



National Aeronautics and Space Administration

Academy of Program/Project & Engineering Leadership

Knowledge Legacy - From the X-15 to the Space Shuttle



The X-15 pilots clown around in front of the #2 aircraft. From left to right: USAF Capt. Joseph Engle, USAF Maj. Robert Rushworth, NASA test pilot John "Jack" McKay, USAF Maj. William "Pete" Knight, NASA test pilot Milton Thompson, and NASA test pilot William Dana. Credit: NASA [View original image.](#)

Introduction

The X-15 program, which ran from the mid-1950s through the late 1960s, sought to learn more about the problems and possibilities of hypersonic flight and human spaceflight. At first glance, the research-focused rocket planes of the X-15 project may appear to have little in common with the space shuttle, which launched nearly a decade and a half later and served NASA for 30 years. Yet in several regards the space shuttle was heir to the X-15 program. As the first reusable fixed-wing lifting-reentry spacecraft since the X-15, many of the technologies developed for the X-15 project were incorporated into the shuttle's design and operational techniques.

In a speech during the thirtieth anniversary celebration of the first X-15 flight, Charles J. Donlan—Deputy Director of the Langley Research Center during the X-15 years—said the X-15 program “established such widespread confidence in aerodynamic, thermal, and structural areas that new designs for operation aircraft for any speed regime could be expected to be successfully achieved if good use was made of all pertinent test facilities and analytical methods. This philosophy guided design of the space shuttle. And this is, in my opinion, the real legacy of the X-15.”¹

X-15 program overview

The X-15 program began as a joint initiative between the U.S. Air Force, the U.S. Navy, and NASA's precursor, the U.S. National Advisory Committee for Aeronautics (NACA). Its primary focus was on achieving hypersonic flight: more than five times the speed of sound (Mach 5). Included in the program objectives was the intention of penetrating space with the rocket-boosted aircraft. Though that remained a goal, it was in some ways a secondary focus, one many thought unachievable at the time.

The program began exploring uncharted territory long before the first X-15 left the ground. No protocol for building hypersonic vehicles existed. Lessons from the X-1 and X-2 programs suggested that pushing into hypersonic territory might cause significant problems in aircraft stability. Aerodynamic heating seemed an even more insurmountable challenge. The need for a structure that could withstand the 2,000 degree-Fahrenheit temperatures associated with reentry was critical, yet no such structure had ever been constructed. And the effects on humans of prolonged weightlessness, dynamic pressure changes, and high *g*-force flight were unknown.

Ultimately, three rocket-powered X-15 aircraft were built. Each was air-launched from beneath the wing of a B-52 at 45,000 feet. The team developed a novel uninsulated Inconel X hot structure that could handle the extreme aerodynamic heat loads. The craft was powered by a reusable 57,000-pound-thrust XLR99 engine that, when the program began, was the largest man-rated rocket engine of its time (though it was soon eclipsed by the much larger Atlas and Titan man-rated engines). The rocket plane included aerodynamic flight controls (for use within the atmosphere) as well as reaction controls (involving small jet thrusters that could maintain the craft's attitude beyond the sensible atmosphere). The reaction control system was a first in every respect. The design

¹ Proceedings of the X-15 First Flight 30th Anniversary Celebration, “The Legacy of the X-15” p. 1. Accessed 25 September 2012 at: <<http://history.nasa.gov/x15conf/legacy2.html>>

featured a three-stick flight control system. Both the center stick and right side stick managed the aerodynamic controls, the difference being that the right side stick was designed for use in high-*g* situations—including acceleration and reentry—and so could be moved with one-third the effort required by the center stick. The left side stick managed the reaction control system, activated when the aerodynamic controls were no longer effective. For the third X-15 plane (X-15-3), a control system was eventually developed that blended the aerodynamic and reaction controls. Finally, the unique X-15 tail design—which incorporated a wedge-shaped vertical stabilizer—addressed concerns regarding stability.

