more high-speed research airplanes with Mach 2.5 performance—the X-1A and the X-1B.

Meanwhile, the third and final D-558-II (BuNo 37975)—delivered with both jet and rocket engines installed—had made its inaugural flight on 8 January 1949, using jet power only. Its first flight using both jet and rocket power took place several weeks later, on 25 February. By November 1949, Douglas pilots had logged some 15 flights with

Ship No. 3, exceeding Mach 1.0 for the first time on 24 June. However, as conventional takeoffs had proven unsatisfactory with the jet/rocket powered *Skyrocket*, the airplane was modified for air launch, while retaining the original jet/rocket power plants. After a series of captive test flights, the third D-558-II was air-launched for the first time on 8 September 1950. This was followed by several contractor pilot flights with jet power only, and two more with combined jet/rocket power, before the aircraft was handed over to NACA on 15 December. From that time through August 1956, the aircraft was flown 66 times by NACA, USMC and USAF pilots performing a variety of tests.

The final flight of a D-558-II, on 28 August 1956, brought the total tally of flights in the three airplanes to 313—123 by the first, 103 by the second and 87 by the third. During more than six years of flying, the three D-558-II *Skyrockets* had rigorously explored the characteristics of swept wing aircraft at transonic and supersonic speeds, accumulating a great deal of data about pitch-up (a problem prevalent in high-speed aircraft of that era) and the coupling of lateral (yaw) and longitudinal (pitch) motions; wing and tail loads; lift, drag and buffeting characteristics of swept-wing aircraft; and the effects of the rocket exhaust plume on lateral dynamic stability. The number three airplane had also gathered data about the effects of external stores (bomb shapes, drop tanks) upon the aircraft's behavior in the transonic region. Assessing the significance of the D-558 program as a whole, Hallion stated: "It's hard to overemphasize how important the D-558s were. It was an extremely productive research program that isn't as well appreciated today as it might be."

4. X-1A: *(For photo, see page 5)*

The X-1A (USAF S/N 48-1384) was one of three second-generation X-1s built by Bell Aircraft. These test assets were envisaged as a logical step beyond the original X-1 and were optimized for nearly twice the high-speed performance potential of their predecessors. The second-generation aircraft (X-1A/B/D) were identical to one another, retaining the basic wing, tail planform and powerplant of the first generation X-1s, but with a completely different fuselage configuration and fuel feed/pressurization system. The planes were also outfitted with stronger landing gear. The X-1A, "B" and "D" models were each powered by a single four-chamber XLR11-RM-5 rocket engine. Sea level thrust rating was 6000 lb with all four chambers operating.

The basic research objective was to explore aerodynamic phenomena at speeds greater than 2.0 Mach and altitudes above 90,000 feet, including research into stability and control, aerodynamic heating, pilot actuated reaction control systems and various high-speed aerodynamic anomalies related to stability and control. Specifically, the original flight test program called for the X-1A and X-1B to be used for dynamic stability and airload investigations, with the X-1D supporting heat transfer research. For these second-generation X-1s, an EB-50 replaced the B-29 as launch aircraft.

The X-1A arrived at Edwards AFB on 7 January 1953, and was first flown by Bell test pilot Jean L. "Skip" Ziegler on 14 February, when the aircraft accomplished its first glide flight. This was followed by a second glide flight six days later. The next day (21 February), Ziegler dropped away from the B-29 launch ship and fired up the XLR-11 engine for the first powered flight. After igniting three cylinders, a fire warning light glared in the cockpit. Unaware that the alarm was false, Ziegler shut off the engine, dumped the remaining propellants, and glided down to a landing. (Maximum Mach number and altitude for this first powered flight are unknown.)

Skip Ziegler conducted several more flights in the X-1A through 25 April 1953 (none of them faster than Mach 0.94). The aircraft was then grounded and returned to Bell's Wheatfield facility for modifications. Sadly, Ziegler was killed in the fiery explosion of the No. 2 X-2 on 12 May 1953, and the X-1A was turned over to the Air Force to complete the contractor demonstration program

Following its return to Edwards, the X-1A resumed flight testing on 21 November 1953, with a powered flight by Major Chuck Yeager who completed the airplane's first supersonic flight that day (Mach 1.15). Efforts to explore maximum speed potential continued and subsequently, on 8 December, Yeager took the X-1A out to Mach 1.9 at 60,000 feet, while gingerly exploring the craft's stability and control envelope. Yet as Yeager approached Mach 2.0, the stability of the airplane began to deteriorate. The X-1A began rolling back and forth from side to side, while exhibiting a yawing motion caused by reduced directional stability. These problems did not come as a surprise; wind tunnel studies had indicated the stability of the X-1A would slowly deteriorate at high Mach numbers and Yeager was advised by Bell engineers to exercise extreme caution as he proceeded to higher speeds.

The next high-speed mission took place four days later, on 12 December, with Yeager attaining an unofficial world speed record of Mach 2.44 (1660 mph) at 75,000 feet. Then the X-1A departed controlled flight. It tumbled violently about all three axes, having encountered the phenomenon known as inertial coupling. As the X-1A plunged toward the earth, Yeager was tossed about the cockpit and knocked into a state of semi-consciousness. During his vicious descent, he plummeted some 50,000 feet in a mere 70 seconds, while enduring accelerations of plus 8gs, minus 1.3g and side loads of 2g's.

Fortunately, as the X-1A entered the denser atmosphere around 35,000 feet, its momentum slackened and the wild gyrations abated. Regaining consciousness, Yeager gradually regained control of the airplane (which had stabilized in a subsonic inverted spin) and landed safely at Edwards. Post-flight data analysis confirmed that the X-1A had indeed experienced the problem of inertial coupling. This had occurred at 1612 mph and an altitude of 74,200 feet. The possibility of this happening to high-performance aircraft had long been predicted, but Yeager's flight was the first to encounter it and, for his accomplishment that data, he was awarded the Harmon International Trophy for that year by President Dwight D. Eisenhower.

Following the 12 December 1953 mission, Air Force declared that no further high-speed flights above 2.0 Mach would be flown. Rather, the X-1A would be used to explore flight at very high altitudes. Air Force Major Arthur L. "Kit" Murray was chosen to fly the altitude missions, and, on 26 August 1954, he climbed to a record-altitude of 90,440 feet. By the spring of 1955, the aircraft had been transferred to NACA for more testing. Joseph A. "Joe" Walker took it up for its first NACA-sponsored flight on 20 July 1955; two weeks later (8 August), an explosion ripped through the plane prior to launch from its carrier aircraft at 30,000 feet. Walker was pulled *in extremis* from the X-1A, which was jettisoned into the Edwards AFB bombing range. Walker had made a narrow escape. The X-1A had completed 26 free flights.

In its brief existence, the X-1A almost doubled the speed and significantly increased the altitude envelope pioneered by its first-generation predecessors. Moreover, the X-1A became the first aircraft to explore, albeit inadvertently, the phenomenon of inertial coupling. Also significant was the major contribution of the X-1A to the initial exploration of yet another high-speed phenomenon—aerodynamic heating. Perhaps equally important, the X-1A contributed exponentially to the basic understanding of pilot physiology in a high-speed, high-altitude environment and proved once again that properly-equipped pilots could survive and remain fully functional in the most hostile of environments.

5. X-1B:

The X-1B (USAF S/N 48-1385) was virtually identical to its sister X-1A. And like the X-1A, the X-1B was originally intended to be used for dynamic stability and airloads investigations. However, by the time the X-1B was ready to fly, the X-1A had already demonstrated the type's maximum speed and altitude capabilities; thus, Air Force program directors decided to use the X-1B for pilot familiarization flights. Following those, it was to be turned over to NACA.

The X-1B arrived at Edwards AFB on 20 June 1954 and its first glide flight was conducted with Lt Col Jack L. Ridley on 24 September. The first powered flight was made by Major Arthur L. "Kit" Murray on 8 October. Following a short series of familiarization flights for Air Force test pilots, the airplane was turned over to the NACA on 3 December.

The airplane was then flown to the NACA's Langley, VA, facility, where it was fitted with dedicated test instrumentation, particularly thermal sensors and associated recorders. NACA X-1B flight testing at Edwards took place from August 1956 through January 1958. Most of the testing was for the purpose of aerodynamic heating research, with the aircraft achieving speeds in excess of Mach 1.8. Interestingly, the final four X-1B missions were flown by a then little-known NACA test pilot named Neil Armstrong. Armstrong, in fact, would have the honor of making the last landing ever in a second-generation X-1, his final flight taking place on 23 January 1958, and bringing the X-1B's total to 27 free flights.

The preliminary exploratory work of the X-1B in the field of aerodynamic heating played a major role in determining the structural and materials requirements for future high-performance research planes, such as the X-15. Specific to the X-1B, a number of relatively minor, albeit historically important, technological problems were confronted in hardware form for the first time, not the least of which was the control of a winged vehicle in flight beyond the measurable atmosphere using a reaction control system to control pitch, roll, and yaw.

6. X-1D:

While serially the last of the second-generation X-1s, the X-1D (USAF S/N 48-1386) was actually the first to be built and flown. The aircraft was delivered from Bell's New York production facility to Edwards AFB in July 1951. As noted above, the original objective was to use the X-1D for high speed heat transfer research. Bell Aircraft test pilot Skip Ziegler made the first and only successful free flight on 24 July 1951, when the X-1D was launched over Rogers Dry Lake—the unpowered glide completed after a nine-minute descent. After touchdown, the nose gear failed and the craft slid for over 1000 feet before coming ungracefully to a stop.

Following a lengthy repair process, a second flight was attempted on 22 August. With the X-1D suspended in the EB-50D's bomb bay, the mission went routinely at first. Yet as the mated aircraft ascended through 7000 feet, Lt Col Pete Everest (the X-1D's USAF test pilot) noted upon entering the cockpit that the nitrogen source pressure indicator was giving an abnormally low reading.

After discussing the problem with Bell engineers aboard the bomber, the decision was made to abort the mission; shortly thereafter, Everest began to jettison the propellants. Moments later, an explosion occurred in the X-1D's aft fuselage. This was followed by flames which were visible to the chase aircraft pilot. Fortunately, Everest was able to quickly egress the X-1D's cockpit following the initial blast. After he cleared the aircraft, Major Jack Ridley pulled the drop handle and released the X-1D's retaining shackles. The plane dropped away smoothly, trailing smoke; less than a minute later, it lay in a twisted pile on the desert floor, some two miles west of the south end of Rogers Dry Lake. It had been a close call for Everest, who managed to return to the carrier plane only seconds before the X-1D was dropped to destruction.

7. X-1E:

The Bell Aircraft Corporation's X-1E was not really a new airplane. It was the product of major modifications to the No. 2 first generation X-1 (USAF S/N 46-063). The airplane was outfitted with an upgraded cockpit, fuel turbo-pumps, pilot ejection seat, and an exotic new wing with a remarkably thin 4% thickness/chord ratio (replacing the original 8% wing). The X-1E was envisaged by NACA engineers as a full-scale, thin-wing test bed. It was powered by a Reactions Motors, Inc., LR-8-RM-5 (advanced XLR11) four-chamber rocket engine rated at 6000 lb thrust at sea level.

After an abortive first attempt at launch on 3 December 1955, the first X-1E glide flight, with NACA test pilot Joe Walker at the controls, was accomplished at Edwards AFB on 12 December. (Walker was the X-1E's pilot for no less than 21 of its total 26 missions.) The first powered flight followed three days later, with the X-1E reaching a speed of Mach 0.53 (355 mph) and an altitude of 18,814 feet. The flight test program progressed rapidly—the X-1E becoming the first aircraft to fly supersonically with a 4% thickness/chord ratio wing and proving that high-Mach capability and adequate stability were possible using such thin airfoil sections. The X-1E attained a peak altitude of 73,458 feet on 15 May 1957 and a top speed of Mach 2.2 (1487 mph) on 8 October 1957. The flight research program ended in November 1958, and with it, testing of first generation X-1s also came to an end. Flight operations with these extraordinary aircraft had been ongoing for more than 12 years, and had resulted in one of the most productive aircraft research efforts ever undertaken. The X-1E survives, and is on permanent display in front of the NASA Dryden Flight Research Center at Edwards AFB.

The Bell X-2 launching from its B-50 mothership.

8. X-2:

Built by Bell Aircraft, the ill-fated X-2 was originally envisaged as a swept-wing version of the X-1, its purpose being to explore flight at speeds and altitudes far beyond those achievable with the first and second generation X-1s. In addition to acquiring stability and control data in the high-Mach and high altitude flight regime, one of the primary objectives was to acquire inflight thermodynamic data on flight in that environment (i.e., the “thermal thicket,” or “heat barrier”). Two X-2 air vehicles were built and assigned the USAF serial numbers 46-674 and 46-675. The aircraft were constructed of stainless steel and a copper-nickel alloy and powered by a two-chamber XLR-25 15,000 lb thrust throttleable rocket engine.

With Bell Chief Test Pilot Jean L. “Skip” Ziegler at controls, captive flights of the X-2 began in July 1951, over Buffalo, with the X-2 mated to its EB-50A carrier aircraft. A number of similar trial captive sorties were completed during early 1952; and, on 22 April 1952, X-2 46-675 was delivered to Edwards AFB, CA, for further ground testing and captive flights prior to its first free flights. (X-2 S/N 46-674 was earmarked to receive the first available XLR-25 rocket engine, and was thus not initially available.)

Following two more captive flights, on 27 June 1952, Ziegler piloted the X-2 on its first unpowered glide flight; upon landing, however, the nose gear collapsed, causing sufficient damage to warrant a two-month delay for repairs. Ziegler completed a second successful glide flight on 10 October 1952, this time landing without incident. Two days later (12 October), Air Force test pilot Lt Col Frank K. “Pete” Everest, Jr., took over X-2 controls for first time, with an initial flight lasting 19 minutes and 14 seconds. By early 1953, both X-2 aircraft were ready at Bell for engine installation.

In March 1953, captive (mated) flights resumed with 46-675 at the Bell facility in New York. During the course of a routine propellant system emergency dump captive test flight on 12 May, the aircraft exploded and fell in pieces in Lake Ontario. Both Skip Ziegler and EB-50A observer Frank Wolko were lost in the accident.

Despite the accident—and the program’s engine and landing gear problems—the X-2 program soldiered on. On 15 July 1954, the second X-2 (46-674), with its untested XLR-25 engine installed, was mated to a new EB-50D (48-096) and flown to Edwards AFB. On 15 August 1954, with Lt Col Everest at the controls, it was flown (unpowered) for the first time; a second and third glide flight followed on 8 March and 6 April. Each of these three flights had ended in the same disturbing fashion: with the X-2 swerving out of control following touchdown, resulting in each case in damage that required repairs at the contractor facility and leading to the decision to redesign the aircraft’s main skid assembly.

Finally, some three years later than originally projected, the X-2 was ready to begin its powered flight program. On 18 November 1955, with Everest again at the controls, the aircraft attained a maximum altitude of 32,000 feet and a speed of Mach

0.95 on partial power, while experiencing no major problems (with the exception of a small fire in the back of the engine compartment that caused minor damage). By the time of his ninth and final flight in late July 1956, Everest had established a new speed record of Mach 2.87 (1900 mph). He warned, however, that serious stability problems could be expected at higher speeds.

