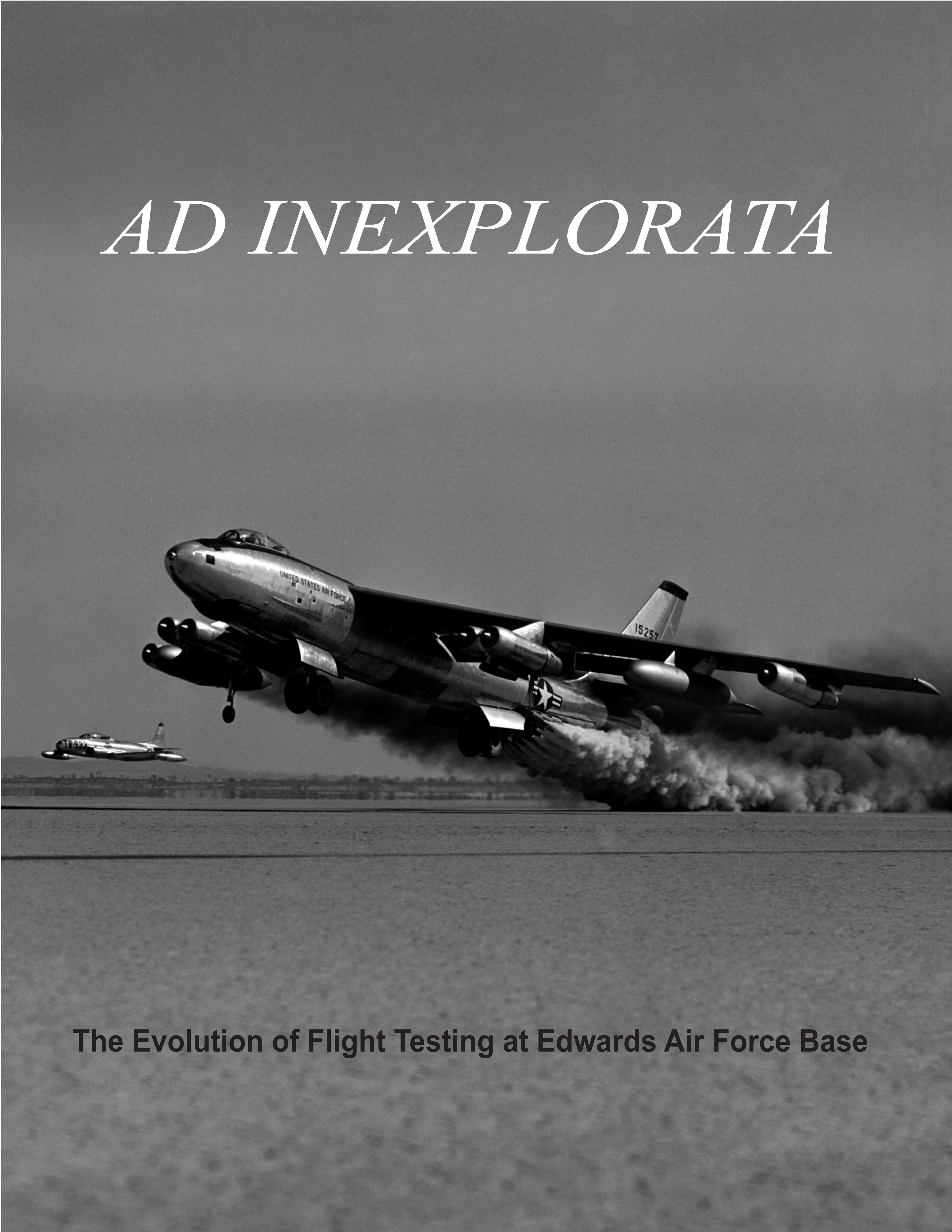
AD INEXPLORATA



The Evolution of Flight Testing at Edwards Air Force Base

(FRONT COVER)
Heavyweight performance testing at Edwards Air Force Base included dramatic takeoffs of a B-47E Stratojet from Rogers Dry Lake. External rocket-assist bottles added their plume to the dark exhaust of the B-47's six jet engines, all under the watchful eye of the pilot of a T-33 chase plane on Sept. 29, 1953.

(BACK COVER)
In his painting "Free Enterprise," artist Mike Machat captured the drama and precision of the first tailcone-off test flight of Space Shuttle 101 – the Enterprise – as it glided free from its 747 carrier aircraft over Edwards Air Force Base on October 12, 1977 during approach and landing tests. Shuttle pilot was Col. Joe Engle; the 747 was piloted by Fitzhugh L. "Fitz" Fulton.

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The Evolution of Flight Testing at Edwards Air Force Base

Air Force Flight Test Center History Office

Edwards AFB, California

1996

The official emblem of the U.S. Air Force Flight Test Center was approved in May of 1953. It depicts a cloud layer separating a desert landscape from the black unknown of outer space upon which is superimposed an aerodynamic shape with shock waves symbolizing the Center's flight test and research mission. "Ad Inexplorata," the Center's official motto, is Latin for "Toward the Unexplored." At Edwards, it has always been more than just a motto; it has served as a thematic bridge extending from the base's past,... through its present...and into its future.

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AD INEXPLORATA

The Evolution of Flight Testing at Edwards Air Force Base

The origins of the Air Force Flight Test Center (AFFTC) date back to 1933 when then-Lt. Col. Henry H. "Hap" Arnold was searching for a bombing and gunnery range for his March Field squadrons. He journeyed northward one day to a remote location called "Muroc" on California's high desert and immediately saw that it was ideal for his purposes. What he saw was the largest geological formation of its kind in the world--the vast, 44-square mile expanse of Rogers Dry Lake. He instantly recognized that its extremely flat, concrete-like surface also made it the world's most spacious natural landing field--one which could be put in service at virtually no cost to the taxpayers. This, combined with the utter isolation of the place and an arid climate which would permit year-round flight operations, prompted him to establish his remote bombing and gunnery range along the east shore of the lake bed.[1]

On the eve of U.S. entry into World War II, construction of facilities was underway on the south side of the lake bed to transform the range into a major air combat training base and this would become the primary mission activity at Muroc throughout the war years. As war approached, however, the Army Air Force (AAF) was also rapidly expanding its research and development (R&D) activities and among its new programs was a highly classified category called "Special Weapons." Designated, at the time, as "glide bombs," "power-driven controllable bombs" and "aerial torpedoes," these were actually early generation ground- and air-launched missile systems. In October 1941, General Arnold directed the Materiel Division at Wright Field to establish a permanent detachment at Muroc for the purpose of testing them and, the following month, tests of the GM-1 "Bug" and other remotely controlled weapons--including an early television-guided system--got underway along the north shore of the lake bed. Northrop was by then already testing its first true flying wing, the N-1M, at the same location and, on December 2, Curtiss-Wright's exotic CW-24B (a flying mock-up for its proposed XP-55) lifted off from the lake bed to become the first aircraft ever to complete its maiden flight at Muroc. These little known events were harbingers of things to come.[2]

In March 1942, project officers for a top secret program selected the north shore location for tests involving a new technology which would completely transform aviation in this country. That summer, facilities for a small Materiel Center Test Base were constructed at the site and, on October 1, the U.S. belatedly entered the jet age as test pilot Bob Stanley completed the first official flight of the Bell XP-59A *Airacomet*. It was an age when flight test, from our perspective, was still in its infancy. The airplanes were never instrumented for more than about 20 different parameters and the instrumentation was often primitive, to say the least. Stick forces, for example, were measured with a modified fish scale and the static thrust of the engines with an industrial spring scale. There was no telemetry and the automatic observer, an instrument panel in the gun bay photographed by a camera activated by the pilot, still represented the state of the art in data recording systems. Though the instrumentation was sparse and the facilities at Muroc truly Spartan, the wisdom of it's selection as the test site for the radical new technology was borne out by experience. The early jet engines, for example, were subject to frequent flameouts and, when pilots were unable to restart them, their only hope was close proximity to a landing field where they could attempt dead-stick landings. With miles and miles of available runways extending in every direction, Rogers Dry Lake provided this luxury and, remarkably, the entire experimental test program was conducted without a single serious mishap--a fact that was not lost on officials at Wright Field. Thus, although the performance of the *Airacomet* proved to be disappointing, it nevertheless represented a start-the first of a long series of aircraft that would make Muroc synonymous with the turbojet revolution in America.[3]

While Wright Field remained the hub of AAF flight test operations throughout the war, the volume of activity at Muroc began to expand even as the XP-59A was still undergoing development.

Bell XP-59A Airacomet

The lake bed and ideal flying conditions, combined with Muroc's relatively close proximity to major southern California aircraft manufacturers, made it especially suitable for the testing of experimental prototypes and concept demonstrators produced by those companies. Thus tests of the graceful XC- 69 *Constellation* got underway there as early as January 1943. It was followed that year by a pair of highly unconventional pusher-prop interceptor designs, the Vultee XP-54 *Swoose Goose* and Northrop's even more exotic, semi-tailless XP-56 *Black Bullet*. Northrop was also testing a pair of flying wing designs: the N-9M, a one-third scale flying model of its proposed XB-35 bomber, and the MX-324 glider which was an aerodynamic test bed for a proposed rocket-powered interceptor. In March of 1944, official performance tests of the Consolidated XB-32 were completed at Muroc (the aircraft had already lost out to the B-29) and, later that year, Douglas' unconventional XB-42 *Mixmaster* pusher-prop bomber demonstrated very impressive 400+ mph performance during trials there. On July 5, Northrop's MX-334 *Rocket Wing* became the first American fully rocket-powered aircraft ever to take to its wings and, later that year, the company's JB-1 *Bat*--a piloted aerodynamic test bed for its proposed JB-1A "jet-powered bomb"--was towed aloft to explore the design's flight characteristics. Combining both a turbojet and America's first turboprop, the Consolidated-Vultee XP-81 commenced its flight trials at Muroc in February of 1945. In addition to an ever-expanding list of airplanes, Muroc was the site for a variety of other types of top secret testing. In late 1944 and early -45, for example, B-29 test crews released what they thought were huge "dam buster" inert bombs over the Muroc Range. They were, in fact, test shapes undergoing evaluation for possible use with the atomic devices then under development. In 1945, a dual-rail track was constructed adjacent to the north shore test base and, later that year, rocket boosters were used to launch the first Northrop

JB-10 pulse-jet "buzz bombs" from it.[4]

But, of all the tests conducted at Muroc during the war years, none was more important than those which got underway on January 8, 1944, as a small group of people assembled on the lake bed to witness the first flight of a new jet prototype. Brainchild of Clarence L. "Kelly" Johnson, the XP-80 had been designed and built by Lockheed's fledgling "Skunk Works" in just ***143*** days. Test pilot Milo Burcham put on an impressive display that morning, as the aircraft accelerated to a speed of 490 mph and, during official acceptance tests just over a month later, the XP-80 became the first American airplane to exceed 500 mph in level flight. The XP-80, however, was really only an aerodynamic test bed for a much larger airplane, the XP-80A, which completed its maiden flight at Muroc the following June. This aircraft served as the prototype for America's first combat-worthy jet fighter, the P-80 *Shooting Star*. Capable of speeds approaching 600 mph and arguably the finest jet fighter in the world, the P-80 convincingly demonstrated just how far and how fast the U.S. had come in three short years. For with its development, the AAF had moved from the back of the pack into the forefront of the turbojet revolution and it was the compelling requirement to continue to accelerate turbojet development that, more than anything else, virtually guaranteed that Muroc would become the center of American flight research in the postwar period.[5]

Indeed, efforts to develop Muroc into a major flight test installation had gotten underway as early as December of 1943, when flight test engineer Capt. Nathan R. "Rosie" Rosengarten, who had just completed the initial AAF tests on the YP-59A, drafted a memo to his superiors detailing the incomparable advantages of the site and suggesting that it would be the perfect place to concentrate flight test operations. They concurred with his suggestion and then took it a step further, recommending that *all* of Muroc AAFB be transferred to Air Materiel Command and dedicated solely to flight testing. The recommendation made its way up the chain and, on February 11, 1944, the commander of Materiel Command sent a formal request to General Arnold *via* Maj. Gen. Oliver P. Echols, the Assistant Chief of Air Staff for Materiel, Maintenance and Distribution. This letter, however, was never delivered because Arnold had already made his feelings quite clear on the issue when Echols had informally approached him on the

Lockheed XP-80A

subject. Though he was in the forefront of those who believed that the AAF would have to mount and sustain a major postwar R&D effort, General Arnold was much more immediately concerned with the conduct of the war and placed highest priority on the training mission at Muroc. He reportedly told Echols: "Get off my back! On that, you can't have it. I'll give it to you as soon as the war is over." He proved to be as good as his word and, just days after Hiroshima, the transfer was approved. On October 16, 1945, the entire installation was formally transferred to the Air Technical Service Command, the functions of the North and Main Base facilities merged and, while flight operations continued to be managed by the Flight Test Division at Wright Field, the full-time mission at Muroc became flight test.[6]

The timing was propitious. The whole field of aeronautics was poised on the brink of perhaps the most dynamic era in its history. The nascent turbojet revolution was just underway and a wide assortment of new prototypes crowded the ramps at both North and Main Base as, with a sense of urgency, the U.S. military attempted to make a rapid transition from the age of props into the jet age. Indeed, virtually all of America's new jets--both Air Force *and* Navy--were initially evaluated at Muroc and it quickly earned a reputation as the place "where the rubber meets the ramp." Even though the technology was rapidly evolving, it was *far* from mature. The early generation engines, for example, were low on thrust and high on fuel consumption. Most of the postwar airframe designs represented little more than relatively crude attempts to adapt existing aerodynamic concepts to the new propulsion systems. Indeed, the XB-43--America's first jet bomber prototype--was a straight-forward modification of Douglas' piston-engined XB-42 and even Northrop's exotic YB-49 flying wing was nothing more than a jet-powered version of its prop-driven XB-35. Most of the others that were designed from the outset as turbojets--such as the XB-46, XF-87, XF-88 and XF-90--never demonstrated enough promise to warrant production while many of those which actually entered operational service --such as the XB-45, XF-84 and XF-89--were never viewed as anything more than transitional designs. Unconventional attempts to extend range--such as with the XF-85 "parasite fighter"--and improve acceleration by means of hybrid jet-and-rocket propulsion systems--such as with the XF-91 "Thunderceptor"--proved to be impractical. Nevertheless, there were some major breakthroughs as advanced aerodynamic concepts began to influence the design process. Swept wings to improve high-speed performance, for example, were employed on the two most successful postwar designs, the Boeing XB-47 and the North American XF-86.[7]

Although turbojet technology remained immature, it was quite apparent that the means were now at hand to propel aircraft into an entirely new flight regime. During World War II, fighter pilots had first encountered 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 the effects of compressibility--loss of control and structurally devastating aerodynamic loads--began to take over with often deadly consequences. Turbojets 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 not 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--the rocket-powered Bell X-1--was designed and built to acquire the necessary data...and to determine whether or not a piloted aircraft could actually penetrate the "sonic wall." [8]

The X-1 was the first in a series of "X"--or experimental--aircraft that were designed to answer fundamental questions, to probe the most challenging unknowns of flight and solve their mysteries. The program was also the Air Force's first foray into experimental flight research and the first collaborative effort in what would become an extraordinarily productive partnership between the Air Force and the National Advisory Committee for Aeronautics (NACA). The first NACA contingent arrived at Muroc in September of 1946 and the NACA and its successor, the National Aeronautics and Space Administration (NASA), have been conducting fundamental flight research there ever

Bell X-1 (October 14, 1947)

since. Among other things, NACA engineers were responsible for data collection, reduction and analysis. Though extremely limited by latter-day standards, the X-1 was the most thoroughly instrumented aircraft of its time. It carried about 500 pounds of instrumentation and recording devices and it pioneered in the use of oscillographs, radar tracking and limited data telemetry.[9]

The X-1 program also represented a turning point. Up until that time, experimental flight research programs had always been flown by contractor or NACA test pilots. Thus it represented a major departure from convention when, after Bell pilots had demonstrated the flight worthiness of the airplane up to a speed of 0.8 Mach, the Engineering Division decided to turn the assault on Mach 1 over to a young Air Force test pilot. The man chosen to make that assault was a 24-year old combat ace named Capt. Charles E. "Chuck" Yeager. What followed is well known. Following launch from a B-29 for his ninth powered flight on October 14, 1947, he accelerated to a speed of Mach 1.06 (700 mph) at 42,000 feet and shattered the myth of the sound barrier forever. Though few people could comprehend its full implications at the time, he had just taken the first step in a chain of events that

Capt. Charles E. "Chuck" Yeager and Capt. Jack Ridley (October 1947)

would ultimately vault man beyond the atmosphere and into space.[10]

His achievement legitimized the role of military test pilots in flight research and, with the flights of the X-1, testing at Muroc began to assume two distinct identities. Highly experimental research programs were typically flown in conjunction with the NACA and conducted in a very methodical fashion to answer largely theoretical questions. In 1948, for example, tests to study the transonic flying qualities of delta wing designs got underway with the Convair XF-92A and, later that year, the exploration of the transonic flying qualities of a sweptwing, semi-tailless design commenced with the first flight of the Northrop X-4. The bulk of the testing at Muroc, however, focussed on highly accelerated Air Force and contractor evaluations of the capabilities of aircraft and systems proposed for the operational inventory. By 1951, this process had evolved into no less than eight distinct phases, each performed by different organizations and frequently at different locations (see Fig. 1). The first four phases were dedicated exclusively to development test and evaluation (DT&E). During Phase I, for example, the contractor was responsible for demonstrating the airworthiness of the prototype. During a brief Phase II program, Air Force DT&E pilots then evaluated it to determine if it met contractual guarantees and was worthy of production. The data from these tests also provided an indication of what modifications and further development work would be required to insure an acceptable production aircraft and, during Phase III, the contractor completed these refinements on the prototype and demonstrated the structural integrity of the airplane. During Phase IV, Air Force test pilots completed a comprehensive evaluation of the first production models of the new aircraft to determine its complete performance, its stability and control characteristics and the operation of each of its systems. The results from these tests were used to compile the Pilots' Handbook of Operating Instructions. While this highly segmented system worked fairly well in the 1940s (the F-86, for example, entered operational service just 16 months after the prototype first flew), it would begin to break down in the 50s as the increasing complexity of the aircraft and the rapid proliferation of their onboard systems required more and more time to refine and develop.[11]

The ever-increasing complexity of the aircraft, combined with major new problems in

PHASE TESTING
1951 - 58

TYPE		ORGANIZATION	AIRCRAFT
I	AIRWORTHINESS	CONTRACTOR	PROTOTYPES
II	CONTRACTOR COMPLIANCE	AFFTC	PROTOTYPES
III	DESIGN REFINEMENT	CONTRACTOR	PROTOTYPES
IV	PERFORMANCE & STABILITY	AFFTC	PRODUCTION
V	ALL WEATHER	AFFTC	PRODUCTION
VI	FUNCTIONAL DEVELOPMENT	AFFTC/LIMITED USING COMMAND	PRODUCTION
VII	OPERATIONAL SUITABILITY	AIR PROVING GROUND COMMAND USING COMMAND	PRODUCTION
VIII	UNIT OPERATIONAL EMPLOYMENT TRAINING	OPERATIONAL UNIT	PRODUCTION

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Fig. 1: Phase Testing

stability and control brought on by the higher and higher speeds of the turbojets, served to magnify the difficulties inherent in what had always been a very dangerous profession and contributed to a horrendous accident rate. The year 1948 was particularly tragic, as *at least* 13 fatalities were recorded (surviving records are very incomplete). One of them was a young captain, named Glen W. Edwards, who was lost in the crash of one of the giant YB-49 Flying Wing bomber prototypes. On December 8, 1949, Muroc AFB was officially renamed in honor of the young test pilot.[12]

By the time the base was officially designated as the U.S. Air Force Flight Test Center, on June 25, 1951, it had already long since become the *de facto* center of American flight research. More than 40 different types of aircraft, many of them exotic research vehicles, had first taken flight in the clear skies above the lake bed. The NACA High-Speed Flight Station was located there and many of the major aircraft contractors had established semi-permanent flight test organizations in the hangars along the flight line. Following a plan initially launched by Captain Rosengarten's 1943 memo, the Air Force had been steadily shifting the bulk of its flight test operations from Wright Field to the high desert location and plans were already well underway to implement a $120 million master plan for the construction of an entirely new flight test complex to the west of the existing main base which would be completed by the mid-50s.[13]