The X-15 program is considered one of the most successful flight research programs in NASA history. Over the course of nearly 10 years—from 1959 to 1968—and 199 flights, the X-15 planes and pilots set unofficial world speed records (Mach 6.7 on 3 October 1967, with Air Force pilot William “Pete” Knight at the helm of the X-15A-2) and altitude records (354,200 feet on 22 August 1963 by NASA pilot Joseph Walker in the X-15-3) in addition to the official world record for altitude of 314,750 feet set on July 17, 1962, which earned Air Force pilot Robert “Bob” White his astronaut wings. The program developed the first full-pressure aviation suits, crafted the first blended adaptive automatic flight control system (combining both aerodynamic and reaction controls), and furthered the energy-management concept later relied on by the space shuttle. It was the first time that wind tunnel findings and hypersonic theory were applied to actual aircraft; data from X-15 flights still offer insight into simulator and wind tunnel work.

While the program’s list of “firsts” goes on, its greatest reverberations were felt in the manned space programs that followed. X-15 findings informed the development of the Mercury, Gemini, and Apollo programs. But its most lasting impact may have been on the design and development of the space shuttle.

X-15 design innovations leveraged by the Space Shuttle Program

The X-15 program broke new ground in terms of structural materials and technology. The team solicited design proposals for the X-15 in 1954. The goal was to develop an aircraft that could withstand the thermal and dynamic pressures of high-altitude and high-speed flight and eliminate the serious stability problems encountered in previous X-plane programs. The technologies to overcome these issues did not yet exist. It was up to the X-15 engineers and the four companies that submitted proposals to develop the airframe—Bell Aircraft Corporation, Douglas Aircraft Company, North American Aviation, and Republic Aviation Corporation—to present reasonable solutions that could literally and figuratively launch the X-15 program. North American was ultimately awarded the project, based in part on their Inconel X hot-structure approach, which appeared able to handle the anticipated heat load.

Novel heat-management structure

The primary design concern was structural overheating. At speeds beyond Mach 5, reentry and flight within the atmosphere caused extreme friction, resulting in temperatures beyond 2,000 degrees Fahrenheit. Aluminum, typically used for airframe construction, has a low melting point, which meant insulation would be essential to meet the goals of the X-15. But in the mid-1950s an insulating material that could withstand the heat extremes of hypersonic flight did not exist. Instead, the X-15 team realized they

needed to build a hot structure out of a different material to handle the aerodynamic heat loads.

The X-15 engineers developed an uninsulated, exposed Inconel X hot structure that incorporated titanium-stainless steel superalloys in sections exposed to lower temperatures. Inconel X was not designed to maintain structural integrity above 1,200 degrees Fahrenheit; however, given the short nature of the flights, it was expected to perform acceptably. Because experience with both Inconel X and titanium was limited in the 1950s, the team developed new fabrication techniques for machining, forming, welding, and heat-treating the materials. "It has not been generally recognized that about 70 to 80 percent of structure of the X-15 are welded assemblies," noted Harrison A. Storms, Jr., Chief Engineer for North American Aviation, in a speech at the thirtieth anniversary celebration of the X-15's first flight.²

To help absorb some of the heat, bars were built into the leading edge of the X-15's wing. Early structures featured an open gap in the high-heat area, which caused the structure skin to buckle. The team knew that most of the heat from hypersonic flight would concentrate on the leading edge because it had the smallest curvature and was where the shock wave generated on reentry lay closest to the vehicle. As a result, the shuttle engineers built reinforced carbon-carbon (RCC) paneling into the leading edges of the wings as well as the nose cap.

In a speech at the National Air and Space Museum, NASA pilot and engineer William H. "Bill" Dana, who flew the X-15 sixteen times, explained, "All the [X-15] airplanes exhibited minor buckling of the exterior skin. During the rocket boost phase of the flight, when the aircraft was accelerating and heating rapidly, the pilot could hear the skin buckling."³ He said that fellow X-15 pilot Joseph Walker observed, "The airplane crackled like a hot stove."⁴ In addition, the frame expanded when exposed to high reentry temperatures.