On 7 September 1956, the X-2 was piloted by Air Force test pilot Captain Iven C. Kincheloe, who became the first pilot to climb above 100,000 feet as he set a new unofficial world altitude record of 126,200 ft. Although he had not departed the atmosphere, news reporters actually hailed him as "the first of the spacemen." Just three weeks later, on 27 September, Captain Milburn G. "Mel" Apt went up for his first flight in the X-2, a flight that was planned to further expand the airplane's high-speed envelope. He became the first pilot to exceed Mach 3 that day, as he took the aircraft to a top speed of 2,094 mph (Mach 3.196 at 65,500 feet). Unfortunately, while still above Mach 3, the X-2 tumbled violently out of control (a victim of the same inertial coupling that had almost claimed Chuck Yeager's life in the X-1A) and he was unable to recover it. Apt was tragically killed in the ensuing crash.

All told, the pair of X-2s completed a total of 20 glide and powered flights during a flight research program that had spanned more than four years. Although plagued by problems and ending on a tragic note, the X-2 program produced a series of technological advances that helped pave the way for future high-speed, high-altitude aircraft, such as the X-15 and the SR-71. Among the most important of these advances was the use of heat-resistant steel alloys in primary structural components. The X-2 also contributed to a rudimentary understanding of high Mach aerodynamics and its associated unknowns. Moreover, the studies generated by the X-2's directional instability at high Mach contributed significantly to an understanding of high-speed aerodynamics that had direct and immediate impact on the design of the North American X-15 rocket plane.

9. X-3: *(For photo, see page 5)*

When reporters first observed the Douglas Aircraft Company's racy, form-follows-function X-3 *Stiletto* on the flight line at Edwards AFB in October 1952, they were certain they were looking into the future of high-powered military aircraft design. The lithe, needle-nosed, trapezoidal-winged airplane *looked* like it was made for speed, and it was. For Douglas had designed the craft to explore high speed aerodynamic phenomena on an aircraft employing low-aspect, high-load wings to speeds of Mach 2.0

(1300 mph) for sustained periods of not less than 30 minutes. Unfortunately, this and other ambitious program goals would never be met—for the most part due to the lack of adequate thrust from the X-3's pair of Westinghouse J34 afterburning turbojet engines.

Construction of the first and, as it turned out, only X-3 (USAF S/N 49-2892)—a second planned aircraft was cancelled due to program difficulties and limited funding—was completed by September 1951. Following ground testing at Douglas' flight test facility, the aircraft was delivered by truck to Edwards AFB on 11 September 1952. A short time later, taxi testing got underway at the base and, during a high-speed taxi run, the X-3 actually made its first flight, albeit unofficially, lifting off the ground from Rogers Dry Lake on 15 October and getting airborne for about a mile before settling back to the ground.

The first *official* flight of the X-3 took place on 20 October 1952, with Douglas test pilot William L. "Bill" Bridgeman piloting the aircraft. He flew for about 20 minutes, reaching a speed of Mach 0.8 and an altitude of 13,560 feet, before returning to base. From this first flight, it was apparent that the X-3 was grossly underpowered and difficult to fly. With its low-power J34 engines and its very-low-aspect-ratio wings, it was hard to control and very sensitive to pitch. Takeoff speed was an astounding 260 mph! Bridgeman actually complained, "This thing doesn't want to stay in the air" (due to the low power rating of the engines and the small stubby wings).

Following completion of the contractor portion of the test effort in December 1953, the X-3 was turned over to the Air Force and, eventually, to the NACA for further testing. The most significant NACA flight occurred on 27 October 1954. During this mission the X-3 departed controlled flight at 0.92 Mach, and test pilot Joe Walker found himself victimized by the same inertial (or roll) coupling phenomenon that had first been encountered by Chuck Yeager in the X-1A (and then affecting early production-model F-100As). Walker managed to recover the aircraft and the highly-instrumented X-3 went on to provide NACA engineers with sufficient data to begin to define and successfully address the problem.

NACA's X-3 program ended in May 1956, the airplane having registered a total of 54 flights. As a high-speed research tool, the *Stiletto* was clearly a failure. The highest speed attained during the entire program was Mach 1.21 (811 mph); in fact, the X-3 was only able to achieve supersonic flight while in a dive. Yet, almost by accident, the X-3 was used to discover the cause-and-effect relationship of load distribution and aerodynamics, thus contributing significantly to the understanding of inertial (or roll) coupling, with the NACA eventually making recommendations leading to a solution which was applied to the F-100 and future high-speed fighter designs. The application of titanium alloys to certain parts of the X-3 pioneered use of this metal in airframes and skins; while the X-3's pioneering efforts in using the short span, low-aspect-ratio wing also proved of great benefit to industry.

During 1953, with data obtained directly from Douglas, the Air Force and NACA, the Lockheed Aircraft Company's legendary designer, Clarence L. "Kelly" Johnson, completed work on a new Mach 2-capable fighter, the F-104 *Starfighter*. The F-104 boasted a short span, low-aspect-ratio wing which was directly influenced by Douglas' work on the X-3. Data from the X-3 program was also of great benefit to the design of the X-15. The X-3 was transferred to the Air Force Museum in 1956.

10. X-4: ***(For photo, see page 5***

Inspired by the wartime Messerschmitt Me 163 *Komet*, the X-4 "*Bantam*" was designed to test the tailless, or semi-tailless configuration on a sweptwing aircraft at transonic speeds of approximately 0.85 Mach. Some aerodynamicists had concluded that by doing away with conventional horizontal tail surfaces, transonic instability caused by the interaction of supersonic shock waves from the wings and horizontal tail surfaces could be eliminated. In place of a horizontal tail, the X-4 relied on combined elevator and aileron control surfaces—called "elevons"—on the trailing edge of the wing for its control in pitch and yaw.

Two of the aircraft were built by Northrop Aircraft Company, Hawthorne, CA, with the USAF serial numbers 46-676 and 46-677. Initially, the X-4 was powered by two non-afterburning Westinghouse XJ30-WE-7 turbojet engines; later these were exchanged for two Westinghouse J30-WE-9 turbojet engines rated at 1600 lb thrust each. With a wingspan of just 26 feet 10 inches, a length of 23 feet 3 inches, and a gross weight of 7820 pounds, the X-4 was one of the smallest X-planes ever built.

Following construction of the first X-4 (#676), it arrived at Muroc via flat-bed trailer on 15 November 1948. After static testing and initial taxi runs, Northrop test pilot Charles "Chuck" Tucker undertook the first flight on 16 December, the aircraft achieving a maximum speed of 290 mph and maximum altitude of 11,000 feet. While the maiden flight was successful, the aircraft had pitched up severely at liftoff and Tucker had observed a slight longitudinal instability at all speeds. After the defects were corrected, the X-4 completed its second flight on 27 April 1949, with Tucker noting the airplane's greatly improved stability. Nevertheless, pitch-up problems persisted and this anomaly was never satisfactorily resolved.

The second X-4 (#677), again with Tucker at the controls, became airborne for the first time on 7 June 1949. Contractor testing continued until February 1950, with Tucker making a total of 30 flights (he was, in fact, the only contractor pilot to fly the X-4). At that time, the X-4 was turned over to the Air Force and NACA for further flight testing. However, only the second X-4 was used in the joint USAF/NACA program, to explore stability problems near the speed of sound. Scott Crossfield, who later became famous as North American's chief test pilot on the X-15, was NACA's principal test pilot on the program, completing 31 flights. Chuck Yeager logged eight flights for the USAF. The final X-4 flight took place on 29 September 1953. The X-4s had made 112 flights (10 by the first, 102 by the second aircraft). The maximum speed attained was Mach 0.94; maximum altitude was 42,300 feet.

Northrop's X-4 marked the first attempt by the U.S. military to explore the transonic flight characteristics of tailless aircraft. While not designed for supersonic speeds, the X-4 helped to determine that conventional tailless or semi-tailless configurations were not then ideally suited for transonic flight. The aircraft exhibited "hunting" about all three axes and test pilots reported a "porposing" [sic] effect so extreme it was compared to driving fast over a washboard road! In the end, the X-4 verified that pitch, roll, and yaw instability would be very difficult to overcome in a tailless aircraft. Still, it did fulfill its design mission by *disproving* a concept and thus the program was judged to be a success.

Both X-4s survived the test program without incident. The No. 1 aircraft is on display at the National Museum of the USAF (Wright-Patterson AFB, OH) and the No. 2 airplane is currently undergoing restoration prior to being placed on permanent display in the Air Force Flight Test Center's museum collection at Edwards AFB.

11. X-5:

The X-5 program came into being in 1948, following many years of domestic and foreign research into the potential advantages offered by variable-sweep-wing aircraft, with the wings fully extended for optimum low-speed handling qualities during takeoffs and landings and then, as an aircraft accelerated, swept back for maximum high-speed performance. The purpose of the program was to investigate the aerodynamic results, in free flight, of varying degrees of sweepback and determine its applicability to potential production aircraft. The Bell Aircraft Corporation built two of the test vehicles (USAF S/Ns 50-1838 and 50-1839). The aircraft were powered by a single Allison J35-A-17A non-afterburning turbojet engine rated at 4900 lb thrust at sea level.

The first X-5 (#1838) arrived at Edwards AFB in early June 1951. On the morning of 20 June, Bell company test pilot Jean “Skip” Ziegler flew the X-5 for the first time, with the wings set at minimum sweep. (While in flight, the pilot could vary the sweep of the wings anywhere from 20 to 60 degrees.) After a takeoff roll of 1000 feet, the aircraft lifted off of Rogers Dry Lake without difficulty. Ziegler noted few problems and, at 15,000 feet, experimented with the X-5’s controls, which he found sufficient if somewhat stiff. He eventually landed the plane without incident. He had attained a top speed of Mach 0.56 (375 mph) and altitude of 15,974 feet on this first flight.

Three more successful flights followed in quick succession as Ziegler accustomed himself to the X-5’s basic handling characteristics. On 16 July, in a major milestone, Ziegler completed the first inflight wing sweeping in history (20-30 degrees); shortly thereafter, he accomplished the first full sweep of the wings from 20 to 60 degrees and back. All told, Ziegler logged 24 flights in the X-5, with Bell’s portion of the Phase I test program coming to a close on 8 October 1951.

The first X-5 was formally accepted by the Air Force on 7 November 1951 (earlier, on 23 August 1951, Brig Gen Albert Boyd, Commander of the AFFTC at Edwards AFB, had become the first Air Force pilot to fly the X-5). The second X-5 (1839) arrived at Edwards on 9 October 1951 for Phase II flight testing by the Air Force, the objective being to gather limited performance, and stability and control data. An extensive NACA-sponsored flight research program using #1838 was also conducted at Edwards, from January 1952 to October 1955, with the final NACA flight (25 October 1953) being made by Neil Armstrong, his only flight on the aircraft. NACA test pilot Joseph A. Walker made by far the largest number of X-5 flights—78 out of a total of 133 flights by NACA and Air Force pilots.

Early on in the flight test program, the X-5 had acquired a reputation for being somewhat difficult to fly and, in fact, was considered “absolutely vicious” when in a stalled condition. The X-5 program suffered its blackest day on 14 October 1953, when Air Force Major Raymond Popson, while performing stall tests in #1839, entered a spin from which he was unable to recover. Popson tried unsuccessfully to eject and died instantly when the X-5 hit the desert floor. Roughly 29 hours of flight time had been accumulated on #1839 prior to its loss.

The X-5 was the first high-performance jet aircraft in the world to successfully fly with and demonstrate the feasibility of an inflight variable-sweep-wing capability. The insights provided into both the aerodynamic and structural aspects of variable-geometry wings would serve the aerospace community well. The X-5 validated the theory of variable sweep, and its influence was felt for years thereafter in the design of aircraft such as the F-111, the F-14, the B-1 and the MiG-23.

12. X-10:

Manufactured by North American Aviation, Inc., the basic mission of the unmanned X-10 was to serve as an aerodynamic and systems test bed for the upper, second-stage cruise component of the Project MX-770, SM-64 *Navaho* missile. At a later date, the X-10 was also evaluated as a cruise missile candidate on its own merits, to be armed with a nuclear warhead. A total of 13 X-10s were build at the start of the *Navaho* program, only 10 of which were ever test flown. Two Westinghouse XJ40-WE-1s (each rated at 10,100 lb static thrust at sea level) were installed in the first X-10 and used for ground run-up, taxi tests and initial flights. As flown in its later configuration, the X-10 was powered by two Westinghouse J40-WE-1 afterburning turbojet engines, each rated at 10,900 lb thrust in full afterburner and 7250 lb thrust in military power. The airframe was constructed primarily of aluminum with some magnesium parts, while stainless steel was used in the empennage section around the powerplant compartment. The basic design was a low delta-wing canard configuration.

Following completion of static (ground) tests by North American in early 1953, the first flight-ready X-10 was trucked to Edwards AFB in May that year. After taxi testing, the first flight took place on 14 October 1953 to evaluate the vehicle's flight worthiness and characteristics at subsonic speeds. During the flight, which lasted 32 minutes and covered 172 miles, the craft was controlled by a ground controller and an air controller in a Lockheed ET-33A chase plane. The second test sortie occurred on 5 December 1953, the purpose of which was to test the ground control system and out-of-sight operating techniques. This flight lasted 35 minutes, the X-10 climbing to an altitude of 24,400 feet and reaching a speed of Mach 0.71. All test objectives were met.

Overall, some 15 X-10 test missions (with several test articles) were performed at Edwards AFB through March 1955, demonstrating the airworthiness of the basic airframe, powerplant, and overall configuration for subsonic conditions. Airworthiness and equipment operation in the supersonic regime were successfully demonstrated during several of these flights at Mach numbers up to 1.84 (10th flight). In general, although there were several accidents caused by system anomalies, vehicle performance was essentially in accordance with design under the test conditions encountered.

In March 1955, it was decided to transfer all X-10 assets from Edwards to the Air Force Missile Test Center (AFMTC) at Cape Canaveral, FL. Testing there began in August 1955 and continued through early February 1957, when the X-10 completed its 27th and final ground takeoff flight. On the 19th flight, it had attained a maximum speed of Mach 2.05, establishing a speed record for turbojet-powered aircraft. While the original program envisaged 40 test flights, continuing technical difficulties with the SM-64 *Navaho* missile, coupled with rapid advances in more sophisticated ICBM designs, led to premature termination of the X-10 flight schedule and, ultimately, the cancellation of the *Navaho* program.

Despite early program termination, the X-10 accomplished its primary design objectives. In so doing, it made major contributions to the *Navaho* missile program, verifying the aerodynamics of the upper, second stage vehicle and the hardware associated with its complex navigation package. Successful operational missions with the X-10 also helped establish a technology base for remote control of high-performance aircraft, with the X-10 later acquiring the distinction of being the world's first Mach 2-capable turbojet aircraft to be used as a target drone.

The X-13 demonstrating a vertical landing to a hook device mounted atop its vertical launch/landing platform.

