NASA Facts

National Aeronautics and
Space Administration

Dryden Flight Research Center
P.O. Box 273
Edwards, California 93523
Voice 661-276-3449
FAX 661-276-3566
pao@dfrc.nasa.gov

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Space Shuttles and the Dryden Flight Research Center

STS-67 Endeavour landing at Edwards.

Among the most prominent aerospace projects associated with the NASA Dryden Flight Research Center, Edwards, Calif., is the Space Transportation System (STS) — the space shuttles developed and operated by NASA.

In 1977, Dryden was the scene of the approach and landing tests (ALT) carried out with the prototype orbiter Enterprise to evaluate the glide and landing characteristics of the 100-ton vehicles. Dryden has also been the primary or alternate landing site for just under half of the space shuttle landings since the first orbital mission April 12-14, 1981. The role of Dryden and its predecessor organizations in the space shuttle program, however, extends beyond the prototype testing and the landings.

Dryden pilots and engineers were testing and validating design concepts that helped in the development of the space shuttle configuration more than a decade before testing began with the prototype Enterprise.

Subsequent flight testing at Dryden also contributed significantly in development of the space shuttle thermal protection system, solid rocket booster recovery system, flight control system computer software, drag chutes that helped increase landing efficiency and safety, and tests of the shuttle landing gear and braking systems with a specially-designed Landing Systems Research Aircraft (LSRA).

The Lifting Bodies

In the mid-1950s, engineering studies and design tests began at the National Advisory Committee for Aeronautics' Ames and Langley Aeronautical Laboratories (later redesignated the NASA Ames Research Center, Moffett Field, Calif., and Langley Research Center, Hampton, Va.) on aerodynamic shapes that could survive the fast, fiery plunge from space back through the atmosphere. The shapes would generate enough lift for a controlled descent and aircraft-like runway landing. This was the concept being studied for a future spacecraft, and it led to the lifting-body program at Dryden, which tested and validated the aerodynamic and controlled maneuvering qualities of the wingless shapes.

The first lifting body, the M2-F1, was built partly at Dryden (then called the Flight Research Center) by employees and partly by a contractor at El Mirage, Calif. It consisted of plywood over a tubular frame. This construction technique led to a very light vehicle, causing the M2-F1 to be referred to as the lightweight lifting body. It had no engines and was towed into the air — first behind an automobile on Rogers Dry Lake and then behind a NASA C-47. It was flown over 70 times behind the C-47 from 1963 to 1966 as a prototype leading to the formal program of heavyweight powered vehicles.

Five heavyweight designs were flown at Dryden from 1966 to 1975. They were the M2-F2, M2-F3 (rebuilt from the M2-F2 following a landing accident), HL-10, X-24A, and X-24B (rebuilt from the X-24A in a new configuration).

Three lifting bodies on the lakebed (X-24A, M2-F3, HL-10).

A typical heavyweight lifting body flight profile began at about 45,000 feet with its air launch from the NASA B-52 carrier aircraft. The research pilot would climb to altitudes of 50,000 to 80,000 feet. The pilot would then glide through a simulated return-from-space corridor into a preplanned approach for a landing on the dry lakebed at Edwards. Two of the final landings on the Edwards Air Force Base runway were representative of the types the shuttles would begin making just six years after the last flight of the X-24B, and verified that precise landings from space were feasible without the need for engines.

Data from each lifting body configuration contributed to the data base used to develop the space shuttles and helped produce energy management and landing techniques used today on each flight of the orbiters. Lifting body data led to the decision by NASA to build the orbiters without airbreathing jet engines that would have been used during descent and landing operations, and would have added substantially to the weight of each vehicle and to overall program costs.

These same airbreathing engines were to be used to ferry the orbiter from the landing site back to the launch site. If the engines were eliminated, another means of ferrying the orbiter had to be devised. Dryden proposed the concept of a mothership to carry out the ferry mission. The Boeing 747 Shuttle Carrier Aircraft (SCA) evolved from Dryden's recommendation. The SCA was subsequently used to launch the prototype orbiter Enterprise during the shuttle approach and landing tests in 1977.

The SCA is now the standard ferry vehicle.

The two shuttle carrier aircraft, nose-to-nose.

X-15 Contributions

The X-15 rocket-powered aircraft program at Dryden has been labeled as the most successful aeronautical research program ever conducted by NASA. It was conceived in the 1950s to investigate the realm of hypersonic flight and phenomena associated with speed in the Mach 6-plus range and altitudes of 250,000 feet — the fringes of space.