The space shuttle, though fabricated from different materials, also experienced expansion due to thermal extremes. Its insulating tiles were carefully applied to accommodate the expansion and contraction of its frame. Despite this similarity, the shuttle structure bore little resemblance to the X-15. Its frame was made of aluminum because, by the early 1970s, insulating materials had advanced enough to protect aluminum frames from the heat extremes associated with flight at Mach 20 and above. However, the space shuttle engineers' choice of insulating material was influenced by the X-15's late-program experiment with ablators—protective heat shields designed to wear away at high temperatures to prevent heat from building up in structurally critical areas of the craft.

² Ibid, "X-15 Hardware Design Challenges" p 1. Accessed 25 September 2012 at: <http://history.nasa.gov/x15conf/design.html>

³ Smithsonian Institution's Charles A. Lindbergh Lecture Series. Speech given by William Dana on 21 May 1998 at the National Air and Space Museum. Text accompanying slide 13. Accessed 25 September 2012 at: <http://www.nasa.gov/centers/dryden/history/Speeches/index.html>

⁴ Ibid.

Ablative coating

The original X-15 objectives specified hypersonic speed explorations of up to Mach 6. Later in the course of the project the envelope was expanded to Mach 8.⁵ Such an increase in speed meant an associated increase in the temperatures the aircraft would endure during reentry. Because the existing Inconel X hot structure could not withstand these increased heating rates, the second X-15 plane was extensively modified, which included incorporating an ablative coating that would provide the needed thermal insulation. Fifteen materials were tested to find the right coating for the aircraft (now dubbed X-15A-2). Eventually, a Martin Marietta sprayable silicone ablator was selected. The coating made the plane heavier and harder to handle. During the second flight incorporating the ablative coating, some of the skin on the aircraft melted and substantial damage was done to the ventral fin. Nonetheless, the flight produced the highest speed associated with the X-15: Mach 6.7, an unofficial new record that would stand for nearly fifteen years (to be broken, finally, by the Space Shuttle *Columbia*). Although the X-15A-2 never flew again, the work done by the X-15 team to explore usable thermal coatings benefitted the Space Shuttle Program, already underway at the time. In his book, X-15: Extending the Frontiers of Flight, author Dennis R. Jenkins—an aerospace engineer and manager within the Space Shuttle Program—stated, “The experience with the X-15 provided very meaningful insights into the problems that the space shuttle undoubtedly would have encountered using this technology.”⁶ Due in part to the problems that the X-15 had with its ablative coating, the space shuttle team chose to explore the emerging ceramic-tile insulation options instead.

Shuttle-related insulation and engine considerations

Ceramic materials had not advanced enough to be viable for the X-15, but they were discussed. The Bell Aircraft Corporation proposal focused on an internal airframe that required external insulation. The problem, they noted, was with current technology: the ideal insulation would be made from a ceramic material, but such material could not yet be manufactured. Decades later, the space shuttle relied on silica-based ceramic tile as insulating material.

Another aspect of the Bell proposal foreshadowed shuttle design. For the engine, Bell proposed using three engines in a triangular shape, one engine on top of the others, a design later used by the space shuttle.

Tail design and stability

In their original proposal for the X-15, North American advocated a novel tail design: a wedge-shaped vertical stabilizer with a split trailing edge that would provide directional stability without increasing the size of the tail.

Stability had been a significant problem for earlier X-plane programs. The X-1 and X-2 experienced yaw difficulties during which the plane would tumble out of control. Resolving the yaw issue was especially critical for the X-15, as its reentry “angle of attack” was anticipated to range from 15-26 degrees, an approach that demanded tremendous stability.

⁵ Despite the envelope expansion, the X-15 aircraft never exceeded Mach 6.7.

⁶ Dennis R. Jenkins, “X-15: Extending the Frontiers of Flight,” p. 458.