13. <u>X-13</u>:

A decade-and-a-half before the U.S. Marine Corps started flying jet-powered British AV-8 Harriers, the United States had its own vertical takeoff and landing (VTOL) concept demonstrator in being and flying. The X-13 *Vertijet* was a relatively low-speed research jet aircraft designed and built to explore the feasibility of building a pure jet VTOL fighter. Two X-13s were produced by the Ryan Aeronautical Company and were the culmination of the contractor's research in the field of jet VTOL which had been launched in 1947 for the U.S. Navy Bureau of Aeronautics. While the aircraft carried the USAF serial numbers 54-1619 and 54-1620, the X-13 was a USAF *and* USN sponsored program.

Compact and diminutive—with a wing area of only 191 square feet and a maximum gross weight of just 7300 pounds—the X-13 was an all-aluminum aircraft with titanium structure in high-heat-sink engine bay areas; its delta wing had a 60 degree leading edge sweepback. The craft was powered by a single, non-afterburning Rolls-Royce Avon RA.28-49 axial-flow turbojet engine. Maximum thrust rating was 10,000 lb at 8000 rpm for 10 minutes. Military thrust rating was 9350 lb at 7800 rpm for 30 minutes; normal thrust rating was 8650 lb at 7600 rpm continuously. Acceleration at full throttle exceeded that of any previous aircraft, because thrust-to-weight ratio could reach 1.25.

The first X-13 (54-1619) was delivered to Edwards AFB in August 1955. Because its conventional flight characteristics were unknown, Ryan decided to conduct flight testing in a conventional mode before attempting actual VTOL operations. On 10 December 1955, employing a temporary tricycle landing gear fitted to the underside of the fuselage, Ryan test pilot Peter F. “Pete” Girard took the X-13 airborne for the first time. The flight lasted but seven minutes, with the aircraft exhibiting a serious oscillation problem about all three axes.

Following installation of a roll and yaw damper, conventional flight testing was successfully completed. The X-13 was then mounted vertically in a tubular structure that was to serve as its initial vertical attitude landing gear. Known as the “pogo” gear, this unit enabled the craft to takeoff, hover, and land while in a vertical attitude. While mounted in the “pogo” assembly, flight tests were undertaken to explore the reaction control system, general maneuverability and handling, and pilot visibility with the X-13 in a vertical attitude. On 28 May 1956, the first Vertijet completed its initial hovering flight, reaching an altitude of less than 50 feet and a horizontal speed of less than 30 mph.

The second X-13 (54-1620) arrived at Edwards in the spring of 1956. After a first flight in conventional mode on 28 May 1956, it was also mounted on to a “pogo” test rig for preliminary hover testing. Following the completion of hook launch and landing tests from a support traier using 54-1619, the next phase of the flight testing began. With the temporary tricycle landing gear reinstalled and Girard in the cockpit, on 28 November 1956, the X-13 lifted off from the runway at Edwards, ascended to 6000 feet, and slowly pitched nose-up until it was effectively hovering in space. For many seconds Girard held the aircraft in a vertical attitude and then slowly pitched over to straight and level flight and regained flying speed. This was the first such VTOL transition of a jet-propelled aircraft ever undertaken.

Yet the ultimate test came four months later: On 11 April 1957, the X-13 lifted off vertically on its most important flight. Hovering away from the hook and its support trailer in the VTOL attitude, it ascended to altitude. Then Girard pitched over into conventional flight attitude and performed a series of conventional flight maneuvers. Then he slowed down the aircraft, pitched nose-up into a hover, and slowly descended back to the Edwards South Base ramp where he was successfully hooked up with the vertical launch platform. The X-13 had become the first jet aircraft in history to takeoff vertically, transition to conventional flight, and then transition back to the vertical for landing.

By mid-1958, however, the X-13 and its technology base had been largely forgotten—the Air Force shifting its focus to space activity and the X-15 program. Nevertheless, the X-13 is still generally regarded as one of the two most successful VTOL research efforts of the 1950s, as it demonstrated for the first time that VTOL flight, on jet thrust alone, was both technically feasible and practical. Perhaps the only failing of the program was its inability to generate follow-on production contracts—due, in part, to the X-13's small payload envelope, powerplant limitations, a conservative military establishment, and, in retrospect, program mistiming.

The X-15 pulling away just after launch.

14. <u>X-15</u>:

A joint NASA, U.S. Air Force and Navy program, the X-15 was designed to explore high aerodynamic heating rates, stability and control, physiological phenomena and other problems pertaining to hypersonic (above Mach 5.0) and near space (above 50 miles) flight in what became arguably the most successful “X” program in history. Three X-15s were built by North American Aviation, Inc., Los Angeles, CA, under the original contract, and allotted the Air Force serial numbers 56-6670, 56-6671 and 56-6672.

While the second aircraft (56-6671) was later modified, the basic X-15 was a single-seat, mid-wing monoplane equipped with low-aspect ratio wings, large dorsal and ventral vertical tail surfaces and a tubular fuselage. The outer skin of the aircraft consisted of a nickel-chrome alloy—called Inconel X—to withstand aerodynamic heating when the airplane was flying within the atmosphere. The cabin was made of aluminum and isolated from the outer structure to keep it cool, while titanium framing was used almost exclusively in the aft fuselage structure where high concentrated loads were expected.

While initially the X-15 was powered by an interim pair of uprated XLR-11 rocket engines, throughout most of the program the airplane was outfitted with a Reaction Motors Thiokol XLR-99 rocket engine which provided a maximum thrust of 57,000 lb (at 100,000 ft) and a minimum thrust of 28,000 lb. Because of the large fuel consumption of its rocket engine, the X-15 was air launched from a B-52 at about 45,000 ft and speeds upward of 600 mph.

X-15 Number #1 (56-6670) arrived at Edwards AFB on 17 October 1958, trucked over the hills from the North American plant in Los Angeles for testing at NASA’s High-Speed Flight Station. In April 1959, it was joined by the second airplane; the third would arrive in June 1959. After months of ground testing, X-15 #1 conducted its first mated (captive) flight under the wing of its B-52 carrier on 10 March 1959; additional captive flights followed, culminating in the first glide flight on 8 June.

The first powered flight (with a pair of XLR-11 engines) took place on 17 September 1959, with North American test pilot Scott Crossfield at the controls of X-15 #2. During the flight, Crossfield attained a maximum speed and altitude of Mach 2.11 and 52,341 feet, respectively, during 224.3 seconds of powered flight. He landed on the dry lakebed at Edwards AFB 9 minutes and 11 seconds after launch. Despite a small engine fire at the end of this flight and some incidents on subsequent flights, the program continued apace through 1960. The top speed attained with the XLR-11s was Mach 3.31 (2,195 mph) on 4 August 1960 with NASA research pilot Joe Walker at the controls and the peak altitude was 136,500 feet on 12 August 1960 with USAF’s Major Robert M. “Bob” White flying the airplane.

Scott Crossfield finally completed the first flight with the mammoth XLR-99 engine three days later, on 15 August; and, once he completed the contractors' flight worthiness demonstration on 6 December 1960, the envelope expansion program got underway in earnest. During an eight-month span in 1961, the X-15 became the first airplane to exceed Mach 4 on 7 March (Mach 4.43; 2,905 mph), Mach 5 on 23 June (Mach 5.27; 3,603 mph) and Mach 6 on 9 November (Mach 6.04; 4,094 mph). Each of these flights was made by Air Force Major Robert M. "Bob" White, who had also become the first pilot to climb above 200,000 feet (217,000 feet) on 11 October 1961. On 17 July 1962, he also became the first man to fly an airplane in space when he piloted the X-15 to an altitude of 314,750 feet (59.6 miles). Just over a year later, on 22 August 1963, NASA's Joe Walker piloted the aircraft to its peak altitude of 354,200 feet—67 miles above the earth's surface. White and Walker were the first of eight pilots to earn their astronaut's wings while flying the X-15.

By the end of 1963, the X-15 envelope expansion program was complete and it had met—and exceeded—its design goals. Over the next few years, the airplanes were flown to acquire detailed flight data on the hypersonic and exoatmospheric flight regimes and to support various science projects and test many of the systems that would be employed in the American space program.

While there was seldom a flight during which nothing went wrong, during the first eight years of the program it had been marred by only one serious accident. On 9 November 1962, the No. 2 X-15 experienced an engine failure and NASA pilot John McKay was seriously injured—and the aircraft almost destroyed—during an emergency landing on Mud Lake, NV.

The airplane was repaired and underwent an extensive modification process designed to enable it to achieve even higher speeds. The fuselage was slightly extended and provisions made to enable the X-15 to carry a pair of external propellant tanks which provided up to 70 additional seconds of burn time for the XLR-99 engine. Envelope expansion flights began on 25 June 1964 and the first flight with the external tanks was flown by Lt Col Robert A. "Bob" Rushworth on 3 November 1965. On 1 July, Rushworth accomplished the first flight of the airplane arrayed in an ablative thermal protection coating; and, on 19 November 1966, Major William J. "Pete" Knight established a new unofficial world absolute speed record of Mach 6.33 (4,250 mph) in the craft. Nearly a year later, on 3 October 1967, in an attempt to further extend the airplane's speed envelope, Knight dropped away from the B-52 launch aircraft and accelerated to a maximum speed of Mach 6.7 (4,520 mph at 102,000 feet). This record remains, to this day, the highest speed ever attained in an airplane.

The 199th and final X-15 mission was flown on 24 October 1968, with NASA test pilot William H. "Bill" Dana at the controls. During the course of this remarkable program, the three X-15s exceeded Mach 5 on 109 occasions—and Mach 6 four times. They climbed above 200,000 feet on 42 flights—and above 300,000 feet on four of these missions. Twelve U.S. Air Force, U.S. Navy, NASA and North American pilots had flown the aircraft, with Air Force Lt Col Bob Rushworth making the most flights (34). Eight of them earned astronaut's wings: White, Rushworth, Knight, Walker, McKay, Dana, USAF Captain Joe Engle, and USAF Major Michael Adams. Adams' wings were awarded posthumously. After climbing to a peak altitude of 266,000 feet on 15 November 1967, he departed controlled flight in the No. 3 X-15 and was unable to recover the airplane. It was his astronaut wings flight, and the only fatal mishap of the X-15 program.

Today, the X-15's legacy is preserved in the two airframes now on display at the Smithsonian Institution and the National Museum of the U.S. Air Force. The contributions of the X-15 to the aerospace community were many and diverse, among them: a) development of the first large restartable "man-rated" throttleable rocket engine; b) first use of reaction controls for attitude control in space; c) first application of hypersonic theory and wind tunnel work to an actual aircraft vehicle; d) first reusable superalloy structure capable of withstanding the temperatures and thermal gradients of hypersonic reentry; e) development of the first practical full pressure suit for pilot protection in space; and, f) demonstration of a pilot's ability to control a rocket boosted aerospace vehicle through atmospheric exit. More generally, lessons learned from the X-15 test program were of incalculable benefit to both the Apollo space program and the development of the Space Shuttle.

15. X-18:

Only one X-18 V/STOL aircraft was built by the contractor, Hiller Aircraft Corporation, Palo Alto, CA, and given the USAF serial number 57-3078. Envisaged purely as a research tool, it was funded by the Air Force in effort to obtain the nation's first real-world flight test data of a transport-sized, tilt-wing V/STOL (Vertical/Short Takeoff and Landing) propeller aircraft. Specifically, the X-18 provided a realistic flight vehicle for acquiring data to design propeller-driven tilt-wing aircraft which would take off and land vertically, yet operate like conventional aircraft having a high forward speed and carrying heavy loads.

To conserve funding and expedite design and manufacture, the contractor built the X-18 from existing components and materials. For example, the fuselage was from a refurbished YC-122 and the craft's two Allison YT40-A-14 turboprop engines and Curtiss-Wright electric contra-rotating propellers were obtained from the Navy's XFV-1 and XFY-1 VTOL concept demonstrators and the RY-3 transport seaplane program. The vertical and horizontal stabilizer group was taken from the USAF Fairchild C-123 transport, as was the nose section. Moreover, the jet engine which provided pitch control in vertical flight regimes (the X-18 was outfitted with three engines) was a proven Westinghouse J34-WE-36 turbojet engine which provided a maximum thrust of 3400 lbs. The two YT40 engines were each rated at 5850 eshp during takeoff, 5850 eshp at military power settings, and 4954 eshp at normal settings. Maximum speed was 250 mph; altitude ceiling was 35,000 feet.

Following completion of an extensive static test program at NASA's Moffett Field, CA, facility, the X-18 was disassembled and trucked to Edwards AFB. Some 11 months later—after a short series of high speed taxi tests up to speeds of 110 mph across Rogers Dry Lake—the 16 1/2 ton X-18 made its first flight in conventional mode on 20 November 1959, with Hiller test pilots George Bright and Bruce Jones at the controls. During the flight, the pilots accelerated to 105 knots and "jumped off" to a height of approximately 14 feet and then settled down again on the dry lakebed at Edwards. Four days later (24 November) the official first flight took place—pilots Bright and Jones climbing to an altitude of 4000 feet and reaching a maximum speed of 170 knots during the 18-minute mission.

The ensuing flight test program was short-lived. A total of 20 flights were completed, yet not without some difficulty. A number of basic performance and flight profile evaluations were obtained and, in general, Hiller's test pilots concluded that while flying in conventional mode the X-18 was a stable and relatively docile aircraft. A maximum tilt angle of 33 degrees was reached (which, when combined with a 17 degree fuselage AOA, gave an effective 50 degree angle), and verification of the pitch, roll, and yaw control system capabilities was completed.

The flight testing came to an abrupt and premature end on 4 November 1960 (the 20th flight): Flying at 11,000 feet with a 10 degree wing tilt angle, the X-18 yawed violently to the left, rolled to the right onto its back, and entered an inverted spin. While the pilots were able to recover the aircraft (at 6,000 feet), the incident underscored what had been suspected from the beginning of flight test—that is, an unacceptable lag in propeller roll control response. Coupled with the nagging concern of no power cross shafting between the engines (e.g., there was no power coupling between the engines; if an engine failed during VTOL operations, the resulting asymmetry would almost certainly lead to loss of the plane), this effectively grounded the X-18 permanently. Still, about 80 percent of the initial program objectives had been successfully accomplished.

Following completion of a static ground test program employing a specially built VTOL thrust stand, the X-18 was dismantled and scrapped at Edwards AFB in 1964. Although its flight test program was very brief and inconclusive, the X-18 made several contributions to V/STOL technology. It was the first large V/STOL-capable aircraft ever flown in the U.S., as well as the first to explore the practicality of using a tilt-wing for VTOL flight. The X-18 also contributed significantly to the design and development of the Vought XC-142 V/STOL transport.

16. X-21A:

Two X-21As (serial numbers 55-0408 and 55-0410) were produced by the Northrop Corporation, Hawthorne, CA. They were originally built as Douglas WB-66Ds reconnaissance aircraft. Modifications to the deactivated WB-66Ds were extensive, including many fuselage changes, a completely new wing and more powerful engines (see below). Each X-21A was powered by two GE J79-GE-13 non-afterburning turbojet engines mounted in pods on each side of the rear fuselage. The engines had a maximum power rating of 9400 lb thrust each; normal thrust rating was 9130 lb. Other specifications included: a) maximum speed, 560 mph; b) maximum altitude, 42,500 feet; and, c) range, 4780 miles.