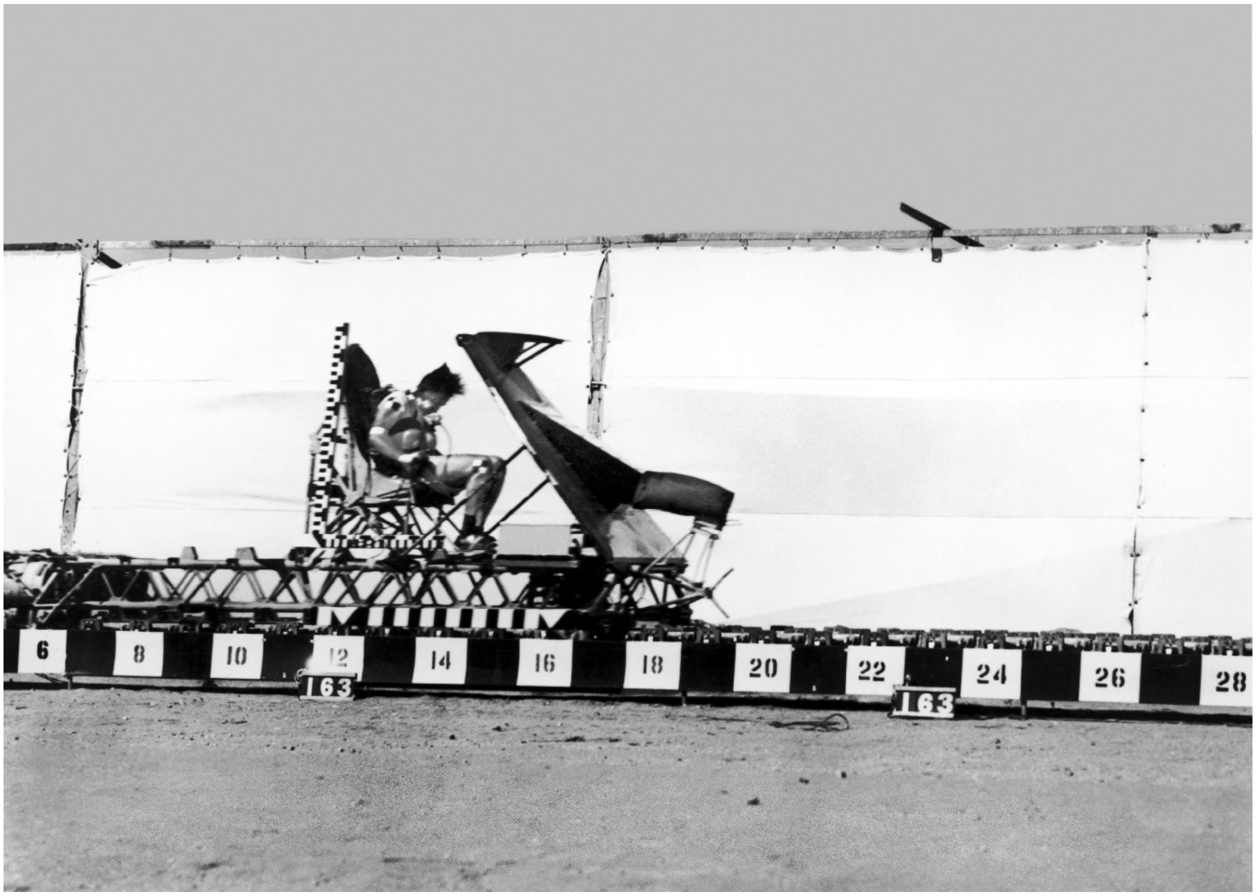
Northrop YB-49

Capt. Glen W. Edwards

The migration of flight test westward also dictated the relocation of flight test training and, in February 1951, what was then called the Air Materiel Command Experimental Test Pilot School (soon to be USAF Test Pilot School) was transferred to Edwards. The technological revolution spawned by World War II had transformed the role of the test pilot. The job had always required exceptional precision flying skills, keen powers of observation, coolness under pressure and the discipline to fly a profile exactly as planned. In the postwar era, it became increasingly necessary for test pilots to combine these talents with the skills and knowledge of trained engineers. They had to have a thorough technical understanding of all of the systems they were evaluating and the phenomena they were encountering in order to be able to translate their experiences into the very precise language of designers and engineers. Thus, in addition to exceptional flying skills, applicants to the school had to have solid engineering backgrounds and, once in the school, students were subjected to an evermore rigorous academic curriculum which included accelerated courses in subjects such as flight mechanics, differential calculus and supersonic aerodynamics. Stepping out of the classroom and into the cockpit, they were taught the intricacies of performance flight testing where they learned to control airspeed to the nearest knot and hold their altitude at extraordinarily precise levels in order to define how far, how fast, and how efficiently an airplane could fly. This was followed by an even more demanding phase during which they learned how to evaluate the subtle nuances of aircraft stability and control as well as how to translate these characteristics into quantifiable terms which would be meaningful to aircraft designers. It was an extraordinarily demanding curriculum and, by the mid-50s, the school had already established a reputation as an institution to which only the best and brightest need apply.[14]

The mission at Edwards was not limited to flight testing. In 1946, the JB-10 track at North Base had been modified and extended into a 2,000-foot deceleration sled track--the first of its kind in the world--and there, from 1947 to 1953, Lt. Col. John P. Stapp and his team of aeromedical researchers had themselves strapped onto rocket sleds to study the effects of "g" forces on the human body as they developed restraining devices and other safety equipment that would save countless lives. Prior to these studies, conventional medical wisdom had maintained that humans could safely endure no more than about 18 instantaneous g's. Using himself as test subject, Stapp ultimately proved that, when properly restrained, the human body is remarkably resilient as, on June 1, 1951, he actually survived a *48-g* deceleration. The success of this operation led to the development of a much longer, 10,000-foot high-speed track at South Base in early 1949. Over the next decade, it served as an "outdoor wind tunnel" where everything from airfoils and aerodynamic shapes to rocket engines, ejection systems and a host of other aircraft components were tested in real-world conditions at speeds in excess of 1,500 mph. In 1959, it was

U.S. Air Force Test Pilot School (1953)



replaced by a new 20,000-foot track on which test sleds attained speeds of up to Mach 3. This track was finally dismantled in 1963 when USAF track operations were concentrated at Holloman AFB, New Mexico. Meanwhile, as the rocket sleds blistered across the flat lands below, another, much different activity got underway high on a granite ridge overlooking the lake bed. In February 1949, construction of test stands and related technical facilities for the Air Force's new Experimental Rocket Engine Test Station commenced and, just three years later, the ridge quaked to the blast of the first of a long series of rocket engines that would ultimately launch the U.S. into the space age. Indeed, over the years since, virtually every U.S. propulsion system which has been employed in

Lt. Col. John P. Stapp on the Deceleration Track

space operations has first undergone development at this facility which is now a tenant organization at Edwards and has been designated as the Propulsion Directorate of the USAF Phillips Laboratory.[15]

By any standard, the 1950s was a remarkable period in the history of aviation and there was no better evidence of this than what transpired at Edwards where, if a concept seemed feasible--or even just desirable, it was evaluated in the skies above the sprawling 300,000-acre base. As the decade opened, the X-1's Mach 1.45 represented the edge of the envelope. By its end, flight researchers were on the brink of exploring the mysteries of hypersonic flight. At least 47 different aircraft completed their first flights at Edwards during the 50s and every aircraft considered for the Air Force or U.S. Army inventory--and most of the high-performance designs destined for Navy service appeared on the ramp. Helicopters, from the YH-21 to the HU-1A; transports, such as the giant C-133 and the versatile C-130; aerial tankers, from the bulbous, prop-driven KC-97 to the sleek, turbojet KC-135; medium bombers, from the exotic XB-51 to the Navy's impressive A3D; heavy bombers, from the lumbering XB-60 to the incomparable B-52; fighters, from the subsonic, straight-winged F-89 to the Mach 2, delta-winged F-106--all made their appearance on the ramp at Edwards while yet others, such as the mysterious, high-flying U-2 were kept under close wraps.

In the early 50s, the tremendous promise of the turbojet revolution finally came to fruition with the marriage of ever more powerful and efficient engines to streamlined airframes which were designed to fully exploit their performance potential. When the Boeing YB-52 first arrived for tests at Edwards in June of 1953, it was powered by eight Pratt & Whitney J57 axial-flow turbojets. The engine-airframe combination proved to be a nearly quantum advance over previous heavy bomber designs, as tests revealed that the *Stratofortress* could outpace F-86Es at altitude while providing an intercontinental range capability which, only a few short years earlier, had been thought to be impossible for jet-powered aircraft. Originally projected to be SAC's principal strategic bomber for the next decade, advanced -G and -H model versions of the aircraft remained under test through the mid-60s. By that time, they had been joined on the ramp at Edwards by the remarkable--though far less satisfactory--B-58 *Hustler.* Though its Mach 2 performance was truly impressive, the B-58 would have a short and trouble-plagued career. The "Buff," on the other hand, would continue to fulfill its strategic nuclear deterrence mission for more than three decades.[16]

Boeing YB-52

North American YF-100 over North Base

Early versions of the J57 provided about 12,000 pounds of dry thrust and 17,000 pounds in afterburner and it was with its burner lit that the J57-powered North American YF-100 *Super Sabre* became the first aircraft in history to exceed Mach 1 on its maiden flight at Edwards in May of 1953. Impressive though it was, the F-100 became a textbook case for proponents of increased Air Force involvement in the DT&E of new aircraft proposed for the operational inventory. When North American completed Phase I tests, the company reported that the airplane was essentially ready to go into production "as is." Lt. Col. Frank K. "Pete" Everest, the AFFTC's chief of flight test operations, had the job of flying the Air Force's Phase II program and, while extremely impressed with the airplane's performance, he disagreed. The flight controls, in his judgement, were "squirelly." The YF-100 exhibited serious high-speed directional and other stability and control problems and, in his final report, he recommended that it undergo substantial modification and re-evaluation before proceeding into production. Neither North American nor the Tactical Air Command (TAC) were very pleased with Everest's findings and, indeed, the contractor succeeded in getting the Air Force to bring a group of operational pilots in to fly the airplane and see what *they* thought. Seduced by its tremendous performance, they were unstinting in their praise. None of them had ever flown *anything* like it before...and none of them had the flight test training necessary to know how to ferret out stability and control problems. TAC desperately wanted the "hot" new fighter--after all, its own pilots had flown and approved it--and acquisition officials ordered it into production. By late 1954, F-100As were rolling off the production line and entering service. Then, within a short span of time, four aircraft and two pilots were lost as the airplanes departed controlled flight and broke apart in the sky. Something, indeed, *was* wrong. The F-100A was susceptible to the little understood phenomenon of inertia coupling--or what was then called "high-speed instability." When these mishaps occurred, more than 70 aircraft had already come off the production line. The *Super Sabre* had to be redesigned and all of the existing aircraft modified into the new configuration. A costly and tragic mistake, this episode confirmed the value of early and independent assessments by objective Air Force flight test professionals.[17]

The F-100 was the first in the remarkable

"Century-series" of prototype supersonic fighters that first took to the skies at Edwards during the 1950s. It was followed, chronologically, by the Convair YF-102 *Delta Dagge*r (October 1953), the Mach 2 Lockheed XF-104 *Starfighter* (February 1954), the McDonnell F-101 *Voodoo* (September 1954), the Republic YF-105A *Thunderchief* (October 1955), and the Convair F-106A *Delta Dart* (December 1956). Each of these aircraft were dazzling technical achievements. Indeed, as a group, they defined the basic speed and altitude envelopes for fighters which still prevail to this day. But, for all their technical merits, each of them arrived at Edwards with serious deficiencies.

The delta-wing YF-102, designed as a supersonic interceptor, was unable to exceed Mach 1 in level flight. This forced a major redesign which transformed the YF-102A into a test bed for a revolutionary concept, called "area ruling," which postulated that transonic drag could be substantially reduced by recontouring the fuselage in direct relationship to the wing. If the length of the fuselage could be increased and the area along the wings compressed, to create a distinctive "Coke-bottle" shape, drag would be reduced enough to permit supersonic flight. The validity of this concept was proven at Edwards when the YF-102A easily exceeded Mach 1, flying straight and level, during its second flight. The F-104 and F-101, both featuring high-T tails, exhibited vicious pitch-up tendencies at high angles of attack which resulted in stalls and spins from which recovery was virtually impossible. Indeed, several aircraft were lost to this phenomenon before satisfactory pitch-inhibitor systems could be developed and their effectiveness demonstrated in tests at Edwards Air Force Base. The YF-105As were designed for Mach 2 performance. Tests, however, revealed that they were unable to exceed Mach 1.2. All subsequent models were redesigned to incorporate area ruling and the "Thud" ultimately went on to become a very reliable Mach 2 fighter-bomber. Configured with the most advanced electronic fire control and armament system yet developed and promising Mach 2 performance, the F-106A was hailed as "the ultimate interceptor" when it arrived at Edwards. Air Force tests, however, revealed that it was far short of living up to its promise. The airplane required seven minutes to accelerate from Mach 1 to Mach 1.8--consuming some 2,000 pounds of fuel in the process--and its poor climbing capabilities left it 15,000 feet short of its advertised 70,000-foot combat ceiling. Moreover, its state-of-the-art subsystems required extensive development and integration before they provided the airplane with satisfactory capabilities. The F-106 ultimately lived up to its promise--in the 1960s--but it had required years of intensive testing and development before it provided the Air Defense Command with the kind of interceptor originally projected to be in service by the late 50s.[18]

For all of their impressive performance, each of the Century Series fighters went through extensive growing pains before they were transformed into satisfactory combat systems. Although, benefiting from flight research data, advanced wind tunnel capabilities, and early generation computer and simulation technologies, the art and science of aircraft design had reached a truly high plateau, the Century Series prototypes reconfirmed the need for rigorous development flight testing. The ever-increasing complexity of these aircraft also posed development and testing problems which underscored the weaknesses inherent in the fragmented eight-phase flight test system. Most of the *Century* fighters required at least four years of testing before they even *began* to enter the operational inventory...and, in reality, each of them still required several more years of test and development before all of their deficiencies were corrected. This meant that the operational users were not receiving fully developed airplanes and the result of this circumstance was extremely drawn-out and costly retrofits. Thus, in 1958, Air Force flight testing was consolidated into a new three-Category structure (see Fig. 2). Under this structure, flight test operations were to be concentrated at fewer locations--principally at Edwards--and at least some Air Force participation was supposed to span all three categories and its management control was supposed to commence much earlier in the process.[19]

When NACA test pilot Scott Crossfield first arrived at Edwards in 1950, he found it "hard to believe that this primeval environment was the center of aviation's most advanced flying." He likened it to an "Indianapolis of the air." But it was even more than that, he concluded: it was "an Indianapolis without rules" because the test pilots at Edwards "lived with the feeling that everything we were doing was something that probably had never been attempted or even thought of before."[20]

CATEGORY TESTING
1958-1972

	TYPE	ORGANIZATION	AIRCRAFT
I	SUBSYSTEM DEVELOPMENT INITAIL AIRWORTHINESS	CONTRACTOR / AFFTC	PROTOTYPE/ EARLY PRODUCTION
II	SYSTEM DEVELOPMENT (INTEGRATION OF SUBSYSTEMS INTO COMPLETE SYSTEM)	AFFTC / CONTRACTOR	EARLY PRODUCTION
III	OPERATIONAL	USING COMMAND	PRODUCTION

A0302.002

Fig. 2: Category Testing

Crossfield would become most closely identified with the series of experimental aircraft that had been launched with the X-1 and perhaps the most publicized activity at Edwards during the 50s continued to be in the realm of flight research where the limits of time, space, and imagination were dramatically expanded.

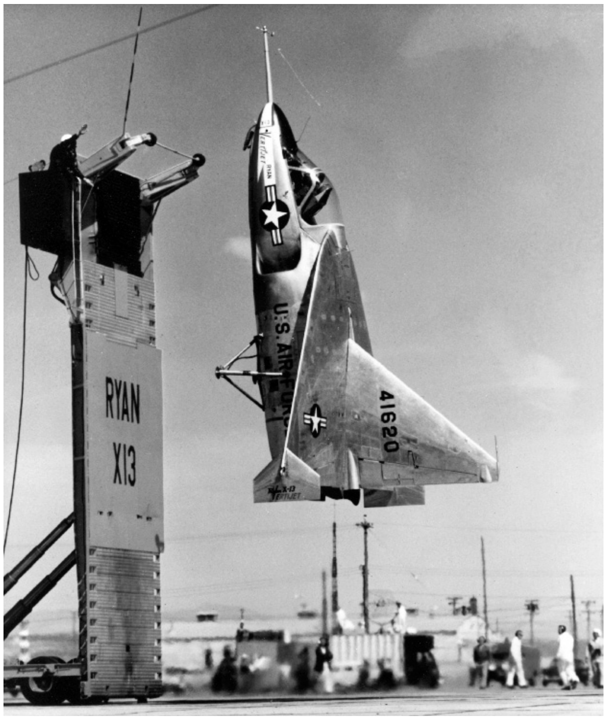
While the rocket-planes were designed to expand the high-speed frontier, each of the other X-planes were designed to explore new concepts in aerodynamics, propulsion and systems. Some concepts were too advanced for the technology of the time. As noted above, the X-4 had been designed to study the potential for transonic drag reduction and improved stability with semi-tailless configurations. As Air Force and NACA test pilots completed tests on this aircraft in the early 50s, however, they compared the airplane's transonic flying qualities to driving fast over a washboard road and concluded that like birds, in Crossfield's words, "aviators need a respectable amount of tail." Truly satisfactory tailless and semi-tailless aircraft would have to await the arrival of computerized stability and control augmentation and fly-by-wire flight control systems.[21]

When reporters first saw Douglas' racy, form-follows-function X-3 *Stilleto* on the flight line at Edwards, in October 1952, they were certain they were looking at the shape of things to come. The slender, needle-nosed, trapezoidal-winged airplane *looked* like it was made for speed...and, indeed, it was. Douglas had designed it to study high-speed aerodynamic phenomena at sustained speeds of up to Mach 2 and to examine the feasibility employing very thin, low aspect ratio, high-load wings on high-performance aircraft. Sustained supersonic flight operations would have permitted flight researchers to acquire much greater amounts of data than could be obtained with the momentary supersonic episodes attainable with the rocket planes. The airplane was bold in concept but, unfortunately, the aerodynamic free-thinking of the Douglas design team could not overcome powerplant difficulties experienced by Westinghouse, whose proposed J46 engines grew much too large to install in the X-3's extremely slender fuselage. From that point, the X-3's promise of sustained high-speed flight exploration vanished as a pair of less-powerful J34 engines were installed just to get the craft airborne and, during flight tests, it could exceed Mach 1 only while in a steep dive. While it failed to achieve many of its stated objectives, serendipity attended an unplanned detour of the X-3 program when, on October 27, 1954, the airplane departed controlled flight and NACA test pilot Joe Walker was

Research Aircraft (clockwise/lower left): X-1A, D-558-I, XF-92A, X-5, D-558-II, X-4 & (ctr) X-3.

victimized by the same inertia coupling phenomenon which was then bedeviling the early production-model F-100As. He managed to recover the aircraft from this and a subsequent excursion and the highly-instrumented X-3 provided NACA engineers with sufficient data to begin to define the problem. Following subsequent tests with an F-100A, they determined that the violent coupled motions encountered with the X-3 and F-100A occurred because both aircraft were loaded primarily along the fuselage, with little spanwise load distribution, thus increasing each airplane's inertia characteristics in the yaw and pitch axes (i.e., the mass forward or aft of the fuselage center of gravity had sufficient moment at high speeds to create inertia of motion that caused unwanted pitch and yaw). With the problem clearly defined, they were able to make recommendations which led directly to a solution which would apply to the F-100, as well as future high-speed designs. Thus, although it was not a satisfactory airplane, the Air Force-NACA X-3 research program paid unexpected and very handsome dividends.[22]

Most of the X-series aircraft, however, achieved their intended purposes. The Bell X-5, for example, fulfilled *all* of the original research plans envisioned for it. The first high-performance aircraft to feature a variable, in-flight wingsweep capability it successfully demonstrated a concept which would be effectively employed in a number of subsequent operational designs. With the ability to sweep its wings from 20-degrees, for optimum low-speed handling qualities, all the way to 60-degrees for maximum high-speed performance, it also provided an inexpensive means of testing an enormous variety of wing-sweep configurations in real-world conditions. Indeed, even its major flaw--its vicious spin and spin recovery characteristics--was put to good use because it yielded reams of data that were used to generate the criteria for determining poor spin design. The Ryan X-13 *Vertijet* was equally successful and even more unconventional. The military had long been interested in the potential advantages offered by Vertical TakeoOff and Landing (VTOL) aircraft and had explored the concept in the early 50s with a pair of tail-sitting turboprop designs, the Ryan XFY-1 and the Lockheed XFV-1. Indeed, the XFV-1 had been



Ryan X-13

tested at Edwards and, although it had successfully demonstrated several in-flight transitions (from horizontal-to-vertical-to-horizontal flight), it never accomplished either a vertical take off or landing. Also a tail-sitter, the X-13 was a much more ambitious turbojet design. On April 11, 1957, this airplane lifted off vertically, pitched over into conventional flight attitude, performed a series of maneuvers, and then pitched up for a successful vertical landing. Although the tail-sitting concept was ill-suited for tactical aircraft, the *Vertijet* demonstrated that VTOL flight, on jet thrust alone, was both feasible and achievable.[23]

Meanwhile, the experimental rocket planes continued to expand the boundaries of the high-speed and stratospheric frontiers. The Air Force's first and second-generation X-1s were joined in this quest by the Navy-NACA Douglas D-558-II *Skyrocket* in a kind of informal competition to see who could fly highest and fastest. The original X-1 had achieved a top speed of Mach 1.45 (957 mph) in 1948 and, in August of 1949, Lt. Col. Pete Everest flew it to a peak altitude of 71,902 feet. These marks were soon surpassed by the sweptwing *Skyrocket*, as Douglas test pilot Bill Bridgeman accelerated to a top speed of Mach 1.88 (l,180 mph) and climbed to a maximum altitude of 74,494 feet in August of 1951. Then, in August of 1953, Marine test pilot Lt. Col. Marion Carl flew it to an altitude of 83,235 feet. Its performance, thus far, was not bad for an aircraft which had not been designed to exceed Mach 1.6...but Scott Crossfield believed that, if pushed to its ultimate extreme, the *Skyrocket* might be able to get to the next magic number: Mach 2. He and NACA technicians did everything they could to coax a little more performance out of the airplane, including minor modifications that would provide modest increases in engine thrust and fuel efficiency, and even taping over panel cracks and covering the airframe with a coat of wax in an effort to reduce drag to the absolute minimum. On the morning of November 20, 1953, he dropped away from the belly of a P2B-1S (Navy B-29) at 32,000 feet, lit his engine and began to climb. At 72,000 feet he pushed over into a shallow dive and, as he passed through 62,000 feet, he became the first man to reach Mach 2--but just barely, at Mach 2.005 (1,291 mph). His victory was sweet but short-lived as, the following month, on December 12, Maj. Chuck Yeager flew the Air Force's X-1A to a speed of Mach 2.44 (1,650 mph). Nine months later, on August 4, 1954, Maj. Arthur


Douglas D-558-II Skyrocket

Maj. Chuck Yeager (top) and Maj. Kit Murray following record flights in the X-1A.

