▶ Chapter Five:
Supporting National Efforts

While Dryden was pursuing its various "exploratory" research projects over the years, the Center was also providing support for other programs and efforts, both in aeronautics and in space. Its unusual research aircraft, desert surroundings, and cadre of flight research specialists gave Dryden unique capabilities for testing new concepts and vehicles and attacking particular problems that surfaced in operational air- and spacecraft. Its support for America's space program has included efforts such as developing and flying a lunar landing research vehicle, pursuing a solution to a potentially dangerous pilot-induced oscillation with the Space Shuttle, and assisting efforts to find a more cost-effective way of putting satellites in space. Dryden has also provided both government agencies and industry with a wide variety of aeronautical support—from trouble-shooting problems with new military aircraft designs, to conducting stall-spin research for both military and general aviation airplanes, to crash-testing a proposed anti-misting fuel additive for the Federal Aviation Administration.

Many of these support efforts were developed quickly in response to problems or needs that arose. Dryden's ability to switch gears and incorporate new or unforeseen projects without dropping the other research already in progress was a tribute to the "technical agility" that was always one of the Center's greatest strengths. The people at Dryden did not do the in-depth theoretical research conducted at some of the other NASA centers. But as flexible, hands-on problem-solvers with actual flight hardware, they had few equals.

Space Shuttle Endeavour *atop a 747 Shuttle Carrier Aircraft being returned to Kennedy Space Center following its first flight from 7 to 16 May 1992 and its landing at Dryden at the end of the STS-49 mission. (NASA Photo EC92 5211-1)*

Supporting the Space Program

Early Efforts

Dryden's involvement in NASA's space program dates back to 1959, when the Center's F-104 aircraft were used to test the drogue parachutes being designed for the Mercury space capsules. The F-104s performed multiple drops of the parachutes from above 45,000 feet, and the flight research uncovered several critical design flaws that were then able to be corrected before the system was used on the actual Mercury spacecraft.

Dryden researchers also provided some backup support for the military X-20 "Dyna-Soar" program that was being developed about that same time. The Dyna-Soar was a delta-wing vehicle that was to be launched on top of a booster rocket and then flown back to a horizontal landing. Large rocket booster safety and performance in those days was uncertain, and planners wanted to design a workable escape system for the pilots in the event of a launchpad booster-rocket explosion. The Dyna-Soar design included a small emergency rocket that could jettison the craft to an altitude of perhaps 6,500 feet, but it was still unclear how a pilot would land the aircraft safely from that point. Using a prototype Douglas F5D "Skylancer" the Center acquired in 1961, Dryden research pilot Neil Armstrong explored several possible techniques and developed a procedure that would have enabled a safe return to landing for Dyna-Soar pilots. As it turned out, the Dyna-Soar program was canceled before the craft was ever built, but the technique developed at Dryden provided the X-20 project managers with valuable information they had not been able to obtain from other sources.[1]

Dryden's involvement with NASA's space program continued in the early 1960s with flight research to support the agency's "parawing" project. The parawing was an inflatable, steerable wing/parachute that was being investigated as a possible alternative to the simple parachutes used by the Mercury space capsules. A parawing might enable follow-on Mercury Mark II capsules (which became the Gemini spacecraft) to be guided to a gentle land touchdown instead of the ocean

F-100 and F-100A on lakebed, showing modifications to the tail that solved the aircraft's deadly tendency to go out of control during rolling maneuvers. The larger tail on aircraft FW-778 (the F-100A) is clearly visible as compared with the unmodified F-100 (FW-773)
(NASA Photo E 1573)

splashdowns simple parachute systems required. The parawing concept was based on research by a Langley Research Center engineer named Francis M. Rogallo, and the soft wing/parachute was known as a "Rogallo wing."

In the spring of 1961, NASA's Space Task Group initiated research into the applicability of Rogallo's design to spacecraft. North American Aviation was awarded a contract to build and test a prototype Rogallo wing, and Dryden was asked to support that test program. Some engineers at Dryden, however, thought that it would be helpful to try flying a small paraglider before North American tested its full-size Rogallo wing. Paul Bikle, the Center's director at that point, agreed and approved the construction and flight of a single-seat paraglider in December 1961. The result was the "Paresev I," a somewhat unsteady-looking vehicle that resembled a hang glider attached to a three-wheeled dune buggy.

The unpowered craft was initially towed behind a ground vehicle, and the pilot, who sat out in the open, controlled its movement by tilting the wing fore, aft, and side to side. The flying characteristics of the Paresev were less than ideal, to say the least, and research pilot Milt Thompson considered it more difficult to fly than even the early lifting-body aircraft. The craft's crude control system led to several tense moments during the research flights and ultimately caused an accident with the vehicle. Pilot Bruce Peterson was flying the Paresev I on a ground tow test when it began an increasingly severe rocking oscillation and finally nosed over into the lakebed. Fortunately, Peterson was not seriously hurt and the vehicle was completely rebuilt with a better wing and control system. The Paresev I-A, as the rebuilt vehicle was named, had better handling characteristics and, after initial ground-tow tests, was taken aloft behind a Stearman biplane and an L-19 Bird Dog.

Eventually, the vehicle was equipped with the same kind of inflatable wing North American was testing and dubbed the Paresev I-B. In two years, the Paresevs completed 100 ground tows and 60 air tows. But although the Dryden Paresev finally got to the point where it had acceptable handling characteristics, the full-size test vehicle being developed by North American was not as successful. In 1964, as costs and time delays increased, NASA dropped the parawing program and research with the Paresevs ended.

The value of the Paresev research at Dryden was that it offered a low-cost way to investigate some of the flight-control issues and problems that a parawing concept might entail. Clearly, there was still a gap between a small test vehicle and a full-size, space-capable system. But some of the information was still useful. And although the inflatable parawing concept has yet to be applied to a spacecraft, it may still be used on a future design.[2]

Lunar Landing Research Vehicles (LLRVs)

One of Dryden's biggest contributions to the space program was its work with the Lunar Landing Research Vehicles (LLRVs)—tubular craft so bizarre looking that they were commonly referred to as the "flying bedsteads." The LLRVs themselves were the brainchild of Dryden engineer Hubert "Jake" Drake, but the research was part of a NASA-wide effort to develop the experience and techniques necessary for a successful Moon landing.

When President John F. Kennedy issued

Paresev in flight, providing a low-cost way to test the flight-control issues of a parawing concept for possible use in returning spacecraft to Earth (NASA Photo E 8013)

his 1961 challenge to have an American walk on the Moon before the end of the decade, NASA and industry researchers went into high gear. They had eight short years to answer all the questions, develop all the technology, and overcome all the obstacles necessary to achieve that goal. One of the questions was how the astronauts were going to successfully land and take off again from the Moon's surface. Aerodynamic features would be useless in the Moon's airless environment, so the lunar module would have to be controlled entirely by propulsion systems.

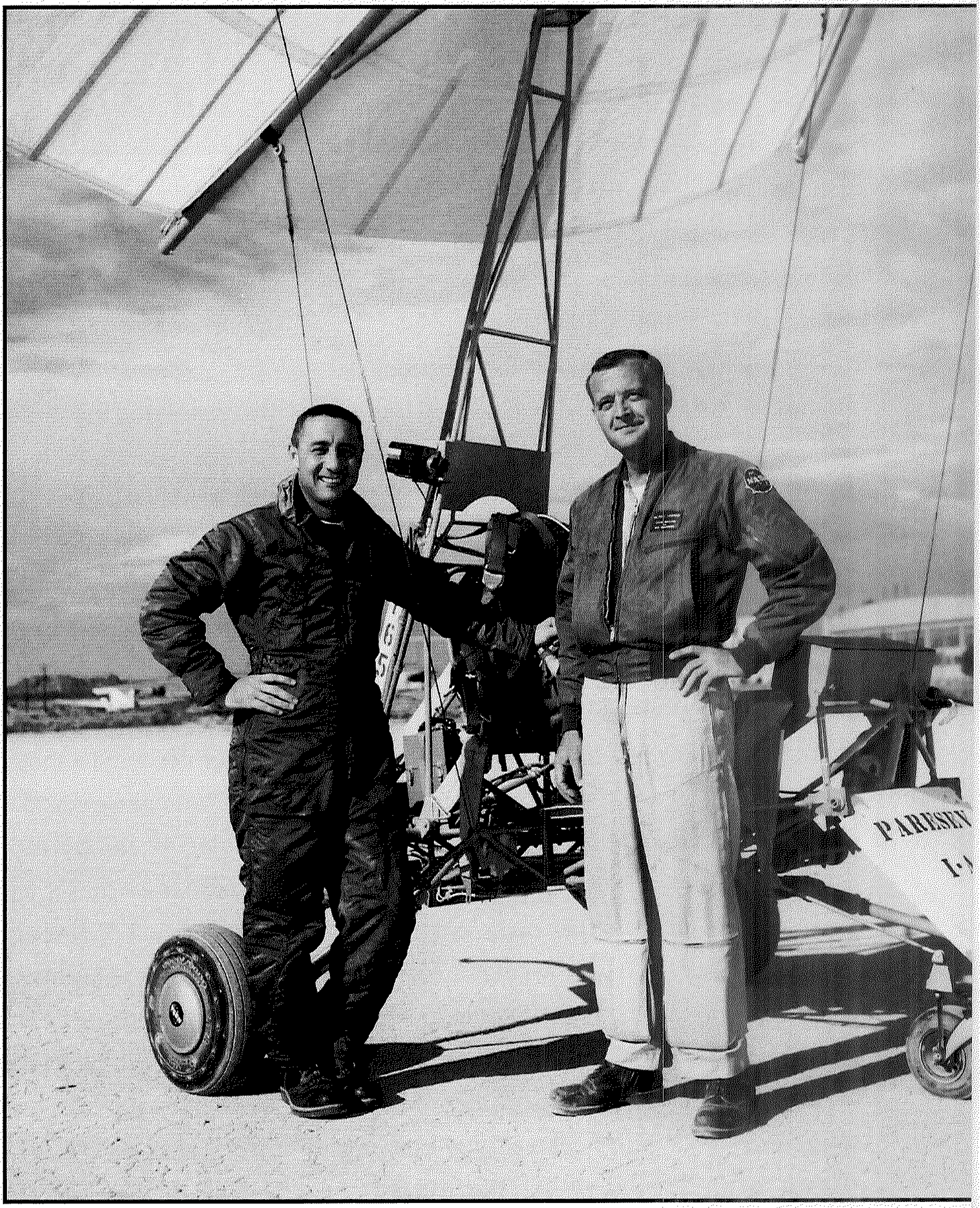
The Grumman Aircraft Corporation was given the contract to design and build the actual lunar module, but NASA managers knew they would also need to find some way to train the astronauts to operate the lander in the Moon's reduced gravity. NASA planned, of course, to design a ground simulator for the craft, and the Langley Research Center was developing a tethered test machine on a large gantry. But Drake, a product of Dryden's hands-on, flight-oriented atmosphere, believed that the only way to get complete information on flying the lander would be to build and operate a free-flying test vehicle. As luck would have it, Drake was not alone in his thinking. Several engineers at Bell Aircraft were also pursuing a design for a free-flying lunar lander simulator. In addition to its history with the X-1 project, Bell was a premier helicopter manufacturer, a pioneer in vertical take off and landing (VTOL) aircraft research, and therefore an obvious partner in the effort.

Dryden and Bell got approval to begin work on the LLRV in December 1961, and in February 1963 Bell was awarded a contract to build two of the vehicles. The vehicles, which looked something like a cross between a child's jungle gym and a science fiction contraption, were not an entirely new concept. "Flying bedsteads" had been used to investigate VTOL aircraft technology as early as 1954. But the LLRVs had the unique task of investigating the flight and propulsion controls, pilot displays, visibility, and flight dynamics of a vehicle designed to land on the Moon.

Because the Moon's gravity is only one-sixth as strong as the Earth's, the LLRVs had a central, gimballed jet engine that would support five-sixths of the vehicle's weight. The gimbal mechanism made sure that the engine remained perpendicular to the ground, regardless of the attitude of the vehicle. In addition, the LLRV was equipped with two lift rockets to manage its climb and descent, and 16 smaller reaction control rocket engines that the pilot used to control pitch, yaw, and roll. The vehicle also had six backup rockets that could be deployed if the main jet engine malfunctioned, and it was equipped with a zero-zero ejection seat[3] for the pilot.[4]

LLRV #1 made its first flight on October 30, 1964. The steam and noise generated by the controlling reaction rockets made the aircraft sound like "a marshaling yard full of steam locomotives," according to one Dryden research pilot,[5] but the awkward-looking contraption performed as promised. Over the next two years, NASA pilots made 198 flights in the vehicle, incorporating several modifications along the way to make the LLRV more like the actual Lunar Module (LM). In early 1967 both LLRVs were shipped to Houston, where NASA began using them as training vehicles for the Apollo astronauts. Redesignated the Lunar Landing Training Vehicles (LLTVs), the two from Dryden were soon joined by three more LLTVs that NASA ordered from Bell.