The purpose of the X-21A program was to conduct extensive research into a low-drag boundary-layer control technique known as laminar flow control (LFC). The boundary layer is a very thin layer of air next to the surface of the aircraft in flight. When the flow of this air is uniform, the air flow is said to be laminar. But this is rare. The boundary layer generally breaks up into a turbulent flow as it passes over wings and fuselage which results in a sharp increase in friction drag, placing an unnecessary burden on aircraft engines, reducing range, payload, etc. Northrop's answer to this problem was the concept of LFC, which promised better fuel economy, reduced drag and longer range. In fact, a range increase of 50 percent or more was anticipated.

In the X-21A, Northrop sought to achieve LFC via two primary modifications to the original WB-66 aircraft. First, the underwing podded J71 engines were removed and replaced by two J79-GE-13 engines mounted in pods attached to the rear of the fuselage sides. Bleed air from the two J79s was fed into a pair of underwing fairings, each of which housed a "bleed-burn" turbine which sucked the boundary layer air out through the wing slots. Secondly, the new wing of the X-21A (increased span and area, with a sweep reduced from 35 to 30 degrees) had a multiple series of span-wise slots (800,000 in all) through which turbulent boundary-layer air was "sucked in," resulting in a smoother laminar flow.

Construction of the first X-21A (55-0408) was completed in about 18 months. On 18 April 1963, Northrop test pilot Jack Wells took the airplane up for the first time, flying from the contractor's Hawthorne, CA, facility to Edwards AFB, where formal flight testing was to begin. On 15 August 1963, the second test article (55-0410), which differed only in having an electrical de-icing system and extra test instrumentation, was also flown from Hawthorne to the Flight Test Center.

Test missions usually took place at altitudes between 25,000 and 45,000 feet and at speeds up to Mach 0.80. On 14 May 1963, the first X-21A established an aeronautical milestone by achieving laminar flow control with a measurable reduction in friction (parasitic) drag for the first time. By the end of the X-21A test program, LFC was being achieved consistently on 73 percent of the upper and 75 percent of the lower wing surface area. Handling characteristics of the aircraft were satisfactory with either laminar or turbulent flows.

Building on these initial successes, the X-21As were used to explore the impact of rain, sleet, snow and other weather anomalies on the LFC system. Still other tests were performed to ascertain the effects of maneuvering, turbulent air, humidity, clouds, and the impingement of dust, dirt, and insects. It was these latter tests which revealed the impracticality of the LFC system. For the high maintenance burden and costs incurred attempting to keep the thousands of tiny slots in the wings (the primary LFC modification to the aircraft) free of particulates convinced the sponsoring agencies that LFC aircraft were impractical in a "real world" environment. The program was terminated in 1964.

From left, the X-24A, M2-F3 and HL-10 Lifting Bodies.

17. <u>HL-10</u>:

Since 1981, millions of Americans and observers throughout the world have marveled at the achievements of the U.S. space shuttles, their launches and gliding return to Earth from orbit seemingly made possible by their "Buck Rogers" technology. What few know, however, is that these achievements were made possible by a small fleet of strange-looking wingless aircraft whose flight testing paved the way for the shuttles. These experimental aircraft were called "lifting bodies"—low-lift to drag shapes evaluated by the U.S. Air Force and NASA from 1963-1975 to determine if, through energy management techniques, they could make precision landings following high-speed (and unpowered) descents from altitudes up to 90,000 feet. The HL-10 was one of the first two of the five "heavyweight" lifting bodies which were flown at NASA's Dryden Flight Research Center.

The HL-10 was built by the Northrop Corporation's Norair Division facility, Hawthorne, CA, and delivered to NASA in January 1966. The "HL" stood for horizontal landing, while the "10" denoted the tenth design studied by engineers at NASA's Langley

Research Center. The odd-looking airplane (described as a "fattened" delta shape) was a negatively cambered airfoil with a 74 degree sweepback delta planform with three aft vertical fins. General specifications included a length of 21 feet 2 inches, a wingspan of 13 feet 7 inches, and a height of about 10 feet. A single-place vehicle with a relatively conventional 1960s cockpit and instrument panel, the HL-10 was powered by one Reaction Motors XLR-11, four-chamber rocket engine fueled by ethyl alcohol and liquid oxygen and generating a maximum thrust of 6,000 lbs. Silver zinc batteries furnished electrical power for the control system, flight instruments, radios, cockpit heat and the stability augmentation system. The pilot ejection system was a modified F-106 system.

Following delivery from the contractor, the HL-10 was instrumented and prepared for flight. The aircraft also underwent wind tunnel testing at NASA's Ames Research Center, Moffett Field, CA, before research flights began. To conduct its test missions, the aircraft was carried aloft by NASA's B-52 launch aircraft, as were all of the lifting bodies which the exception of the lightweight M2-F1. The B-52 had earlier been modified to launch the X-15 hypersonic airplanes from a right wing pylon; to carry and launch the lifting bodies, a special adapter was fitted to the pylon.

The HL-10's first glide flight, originally scheduled for 21 December 1966, was aborted due to an electrical failure. The next day, at 10:40 a.m., it was released by the B-52 at 45,000 feet above Rogers Dry Lake with research pilot Bruce Peterson at the controls. The first flight, however, was a bust. The aircraft flew for only three minutes and nine-seconds and was almost uncontrollable, pitching up excessively during flight maneuvers. Somehow, Peterson managed to land the craft safely. To correct the HL-10's poor handling, project engineers extended and cambered the leading edges of the outboard vertical fins. The aircraft remained grounded until all modifications were completed.

The modified HL-10 flew for the first time on 15 March 1968, performing a successful unpowered glide flight and demonstrating that changes to the aircraft had corrected the handling deficiencies. During the flight, the craft attained a top speed of 220 mph before making a smooth landing at Rogers Dry Lake. After 11 unpowered glide flights, the first powered flight took place on 23 October 1968, with Air Force Captain Jerauld R. "Jerry" Gentry at the controls. Yet the rocket failed shortly after launch, requiring the pilot to jettison the propellant and make an emergency landing on Rosamond Dry Lake (10 miles SW of Rogers Dry Lake). The first successful powered flight was on 13 November, with NASA test pilot John A. Manke in the cockpit. Manke reached a top speed of Mach 0.84 during the six minute 25 second flight.

On 9 May 1969, a lovely spring day in California's Mojave Desert, the HL-10 made history by successfully conducting the world's first supersonic lifting body flight. Once again, NASA's Manke was at the controls, and during a relatively uneventful six minute 50 second flight (except for going supersonic!) he reached a top speed of Mach 1.127. Some 9 months later (18 February 1970), on the 34th test flight, Air Force test pilot Major Peter C. "Pete" Hoag piloted the craft to a speed of Mach 1.86 (1,228 mph), the fastest speed that would be achieved in the HL-10 test program. Nine days later, NASA pilot Bill Dana flew the vehicle to 90,030 feet, the highest altitude reached in the test program and the highest any lifting body would achieve. (Note: Bill Dana was the third NASA research pilot to fly the HL-10. He had flown the final X-15 flight in late October 1968 and had conducted his initial HL-10 glide flight on 25 April 1969.) When asked about his record-setting achievement, Dana recalled that the flight involved no special challenges: "The view was the same as from any other vehicle flying at that altitude, and the glide down to the lakebed runway on that low wind-shear day was routine." The final flight of the HL-10 (37th overall) was logged on 17 July 1970, with Major Hoag in the cockpit; it was his eighth flight in the aircraft.

The design, development, fabrication and flight testing of the HL-10 lifting body were signal achievements made possible by a dedicated team of NASA, USAF and contractor employees. Though still little recognized, the HL-10 and the other lifting bodies "blazed the way for the development of reusable spacecraft and the space shuttle. Their flights developed the procedures necessary to make routine unpowered landings possible. They allowed designers to eliminate landing engines from the space shuttle design, thus greatly enhancing the craft's performance, simplicity and payload capacity." Today, the restored HL-10 is on display where it made history, at the Dryden Flight Research Center at Edwards AFB.

18. M2-F2:

Evolving from the M2-F1 lightweight lifting body design, the M2-F2 was one of two heavyweight lifting bodies (the other being the HL-10) based on studies at NASA's Ames and Langley research centers and built by the Northrop Corporation in the mid-1960s. (The "M" referred to "manned" and "F" to "flight.") The aircraft completed its first flight on 12 July 1966 and, over a period of 10 months, it made a total of 16 glide flights, demonstrating the subsonic approach, flare, and landing capability of a typical lifting body configuration. The program came to an abrupt end when the 16th glide flight ended in disaster when the aircraft suffered a landing accident. As a result, no powered flights were made by the M2-F2.

The M2-F2 was basically a half-cone (26-degree cone) with a blunt nose and leading-edge radii, thick stabilizing and control surfaces and a squared-off thick base. The cockpit, canopy, and nose window were located on the craft to provide the pilot the best visibility possible. The vehicle was also outfitted with a battery power system, an irreversible dual hydraulic flight control system (with artificial feel for pitch, roll and yaw control), a three-axis stability augmentation system (SAS), cabin pressurization, cabin heat, defog systems, breathing oxygen, pressure-suit provisions, a hydrogen peroxide landing rocket system, and provisions for an XLR-11 rocket engine (uprated to 8,000 lbs thrust). The M2-F2 also boasted a modified F-106 zero-zero ejection seat and quick-acting pneumatically extended landing gear. The aircraft was not equipped with on-board data recording equipment, using instead a pulse code modulation (PCM) telemetry data acquisition system.

The heavyweight lifting body (4630 lbs unfueled; about 10,000 fueled) made its first captive flight on 23 March 1966, attached to its B-52 carrier aircraft throughout the mission. The first glide flight followed several months later, on 12 July, with NASA research pilot Milton O. "Milt" Thompson at the controls. Thompson was dropped from the B-52's wing pylon mount at 45,000 feet; during this maiden flight, he reached a gliding speed of about 450 mph. Thereafter, the glide flights continued at the rate of several per month through November, attaining a top speed of Mach 0.707 (2 September 1966). The average glide flight lasted about four minutes. Once the lifting body was jettisoned from the B-52, the research pilot conducted his flight maneuvers and then landed on Rogers Dry Lake. During the course of these test activities, the M2-F-2 evinced lateral-directional control problems—despite its SAS—and was considered a challenge to fly due to its stability characteristics.

What became the final flight, culminating in a spectacular crash landing upon the lakebed, took place on 10 May 1967. With NASA test pilot Bruce Peterson at the controls, the M2-F2 suffered a pilot-induced oscillation (PIO) as it approached the lakebed for landing. Peterson described the flight:

> It was another research flight [to prepare the M2-F2 for its powered flight test program]. We were supposed to be doing a lot of test maneuvers—checking the stability, the controls and the performance. It had been calm. Then, the winds started to increase. I went to a low angle of attack on final approach. Then, all of a sudden, the nose of the M2-F2 slide out to one side. I figured I flew into a windshear, which is not uncommon in those conditions. I tried to bring the nose back with the rudder, but the nose overshot. I then tried to counter it with aileron, but I was suddenly in a severe lateral-directional oscillation [aircraft roll and yaw]. I mean, severe! It was banging my head against the canopy. I was in a world of hurt right there. I knew I had to recover wings-level, because I was getting close to the ground. I was probably doing 300 knots and coming down in about a 30-degree dive-bombing run.

The M2-F2 pitched from side to side as Peterson sought to bring it under control. He did manage to recover the craft, only to observe a rescue helicopter that seemed to pose a collision threat. Distracted, Peterson drifted in a cross-wind to an unmarked area of the lakebed where it was difficult to judge the height over the ground due to a lack of guidance the markers provided on the lakebed runway. He fired the landing rockets to gain lift, but hit the lakebed at about 250 mph before the landing gear was fully down and locked. The M2-F2 rolled over six times before coming to halt upside-down:

> After I hit the ground, the last thing I remember was a bunch of glass from the nose window coming at me. I then recall being upside down, lying on the lake bed. I was pretty badly hurt. I couldn't see anything at all. I was trapped in there and having a hard time breathing. I was lying on my head, which was scrunched over. I heard someone say, 'He's dead.' I then made some kind of noise to let them know I was alive. They cut me out of the straps and got me out of there. I was then put on a stretcher, and that's the last thing I remember.

Peterson was first taken to the hospital at Edwards AFB, then to the hospital at March AFB, and finally to UCLA Hospital. His injuries included a fractured skull, a broken hand and significant facial damage; and although he eventually recovered, he lost the vision in his right eye due to a staphylococcal infection. The badly damaged M2-F2 was dispatched to the Northrop facility in Hawthorne, CA, to be rebuilt. The main gear, canopy and right vertical fin were missing from the craft, and almost every external panel was damaged. After three years of repairs and modifications, the M2-F2 would return to flight research as a new air vehicle—the M2-F3. (Note: Portions of the M2-F2 footage, including Peterson's spectacular crash, were used for the 1973 TV movie the "Six Million Dollar Man," and later for the opening credits of each episode of the television series.)

19. <u>M2-F3</u>: ***(For photo, see page 35)***

The M2-F2 was redesigned and rebuilt by Northrop, NASA and Air Force engineers and redesignated the M2-F3. The primary modification was the addition of a third vertical fin centered between the tip fins. While the "new" lifting-body would still prove a challenge to fly, the center fin did eliminate the high risk of pilot-induced oscillation (PIO) that was characteristic of its predecessor.

On 2 June 1970, with NASA test pilot Bill Dana at the controls, the three-finned M2-F3 made its maiden flight (unpowered) after release from the B-52 carrier over Edwards AFB. Aloft for 3 minute and 38 seconds, the modified craft demonstrated much better lateral stability and control characteristics than the M2-F2. In fact, only three unpowered glide flights were necessary before the first powered flight on 25 November 1970. Again piloted by Dana, the aircraft achieved Mach 0.809 at 51,900 feet after igniting three of the four XLR-11 rocket engine chambers; it flew for six minutes and 17 seconds before landing safely at Edwards.

Flight testing continued during 1971 and 1972, with most of the missions accomplished by Bill Dana, who recorded 17 of the 19 flights through 5 October 1972. On this day, Dana soared to an altitude of 66,300 feet and a Mach number of 1.37 (slightly more than 900 mph). It was the 100th flight of the heavy-weight lifting bodies overall. Eventually, the M2-F3 was fitted with a reaction control thruster (RCT) system—similar to an orbiting spacecraft—to obtain research data about their effectiveness for vehicle control. Near the end of the test program, the M2-F3 evaluated a rate of command augmentation control system and a side-arm control stick similar to side-arm controls which now equip many modern airplanes. The final flight of the M2-F3 took place on 20 December 1972. During this flight (the 27th overall), with NASA's John Manke at the controls, the craft reached its highest altitude—71,500 feet. Seven days earlier, Dana had flown it to a top speed of Mach 1.6 (1,064 mph).

NASA donated the M2-F3 to the Smithsonian Institute in December 1973. It is currently on display in the National Air and Space Museum alongside the X-15 No. 1, which was its "hangar partner" at Dryden from 1965-69.