Using three research vehicles (one was lost in an accident late in the program), 12 pilots assigned to the program at the Flight Research Center collected a wealth of data between 1959 and 1968 on 199 research flights. Much of this information fanned out across the aerospace industry and has been applied to commercial and military aircraft and to the nation's space programs.

X-15 #3 and F-104A chase plane landing.

The areas of research pioneered by the X-15 program that have contributed directly to the space shuttle program, or aided in its development, are numerous. Among the most significant are:

- First use of reaction controls for attitude control in space
- First practical use of full-pressure suits for pilot protection
- Development of inertial flight data systems in high-dynamic-pressure and space environment
- Discovery of hot spots generated by surface irregularities
- Discovery that the hypersonic boundary layer is turbulent and not laminar
- First demonstration of pilot's ability to control rocket-boosted aerospace vehicle through atmospheric exit
- Successful transition from aerodynamic controls to reaction controls, and back again
- Demonstration of pilot's ability to function in a weightless environment
- First piloted, lifting atmospheric reentry
- First application of energy-management techniques for reentry guidance
- First application of hypersonic theory and wind tunnel work to actual flight vehicle
- Development of improved high-temperature seals and lubricants

As the X-15 program was establishing winged aircraft speed (4,520 mph) and altitude (354,200 feet) records that still stand (except for those established by the space shuttles), it was generating information on aerodynamics, structures, thermal properties, and flight controls that quickly found its way to not only designers and engineers associated with conventional aircraft, but to those connected with the early stages of space shuttle development.

High Speed Research Contributions

In the early 1970s, Dryden began a high-speed flight research program with YF-12 aircraft, an early variant of the famed SR-71 reconnaissance aircraft. YF-12s (including an actual SR-71 that was designated YF-12C to preserve the secrecy surrounding the SR-71s) were flown over a nine-year span to collect data in a variety of areas associated with sustained high speeds and high-altitude flight in a jet-powered aircraft.

During the program, Dryden engineers developed a central airborne performance analyzer that monitored a number of aircraft maintenance parameters, including the electrical, inlet control, and hydraulics systems. The analyzer was able to detect problems arising in flight and present enough information for pilots to decide whether to abort the mission or continue. The analyzer also provided data for post-flight maintenance checks. Though it was just a research project, the analyzer was a forerunner of on-board diagnostic systems used on the space shuttles and on a variety of aircraft today.

The YF-12 program also produced some of the first measurements of aeronautical-induced structural loads. These data were subsequently used to update analytical tools used by aircraft designers for advanced high-speed aircraft. These updated analytical tools were also used in designing the space shuttle.

Shuttle Software

In 1972, Dryden began research flights with the first aircraft equipped with an all-electric, digital flight control system. This was the F-8 Digital Fly-By-Wire, which used electrical impulses instead of mechanical means to link cockpit controls and actuators moving the rudder, elevators, and ailerons. This same all-electric F-8 was used to test and verify the computer hardware and software used in the space shuttle's flight control system before the first orbital flights began.

YF-12A in flight with "cold wall" experiment.

Booster Recovery System

In 1977 and 1978, tests of the parachute recovery system used on the space shuttle solid rocket boosters were carried out with the same NASA B-52 used as the air-launch platform for the X-15 and lifting body programs.

The series of 31 tests were staged out of Dryden, with the actual test drops made over the National Parachute Test Range, El Centro, Calif.

The tests, using a dummy solid rocket booster, verified the performance and reliability of the parachute recovery system used now to recover the solid rocket booster casings after they separate from the shuttles' external fuel tank during launch operations. The booster casings are refurbished for reuse after they are retrieved from the ocean.

Simulated (smaller) version of the shuttle's solid rocket booster under the wing of the B-52.

Tile Testing

In 1980, Dryden research pilots flew 60 flights to test space shuttle thermal protection tiles under various aerodynamic load conditions.

F-104 engaged in shuttle tile research.

Dryden used two research aircraft — an F-15 and an F-104 — for the series of tests, which subjected shuttle tiles to speeds of Mach 1.4 (nearly 1 and 1/2 times the speed of sound) and dynamic pressures of 1140 pounds per square foot to test them for deformation or structural changes as a result of the flight loads.

The tiles flight tested represented six locations on the orbiters: the forward wing glove area, vertical tail leading edge, window post area, elevon trailing edge, elevon hinge area, and closeout tiles aft of the wing leading edge area.