All the Moon mission commanders and back-up pilots flew the LLTVs before their flights and considered their experiences with them extremely valuable. In fact, when Apollo



Gus Grissom (with right hand on hip) and Milt Thompson next to the Paresev. In 1962, when this photo was taken, Milt checked the Mercury astronaut out on the vehicle. (NASA Photo E 8937)

11's "Eagle" LM was descending to that first historic Moon landing, Neil Armstrong realized the craft was heading for an undesirable touchdown spot. So although the LM was equipped with an automatic landing system, Armstrong took over and flew the craft manually for the final 30-40 seconds of its descent, guiding it to a more suitable site. It was his flights in the LLTV, Armstrong reportedly said later, that gave him the confidence to take over from the automatic system.[6]

Lunar Landing Research Vehicle (LLRV) in flight (NASA Photo ECN 506)

The LLTVs were far from perfect aircraft, as Armstrong and two other pilots discovered when control or system problems forced them to eject from the complex and totally non-aerodynamic vehicles. But the LLTVs were unquestionably extremely useful for America's piloted lunar space missions. As chief astronaut Donald "Deke" Slayton said at the time, there was "no other way to simulate Moon landings except by flying the LLTV." [7]

The Space Shuttle

Although the lifting-body shapes that were researched at Dryden were not selected as the final shape for the Space Shuttle, the Center has played an important support role with the Shuttle since the very first flight tests of the orbiter in 1977. While Rockwell was building the first Shuttle orbiter, the Air Force and NASA signed an agreement to establish Shuttle support facilities at Edwards Air Force Base. The clear skies, open landscape and lakebed landing site at Edwards would provide more leeway and options for returning Shuttle pilots than any other location. NASA planned to transport the Shuttle back and forth between Edwards and the Kennedy Space Center launch site in Florida on the back of a Boeing 747, and the agency had already bought and modified one of the jumbo jets for that purpose.

Computer and simulator calculations predicted that the mated Shuttle/747 pair could fly together safely, but NASA wanted to verify that prediction in a controlled flight-test environment before the Shuttle went into operation. NASA also wanted to glide-test the orbiter to make sure it could execute a safe landing before attempting an actual mission. To accomplish both of these goals, NASA's Johnson Space Center designed a three-phase test program. The first, "unmanned-captive," phase would test the Shuttle/747 combination without any crew in the orbiter, so that if there was a problem, the Shuttle could be jettisoned. The second, "captive-active," phase would test the combination with a two-person crew aboard the orbiter. The third phase would be "free-flight" tests in which the orbiter and its two-person crew would be carried aloft on the 747 and then launched off its back to glide back down to a landing.

Joe Walker in a Lunar Landing Research Vehicle (LLRV) (NASA Photo ECN 453)

As a safety precaution during the tests, a special escape system was installed in the 747. Ejection seats were impractical, especially with the Shuttle on top of the aircraft, so a laundry chute-type slide was installed right behind the cockpit that would exit out the bottom of the plane. The pilots would wear parachutes, and an explosive charge would blow a panel off the bottom of the chute/slide prior to the pilots' emergency exit. To insure that they could reach the exit even if the aircraft was spinning or out of control, a rope with knots tied in it was installed on the floor from the front of the cockpit to the escape chute.

The first unmanned-captive test flight went off without a hitch, which was fortunate because it was attended by a level of media attention and exposure beyond anything Dryden and its staff had ever experienced. After five captive tests and three successful captive-active tests, managers were ready to begin the more difficult free-flight portion of the test program.

Researchers knew the air-launch of the Shuttle from the 747 would be a high-risk maneuver. There were concerns about the orbiter causing aerodynamic buffeting of the 747's tail and the consequences of an incomplete separation. But the biggest concern was the risk of the Shuttle recontacting the 747 after separation, which might have catastrophic results. Special valves were installed in the Boeing jet to close off the hydraulic lines to the rudder so the rest of the control surfaces would be operable even if the tail were lost. Engineers conducted numerous simulations, wind tunnel tests, and studies to try to predict the behavior of the two aircraft after they separated. But concerns remained. Finally, Chuck Yeager, who had not only broken the sound barrier with the X-1 but had also flown a French ramjet-powered aircraft off of a French transport aircraft after World War II, was brought in as a consultant. As veteran research pilot Bill Dana remembered it, "Chuck listened politely to Dryden's interpretation of the laws of physics and aerodynamics, and then he walked over to a model of the mated 747/Shuttle combination and said, 'If you mount the Shuttle on the 747 with a positive angle-of-attack difference and get some air flowing between the two, nothing can happen but separation.' So we studied the problem some more and Chuck, of course, was right."[8]

Indeed, the first four free flight tests of the Shuttle went flawlessly, and the launch of

747 wake vortex research with smoke generators. A Learjet and T-37 Cessna are flying through the wake to measure the forces and effects of the vortices. (NASA Photo ECN 4243)

the orbiter off the 747 was never a problem. The biggest and scariest problem encountered during the approach and landing test (ALT) program was on the fifth and final flight, and it involved the control system of the orbiter itself. The fifth ALT flight was the first to attempt a landing on Edwards' paved runway instead of the Rogers lakebed. In addition, Shuttle pilots Fred Haise and Gordon Fullerton[9] were attempting a spot-landing at a particular point on the runway to see whether the orbiter could be landed precisely enough to permit landings at sites other than Edwards. Adding to the pressure on the pilots was the fact that Prince Charles of England was on hand to watch the landing, in a gazebo out by the runway.

The flight was also the first time Haise and Fullerton had flown the orbiter without its tail-cone faring, so they were relying on their practice in NASA's Gulfstream II in-flight simulator to judge how much to adjust their approach profile. But as often was the case, the simulator performance was not quite the same as the actual aircraft, so Haise was about 40 knots too fast as the Shuttle approached the runway. He deployed the orbiter's speed brakes and was trying very hard to still hit the target touchdown spot. But with the stress putting Haise in a keyed-up, or what pilots sometimes call a "high-gain," mode, he over-controlled the craft and entered a pilot-induced oscillation (PIO), both in roll and pitch. After the Shuttle bounced on one tire and then another, Fullerton finally got Haise to relax his pressure on the controls and the Shuttle landed safely. But the incident uncovered a potentially serious problem in the Shuttle's control system. In the high-stress environment of an actual re-entry and landing from space, pilots could easily get into the same difficulty that Haise did, with potentially disastrous consequences.

NASA immediately began a high-priority, agency-wide research effort to identify the cause of the problem and develop a solution. Dryden assigned a flight-controls group to research the issue, and the Center's F-8 Digital Fly-By-Wire was recruited to support the effort. Dryden's engineers suspected that the 270-millisecond time delay in the Shuttle's fly-by-wire control system was causing the problem, so the F-8 conducted a series of approach and landing tests with increasing time delays programmed into its control system. For safety, the aircraft was equipped with a switch that would turn off the experimental time delay and return the aircraft to its standard fly-by-wire control system.

The F-8 performed well until the added time delay reached 100 milliseconds. On that flight, as pilot John Manke was completing a touch-and-go landing and takeoff, he entered a severe PIO at a high angle of attack and low speed. Hearts stopped in the control room as researchers watched the jet fighter porpoise up and down in increasingly severe oscillations. Controller pilot Gary Krier quickly told Manke to turn the time delay off, and Manke managed to regain control and climb to a safe altitude. But it was close. Researchers estimated that if the oscillation had gotten any larger, Manke would have stalled and lost the airplane. Even after Manke gained a little altitude, the control-room engineers sat in stunned, relieved silence. Finally, Krier keyed his mike again and said, "Uh, John? I don't think we got the data on that—we'd like to have you run that one again." Laughter erupted, breaking the tension and illustrating once again the balancing power of humor in a high-stress environment.[10]

Clearly, there seemed to be a critical threshold in the time delay of a control system. One solution would have been to redesign the control system of the Shuttle, but that would have seriously delayed its development. Fortunately, the Dryden researchers were able to come up with another fix. They designed a suppression filter for the outer loop of the control system that would correct the problem without forcing any changes to the basic control laws. The filter was installed, and the Space Shuttles have used it ever since, accumulating a perfect safety record for landings. Another

Top: F-104 shown head-on while engaged in Space Shuttle tile research. Flights of this aircraft in rain and through clouds provided valuable data on the extent to which the tiles could withstand rainy conditions during launch. (NASA Photo EC90 224)

Top Right: PA-30 Twin Comanche general aviation aircraft, one of the types studied in the 1960s by the Flight Research Center in an investigation of their handling characteristics. It was later used to train pilots to operate Remotely Piloted Vehicles from the ground. No longer part of the Dryden fleet of aircraft, it now resides at Kings River College, Reedley, California. (NASA Photo 2089) result of the F-8 flight research was a specification for future military fly-by-wire aircraft, limiting their control-system time delays to less than 100 milliseconds.[11]

Convair 990 landing on the lakebed during the final Space Shuttle tire test (NASA Photo EC95 43230-4)

For a couple of years following the developmental research on the Shuttle, Dryden's efforts in support of NASA's space program lessened. But the Shuttle—and the world's attention—returned to Dryden in April 1981 when pilots John Young and Robert L. Crippen landed the orbiter *Columbia* at Edwards after the first Space Shuttle mission. Dryden continued to support the Shuttle missions through ground support of the landings and with its three-story steel Mate-Demate Device (MDD), which is used to mount and remove the Shuttles from their two Boeing 747 carrier ships. In 1993, the Kennedy Space Center in Florida became the primary landing site for the Shuttle program, but Edwards continues as an important backup location if the weather in Florida is not suitable for a landing.

Convair 990, equipped with a new landing gear test fixture representative of the Shuttle's landing gear system, is taking off on a flight from Dryden. In the background is a T-38 flying safety chase. (NASA Photo EC92 12221-2)

Space Shuttle Support Research

In the 1980s, Dryden once again took on a research role with the Space Shuttle program. In one effort, Dryden conducted a series of flight tests on the tiles being used for the orbiter's thermal-protection system. Since the Shuttle would be launched in Florida, where rain was a common occurrence, managers at the Johnson Space Center wanted to determine what kind of damage rain would inflict on the critical thermal tiles. Dryden researchers installed some of the rigid thermal tiles on a special flight-test fixture underneath one of the Center's F-104 aircraft and measured the results from flight in both actual rain conditions and behind a KC-135 spray tanker.

The KC-135 proved incapable of simulating rain impact damage and was dropped from the tests, but the flights in actual rain and cloud conditions provided some very valuable data. Tiles that had been through several launch cycles, for example, appeared to fail at lower impact forces than new tiles. But the research indicated that it might be possible to launch or land the Shuttle in light rain, although there were numerous variables that needed additional investigation. Related research with the F-104 and the Shuttle tiles also indicated that the flexible protective tiles could actually withstand launch airloads as much as 40 percent higher than those they were designed to bear. [12]

Following the *Challenger* accident in January 1986, NASA began looking not only at the booster rockets, but also at any other potential weak spots that could cause problems for future missions. One of the other areas investigators identified was the Shuttle's landing gear and tires. Because of the difficulty of protecting tires and gear in the extreme temperatures and environments experienced by the Shuttle, the orbiters were equipped with only four small wheels, two on each main gear. The main gear systems of a similar-weight commercial airliner, by comparison, would incorporate anywhere from eight to sixteen wheels.

Although the Shuttle tires had been tested at the Langley Research Center test track and on a stationary device called a dynamometer, the "dyno" could not test all the real-life effects the tires had to endure. Several engineers from the Johnson Space Center and Dryden agreed that it would be helpful to research the actual limits and failure modes of the Shuttle tires and wheels in realistic conditions, if a suitable test aircraft could be found.

NASA crew in front of 747 Shuttle Carrier Aircraft with Shuttle Columbia mounted above it, in 1981. Crew, from viewer's left: Tom McMurtry, pilot; Vic Horton, flight engineer; Fitz Fulton, command pilot; and Ray Young, flight engineer. (NASA Photo ECN 15325)

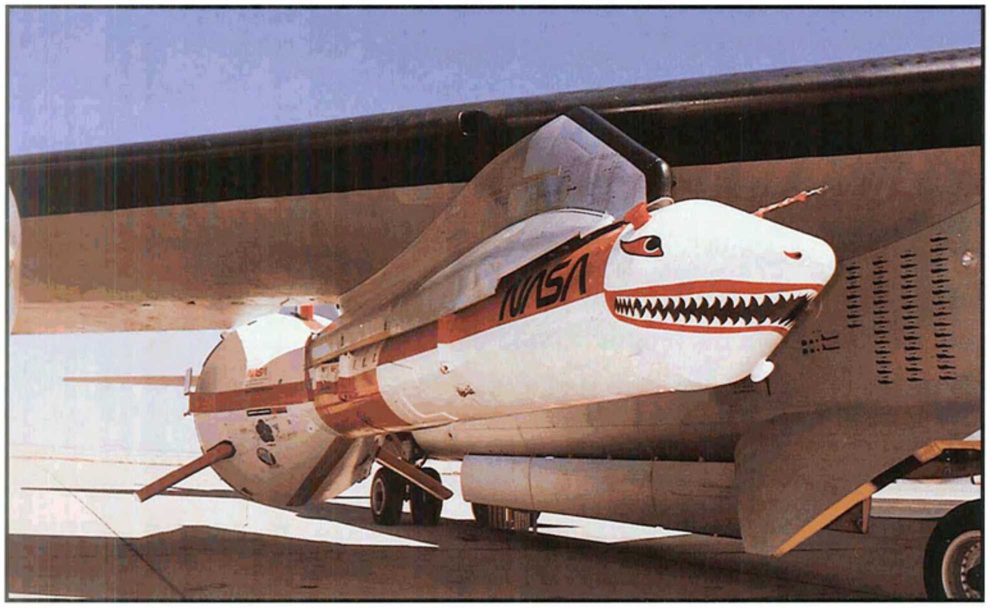
Space Shuttle prototype Enterprise, *tested at Dryden, being worked on in a hangar (NASA Photo EC83 22740)*

As it turned out, NASA already had a transport aircraft that could achieve both the gross weight and speeds of the Shuttle. The airplane was a Convair 990—a plane whose heavy, overbuilt design helped prevent it from being a commercial success but made it perfect for flight research. It had been operated by the Ames Research Center but was in storage in Marana, Arizona, when the Johnson-Dryden joint landing-systems research program was organized.

The Convair was pulled out of storage and modified with a separate test gear mechanism in between the aircraft's existing main landing gear. The test mechanism used landing gear components from the Shuttle and was powered by a high-pressure hydraulic system that allowed it to be extended and tested at various loads after the Convair touched down on its own gear. This set-up also provided an important margin of safety for testing tire failures, since the test apparatus was supplemental to the Convair's existing gear.