Engineers determined that the stability problem of the earlier X-planes was due to the fact that their thin horizontal and vertical stabilizers lost effectiveness at high speed. The traditional solution to counter this and enhance stability would be to increase the X-15's tail size. One proposal even suggested making the tail as large as the wing. But calculations by Langley Research Center aerodynamicist Charles McLellan, along with subsequent wind tunnel testing, revealed an alternative solution. A wedge-shaped tail, narrow at the front and wide at the back, kept the air streams apart longer during hypersonic flight, creating the needed stability. Panels that could extend out from the side of the tail provided additional stability, and also acted as speed brakes. This wedge tail design—conceived for the X-15—became the accepted standard for hypersonic flight. However, even though the unique tail design provided the ultimate stability during hypersonic flight, modern spacecraft—including the space shuttle—don't use it, as they rely on computer control to achieve stability.

The initial North American proposal called for a wedge-shaped stabilizer that reflected McLellan's findings. The final X-15 tail featured a blunt trailing edge rather than the split trailing edge proposed by North American. But while that design element wasn't used on the X-15, it was ultimately incorporated into the tail design for the space shuttle. The orbiter has a wedge-shaped vertical stabilizer that controls yaw and a split rudder that acts as a speed brake during reentry. However, the shuttle never flew with its speed brake in the open position, forming the wedge, because its reentry position and computer-controlled stability rendered the tail shape irrelevant.⁷

Pressure suits

The aggressive velocity and altitude objectives of the X-15 program meant that the pilots would fly higher and faster than ever before. The pressure they would encounter during atmosphere climb-out and reentry would be extreme. Although the cockpit was pressurized, they required a back-up system should the cabin lose pressure. This drove the need for the first full pressure suit. Walter C. Williams, chairman of the X-15 Flight Test Steering Committee (later the Joint Operating Committee), said, "It was felt important to develop a full pressure suit.... This suit became the foundation on which suit technology was built for use in the space programs."⁸

The David Clark Company developed the suits used in the X-15. Their first creation was the MC-2. It was cumbersome and limited both movement and peripheral vision. Thirty-six flights were conducted in the MC-2, though the pilots disliked it.

Meanwhile, the David Clark Company was working on a technological breakthrough: the A/P22S-2. This suit was crafted from Link Net, a more lightweight, bendable nylon fabric that nonetheless was equipped with an integral *g* suit. It was much easier to handle than the MC-2. Because the cockpit was filled with nitrogen to protect pilots from the extreme heat during flight, oxygen was provided through the faceplate of the A/P22S-2. Instead of using a neck seal, the A/P22S-2 featured a face seal that was both more comfortable and more durable. Durability was critical as that seal was the only thing keeping the nitrogen in the body of the suit from entering the oxygenated face mask. To the pilots, the new suit was a huge advance. Easier to wear and see out of, it also included a

⁷ Thanks to Dennis Jenkins for clarifying this point.

⁸ X-15 First Flight 30th Anniversary, "X-15 Concept Evolution" p 1. Accessed 25 September 2012 at: <<http://history.nasa.gov/x15conf/concept.html>>

feature they'd asked for: removable gloves. The A/P22S-2 set the standard for future suits.

Inertial flight data system

At all times during flight—both in and outside the sensible atmosphere—X-15 pilots needed a system to determine the aircraft's altitude, velocity, and attitude. Due to the high speeds and altitudes flown by the program, conventional pressure-measuring devices couldn't provide accurate data. Two inertial flight data systems (IFDS) were incorporated into the X-15: the first was an analogue system developed by the Sperry Gyroscope Company specifically for the X-15, and the second—brought in later—was a Honeywell digital inertial guidance system made available by the cancelled X-20 program.

Developing the Sperry system was challenging and more time-consuming than anticipated. Simply put, technology had not yet advanced to meet the needs of the X-15 project. As a result, a number of problems plagued the system, ranging from the unexpected weight of the platform to its cooling requirements. Even when those were resolved, the system performed erratically and often sub-optimally. Later design reconfigurations improved performance. When the X-15 program expanded to Mach 8 in the mid-1960s, the Sperry analogue system was selected as the preferred IFDS.

Designed originally for the Dyna-Soar program, the digital system was better understood than the analogue version by the time it was installed on the X-15-1 in 1964 and on the X-15-3 at the end of 1965. While difficulties arose in modifying the system to work in the X-15, the Honeywell IFDS exhibited a smaller margin of error than the analogue IFDS and could be relied on for greater precision.