20. <u>X-24A</u>: ***(For photo, see page 35)***

The X-24A was also one of several peculiar-looking, wingless aircraft designs called "lifting bodies," which were evaluated by the Air Force and NASA from 1963-1975. The primary objective of the X-24A was to investigate the low speed—transonic and supersonic—flight characteristics of such designs, which derived lift from their shape alone. To accomplish its test mission, the aircraft was capable of simulating a manned re-entry vehicle from a speed of about Mach 2.0 to tangential landing.

Only one X-24A was built by the contractor, Martin Marietta Corporation, and assigned the Air Force Serial Number 66-13551. The body of the X-24A was basically a semi-monocoque structure of conventional aluminum alloy construction; it was bulbous and wedge-shaped with the bottom flat and the top a curved airfoil surface with three vertical fins. The cockpit comprised typical aircraft instrument panels, stick and pedal surface controls, an ejection seat and bubble canopy; the landing gear was a typical retractable tricycle landing gear. The primary propulsion system was a single Thiokol XLR11-RM-13 liquid propellant rocket engine rated at over 8,000 lb of thrust; propellants included water/alcohol and liquid oxygen. The engine provided enough thrust to boost the craft to an altitude of about 90,000 feet and a maximum speed of Mach 2.0. The X-24A also boasted two 500 lb thrust hydrogen peroxide "thrusters," which enabled the pilot to increase the effective lift-over-drag of the vehicle when required during landing maneuvers.

After wind tunnel testing was completed at NASA Ames, near San Francisco, CA, the X-24A was dispatched to Edwards AFB on 15 March 1968. Following a series of low- and high-speed taxi tests, as well as taxi tests with the X-24A mated to the NB-52B launch aircraft, the first captive flight with the combination took place on 4 April 1969. Two weeks later, on 17 April, USAF test pilot Major Jerauld R. "Jerry" Gentry completed the craft's first glide flight, which was followed by eight more glide flights (all but one by Gentry) through February 1970. A major objective of the glide flight program was to obtain basic aerodynamic data while expanding the flight envelope. Gentry attained a maximum speed of Mach 0.771 (509 mph) and maximum altitude of 47,000 feet—both on his eighth glide flight.

The powered flight program got underway on 19 March 1970. After the wingless air vehicle was airdropped from the NB-52B at 40,000 feet, Major Gentry ignited the rocket engine three times (for a total 160 second burn) and climbed to 44,384 feet. Top speed of the flight (its objective was to evaluate engine performance and the stability, control system and handling characteristics of the aircraft in powered flight) was Mach 0.865 (571 mph). After the engine burn-out, he glided the craft to a landing on Rogers Dry Lake.

The initial powered flight was followed by a series of envelope expansion missions, flown by NASA pilot John Manke and USAF test pilot Major Cecil Powell. On 14 October 1970, Manke completed the first supersonic flight, reaching a speed of Mach 1.186 and an altitude of 67,900 feet. Less than two weeks later, on 27 October, he piloted the craft to 71,400 feet (the highest altitude attained by the X-24A) and simulated—for the first time in an aircraft with similar performance and handling characteristics—a shuttle-type approach and landing. Several flights later, on 29 March 1971, Manke flew it out to Mach 1.60—the fastest speed recorded by the X-24A. The test program ended in June 1971.

The X-24A, or "flying potato" as it was affectionately known, flew a total of 28 times, including 18 powered flights. Like the HL-10, it helped to validate the concept that a wingless vehicle could perform precision landings after high-speed unpowered descents. In this manner, the X-24A made an important contribution to the United States space program by helping to validate the approach and landing techniques which would later be employed by the world's first true spaceship, the Space Shuttle *Columbia*. Some three decades later, X-38 program managers elected to use the X-24A design to save money, since the existing X-24A aerodynamic database was complete. This limited the number of wind tunnel tests that would have been required for a totally new design.

21. X-24B:

Following the X-24A flight test effort, the aircraft was modified into a markedly different configuration and designated the X-24B, while retaining the serial number of its predecessor (66-13551.) The basic change was a new aluminum alloy exterior structure which was delta shaped and doubled the craft's lifting surface. The aircraft's dimensions were also increased—from 24 to 37.5 feet in length and from nearly 14 to 19 feet in span (at the widest point). Empty (unfueled) weight was increased from 6,600 lbs to 7,800 lbs and the Thiokol XLR-11 rocket engine was uprated to 9,800 lbs thrust. Still, the X-24B used the same basic structures, cockpit and subsystems of the X-24A and retained the two 500-lb thrust hydrogen peroxide rocket engines for use when required during landing maneuvers.

Like the X-24A, the X-24B was part of an ongoing effort by the Air Force and NASA to demonstrate the ability to maneuver and land a vehicle designed for earth re-entry from space flight. Although the X-24B's shape offered an improved hypersonic lift-to-drag ratio, and data from the craft would be used to help develop technology for the design of future air vehicles capable of hypersonic (Mach 5-plus) speeds, the overarching objective of the test program was to see how well a vehicle designed for good hypersonic performance would perform at low, transonic, and supersonic speeds, with emphasis on conventional landing approach and the landing itself. Initial program goals, in fact, were to fly no faster than about Mach 1.5 to obtain performance data primarily from 900 miles/hr down to landing speed.

On 1 August 1973, the X-24B recorded its first unpowered glide flight when NASA pilot John Manke dropped away from the NB-52 launch plane at 40,000 feet and flew for four minutes. After several more glide flights, on 15 November 1973, he successfully completed the first powered flight, reaching a top speed of Mach 0.917 (597 mph) and an altitude of 52,764 feet.

During the 16th flight, on 25 October 1974, Air Force Lt Col Michael Love accelerated to Mach 1.76 (1163 mph) during a 135-second burn of the rocket engine and achieved the highest velocity of the X-24B program. A later mission by Manke, on 22 May 1975, resulted in the highest approach for landing, touching down on the Edwards AFB dry lakebed after having attained an altitude of 74,130 feet. On 5 August 1975, the Manke made the first landing of a lifting body aircraft on a conventional runway; a second landing on the same runway, by Lieutenant Colonel Love, occurred two weeks later. The runway landings were capstone events of the X-24B program and of the *entire* lifting body program, for they confirmed that a lifting body could safely be landed like normal aircraft on conventional runways.

On 23 September 1975, NASA test pilot William H. "Bill" Dana made the X-24B's final powered flight, bringing an end to the X-24B test program and, with it, to the era of manned, rocket-powered research aircraft at Edwards, which had begun in 1946. (Note: The X-24B completed a half dozen more unpowered glide flights through 26 November 1975.)

Over a period of 27 months the X-24B flew 36 times, piloted by four NASA and two Air Force test pilots. One of the more exotic-looking X-planes, the X-24B was also one of the more successful. Simply put, the aircraft exhibited excellent subsonic handling and power off landing characteristics and data derived from the testing provided vital insight into the low-speed/landing flight characteristics of potential hypersonic vehicles, helping pave the way for the Space Shuttle and a variety of hypersonic research proposals, including the Mach 6-capable X-24C (which was never built). X-24B landing accuracy tests demonstrated a touchdown accuracy within plus or minus 500 feet, providing sufficient confidence in lifting body controllability to allow two successful test landings on a concrete runway at Edwards (all other landings were made on Rogers Dry Lake). In November 1976, the X-24B was delivered to the National Museum of the U.S. Air Force.

The X-29

22. <u>X-29A</u>:

The X-29A flight test program was sponsored by the Defense Advanced Research Projects Agency (DARPA), USAF and NASA. Its purpose was to demonstrate a host of advanced technologies on a single airframe and, if they proved feasible, to incorporate them as rapidly as possible on the next generation of USAF tactical aircraft. These technologies included the use of advanced composites in aircraft construction; variable camber wing surfaces; strake flaps; close-coupled (movable) canards; a computerized fly-by-wire flight control system (to maintain control over an otherwise unstable aircraft); and a unique, aeroelastically tailored forward-swept wing (FSW) and its thin supercritical airfoil.

Two X-29As were built by Grumman Aerospace Corporation, Bethpage, NY, and assigned the Air Force serial numbers 82-0003 and 82-0049; the aircraft were adapted from existing Northrop F-5A "Freedom Fighter" airframes. Except for its extremely thin advanced composite construction FSW (thickness/chord ratio of 6.2% at the root and 4.9% at the tips), the X-29 generally was of conventional all-aluminum construction with steel employed in high structural load areas. Each X-29 was powered by a single General Electric F404-GE-400 turbofan jet engine rated at 16,000 lbs of thrust, static at sea-level. The aircraft had a maximum operating altitude of about 50,000 feet and a maximum speed of about Mach 1.8.

Following construction and the completion of low-speed taxi runs at the contractor's Calverton, NY, facility, X-29A-1 arrived at Edwards AFB on 11 October 1984. After a series of high-speed taxi trials, Grumman test pilot Charles A. "Chuck" Sewell conducted a successful first flight on 14 December 1984, climbing to 15,000 feet and accelerating out to more than 200 knots. Total flight time was 66 minutes. No additional flights were completed during 1984 due to unusually bad weather at Edwards AFB.

The second and third flights occurred on 4 and 22 February 1985, and were also successful. On 12 March 1985, the aircraft was officially turned over to the Air Force. The first Air Force pilot to fly the X-29 was Col Theodore J. "Ted" Wierzbanowski (4 April 1985/sixth flight of the aircraft). The test program proceeded at a brisk pace with few difficulties. On 13 December 1985, X-29A-1 became the world's first forward-swept wing airplane to exceed the speed of sound in level flight, when NASA's Steve Ishmael flew it to a speed of Mach 1.03 (690 mph) in the process. The X-29A-1 completed its final test flight on 5 August 1990, having logged 200 hours total flying time, while reaching a maximum speed of Mach 1.87 and altitude of 50,200 feet.

The second X-29A (82-0049) made its maiden flight on 23 May 1989, at Edwards AFB, with NASA's Steve Ishmael again at the controls. Ishmael, in fact, completed the most flights in an X-29—105 to be precise; while Major Harry Walker made the most by an Air Force pilot—33. When the multi-phased test effort finally ended in September 1991, the pair of X-29s had accumulated the prodigious total of 436 flights, including 14 non-research missions.

The X-29 program provided an engineering data base which was available for the design and development of future USAF tactical aircraft. Research results demonstrated that the forward-swept wings, coupled with movable canards, gave pilots excellent control response up to 45 degrees AOA. The program also underscored the advantages of several other new technologies as well as new uses for proven technologies, among them: aeroelastic tailoring to control structural divergence; use of a relatively large, close-coupled canard for longitudinal control; control of an aircraft with extreme instability while still providing good handling qualities; use of three-surface longitudinal control; use of a double-hinged trailing-edge flaperon at supersonic speeds; and vortex control. Finally, the testing confirmed the military utility of the overall X-29A aircraft design.

Yet while test program data was disseminated via select government technical documents, to date no further emphasis has been placed on forward swept wing technology in the U.S. The first X-29A is now on display in the National Museum of the U.S. Air Force, while the second aircraft is on display at the Dryden Flight Research Center at Edwards AFB.

The X-31 in controlled flight at a high angle of attack.

23. X-31:

The X-31 Enhanced Fighter Maneuverability (EFM) demonstrator was the first *international* experimental aircraft program administered by a U.S. government agency and was a major part of NATO's Cooperative Research and Development Program. An international test organization (ITO) managed by the Defense Advanced Research Projects Agency (DARPA) conducted flight testing at both Dryden and Palmdale, with NASA directly responsible for test operations at Dryden. During its test program the X-31 logged 580 flights, more than any other X-plane, furnishing data applicable to the design and development of highly maneuverable, next-generation fighters. In addition to 559 research sorties, the X-31 made 21 flights in 1995 at the Paris Air Show.

The aircraft, designed and constructed by Rockwell International Corporation's North American Aircraft and Deutsche Aerospace, was over 43 feet in length (fuselage) and had a wingspan of nearly 24 feet. Three thrust vectoring paddles were mounted on the aft fuselage and directed into the engine exhaust plume to provide control in pitch (up and down) and yaw (right and left). The X-31 was also configured with movable forward canards, and eventually with fixed aft strakes. The aircraft was operated with a digital fly-by-wire control system and powered by a single General Electric F404-GE-400 turbofan engine rated at 16,000 lbs of thrust in afterburner. The X-31 was designed to attain Mach 0.9 and an altitude of 40,000 feet. For specific testing related to the effectiveness of thrust vectoring at supersonic speeds the aircraft was flown to Mach 1.28.

The two X-31 demonstrators were assembled at the Rockwell International (now Boeing) facility at AF Plant 42, Palmdale, CA. Following roll out of the first aircraft on 1 March 1990, the first flight took place on 11 October of that year. With Rockwell chief test pilot Ken Dyson at the controls, the aircraft reached a speed of 340 mph and an altitude of 10,000 feet during a 38-minute fight. X-31 No. 2 flew for the first time on 19 January 1991, this time with Deutsche Aerospace chief test pilot Dietrich Seeck in the cockpit. During the initial phase of test operations, at Palmdale, pilots performed 108 test missions, achieving thrust vectoring in flight and expanding the post-stall envelope to 40 degrees angle-of-attack (AOA) before flight testing was moved to Dryden in February 1992.

The first flight at Dryden followed in April 1992. Thereafter, an international team of test pilots and engineers sought to expand the aircraft's flight envelope, an effort that embraced military utility evaluations pitting the X-31 against comparable—albeit non-thrust vectoring—aircraft to assess its maneuverability in simulated aerial combat. Participants in this flight test phase included NASA, the U.S. Navy, the U.S. Air Force, Rockwell Aerospace, the Federal Republic of Germany, and Daimler-Benz (formally

Messerschmitt-Bolkow-Blohm and Deutsche Aerospace). Data gleaned from the envelope expansion testing forced the team to make many modifications to the X-31's control laws, for the actual aerodynamics of the airplane were slightly different from what wind tunnel testing had predicted. The changes, however, were made quickly, and rarely delayed testing.

On 6 November 1992, the No. 2 demonstrator executed a controlled flight at 70 degrees angle-of-attack. Several months later (April 93), the same aircraft successfully performed a minimum radius, 180-degree turn employing a post-stall maneuver, flying well beyond the aerodynamic limits of conventional aircraft. (Note: The revolutionary maneuver was dubbed the "Herbst Maneuver," in honor of Wolfgang Herbst, a German proponent of using post-stall flight in air-to-air combat.) June 1993 witnessed the first tactical maneuvers with F/A-18s acting as adversary aircraft and, in August, the X-31 demonstrated full capability in flying basic fighter maneuvers. By the end of the year, the two EFM demonstrators had logged over 300 flights and reached supersonic speed (Mach 1.28).

In 1994, special software was added to the X-31 to simulate stabilizing a tailless aircraft at supersonic speeds using thrust vectoring. During these test flights, the pilot destabilized the aircraft with the rudder to stability levels that would be encountered if the aircraft had a reduced-size vertical tail. This so-called "quasi-tailless" flight test experiment showed the feasibility of tailless and reduced-tail fighters, while providing data to industry on the benefits of drag reduction, radar cross section and weight reduction potentially applicable to both commercial and military aircraft designs.