The initial goal of the research was to analyze failure modes of the Shuttle tires and gear. But while the Convair was still being modified for the work, the NASA managers in charge of the orbiter program decided that a more important priority was learning about tire wear on the Shuttle. Ground analysis had led program managers to limit the Shuttle to landing with less than a 12-15-knot crosswind. This also limited launches, because conditions had to be good enough for the Shuttle to perform an emergency return-to-launch-site (RTLS) maneuver in order for a launch to be approved. But if data from flight tests showed the tires could withstand greater forces, the crosswind limit could be increased.

The flight research with the modified Convair 990 occurred between 1993 and 1995. During that time, the aircraft was taken twice to Florida to test the tires at the speeds and weight the Shuttle would have if it had to perform an emergency RTLS. The results were surprising, and not encouraging. The tests indicated that the tires might not even sustain crosswinds as high as the predicted 12-15 knot limit. The Kennedy Space Center runway had grooves cut into the concrete, which improved traction in wet weather but created extra friction wear on the tires, especially the small, heavily-loaded tires of the Space Shuttle. As a result of the Convair tests, NASA decided to smooth the runway surface somewhat, raising the crosswind capability of the tires from 15 to 20 knots.



A simulated (smaller) version of the Shuttle's solid rocket booster (SRB) mounted under the wing of NASA's B-52 in preparation for the flight testing of the parachute system to be used in SRB recovery (NASA Photo ECN 9874)

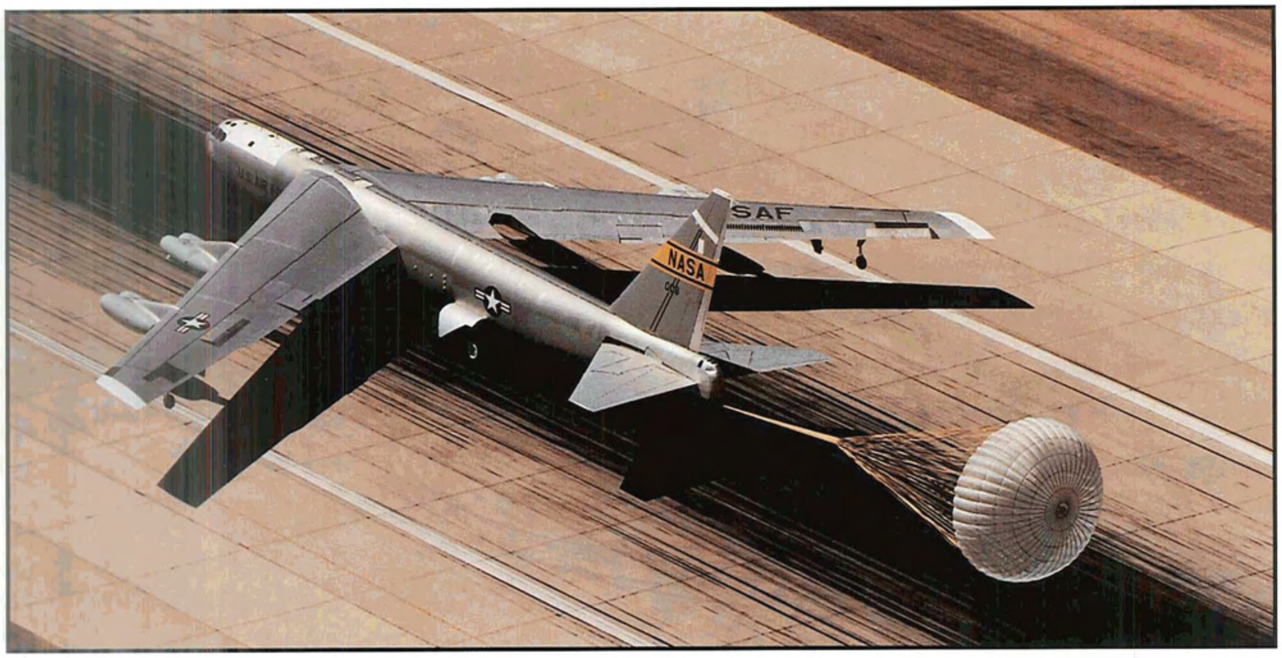
The Convair also conducted high-speed landing research on the tires, showing they could land safely at speeds up to 242 miles an hour—17 miles faster than the top speed for which they were rated.

In addition, the Convair investigated the performance of the tires in low pressure conditions. Pressure in the Shuttle's tires is monitored while the orbiter is in space, and the established procedures required the Shuttle to return and land immediately if any tire pressure went below 310 pounds per square inch (psi). Yet after the Convair test gear showed that the tires could still operate safely down to 200 psi, the required minimum pressure was reduced to 270 psi, giving the Shuttle some extra operating margin.

Near the end of the Convair landing systems research program, the researchers finally got back to their initial area of interest—the failure modes of the tires and wheels. In two August 1995 flights a test tire was intentionally failed and kept rolling under load, first on the paved Edwards runway and then on the Rogers lakebed. The results on the runway were dramatic. As the wheel was ground down by the concrete surface, the fire ignited by the heat stretched as high as the passenger windows and beyond the tail. The same test on the lakebed produced very different results. The tire and wheel kept rolling, and there was no fire. The research results still have to be analyzed further, but the information provided by the Convair tests will help managers reevaluate the best course of action for the Shuttle if it ever has to land with a defective tire.[13]

Dryden's B-52 Launch Aircraft

In several instances, Dryden became



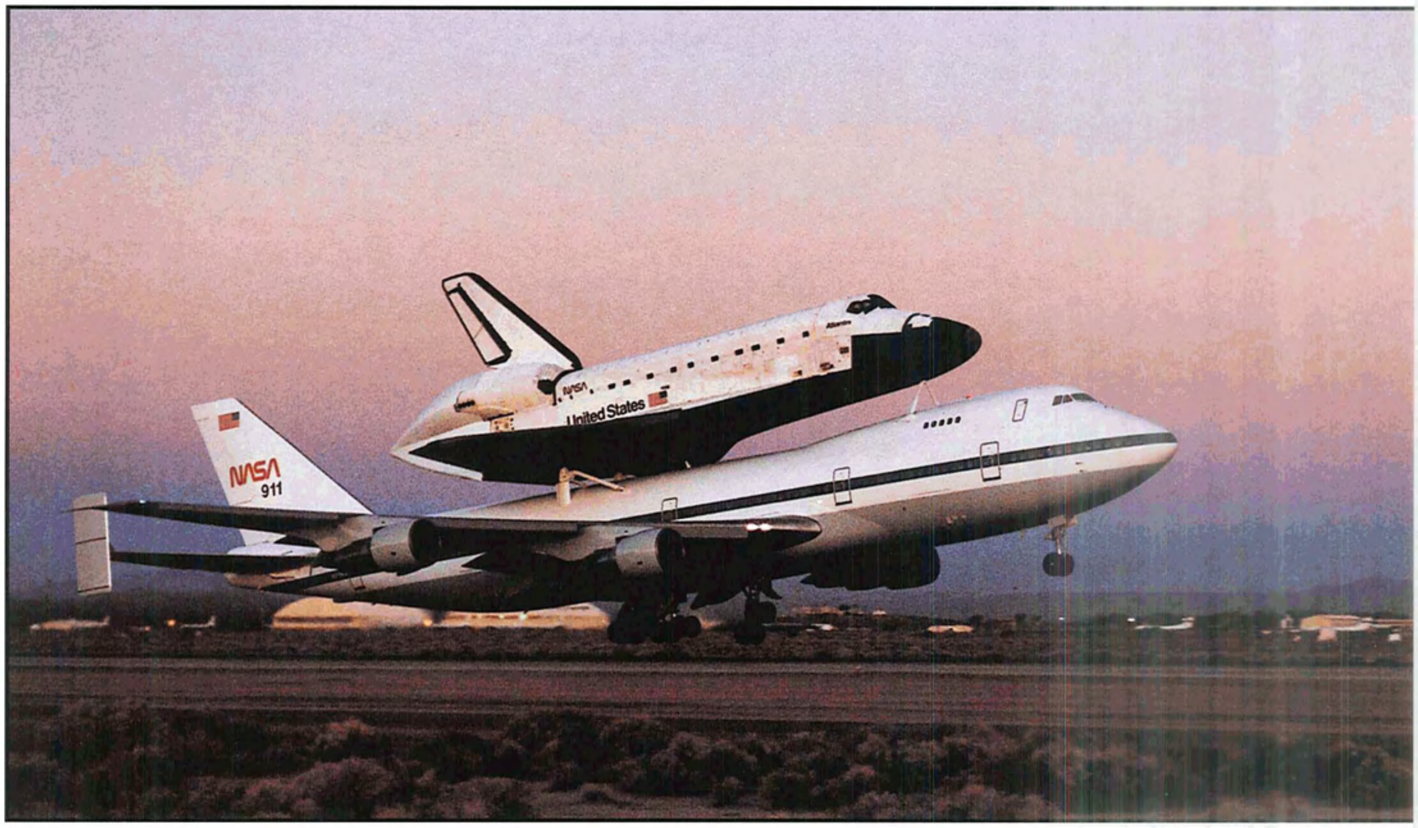
B-52 testing a drag chute being developed for the Space Shuttle to increase the safety of landings and reduce the wear on the orbiter's braking system (NASA Photo EC90 262-27)

involved with space-related research efforts because of its unique B-52 mothership aircraft. In the 1970s and 1980s, for example, Dryden conducted a series of drop tests for the parachute system designed to recover the Shuttle's solid rocket boosters. The Marshall Space Flight Center and the Martin Marietta company had developed a test cone to check the deployment mechanism and the maximum loads for both the booster's drogue and main parachutes, but they needed a launch vehicle for the unit. Dryden's B-52, with its wing pylon modified specifically for drop tests of various aircraft and objects, was an ideal platform.

In 1990, the B-52 was tapped once again by the Johnson Space Center to test a drag chute that was being developed for the Space Shuttle. The orbiter was already landing on concrete runway surfaces both at Edwards and at the Kennedy Space Center, but a drag chute could enhance the safety of the landings and also reduce the wear on the Shuttle's braking system. Dryden's B-52 was recruited as the test aircraft because it was already equipped for a drag chute and was heavy enough to produce a load on the chute similar to that of the orbiter. A series of landing tests on both Rogers Dry Lake and the Edwards runway showed the drag chute worked well, and it was installed and used for the first time on the new orbiter *Endeavour* in 1992. The other orbiters were subsequently retrofitted with the drag-chute mechanism.

Space Shuttle <u>Columbia</u> *with reflection in a pool of water created by recent rain on the normally dry lakebed, 16 November 1982*
(NASA Photo EC82 21081)

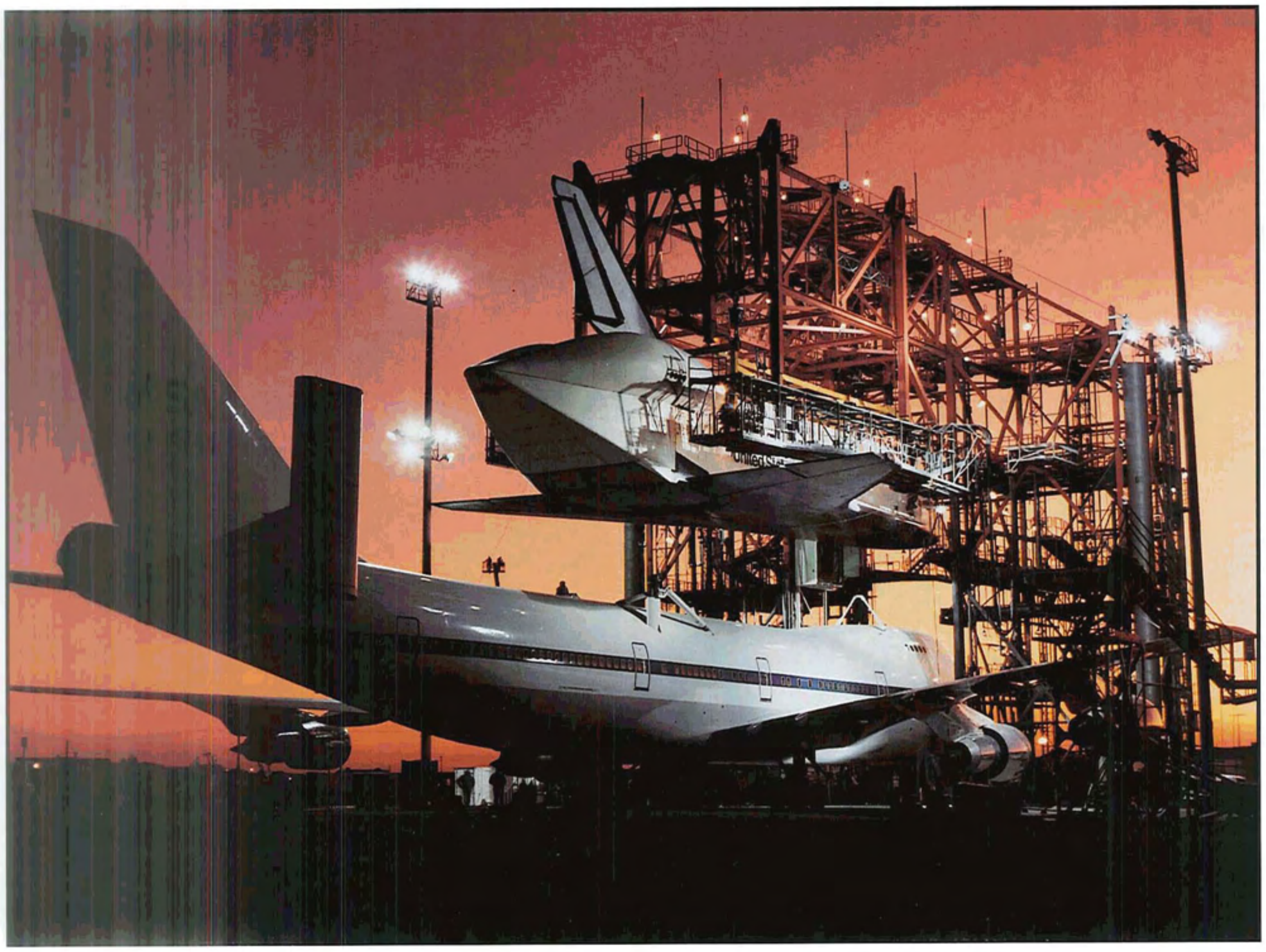
A group of industry entrepreneurs also approached Dryden in the late 1980s about using the Center's B-52 to help them test a new and potentially more cost-effective way of