But the true advance in guidance systems came later, when the X-15-3 was equipped with a groundbreaking system developed by Ames Research Center. It included the Honeywell IFDS, an MH-96 adaptive control system—which blended aerodynamic and reaction controls—a ball nose system, and an Alert digital computer. This system was so advanced that the space shuttle used a similar set up later in its program.⁹

Blended adaptive flight control system

The X-15 was the first aircraft to use an automated flight control system that switched seamlessly from aerodynamic controls to reaction controls—also known as ballistic controls—as the plane moved in and out of the atmosphere.

Earlier X-plane programs had determined that aerodynamic controls were ineffective in the upper atmosphere. A reaction control system was required beyond the *sensible atmosphere*—that is, the part of the atmosphere in which resistance to the aircraft could be felt—to guide the X-15's attitude and velocity. Without it, the plane was as likely to fly sideways or even upside down as it was to fly right side up and forward. Attitude control was particularly critical in preparing for reentry: if the aircraft was not perfectly positioned, it could bounce off the atmosphere back into space and potentially overshoot its destination. NASA pilot Neil Armstrong was at the stick of an X-15 when he positioned it inaccurately for reentry and the plane bounced off the atmosphere. That flight proved to be the longest in X-15 history—a feat no one cared to repeat.

⁹ Dennis R. Jenkins, "X-15: Extending the Frontiers of Flight," p. 165.

X-15 was the first program to demonstrate a successful transition between aerodynamic and reaction controls. Initially, the team assumed there would be a clear boundary between atmosphere and space where the shift from aerodynamic controls to reaction controls would take place. "Engineers asked us to find out where that magic altitude was," said Air Force pilot Joe Engle. But there wasn't one. Eventually the team developed a blended adaptive control system that automatically switched from the aerodynamic controls to the reaction controls as needed during flight. The system obviated the need for multiple control sticks in the cockpit; a single stick sufficed. This system provided the basis for future space control flight systems.

"The same flight control system developed on X-15 was used on the Space Shuttle," confirmed Engle, the only person to pilot both vehicles.

Landing gear

The landing gear for the X-15 was relatively simple, consisting of instrumented landing skids plus a nose wheel. Its nose strut was quite short, the length dictated by a need for the landing gear to take up as little room as possible when stowed during flight. As a result, the X-15 put a lot of pressure on the equipment during landing. When the X-15 came in for landing, the skids touched down at speeds of 200 miles per hour, followed by the nose of the aircraft. "It was a really ugly thing," recalled Engle. "You just kind of made sure that your teeth were together when the nose started down. It was a pretty good smack."¹⁰ A similar short-nose tricycle-style landing gear concept—designed, like the X-15's, by Charlie Feltz—was used for the space shuttle.

Additional air data

While both the X-15 and the space shuttle were highly instrumented vehicles, additional air data were needed during approach and landing. Typically, the X-15 was equipped with a static dogleg pitot tube: a pressure-sensitive instrument that provided critical information on airspeed. But when the X-15A-2 was modified for Mach 8 flight, a retractable pitot was designed to extend, when required, below Mach 2 to indicate airspeed and assist with landing. A similar retractable design was later used on the space shuttle.

Additional sensors for evaluating air data in extreme flight environments were explored in X-15 experiments. A hypersonic flow-direction system—called the ball nose—was placed on the nose of the airplane to measure the angle of attack and sideslip. As the program progressed, the team found that the standard ball nose system on the X-15 planes was more complicated than it needed to be, making it vulnerable to failure. A fixed ball nose was designed and placed on the left wingtip. Following positive results, a fixed ball nose was included for experimental purposes on six of the final seven X-15 flights. This design provided the basis for an experiment using a similar system on the Space Shuttle *Columbia*: the Shuttle Entry Air Data System (SEADS).

¹⁰ "From X-15 to Shuttle" presentation by Major General Joe Engle at NASA Headquarters in Washington, DC on 18 February 2010.