Although the X-31 offered greater flight safety since it was fully controllable and flyable in the post-stall region (unlike other fighter aircraft without thrust vectoring), X-31 No. 1 was lost in an accident on 19 January 1995. The pilot, Karl Lang, managed to eject safely at 18,000 feet after the airplane went out of control. It plummeted to the ground and crashed in an unpopulated region of the desert just north of Edwards AFB. A Mishap Investigation Board concluded that an accumulation of ice in or on the unheated pitot-static system resulted in false airspeed data to the flight control computers, causing Lang to lose control of the aircraft.

The X-31 test program ended in June 1995. The nearly five years of testing and the hundreds of flights (580 in all) had produced reams of technical data on angles-of-attack up to 70 degrees—an "unfriendly" environment well beyond the aerodynamic limits of conventional fighter aircraft. Moreover, a "glimpse into the aerospace future" was provided through the X-31's use of thrust vectoring, state-of-the-art technologies, and digital flight controls.

In 2003, the X-31 team received the prestigious International Council of the Aeronautical Sciences-von Karman Award for international cooperation in aeronautics. As explained in the *NASA X-Press*, "the ICAS-von Karman Award…is usually granted biannually. However, in conjunction with the Centennial of Flight year, the organization bestowed a special von Karman on the U.S. and German Team, in which NASA was a partner. The award was presented 'for over 20 years of successful Trans-Atlantic [research and development] teamwork producing the first-ever International X-plane and significant breakthroughs in thrust-vectoring control.'"

24. <u>X-32A</u>:

Two X-32 concept demonstrators (X-32A/B) were built by the Boeing Company, Seattle WA, in support of the Joint Strike Fighter (JSF) program. (For Lockheed Martin's JSF entry, the X-35, see below.) Initiated in 1993, the objective of the JSF effort was to produce nearly 3000 strike fighters to meet future tactical aviation needs of the three U.S. service branches, the United Kingdom's Royal Navy (RN), and the Royal Air Force (RAF). Specifically, the Pentagon sought to design, develop and produce three distinct (albeit highly common) variants of a *single* core JSF airframe design: a) a multi-role, conventional take off and landing (CTOL) aircraft for the USAF; b) a carrier-based (CV) strike fighter to for the U.S. Navy; and, c) a supersonic, short take off/vertical landing (STOVL) aircraft for the U.S. Marine Corps, the RN and RAF. The X-32A was Boeing's CTOL/CV version of its JSF design.

Both the X-32A and X-32B (the STOVL variant) were constructed from a mix of composites and lightweight metal alloys, including titanium. Designed to support a focused test program that was limited in scope, the aircraft were low-cost (yet full-scale), used off-the-shelf components where possible, and had no mission avionics or stealth treatments. Both X-32 concept demonstrators were outfitted with the Pratt & Whitney F119 afterburning turbofan engine, rated in the 35,000 lb thrust class. Maximum estimated speed of the X-32A was Mach 1.6.

The overarching objectives of the X-32 flight test program were to demonstrate the following: a) commonality and modularity for an affordable family of multi-service aircraft; b) successful short take off, vertical landing, hover, and transition; and,

c) satisfactory low speed carrier approach and handling qualities. For its part of the test program, the X-32A CTOL/CV variant was to conduct airworthiness and "up and away" flight testing for the Air Force, while also demonstrating the low speed carrier approach and handling qualities for the Navy (CV) version.

On 14 December 1999, Boeing formally rolled out both of its JSF concept demonstrator air vehicles (X-32A/B) at the company's facility at Air Force Plant 42, Palmdale, CA. Following a series of taxi tests, the first flight of the X-32A took place on 18 September 2000, with Boeing JSF chief test pilot Fred Knox at the controls. Although the flight was planned to last 30-40 minutes, it was terminated after 20 minutes in a routine landing at Edwards AFB after the two F/A-18 chase pilots discovered a small hydraulic leak on the right side of the fuselage forward of the weapons bay. (The leak, from a loose O-ring in a pressure transducer, was repaired after landing with no impact to the test schedule.)

By 19 November 2000, the X-32A had logged some 18 flights and completed 24 percent of the program's overall flight test objectives. Unfortunately, hydraulic problems continued to plague the test program, resulting in serious flight delays. In mid-November 2000, with Navy Commander Phillip Yates in the cockpit, the craft began a series of carrier-landing practice tests (i.e., low-speed approach CV tests); these trials were completed in early December, Yates having flown up to five flights a day without major difficulty. The first aerial refueling also took place in December.

Another noteworthy milestone was reached when the X-32A went supersonic for the first time (21 December 2000); during the flight, AFFTC test pilot Lt Col Edward Cabrera climbed to 30,000 feet and reached a maximum speed just above Mach 1.0. In January 2001, Boeing successfully completed vibration and acoustic testing of its unique side-mounted weapons bay. Shortly thereafter, on 3 February 2001, the X-32A accomplished its 66th and final flight and returned to contractor facilities in Palmdale. The aircraft had logged 50.4 flight hours with six different Boeing and government pilots at the controls, in the process demonstrating key JSF technologies and reducing program risk should the aircraft be selected to enter the Engineering & Manufacturing Development (E&MD) phase of the JSF program.

25. X-32B:

The X-32B was the STOVL variant of Boeing's JSF concept demonstrator design. For STOVL operations, the aircraft incorporated third generation "direct lift" technology—the propulsion system closing the rear exhaust nozzle and redirecting engine thrust downward through two lift nozzles. For conventional flight, the lift nozzles were closed and thrust directed rearward through the two-dimensional thrust-vectoring cruise nozzle—the same as in the X-32A—to propel the craft forward to supersonic speeds. As noted, the X-32B utilized the same engine as the X-32A, the Pratt & Whitney F119.

The mission of the X-32B was to demonstrate short take off, vertical landing, hover, and transition (between horizontal and vertical flight) in an effort to reduce program risk prior to entering the E&MD phase. Boeing began flying the aircraft on 29 March 2001, executing a 50-minute flight from its facility at Palmdale to Edwards AFB. During the conventional flight, the contractor's JSF lead STOVL test pilot Dennis O'Donoghue performed a series of initial airworthiness tests, including flying qualities and subsystems checkouts, reaching an altitude of 10,000 feet and a speed of 200 knots.

Per plan, the flight testing proceeded at a rapid clip. On 13 April 2001—the third and fourth flights of the X-32B—the aircraft completed the JSF program's first in-flight transitions (conversions) from conventional to STOVL flight and back again, confirming the flexibility and ease of operation of the Boeing direct lift system. (Note: More than 100 rapid one-to-three second in-flight transitions to and from STOVL mode were made over the course of the X-32B flight test effort.)

Evaluation of the X-32B at Edwards continued through 2 May 2001; in all, 14 test sorties were flown at the Flight Test Center, clearing the basic flight envelope and working on transitions between horizontal and vertical flight. The testing then shifted to the Navy test site at Patuxent River NAS, MD, the X-32B arriving there on 11 May and, in the following weeks, completing a series of key test milestones. On 24 June 2001, the aircraft became the first JSF demonstrator to transition from conventional flight to a hover. Three days later (27 June), it accomplished the program's first vertical landings, after transitioning from conventional to vertical flight. On 17 July, the airplane went supersonic for the first time (during both its 67th and 68th flights). The flying ended on 28 July, a very busy day with five test missions. The fifth and final flight that day—the 78th and final flight of the X-32B test program—was flown by U.K. Royal Navy Lt Cdr. Paul Stone and included a series of supersonic runs. Over the course of its flight testing, the X-32B made 78 test flights in all (93.6 test hours), while validating the efficacy of

Boeing's direct lift system for STOVL operations. The contractor's approach to the STOVL requirement was shown to be simple, reliable and low-risk.

26. X-34:

The ill-fated X-34 unmanned aerospace vehicle was a technology demonstrator for a reusable launch vehicle (RLV); as such, the program was one of several NASA initiatives to reduce the cost of delivering payloads into low earth orbit (LEO). Three X-34s were constructed by the prime contractor, Orbital Sciences Corporation, Dulles, VA, and referred to as X-34A-1, X-34A-2 and X-34A-3. The unpiloted, winged vehicles, resembling an unmanned version of the X-15, were slightly more than 58 feet long, boasted a 27.7-foot wingspan and stood 11.5 feet tall. They utilized composite primary and secondary airframe structures and skins, and were equipped with composite reusable propellant tanks (though the first two vehicles had aluminum liquid-oxygen [LOX] tanks) and cryogenic insulation. The system's avionics included a differential Global Positioning System (GPS) and Inertial Navigation System (INS). The X-34 was to be powered by a single MC-1 *Fastrac* liquid fuel rocket engine—a single-stage, gas-generator-cycle 60,000 lb thrust unit that burned a mixture of liquid oxygen (LOX) and refined kerosene. The craft was intended to reach a maximum altitude of at least 250,000 feet and a velocity of Mach 8.0 (5360 mph).

After departing the contractor's Dulles, VA, facility on 22 February 1999, the X-34A-1 test article (essentially a bare-bones airframe without a propulsion system or a full-up electronics/avionics suite) arrived at Edwards AFB on 24 February. Following completion of static testing at the DFRC, the first captive-carry flight mated to Orbital's specially configured L-1011 (known as "Stargazer") occurred at Edwards on 29 June 1999. The flight, however, was cut short when an F/A-18 chase plane pilot noticed a panel vibration anomaly on the L-1011, just aft of the X-34A-1. Program officials said aerodynamic wake from the mated X-34 had apparently caused panel fasteners to come loose, allowing two panels on the right and left side of the L-1011 to vibrate.

A second captive-carry flight was performed successfully on 3 September 1999, while a third—and, as events turned out—final flight took place on 14 September. Unpowered glide and powered flights, planned to begin in the spring and summer of 2000, respectively, never did take place. After experiencing a number of setbacks—i.e., on-going problems with the MC-1 engine, problems with the manufacture of composite structures for the airframe, lack of redundant back-up systems, etc.—the X-34 program was cancelled in the March 2001. The basic feeling was the technologies required for X-34 had not matured sufficiently to justify the program.

The X-35A

27. X-35A:

Two aircraft (X-35A/X-35C) were built by Lockheed Martin, Fort Worth, TX, to serve as the contractor's Joint Strike Fighter test vehicles during the concept demonstration phase (CDP) of the JSF program. The X-35A was the conventional takeoff and landing (CTOL) version proposed for the USAF, while the X-35C was the U.S. Navy variant (CV). (Note: The X-35B, the short takeoff/vertical landing (STOVL) variant for the USMC, RAF and RN, was the converted "A" model; see below.) The X-35A was not given a USAF serial number; however, it carried the number "301" on its vertical fins.

Both aircraft were manufactured from a mix of composites and lightweight metal alloys, including titanium. Like the Boeing Company's X-32 (Lockheed's challenger in the JSF program), the X-35 consisted in the main of off-the-shelf avionics, contained neither radar nor sensor suites, and had no stealth (LO) treatments. Many of the airplanes' components were taken from other weapon systems, including the F/A-18, AV-8 and F-15. With their clipped delta wing planform, large horizontal tail surfaces, and twin outwardly canted vertical fins, both of Lockheed's X-35 demonstrators resembled scaled-down versions of the company's F-22 Raptor in their basic aerodynamic shaping. The basic powerplant for both aircraft was a variant of the Pratt & Whitney (P&W) F119-PW-100 afterburning turbofan engine, rated in the 35,000 lb thrust class. Maximum estimated speed for both X-35 aircraft (i.e., all three variants) was Mach 1.8.

As noted, the X-35A was the CTOL variant of the X-35 and intended to demonstrate future fighter aircraft capabilities for the Air Force. The X-35A flight test regimen at Edwards AFB included: flying/handling qualities ("up and away" flight, envelope expansion, etc.), propulsion system testing, structural loads, subsystems, in-flight refueling, and limited aircraft performance (supersonic flight, etc.). No spin testing or weapon separation test points were to be conducted.

Lockheed Martin completed the first flight of its "A" model on 24 October 2000, the airplane lifting off from the contractor's Palmdale facility (Air Force Plant 42) at 9:06 a.m. PDT. Lockheed X-35 test pilot Tom Morgenfeld climbed quickly to altitude of 10,000 feet and maintained an airspeed of 250 knots, while performing a series of figure-eight maneuvers to demonstrate key handling qualities. After 22 minutes in the air, he touched down at Edwards AFB, the flight having gone smoothly except for a malfunction involving the two front doors on the main landing gear door system.

On 3 November 2000, Lt Col Paul Smith, Air Force chief JSF test pilot, became the first USAF pilot to fly the X-35A (5th flight overall). By 7 November, the test aircraft had flown 10 missions, including airborne refueling (conducted that very day), for a total of 8.1 flight hours, reaching a speed of Mach 0.85 and an altitude of 25,000 ft. The X-35A test team continued to open up the flight envelope when, on 21 November, the aircraft went supersonic for the first time, registering Mach 1.05 and an altitude of 25,000 feet during the 25th flight. The impressive flight test program, with all objectives and test points achieved, ended the next day when Morgenfeld ferried the plane to Palmdale, where it was to begin its conversion to the X-35B (STOVL) configuration. Final flight test figures included the following: total flights (27); total flight hours (27.4); maximum Mach (1.05); maximum "g" (5.0); peak altitude (34,000 feet); maximum AOA (20 degrees).

28. <u>X-35B</u>:

The X-35A became the X-35B, Lockheed Martin's short takeoff/vertical landing Joint Strike Fighter (JSF) demonstrator variant, when the contractor fitted it with the STOVL propulsion system in December 2000. The key to the company's STOVL variant was its shaft driven lift fan (SDLF) propulsion system, which greatly amplified lifting power without straining the engine or compromising up-and-away flight characteristics. Unlike traditional direct-lift systems which simply redirected hot engine exhaust (such as the Harrier, or Boeing's JSF STOVL design), Lockheed's system used a drive shaft to connect the engine to a counter-rotating fan located directly aft of the cockpit. The fan blades generated a column of cool air that produced some 18,000 lbs of lifting power at the front of the aircraft. In addition, smaller "roll post" ducts in each wing provided about 1500 lbs of lifting thrust on each side of the plane. All told, the X-35B's afterburning turbofan engine (a derivative of the P&W F119-PW-100) was the source of about 40,000 lbs of thrust in STOVL mode.

The mission of the X-35B was to demonstrate STOVL, hover and transition in support of USMC, Royal Air Force (RAF) and Royal Navy (RN) requirements, thus reducing risk before beginning the Engineering & Manufacturing Development (E&MD) phase of the JSF acquisition effort. Specific tests included: sustained hovers, conversions to and from conventional and STOVL modes, transitions from wing-borne to jet-borne flight, short takeoffs, and vertical landings.

Of course, the X-35B airframe had actually made its first flight on 24 October 2000, as the X-35A CTOL demonstrator (see above). On 23 June 2001, the X-35B took off and landed vertically, marking the first time in aviation history that a shaft-driven lift fan propulsion system had lifted an aircraft into the sky. The brief flight took place at Lockheed's Palmdale facility at AF Plant 42. According to pilot Simon Hargreaves of BAE Systems, "the airplane performed and handled extremely well, and we demonstrated abundant levels of thrust even at this altitude with the temperature above 80 degrees Fahrenheit."