The Dryden flight test program led to several changes to improve bonding and attachment techniques.

Approach and Landing Tests

On July 26, 1972, NASA selected the Space Transportation Systems Division of Rockwell International, Downey, Calif., as the prime contractor for the design, development, test, and evaluation of the orbiter.

After five years of planning, assembly, and systems testing, the space shuttle approach and landing tests (ALT) began at Dryden. On Feb. 15, 1977, three taxi tests were conducted to validate structural loads and ground-handling and control characteristics of the NASA 747 SCA mated with the prototype orbiter Enterprise.

NASA chose the 747 as the aircraft to ferry the orbiters between the launch and landing sites, and to other manufacturing and program facilities when overland transportation was unsuitable or unfeasible. The same modified 747 was also used to carry Enterprise aloft for the ALT program.

Following the taxi tests were five captive-carry flights with Enterprise atop the SCA, but without a crew in the prototype orbiter. This series of flights produced important aerodynamic data about the flight characteristics of the mated vehicles during takeoff, climb, cruise and landing. The data were necessary not only for the initial glide flights of the orbiter, but also for ferry flight operations in years to come. Dryden conducted these tests. The remainder of the tests were conducted by NASA's Johnson Space Center, Houston, Texas, with Dryden support.

Three captive-carry flights came next, during which crews of astronauts were in the Enterprise cockpit with systems powered up. These tests verified crew procedures and systems operations during the approach and landing phases of flight. The captive-carry flights also included flutter tests of the mated craft at typical ferry flight speeds.

The five free flights, which began Aug. 12, 1977, and continued through Oct. 26, 1977, verified the orbiter's approach and landing capabilities and demonstrated its subsonic airworthiness. During each of the free flights, the Enterprise was released at an altitude of between 19,000 and 24,700 feet from the attach struts of the SCA and was flown, powerless, to a landing. Validated were not only the approach and landing capabilities of the vehicle, but also the automatic flight control and navigation systems — prerequisites for orbital flights.

The original plan for these tests called for eight free flights, but the tests produced sufficient data to cut the number to five — the last two with the ferry flight tail cone, a fitting to reduce aerodynamic drag and turbulence, removed.

Four of the free flight landings were made on Rogers Dry Lake at Edwards. The final free flight landing was on the main 15,000-foot concrete runway at Edwards.

Enterprise separates from 747 SCA for first tailcone off free flight.

On the final free flight, a serious flight control system problem occurred which caused uncontrolled orbiter oscillations in pitch and roll. Dryden was asked to solve this problem because of its extensive flight control and handling qualities expertise. After extensive analysis and simulation, Dryden engineers identified the cause of the problem. They verified the analysis in flight with experiments on the F-8 Digital Fly-By-Wire aircraft and developed a control system modification — a pilot-induced-oscillation suppressor — which eliminated the problem. This modification was incorporated into the orbiter flight control system before its first orbital flight.

Piloting Enterprise on the free flights in 1977 were astronauts Fred Haise and Gordon Fullerton on flights 1, 3, and 5. Astronauts Joe Engle and Richard Truly were aboard Enterprise on flights 2 and 4.

Haise was a former Dryden research pilot who had been an astronaut aboard the Apollo 13 mission.

Engle was a former Air Force test pilot who had flown the X-15 research aircraft at Dryden. Later he was the pilot aboard Columbia on the second shuttle flight in November 1981, and he was mission commander aboard Discovery on the twentieth shuttle mission in August and September of 1985.

Richard Truly also flew aboard Columbia with Engle on STS-2. Truly later commanded the eighth shuttle flight in August 1983.

Fullerton went on to fly aboard Columbia as the pilot of the third orbital mission in March 1983, and he commanded the nineteenth shuttle mission in 1985. He is now a research pilot at Dryden and the facility's project pilot on the SCA and B-52 launch aircraft, along with flying almost all other Dryden research aircraft.

Pilot crew of the 747 SCA during the ALT program was Fitzhugh Fulton and Tom McMurtry, NASA research pilots at Dryden. McMurtry later headed the research aircraft operations division at Dryden. He and Fulton have since retired from NASA.