Space Shuttle Atlantis mounted on top of a 747 Shuttle Carrier Aircraft for its return to Kennedy Space Center following its landing at Dryden at the end of the STS-66 mission, which lasted from 3 to 14 November 1994. (NASA Photo EC94 42853-6)

Shuttle prototype Enterprise separating from 747 Shuttle Carrier Aircraft for approach and landing test (ALT) research (NASA Photo ECN77 8608)

launching small payloads into orbit. Under the sponsorship of the Advanced Research Projects Agency (ARPA, now the Defense Advanced Research Projects Agency), the Orbital Sciences Corporation had developed an air-launched rocket-booster system in which the launch aircraft would replace the first stage of what would otherwise have been a four-stage launch system. The launch aircraft would release a winged booster rocket, which would carry a second booster rocket and payload even higher. The final rocket stage carried the 1,500-pound payload into orbit. Orbital Sciences named the vehicle "Pegasus" and teamed with the Hercules Corporation for manufacture of the rocket motors and Scaled Composites for the booster system's wing. But the vehicle still needed a suitable launch aircraft and, with its



Space Shuttle Atlantis *in Dryden's Mate-Demate device, about to be mated to the Shuttle Carrier Aircraft for its flight back to the Kennedy Space Center following its Space Transportation System-44 flight from 24 November to 1 December 1991 (NASA Photo EC91 659-2)*

custom launch pylon, Dryden's B-52 was a logical choice.

Dryden research pilots carried the first Pegasus aloft under the B-52's wing in April 1990. The launch was successful, and it marked one of the first times a commercial company had successfully launched a payload into Earth orbit. Five additional launches between 1990 and 1994 were also successful, opening a door not only to potentially less expensive but also to nongovernmental access to space.[14]

Safety and Problem Solving Efforts

Aircraft Design Problems

Even before the research station at Muroc was established, the National Advisory Committee for Aeronautics (NACA) had been involved in helping the military and manufacturers iron out problems in new aircraft designs. The NACA's wind tunnels were frequently-used resources, and NACA test pilots often helped evaluate prototype aircraft. As aircraft technology began advancing more rapidly in the 1940s and pressure to get new aircraft into service increased, the NACA's assistance became even more important.

With the dawning of the supersonic jet age, new production aircraft were beginning to push into the same areas that were being researched with the X-series aircraft at Dryden. So at the same time as Center pilots and engineers were exploring new research territory, they were also being tapped to help solve developmental problems in some of the country's new supersonic aircraft.

One of the earliest production aircraft Dryden assisted was the Northrop F-89. The F-89 was a high priority air defense program, and the Air Force had placed an order for more than 1,000 of the jet aircraft. But in early 1952, six of the new F-89s lost their wings in flight. The accidents pointed to a serious flaw in the aircraft's design and put the whole program in jeopardy. The Air Force and Northrop began an intense effort to determine the cause of the accidents and asked for Dryden's help. Dryden engineers put strain gauges on an F-89 and conducted a series of research flights to evaluate the in-flight loads on various components, especially the wings. The flights uncovered a serious weakness in an area of the wing's structure, which Northrop then redesigned. After the modification, the F-89 went on to a long and useful service life in the Air Force.

F-100 protruding through the hangar wall following Scott Crossfield's emergency landing in which he skillfully executed a dead-stick landing in the less than docile aircraft, then decided to glide off the lakebed and coast to a stop in front of the NACA hangar. Not realizing that he had used up the braking power, Crossfield went partly through the hangar wall without doing extensive damage to the aircraft, which flew again. (NASA Photo E 1366)

The next trouble-shooting effort with a military aircraft came with the North American F-100A—the first of the Century Series fighters and the first fighter designed to go supersonic in level flight. The F-100A had barely entered service in 1954 before a series of accidents and in-flight structural failures of the aircraft led the Air Force to ground the airplane. Dryden was already experiencing a phenomenon known as "inertial coupling" with the X-3 research plane,[15] and researchers suspected that the F-100A's problems stemmed from the same cause. North American, in fact, had the same thought and was considering a larger tail design as a possible fix. The Air Force and NACA got North American to reduce production time on its new tail design from 90 to a mere 9 days, and Dryden began an intensive flight research program defining the F-100A's roll coupling problem and evaluating the impact of various modifications, including the larger tail. The program was considered such a high priority that it even eclipsed the X-plane research Dryden was conducting at the time.

The F-100A was not a docile aircraft, and on the very first research flight at Dryden, pilot Scott Crossfield was faced with an emergency landing after an engine-fire warning. North American's pilots considered an unpowered, or "deadstick," landing in the fighter extremely risky because of its high landing speed and poor glide performance. Nevertheless, Crossfield elected to try to land the airplane and executed an almost flawless approach and landing on the Rogers lakebed—a tribute to his excellent pilot skills. That might have been the end of it, but, his confidence buoyed by the landing, Crossfield decided to try to top it by gliding off the lakebed and coasting to a precision stop in front of the NACA hangar on the ramp. Unfortunately for Crossfield, he didn't realize that he had already used up the aircraft's emergency braking power. He coasted off the lakebed, up the ramp and then, unable to stop, continued right through the open doors of the NACA hangar. He managed to miss the X-planes parked inside but ran the nose of the F-100A through the side wall of the hangar, causing at least as much damage to his pride as he did to the airplane.

Following that incident, however, the research effort proceeded without a hitch and was very successful. The flights showed that inertial coupling was, indeed, the cause of the F-100A's difficulties, and that a larger tail and slightly extended wing span would alleviate the problem. North American made the modifications, and the F-100 "Super Sabre" became one of the country's lead fighters in the 1950s.

The next military aircraft development program Dryden supported was the Lockheed F-104 "Starfighter." Dryden initially requested and received a pre-production model of the Mach 2 fighter for its own research efforts on phenomena such as roll coupling and pitch-up. But Lockheed was having numerous problems with its basic F-104 flight test program and at one point found itself without a single instrumented Starfighter. Dryden's prototype YF-104A was the only remaining instrumented aircraft, and Lockheed asked the Center to return it. Instead, Dryden suggested that it

Orbital Sciences Corporation's Pegasus booster under the wing of a B-52 at night (mid-1994). NASA's B-52 launched this standard Air-Launched Space Booster on its fifth and sixth missions on 19 May and 3 August 1994. On both occasions Pegasus carried Department of Defense satellites into orbit The 3 August mission was the last Pegasus launch from the B-52. (NASA Photo EC94 42690-7)

F-15 Remotely Piloted Research Vehicle mounted under NASA's B-52 in preparation for flight testing of the 3/8 scale model of the "Eagle" fighter to test the spin characteristics of the design before committing to a piloted test program in a full-scale F-15. (NASA Photo ECN 3804)

F-14s in formation above Rogers Dry Lakebed testing a new control law to improve the aircraft's spin response, 1982 (NASA Photo 20325)

complete the F-104 testing for Lockheed, using Dryden research pilots and instrumentation. Lockheed and the Air Force agreed, and Dryden conducted a series of flight tests for Lockheed over a nine month period of time in 1957. As a result of the cooperative flight tests, Lockheed built mechanical aileron limits into the plane, installed a yaw damper, and added several operational cautions into the pilots' operating handbook. The sleek and fast F-104 with its razor-thin wings still commanded respect from pilots who flew it, but the changes made as a result of the flight testing at Dryden helped it become a highly successful Air Force fighter.

F-104 (tail number 826), F/A-18 (tail number 841) and T-38 chase aircraft (tail number 821). Through the years, Dryden has used a variety of chase and support aircraft, including all three of these. This particular formation flew in March 1990 on the 30th anniversary of research pilot Bill Dana's first flight in an F-104, with Bill again in the cockpit of that aircraft, Gordon Fullerton in the T-38, and Jim Smolka in the F/A-18. First acquired in August 1956, F-104s were the most versatile work-horses in Dryden's stable of research and support aircraft, with 11 of them flying mostly research missions over the next 38 years. Tail number 826 flew the last of these missions on 31 January 1994. By then the 11 F-104s had accumulated over 18,000 flights at Dryden in a great variety of missions ranging from basic research to airborne simulation and service as an aerodynamic testbed. (NASA Photo EC90 128-5)

As NASA's focus turned to space flight in the 1960s, the agency became less involved in production aircraft development programs, but Dryden did help iron out problems with General Dynamics' F-111 fighter. The early F-111As were plagued with engine problems, and Dryden conducted a series of research flights to analyze the fighter's engine inlet dynamics. Eventually, the combined efforts of Dryden, the Air Force, and General Dynamics led to a redesign of the F-111 engine inlet, which corrected the problem. Later on, Dryden provided additional assistance to the F-111 program by drop testing the parachute system for the F-111's crew escape pod, using the Center's B-52 launch vehicle. Four different series of research experiments from 1977 to 1995 worked toward both extending the life of the parachutes and investigating ways to decrease the velocity at which the cockpit pod hit the ground.[16]

In the early 1980s, Dryden's assistance was sought again after the Navy lost several Grumman F-14 "Tomcat" fighters in spin incidents. The aircraft was having engine difficulties at high angles of attack, and if one engine stalled or flamed out, the asymmetric thrust from the remaining engine had a tendency to send the plane into a spin. The Tomcat had a flat spin mode that was proving very difficult to recover from and had resulted in the loss of several aircraft and crews. The Navy asked Grumman to look into the problem, and Grumman enlisted NASA's help in developing a solution. Working with Grumman, engineers at Dryden and Langley came up with a new control law that they thought might help the F-14's spin response. The new control law was then tested extensively in simulators before it was gingerly explored in flight with an F-14 loaned to Dryden for the research.

The flight research showed that the new control law did, in fact, make a significant improvement in the controllability of the F-14 in spins. Yet by the time the research was completed, Navy priorities had apparently changed and the control law was not implemented in fleet F-14s. The F-14 spin research program illustrated why technology transfer can be such a complex and sometimes difficult process, even if the technology itself is valid. Nevertheless, the concept had been proven. And although the control law was not incorporated into fleet aircraft at the time, it may be retrofitted into F-14D model fighters.[17]

Over the years, Dryden was also involved in several research efforts with production aircraft that did not stem from any particular problems, but served instead to provide additional information on a specific aircraft or type of design. In the early 1950s, for example, Dryden obtained a B-47 bomber and used it to gather useful information on the dynamics and characteristics of a large, flexible swept-wing aircraft. That data, in turn, helped engineers design future swept-wing aircraft, including the Boeing KC-135 and B-707 transport and every other swept-wing Boeing aircraft that followed.

Then in 1973, Dryden began flight testing three remotely piloted 3/8 scale models of the F-15 "Eagle" fighter that was being developed by McDonnell Douglas and the Air Force. Program managers wanted to test the spin characteristics of the design on a scale model before committing to a piloted test program, and Dryden had both experience in remotely piloted vehicles (RPVs) and a B-52 aircraft capable of launching such a model. The F-15 RPV flights were successful, and the results gave McDonnell Douglas and the Air Force the confidence they needed to go ahead with a spin test program on a full-scale, piloted F-15.[18]

Dryden's work with production aircraft programs has never been the primary focus of its research. But the Center was well suited for this kind of support work. For one thing, the daily requirements of keeping research aircraft flying meant that Dryden's staff was already very experienced in trouble-shooting aircraft and coming up with practical test methods and solutions. But these efforts also benefited greatly from the "technical agility" of Dryden's staff. Support projects tended to materialize suddenly when an aircraft program ran into trouble, requiring quick action and quick answers. Dryden was able to support these various efforts, on short time frames, because its management and staff were accustomed to juggling different programs and switching gears and priorities quickly.