X-15 operational techniques leveraged by the Space Shuttle Program

Angle of attack: the blunt body principle

In the early 1950s, the world envisioned space flight as taking aerodynamic design to the extreme. To achieve supersonic speeds, engineers assumed that a streamlined design—a spacecraft with a needle-thin nose and ultra-slim wings—was essential. And they were right. For supersonic flight, streamlined aerodynamics were ideal. But for hypersonic flight—over Mach 5—the opposite was true.

This first came to light as scientists sought to design effective intercontinental ballistic missiles (ICBMs). While a streamlined, pointed nose would help the enormous missile soar thousands of miles through space, the incredible friction—and associated thermal extremes—created when it reentered Earth’s atmosphere could cause the missile to burn up. In wind tunnel simulations, the tips of the missile nose cones would melt on reentry. Aerodynamic design was clearly not the answer for hypersonic vehicles.

In 1951, a blunt body concept was introduced by H. Julian Allen, a researcher at Ames Research Center. Applying physics to the problem, he determined that while drag was a hindrance in supersonic flight—hence the need for aerodynamic shapes—it actually benefitted hypersonic craft. A blunt-shaped aircraft body would create more drag, slowing down reentry and reducing the associated heat. Its shape would also produce a thicker shock wave upon reentry, insulating the missile from much of the heat by pushing the shock wave away from the missile body much like the prow of a boat pushes the wake away from the sides of the vehicle as it cuts through water.

For the X-15, the blunt body concept was incorporated into the reentry position, known as the “angle of attack.” The X-15 reentered the atmosphere nose up at roughly 20 degrees, presenting the broad lower surface of the craft to increase its profile and create more drag. This forced deceleration at higher altitudes and helped dissipate energy by heating the atmosphere. It decreased frictional heating of the aircraft and lowered heat loads and heating rates, rendering heat transfer less extreme.

The space shuttle perfected its angle of attack to 40 degrees. This maneuver, which resembled a lengthy swan dive, adequately slowed reentry, limiting overheating and facilitating a precise landing. Both the X-15 and the shuttle had to reenter at specific angles of attack: too steep and they could burn up; too shallow and they could skip off the atmosphere like a rock across a pond.

Unpowered landings and energy management

The X-15 refined the unpowered landing technique later employed by the space shuttle. Early discussions about landing requirements for the shuttle assumed the vehicle would have to include an air-breathing engine that would function within the atmosphere and power it safely back to Earth, similar to conventional airliner landings. “People didn’t think we could land the shuttle without a bit of powered flight,” said pilot Joe Engle.¹¹

Christian Gelzer, Dryden Flight Research Center Chief Historian, elaborated: “They were going to put jet engines on the shuttle so that once it entered the atmosphere, they would pop these jet engines out and school them up. That way the pilots would be able to fly the orbiter like an airplane back to the landing site.”

¹¹ Ibid.

But the X-15 program set a different example.

Though powered by the largest man-rated rocket engine of its time, the X-15 relied on a sustained unpowered glide through reentry, approach, and landing. To achieve the ideal glide leading to a precision landing, energy management was essential. Once the engine died, the pilot carefully balanced the plane's speed and energy. As he arrived at the high key—the ideal position from which to land without overshooting or missing the runway—the pilot executed what later became known as the Terminal Area Energy Management maneuver, carefully controlling speed and altitude.

In their article, "The Contributions of Lifting Bodies,"¹² authors Christian Gelzer and Peter Merlin explained, "A typical flight for the X-15 meant launching over eastern Nevada. If everything went according to plan, the pilot lit the engine shortly after falling away from the B-52 and began a fast, steady climb. Usually he shut the engine down after 90 seconds, rarely letting it run more than two minutes; at which point the fuel tanks were virtually empty anyway. The X-15 carried so much energy by then that it continued its trajectory, sometimes into space, before reaching its apogee and starting its descent."¹³ The X-15 was back on the dry lakebed at Edwards in 9-10 minutes—a figure that includes the 90-120 second engine burn, not to mention the time spent at "high key" completing a 360 degree circle at some 50,000 feet above the base while setting up for a landing, meaning that X-15 pilots used energy management for nearly four-fifths of each flight and always landed without motive thrust."