Pre-Flight Analysis

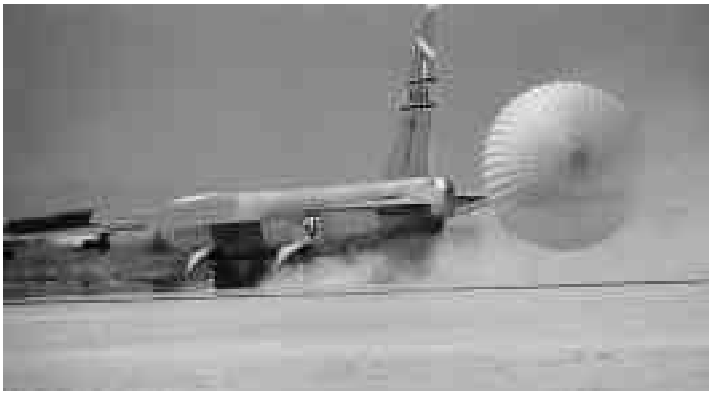
The Johnson Space Center asked Dryden to conduct an independent analysis of two crucial areas of the orbiter design prior to its first orbital flight. These areas were the aerothermal- induced structural loads and orbiter handling qualities. Dryden had accumulated extensive expertise in both of these areas from the X-15, YF-12, and lifting body programs. Based on this experience, Dryden established the levels of uncertainty that would exist in the predicted shuttle aerodynamic characteristics. The shuttle control system was found to be capable of compensating for these uncertainties. Dryden's independent analysis of these areas identified some minor design deficiencies but verified the overall adequacy of the design to accomplish a successful entry from Earth orbit.

Shuttle management officials also asked Dryden to conduct a test of the orbiter elevon seals under simulated entry flight conditions. Dryden's Thermostructures Research Facility applied mechanical loads and heat to a test specimen that included a portion of the orbiter wing and elevon. This test was intended to verify proper functioning of the seals. The seals are designed to prevent free stream air from entering the gap between the aluminum wing structure and the elevons during movement of the control surfaces. The free stream air temperature at atmospheric entry speeds greatly exceeds the melting point of the aluminum wing structure and it was essential to prevent air from entering this gap and causing structural failure. The Dryden tests verified the design.

Drag Chute Tests

Dryden used its B-52 in the summer and early fall of 1990 to test the drag parachute system now used by the orbiter fleet during routine landings to reduce brake wear and shorten runway rollout.

A series of eight drag chute deployment tests were carried out, with the B-52 landing at speeds ranging from 160 to 230 miles per hour on a lakebed runway and also on the main 15,000 foot concrete runway at Edwards.



B-52 testing developmental space shuttle drag chute.

Instrumentation on the B-52 obtained data during the deployments to validate predicted drag loads that an operational orbiter would sustain with a drag chute.

The drag chutes give the orbiters better deceleration capabilities on shorter runways, and help reduce tire and brake wear.

Landing Gear and Brake Testing

Tests of shuttle tires with a modified Convair CV-990 jetliner in 1993 through 1995 helped in the decision to resurface the runway at the Kennedy Space Center, Fla., to reduce tire wear and extend the crosswind landing limits up to 20 knots.

The CV-990, modified at Dryden and operated by Dryden personnel, had a landing gear retraction system installed in the lower fuselage between the aircraft's main landing gear. During tests, the shuttle test component was lowered once the aircraft's main landing gear had contacted the runway. This allowed much higher speeds and loading than the existing ground facilities and could duplicate the condition of the actual shuttle landings.

CV-990 Landing Systems Research Aircraft.

Engineers assessed and documented tire wear as loads of up to 140,000 pounds were applied.

Shuttle Landings

Dryden was selected as the site for the ALT program and the initial orbital landings because of the safety margin presented by Rogers Dry Lake and its lakebed runways. After operational landings resumed at the Kennedy Space Center, Dryden has continued to be an alternate site when unfavorable weather in Florida or special circumstances prevent a landing there. It will also be a landing site on missions when developmental tests are being carried out and specific payloads in the orbiters require a lakebed runway.

Rosamond Dry Lake at Edwards Air Force Base also has two lakebed runways available for special landings, if needed.

The space shuttle Atlantis lands with its drag chute deployed on Runway 22 at Edwards, Calif., to complete the STS-66 mission.

Scores of Dryden personnel support each shuttle landing at Edwards. These activities include staffing and operating the Dryden Mission Control Room where orbiter reentry and descent parameters are monitored; post-landing orbiter servicing and processing operations; post-landing crew physicals; hosting agency and program visitors viewing the landings; and staffing and operating a media information center for domestic and international news personnel covering the landings.

Dryden personnel maintain and operate one of the two SCA's used to ferry orbiters between landing and launch sites, and other locations too distant for the orbiters to be delivered by ground transportation.