After several more hover flights at Palmdale, the X-35B was ferried to Edwards AFB on 3 July 2000 to continue its STOVL flight-envelope expansion. On 9 July, it conducted its first airborne transition from STOVL propulsion mode to conventional mode, while going supersonic on the same flight. Less than two weeks later, on 20 July, the X-35B accomplished what Lockheed called Mission "X"—a short takeoff, level supersonic dash, and vertical landing all on the same flight. Flown by test pilot Major Art Tomassetti (USMC), this impressive test flight embraced an automatic short takeoff at 80 knots, an in-flight conversion from the STOVL propulsion system to the conventional system, a climb to 25,000 feet and acceleration to Mach 1.05. Following a series of flying qualities tests, Major Tomassetti converted back to STOVL mode, decelerated to a hover at 150 feet above ground level, and landed vertically. This Mission "X" profile—which, according to a contractor press release, no other aircraft had ever done—was repeated by BAE Systems test pilot Simon Hargreaves several days later.

The X-35B finished its flight test program on 30 July 2000. On 6 August, it flew back to Palmdale, bringing all JSF X-35 flight test activities to a close. The X-35B had flown 39 times (21.5 total flying hours), achieved a maximum speed of Mach 1.2 and a maximum altitude of 34,000 feet. It had also accomplished 27 vertical landings, 14 short take-offs and 18 vertical take-offs, while exceeding the speed of sound on five separate occasions and performing five aerial refuelings. The flight test program had achieved all its objectives; most importantly, it had validated Lockheed Martin's innovative STOVL concept—a concept many analysts had viewed with skepticism due to its high level of technical complexity—giving the contractor a "leg up" in the JSF competition.

29. X-35C:

The primary objective of the X-35C flight test program was to demonstrate that Lockheed Martin's Navy-Joint Strike Fighter (JSF) design would meet the service's requirement for a stealthy, longer-range attack airplane and fighter. The need to operate from the decks of USN aircraft carriers accounted for most of the difference between the X-35C and Lockheed's other JSF variants (X-35A/B). Externally, the wing area and control surfaces of the X-35C were larger to improve the low-speed handling characteristics essential for carrier landings, while the aircraft's greater wingspan offered increased range and payload capacity. The internal structure was strengthened to address the loads associated with catapult launches and arrested landings. The landing gear was also more robust. The "C" model, however was equipped with the same engine (a variant of the P&W F119) as the X-35A/B. While no US military service serial number was assigned, the X-35C carried the number "300" emblazoned on its vertical fins.

Following a series of engine run tests, the X-35C first took to the skies on Saturday morning, 16 December 2000, as Lockheed test pilot Joe Sweeney lifted off from the contractor's Palmdale plant and completed a 27-minute flight to Edwards AFB. After the next two flights on the 19th, Lt Cmdr Brian Brian Goszkowicz became the first U.S. Navy pilot to fly the X-35C, on 22 December. A month later, 25 January 2001, the X-35C completed tanker qualification trials with a series of air-to-air refuelings behind a USAF KC-10. On 31 January 2001 it attained another milestone, when it became the second Lockheed Martin JSF concept demonstrator to exceed the speed of sound. In two separate flights that day, test pilot Sweeney climbed to 25,000 feet and accelerated to Mach 1.05, then to Mach 1.10, validating the Navy JSF supersonic performance requirement.

On 9-10 February 2001, with its flight testing at Edwards complete, the aircraft made a 2500-mile transcontinental flight from the high-desert of Southern California to the Patuxent River NAS, MD, where it continued the test program. (Note: At the completion of the trip, the airplane had made a total of 40 flights and spent just over 39 hours aloft.) As Lockheed officials announced at the time, the flight from Edwards to Patuxent River was believed to be the first transcontinental flight ever for *any* X-plane.

Moving the X-35C from Edwards to the sea-level environment at the Navy test center had an important technical rationale. As Joe Sweeney explained, "Edwards sits at 2200 feet above sea level. Aircraft carriers sit at sea level. For a true one-to-one comparison and evaluation of the fidelity of our airplane and its capabilities in a carrier environment, [Patuxent River] is the place to be." Moreover, Patuxent River had the infrastructure and flight test engineers best suited to conduct carrier suitability evaluations.

Flight testing in Maryland went forward aggressively and, by 7 March, the X-35C had conducted 56 total flights (47 flying hours); achieved a top speed of Mach 1.15; and an altitude of 34,000 feet. By this time as well, the airplane had reached a milestone in carrier suitability testing, having logged well over 100 field carrier landing practice (FCLP) tests at the Navy's premier flight test facility. (Note: During an FCLP, the pilot "shoots" the landing approach exactly as he would on a carrier, guided to touchdown by a Fresnel lens and a landing signal officer [LSO]). The test flying concluded on 10 March 2001—the X-35C having demonstrated a high degree of carrier suitability, extremely precise handling qualities, and prodigious engine power. In nearly three months time, it had registered 73 test flights and 58 total flying hours (totals for *both* Edwards and Patuxent River), while achieving a maximum speed and altitude of Mach 1.22 and 34,000 feet, respectively.

30. X-36A:

The revolutionary X-36A Tailless Fighter Agility Research Aircraft was the outcome of a cooperative research and demonstration program between NASA Ames Research Center (Moffett Field, CA) and the McDonnell Douglas (now Boeing) Phantom Works division, St. Louis, MO. The subscale (28 percent), remotely piloted vehicle (RPV) was designed to use engine thrust vectoring and unconventional control surfaces to demonstrate tailless, high angle-of-attack (AOA) fighter agility with an airframe featuring stealthy design elements. Two of the aircraft were built, with the first X-36A unveiled to the public on 19 March 1996. No conventional military serial numbers are known to have been assigned.

With its highly maneuverable, albeit unorthodox planform (unconventional, canard configuration with no vertical tail surfaces), the X-36A was projected to have a better maneuvering envelope than the F/A-18. The craft had a conventional aluminum frame with skins of temperature-cured graphite composites (some titanium was used in and around the thrust vectoring exhaust nozzle area); it employed an advanced, single-channel digital fly-by-wire flight control system made from off-the-shelf components. The X-36 was 18 feet long with a 10-feet wingspan; it was 3 feet high and weighed 1270 lbs. It was powered by a Williams Research F112 turbofan engine that furnished about 700 lbs of thrust.

The first X-36A was delivered to NASA's Dryden Flight Research Center at Edwards AFB on 2 July 1996. (Dryden hosted the flight test program and provided range support, while NASA Ames managed the overall effort.) Following high-speed taxi tests, the aircraft conducted its first Phase I contractor flight on 17 May 1997. Under the control of project test pilot Laurence A. "Larry" Walker, the RPV lifted off from Rogers Dry Lake at 7:08 a.m. PDT. During the five-minute flight, it reached an altitude of about 4900 feet. The Phase I testing continued thorough 29 July, with the following results: Upper Level 2 handling qualities; 2 g, 20 degrees AOA; 160 knots equivalent airspeed (KEAS), and eight flights with four hours flight time.

Phase II testing began on 6 August 1997, and embraced low- and high-g agility maneuvers (i.e., 360 degree rolls at angles of attack up to 15 degrees and rapid turningrolling maneuvers up to 35 degrees AOA). Results achieved during this phase included: Level 1 handling qualities; 4.8g, up to 40 degrees AOA; and 177 KEAS. Phase III commenced shortly thereafter and included demonstrations of how the X-36A could maneuver at lower speeds and high angles-of-attack. All told, the first test aircraft accumulated 15 hours and 38 minutes of flight time on 31 successful test sorties, with the final mission of the *original* test program flown on 12 November 1997. Final results for this program included a peak altitude of 20,200 feet; top speed of 206 KEAS (234 mph); and peak structural loading of 4.8g. The X-36A had proven to be extremely agile while successfully flying maneuvers at AOAs ranging from 3 degrees to 40 degrees.

For some two decades, aeronautical engineers had been concerned about what would happen if a tailless aircraft's control system experienced in-flight damage or malfunctioned. To address the problem, the Air Force Research Laboratory (AFRL) developed the Reconfigurable Control for Tailless Fighter Aircraft (RESTORE) software. To test the software, in December 1998 the X-36 made two more flights, demonstrating that the software could successfully compensate for problems with the control surfaces.

Despite being short-lived, X-36A flight testing met or exceeded all project goals, offering meaningful insight into advanced, low-observable fighter designs. For example, the testing confirmed that the craft was extremely agile and able to perform comfortably at high AOA. The project also provided useful data in the esoteric arena of pilotless flight. Yet perhaps the most significant finding was the efficacy of the technology used to control the aircraft. As noted by Gary Jennings, Boeing's X-36 program manager, "We had a very new-technology flight control system, and it worked great. We flew four different control law [packages]," reflecting refinements over the six-month flight test period. (Note: The FCS was considered unique in that the X-36's entire aeronautical database was carried in an onboard computer.) One of the two X-36 aircraft—the only one to have ever flown—is now on display at the National Museum of the Air Force, Wright- Patterson AFB, OH.

31. X-38:

Built by Scaled Composites, Inc., Mojave, CA, the X-38 was a concept demonstrator for a space vehicle to be used as a crew return vehicle (CRV) for the International Space Station (ISS). Designed to respond to emergencies, the CRV was to be able to find its way home autonomously if crew members were incapacitated or injured. The overall program was managed by NASA's Johnson Space Center (JSC), Houston, TX, while the Dryden Flight Research Center (DFRC) at Edwards AFB furnished flight test support. Additional support was provided by other NASA agencies, the U.S. Army and U.S. Air Force. While unusual for an X-Plane program, the X-38 also involved the European Space Agency and German Space Agency.

The unmanned X-38 employed a lifting body configuration that closely resembled the X-24A lifting body. (Wingless lifting bodies generate aerodynamic lift—vital to flight in the atmosphere—from the shape of their bodies alone.) A series of five increasingly complex X-38 flight research vehicles were planned, ranging from unmanned subsonic atmospheric test vehicles to a spaceflight-qualified test asset. However, only three of the prototypes were built—the **V131**, **V132**, and the **V131R**—and used for the atmospheric portion of the flight test program. Each of these vehicles was 24.5 feet long, 11.6 feet wide and 8.4 feet high; that is, approximately 80 percent of the size of the planned crew return vehicle (CRV). They were made of composite materials, such as fiberglass and graphite epoxy, and strengthened with steel and aluminum at critical stress points. All of the X-38 test assets were to use a parafoil recovery system for the final descent to earth; and, like the X-15, they landed on skids instead of wheels. (Note: Neither the **V133**, intended as a full-scale replica of the planned CRV, nor the **V201**, the actual CRV prototype and the X-38 program's space test vehicle, were ever completed.)

Testing began in 1995, with more than 300 subscale flight tests of the parafoil and lifting body. Following delivery of the first X-38 atmospheric test vehicle (V131) to Edwards AFB, large-scale flight testing began in July 1997, when the first "captive carry" test was conducted using NASA Dryden's NB-52B test aircraft. On 12 March 1998, the V131 was dropped from the NB-52 at an altitude of 23,000 feet and completed the first glide flight of the X-38 program. The mission's primary objective was to test the parafoil parachute, steering mechanisms and landing apparatus; it amounted to only about four seconds of actual free flight, with total flight time amounting to seven minutes and 19 seconds. The first glide flight, however, was only a partial success, as the parafoil became temporarily entangled in the drogue chute when it deployed, and the landing gear proved inadequate.

On 9 September 1998, the second X-38 prototype (V132) was delivered from Johnson Space Center (via C-17 transport) to Edwards AFB, and, on 30-31 October, it completed two captive carry flights. On 6 February 1999, after initial problems with the parafoil had been resolved, the V131 was dropped without difficulty. Following this second glide flight, the V131 was sent back to Scaled Composites to be recast into the V131R configuration, which with its modified shell, more closely resembled the planned X-38 space test vehicle, the V201.

On 5 March 1999, the more advanced V132 (that is, more advanced than the V131) flew for the first time; a second free flight followed on 9 July. On 30 March 2000, the V132 flight demonstrator performed its third, and final, free flight. Dropped from the NB-52 at 39,000 feet, the aircraft flew free for 44 seconds, reaching a speed of more than 500 mph before drogue deployment. The flight demonstrated improved electromechanical actuators; a new, more stable parafoil design; and the first use of dynamic inversion flight control. The craft touched down safely on the south end of the lakebed, right on target, although one of the three landing skids failed to deploy.

On 11 July 2000, what would be the final X-38 design to fly, the V131R, was delivered to NASA Dryden at Edwards AFB. On 4 August, the "new" test vehicle accomplished its first captive carry flight. Several months later, on 2 November 2000, the modified V131 successfully conducted its initial glide flight, despite an inadvertent 360 degree roll after release from its B-52 carrier plane. Test flights of the V131R continued into 2001. On 10 July 2001, the aircraft performed a research flight which verified enhancements to the X-38's flight control software; the flight also evaluated advances in the two-stage repositioning deployment of a drogue parachute, which slowed the vehicle from 600 mph to about 60 mph and set the stage for deployment of the large, 7500-square foot, parafoil wing.

Flight testing of the V131R continued until 13 December 2001, when what proved to be the final flight of the X-38 program occurred. On this day, the test vehicle performed the highest, fastest and longest flight of the X-38 program. NASA's B-52 carrier aircraft released the X-38 from an altitude of 45,000 feet, more than a mile higher than any previous flight. During the mission, it reached transonic speeds and flew free for almost a minute, descending three miles before its drogue parachute was deployed. The flight also involved the first ground-guided free flight, remotely piloted by astronaut Ken Hamm. The craft landed safely on the south end of the lakebed at Edwards AFB.

As noted, the V201 orbital prototype (i.e., the planned X-38 space test vehicle) never actually flew, although it was 80 percent completed by the contractor. On 29 April 2002, the X-38 program was cancelled due to budget cuts. Overall flight data for the X-38 air vehicles included: V131 (7 captive carry/2 free flights); V132 (4 captive carry/

3 free flights); V131R (3 captive carry/3 free flights). Thus, the program produced a total of eight (8) free flights with the three test articles.

32. X-43A:

The X-43 was an unpiloted experimental hypersonic air vehicle designed to extend the speed boundaries of "air-breathing" propulsion systems by being the first to demonstrate an airframe-integrated, scramjet-powered aircraft in free-flight. (At the time, the world's fastest air-breathing aircraft was the since retired SR-71, cruising at slightly more than Mach 3.) In fact, the X-43 was designed and built to fly significantly faster than any previous air-breathing aircraft. The aircraft was an integral part of NASA's "Hyper-X" Program, whose objective was to demonstrate air-breathing engine technologies which would increase payload capacity—or reduce vehicle size for the same payload—for future hypersonic aircraft and/or reusable space launch vehicles. NASA Langley, Hampton, VA, had overall management responsibility for the Hyper-X Program, while NASA Dryden managed flight-research activities.

In March 1997, NASA selected MicroCraft, Inc., Tullahoma, TN, to build the X-43A. The contractor was supported by the Boeing Company, which designed the vehicle, developed flight control laws, and provided the thermal protection system. Perhaps the most exotic of all the "X" planes, the diminutive X-43A was a lifting body design slightly more than 12 feet in length and weighing about 2200 pounds. The aircraft was constructed using a fairly conventional internal aluminum and steel structure, which was covered with an alumina enhanced thermal barrier (AETB) protection system, making it highly heat resistant (a vital requirement for traveling at hypersonic speeds). The craft's scramjet engine, built by General Applied Science Laboratory (GASL), Inc. (Ronkonkoma, NY), was the product of almost three decades of research in the field of scramjet technology. Simply put, scramjets are ramjet engines in which the airflow through the entire engine remains supersonic; they operate by supersonic combustion of fuel in a stream of air compressed by shock waves generated by the shape and speed of the aircraft. Performance parameters for the X-43A included Mach 7-10 and a maximum altitude of 100,000 feet. Three of the aircraft were eventually built; serial numbers, if any, are unknown.