X-2 Record Breakers: Capt. Iven Kincheloe and Capt. Mel Apt (seated in cockpit)

Bell X-2

“Kit” Murray flew the same aircraft to a new altitude record of 90,440 feet. On Yeager’s high-speed flight, however, the X-1A had nearly been lost to inertia coupling and it was quite apparent that there were still many mysteries to be solved concerning supersonic flight.[24]

Providing adequate stability and control for aircraft flying at high supersonic speeds was only one of the major difficulties facing flight researchers as they approached Mach 3. For, at speeds in that region, they knew they would also begin to encounter a “thermal barrier”--severe heating effects caused by aerodynamic friction. Constructed of stainless steel and a copper-nickel alloy, and powered by a 15,000-pound thrust throttleable rocket engine, the sweptwing Bell X-2 was designed to probe this region and to be the first aircraft to take man well above the measurable atmosphere to the very edge of space. Lt. Col. Pete Everest completed the first powered flight of the airplane in November 1955 and, by the time of his ninth and final flight in late July the following year, he had established a new speed record of Mach 2.87 (1,900 mph). The X-2 was living up to its promise...but not without difficulties. At high speeds, Everest reported that its flight controls were only marginally effective. Moreover, simulation and wind tunnel studies, combined with data from his flights, suggested that the airplane would encounter very severe stability problems as it approached Mach 3.[25]

A pair of young test pilots, Captains Iven C. Kincheloe and Milburn G. “Mel” Apt, were assigned the job of further expanding the envelope and, on September 7, 1956, Kincheloe became the first pilot to climb above 100,000 feet as he flew the X-2 to a peak altitude of 126,200 feet. Just 20 days later, Apt was launched from the B-50 carrier aircraft for his first flight in the airplane. Flying an extraordinarily precise profile, he became the first man to exceed Mach 3, as he accelerated to a speed of Mach 3.2 (2,094 mph) at 65,500 feet. Shortly after attaining top speed, however, the X-2 tumbled violently out of control and Apt found himself struggling with the same problem of inertia coupling which had overtaken Yeager in the X-1A nearly three years before. Unlike Yeager, however, Apt was unable to recover and both he and the aircraft were lost. While the X-2 had delivered valuable research data on high-speed aerodynamic heat build-up and extreme high-altitude flight conditions, this tragic event terminated the program before the NACA could commence detailed flight research with the craft and the search for answers to many of the riddles of high-Mach flight had to be postponed until the arrival of the most ambitious of all the rocket planes.[26]

That airplane was the North American X-15 and no other aircraft, before or since, has come close to approaching its truly awesome performance. Designed to achieve hypersonic speeds--speeds in excess of five times the speed of sound--and to climb more than 50 miles above the earth’s surface, the dart-like X-15 would become the first aircraft to actually be piloted into near space. Roughly the same size as the X-2, the X-15 was configured with a mammoth XLR99 rocket engine providing 57,000 pounds of thrust. While its internal structural framework was largely made from lightweight titanium, the airplane’s skin surface’s were fabricated from a special Inconel X chrome-nickel alloy which would enable it to withstand the searing 1200-degree temperatures predicted in the hypersonic flight environment. The airplane would cover a lot of space in a very short span of time and thus NASA and the Air Force developed the “High-Range,” a 400-mile chain of radar tracking and data acquisition sites. Equipped with radio and telemetry systems capable of relaying continuous voice communication and up to 600,000 data bits per minute (1250 bytes per second) back to Edwards, this range network permitted flight controllers and test engineers, for the first time, to monitor each mission in real time by following data trends on strip charts.[27]

The first of three X-15s arrived at Edwards in the Fall of 1958 and, following an extended series of ground tests and flight worthiness trials, the research program finally got underway in earnest, on March 7, 1961, when AF Maj. Robert M. “Bob” White, employing only 50 percent of the engine’s thrust, leveled off at 75,000 feet and became the first man to exceed Mach 4, as the aircraft attained a speed of 2,905 mph (Mach 4.43). Just three months later, on June 23, White again employed only partial thrust to rip through Mach 5, pegging a speed of 3,603 miles an hour (Mach 5.27). Then, on November 9, he dropped away from the B-52 carrier aircraft at 45,000 feet and lit the engine for the X-15’s first full throttle flight. Pressed hard by

North American X-15

Maj. Robert M. White

Maj. William J. "Pete" Knight

the tremendous acceleration forces, he climbed to 100,000 feet, nosed over into level flight and continued to accelerate. At engine burnout, just 86 seconds after ignition, Bob White was flying at 4,094 mph (Mach 6.04). It had taken nine years to get from Mach 1 to Mach 3. Bob White and the X- 15 had claimed three Mach numbers in just eight months. His milestone flights, however, were only part of a 199-flight research program. During its course, 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. Among the eight test pilots who earned their astronaut's wings in the X-15, NASA's Joe Walker claimed the peak altitude of 354,200 feet (67 miles) and, flying the modified X-15A-2 in October of 1967, AF Maj. William J. "Pete" Knight reached Mach 6.72 (4,520 mph) which remains, to this day, the highest speed ever attained in an airplane.[28]

The X-15 program, however, was concerned with much more than just dazzling, ultra-performance records. It generated nearly 800 technical reports on research stimulated by the airplane's development and flight tests, *and* it had a profound impact on America's manned space program. It demonstrated, for example, that pilots could ably perform under the stresses of hypersonic accelerations, as well as the weightlessness of space. In doing so, it clearly documented man's ability to pilot a rocket-boosted vehicle out of the atmosphere and then perform a lifting re-entry upon its return. While offering palpable evidence that piloted reusable spacecraft were a genuine near-term possibility, it was also used as a test bed for a variety of other space-related experiments. The celestial navigation equipment ultimately destined for use in the Apollo program, for example, was first tested on the X-15. Generally considered to be the most productive effort of its kind in history, the X-15 program remains, to this day, the high-water mark for flight research worldwide.[29]

But the X-15's pioneering journeys beyond the atmosphere were only part of the space flight revolution developing at the Center during the 1960s. Some of these efforts would have near-term payoffs. At the NASA facility, for example, test pilots evaluated a pair of ungainly, spindly legged contraptions which portended the fulfillment of one of mankind's oldest aspirations. The tests with these "flying bedsteads" validated the technologies which would be employed in the Lunar Landing

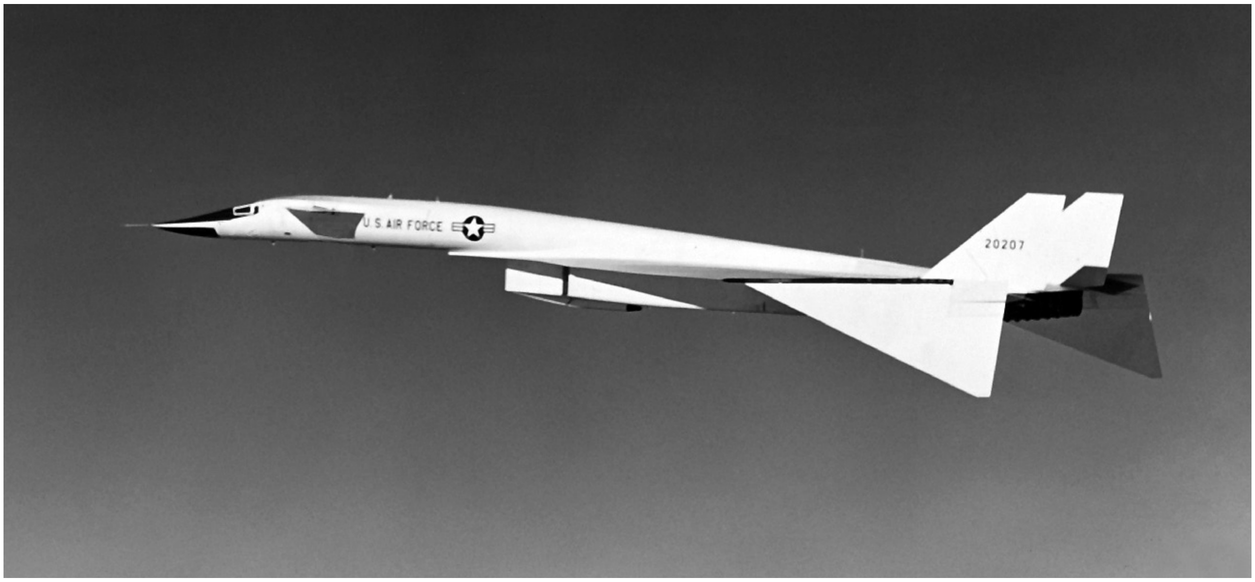
Three of the Lifting Bodies: (left to right): X-24A, M2-F3, and HL-10.

Vehicles. Other tests would provide longer-term benefits. From 1963 through 1975, for example, NASA and Air Force test pilots evaluated a series of curious-looking, wingless aircraft called "Lifting Bodies." These airplanes--the plywood M2-F1, and the all-metal, rocket-powered M2-F2, -F3, HL-10, X-24A & X-24B--were used to determine whether or not, through the use of energy management techniques, such low-lift-to-drag shapes could make precision landings after high-speed, unpowered descents from altitudes as high as 90,000 feet. The program came to a successful climax when, in 1975, the X-24B rolled out after a pair of perfect landings on Edwards' main concrete runway and thereby demonstrated that such wingless craft could, indeed, make precision landings with remarkable touchdown accuracies. Indeed, the lifting bodies made a signal contribution to the American space effort because they validated the approach and landing techniques which would later be employed by the world's first *true* space ship, the Space Shuttle *Columbia*.[30]

An equally important contribution to America's future in space got underway in 1961 when the USAF Test Pilot School was redesignated the USAF Aerospace Research Pilot's School (ARPS). By that time, the Air Force had defined a distinct man-in-space mission (encompassed in the ultimately canceled X-20 *Dyna Soar* and Manned Orbiting Laboratory [MOL] programs) and ARPS provided the nation's first formal astronaut training course. For the U.S. military pilots who were admitted to the year-long program, the traditional performance and flying qualities curriculum served as but a prelude to an incredibly rigorous space-related program which included highly accelerated, post-graduate level courses in subjects such as Newtonian mechanics, the dynamics of rarified gases, computer theory, thermodynamics, bioastronautics and orbital mechanics. This was combined with an innovative flight and simulation training program which prepared students for all phases of a space mission--from launch through re-entry. The excellence--and lasting impact--of this training can be surmised from the fact that 37 ARPS graduates were selected for the U.S. space program and 26 of them actually earned astronaut's wings by flying in the X-15, Gemini, Apollo and Space Shuttle programs (ARPS existed from 1961 to 1972; altogether, through 1995, some 75 graduates of ARPS and the USAF Test Pilot School have been selected for astronaut duties by NASA).[31]

Rocket-boosted NF-104 Space Trainers Employed by ARPS Could Climb Above 100,000 Feet.

The dawn of the space age certainly did not signal the end of more conventional flight research at Edwards; quite to the contrary. During the 60s, for example, flight researchers developed and refined the state of the art in vertical and short takeoff and landing (VSTOL) technology during evaluations of an extraordinarily wide variety of airframes. At the start of the decade, for example, the twin-prop, tilt-wing Hiller X-18 served as a successful proof-of-concept demonstrator for the much more ambitious four-engine Ling-Temco-Vought XC-142 which was actually considered for tri-service military use. Far more radical yet was the Ryan XV-5A which was configured with a pair of contra-rotating fans in its wings and a smaller pitch-control nose fan, for VTOL and hovering operations, that were driven by the exhaust from a pair of turbojets which provided the airplane with Mach 0.7 performance in straight-and-level flight. However, the most stunning technology, by far, was



North American XB-70 Valkyrie

incorporated into the Hawker XV-6A *Kestrel*. The VTOL capability of this truly pathbreaking design depended entirely on the vectored thrust-depended entirely on the vectored thrust--channeled through four rotating nozzles--supplied by its powerful turbofan engine. While proving the validity of thrust vectoring, this aircraft effectively served as the immediate forerunner of the Royal Air Force's highly successful Harrier fighters and the U.S. Marines' AV-8A.[32]

Though modern surface-to-air missile technology had rendered it obsolete for its projected role as a strategic bomber even before it completed its first flight at Edwards in September 1964, the mammoth, 500,000-pound North American XB-70 *Valkyrie* was nevertheless a technological marvel. Capable of sustained triplesonic flight operations at altitudes above 70,000 feet, it was used to conduct fundamental high-speed flight research and even served, for a time, as the test bed for the projected--and ill-fated--U.S. Supersonic Transport program. Meanwhile, flight researchers were also beginning to explore concepts which promised more efficient transonic and supersonic flight. A pair of Northrop X-21As, for example, were used to conduct pioneering research in the field of laminar flow control--reducing or even eliminating the drag induced by turbulence in the very thin layer of air which literally hugs an airplane in flight. The wings of these airplanes contains hundreds of thousands of tiny spanwise slots which, by means of a complicated network of tiny ducts, were connected to a pair of gas turbine pumps which were used to literally suck away the turbulent boundary layer of air, thereby inducing laminar flow around the wings. Though the technology had not yet evolved to the point where such a system could be employed on an operational aircraft, the X-21As nevertheless convincingly proved the viability of the boundary layer control concept.[33]

While space and atmospheric flight research garnered the lion's share of public attention during the 60s, the volume of these activities paled by comparison with DT&E operations as the AFFTC introduced a whole generation of aircraft which would become mainstays of the U. S. Air Force's operational inventory into the 1980s and, in many cases, well beyond. Under the new category system of testing, the Center was able to start delivering the nation's first supersonic trainer, the Northrop T-38 *Talon*, to the USAF Air Training Command in March of 1961, less than two years after the first flight of the prototype at Edwards. Subsequent tests of a derivative of the basic design, the nimble F-5 *Freedom Fighter*, were conducted in a similarly expeditious fashion and it started entering the inventories of Mutual Assistance Pact nations by the mid 60s. Lockheed's C-141A *Starlifter* commenced what was judged as "a model" test program in 1964. Indeed, the fleet of test aircraft accumulated 2500 flight test hours--2.5 times the program goal--during the first 11 months of its

Category II and -III testing at Edwards. Even as the *Starlifter* was shattering existing airlift records and establishing a record for reliability in the late 1960s, the Center started evaluating Lockheed's gargantuan C-5A *Galaxy* super-heavyweight airlifter which first flew in 1968. After a remarkably compressed--though far from trouble-free--test program, C-5s became operational in 1970 and entered the wartime airlift flow to and from southeast Asia.[34]

Reconnaissance designs were easily the most exotic of the prototypes that underwent development at the Center during the 60s and the most famous of these were, of course, the Lockheed *Blackbirds*. The designation actually applied to a family of aircraft--the A-12, YF-12A, and SR-71--which incorporated first-generation stealth technology and were capable of cruising at speeds in excess of Mach 3 and at altitudes *well* above 80,000 feet. The early A-12 and YF-12A programs had been conducted under "top secret" security at a remote location but, after President Lyndon B. Johnson announced the existence of these dazzling performers in February of 1964, the YF-12A program was transferred to Edwards where the aircraft were first displayed for the press the following September. The three YF-12As were prototypes for a proposed interceptor to replace the canceled F-108 and at least a hint of their extraordinary performance capabilities was put on public display at Edwards when, on a single day in May 1965, one of the airplanes set no less than seven world speed and altitude records, including an absolute speed of 2,070 mph and a sustained altitude of 80,258 feet--without, in any way, taxing its full potential. During tests, the airplane also demonstrated that it could excel as an interceptor but, for a variety of reasons, the program was canceled and the full focus of testing shifted to the remaining SR-71 design which would go on, of course, to play a major role in world events over the next 2-1/2 decades while fulfilling its strategic reconnaissance mission. Meanwhile, and with much less fanfare, yet another Lockheed reconnaissance airplane completed its maiden flight at the old North Base facility at Edwards in August of 1967. While the U-2R appeared to be little more than a larger version of the classic U-2 first conceived by Kelly Johnson back in the early 50s, it was actually an entirely new aircraft with substantially improved performance and a more sophisticated array of recon capabilities.[35]

The doctrine of "commonality"--the development of common weapon systems to meet the requirements of two or more services --dominated 60s-era fighter and attack aircraft procurement and the aircraft that underwent development at the Flight Test Center demonstrated both the wisdom and the folly of such an approach.