X-15 pilot Bill Dana, in his speech at the National Air and Space Museum, further described the high key maneuver used by both the X-15 and the space shuttle "All the pilots used a circling approach that was commenced at 30,000 to 50,000 feet above the runway and they stayed high on profile until it was assured that they would reach the runway, at which time speed brakes were used to descend onto a nominal glidescope."¹⁴

Any remaining propellant was jettisoned to eliminate potential explosives and lower the plane's landing weight. This action alerted two chase planes to the X-15's location. The chase planes then followed the X-15 down, providing needed information to ensure a safe landing.

The unpowered landings perfected by the X-15 convinced engineers that the next reusable fixed-wing lifting-reentry vehicle—the space shuttle—could abandon the plan to carry air-breathing engines along with additional fuel for powered landings. Although some skepticism lingered that a vehicle as large as the space shuttle could land without power, the space shuttle ultimately followed the X-15's unpowered reentry flight pattern almost exactly.

Simulators

While the X-15 program was not the first to train pilots using simulators, it was the first to do so extensively, encouraging pilots, engineers, and flights controllers to train together.

¹² In NASA's Contributions to the Shuttle Program, forthcoming.

¹³ Of the 199 total flights the X-15s made, 13 reached space.

¹⁴ Lindbergh Lecture Series, 21 May 1998. Text accompanying slide 17. Accessed 25 September 2012 at: <<http://www.nasa.gov/centers/dryden/history/Speeches/index.html>>

The simulators served other critical purposes as well, informing aircraft development and mission planning. Author Dennis Jenkins noted, “The X-15 demonstrated that simulators were useful for engineering simulations, mission planning, flight profile investigations, as well as pilot training. Shuttle used them for all those functions. [Simulators] may well be the X-15’s most lasting legacy.”

Two analogue simulators were used exhaustively during the years of the X-15 program. A third hybrid analogue-digital simulator was recruited from the defunct Dyna-Soar program specifically for the X-15A-2 Mach 8 initiative. The function of the hybrid simulator, however, was more for heating and control predictions than pilot training, and was not integral to the program. As a result, engineers used the opportunity to design a more generic simulator that could be used for other aircraft as well. This hybrid analog-digital simulator was later used by the Space Shuttle Program to learn more about heating on reentry.

“For planning X-15 flights and for pilot practice, extensive use was made of a fixed base analogue simulator,” recalled Bill Dana. “Every flight was preceded by ten or twenty hours of simulation of normal and emergency procedures. The simulator had to be continually updated with data gathered in flight.”¹⁵

“They would let the crew practice going to Mach 2.5 in the simulator before they flew the X-15 in the air. That evolved into the same type of approach for the space shuttle. Of course, the [space shuttle] orbiter had to fly the whole Mach range the first time except for the approach-to-landing test,” said Fred Martin, a senior engineer in the Applied Aeroscience and Computational Fluid Dynamics Branch at Johnson Space Center.

The simulator was linked to the control room so that pilots, engineers, and flight controllers could practice together. For the space shuttle, “The crew would interactively help the engineers adjust the flight control system before it ever flew, based on the simulations,” said Martin.

The X-15 program also used airborne simulators. A JF-100C simulator, modified to express the flight characteristics of the X-15, included the “beta-dot” technique. Developed to explore reentry from high altitudes in the event of damper failure, it was a technique that few X-15 pilots mastered. Fortunately, it was rarely relevant to X-15 flight. But the equation was later used during the Space Shuttle Program to investigate and overcome problems with unstable control coupling.

Rogers Dry Lake

A final operational element in both the X-15 and space shuttle programs was their use of Rogers Dry Lake in the Mojave Desert as a runway. Both projects used other runways as well—the X-15 unintentionally (for emergency landings), the space shuttle as a matter of course. For its role in the development of the U.S. space program—by providing a runway resource that could accommodate the long landing-distance requirements of hypersonic landing skid-equipped vehicles—Rogers Dry Lake was designated a National Historic Landmark in 1985.