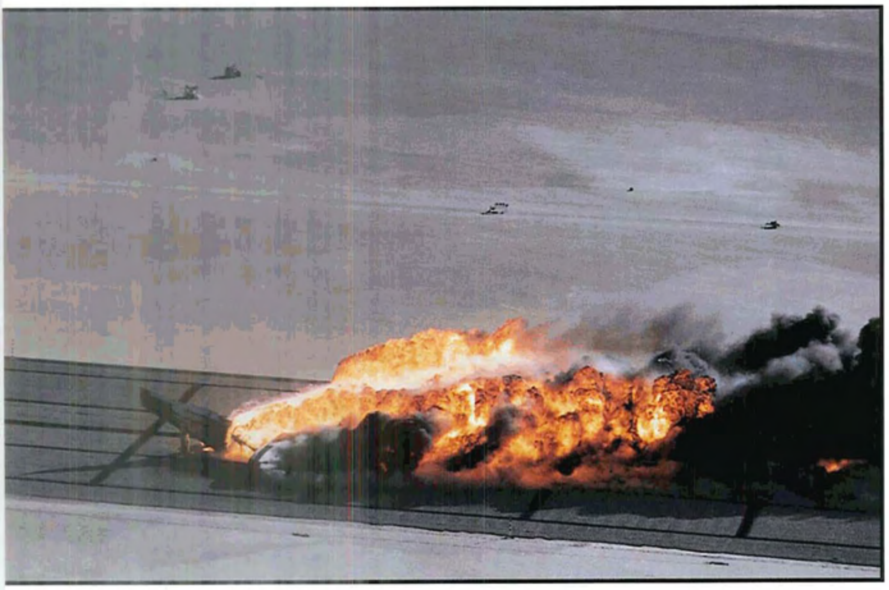
Aviation Safety

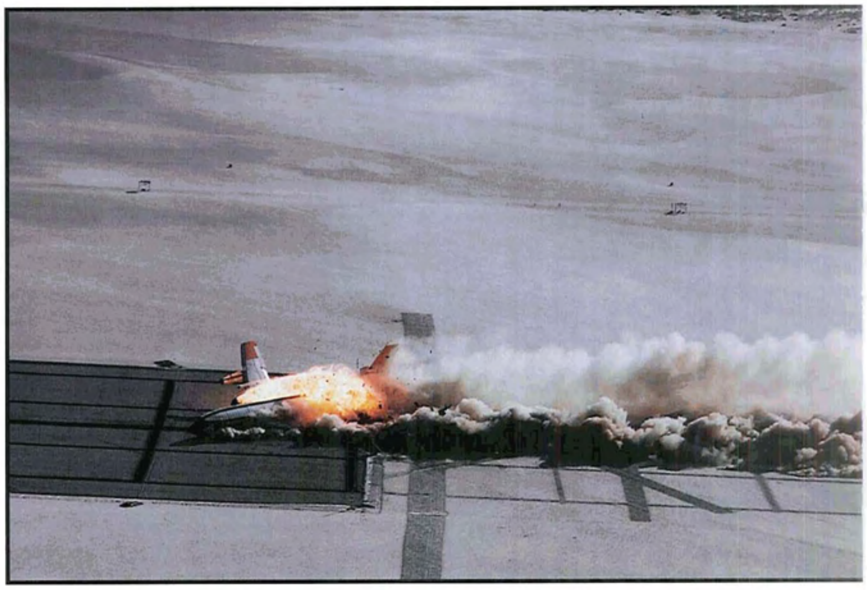
In addition to supporting various military aircraft design programs, Dryden also provided support to national civil aviation efforts, especially in the area of safety. The Center's focus on high-speed flight meant that it was less involved in civil aviation research than other NASA centers, since civil aircraft tended to have lower performance than military designs. But in 1957-1958, Dryden was asked to conduct a series of research flights for what was then the Civil Aeronautics Administration (absorbed into the Federal Aviation Administration during 1958). Boeing was getting ready to introduce its first jet airliner, the B-707, and the CAA needed to establish new approach procedure guidelines on cloud-ceiling and visibility minimums for the new generation of jet transports. Using the military KC-135 variant of the 707, Dryden pilots conducted a series of flights that gave the CAA the data it needed to develop safe instrument guidelines and approach procedures.[19]

In the 1960s, the aviation community became concerned about an increasing number of accidents among general aviation (GA) aircraft. In an effort to see whether there were any common design weaknesses or problems in GA airplanes, Dryden was asked to investigate the handling characteristics of several different designs throughout their flight envelopes. In the end, Dryden pilots surveyed a total of seven different GA aircraft in order to include a cross-section of aircraft types in the study. The results showed that there was no single weakness or design problem and the designs were generally adequate, although the criteria for handling qualities in small aircraft had not kept pace with advances in aircraft technology. The point of the research was not to point out design flaws in particular models, but the research did produce the side-benefit of uncovering several problems with individual aircraft designs. One aircraft, for example, developed a serious flutter in its horizontal stabilizer while still within its normal operating limitations. And the poor stall-spin performance of another twin-engine model led its manufacturer to modify the design with contra-rotating propellers.[20]

The introduction of jumbo jets in the late 1960s and early 1970s led to a new area of concern in aviation safety—wake vortices. Wingtip, or wake, vortices are very powerful tornado-like disturbances in the air coming off the wingtips of an airplane that trail behind the aircraft. The bigger and heavier the airplane, the more powerful these disturbances are, and a small plane trailing too closely behind a larger one can easily be flipped upside down by these powerful vortices at the edges of the larger aircraft's wake. Wingtip vortices are a particularly dangerous hazard during approaches or departures from airports since trailing aircraft have little altitude in which to recover. So when jumbo jets began mixing with smaller aircraft at airports, the aviation community began looking for more detailed information on the behavior and strength of wake disturbances from large aircraft.

In late 1969, Dryden pilots began investigating wake vortices by flying an instrumented F-104 fighter behind a B-52 bomber and C-5 transport. The C-5's vortices were so strong that on one flight, they caused the F-104 to roll inverted and lose 3,000-4,000 feet of altitude, even though the fighter was flying 10 miles behind the larger airplane. In 1973, Dryden expanded its wake vortex research to





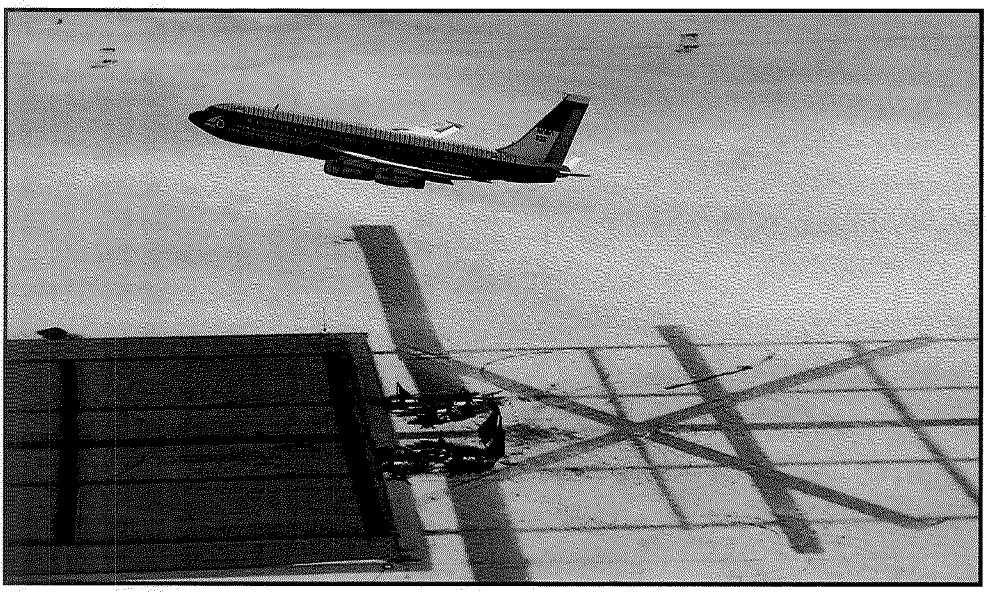
Above Left: *Remotely piloted Boeing 720 Controlled Impact Demonstration aircraft following impact with iron posts (cutters) implanted in the lakebed to pierce the fuel tanks and test an anti-misting fuel for its ability to prevent fuel fires during airplane crashes (NASA Photo EC84 31806)*

Above Right: Remotely piloted Boeing 720 Controlled Impact Demonstration aircraft burning after failure of anti-misting fuel to prevent a fire in a simulated post-crash situation (NASA Photo EC84 31809)

include a Boeing 727. The following year, Dryden got approval to use NASA's 747 Shuttle Carrier Aircraft for some additional wake-vortex research before the jumbo jet was modified for Shuttle use. Following a trail left by wingtip smoke generators installed on the 747, research pilots flew a Learjet business plane and a T-37 Air Force jet trainer through the 747's vortices to measure their forces and effects. After the 747's wake caused the T-37 to perform two unplanned snap rolls and develop a roll rate of 200 degrees per second despite trailing the jetliner by more than three miles, one research pilot speculated that a safe separation between the two aircraft in a landing configuration would have to be three times that distance.

As more jumbo jets entered service, Dryden expanded the research to examine the wake vortices of Lockheed's L-1011 and McDonnell Douglas' DC-10 as well. Follow-on flights also looked at how use of wing flaps, speed brakes or spoilers might affect the formation and behavior of wing vortices. Although the results indicated that use of wing devices could help reduce the severity of the vortices, researchers were unable to find a configuration that was practical. For example, certain flap combinations reduced wingtip vortices, but only if the gear remained retracted. The wake-vortex flight research conducted at Dryden did, however, play a central role in helping the FAA establish safe separation minimums for airline traffic at airports across the country.[21]

In 1984, the FAA once again teamed up with Dryden to conduct another research project concerned with flight safety. The FAA was evaluating an anti-misting jet-fuel additive that seemed capable, at least in laboratory testing, of preventing fuel fires in airplane crashes. The concept seemed so promising, in fact, that the FAA was preparing to publish a Notice of Proposed Rule Making (NPRM) as a first step toward requiring the additive in certain types of jet aircraft. Before proceeding with the NPRM, however, the agency wanted to test the additive in a real airplane crash. Dryden's desolate surroundings and the staff's experience in remotely piloted vehicle research made it a logical support resource for the test. Dryden engineers rigged up an old Boeing 720 jetliner with remote controls, fueled it with the anti-misting fuel, and guided it to a controlled crash landing on the lakebed. Iron posts had been set



Boeing 720 Controlled Impact Demonstration aircraft flying above cutters (iron posts) on lakebed, showing the setting for the demonstration portrayed in the photos on the preceding page (NASA Photo EC84 31672-12)

up on the lakebed to ensure that the fuel tanks would be ripped open upon impact, since that was the scenario most likely to result in a post-crash fire. The experiment was called the Controlled Impact Demonstration (CID), and the FAA expected that it would be a relatively tame event.

The expectations were wrong. In one of the Center's most dramatic moments of discovery, the remotely piloted 720 settled gently onto the desert floor . . . and exploded into a staggering fiery inferno. Needless to say, plans to require the fuel additive were discontinued, and from that point forth, Dryden researchers informally referred to the CID experiment as the "Crash In the Desert." Nevertheless, the experiment was a very strong illustration of why flight research is such an important element in technology development. The fuel additive worked well in laboratory testing. But in the real world environment of an airplane crash, it was clearly a failure.[22]

Conclusion

Throughout its history, Dryden's unique resources, organizational style and single mission focus have enabled it to play a key role not only in exploratory research but also in a wide variety of other government and industry aerospace efforts. The Center's open sky and lakebed landing sites provided a safe location for projects such as testing and landing the Space Shuttle or testing a new fuel additive in an actual crash situation. Its unique B-52 research aircraft allowed NASA to test a new drag chute for the Shuttle and provided a launch vehicle for everything from scale model aircraft and parachute systems to a low-cost method for putting payloads into space. Its ongoing research partnerships with military and industry put the Center in a position to help aircraft development programs when they ran into trouble.

But the driving force behind the success of Dryden's many support efforts was the attitude and experience of its staff members. They didn't do the wind tunnel testing or in-depth theoretical analysis that researchers at other centers did, but they had an unparalleled level of experience in flight research. They could figure out how to rig a jetliner to be flown by remote control, or how to design a free-flying lunar landing simulator. They could design a flight research program to safely investigate aircraft characteristics that had killed other pilots. And they had the enthusiasm and creativity to pursue these projects with success. The employees at Dryden prided themselves on their ability to trouble-shoot aircraft and find quick solutions to operational problems. So whether the problem was a dangerous pilot-induced oscillation in the Space Shuttle, a need to train astronauts to land on the Moon, or a flawed aircraft design that was costing pilots' lives, it was the kind of work at which Dryden excelled.

Still, the Center staff could not have taken on so many unscheduled support efforts in addition to its exploratory research without a management environment that stressed flexibility. Staff members were already used to juggling several research projects at once, and the daily operational philosophy at the Center might have been summarized as "all plans subject to change." It was simply a fact of life at a flight research center where mechanical problems, weather, and other factors could always force last-minute changes in schedules and priorities. But Dryden's flexible, innovative management style created a kind of "technical agility" that allowed the Center to support a surprisingly wide variety of other government and industry efforts even as it continued its exploratory research.

Dryden's research in support of other programs was not always as glamorous as its work on the frontiers of science and flight, but those support efforts had direct, real-life consequences. The Center's work with the F-89, F-100A, F-104 and F-111 helped save pilots' lives and helped turn the designs into successful fighter aircraft. The Lunar Landing Research Vehicle gave Neil Armstrong the confidence he needed to land the Lunar Module manually on the Moon's surface. The Center's PIO flight research and suppression filter design solved a potentially dangerous problem with the Space Shuttle, and the landing systems research with the Convair 990 might save future astronauts' lives in an emergency situation. And Dryden's wake vortex research helped national efforts to maintain the safety of civil aviation. Testing tires or thermal tiles for the Space Shuttle might not be as exciting as flying an X-15 to the outer reaches of the atmosphere, but those efforts, and the many support projects like them, were every bit as important.

F-15 Advanced Controls for Integrated Vehicles (ACTIVE) research aircraft in flight over Edwards in March 1996. The Pratt & Whitney nozzles can turn up to 20 degrees in any direction and enable the aircraft to use thrust control in place of conventional aerodynamic controls, thereby reducing drag and increasing fuel economy or range. (NASA Photo EC96 434585-13)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▶ Chapter Six
Future Directions

As the Dryden Flight Research Center begins its second 50 years, it faces a very different world than the one the original X-1 team knew. Advances in technology have revolutionized Americans' daily lives and changed our view of what is possible in fields ranging from data processing and communication to transportation, aircraft design, and space flight. We have moved from an essentially manual, manufacturing-based society into the automated information age where personal computers, satellite communications and the information superhighway have become an integral part of individual, business and government transactions. From a time when space flight was a science-fiction fantasy and the speed of sound seemed an impenetrable barrier, we have moved into an era where the Space Shuttle flies regularly to and from space and aircraft reach speeds of Mach 2 and beyond.