Lockheed YF-12A

Both the Mach 2+ F-4C/RF-4C and A-7D, for example, were based on airplanes--with essentially proven technologies and well-demonstrated performance capabilities--which had already been acquired by the U.S. Navy. The F4H (F-4A) *Phantom II* had been developed by the Navy in the late 50s and its superior speed, range, load-carrying capability, and low maintenance man-hour requirements so impressed the Air Force that the F-4C was procured as a multi-mission tactical fighter to meet a requirement which it desperately needed to fulfill in the Vietnam conflict. The job of adapting a basic Navy aircraft to a land-based role posed some very real challenges which had to be solved during DT&E of the prototypes. Tests revealed a number of potentially serious deficiencies and mission-limiting problems that had to be rectified before the airplane could enter useful operational service. Nevertheless, the basic design was sound and, with so many of its initial development problems already overcome, the F-4C and the RF-4C both completed *relatively* troublefree CAT I, -II, and -III testing within just 2-1/2 years and they began to enter service in Vietnam by the mid-60s. There the *Phantom* quickly established itself as perhaps the finest fighter aircraft of the era. Though it incorporated a vast number of advanced systems and capabilities that were lacking in the Navy's A-7A subsonic attack aircraft (including the first Head-Up Display [HUD] incorporated into the cockpit of an Air Force fighter), the story of the A-7D was much the same. Following the maiden flight of the prototype YA-7D at Edwards in September of 1968, the airplane progressed, once again, through a relatively smooth DT&E program and delivery of production models

McDonnell F-4C Phantom

Vought A-7D Corsair II

General Dynamics F-111A

to operational squadrons for transition training got underway by the end of the following year.[36]

While, in many regards, the F-4C and the A-7D were "off-the-shelf" designs, the General Dynamics F-111 was something else altogether. Conceived under the umbrella of commonality *and* "total package procurement" (concurrent development, testing and production), it was developed from the *outset* as a system intended to meet both the Air Force's requirement for a Mach 2 low-level strike aircraft and the Navy's requirement for a high-altitude, long-range fleet defense interceptor. Though the Air Force and the Navy both argued that developing a common airframe to meet incompatible requirements was totally unrealistic, they were directed to proceed with procurement. On top of this, the TFX, as it was called, was by far the most technologically complex fighter ever developed by either service. Advanced technologies then under early development, such as variable-sweep wings, turbofan engines with afterburning, and new modular avionics maintenance concepts, were incorporated into the basic design. The resulting aircraft, the Air Force's F-111A and the Navy's F-111B, were so compromised that they were incapable of meeting the needs of either service and, indeed, the Navy ultimately canceled the F-111B program. Meanwhile, the Air Force proceeded with an *extended* DT&E program. Following the first flight of the F-111A, the aircraft commenced CAT I tests at the contractor facility in Fort Worth, Texas. But it was only *after* the airplanes arrived at Edwards for Air Force CAT II tests in January 1966 that an extraordinarily wide range of deficiencies were detected. The airplane was overweight and underpowered. It also suffered from engine-airframe incompatibility, extremely poor engine inlet design, poor avionics performance, and a deficient wing carry-through structure. The program's woes also highlighted critical flaws in the whole Category I, -II and -III process. The contractor had commenced CAT I tests in 1964 and the Air Force had started CAT II testing in early 1966. The airplane was still undergoing CAT I tests in 1972, CAT II tests in 1973 and CAT III operational testing was ultimately skipped altogether. While subsequent models of the F-111 were eventually developed into exceptional combat systems, the upshot of this incident was that a minimally satisfactory "product" was at least five years late in getting to its customer. From the Air Force's point of view, the test program had consumed far too much time, involved far too much duplication of contractor and AFFTC effort, and it had delayed initial Air Force evaluation until far too late in the process.[37]

Based on this experience, in 1972, the Department of Defense returned to a "fly-before-buy" policy which meant that test and evaluation would thereafter play a greater role in the acquisition process. Moreover, General Dynamics had won the contract for the F-111 against a competing design from Boeing in a competition in which "paper flew against paper." The failure of this and similar programs prompted a reversion to the old practice of prototyping and, whenever it was an affordable option, competing designs would thereafter be required to compete in the air, not just on paper. Meanwhile, the Air Force once again restructured flight testing into a two-part process by simply splitting it into DT&E and initial operational test and evaluation (IOT&E) and then combining the conduct of the two elements so that meaningful OT&E could be completed prior to any production decisions (see Fig. 3). Since then, the vehicle for accomplishing this has been the combined test force (see Fig. 4) which has typically functioned under the direction of an AFFTC military commander. In addition to mandating early Air Force involvement, the other advantages offered by this system have been substantial because it has permitted each organization to define its own test requirements and report results independently while taking advantage of common-use facilities, joint-use aircraft, combined maintenance and aircrews, and combined missions and data bases.[38]

COMBINED TESTING
1972 - PRESENT

	TYPE	AIRCRAFT
I	DEVELOPMENT TEST & EVALUATION INITIAL OPERATIONAL TEST & EVALUATION	PREPRODUCTION
II	OPERATIONAL T & E DEVELOPMENTAL T & E	EARLY PRODUCTION

A0302.004

Fig. 3: Combined Testing

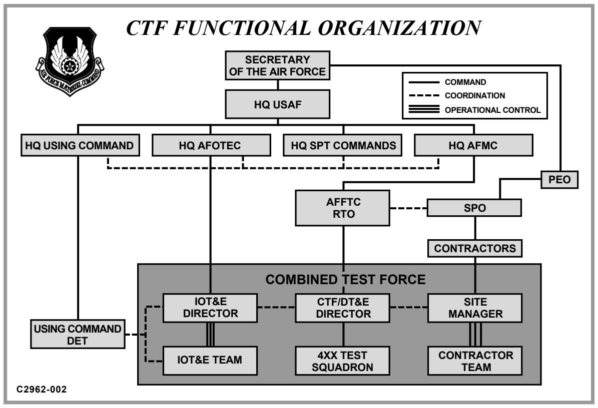


Fig. 4: Combined Test Force Structure

When the USAF Aerospace Research Pilot's School was once again redesignated the USAF Test Pilot School in 1972, the name change was more than symbolic. As the Air Force's manned spaceflight mission disappeared with the cancellation of the MOL program in the late 60s, school officials sent a survey out to graduates working in the aerospace industry to get their reading on the direction in which the business was headed. Based on the results, the school completely revamped its curriculum to reflect major changes that were already underway. Experiences with aircraft such as the F-111 had demonstrated that the proliferation of increasingly sophisticated on-board systems would become a constant and that the supervision of increasingly complex test programs would require strong management skills. Thus, while retaining the traditional performance and flying qualities curricula, the school replaced the space-oriented curriculum with a whole battery of courses focussing on systems test and test management. These new elements of the curriculum would, of necessity, remain in a continuous state of evolution because the only constant in the coming years would be that each generation of new systems would invariably embody dynamic advances requiring new test methods and techniques. The increasing complexity of modern flight testing also highlighted the compelling need for effective teamwork and communication between all members of a test team. Thus, in 1973, flight test engineers and, the following year, flight test navigators joined pilots in the curriculum and, over the years since, they have comprised about 40% of each class.[39]

Events of the 70s more than bore out the wisdom of these changes. The AFFTC was entering a systems revolution that has only accelerated over the years since, as avionics, sensors, fly-by-wire flight controls and a host of other sophisticated electronic and computer-driven systems have grown ever more complex. Whereas, in the past, the emphasis had been on developing airplanes that could fly higher and faster, the new systems revolution focussed on making them fly more efficiently, with greater responsiveness and agility, and on providing them with the capability to put their weapons on target more effectively. Most of the new--and upgraded--aircraft that have appeared on the ramp at Edwards since the early 70s have reflected this increasingly dynamic transformation.

Most...but not all. The first pair of new airplanes to undergo evaluation in the 70s certainly did not push the state of the art in terms of onboard systems. Indeed, the Northrop YA-9A and Fairchild YA-10A both incorporated essentially "off-the-shelf" technologies into their rugged airframes. But they *were* engaged in the first major program to employ the "fly-before-buy" and competitive fly-off philosophy in the post-total package procurement era. During a brief two-month evaluation in late 1972, the two designs flew head-to-head in an extremely close competition to determine which would be selected for development as the Air Force's first dedicated close air support aircraft since World War II. The YA-10A was proclaimed the victor, in part, because it was deemed the more survivable of the two designs. Its engines, for example, were mounted in separate pods above and to the rear of the fuselage thus reducing the likelihood of losing both to ground fire. Although the YA-10A had "won" the competition, final production go-ahead did not come until after preproduction models of the *Thunderbolt II* had completed three more years of DT&E and IOT&E. Even then, several more years of development testing were required to solve a number of problems. Ironically, for example, the "survivable" high-mounted engines proved to be susceptible to

McDonnell Douglas F-15A Eagle

stalls caused by the ingestion of gun gases from the A-10's huge 30mm rotary cannon. Thus, although the A-10 was not a systems-intensive airplane, flight testers found themselves challenged by a major systems integration problem.[40]

In contrast to the A-10, the McDonnell Douglas F-15A *Eagle* pushed the state of the art in every regard and, because of its high development costs, the design was not forced to engage in a fly-off competition prior to entering full-scale development testing at Edwards in July of 1972. Nevertheless, the airplane still had to prove itself in the air before any production decisions were rendered. Designed as the Air Force's first true air superiority fighter since the F-86, the F-15 incorporated a host of cutting edge technologies including a new electronic stability augmentation system, a compact, multi-mode, high-frequency pulse-Doppler fire-control radar, and a pair of 24,000-pound thrust afterburning Pratt & Whitney F100-PW-100 turbofans which, for the first time, combined to provide an American fighter with thrust greater than its normal tactical gross weight. Given the extraordinary complexity of the airplane and its sophisticated systems, the F-15 program represented a major proof-of-concept test for the new combined approach to DT&E and IOT&E. The new system functioned remarkably well, as the F-15A started entering squadron service in November 1974--just *28 months* after the first flight of the original full-scale development airplane and it achieved initial operational capability with the Tactical Air Command just ten months later. The expeditious conduct of the F-15 program was also due, in no small measure, to major advances in data acquisition and reduction capabilities. These advances had gotten underway, in the 1960s, with the introduction of digital Pulse Code Modulation (PCM) acquisition techniques which could interface directly with digital data processing computers.

The confluence of this development with the micro-miniaturization of high-speed digital computers and other electronic components triggered the development of extremely high-capacity data acquisition, telemetering and processing systems. The near realtime capability afforded by these systems had the effect of sharply reducing the number of test sorties required to evaluate the F-15. Pilots were able to complete more test points on each mission because they no longer had to land and wait--sometimes for days--for the data to be reduced and analyzed before proceeding to the next point. Engineers on the ground were now able to give them almost immediate clearance to proceed while a mission was still in progress or, if the data were unacceptable, directions to refly the point in question. As impressive as it was, however, the capability introduced during the F-15 program was only a starting point. The next two decades would bring an exponential increase in the capacity and speed of data acquisition and processing systems.[41]

Advanced prototyping, a concept new to the 1970s, was conceived to permit the U. S. Air Force to investigate promising new technologies and aerodynamic concepts for the possible future applications without a commitment to the full-scale production programs. While the General Dynamics YF-16 and the Northrop YF-17 aircraft were both originally designed to meet this requirement, in April of 1974, the evaluation of the two designs was transformed into a full-fledged competitive fly-off for a contract to develop a lightweight fighter aircraft. Given the fact that they were supposed to reflect low-cost approaches to fighter development, both aircraft demonstrated remark remarkable performance. Shortly after its first flight in June of 1974, for example, the twin-engine YF-17 was able to exceed the speed of sound in level flight without the use of afterburners.

General Dynamics F-16A Fighting Falcon

The single-engine YF-16 blended at least four major advanced technology features into a single airframe for the first time: the use of computer-control to vary the camber of the wing by means of flaperons, blended wing-body design, the use of vortex lift from fore-body wing strakes, and a "relaxed" static stability/fly-by-wire flight control system. The airplane's unorthodox design negative static margin capability (center of gravity aft of its center of lift) made it both inherently unstable and much more responsive than conventional aircraft and only the speed and precision of the new fly-by-wire flight control system could provide "artificial" stability while maximizing the YF-16's remarkable agility. In January 1975, following an extremely close competition which thoroughly examined the capabilities of each design, the YF-16 was finally proclaimed the winner due to its superior speed, altitude performance, combat radius and lower cost. The first preproduction F-16As arrived at Edwards for full-scale development testing in December of 1976 and, by January of 1979, the Air Force was able to activate its first squadron of *Fighting Falcons*. Moreover, though it "lost" in the Air Force competition, Northrop's YF-17 had performed so impressively in its trials at Edwards that the design spawned the F/A-18 *Hornet* which would later enter widespread service with the U.S. Navy and Marine Corps.[42]

Though originally conceived as potential replacements for the venerable Lockheed C-130, funding cuts had limited the Boeing YC-14 and McDonnell Douglas YC-15 to the role of advanced prototypes when they arrived at Edwards in the mid-70s. Because the Air Force was primarily interested in examining advanced Short-Takeoff and Landing (STOL) technologies for medium transport-sized aircraft, the contractors were given wide latitude in the design of their airplanes and each employed quite different--and extremely radical--approaches to the problem of achieving the powered lift necessary for takeoffs and landings within the confines of 2,000-foot runways. The YC-14 demonstrated the feasibility of "upper-surface blowing."

Boeing YC-14

Based on a concept called the "Coanda effect" (caused by air turning on the convex side of an aerodynamic surface), the exhaust from the YC-14's pair of high-mounted 55,000-pound thrust turbofans "blew" across the upper surface of the wing and, with the flaps extended downward, followed their curvature to produce sufficient powered lift for short-field operations. The YC-15 employed "under-surface blowing" to achieve the same effect. Its wings were configured with sets of double-slotted flaps which could be extended downward directly into the jet flow from the airplanes four turbofan engines. Part of the exhaust was directed downward by the flaps while the rest passed through and then downward over the flaps via the Coanda effect. The tests conducted with these airplanes convincingly demonstrated the feasibility of both approaches and the program ultimately paid handsome dividends. In the 1980s, for example, McDonnell Douglas would incorporate under-surface blowing into the design of its giant C-17 heavy transport.[43]

When the North American Rockwell B-1A landed at Edwards Air Force Base at the end of its maiden flight in December 1974, the prototype bomber reflected a major transition in strategic bomber design. While it boasted a Mach 2 capability at altitude, it was point designed to meet a much different requirement: to contend with a revolution in air defense capabilities which had taken place since the late 1950s. Instead of speed and altitude, *elusiveness* was now the key to the penetration of enemy airspace. Configured with a sophisticated terrain-following and -avoidance radar system and boasting a radar cross section which was only 1/10th that of the B 52, the B-1A was designed to evade enemy radar by taking advantage of terrain-masking as it flew on the deck at just under Mach 1. The tremendous natural advantages enjoyed by Edwards AFB made it the ideal place to test such a system. Located less than 100 miles from the California coastline, the region around Edwards offered every conceivable type of terrain--from the lowest to the highest elevations in the continental U.S.--over which to evaluate the penetration

Rockwell B-1A Prototype

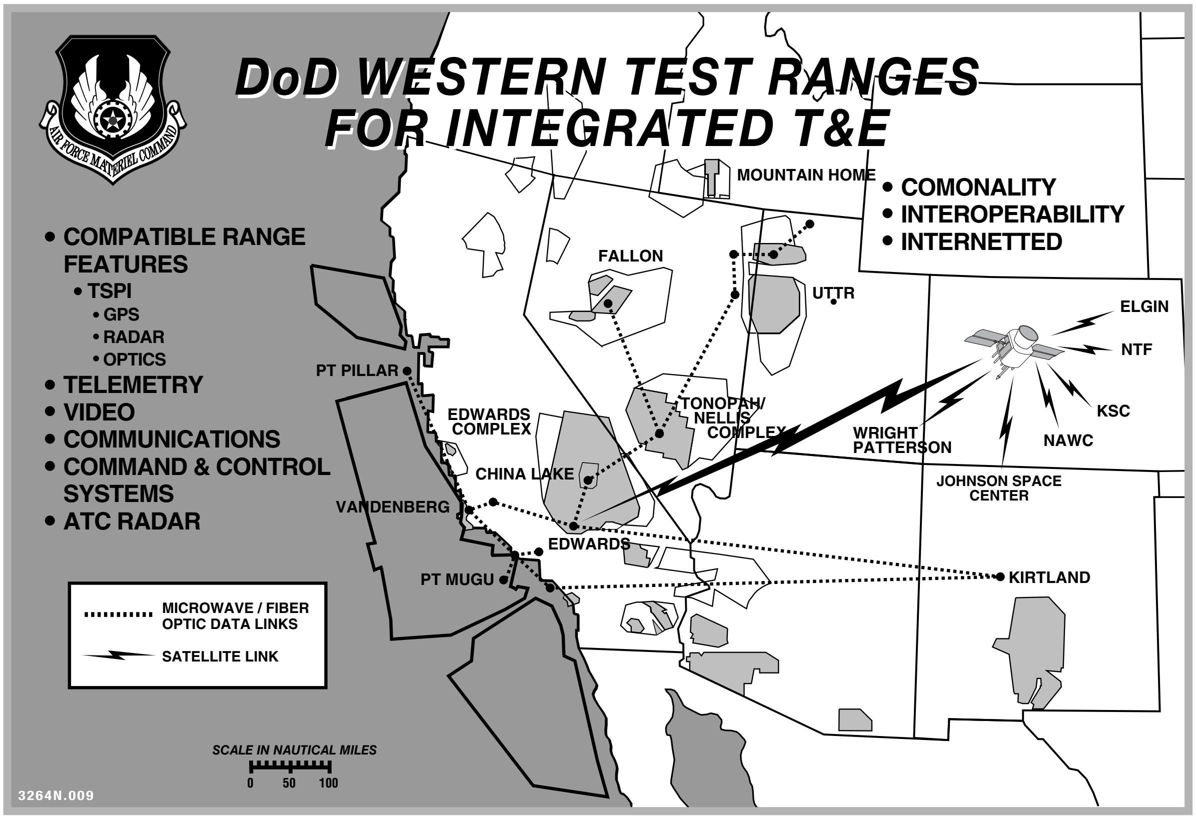


Fig. 5: Southestern Range Complex

capabilities of the big swingwing bomber. Despite the impressive potential demonstrated by the airplane, the B-1A program never enjoyed whole-hearted congressional support many critics contending that the day of the manned penetrating bomber was past--and the Carter administration canceled it, in 1977, before it had completed development.[44]

For the interim, an old warhorse--the venerable B-52 aircraft--was updated with new offensive avionics and the G-model airplanes were tested as "standoff" launch platforms for sophisticated Air-Launched Cruise Missiles (ALCMs). Part of this late 1970s effort encompassed a competitive flyoff between a pair of rival ALCM designs--the Boeing AGM-86B and the General Dynamics AGM-109--which were capable of navigating, at tree-top level, over hundreds of miles of terrain before hitting a target with pinpoint accuracy. Mammoth in its proportions, the ALCM program required the development of an the development of an in an instrumented test corridor extending some 800 miles from the Pacific Ocean to the old Hill-Wendover-Dugway complex of ranges in northwestern Utah where the AFFTC had conducted a variety of remotely piloted vehicle (RPV) tests over the years. For the ALCM program, the Center had to invest heavily to provide a comprehensive low-level radar tracking capability throughout those ranges and, indeed, because of the need to carefully coordinate test and training operations throughout the complex, the existing ranges were consolidated into the Utah Test and Training Range (UTTR) and placed under AFFTC management in January of 1979. The UTTR constituted the largest overland complex of its kind in the United States, including 1.7 million acres of land, 3.6 million acres of re-stricted airspace, and an addition 6.9 million acres of airspace available for military test and training purposes. Linked to Edwards *via* a microwave data transmission system and ideal for RPV, cruise missile and large "footprint" weapons testing, the UTTR became a key component in a complex of western ranges which provided the Department of Defense with an incomparably diverse array of test range capabilities all within easy flying distance of the AFFTC which was located at its hub (see Fig. 5). Following completion of the ALCM fly-off--which was won by Boeing's

AGM 86B, the --UTTR continued to serve as the termination point for ongoing ALCM DT&E and OT&E and tests of General Dynamics' BGM-109 Ground-Launched Cruise Missile (GLCM) were conducted entirely within its spacious confines.[45]

Both the Air Force and NASA employed existing airframes to serve as test beds to explore a large variety of new concepts and systems in the 1970s. In the early 70s, for example, NASA modified two Vought F-8 *Crusaders* to conduct a pair of research programs which had important implications for the future of aviation. One of the aircraft was used to confirm the practical viability of fly-by-wire flight control technology (which the YF-16 was also pioneering) while the other was used to explore the potential transonic performance benefits offered by a supercritical wing. Flattened on the upper surface and tapering downward at the trailing edges, the thin supercritical wing demonstrated significant performance advantages which would permit jet airliners and transports to increase their cruise speeds while burning substantially less fuel. The success of this wing technology program gave rise to the NASA-Air Force F-111 Transonic Aircraft Technology Program in which the concept was explored through a full range of wing-sweep configurations for possible military applications. Meanwhile, the development of digital flight control computer technology enabled the Air Force to pursue the logic of the electronics revolution with a modified YA-7D aircraft. The DIGITAC A-7 provided the pilot with selectable control modes, each of which was tailored to optimize the airplane's tracking and handling qualities for a specific weapons delivery task such as bombing or air-to-air or air-to-ground gunnery. The YF-16's fly-by-wire flight control system made it an ideal test bed for the Air Force's Control Con-figured Vehicle (CCV) program. The airplane was modified with a pair of eight-square foot forward-mounted canards which added side forces and enabled the aircraft, for the first time, to change direction without having to bank or alter its heading. The advantages offered by each of these--and many of the other new technologies and concepts evaluated at the Center during the 70s would have a major impact on the military and civil aviation designs of the 80s.[46]

The most revolutionary development, by far, however, did not take place at Edwards but at a remote location where a small team of Lockheed and Air Force personnel conducted a series of tests which would forever alter the nature of air combat. A major breakthrough in the prediction of aircraft radar cross section (RCS) had enabled a team of Skunk Works' designers and engineers to build a pair of small, radically unconventional airplanes with--by several orders of magnitude--the lowest RCS in the world. They were point designed for stealth and thus, instead of smooth, gracefully curved, streamlined surfaces, each airplane was essentially a collection of flat surfaces. These faceted surfaces, along with the airplanes' radically sweptback, semi-tailless planform and the lack of any high-lift devices raised some question as to whether such shapes could even fly, let alone perform any useful tactical functions. Indeed, it was only the availability of quad-redundant, fly-by-wire flight control systems