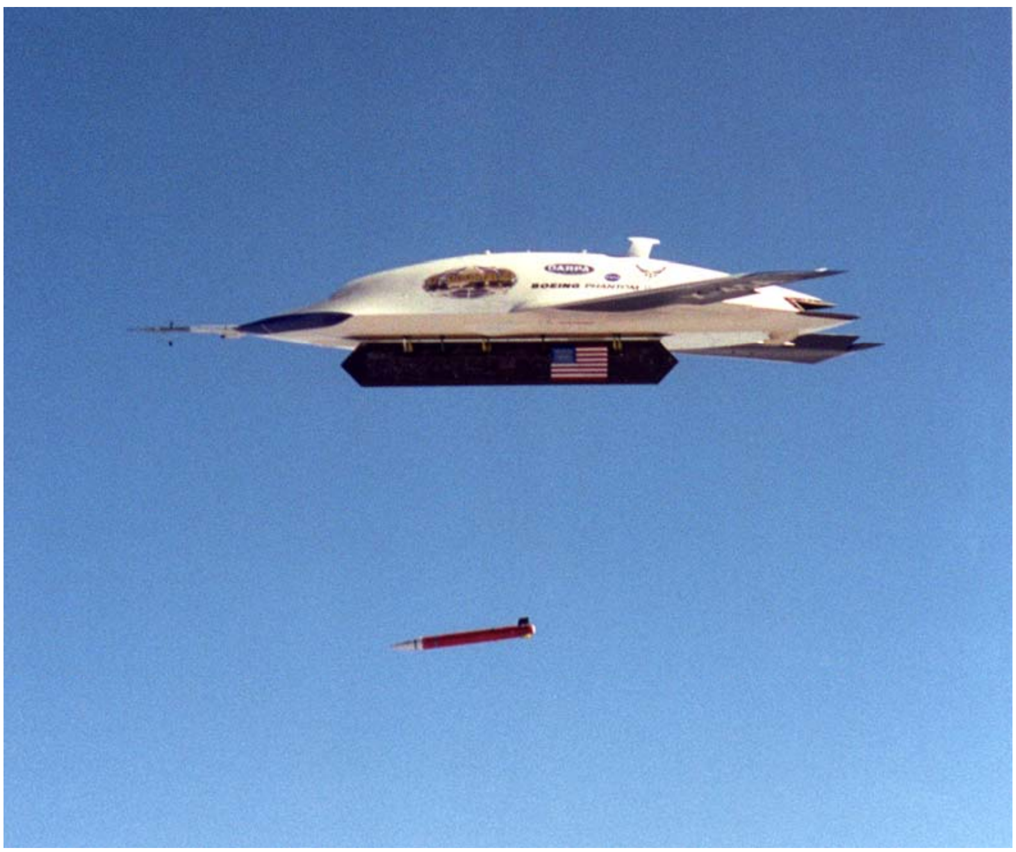
Since the X-43As would not be recoverable, the flight schedule envisaged three flights only, one with each test vehicle. Unlike conventional aircraft, the X-43A did not take off under its own power and climb to altitude; rather, the vehicle was to be carried aloft and released by NASA's NB-52B. It would then be boosted to scramjet ignition speeds by an Orbital Sciences' *Pegasus* booster, equipped with a special adapter/fairing. Following release from the NB-52B, the booster was to accelerate the X-43A to test conditions, where it was to separate from the booster and fly under its own power and preprogrammed control. All flights were to originate from the Dryden Center at Edwards AFB, with test missions conducted within the Western Sea Range off the coast of southern California, near Vandenberg AFB. Flight profiles called for launching each of the X-43s in a westerly direction, with the flight path completely over water.

On 11 August 1998, the first piece of hardware was delivered to NASA—a scramjet engine to be used for a series of ground tests in Langley's 8-Foot High Temperature Tunnel. The first completed X-43A arrived at Dryden in October 1999. Plans to fly as early as January 2000 were eventually shelved, with delays attributed to software problems, vendors who failed to ship equipment in timely fashion, and difficulties integrating systems into the air vehicle. These problems continued throughout the year.

The first flight of an X-43A finally took place on Saturday, 2 June 2001. Seventy-five minutes after takeoff, at an altitude of about 24,000 feet, the *Pegasus* booster was released from the B-52 carrier airplane. Its solid rocket motor ignited 5.2 seconds later, propelling it and the X-43A on the test flight. Eight seconds later, the booster vehicle initiated a planned pitch up maneuver, which was expected to take it to an altitude of about 95,000 feet. Yet shortly thereafter the flight failed catastrophically, the Hyper-X "stack" (X-43A and *Pegasus* booster) departing controlled flight and deviating significantly from its planned trajectory. As a result, the stack was destroyed by the range safety officer—the debris falling harmlessly into the Pacific Ocean. The mishap occurred at 1:45 p.m. PDT. A NASA-convened mishap investigation board eventually attributed the failure to inaccuracies in data modeling for the test, resulting in an inadequate control system for the *Pegasus* booster.

The second test flight of an X-43A took place on 27 March 2004 The hypersonic test vehicle was released from the wing of its carrier plane, lofted to nearly 100,000 feet by its booster rocket, and released over the Western Sea Range, where it flew briefly under its own power at Mach 6.8 (almost 5,000 mph). After burnout (fuel had flowed to the engine for 11 seconds), controllers still managed to maneuver the X-43A and manipulate the flight controls for several minutes, while the craft was slowed by wind resistance before diving into the Pacific Ocean. This successful mission made the X-43A the fastest free flying air-breathing aircraft in the world, although it was preceded by an Australian "HyShot" as the first operating scramjet engine flight.

The final flight of the program occurred nearly eight months later, on Tuesday, 16 November 2004. At an altitude of over 43,000 feet, the *Pegasus* booster rocket fell away from the B-52. Following release from the booster, the scramjet-powered X-43A accelerated to Mach 9.6 (nearly 7,000 mph), establishing a new air speed record, while demonstrating that an air-breathing engine could fly at nearly 10 times the speed of sound and that the test vehicle could withstand the tremendous heat loads involved. After operating the scramjet for about 10 seconds the X-43A, as planned, plunged into the Pacific Ocean off the coast of southern California.



The X-45A

33. X-45A:

Unmanned aerial vehicles (UAVs) have played an integral role in U.S. military operations since the Vietnam War, where they performed aerial reconnaissance, signals intelligence (SIGINT) and communications intelligence (COMINT). Supported by dramatic technological advances in the 1980s and 1990s, UAVs served as intelligence gathering platforms in the Balkan theater and in the no-fly zones over Iraq. During the ongoing Global War on Terror (GWOT), reliance on such unmanned aerial assets has increased dramatically, and now includes actual combat operations conducted by unmanned *combat* aerial vehicles—or UCAVs, such as the General Atomics RQ-1 *Predator*—in support of Operations ENDURING FREEDOM (War in Afghanistan) and IRAQI FREEDOM (War in Iraq).

The Boeing X-45A *Stingray* was a UCAV technology demonstrator designed with strike missions (such as suppression of enemy air defenses, or SEAD), electronic warfare and related operations in mind. The Boeing UCAV concept envisaged real-time, on-board and off-board sensors to rapidly detect, identify and locate fixed and mobile targets. Secure communications and advanced cognitive decision aids were to provide the human operator with the requisite situational awareness and air vehicle control to accomplish munitions release. Unlike the *Predator*, which was slow (ca. 140 knots) and relatively easy to shoot down, the X-45 was designed to fly at higher speeds, to be stealthy, and to carry more than 3000 lbs of munitions. It was also to fly and perform missions *autonomously*—that is, to be capable of identifying, tracking, and hitting targets on its own. (Human controllers were only necessary to confirm and authorize targets, and to avoid hitting "friendly" forces on the ground or civilian structures. The *Predator*, by contrast, relied on a remote operator to monitor data picked up by the plane and then instruct it to bomb the target.)

The subscale X-45A was built from state-of-the-art materials to meet critical low observable requirements; the primary load bearing structure was made of aluminum, while the craft's aerodynamic shell was constructed using graphite epoxy composites. (If the system entered production, plans called for replacing the aluminum structure with composite materials.) It was powered by one Honeywell F124 twin-shaft turbofan engine, rated at 6300 lbs of thrust. Maximum estimated speed was Mach 0.95. Six of the diminutive aircraft (about 27 feet long, with a 34-foot wingspan) could fit inside a single C-17 cargo plane. However, only two X-45As were built by the Boeing for testing. Along with the contractor, program sponsors included both DARPA and the U.S. Air Force.

The first X-45A, in "Block 1" configuration (UHF link and L-band/flight test telemetry system), was officially rolled-out on 27 September 2000 at Boeing's

St. Louis, MO, facility. Following flight testing of select aircraft systems, avionics, software and communications links at the contractor site using a surrogate air vehicle—a Boeing-operated Canadair T-33A—the first X-45A (AV-1/BLUE/"The Elsie May") arrived at NASA Dryden on 8 November 2000. The second air vehicle (AV-2/RED/"Wicked Wanda") reached the NASA facility in southern California the following spring (15 May 2001).

After both static and taxi testing, the initial flight of the X-45A took place on Wednesday, 22 May 2002. At 7:26 a.m., AV-1 lifted off from the dry lakebed at Edwards AFB. The craft completed its autonomous mission at 7:40 a.m., having attained an airspeed of 195 knots and an altitude of 7,500 feet, while demonstrating basic handling qualities and checkout of command and control links between the aircraft and the mission control station. The successful 14-minute flight was seen as a first step toward providing the Air Force with a transformational combat capability later in the decade.

Flight testing with the first air vehicle continued and, by mid-October 2002, it had accomplished five test missions. The second air vehicle, AV-2, flew for the first time on 21 November, reaching an airspeed of 195 knots, an altitude of 7,500 feet, and validating the functionality of its UCAV flight software. Flight time was 30 minutes. The second flight of AV-2 took place two weeks later, on 5 December 2002, and involved low-speed flight envelope expansion clearance.

While the second X-45A would not fly again for almost a year, AV-1 flew nine more missions through February 2003, completing the Block 1 portion of the flight test program and expanding the flight envelope to Mach 0.75 (250 KCAS) at 35,000 feet (with the weapons bay door both open and closed). Block 2 testing began with the first X-45A on 4 November 2003—the 17th overall flight and 15th by AV-1. On 18 April 2004 (flight #26), AV-1 conducted the first bombing run test, successfully releasing an inert 250-pound precision guided weapon (PGW) which struck within inches of its stationary ground target (a truck) on the test range at the Naval Air Warfare Center (NAWC), China Lake Naval Air Station (NAS), CA. The weapon was released at a speed of 442 mph from 35,000 feet, marking the first time a PGW had been released from the internal bay of an autonomous unmanned vehicle.

In another historic mission, on 1 August 2004 (flights #34-35) both X-45As, for the first time, were controlled in flight *simultaneously* (for approximately 40 minutes) by one ground controller. On 4 February 2005, the 50th flight overall and final Block 3 flight test (flying with Block 3 software had begun in October 2004), the test articles performed a two-ship reactive suppression of enemy air defenses (RSEAD) exercise. During the exercise the X-45s, in patrol pattern, were alerted to the presence of a target. They then autonomously determined which air vehicle (AV-1 or AV-2) held the better position, weapons (notional) and fuel load to attack it. After making this decision, one of the aircraft changed course and attacked a simulated anti-aircraft emplacement. Following the successful strike, a second simulated threat—this time disguised—appeared and was destroyed by the other X-45A. The exercise underscored the ability of these UCAV technology demonstrators to autonomously work as a team, manage their resources, and engage previously undetected targets.

The final Block 4 test, and final flights of the X-45A test program, took place on 10 August 2005. The two-ship mission included the 63rd and 64th flights overall—40 by AV-1 (38.3 flying hours) and 24 by AV-2 (25.1 flying hours). In the eyes of some observers, the X-45A signified a true "paradigm shift" away from the "old school" of manned air combat vehicles. Moreover, some aviation and Defense Department officials believed that UCAVs such as the X-45A might eventually provide competition to Lockheed Martin's manned Joint Strike Fighter (JSF) weapon system. Be that as it may, the Boeing X-45 program was canceled and both X-45As found their final resting places in museums—one going to the National Air and Space Museum, the other to the National Museum of the USAF at Wright-Patterson AFB, OH, where it was inducted on 13 November 2006.

34. X-48B:

Boeing Phantom Works, NASA and the Air Force Research Laboratory have teamed to study the structural, aerodynamic and operational advantages of the Blended Wing Body concept. The BWB technology demonstration aircraft resembles a flying wing, yet differs in that the wing blends smoothly into a wide, flat, tailless fuselage—a design concept which provides additional lift with less drag than a traditional circular fuselage. The Air Force designated the prototype the X-48B, and has expressed interest in its potential as a multi-role, long-range military transport aircraft.

Two X-48Bs were built to Boeing's specifications by Cranfield Aerospace in the United Kingdom. The subscale (8.5 percent) prototypes have a gross weight of 523-lbs and a wingspan of 20.4 feet, with prominent vertical fins and rudders at the wingtips and elevons along the trailing edges of the wings. Three diminutive model aircraft turbojet engines power each of the remotely-piloted planes, providing a maximum combined thrust of about 160 lbs. The X-48B has an estimated top airspeed of 118 knots (138 mph), a peak altitude of about 10,000 feet and can stay aloft for approximately 40 minutes.

In May 2006, the Blended Wing Body research team completed 250 hours of wind tunnel testing on Ship No. 1 at NASA's Langley Research Center, Hampton, VA. Following installation of requisite test instrumentation, the second X-48B technology demonstrator began ground checkout at NASA Dryden in late 2006. Flight testing at Dryden will focus on the low-speed, low-altitude flight characteristics of the blended-wing body design, including engine-out control, stall characteristics and handling qualities. The flight test program will also demonstrate that the novel design can be flown as safely as current transport aircraft with traditional fuselage, wing and tail configurations.

The collaborative efforts of the contractors and U.S. government agencies culminated in the first flight of the X-48B on 20 July 2007. At precisely 8:42 a.m. PDT, Ship No. 2 lifted off the ground at Edwards AFB and climbed to an altitude of 7,500 feet. The aircraft was flown from a ground control station, with the "pilot" using conventional aircraft controls and instrumentation while looking at a monitor fed by a forward-looking camera on the aircraft. The X-48B landed after 31 minutes of flight, successfully completing the first of up to 25 flights to gather data in the low-speed flight regime. "Friday's flight marked yet another aviation first," said Gary Cosentino, Dryden's Blended Wing Body project manager for NASA's Subsonic Fixed Wing Project. "The X-48B flew as well as we had predicted, and we look forward to many productive data flights this summer and fall."

Dr. Craig W. Luther, AFFTC History Office, Sept 2007.