F/A-18 vertical tails. These aircraft serve as chase planes for Dryden's research airplanes (NASA Photo EC96 43505-9)

F/A-18 High Angle-of-Attack Research Vehicle, X-29, F-15 Highly Integrated Digital Electronic Control aircraft, single-seat F-16XL, three F/A-18s in a row with the middle one being the F-18 Systems Research Aircraft, Pegasus in front of B-52 mothership, T-38, F-104, B-52, SR-71, 747 Shuttle Carrier Aircraft, with Dryden Flight Research Center facilities in the background. (NASA Photo EC90 280-1)

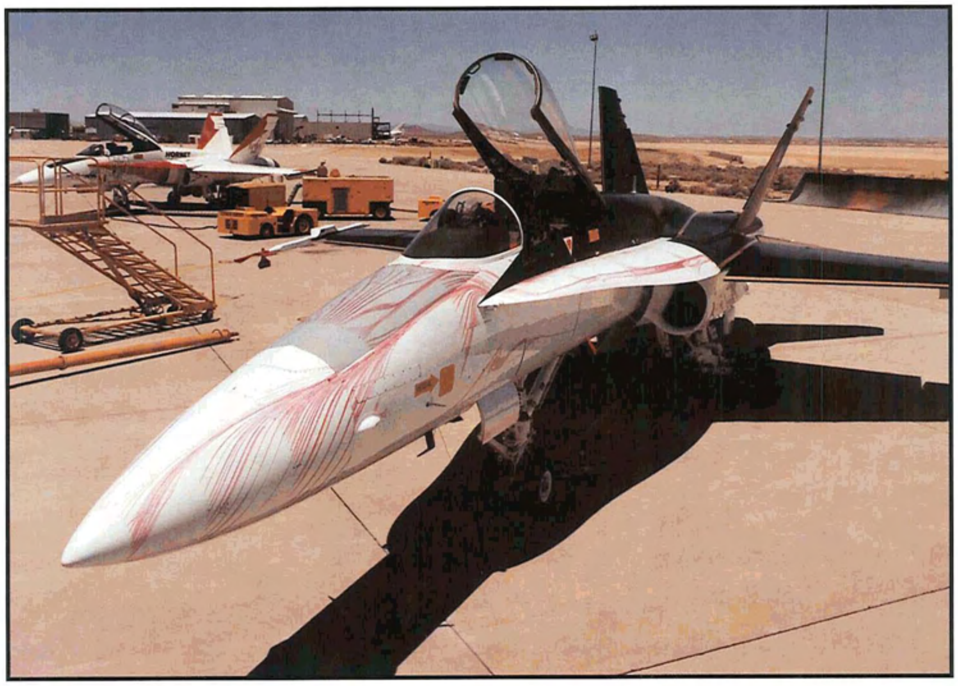
Yet along with the vastly expanded capabilities of today's world have come new concerns, issues and priorities. The price of fuel has risen sharply, making fuel efficiency a much higher priority for both end users of aircraft and national policy-makers. There is much more concern about protecting the environment and atmosphere. Advances in technology and changes in warfare have created tougher demands on military aircraft, requiring designs that are radar-resistant and maneuverable, for example, as well as fast. An increasingly global economy and improved technology bases in other countries have helped shake the United States' unquestioned position as the world's technological and economic leader and have contributed to an unfavorable balance of trade. Consequently, while international partnerships are on the rise, the issue remains of how to cooperate without giving away critical U.S. technology. Furthermore, while new aerospace technology has greatly expanded capabilities, its cost and complexity make it even riskier for industry to research or apply. This inherently makes government involvement in technology development more important. But the United States government also faces budget difficulties, leaving less funding available for federal research and development work.

What all of this means for Dryden is simply that for all the technological progress made since that first small group of engineers arrived in the desert in 1946, the challenges the Center faces are no less demanding. Technology has become more capable, but the problems have become more complex. Even as new technology has overcome existing obstacles, it has opened doors onto whole new sets of questions or problems. Computerized flight-control systems, for example, have made highly unusual aircraft such as the highly unstable X-29 and the thrust-vectored X-31 possible. But that same technology has created new problems and has greatly increased the system complexity of aircraft. As a result, there are more opportunities to overlook something, and software configuration control is now as flight-critical an element as the spar in an aircraft's wing.

In 1946, the X-1 was designed to tackle the issues and problems with basic transonic/supersonic flight. Today, research aircraft are trying to meet more complex challenges. Supersonic speed itself is no longer the cutting edge of possibility. But achieving supersonic laminar flow, integrated flight and engine control operations, or thrust-vectored maneuvering at supersonic speeds still is. And the requirements and restrictions of a changing world demand that we continue to operate at that cutting edge. Our spacecraft must create less waste and pollution and deliver payloads into space more cost-effectively. In addition to flying high and fast, today's aircraft must also operate more economically and without damaging the environment. Indeed, we need to find a way to learn more about changes and damage to the atmosphere itself. We have made great progress, but the goalposts are continually moving outward as our world changes and we expand our knowledge base and technical ability.

A 1976 NASA report noted that "how to meet international competition with improved performance and better economics and still provide increased environmental protection and greater safety is a task requiring the best efforts of government and industry."[1] That statement

Flow-visualization smoke marks strong vortex flows along the leading edge extension (LEX) of the NASA F/A-18 High Angle-of-Attack Research Vehicle during tests of the white LEX fences located close to the fuselage, ahead of the wing. The LEX fences caused the vortices to burst and lose energy, reducing the structural loads on the rudders and increasing the life of the airframe. This modification has been added to Dryden's F/A-18 fleet as well as to F/A-18s in military service. (NASA Photo EC89 0096 149)



F/A-18 High Angle-of-Attack Research Vehicle showing the results of releasing a glycol-based liquid dye from very small holes around the nose of the aircraft during flight at about 30 degrees angle of attack. The airflow pattern revealed by the lines on the fuselage and wing helped researchers from Dryden, Ames and Langley research centers to visualize what was happening in flight and to compare forebody flows with predictions obtained from wind-tunnel testing and computational fluid dynamics simulations. (NASA Photo EC88 0115-79)

was true then, and it is even more true today. The challenges have changed; the problems are more complex. But the role and importance of Dryden are the same today as they were in 1946. With its many government and industry partners, Dryden is still working at the boundary between the known and the unknown, trying to learn enough and push technology enough to allow the country to meet the challenges not only of the present but also of the near and distant future.

Current Projects

Like many of the focused research programs throughout Dryden's history, the four major research efforts the Center is currently pursuing reflect some of the nation's present-day aerospace priorities. Interestingly enough, some of them also incorporate ideas that date back as far as the Wright brothers but are being revisited as new technologies and/or mission needs have developed to support their use.

One of the major efforts underway at Dryden is, once again, a high speed research (HSR) program, focused primarily on supporting the High Speed Civil Transport (HSCT). Dryden had supported supersonic transport research in the 1960s, but the HSCT has more challenging requirements for fuel-efficiency and low environmental impact. So Dryden's current HSR efforts include projects such as the F-16XL supersonic laminar-flow research—a technology that could help make a supersonic aircraft efficient enough to be economically viable. The need for the HSCT to be environmentally sensitive has also prompted new research into the characteristics of sonic booms, using its SR-71 Blackbird aircraft.

The increasing concern about damage to the environment and the atmosphere is behind the Environmental Research Aircraft and Sensor Technology (ERAST) program at Dryden as well. The ERAST research is trying to develop high-altitude, low-speed, remotely-piloted aircraft that could be used to gather currently unavailable information about the atmosphere. And remotely-piloted research vehicles are likely to play a larger role in future research efforts.[2]

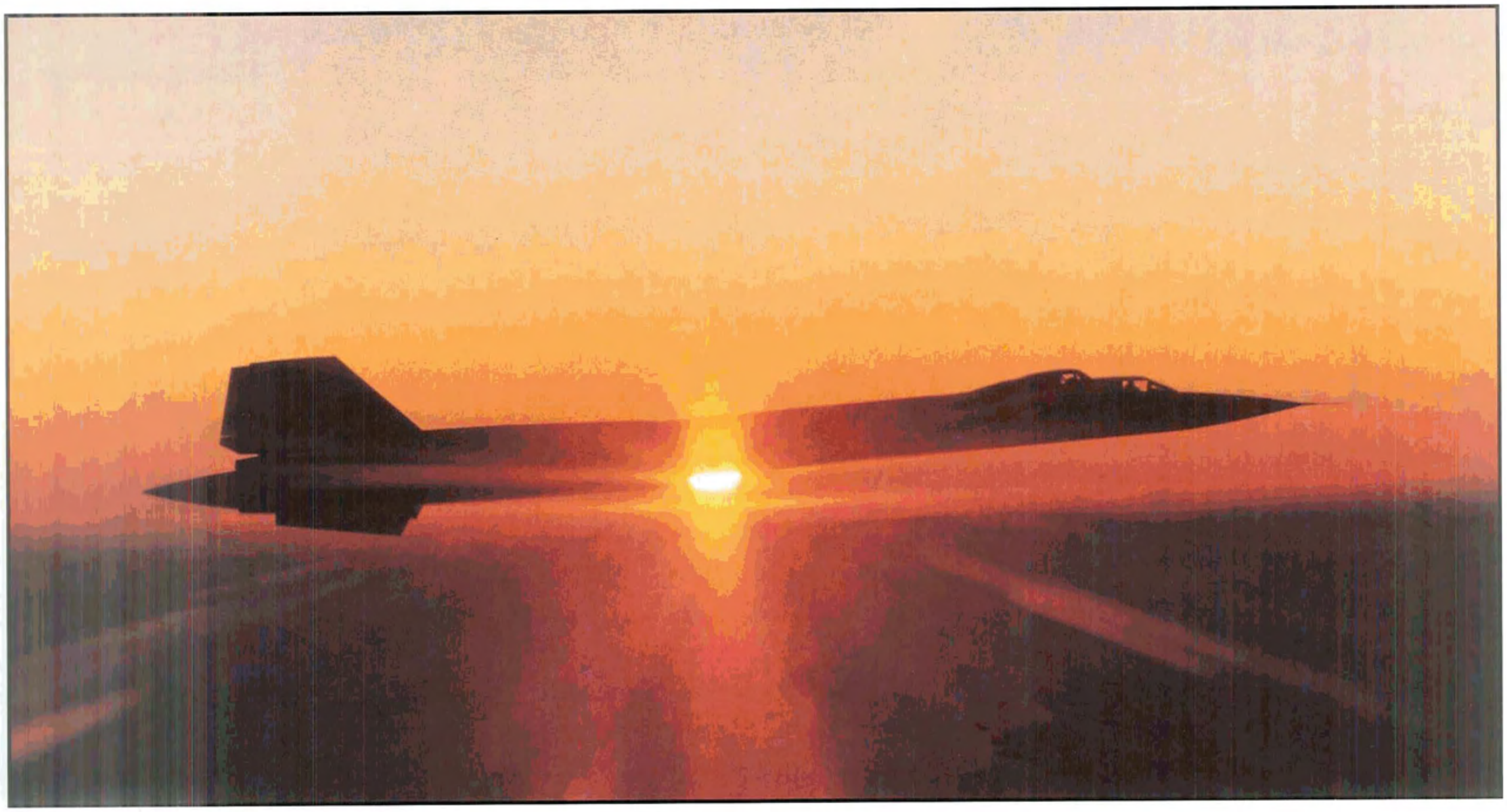
The changing requirements of military aircraft are driving other Dryden research efforts in the area of high-performance aircraft operation. The F-15 ACTIVE research, for example, is working toward a practical application of thrust-vectoring technology, which has the potential of making aircraft much more

F-16XL (foreground) and SR-71 in formation during 1995, when this single-seat F-16XL and the SR-71 were studying the characteristics of sonic booms. This project was part of NASA's High Speed Research program dedicated to developing technologies for a new generation of economically viable and environmentally compatible high-speed civilian transports. (NASA Photo EC95 43024-5)

maneuverable.[3] The Center's plans also include a joint effort with the Air Force's Wright Laboratory to pursue further research on tailless aircraft, which could improve the stealth capabilities and reduce the weight and drag of aircraft designs. In addition, Dryden and the Wright Laboratory are working together on an advanced flexible-wing project. The flexible-wing research plans to use aeroelastic, or twisting, properties of a wing to help control an aircraft, reducing the drag and structural weight of the wing and thereby increasing the aircraft's overall efficiency and performance. This project is especially interesting because the base concept behind the research is similar to the wing warping approach used by Orville and Wilbur Wright to control their pioneering Wright Flyer back in 1903.[4] Some of these projects are still in the planning stages, but the common thread running through all of them is that they focus on technology to meet the expanded maneuverability and stealth requirements of high-performance military aircraft designs.