Have Blue Concept Demonstrator Aircraft

which made it possible to compensate for the obviously inherent instability of these airframes. The project was code named "Have Blue" and it was the job of Lockheed test pilot Bill Park and the AFFTC's Lt. Col. Norman K. "Ken" Dyson first to demonstrate the air-worthiness of the design and then to prove its tactical utility. Although it was far from an ideal flying machine, its basic airworthiness was demonstrated during a series of 36 flights with the No. 1 aircraft between December 1977 and May of 1978. When this airplane was lost and Bill Park seriously injured in an accident, Lieutenant Colonel Ken Dyson--supported by AFFTC flight test engineers Roger Crane and, later, Ed Bradfield--took over responsibility for the critical RCS tests which got underway with the No. 2 airplane in July of 1978. Over the following year, the airplane completed 52 flights during which it convincingly demonstrated its very low observability against a wide array of the most sophisticated air- and ground-based air defense systems. The successful conduct of these tests led immediately to the development of a new subsonic attack aircraft which would be designated the F-117A and a new revolution--the stealth revolution--was underway.[47]

One of the major episodes in all of the Center's history commenced in 1977. The Space Shuttle *Enterprise* would never fly in space--or even exceed the speed of sound--but it set the stage for sister ships that would. Launched from atop a Boeing 747 at altitudes ranging from 20-25,000 feet, it made an extraordinarily successful series of five unpowered approach and landing tests that year which validated the techniques that would be employed for mankind's first gliding descents from outer space. And, indeed, less than four years later, at 10:20:57 on the morning of April 14, 1981, Edwards once again became the scene of high drama, as the Space Shuttle *Columbia's* wheels touched down on historic Rogers Dry Lake. NASA Astronauts John Young and Robert Crippen had just successfully landed the

Shuttle Enterprise Approach and Landing Tests

Space Shuttle Columbia (April 14, 1981)

first orbiting vehicle ever to leave the earth under rocket power and return on the wings of an aircraft, and a new era in space exploration--the era of reusable space vehicles--had dawned. It seemed only fitting that *Columbia* should make its first landings at Edwards where so many major milestones in flight had been accomplished and where so many of the shuttle's antecedents had proven the concepts that had made it possible. But Edwards was more than just the place where the shuttles landed. Flight test engineers from the AFFTC joined with their NASA counterparts in the planning of missions and in the subsequent evaluation of test results. The AFFTC's Office of Advanced Manned Vehicles, for example, joined in the responsibility for that last critical hour when, after deorbit burn half-way around the globe, the shuttle decelerated from a speed of over 17,000 miles per hour, descended from the cold vacuum of space through the blazing inferno of reentry, maneuvered to dissipate its enormous hypersonic energy, and landed smoothly on the hard-baked surface of the lake bed or on Edwards' main concrete runway. The formal shuttle test program was completed in just four missions. With STS-5, the space transportation system was declared operational and a once fantastic concept had matured into a practical system. The magnitude of this accomplishment may be placed in proper perspective by recalling that it had only been a little over 30 years since the X-1 had first penetrated the sonic "wall." By the early 80s, pilot-astronauts were almost routinely flying an operational aerospace vehicle at speeds in excess of Mach *24*. In that relatively short interval between the X-1 and the shuttle, the mysteries of hypersonic flight, lifting reentry, and aerothermodynamics had all been fathomed and mastered by flight researchers at Edwards.[48]

While space shuttle operations proceeded at Edwards Air Force Base throughout the 1980s and 1990s, flight researchers continued to advance knowledge in the aeronautical realm as they explored a remarkably wide spectrum of new concepts and technologies with an assortment of one-of-a-kind aircraft. As the 1980s opened, for example, NASA was testing the oblique-wing AD-1 in order to investigate the potential performance advantages that might be gained by pivoting an airplane's entire wing while in flight. Benefiting from major advances in lightweight composite materials and fly-by-wire technology, the X-29 featured blade-thin, forward-swept wings which enabled NASA and Air Force researchers to explore the configuration's potential for enhanced fighter agility, better low-speed handling qualities and reduced stall speeds. The data from this long-running and highly productive program were valuable, not only because they confirmed the advantages of the forward-swept configuration and a host of other new aerodynamic concepts, but also because they were used to validate sophisticated new computer modeling techniques which were becoming such an essential element of the design process. Indeed, by the 1980s, this had become a primary objective of virtually all flight research and proof-of-concept programs.[49]

Because of their high cost and extended service lives, front-line combat aircraft were designed with growth potential in mind so that they would be compatible with rapidly evolving technologies and this made them ideal test beds for the evaluation of new concepts. During the early 1980s, for example, an F-15B was modified to incorporate an integrated flight and fire control (IFFC) system which, even in the most demanding gun-attack profile, for example, enabled the pilot to fire on airborne targets from virtually any aspect angle. The remarkably promising capabilities of this system were demonstrated in 1982 against a hard-maneuvering PQM-102 drone as it turned sharply toward the *Eagle*. Employing the IFFC system, the F-15 pilot fired a 2-second burst from his 20mm cannon and--in a virtual head-on engagement--destroyed the unmanned adversary aircraft. Exotic though it was, IFFC was but a first step; total system integration was looming just over the horizon.[50]

The Advanced Fighter Technology Integration (AFTI)/F-16 was certainly among the most productive of the new technology demonstration programs. Originally conceived as a follow-on to the F-16 CCV program to explore advanced flight control technology and maneuvering concepts, the joint Air Force/NASA AFTI/F-16 program has continued to fly at Edwards since 1982. The airplane, one of the original F-16A full-scale development vehicles, has undergone extensive and repeated modifications in order to provide a relatively low-cost means of determining the real-world feasibility of highly advanced, integrated

Grumman X-29

AFTI/F-16

AFTI/F-111

sensor, avionic and flight control technologies for possible incorporation into new or even existing fighter aircraft designs. Early on, for example, it was used to demonstrate the operational value of voice command and automated ground collision avoidance systems. More recently, it has been used to explore an automated maneuvering attack system and a host of other advanced technology systems--such as an automated terrain-following and threat avoidance system, a pilot-activated unusual attitude recovery system, an automatic target handoff system providing digital data link communications with forward air controllers, an integrated night vision helmet and a dual line-of-sight, head-steered forward-looking infrared (FLIR) system-all of which were designed to ease pilot workload and insure first-pass strike effectiveness in the extremely demanding and hazardous low-level, close air support environment.[51]

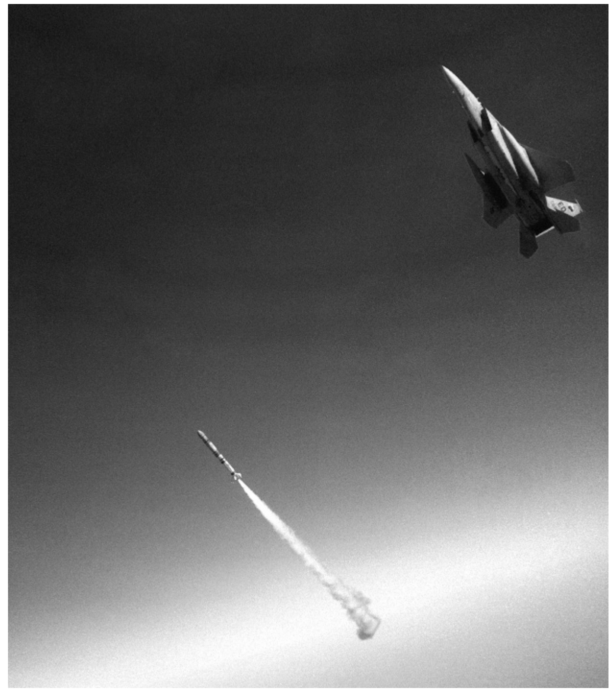
Fly-by-wire technology and the continuing development of lightweight--and, in this case, flexible--composite materials made it possible for Air Force and NASA test pilots, in the mid-80s, to evaluate the potential of a "mission-adaptive wing." The AFTI/F-111 was modified with a digital flight control system and moveable wing leading- and trailing-edge surfaces, fabricated from fiber-glass reinforced epoxy, which made for a flexible, absolutely smooth-surfaced variable-camber wing which could be automatically configured for optimum maneuverability, performance and fuel efficiency for each phase of the airplane's envelope. Digital electronics also made it possible to begin to explore the potential of fully integrated flight and engine control systems which, in turn, permitted flight researchers to investigate the tactical benefits offered by vectoring the thrust of high-performance fighters. This effort got underway in 1989 with the flights of the F-15 STOL/Maneuvering Technology Demonstrator (MTD) which was modified with two-dimensional thrust vectoring-and-reversing nozzles, an autonomous landing guidance (ALG) system and forward-mounted canard surfaces. The NF-15B STOL/MTD aircraft not only demonstrated reductions of 35% and 65% in takeoff and landing roll-out distances, it also demonstrated a 25% improvement in flight deceleration performance, dramatic improvements in pitch response and

F-15 STOL/MTD

controllability at high angles of attack (AOAs), and its ALG system proved that it was possible for a single-seat fighter pilot to make extremely precise adverse weather or nighttime landings using only onboard sensors.[52]

This highly successful program was followed by three complementary and even more ambitious NASA and Air Force programs employing different approaches to multi-axis thrust vectoring. Since the earliest days of flight, loss of control at high AOAs, especially while maneuvering, has posed a major problem. In the early 90s, the NASA Dryden Flight Research Center at Edwards modified an F-18 with three inconel vanes replacing the secondary nozzles on each of the engines--and, later, with activated forebody controls (mechanical strakes added to the nose section) for improved yaw control. This High-Alpha Research Vehicle (HARV) was joined by a pair of purpose-built X-31 Enhanced Fighter Maneuverability aircraft which also employed a three-vane system for each of the single-engine vehicles. Meanwhile, in 1993, the Air Force modified its new NF-16D Variable Stability Inflight Simulator Test Aircraft with a production-representative system employing a vectoring ring to provide a full circular envelope of nozzle vector angles for its Multi-Axis Thrust Vectoring (MATV) demonstrator. The results from each of these programs were stunning, to say the least. The F-18 HARV and the X-31 both demonstrated

X-31



F-15 ASAT Launch (September 13,1985)

departure resistance and "carefree" controllability at AOAs of up to 70 degrees. Indeed, the X-31 went on to demonstrate that multi-axis thrust vectoring would permit designers to dispense with tail surfaces altogether and, at the 1995 Paris Air Show, it performed a variety of post-stall maneuvers at *far* lower altitudes than had ever before been attempted, including: stabilized flight at 70 degrees AOA just 500 feet above ground level (AGL); fully controlled and stabilized flight at 70 knots indicated airspeed, above 50 degrees AOA, at 500 feet AGL; and high-rate velocity vector rolls at 70 degrees AOA. Meanwhile, the F-16 MATV aircraft achieved steady state AOAs in excess of *85* degrees, with transients to well over 100 degrees, while providing pilots with the ability to maintain directional stability and roll the airplane at virtually *any* AOA. Most important, each of these aircraft demonstrated dramatically improved agility and lethality during mock close-in combat engagements against a wide variety of front-line high-performance fighters. As a result of these tests, thrust vectoring was no longer merely a research concept; it had become a viable design option for present and future fighter aircraft.[53]

Thrust vectoring was only one of many new technologies demonstrated during the 80s and early 90s. Perhaps the most dazzling demonstration--and one which had an immediate impact on international politics--occurred high over the Pacific, on September 13, 1985, as Maj. Doug Pearson pulled into a near-supersonic, 65-degree climb in a highly modified F-15 which had been aptly nicknamed the *Celestial Eagle.* Flying an extraordinarily precise profile, he climbed through 38,000 feet and launched a 17-foot long, three-stage missile toward Satellite P78-1 orbiting 340 miles overhead. In a feat which must be compared to finding the proverbial "needle in a haystack," the fighter-launched anti-satellite (ASAT) missile scored a direct hit. It was a technological display which shook the walls of the Kremlin and, depending on the vicissitudes of international politics, would probably never again be duplicated.[54]

One-of-a-kind airplanes and spectacular events have become almost commonplace at Edwards over the years but, as noted above, they have always represented only a small part of the AFFTC's workload. The primary job has always been to assure that, if and when the need arises, American aircrews will go into combat with the most effective and reliable operational aircraft in the world...and it continued to meet this challenge throughout the 80s and 90s as the capabilities of existing aircraft--such as the F-15 and F-16--were continuously refined and expanded and as new aircraft and systems were introduced into the inventory.

As the 80s opened, the Center was completing certification of the McDonnell Douglas KC-10 *Extender* and it started entering the Strategic Air Command (SAC) inventory in 1981. In June of 1981, the initial flight tests of the F-117A quietly got underway at a remote location and, though very few people knew of it, the "stealth fighter" achieved initial operational capability in October of 1983. In 1982 and early '83, the Center conducted an operationally oriented fly-off comparison between an F-15C and a radically modified F-16XL, featuring a large "cranked arrow" wing, to meet a new requirement for a fighter combining air-to-air and interdiction capabilities. Based on these tests and a variety of technical considerations, the twin-engined *Eagle* was selected for development as the Air Force's new F-15E dual-role fighter, an aircraft which underwent highly successful combined DT&E/IOT&E at Edwards in the mid-to-late 1980s and thereafter went on to demonstrate remarkable combat effectiveness in the Persian Gulf conflict of the early 1990s.[55]

McDonnell Douglas F-15E Dual Role Fighter

As development costs for major new weapon systems skyrocketed, DT&E for many of the "big ticket" programs came under ever more intense political scrutiny and, indeed, test objectives and milestones sometimes seemed to be driven more by political than technical considerations. Thus, when the B-1 bomber was resurrected and the B-1B program got underway in 1983, new pressures were imposed on the DT&E process. In addition to greater stealth resulting from RCS reductions, the B-1B incorporated a wide array of new state-of-the-art systems, including a defensive avionics system which was designed to detect and jam the most sophisticated air defense networks in existence. It was a *very* complex weapon system and, despite objections from veteran flight testers at the AFFTC who argued that the technical risks involved in integrating all of these systems would be extra-ordinarily high, the program office apparently felt compelled to project a remarkably ambitious, "success-oriented" 1,000 hour flight test schedule and a robust initial operational capability by October of 1986. The B-1B program offered prime examples of *why* flight testing is such a necessary component of the acquisition process *and* of the problems that can arise if the advice of experienced flight test professionals goes unheeded. *All* airplanes --especially highly sophisticated modern combat aircraft--suffer growing pains as they pass through the ordeal of DT&E and OT&E but the B-1B became a *cause celebre* because deficiencies detected in flight test were far more extensive than had been anticipated and the promises made for it had been far too ambitious. Integration of the airplane's complex systems, especially its defensive avionics, became a lengthy and highly controversial process. Formal DT&E was not completed until June of 1989--after more than *3,000* flight test hours--and, even then, the performance of the B-1B's defensive systems still did not fully meet the original design requirements. Indeed, the bomber resumed DT&E at Edwards in the early 90s, in part at least, in an effort to remedy some of those deficiencies.[56]

Initial projections for development of the Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) fire control system proved to be similarly optimistic. This system was composed of three major components: a wide field-of-view head-up display; a navigation pod incorporating terrain-following radar and FLIR sensor systems; and a targeting pod incorporating a FLIR, laser target designator and range-finder, automatic target trackers, and a missile boresight correlator. Proposed for initial incorporation into late-model F-16Cs and Ds, the system promised to open up a whole new arena in air-to-ground combat by permitting fighter pilots to fly on the deck at night or in adverse weather over any type of terrain. The F-16 LANTIRN DT&E program was originally projected to run from mid-1982 to mid-1985 and encompass approximately 875 test sorties. But system component problems delayed program start-up until mid-1983 and, as testing got underway, it soon became apparent that the system still required a *lot* of development. Indeed, a host of problems--particularly with the targeting pod--delayed a decision on high-rate production until 1989. By that time, F-16 LANTIRN DT&E had consumed more than 2,000 flight test hours while the F-15E LANTIRN program had required another 1400 hours. Nevertheless, the system's flaws were detected and remedied and it ultimately demonstrated eye-opening capabilities when they were actually needed. In the Persian Gulf conflict, LANTIRN became one of those systems which helped revolutionize air combat operations by denying our adversary the once comforting sanctuary of night.[57]

As the Air Force Flight Test Center entered the 1990s, the capabilities of a pair of major new aircraft--which promised to provide worldwide power projection capabilities until well into the 21st century--were undergoing evaluation. For the first time in nearly four decades, a giant flying wing soared over Edwards as the Northrop B-2 bomber completed its maiden flight in July of 1989. With its thin silhouette, compound curves and other advanced low-observable characteristics, the B-2 represented what

Northrop B-2 Spirit

might be called a third-generation stealth aircraft (following the SR-71 and Have Blue F-117) and it performed impressively as it underwent painstaking RCS, infrared, visual and acoustic signatures tests against a full spectrum of threat simulators. But there was much more to the B-2 than just stealth. By far, the most complex airplane ever built, it required the most intensive DT&E/IOT&E effort ever mounted at the AFFTC, with more than 140 individual system and subsystem test plans and a total of more than *26,000* individual test points--varying in duration from less than one minute to more than 13 hours--which had to be successfully accomplished. Indeed, though the bulk of the testing focused on stealth and the integration of various state-of-the art systems, the unique flying wing planform itself required very close attention. Flying wings, for example, do not have classic--and, hence, desirable--stall warning characteristics and simulator predictions of high AOA responses proved to be only partially accurate, as test pilots encountered several unexpected pitchups at elevated AOAs. Limits were incorporated into the final flight control software to insure that operational pilots would not enter these conditions. While sophisticated mathematical and computer models and simulations have become remarkably precise and essential predictive tools, there were more than enough such occurrences during the B-2 program to confirm, once again, why flight testing remains such an indispensable element of the acquisition process.[58]

And, indeed, although it was essentially based on so-called "off-the-shelf" technologies, even the new McDonnell Douglas C-17 STOL heavy airlifter aircraft reconfirmed the validity of this truism. Because it incorporated well-proven technologies, McDonnell Douglas originally projected a fast-paced, highly success-oriented 2500-hour DT&E/IOT&E program employing a total of five C-17 test airplanes which would require only eighteen months to complete. But, while the individual technologies had been proven, they were not necessarily mature nor had all of them ever before been previously incorporated

McDonnell Douglas C-17 Globemaster III

into a single airframe intended for everyday operational use. Indeed, one of the major purposes of DT&E is to detect anomalies, fix them and thereby mature the system as it proceeds to increasingly demanding test points. This is ultimately what happened to the C-17. A plethora of major system and airframe problems--many of them safety-of-flight related--were detected; so many, in fact, that the future of the C-17 acquisition program remained in doubt throughout the early 90s. In 1993, the AFFTC finally convinced program managers that meeting a highly success-oriented test schedule should not be the purpose of the program; rather, that it should be to mature the airframe and its onboard systems so that a high-quality, mission-capable airplane could be delivered for critical OT&E service tests which would ultimately decide the fate of the C-17 production program. The program was extended and its focus shifted toward patient, very methodical development of the aircraft and its onboard systems. The formal DT&E/ IOT&E program ultimately required 39 months but, before its completion in December of 1994, the C-17 had demonstrated some *very* impressive capabilities--such as landing with a 161,000-pound payload in less than 3,000 feet. Even more important, it was ready to demonstrate its full range of capabilities during the all-important operational service tests...and, during those tests, the once scorned C-17 performed like a champion as it met every challenge in one of the most exhaustive such evaluations ever conducted on a new USAF aircraft.[59]

A great many challenges lie ahead. As the USAF was approaching its 50th anniversary, the AFFTC was preparing for the DT&E of a fighter which would give a new definition to the term “air superiority.” Indeed, between late August and late December 1990, the Center caught a glimpse of this future as a pair of rival prototypes completed a brief demonstration and validation (DEM/VAL) flight test program. While both the F-117A and the B-2 had been point designed for stealth, the Lockheed-Boeing-General Dynamics YF-22A and the Northrop-McDonnell Douglas YF-23A Advanced Tac-