¹⁵ Ibid, text accompanying slide 16.

The X-15-space shuttle legacy

Summary of X-15 innovations leveraged by the Space Shuttle Program:

- Wedge-shaped tail design¹⁶
- Blended adaptive flight control system
- Angle of attack for reentry and landing
- Unpowered landings and Terminal Area Energy Management maneuver
- Extra insulation on leading edges of craft
- Short-nose tricycle-style landing gear
- Full pressure suits¹⁷
- Advanced inertial flight data system
- Retractable pitot tube air data system for landing
- Fixed ball nose hypersonic flow-direction system¹⁸
- Hybrid analogue-digital simulator as well as an overall emphasis on the importance of simulator use

Given the time that has passed since the last X-15 plane flew and the remarkable advances in computer technology and materials that have occurred since, no one would be surprised if the X-15 program were now simply an interesting historical note in the annals of flight history.

But the X-15 program was, and still is, much more. It was born at an opportune moment: NACA, Air Force, and Navy were all driven to push past the boundaries of supersonic flight, and no competing programs were consuming the available budget. Still, the program faced challenges.

Some obstacles were conceptual: many believed, when the program was conceived, that human spaceflight was decades away. As a result, spaceflight was almost excised from the program's objectives. But the program persevered.

Other challenges were more practical: when the program began, the technology simply didn't exist to realize the ambitions of the X-15 project. So the team uncovered new materials, designed new technology, and conceived new systems to meet their goals.

The X-15 team was made up of diverse institutions and individuals who possessed what might be called single-minded focus—except that one of the strengths of the program was that it leveraged divergent thinking and found solutions in an array of emerging innovations. The team's broadminded thinking was complemented by what Harrison Storms, North American Aviation Chief Engineer, called *thoughtful courage*. At the 30th anniversary celebration of the X-15's first flight, he explained, "There is a very fine line between stopping progress and being reckless. [...]he necessary ingredient in this situation of solving a sticky problem is attitude and approach. The answer, in my opinion, is what I refer to as 'thoughtful courage.' If you don't have that, you will very easily fall into the habit of fearful safety and end up with a very long and tedious-type solution at

¹⁶ Although the wedge tail was used on the space shuttle, it wasn't strictly needed for stability as the shuttle relied on computer control to maintain stability.

¹⁷ Full pressure suits were used on 75 of the shuttle's 135 missions.

¹⁸ Used on both the X-15 and the space shuttle as experiments, not primary air-flow data systems.

the hands of some committee. This can very well end up giving a test program a disease commonly referred to as 'cancelitis,' which results in little or no progress and only creates another 'Hangar Queen.'"¹⁹

The X-15 team made an art of pushing the boundaries of engineering design, technological innovation, flight profiles, and courage.

The space shuttle developed under very different circumstances. The atmosphere in the 1970s was thick with budget concerns, and attention was regularly diverted away from the space shuttle toward a potential space station. Fortunately, when the shuttle program finally got the green light, it didn't have to start from scratch. In X-15: Extending the Frontiers of Flight, Dennis Jenkins wrote, "It is certain that the development of the Space Shuttle would have carried a far greater risk if not for the lessons learned from the development and flight testing of the X-15."

Though there were many differences between the vehicles, the space shuttle was able to capitalize on technological, design, and flight-technique innovations arising from the X-15 program. Even in the last years of the Space Shuttle Program, it revisited advanced concepts introduced by the X-15 and incorporated them into the shuttle, such as the Ames-designed guidance system that graced the X-15-3.

Another critical lesson is not found in the specifics passed from the X-15 to the space shuttle. It is reflected in the need for broadminded thinking when conceiving of programs and courage in implementing them; and in the careful examination and transference of knowledge from past programs to present ones. It stands as an example of how the knowledge legacy of one generation of flight vehicles can shape the next.

¹⁹ X-15 First Flight 30th Anniversary, "X-15 Hardware Design Challenges" p 1. Accessed 25 September 2012 at: <<http://history.nasa.gov/x15conf/design.html>>