The fourth current research thrust at Dryden is being driven by the need to find more cost-effective methods of getting payloads into space. Historically, the cost and complexity of launch systems have kept industry from attempting its own launch infrastructure and/or operations. But decreasing federal budgets mean that NASA itself needs to find more economical ways of accessing space. Whether the operations are managed by NASA or industry, they must be made more affordable. In 1993, a NASA study initiated by Congress concluded that advances in technology could make a fully reusable launch vehicle practical in the near future. This kind of vehicle might be cost-effective enough that industry could afford to build and operate it, relieving the burden on NASA. In order for industry to commit the significant resources necessary for this kind of venture, however, the report also concluded that numerous relevant technologies needed to be matured and demonstrated. Thus was born the Reusable Launch Vehicle (RLV) technology program, which includes several different research efforts that Dryden is supporting.[5]

The primary thrust of the RLV program is the X-33—a technology demonstration craft designed to answer the question of whether the technology exists to make a rocket-powered, single-stage-to-orbit (SSTO) vehicle a viable, profitable concept. It is a question that encompasses a multitude of challenges. First, there are the obstacles inherent in the actual physics of a

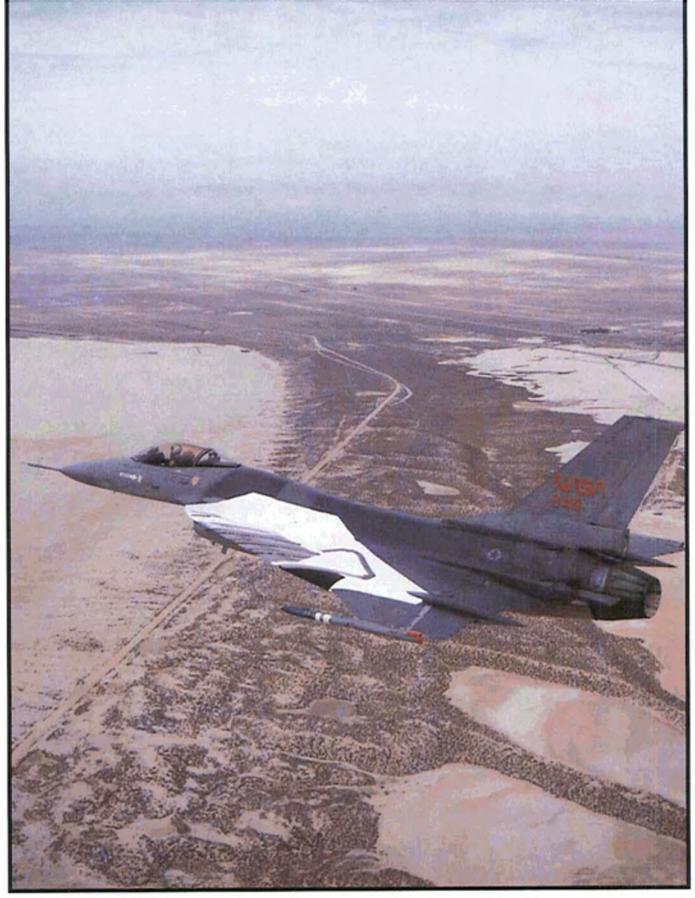


SR-71B Blackbird at sunset during early 1995 (NASA Photo EC95 43351-2)

single-stage-to-orbit vehicle. It has never been done before, and researchers estimate that only one percent of a SSTO vehicle's gross liftoff weight could be devoted to its payload. The rest of its weight would be taken up by the structure and propellant necessary to get it into orbit. But even if those challenges are met, there is still the question of whether the vehicle can be built and operated cost-effectively enough to make it a viable economic proposition.

The X-33 effort began in April 1995 with a 15-month concept definition and design phase. Three industry teams—Lockheed-Martin, McDonnell Douglas/Boeing, and Rockwell/Northrop-Grumman—have developed different concepts for an X-33 vehicle. Lockheed-Martin's design is a vertical-takeoff/horizontal-landing lifting body; McDonnell Douglas/Boeing pursued a vertical-takeoff and vertical-landing vehicle; and Rockwell/Northrop-Grumman designed a vertical-takeoff/horizontal-landing winged craft that, not surprisingly, bears some resemblance to Rockwell's Space Shuttle orbiters. Dryden provided support for each of the design teams, including its scheduled flight tests of the linear aerospike engine for Lockheed's proposed design.[6] NASA planned to recommend one of the designs to Congress in June 1996, leading to the actual construction and test flying of an X-33 vehicle. The X-33 would not be put into actual orbit, but it would be flown to an altitude that would expose the critical technologies to the environment necessary to evaluate their acceptability.[7]

The X-33 is designed primarily to mature and demonstrate the technology necessary for commercial RLVs that would follow. Future research efforts also may explore other reusable launch vehicle options, such as plane-launched systems similar to the Pegasus concept and designed for small payloads. In addi-



Single-seat F-16XL known as "ship number one" during 1992 when the aircraft was equipped with an active experimental wing section designed to promote laminar (smooth) airflow over a larger proportion of the wing than occurred naturally. Tests with this aircraft during 1991-1992 showed that laminar flow was achievable over a significant portion of the wing during supersonic flight. A more extensive "glove" for active laminar flow research continued this effort on a two-seat F-16XL during 1995 and 1996. (NASA Photo EC92 09032-2)

tion, Dryden is supporting a Johnson Space Center program that is investigating one potential payload for an X-33 type of RLV. The research craft is called the X-CRV, or Experimental Crew Return Vehicle, and it is, interestingly enough, a legacy of the lifting-body and Paresev research conducted at Dryden in the 1960s and early 1970s. The X-CRV design is based on the Martin X-24A lifting body, and it is envisioned as a means for getting crew members back to Earth from a space station in case of an emergency. The lifting-body shape would enable the vehicle to fly back from space and control its general touchdown location. But to allow the emergency vehicle to land without a trained pilot on board, the X-CRV is being designed to use a parafoil device, deployed under Mach 1 speeds, for its final descent and touchdown.

In December 1995 Dryden began drop tests of a scale-model X-CRV from a small airplane, and plans called for the Center to eventually flight test a vehicle from Mach 0.8 at 40,000 feet down through landing. Yet some would argue that Dryden's largest contribution to the effort was made more than 30 years ago, when a small group of engineers and technicians built a stubby plywood-and-tubing craft they dubbed the "flying bathtub." If it had not been for that M2-F1 effort, which led to Dryden's extensive lifting-body research, the X-CRV design would probably not be a lifting body shape. The X-CRV design choice was undoubtedly also influenced by yet another 1960s military research project called the X-23, or "Prime" program. In that classified program, a model shaped much like the X-24A lifting body was launched into space and brought back, accumulating actual reentry data that is now proving extremely useful to X-CRV engineers.[8]

Future Directions

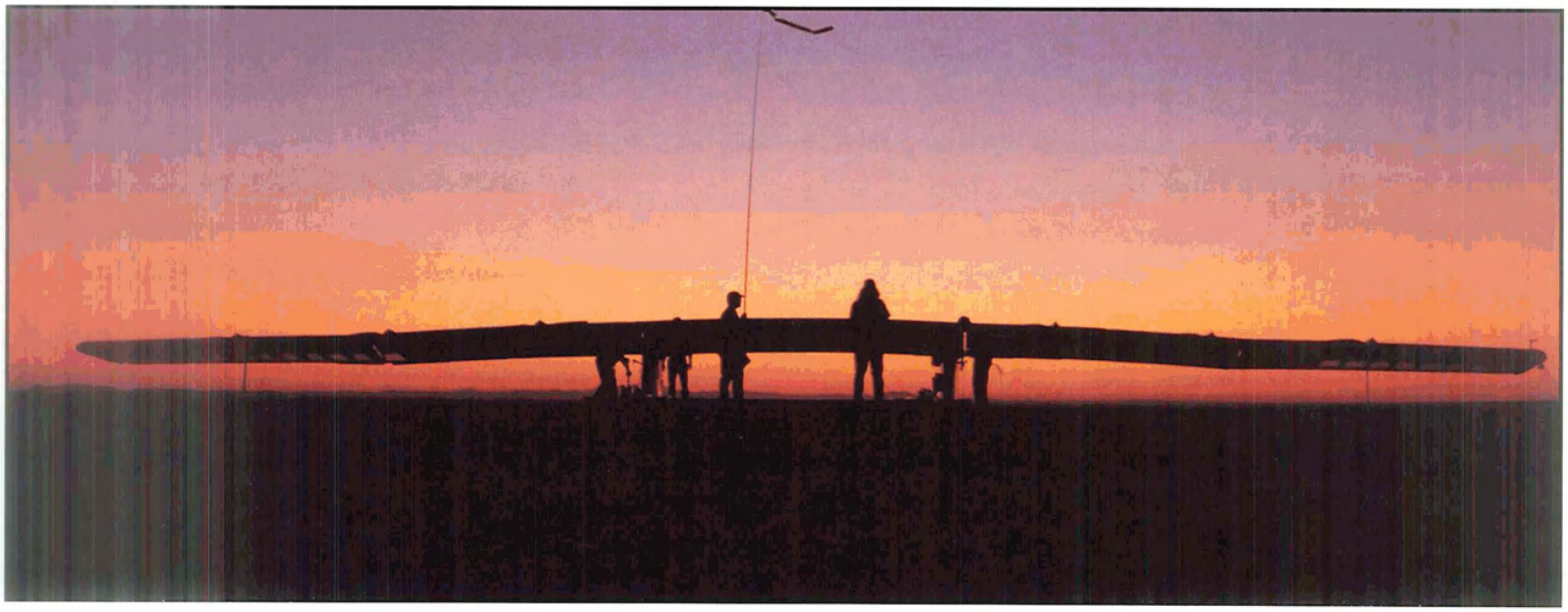
In the same way as the X-1 reflected the "need-for-speed" philosophy that dominated post-World War II defense strategies, the current Dryden research efforts reflect the concerns of the more complex, computerized, cost- and environment-sensitive society in which we now live. Of course, these planned research projects will undoubtedly be supplemented with other support or problem-solving efforts that develop as new problems or high-priority needs arise. They will also continue to change as the needs and concerns of the nation evolve in the years to come.

Exactly how Dryden's research will change remains to be seen. Trying to predict specifics about the future is always a risky proposition, but it is especially so with a place like Dryden, where projects arise quickly in response to unforeseen needs and one technological breakthrough can make a dramatic impact on future research directions. One year before the F-8 Digital-Fly-By-Wire research airplane flew at Dryden, for example, few at the center would have predicted the amount of effort that would be devoted to computerized flight control systems over the next 10 years. By the same token, one external change, such as a dramatic increase in fuel prices, could also significantly affect the priorities attached to different research projects.

Yet if current trends are any predictor, there are certain general characteristics that seem likely to define Dryden's research in at least the near future. An increasingly global economy may strengthen the need for high-speed global transportation, fueling research efforts such as the High Speed Civil Transport. Many of the changes in aircraft design will be internal system improvements, but advanced technology may also generate more interest in configurations that were previously impossible to design or support. The need for more cost-effective access to space will undoubtedly continue. Indeed, decreasing budgets will create an ongoing challenge to do the same work with fewer people and with less money.

Budget constraints have already resulted in an increased emphasis on joint partnerships, as illustrated by the recent Air Force Flight Test Center Alliance agreement with Dryden. Partnership efforts have always played a big part in the Center's work, but those agreements will undoubtedly become even more important if federal budgets continue to decrease and NASA has to rely more on industry funds and participation to make research projects possible. The current trend of downsizing military budgets will also tend to focus more research on civil applications of technology, including subsonic transport aircraft operations. Interest in learning more about our atmosphere and the impact our actions have on it means that efforts in high-altitude, low-speed sampling aircraft and technology are likely to continue. Finally, researchers will undoubtedly continue to find themselves revisiting old concepts and configurations, drawing on

Pathfinder silhouette at sunrise in 1995. This unpiloted, remotely-controlled aircraft that uses the Sun's energy to power its engines, reached the record altitude for a solar-powered aircraft of 50,567 feet during a 12-hour flight on 11 September 1995. The all-wing aircraft, weighing less than 600 pounds, is being evaluated by a NASA-industry alliance in a program to develop technologies for operating unpiloted aircraft at altitudes up to 100,000 feet on environmental sampling missions lasting up to a week or more. The effort is labeled the Environmental Research Aircraft and Sensor Technology (ERAST) program and is part of NASA's mission to study and protect the environment. (NASA Photo EC95 43207-6)



Team from Aerovironment, Inc. getting Pathfinder ready for flight from the lakebed in September 1995 (NASA Photo ES95 43373-17)

the legacy of past research efforts. One of the oldest lessons of research is that sometimes ideas have to wait for technology to catch up with them. Concepts once discarded as unsupportable or unnecessary may become both possible and practical as technology and mission needs change.[9]

The Role of Flight Research

Yet regardless of how the specific research directions at Dryden change in the years to come, one thing that will not change is the importance of flight research itself. In some cases, such as atmospheric research, flight is the only way to obtain any data. But the value of flight research goes far beyond those few instances. What Wilbur Wright said in 1901 still holds true. To really learn about flight requires mounting a machine and experiencing its behavior in actual trial.[10] The reasons for this are many, and they have been proven over and over by the people who have worked at Dryden over the years.

It is often said at Dryden that there are no secrets in flight research. On one level, that means that members of a flight research project learn to speak frankly, because overlooked items or mistakes can cost someone's life. But it also helps explain the value of testing an idea in flight. The consequences and results of flight research are real, tangible, and inescapable. It is a place where new technology faces a moment of truth, where theory and reality meet face to face. It is also by necessity a multidisciplinary effort that allows all the elements of a technology or system to come together in a real world environment. Individually, or in a simulated situation, elements of the technology may appear to work. But as research efforts at Dryden have repeatedly demonstrated over the years, laboratory predictions and real-life performance are not always the same. This is especially true when one of the elements in the loop is a human being. Pilots do not react the same in a simulator as they do in an actual flight situation, where

Group photo at edge of lakebed showing (viewer's left to right) a full-scale X-15 mock-up, two-seat F/A-18, SR-71, X-31, and X-29 (NASA Photo EC93 41012-3)

the consequences and stresses are significantly higher.

In addition, computers and simulators can only model what is known. Yet to advance technology we have to stretch into the unknown, and the only way to truly explore beyond a frontier is to actually go there. This was true in the days of Magellan, and it is still true today. In order to know what lies beyond our current aeronautical knowledge; in order to tell if our predictions of what lies beyond are accurate, we need to test our theories, at some point, in the real world. Indeed, there have been few, if any, research projects in Dryden's 50-year history where prediction and actual performance have matched in every aspect. Every effort has had at least one moment of discovery, where researchers found themselves surprised by their results.