YF22A and YF-23A in Formation

tical Fighter (ATF) prototypes were the first aircraft ever to blend stealth with agility and supersonic cruise capability. An effort to minimize the risks of proceeding into full-scale development with either design, the DEM/VAL program also included Pratt & Whitney YF119 and General Electric YF120 prototype engines which incorporated major advances over 35,000 pounds of static thrust in afterburner and at 23,500 pounds in military power, these engines provided approximately 35-percent more thrust, for example, than the F100 engines powering the F-15 and thereby permitted the ATF prototypes to become the first fighters in history to cruise at supersonic speeds for extended periods without the use of afterburners. Both of the competing ATF prototypes attained Mach 1.58 in demonstrating this "supercruise" capability in a remarkably fast-paced program during which 124 test flights were completed in just 124 days. Moreover, each of the prototypes demonstrated a wide array of other impressive capabilities. Increased reliability, for example, was one of the most important requirements for the ATF and the YF-23A demonstrated an impressive surge capability by logging six missions in a single day. Increased agility was another and the YF-22A, which was configured with two-dimensional thrust vectoring nozzles, demonstrated complete controllability at 60 degrees AOA and 82 knots calibrated airspeed (KCAS). In addition to providing data for the decision on which contractor team would proceed into the engineering and management development (EMD) phase of the program, the DEM/VAL flight test program also proved to be invaluable as a risk reduction effort. After just 19 flights, for example, Lockheed reported that it had already incorporated 30 engineering changes into the basic design of the F-22A as a result of the flight tests. In April of 1991, the F-22A and F119 engines were selected for full-scale development. The EMD program would pose perhaps the greatest technical challenge ever faced by the Center because, in addition to all of the advanced features of the prototypes, the EMD airplanes would incorporate a state-of-the-art, fully integrated avionics and sensor suite which would employ a family of common hardware and software modules linked to a single supercomputer capable of up to 10 *billion* signal processing operations per second. The time-sharing capability of this system would enable it to fuse and analyze diverse streams of data from each of the fighter's highly advanced sensor systems into a synthesized and highly readable "glass cockpit" display. The successful integration of this system, alone, would be a daunting challenge, indeed.[60]

YF-22A Advanced Tactical Fighter Prototype

In an age of spiraling technology, flight test has become a remarkably complex process and this has forced a virtual revolution in the Flight Test Center's data acquisition and processing capabilities (Fig. 6). In the early 70s, the F-15 and YF-16 had been instrumented to cover approximately 300 parameters and onboard systems were capable of transmitting data to ground stations at the rate of 160,000 bytes per second. The systems-intensive fighters of the 90s are instrumented for as many as 6,000 different parameters--and the figure increases to *9,000* for the B-2--and millions of bytes of data per second can be telemetered to the ground for

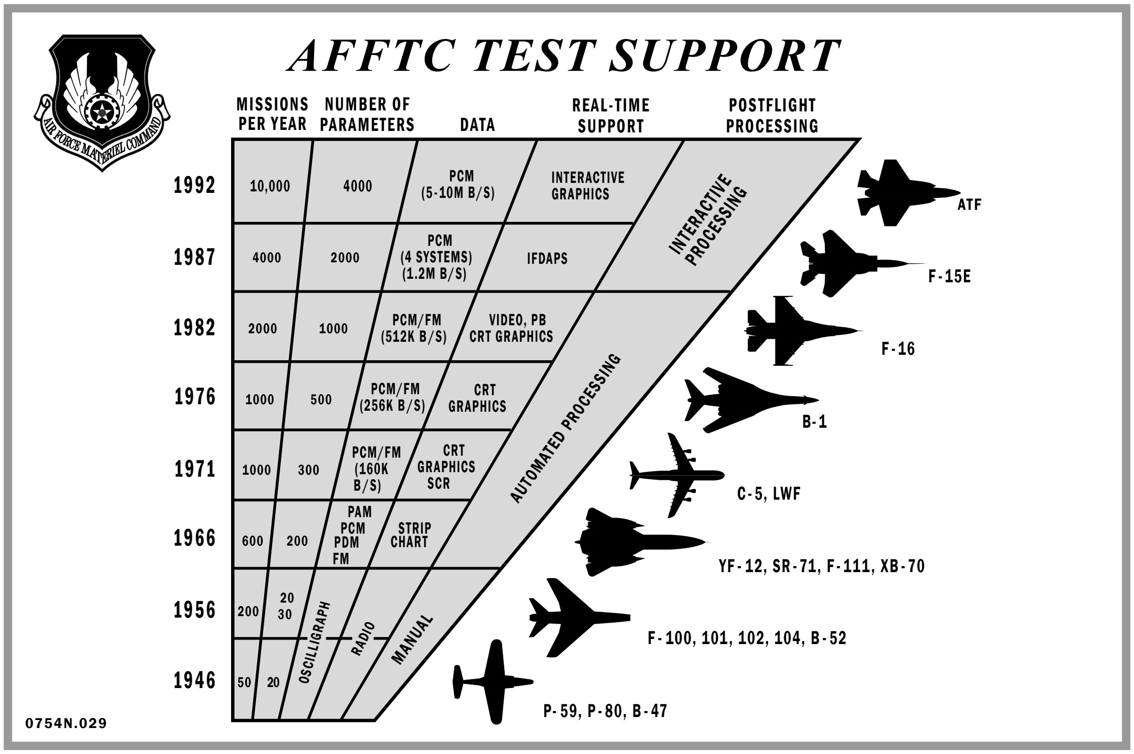
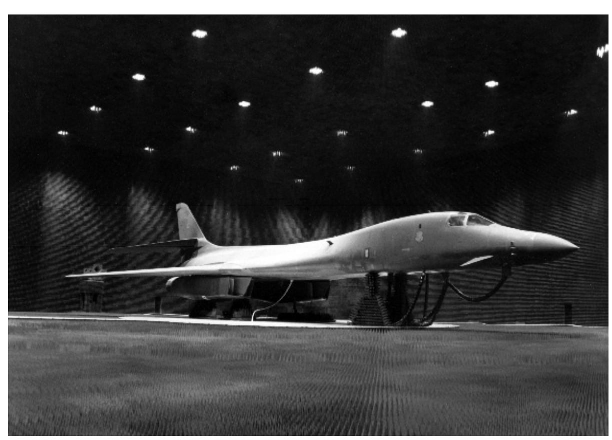


Fig. 6: Test Support Infrastructure

near-real-time reduction and initial analysis even before the aircraft touches down. In the 70s, all TSPI data were acquired with optical and radar trackers. By the mid-90s, precise TSPI data was also beginning to be acquired in real-time by means of the satellite-based Global Positioning System. The burgeoning complexity of aircraft with increasingly integrated systems coupled with this information explosion have made each flight test hour incredibly valuable...and costly. In an effort to reduce the volume of flying hours and the rapidly escalating costs incurred with the old "fly-fix-fly" method of testing, the AFFTC had started rethinking its whole approach to DT&E in the late 1970s. And, during the 1980s, it commenced development of facilities such as the Integration Facility for Avionic Systems Test, the Test and Evaluation Mission Simulator, and the Benefield Anechoic Facility which permitted a wide spectrum of flight control, avionic and electronic warfare systems test and integration to be conducted on the ground *before* new software-intensive systems were put through the time-consuming and resource-intensive ordeal of flight test. The development of these collocated and linkable facilities (which comprise the Avionics Test and Integration Complex) at Edwards AFB enabled the Air Force Flight Test Center to provide a comprehensive and remarkably synergistic T&E capability at a single location and served as the basis for its selection, in the mid-1990s, as the Air Force's single manager for the DT&E of avionic and electronic warfare systems in addition to its more traditional responsibilities with regard to the air-



B-1B Under Test in Benefield Anechoic Facility

frames and the onboard propulsion systems. Finally, the expansion of the Center's test and test support capabilities was not just limited to ground-based facilities. With the merger of the 4950th Test Wing into the 412th Test Wing at Edwards AFB in April of 1994, the Flight Test Center acquired a whole fleet of modified multi-engine aircraft equipped with an impressive array of airborne sensor, data acquisition and telemetry systems. With the acquisition of these uniquely configured C-18, C-135, C-141 and T-39 aircraft, the AFFTC's test and test support mission expanded into worldwide operations.[61]

Flight testing at Edwards has come a long way since the XP-59A first lifted off more than five decades ago. Over the years since, the U.S. Air Force and, indeed, the world of aerospace, in general, have continued meet their future in the clear blue skies above the base's sprawling expanse. Every aircraft that has entered the Air Force inventory (and a *great* many that failed to do so) has first been put through its paces at Edwards and, arguably, more major milestones in flight have occurred there than anywhere else in the world. During the past half-century, the ever-accelerating pace of technological change has been daunting, to say the least, but the flight test community at Edwards has repeatedly demonstrated the ability to adapt to such change and to master the many challenges it inevitably imposes. The turbojet revolution, the supersonic, hypersonic and space revolutions, the systems revolution and, most recently, the stealth revolution, each has imposed seemingly insurmountable obstacles--obstacles that have been overcome through a combination of technical skill, daring ingenuity and resourceful management. Indeed, the U.S. Air Force Flight Test Center's unique blend of natural, technical and human resources have transformed it into something much more than just an Air Force asset; it is, indeed, an irreplaceable *national* asset.

Edwards Air Force Base flightline, looking toward Rogers Dry Lake, May 1994

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Appendix A

Capt. Glen W. Edwards

Born in Medicine Hat, Alberta, Canada, on March 5, 1918, and raised in Lincoln, CA, Glen Edwards maintained dual U.S.-Canadian citizenship throughout his life. After graduating with a degree in chemical engineering from the University of California, Berkeley, Edwards enlisted in the U.S. Army Air Forces on July 15, 1941. After completing his flight training, he was commissioned as a second lieutenant at Luke Field, AZ, in February 1942. Assigned to the 86th Light Bombardment Squadron of the 47th Bombardment Group, he departed for the North African theater of operations (Tunisia) as a flight commander in October of 1942. There he led his flight of A-20 Havocs on extremely hazardous, low-level missions against German tanks, convoys, troop concentrations, bridges, airfields and a variety of other tactical targets. When the Germans broke through the Kasserine Pass in February of 1943, his undermanned and undersupplied squadron flew 11 missions in a single day, repeatedly attacking advancing armored columns and blunting their thrust. On one of these missions, Edwards and his crew set a record by completing a combat mission--from takeoff to landing--in just 19 minutes. His squadron received a Distinguished Unit Citation for this action. During his tours in the North African campaign and the invasion of Sicily, Edwards completed 50 combat missions and was awarded four Distinguished Flying Crosses and six Air Medals.

Returning to the U.S. in December of 1943, he was assigned to the Pilot Standardization Board at Florence Army Air Field, SC, and then, in late 1944, to the Flight Test Division at Wright Field, Ohio. He graduated from the Flight Performance School (initial designation of the USAF Test Pilot School) there in May of 1945 and was assigned to the Bomber Test Operations Section. Though assigned to Wright Field, he spent much of his time at Muroc AAFB, on California's high desert, testing a wide variety of experimental prototypes such as Douglas' highly unconventional pusher-prop light bomber, the XB-42 Mixmaster. Indeed, in December of 1945, he and Lt Col Henry E. Worden set a new transcontinental speed record when they flew this airplane from Long Beach, CA, to Bolling AFB, in Washington, DC, in just 5 hours and 17 minutes. In 1946, he was the principal project pilot for the jet-powered Convair XB-46 prototype bomber. It was also during this period that he acquired his first experience with a flying wing, as he familiarized himself with the flying qualities of the Northrop N-9M, a single-place, 1/3-scale mock-up of the giant XB-35 prototype bomber. Living modestly on a captain's salary at the time, he also somehow managed to help put two of his nephews through college. His superb skills as a pilot, engineer and officer were held in such high esteem that his immediate superior, Maj Robert M. Cardenas, recommended him as project pilot for an unprecedented program--the first attempt to exceed the speed of sound in the Bell X-1. That assignment, however, went to Capt Chuck Yeager. Edwards was, instead, selected to be among the first to be sent to Princeton University for graduate study in the aeronautical sciences. The recent war had spawned truly revolutionary advances in aviation technology and it had become apparent to men such as Col Albert Boyd, the chief of the Flight Test Division, that a new breed of military test pilot--one who combined the talents of a highly skilled pilot with the technical expertise of an engineer--would be required to effectively evaluate increasingly complex aircraft and onboard systems. Thus, when Glen Edwards graduated from Princeton with an M.S. in aeronautical engineering in 1947, he represented one of the first of this new breed.

In May of 1948, he was selected to join the team of test pilots and engineers at Muroc who were then evaluating the Northrop YB-49, the all-jet version of the exotic flying wing bomber. After his first few flights, he was not favorably impressed, confiding to his diary that it was "the darndest airplane I've ever tried to do anything with. Quite uncontrollable at times." Then, on June 5, 1948, he was flying as co-pilot with Maj Daniel Forbes when the airplane departed from controlled flight and broke apart in the sky northwest of the base. All five crewmembers were lost. One of Colonel

Boyd's first orders of business, when he assumed command of Muroc in late 1949, was to rename the base in honor of someone who had given his life to the cause of experimental flight research. By tradition, Air Force bases were named after distinguished individuals who were native sons of the state in which a base was located. Boyd could think of no one more deserving than the bright young Californian whose promising career had ended so tragically in the skies over the western Mojave. On December 8, 1949, Muroc AFB was officially redesignated Edwards AFB and, during ceremonies on January 27, 1949, a plaque was unveiled which commemorated his achievements. That plaque is now located in a place of honor in front of the headquarters of the Air Force Flight Test Center. The tribute at its base reads: "A pioneer of the Flying Wing in the western skies, with courage and daring unrecognized by himself."

Appendix B

First Flights at Edwards Air Force Base

First flights are always considered a risky business. Test pilot, astronaut and manager for the space shuttle orbital test program Donald K. "Deke" Slayton put it very well when he cautioned prior to the first flight of *Columbia*: "In my opinion, about 90 percent of your risk in a total program comes with a first flight. There is no nice in-between milestone. You have to bite it all in one chunk." In a similar vein, NASA's associate administrator for Space Transportation Systems, John Yardley, explained at the same time: "I'm not worried over any of the problems we have worried about. They're in good shape. The things that you have to be careful about are the unknowns, things that have never happened before...A new engineering gremlin could crawl out of the woodwork, one nobody could have predicted." Others have been more succinct: "The object of a first flight is to get it back down in one piece."

Muroc Army Air Force Base (now Edwards AFB) was selected for the maiden flight of the XP-59A *Airacomet*, America's first jet-powered aircraft, because of the remoteness of its high-desert location, the clear and uncrowded skies overhead, and the incalculable measure of safety afforded by the vast expanse of Rogers Dry Lake which could (and would, again and again) serve as an emergency landing field should any inflight problems occur.

In the years since, these unsurpassed natural advantages have been augmented by the installation of sophisticated range tracking and communications equipment, as well as the development of a corps of technical and emergency response personnel who are trained to deal effectively with any kind of contingency. All of these resources, when combined, continue to make Edwards the optimum location for the first flights of high-performance and experimental aircraft.

"First flight" is here defined as the first flight of an air vehicle that took off (launched), landed, or both, at Edwards AFB. This list represents a conservative compilation of confirmed first flights of new experimental and prototype air vehicles in addition to subsequent models which encompassed major configuration or system modifications.

DATE	***AIRPLANE***	***CONTRACTOR***
1917 – August 10	2-seat scout	California Aeroplane & Motor Company (first recorded use of lakebed for flight test purposes)
1929 – September 26	X-216H	Northrop Avion (proto-flying wing; may have been 2nd flight)
1941 – November 15	A-1	General Motors Bug (radio-controlled "flying bomb" prototype crashed on takeoff; 1st successful flight on December 5, 1941)
1941 – December 2	CW-24B	Curtiss (flying mockup for the XP-55 *Ascender*)
1942 – October 1	XP-59A	Bell (prototype for P-59A *Airacomet*)
1943 – January 9	C-69	Lockheed *Constellation*
1943 – January 15	XP-54	Vultee *Swoose Goose*
1943 – August 27	JB-1	Northrop *Bat* flying bomb (MX-543) unpowered
1943 – September 6	XP-56	Northrop *Black Bullet*
1943 – October 2	MX-334	Northrop (unpowered XP-79 concept demonstrator)
1944 – January 8	XP-80	Lockheed (concept demonstrator for single-engine jet fighter)
1944 – June 6	XP-58	Lockheed *Chain Lightning*
1944 – June 10	XP-80A	Lockheed (prototype for F-80 *Shooting Star*)
1944 – July 5	MX-324	Northrop rocket powered version of MX-334 (1st powered flight)
1945 – February 7	XP-81	Consolidated Vultee turbojet/turboprop fighter
1945 – September 12	XP-79	Northrop *Flying Ram*
1946 – February 28	XP-84	Republic *Thunderjet*
1946 – May 17	XB-43	Douglas *Jetmaster* (1st U.S. jet bomber prototype)

1946 – June 25	XB-35	Northrop Flying Wing
1946 – September 12	XFJ-1	North American *Fury* (1st pure-jet Navy fighter)
1946 – October 2	XF6U-1	Vought *Pirate* (Navy)
1946 – November 1	XF2R-1	Ryan *Dark Shark* (Navy)
1946 – November 9	XR60-1	Lockheed *Constitution* (Navy)
1946 – December 9	X-1	Bell (1st powered flight)
1947 – March 17	XB-45	North American *Tornado*
1947 – April 2	XB-46	Convair
1947 – April 5	XF-11	Hughes (1st complete--takeoff/safe landing--flight)
1947 – April 15	D-558-I	Douglas *Skystreak* turbojet research plane
1947 – May 27	XB-42A	Douglas (*Mixmaster* with two podded jet engines)
1947 – October 1	XF-86	North American *Sabre*
1947 – October 21	YB-49	Northrop jet version of XB-35 flying wing
1948 – February 4	D-558-II	Douglas *Skyrocket*
1948 – March 5	XF-87	Curtiss *Blackhawk*
1948 – March 23	XF3D	Douglas *Skyknight* (Navy)
1948 – August 16	XF-89	Northrop *Scorpion*
1948 – August 23	XF-85	McDonnell *Goblin* parasite fighter
1948 – September 18	XF-92A	Convair *Dart* (world's first delta wing)
1948 – October 20	XF-88	McDonnell *Voodoo* (name later used for F-101)
1948 – December 16	X-4	Northrop *Bantam*
1949 – May 9	XF-91	Republic *Thunderceptor*
1949 – June 3	XF-90	Lockheed
1949 – December 22	YF-95A	North American *Sabre Dog* (soon redesignated YF-86D)
1950 – January 19	YF-94C	Lockheed *Starfire*
1950 – January 25	YF-93	North American (F-86 variant)
1950 – May 4	YRB-49	Northrop reconnaissance YB-49 with two podded jet engines
1950 – May 26	XA2D-1	Douglas *Skyshark* (Navy) turboprop AD-1
1950 – June 3	YF-96A	Republic *Thunderstreak* (later redesignated YF-84F)
1950 – June 27	YF-89A	Northrop (redesigned production version)
1950 – November 22	XSSM-N-8	Chance Vought *Regulus I* Navy cruise missile
1951 – January 23	XF4D	Douglas *Skyray* (Navy)
1951 – February 14	YF-84F	Republic *Thunderstreak* (enlarged fuselage production version)
1951 – June 20	X-5	Bell variable wing-sweep angle in flight
1952 – January 4	XA2J-1	North American turboprop version of AJ Savage
1952 – February 3	YRF-84F	Republic *Thunderflash*
1952 – May 19	XF10F-1	Grumman *Jaguar* (Navy)
1952 – June 27	X-2	Bell (glide flight; 1st powered 11/18/55)
1952 – October 20	X-3	Douglas *Flying Stiletto*
1952 – October 28	XA3D	Douglas *Skywarrior* (Navy)
1953 – February 14	X-1A	Bell second-generation X-1 (glide flight; 1st powered 2/21/53)
1953 – April 30	YF-86H	North American (fighter-bomber version of the *Sabre*)
1953 – May 25	YF-100	North American *Super Sabre*
1953 – September 16	A3D-1	Douglas. First production *Skywarrior*, #130352
1953 – October 14	X-10	North American RPV *Navajo* cruise missile testbed
1953 – October 24	YF-102	Convair *Delta Dagger*
1954 – January 5	F-84G	Zero-length launch and mat landing (ZELMAL) Program
1954 – March 4	XF-104	Lockheed *Starfighter*
1954 – May 7	YF-84J	Republic
1954 – June 16	XFV-1	Lockheed Salmon VTOL fighter

1954 – June 22	XA4D	Douglas *Skyhawk* (Navy)
1954 – June 28	RB-66	Douglas *Destroyer* USAF version of Navy A3D Skywarrior
1954 – August 23	YC-130	Lockheed *Hercules*
1954 – September 29	F-101	McDonnell *Voodoo*
1954 – December 20	YF-102A	Convair *Delta Dagger* (first area-ruled aircraft)
1955 – March 25	XF8U	Chance Vought *Crusader* (Navy)
1955 – June 30	YRF-101A	McDonnell photo-recon *Voodoo*
1955 – July 22	XF-84H	Republic (turboprop w/ supersonic prop)
1955 – October 22	YF-105	Republic *Thunderchief*
1955 – October 31	TF-102A	Convair (side-by-side trainer version of F-102)
1955 – December 10	X-13	Ryan *Vertijet*
1955 – December 12	X-1E	Bell (3rd generation X-1; glide flight; 1st powered 12/15/55)
1956 – February 17	YF-104A	Lockheed Starfighter (redesigned production mod)
1956 – April 21	F5D-1	Douglas *Skylancer* (Navy)
1956 – April 23	C-133	Douglas *Cargomaster*
1956 – May 25	F11F-1F	Grumman *Super Tiger* (re-engined F11F)
1956 – May 29	XSSM-N-9	Chance Vought *Regulus II* cruise missile (Navy)
1956 – September 10	YF-107A	North American *Ultra Sabre*
1956 – December 26	F-106A	Convair *Delta Dart*
1957 – September 4	C-140	Lockheed *Jet Star*
1958 – March 26	F-100D	Zero-length launch (ZEL) program
1958 – April 9	F-106B	Convair *Delta Dart* combat trainer
1958 – May 30	DC-8	Douglas
1958 – June 3	XF8U-3	Chance Vought *Crusader III*
1959 – April 10	T-38	Northrop *Talon*
1959 – June 8	X-15	North American (1st glide flight; 1st powered 9/17/59)
1959 – July 30	N-156F	Northrop (became F-5, below)
1959 – November 4	CL-475	Lockheed (rigid-rotor test bed)
1959 – November 24	X-18	Hiller (tilt-wing V/STOL)
1962 – January 25	*Paresev*	NASA-Dryden Paraglider Research Vehicle
1963 – April 18	X-21A	Northrop heavily rebuilt B-66
1963 – July 23	F-104 ZELL	Lockheed Zero Length Launch
1963 – July 31	YF-5A	Northrop *Freedom Fighter*
1963 – August 16	M2-F1	NASA-Dryden (unpowered Lifting Body aircraft)
1964 – May 15	XV-5A	Ryan (Army)
1964 – June 25	X-15A-2	North American
1964 – September 21	XB-70	North American *Valkyrie*
1964 – October 30	LLRV	Bell Lunar Landing Research Vehicle
1965 – February 25	DC-9	Douglas
1966 – July 12	M2-F2	Northrop Lifting Body (glide flight)
1966 – December 22	HL-10	Northrop Lifting Body (glide flight; 1st powered 11/13/68)
1967 – 28 August	U-2R	Lockheed up-sized version of the U-2
1968 – September 26	YA-7D	LTV *Corsair II* (1st flight w/ TF41-A-2 engine)
1969 – April 17	X-24A	Martin Marietta Lifting Body (glide flight;1st powered 3/19/70)
1969 – December 12	*Hyper III*	NASA Dryden Concept demonstrator high speed Lifting Body vehicle
1970 – June 2	M2-F3	Northrop Lifting Body (glide flight; 1st powered 11/25/70)
1970 – August 29	DC-10	Douglas
1971 – August 31	YQM-93A	Martin Marietta *Compass Dwell* RPV
1972 – May 10	YA-10A	Fairchild Republic *Thunderbolt II*

1972 – May 30	YA-9A	Northrop *Cobra*
1972 – July 27	F-15	McDonnell Douglas *Eagle*
1972 – August 11	F-5E	Northrop (first *Tiger II*)
1973 – July 28	YQM-94A	Boeing *Compass Cope-B RPV Gull*
1973 – August 1	X-24B	Martin Marietta Lifting Body (modified X-24A; glide flight; 1st powered 11/15/73)
1974 – February 2	YF-16	General Dynamics *Fighting Falcon*
1974 – June 9	YF-17	Northrop (evolved into Navy F/A-18 *Hornet*)
1974 – August 1	*Mini-Sniffer*	NASA Dryden Flight Research Center remotely piloted research vehicle (used to monitor the upper atmosphere for pollution)
1974 – August 17	YQM-98A	Ryan *Compass Cope-R RPV Tern*
1974 – September 25	F-5F	Northrop (2-seat version of F-5E *Tiger II*)
1974 – December 23	B-1A	Rockwell *Lancer*
1975 – August 26	YC-15	McDonnell Douglas
1977 – August 12	OV-101	Rockwell Space Shuttle *Enterprise* (unpowered)
1979 – May 4	YA-10B	Fairchild (2-seat night-attack version)
1979 – August 27	HiMAT	Rockwell (RPV)
1979 – December 21	AD-1	NASA oblique-wing concept demonstrator
1981 – April 14	STS-1	Rockwell Space Shuttle *Columbia* (orbital flight)
1982 – August 30	F-20	Northrop *Tigershark*
1984 – December 14	X-29A	Grumman forward-swept wing concept vehicle
1985 – October 15	T-46	Fairchild *Republic*
1987 – December 2	X-Wing	NASA/DARPA/Sikorsky
1989 – July 17	B-2	Northrop *Spirit*
1990 – August 27	YF-23A	Northrop (Advanced Tactical Fighter demonstrator)
1990 – September 29	YF-22A	Lockheed(Advanced Tactical Fighter demonstrator)
1990 –December 20	AC-130U	Lockheed/Rockwell *Gunship*
1991 – September 15	C-17	McDonnell Douglas *Globemaster III*
1993 – October 20	*Pathfinder*	AeroVironment solar powered vehicle
1993 – December 21	*Perseus A*	Aurora Flight Services Corp. (RPV)
1996 – March 29	*DarkStar*	Lockheed Tier III Minus stealth UAV
1996 – May 24	*Theseus*	Aurora Flight Services Corp. (RPV)
1996 – June 22	*Spectrum*	Flight Technology Corp. ducted fan single-seat private a/c.
1996 – December 16	*LoFLYTE*	Subscale model of NASA hypersonic waverider Vehicle
1997 – May 17	X-36	McDonnell Douglas 28% subscale model of tailless fighter
1998 – February 28	RQ-4A	Teledyne Ryan (now Northrop Grumman) *Global Hawk*
1998 – March 12	X-38	Scaled Composites subscale space rescue vehicle
1998 – November 10	*Centurion*	Aero Vironment Inc. solar-powered high-altitude RPV
1999 – September 8	*Helios*	Aero Vironment Inc. high altitude RPV
2000 – September 18	X-32A	Boeing Joint Strike Fighter (JSF) demonstrator
2000 – October 24	X-35A	Lockheed-Martin Joint Strike Fighter (JSF) demonstrator
2000 – December 16	X-35C	Navy carrier version of Lockheed Martin JSF demonstrator
2001 – March 29	X-32B	STOVL version of Boeing JSF demonstrator
2002 – May 22	X-45A	Boeing/DARPA UCAV technology demonstrato
2004 – March 27	X-43A	Microcraft Hyper-X UAV air-breathing hypersonic research vehicle (first successful flight; after launch on first flight on 2 June 2001 the vehicle had departed controlled flight within seconds)
2004 – October 6	RQ-4A(N-1)	Northrop Grumman *Global Hawk* (U.S. Navy version)
2006 – April 7	X-37	Boeing unmanned Approach and Landing TestVehicle (ALTV)

2007 – March 1	RQ-4B	Northrop Grumman Block 20 *Global Hawk* UAV
2007 – July 20	X-48B	Boeing RPV Blended Wing Body (BWB) concept demonstrator
2007 – Nov 16	RQ-4B	Northrop Grumman Block 30 *Global Hawk* UAV
2009 – Nov 16	RQ-4B	Northrop Grumman Block 40 *Global Hawk* UAV
2010 – May 26	X-51A	Boeing/Pratt & Whitney Rocketdyne *Waverider* air-breathing scramjet hypersonic concept demonstrator
2010 – June 29	RQ-4	Block 20/30i *Euro Hawk* UAV (RQ-4 variant for German military)

AFFTC History Office, July 2010

Appendix C

Milestones in Aerospace History at Edwards AFB

Over the past six decades, Edwards AFB has arguably been the scene of more major milestones in flight than any other location in the world. The following list briefly summarizes just some of the significant milestones which have taken place at Muroc/Edwards AFB (or which involved Edwards-based test pilots and/or technical personnel) since the 1940s:

October 1, 1942 - As Bell test pilot Bob Stanley was completing the final series of high-speed taxi tests with the XP-59A *Airacomet*, the craft's wheels lifted off from the surface of Rogers Dry Lake and, for the first time, an American turbojet-powered airplane became airborne. The "official" first flight of the airplane actually occurred the next day when all of the high-ranking program officials were on hand to witness it.

December 15, 1943 - Bell test pilot Jack Woolams established an unofficial U.S. altitude record when he climbed to 47,600 feet in a YP-59A *Airacomet*.

January 8, 1944 - First flight of the Lockheed XP-80, the first American aircraft to exceed 500 mph in level flight and the concept-demonstrator for the nation's first operational jet aircraft--the P-80 (later F 80) *Shooting Star*. The F-80, which was the first American aircraft capable of speeds approaching 600 mph, went on to record the first all-jet aerial victory in history when it downed a MIG-15 in Korea on November 7, 1950.

June 19, 1947 - The world's absolute speed record was returned to the United States for the first time in 24 years, as Col Albert Boyd (then Chief of the Flight Test Division at Wright Field) piloted a highly modified Lockheed P-80R to an average speed of 623.608 mph as he flew less than 100 feet above a speed course laid out on Rogers Dry Lake. This was the first of 12 absolute world speed records that would be accomplished at Muroc/Edwards or by Edwards test pilots over the next 18 years.

August 20, 1947 - Navy Commander Turner Caldwell established a new official world absolute speed record as he piloted the Douglas D-558-I *Skystreak* to an average speed of 640.743 mph during four passes over the speed course at Muroc.

August 25, 1947 - Marine test pilot Maj Marion Carl broke Caldwell's five-day old record, as he flew the *Skystreak* to an average speed of 650.796 mph over the same course.

October 14, 1947 - Air Force Capt Charles E. "Chuck" Yeager piloted the rocket-powered Bell X-1 to a speed of Mach 1.06 (approximately 700 mph at 42,000 feet) and thereby became the first man to penetrate the so-called "sound barrier." Though few people could comprehend its full implications at the time, Yeager's supersonic flight that morning marked the first step in a chain of events that would ultimately vault man beyond the atmosphere...and into space.

September 15, 1948 - Air Force test pilot Maj Richard L. "Dick" Johnson extended the official world absolute speed record to 670.981 mph as he piloted a North American F-86A *Sabre* during four low-level passes over the lake bed.

January 5, 1949 - Capt Chuck Yeager completed the first—and, to this date, only—ground takeoff of an experimental rocket plane in the Bell X-1 as he lifted off from Rogers Dry Lake and climbed to an altitude of 23,000 feet before exhausting his propellants approximately 100 seconds after engine ignition.

August 8, 1949 - Air Force Maj Frank K. "Pete" Everest piloted the Bell X-1 to a peak altitude of 71,902 feet. This was an unofficial world record and the highest altitude achieved by the first generation of X-1 research aircraft (all speed and altitude records for the rocket planes were cited as "unofficial" because the airplanes were air launched).

June 1, 1951 - Air Force aeromedical researcher Maj John P. Stapp was carefully strapped into a rocket sled which was poised on a 2,000-foot deceleration track at North Base. Moments later, 4,000 pounds of rocket thrust blasted him down the track and into the braking system (from 88.6 mph to a full stop in 18 feet). For a brief instant, he endured 48 "g's," with a rate of onset of approximately 500 "g's" per second. In other words, his body had absorbed an impact of over four tons. Prior to Stapp's sled experiments, conventional medical wisdom had maintained that the human body could probably survive no more than 17-18 instantaneous g's.

July 27, 1951 - With company test pilot Jean "Skip" Ziegler at the controls, the Bell X-5 became the first variable-geometry aircraft in history to "swing"—or sweep forward or back—its wings while in flight.

August 7, 1951 - Douglas test pilot Bill Bridgeman piloted the rocket-powered D-558-II *Skyrocket* to a record speed of Mach 1.88 (1,180 mph) at an altitude of 66,000 feet.

August 15, 1951 - Bill Bridgeman piloted the *Skyrocket* to a new altitude record of 74,494 feet.

November 19, 1952 - AFFTC test pilot Capt J. Slade Nash set a new official world absolute speed record as he piloted an F-86D to an average speed of 698.511 mph over a speed course laid out adjacent to the Salton Sea in southern California's Imperial Valley.

May 18, 1953 - Flying a Canadian-built (Canadair) F-86 *Sabre* and with Maj Chuck Yeager flying chase, famed aviatrix Jacqueline Cochran became the first woman to exceed the speed of sound. That same day, she established a new women's absolute speed record of 652.337 mph over a low-level course at Edwards.

May 25, 1953 - The prototype North American YF-100A *Super Sabre* became the first aircraft in history to fly supersonic on its maiden flight. Though earlier fighter-type airplanes had attained supersonic speeds in dives, the *Super Sabre* was America's first true supersonic fighter.

August 21, 1953 - Marine test pilot Lt Col Marion Carl piloted the D-558-II *Skyrocket* to a new unofficial altitude record of 83,235 feet, the peak altitude achieved by this airplane.

October 29, 1953 - AFFTC test pilot Lt Col Frank K. "Pete" Everest established a new official world absolute speed record as he piloted the YF-100A to an average speed of 755.149 mph during four runs over a new 9.3-mile speed course laid out at the Salton Sea. This record, which approached the speed of sound (0.96 Mach) at sea level, was the last world absolute speed record to be achieved at low altitude (within 330 feet of the ground).

November 20, 1953 - NACA test pilot A. Scott Crossfield piloted the Douglas *Skyrocket* to a speed of 1,291 mph (Mach 2.005) in a dive at an altitude of 62,000 feet and thereby became the first man to fly at twice the speed of sound.

December 12, 1953 - Major Charles E. "Chuck" Yeager shattered Scott Crossfield's recent record in the D-558-II when he piloted the Bell X-1A (second generation of the X-1 series of rocket aircraft) to a speed of Mach 2.44 (1,650 mph) in level flight at an altitude of 74,700 feet. It was on this flight that Yeager first encountered inertia coupling (then called "high-speed instability") as, shortly after attaining top speed, the craft tumbled violently out of control. Even though the X-1A was literally tumbling about all three of its axes simultaneously as he plummeted downward for more than 40,000 feet, Yeager somehow managed to recover to level flight and bring the craft in for a safe deadstick landing on Rogers Dry Lake.

August 26, 1954 – AFFTC test pilot Maj Arthur "Kit" Murray piloted the rocket-powered Bell X-1A to a new unofficial world altitude record of 90,440 feet (all speed and altitude records for the rocket planes were cited as unofficial because the aircraft were air launched). During his post-flight debrief, he laid claim to having become the first man to actually see the curvature of the earth.

August 20, 1955 – The AFFTC's Col Horace A. Hanes established a new official world absolute speed record as he piloted an F-100C to an average of 822.26 mph during two runs over a new Antelope Valley speed course at an altitude of 41,000 feet. This was the first absolute speed record to be achieved at high altitude and the first to exceed the speed of sound. He was awarded the Thompson Trophy for the feat, making him the third AFFTC pilot to win the prestigious award.

July 23, 1956 - Following release from a B-50 launch aircraft, Lt Col Frank K. "Pete" Everest piloted the Bell X-2 to an unofficial world speed record of Mach 2.87 (1,900 mph at 68,000 feet). Powered by a 15,000-pound thrust Curtis-Wright XLR25 rocket-engine, the X-2 was the first airplane capable of exploring the "thermal thicket"—the region above Mach 2.5 where heat caused by aerodynamic friction caused extraordinary surface temperature increases.

September 7, 1956 - AFFTC test pilot Capt Iven C. Kincheloe became the first man ever to fly above 100,000 feet, as he piloted the rocket-powered Bell X-2 to a peak altitude of 126,200 feet. Though newspaper reporters were incorrect when they hailed him as "the first of the spacemen," he had, indeed, flown above 99% of the earth's atmosphere.

September 27, 1956 - AFFTC test pilot Capt Mel Apt became the first man to exceed Mach 3, as he piloted the rocket-powered Bell X-2 to a top speed of 2,094 mph (Mach 3.2 at 65,000 feet). Unfortunately, the craft tumbled violently out of control (a victim of the same inertia coupling that had almost claimed Yeager's life in the X-1A) while Apt was still above Mach 3 and he was unable to recover it. He was killed in the ensuing crash.

April 11, 1957 - The Ryan X-13 *Vertijet*, an experimental testbed designed to prove that vertical takeoff and landing (VTOL) flight could be achieved on jet thrust alone, became the first jet aircraft in history to takeoff vertically, transition to conventional level flight, and then transition back to the vertical for landing.

December 12, 1957 - Air Force Maj Adrian Drew established a new official world absolute speed record when he piloted a McDonnell F-101A *Voodoo* to an average speed of 1,207.60 mph at Edwards.

May 16, 1958 - AFFTC test pilot Capt Walter Irwin set a new official world absolute speed record when he piloted a Lockheed F-104A *Starfighter* to an average speed of 1,404.09 mph.

December 14, 1959 - With AFFTC test pilot Maj Joe Jordan at the controls, a Lockheed F-104C became the first jet-powered (i.e., air-breathing) aircraft to climb above 100,000 feet as it soared to a peak altitude of 103,389 feet high above Edwards AFB.

December 15, 1959 - AFFTC test pilot Maj Joseph Rogers set a new official world absolute speed record at Edwards when he piloted a Convair F-106A *Delta Dart* to an average speed of 1,525.065 mph.

February 10, 1961 – Rocketdyne engineers at the Rocket Propulsion Laboratory atop Leuhman Ridge at Edwards AFB conducted the first captive firing of the whole F-1 Saturn rocket engine. The Saturn engine would be the launch vehicle for Project Apollo, the missions to the moon. The F-1 prototype engine was capable of producing 1.55 million pounds of thrust within a few seconds of firing.

March 7, 1961 - AFFTC test pilot Maj Robert M. "Bob" White became the first man to exceed Mach 4, as he piloted the rocket-powered (57,000-pound thrust XLR99) North American X-15 to a speed of 2,905 mph (Mach 4.43).

June 23, 1961 - Major White became the first man to exceed Mach 5, as he piloted the X-15 to a speed of 3,603 mph (Mach 5.27).

August 24, 1961 - Jacqueline Cochran claimed a new official world absolute speed record for women when she piloted a Northrop T-38 *Talon* to a speed of 844.202 mph.

October 11, 1961 - Major Bob White became the first man to fly an airplane above 200,000 feet as he piloted the X-15 to an altitude of 217,000 feet.

October 12, 1961 - Jacqueline Cochran established a new official altitude record for women as she climbed to 56,071 feet in a T-38 *Talon*.

November 9, 1961 - Major Bob White became the first man to exceed Mach 6, as he piloted the X-15 to a speed of 4,094 mph (Mach 6.04).

November 22, 1961 – U.S. Marine Corps pilot Lt Col R.B. Robinson established a new official world absolute speed record at Edwards when he piloted a McDonnell F4H-1 (original designation of the F-4 *Phantom II*) to an average speed of 1,606.505 mph.

July 17, 1962 – Maj Robert M. "Bob" White flew the X-15 to an altitude of 314,750 feet (59.6 mi.), an official world absolute record for an aircraft launched from a carrier airplane. This was the first time a piloted airplane had been flown in space (above 50 mi.), making him the nation's fifth astronaut, overall, and the world's first "winged astronaut." Seven more X-15 pilots ultimately earned astronaut's wings by piloting the rocket plane to altitudes in excess of 50 miles.

September 18, 1962 - Long-time Edwards test pilot Maj Fitzhugh L. "Fitz" Fulton piloted a Convair B 58 *Hustler*, carrying an 11,023-pound payload, to an altitude record of 85,360.84 feet, a record for this category which still stands.

May 14, 1963 – The Northrop X-21A recorded a significant aeronautical milestone by achieving laminar airflow control over its wings with a measurable reduction in parasitic (friction) drag for the first time.

August 22, 1963 – NASA test pilot Joseph A. "Joe" Walker piloted the No. 3 X-15 to a peak altitude of 354,200 feet (67 miles above the earth's surface) and thereby became the second X-15 pilot to earn astronaut's wings by flying an airplane in space. This was the highest altitude attained during the X-15 flight research program.

May 11, 1964 - Jacqueline Cochran established a new official world's absolute speed record for women when she piloted a Lockheed F-104G *Starfighter* to an average speed of 1,429.3 mph.

May 1, 1965 - The exotic Lockheed YF-12A (a stablemate of the SR-71 *Blackbird*) set no less than seven official world absolute speed and altitude records on a single day at Edwards without, in any way, taxing its full—and highly classified—potential. Among the records, were an absolute top speed of 2,070 mph and a sustained altitude of 80,257 feet with AFFTC test pilot Col Robert L. "Fox" Stephens at the controls.

October 14, 1965 – With North American's Al White and copilot Col Joe Cotton at the controls, the No. 1 XB-70 *Valkyrie* accelerated to a speed of Mach 3.02 at 70,000 feet (approximately 2,000 mph) and thereby achieved the design speed for the mammoth, 500,000-pound prototype long-range bomber for the first time. In doing so, it became the first (and, so far, only) bomber-type aircraft to ever come even close to triple-sonic speeds.

October 3, 1967 - AFFTC test pilot Maj William J. "Pete" Knight piloted the modified X-15A-2 to a speed of Mach 6.7 (4,520 mph) and thereby recorded the top speed achieved in the X-15 program. The speed attained on this flight remains, to this day, the fastest that anyone has ever flown in an airplane.

August 16, 1969 – Civilian racing pilot Darryl Greenamyer established a world absolute speed record for piston-engine aircraft of 482.462 mph while flying a modified Grumman F8F-2 *Bearcat* over a measured course at Edwards AFB. In doing so, he broke a record that had been on the books since April of 1939 when German test pilot Fritz Wendel flew the *Messerschmitt* Me-209V-1 to a speed of 469.224 mph.

October 1, 1969 – A C-5 *Galaxy* lifted off the main Edwards runway at a total weight of 790,100 pounds (395 tons), establishing an unofficial world record for weight.

February 18, 1970 - AFFTC test pilot Maj Pete Hoag piloted the rocket-powered Northrop HL-10 lifting body to a speed of Mach 1.86 (at 67,310 feet), the highest speed attained by any of the experimental lifting body designs throughout the multi-phase test program. The lifting body aircraft were designed and tested to determine whether or not these wingless body shapes could make precision landings, after powerless, high-speed gliding descents from high altitudes. They pioneered many of the approach and landing techniques which were later employed by the Space Shuttles at the end of their orbital flights.

February 27, 1970 - NASA test pilot Bill Dana piloted the rocket-powered Northrop HL-10 to an altitude of 90,303 feet, from which it made a successful, powerless descent to a deadstick landing on Rogers Dry Lake. The altitude attained during this flight was the highest recorded throughout the entire lifting body test program.

October 27, 1970 – After flying the X-24A lifting body to its peak altitude of 71, 400 feet, NASA research pilot John Manke completed the first simulated space shuttle-type approach and landing with a vehicle that was roughly similar in subsonic performance and handling qualities.

March 9, 1971 - Flying an extensively modified F-8, NASA test pilot Tom McMurtry completed the first flight of an airplane configured with a supercritical wing. Flattened on the upper surface and tapering downward at the trailing edge, the thin wing was shaped to modify shock-wave formation and associated boundary-layer separation, thereby delaying the typically sharp increase in drag that occurred as an aircraft approached the speed of sound. The successful results from this program would lead to the incorporation of fuel-saving/range-extending supercritical wings on a number of future transport designs.

December 14, 1971 – A television-guided AGM-65 *Maverick* missile was launched from a Teledyne Ryan BQM-34A remotely piloted vehicle (RPV) against an obsolete radar control van (serving as simulated a surface-to-air missile launch site) on the Edwards Flight Test Range and scored a direct hit—reportedly the first launch of a guided weapon from an RPV ever to score a direct hit.

May 25, 1972 - Flying the highly modified F-8 Digital Fly-by-Wire research airplane, NASA test pilot Gary Krier completed the first flight of an aircraft which was completely dependent upon an electronic flight control system.

August 5, 1975 – NASA test pilot John Manke brought the rocket-powered X-24B lifting body in for a near-perfect landing on Edwards' main concrete runway after an unpowered descent from 57,050 feet. This was the first time a landing—within the confines of a conventional concrete runway—had been attempted. Along with a subsequent flight by Maj Michael Love, it demonstrated that these unconventional wingless lifting body shapes could make precision runway landings attaining touchdown accuracies of plus-or-minus 500 feet after unpowered descents from high altitudes. These flights provided an important additional measure of confidence to those planning for the upcoming space shuttle program.

July 27, 1976 - Air Force Capt Eldon Joersz established a new official world absolute speed record when he piloted a Lockheed SR-71A to an average speed of 2,193.64 mph at Edwards.

August 12, 1977 - The Space Shuttle *Enterprise* (the first, non-orbiting craft which was built to complete unpowered approach and landing [ALT] tests to confirm the design's low-speed controllability and airworthiness) was launched from the back of a 747 carrier aircraft at 24,100 feet and successfully completed a five minute 21 second descent to a landing and roll out on Rogers Dry Lake. This (along with four subsequent ALT tests) demonstrated the soundness of the shuttle design and confirmed the approach and landing techniques that would subsequently be employed by shuttle astronauts returning from orbital space missions.

July 11, 1979 – AFFTC test pilot Lt Col Ken Dyson was forced to eject from the highly classified *Have Blue* low observables concept demonstrator when it suffered a double hydraulic failure and departed from controlled flight. Nevertheless, over the previous year, he had completed more than 50 successful flights during which the airplane had convincingly demonstrated its very low observability against a wide array of the most sophisticated air- and ground-based air defense systems. The successful conduct of these tests led immediately to the development of the Lockheed F-117A Nighthawk in the early 80s and the stealth revolution was underway in earnest.

April 14, 1981 - The Space Shuttle *Columbia* landed safely on Rogers Dry Lake following its first orbital mission. This marked the first time in history that an orbital vehicle had left the earth under rocket power and returned on the wings of an aircraft.

November 14, 1981 - The Space Shuttle *Columbia* touched down on Rogers Dry Lake following its second orbital spaceflight mission. During the re-entry through landing phase, Shuttle commander Col Joe Engle had manually flown the profile—performing 29 flight test maneuvers—from Mach 25 through landing roll out. This was the first and, so far, only time that a winged aerospace vehicle has been manually flown from orbit through landing. With this flight, the central concept of the shuttle test program had been clearly demonstrated; the era of reusable spacecraft had dawned.

July 4, 1982 – Flown by Navy Capt Thomas K. Mattingly and Air Force Col Hank Hartsfield (both USAF TPS grads), the Space Shuttle *Columbia* landed on the main runway in front of President Ronald Reagan and some 500,000 visitors. The Shuttle's fourth orbital flight had ended with its first landing on a concrete runway and concluded its formal flight test program. This marked a major milestone in the shuttle program because it demonstrated that the vehicles could be safely recovered on conventional runways such as the one at the Kennedy Space Center in Florida. Later, while President Reagan was addressing the crowd, the second Shuttle, *Challenger*, departed for the Kennedy Space Center atop the 747 carrier aircraft flown by NASA's Fitz Fulton… who dipped the airplane's wing in salute to the president.

July 29, 1983 - With AFFTC test pilot Col Michael D. Hall at the controls, the McDonnell Douglas F-15 *Eagle* passed 10,000 hours of accident-free flight testing time. This was the first time in the history of fighter development that such a milestone had been achieved.

September 5, 1983 - Space Shuttle *Challenger* (STS-8) landed at Edwards at 12:40 a.m. for the first night landing of a space vehicle.

December 14, 1984 - Veteran Grumman test pilot Chuck Sewell lifted the wheels of the No. 1 X-29A off the main runway and, for the first time in over a decade, an experimental--"X-series"--test program got underway at Edwards. As Sewell pulled up from the runway that morning, it also marked the first time in history that an aircraft had taken to the air on blade-thin, forward-swept wings made of composite materials.

September 13, 1985 - AFFTC test pilot Maj Wilbert D. "Doug" Pearson pulled into a near-supersonic, 65-degree climb in a highly modified F-15 which had been aptly nicknamed the *Celestial Eagle*. Flying an extraordinarily precise profile, he climbed through 38,000 feet and launched a 17-foot long, three-stage missile toward Satellite P78-1 orbiting 340 miles overhead. In a feat which must be compared to "finding a needle in a haystack," the fighter-launched anti-satellite (ASAT) missile scored a direct hit. It was a first in history and a technological display which may never again be duplicated.

December 13, 1985 – The No. 1 Grumman X-29A became the first forward-sweptwing aircraft in history 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) at 40,000 feet altitude.

December 23, 1986 - With Dick Rutan at the controls (Jeanna Yeager serving as co-pilot), nine days, three minutes and 44 seconds after taking off from Edwards, the experimental *Voyager* aircraft touched down on Rogers Dry Lake after completing the first-ever non-stop, unrefueled flight around the world.

December 18, 1989 - The first "self-repairing" flight control system was demonstrated on NASAs F-15 HIDEC (Highly Integrated Digital Electronic Control) research aircraft with test pilot Jim Smolka at the controls. The system identified control surface failures or damage and then automatically repositioned other control surfaces to allow the pilot to continue the mission or land the aircraft safely.

November 3, 1990 - With Lockheed test pilot Dave Ferguson at the controls, the YF-22A Advanced Technology Fighter (ATF) prototype, configured with General Electric YF120 prototype turbofans, became the first fighter aircraft in history to achieve sustained supersonic flight without employing afterburner. The aircraft attained a "supercruise" speed of Mach 1.58 at 40,000 feet.

April 21, 1993 - Employing a computerized propulsion control system to turn, climb and descend in the F-15 HIDEC research aircraft, NASA test pilot Gordon Fullerton completed the first fully successful approach and landing ever to be accomplished without using flight controls.

April 29, 1993 - Employing thrust vectoring, the X-31 executed a minimum-radius 180-degree turn--the "Herbst Maneuver"--while flying at more than 70-degrees angle-of-attack, well beyond the limits of any previous aircraft in history.

August 29, 1995 - Using a computerized propulsion control system similar to that employed on the F-15 HIDEC aircraft, NASA test pilot Gordon Fullerton completed the first-ever fully successful landing of a widebody transport using only engine power for control as he landed a McDonnell Douglas MD-11 on the main Edwards runway.

September 11, 1995 - The AeroVironment *Pathfinder*, an all-wing, remotely piloted, solar-power aircraft achieved a new record altitude for solar-powered aircraft as it climbed to 50,567 feet while being controlled from a ground station at the NASA-Dryden Flight Research Facility at Edwards. The previous record had been 14,000 feet.

August 25, 1999 – Lockheed Martin test pilot Jon Beesley was at the controls of the No. 2 F-22 *Raptor* when, for the first time, the pre-production fighter aircraft flew at 60-degrees angle-of-attack and demonstrated post-stall controlled flight with thrust vectoring.

July 20, 2000 – The X-35B, Lockheed Martin's short takeoff and vertical landing (STOVL) concept demonstrator in the Joint Strike Fighter competition achieved a milestone when it completed what the company called a "Mission X" flight profile—a short takeoff, level supersonic dash, and vertical landing all in one flight. Piloted by U.S. Marine Corps test pilot Major Art Tomassetti, the mission included a short takeoff at 80 knots, followed by conversion from the STOVL mode to conventional flight, a climb to 25,000 feet and acceleration to Mach 1.05, conversion back to the STOVL mode and deceleration to a hover 150 feet above ground level, followed by a vertical landing. The company reported that this was the first time in history that such a flight profile had been successfully accomplished.

April 22-23, 2001 – The No. 5 Northrop Grumman RQ-4A *Global Hawk* successfully completed a record non-stop trans-Pacific flight from Edwards AFB, CA, to the Royal Australian Air Force Base at Edinburgh, Australia. Renamed "Southern Cross II" in honor of the first manned trans-Pacific flight by Sir Charles Kingsford-Smith and his crew in 1928, the vehicle completed the mission in 23 hours and 23 minutes and, reported Northrop Grumman, was the first UAV to cross the Pacific Ocean.

October 11, 2001 – The F-15 Combined Test Force at the AFFTC achieved a major milestone when Lt Col Bill Thornton landed his *Eagle* on the main Edwards runway. With the landing, the CTF had surpassed a remarkable 40,000 flight hours without incurring a single serious mishap (Class A or B mishap) since the onset of the F-15 program more than 29 years earlier. No other fighter-type aircraft had ever come close to this extraordinary safety record.

June 7, 2002 – An RQ-1 *Predator* UAV launched an Inserted Detector Expendable for Reconnaissance (FINDER) mini-UAV while in flight at 10,000 feet over the Edwards Flight Test Range. The FINDER successfully completed a 25-minute preprogrammed mission before a flight technician took control and landed it on Rogers Dry Lake. This was the first time that an operational UAV demonstrated the capability to carry and successfully launch another such craft.

September 10, 2003 – A B-2 test crew from the AFFTC successfully released a full load of 80 independently targeted, Global Positioning System (GPS)-guided 500-pound GBU-38 Joint Direct Attack Munitions (JDAMs) against 80 different targets in a single pass over the Utah Test and Training Range and thereby achieved a remarkable milestone in the development of precision-guided weapons capabilities as all 80 JDAMs scored either direct hits or impacted within lethal range of their targets.

March 20, 2004 – An X-45A Joint Unmanned Combat Aerial System (J-UCAS) performed the first-ever weapons release from the internal bay of a high-speed, stealthy unmanned aircraft when it released an inert unguided Small Smart Bomb from an altitude of 35,000 feet and at a speed of 495 mph over the Edwards Flight Test Range. The inert weapon impacted within inches of its target, a truck parked on the range.

March 27, 2004 – The supersonic-combustion ramjet (scramjet)-powered X-43A unmanned hypersonic research aircraft (HYPER-X) attained a speed of Mach 7 during its first successful flight. It not only became the first scramjet-powered vehicle to achieve free flight, it also set a speed record (approximately 5,000 mph and 95,000 feet altitude) and thereby easily surpassed all previous records for aerospace vehicles powered air-breathing engines.

August 1, 2004 – A pair of X-45A UCAVs became the first unmanned air vehicles ever to be autonomously flown in formation throughout their pre-programmed mission while being monitored by only a signal system operator. This represented a significant step in the development of multi-ship UAV combat capabilities.

August 10, 2005 – In the final two missions of the X-45 Unmanned Combat Air Vehicle (UCAV) program, the two UCAV concept demonstrators flew a pair of simulated preemptive destruction-suppression of enemy air defense (PD-SEAD) “graduation exercise” scenarios as they flew in formation autonomously and successfully identified, attacked and destroyed pre-identified ground-based threat systems before they could launch surface-to-air missiles. They also faced a simulated “pop-up” threat, used evasive maneuvers to avoid it, and autonomously determined which vehicle held the optimum position, weapons and fuel to attack it. Once the system operator authorized the attack, the UCAV simulated dropping weapons on the target and destroyed it.

November 16, 2004 – In the final flight of the program, the X-43A *Hyper-X* attained a speed of Mach 9.6 (approximately 6,500 mph) at 110,000 feet altitude for nearly 12 seconds and thereby far surpassed its own record (set on March 27, 2004) for a vehicle powered by an air-breathing propulsion system.

February 20, 2006 – No. 3 pre-production RQ-4 *Global Hawk* unmanned aerial vehicle advanced concept technology demonstrator (ACTD) aircraft returned to Edwards AFB after extended deployments overseas that totaled more than four years of operations in support of the Global War on Terror. Despite the fact that it was still undergoing ACTD testing at the Air Force Flight Test Center, it was deployed after the terrorist attacks on September 11, 2001, to fly in support of Operation Enduring Freedom. All told, it acquired tens of thousands of high-resolution target images while logging 4,245 flying hours in all-weather conditions during 191 combat missions in support of Operations Enduring Freedom and Iraqi Freedom.

August 30, 2006 – In a joint Defense Advanced Research Projects Agency and NASA Dryden Flight Research Center effort, a significant milestone was achieved when the first-ever fully autonomous airborne refueling operation was successfully completed by a tanker and an F/A-18 modified to operate as an unmanned air vehicle (UAV). Though safety pilots were aboard the F/A-18, they kept their hands off all controls as the airplane successfully hooked up with the tanker's probe-and-drogue receptacle.

July 24, 2007 – The YAL-1 *Airborne Laser* (ABL) demonstrator aircraft, a highly modified Boeing 747-400F, successfully demonstrated an entire engagement sequence for the first time when its infrared sensors acquired an instrumented target board on the Air Force's NKC-135E *Big Crow* aircraft, the system tracked it with a Target Illuminator Laser (TILL), employed its Beacon Illuminator Laser (BILL) to compensate for atmospheric disturbances, and then fired its Surrogate High-Energy Laser (SHEL) at the target board to simulate a missile shootdown. The event was a key milestone in preparation for the eventual firing of the ABL system's high-powered Chemical Oxygen-Iodine Laser against an in-flight ballistic missile projected for 2009.

August 8, 2007 – In a signing ceremony at Edwards AFB, Secretary of the Air Force Michael W. Wynne announced the completion of the service's certification of the Fischer-Tropsch synthetic fuel blend for use in all B-52H aircraft. Certification testing had commenced at Edwards on 19 September 2006 when a B-52H was flown with two engines running on a half-and-half blend of standard JP-8 jet fuel and Fischer-Tropsch synthetic fuel and the six remaining engines on JP-8 fuel. The demonstration had been completed three months later, on 19 December 2006, when the bomber was flown with all eight engines running on the Fischer-Tropsch/JP-8 blend. Calling it a "great day for the United States Air Force…and another milestone for the Flight Test Center," Secretary Wynne described the certification process as "the tip of the spear for national energy independence" and he announced that all Air Force aircraft would be certified to fly on a domestically-produced synthetic fuel blend by 2011.

March 22, 2008 – The first Block 20 RQ-4 *Global Hawk* unmanned air vehicle (UAV) surpassed both the official and unofficial world un-refueled endurance records for operational UAVs when it completed a flight of 33.1 hours at altitudes up to 60,000 feet over Edwards AFB.

September 7, 2008 – The Northrop Grumman-built high-energy chemical oxygen iodine laser (COIL) was successfully fired onboard the YAL-1 ABL aircraft for the first time during a ground test. The test firing, called "first light," demonstrated that the laser was ready to demonstrate the power output sufficient to destroy a ballistic missile in flight. The test also validated the integration, and operation and control of the six laser modules and their associated optics that formed the core of the ABL system.

August 10, 2009 – The ABL test team successfully completed the system's first in-flight test against an instrumented target missile. During the test, crew members aboard the YAL-1 used its infrared sensors to detect a target missile launched from San Nicholas Island, CA. The battle-management system aboard the aircraft then issued engagement and target location instructions to the beam control/fire control system, which acquired the target and fired its two-solid state illuminator lasers to track the target and measure atmospheric conditions for disturbances. The system then fired a surrogate high-energy laser at the target, simulating a missile intercept. Instrumentation on the target missile then confirmed the high-energy laser had successfully struck the target.

August 18, 2009 – The ABL test team successfully fired the high-energy COIL onboard the modified Boeing 747-400F YAL-1 aircraft in flight for the first time. The laser was fired into an onboard calorimeter which captured the beam and measured its power.

February 3, 2010 – The recently redesignated YAL-1 Airborne Laser Test Bed's (ALTB's) infrared sensors detected a solid-fuel ballistic missile during its boost phase within seconds after launch over the Point Mugu Naval Air Warfare-Weapons Division Sea Range. The ALTB's battle management system issued engagement and target location instructions to the beam control/fire control system and its low-energy solid-state lasers tracked the target and measured atmospheric conditions to compensate for any disturbances. Then the megawatt-class COIL fired its beam which heated the target missile's surface causing it to fail. This marked the first time in history that an airborne directed energy weapon was used to destroy any kind of ballistic missile in flight and the first time any system had destroyed one during the boost phase shortly after launch.

February 11, 2010 – At 8:44 p.m. (PST), a liquid-fueled, short-range threat-representative ballistic missile was launched from a sea-based platform over the Point Mugu Naval Air Warfare-Weapons Division Sea Range, off the central California coast. Within seconds, the infrared sensors onboard the YAL-1 Airborne Laser Test Bed (ALTB) aircraft detected the boosting missile, the battle management system issued engagement and target location instructions to the beam control/fire control system and the ALTB's low-energy solid-state lasers tracked the target and measured atmospheric conditions to compensate for any disturbances. Then the megawatt-class COIL fired its beam which heated the surface of the target missile causing it to fail. The entire engagement transpired within two minutes from the launching of the ballistic missile. This marked the first time in history that an airborne directed-energy weapon was used to destroy a liquid-fueled ballistic missile in flight and it was reportedly the first time any system had destroyed one during the boost phase shortly after launch. Following close behind the destruction of a solid-fueled system just eight days earlier, this mission represented an overwhelming convincing proof of concept for a technology that could be legitimately described as transformational.

May 26, 2010 – The unmanned Boeing X-51A *Waverider* supersonic combustion ramjet (scramjet) hypersonic concept demonstrator was released from its B-52H launch aircraft at about 50,000 feet and Mach 0.8 over the Point Mugu Naval Air Warfare Center Sea Range off the coast of California. Seconds later, the Army Tactical Missile solid-fuel rocket booster ignited and accelerated the vehicle to Mach 4.8 where the X-51A separated and executed a planned roll maneuver. After ignition, the air-breathing Pratt & Whitney Rockedyne scramjet transitioned to JP-7 jet fuel and burned for approximately 200 seconds during which it boosted the X-51A to approximately Mach 5 and an altitude of 70,000 feet. This was the first-ever flight of a vehicle powered by an air-breathing scramjet using hydrocarbon fuel and the longest inflight burn time ever recorded for any scramjet, easily exceeding the 12-second burn time of X-43's engine in 2004.

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