Furthermore, as Hugh L. Dryden himself once said, flight research separates the real from the imagined. Applying concepts to actual flight hardware, as opposed to laboratory computers or simulators, quickly brings to the surface the critical issues and obstacles that have to be tackled in order for a technology to succeed in a real-life environment. Making the decision to remove the mechanical backup controls on the F-8 Digital-Fly-By-Wire, for example, made it instantly clear to researchers that software integrity and configuration control, more than any other issue they might have pursued in simulators, was the crucial issue for that technology. And because flight research forces the resolution of critical technological issues, it unavoidably matures technology beyond the level achieved by simulation or laboratory work. This has important implications for technology transfer, because often there is too large a gap between basic laboratory research and a practical application of a technology for industry to bridge. The risks or costs of maturing the concept without the intermediary step of flight research are often simply too high.

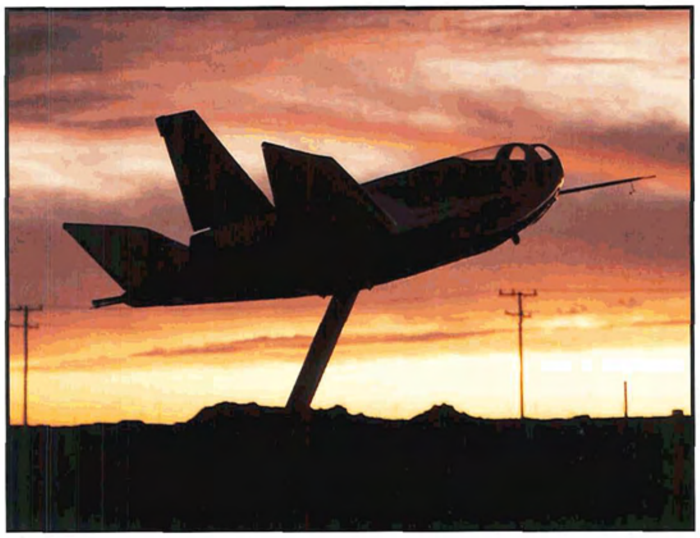
By the same token, proving a technology in actual flight conditions helps give it a level of credibility that is equally important in getting industry to commit to its commercial development. Whether the concept is a fly-by-wire control system or a new wing design, the barriers to transferring the technology are as much psychological and financial as they are technical. Flight research is an extraordinarily effective method of overcoming those barriers, and sometimes a single flight can change what people believe is possible. Furthermore, the government/industry partnerships required by a research discipline that involves actual hardware generate relationships and experience that can significantly affect a company's decision to apply a given technology. Flight research is one of the only types of research where a degree of technology transfer can occur simultaneously with the research itself.

These technology-transfer considerations will only become more important as global competition increases. For many years, the United States held an undisputed position as the technological and economic leader of the world. Today, advances in the technology bases and products of other countries are beginning to change that picture. In 1986, the United States' high-technology imports exceeded exports for the first time. Aerospace is one of the only fields in which a positive balance remains, but even there, the edge held by American manufacturers is slipping.[11] What this picture looks like in 20 years will be determined in large part by how well American aerospace products can measure up against the technology offered by international competitors. And that, in turn, will be influenced both by near-term applications of technology and longer-term contributions to the nation's technology base to support future-generation aircraft designs.

A Unique Flight Research Resource

Despite the advances in computers and aeronautical research facilities since 1901, flight research is, and will remain, a crucial

Side-view of the Linear Aerospike SR-71 Experiment (LASRE) pod on NASA SR-71, tail number 844. This hoto was taken during the fit-check of the pod on 15 February 1996, at Lockheed Martin's Skunkworks in Palmdale, California. The LASRE will be flight tested ring 1996 at Dryden. LASRE is designed to flight test the inear aerospike rocket engine ounted on a 10-percent-scale, half-span model of Lockheed rtin's X-33 Reusable Launch ehicle concept. Among other rtners involved in the project are Rockwell's Rocketdyne Division, builder of the rospike engine, the Marshall Space Flight Center, Dryden, the Air Force's Phillips Lab, and Lockheed Martin Astronautics. (NASA Photo EC96 43419-25) element in the process of furthering aeronautical knowledge and technology. And when it comes to flight research, the Dryden Flight Research Center has few equals. Ever since its beginnings in 1946, Dryden has been a specialty shop. Walt Williams brought the first group of engineers from Langley to Muroc to assist not in the design or theoretical analysis of the X-1, but in its flight research activities. Since that time, the employees at Dryden have continued to provide that service for NASA, other government agencies, and industry. The ideas come from many places, and most of Dryden's research projects are partnership efforts of one kind or another. Yet for half a century, Dryden has been able to provide the physical environment, facilities, and staff expertise to take those ideas and research efforts to flight.



HL-10 mounted on a pedestal in front of the Dryden main gate at sunset in 1992. This current landmark at the research center first flew in late 1966 and became the first lifting body to fly supersonically. It set other records, but more importantly, it contributed substantially to the decision to design the Space Shuttles without the air-breathing engines that would otherwise have been used for landings. (NASA Photo EC92 2131-01)

Part of the reason Dryden has flourished as a flight research center is its unique physical location. Its clear skies, unpopulated surroundings, and dry lakebed landing sites have made it ideally suited for a wide variety of flight activities, from research with the X-1 to landings of the Space Shuttle. It also has benefited immeasurably from its ongoing partnership with the Air Force Flight Test Center at Edwards. Aside from the specific joint-research projects the two Centers have done together, the physical facilities and support provided by the Air Force have always been critical to Dryden's operations.

But there are other factors that have played an equally important role in the Center's success. Dryden has always been a small, remote facility, requiring its staff to develop a frontier resourcefulness, flexibility and versatility that helped the Center adapt to NACA and NASA's changing needs and priorities over the years. Its small size also allowed an informal management style that encouraged innovation and helped empower individual employees to solve problems as they arose. These traits led to research efforts such as the M2-F1 lifting body and have played a role in the success of virtually every research project the Center has undertaken.

Dryden's focus on the single mission of flight research also allowed all its staff members to gain a great deal of experience in that area, and the daily requirements of a Center revolving around flight operations meant that its employees soon developed a talent for quick, pragmatic problem-solving. Of course, it helped that most of the people drawn to Dryden inherently enjoyed that kind of work. One advantage of Dryden's remote and harsh location has been that the people who have come to work at the Center have come not for the surroundings or pay, but because they love flight and want to work with living, breathing airplanes. As a result, Dryden employees tend to have what one staff member described as a "technical passion"[12] that has played a significant role in the success of their research efforts.

Space Shuttle Columbia atop NASA's 747 Shuttle Carrier Aircraft over Dryden as sister Shuttle Endeavour sits on the runway following its landing 11 October 1994, at the end of mission STS-68. Columbia was being ferried from the Kennedy Space Center, Florida, to Air Force Plant 42, Palmdale, California, for six months of inspections, modifications, and systems upgrade. (NASA Photo EC94 42789-5)

The fact that many employees chose to spend their careers at the Center also has enabled them to carry forward the experience gained from one project to the next.

Dryden Contributions

This combination of factors at Dryden has allowed it to make a wide variety of contributions over the years. Sometimes, the Center played a role in developing tangible items that were applied directly to operational air- or spacecraft. Certainly the Center's trouble-shooting efforts with the F-100A, the F-104, the F-111, and its later work with F-14 and F-15 spin-testing fall into this category. But there are other examples, as well. Reaction controls and navigation equipment used on the X-15 were applied to the Mercury, Gemini, and Apollo spacecraft, as well as the Space Shuttle. The Lunar Landing Research Vehicle trained astronauts to land on the Moon. The digital electronic engine-control technology has been applied to numerous commercial engines, and the F-15 ACTIVE program is helping to develop a production version of a thrust-vectoring engine nozzle. A thrust-vectoring engine system, in turn, will draw heavily on the integrated

X-29s on lakebed near sunrise with the Moon still visible. (Pitot tube of second aircraft at viewer's left.) Both of these forward-swept-wing aircraft were flown at Dryden from 1984 to 1992 as technology demonstrators to investigate a host of advanced concepts and technologies. These included advanced composite materials, the forward-swept wing, and a computerized fly-by-wire flight control system that overcame the aircraft's inherent instability. The 434 total missions flown by the two X-29s provided an engineering data base that is available in the design and development of future aircraft. (NASA Photo EC90 357-7)

engine- and flight-control research done with Dryden's F-15 HIDEC aircraft. The supercritical wing and winglet concepts flown at Dryden have helped make a whole generation of business and transport aircraft more fuel-efficient. Improvements for the YF-12 inlet system were retrofitted into the entire SR-71 fleet.

Dryden's pilot-induced-oscillation research and suppression filter identified and solved a potentially dangerous problem with the Space Shuttle. Its Controlled Impact Demonstration illustrated conclusively that anti-misting fuel did not help prevent post-crash fires, and its wake-vortex research helped maintain safety in the national airspace system. And while it has not yet been applied, the propulsion-controlled aircraft system developed by Dryden researchers may well be integrated into future airliners, helping to prevent tragedies resulting from massive hydraulic damage or failures.

Not all of Dryden's contributions were tangible pieces of technology, however. Many research projects simply expanded the available knowledge base in aeronautics and, to a lesser degree, space. Much of the research with the YF-12/XB-70, the F-18 High Alpha Research Vehicle, the X-29, the HiMAT, and even the X-15 and the early X-series research aircraft fall into this category. Many engineers have drawn upon this knowledge and data in designing new aircraft, but the trail between the research and its applications is not as easy to trace. Indeed, one of the difficulties in evaluating flight research in an exact way is that contributions to knowledge are often so difficult to isolate or quantify.

In yet other cases, the "technology" transferred from Dryden to industry was not so much a particular item but a process. The software qualification and configuration control process the Center used for its Digital-Fly-By-Wire program, for example, aided numerous manufacturers in designing their own fly-by-wire aircraft. More recently, the Cedars-Sinai Hospital was able to benefit from Dryden's quick and pragmatic design and fabrication procedures. Because unique parts often have to be designed and built quickly in order to keep a flight program on schedule, Dryden staff members have developed a knack for building a piece and then creating the drawings after the fact. Physicians at Cedars-Sinai described a need they had to help them perform laparoscopy surgery. But the physicians could only describe what they needed the part to do, not what it should look like. Dryden researchers and technicians were able to listen to the physicians' needs and design a part to do the job, without a lot of time or extensive drawings.[13]

Even harder to trace are those instances where the real value of Dryden's flight research was simply to generate enough confidence in a technology or idea for someone to apply it. The Space Shuttle was not a lifting body. But the lifting-body research at Dryden gave Shuttle managers the confidence to design the vehicle for unpowered landings. The system hardware and software on today's fly-by-wire aircraft are not the same as those flown on Dryden's F-8. But the mere fact that Dryden had flown an aircraft totally dependent on fly-by-wire flight controls gave companies and users the confidence to incorporate the technology into production aircraft. Like the early explorers and pioneers, Dryden's contribution was sometimes simply a matter of going into uncharted waters first and proving that they were navigable.

NASA's F-15 Highly Integrated Digital Electronic Control (HIDEC) aircraft cruises over California's Mojave Desert on a flight out of Dryden. The aircraft was used to carry out research on engine and flight control systems. Among other things, in April 1993 it demonstrated the use of computer-assisted engine controls as a means of landing an aircraft safely with only engine power if its normal control surfaces such as elevators, rudders and ailerons are disabled. This Propulsion Controlled Aircraft technology was later demonstrated on the McDonnell Douglas MD-11 transport aircraft. (NASA Photo EC90 312-30)

Conclusion

Since its inception, the facility known today as the Dryden Flight Research Center has been a unique place. It is situated in a bleak, desolate area that has blistering summers and bone-chilling winters. Yet to the aeronautics and space community, Dryden is a place of many gifts. Its clear skies, open landscape and lakebed landing sites have allowed numerous flight activities to take place there that could not have been accomplished elsewhere. Its small size, single-mission focus, and informal, flexible, innovative and pragmatic approach have created a staff with both technical passion and technical agility—traits that have allowed the Center to adapt to changing times and support a wide variety of programs and priorities.

Some of Dryden's projects have been longer-range exploratory research, while other efforts have been to support the nearer-term needs of industry or the nation's air and space programs. Sometimes the Center's contribution was a specific technology, sometimes it was a process or new insight or piece of knowledge, and sometimes it was simply a matter of going into new territory first and leaving a trail for others to follow. But its various types of research and contributions have made Dryden an extremely valuable resource for the nation's aerospace efforts and industry for half a century. And as the world becomes more complex, with an increasingly global economy and a growing concern about the ability of the United States to retain its competitive and economic edge, the role Dryden plays will become even more important.

Flight research is a unique discipline. It is an area where researchers are forced to address issues critical for flight and must develop a very pragmatic, flexible approach. It can give technology the maturity and credibility necessary for industry to commit to its use. In addition, the partnerships flight research requires and the very process of flight itself can greatly assist technology-transfer efforts, proving that a new idea or technology is, at the very least, possible. The technology may still prove impractical, but once it has been proven in flight, few can argue that it can't be done. In addition, flight generates a moment of truth for technology and ideas because it is that unique spot where the rubber meets the road, where all of the elements of a technology come together in a real-life environment for the first time. And unlike laboratory work, it is an area where the cost of a deficiency or mistake can be someone's life.

Drop test of a model of the Experimental Crew Return Vehicle (X-CRV) in 1995. The X-CRV is envisioned as a means for getting crew members back to Earth from a space station in case of emergency. Its design is based on the Martin X-24A lifting body flown at Dryden from 1969 to 1971, but to permit the emergency vehicle to land without a trained pilot, the X-CRV is being designed to use a parafoil device for final descent and touchdown. (NASA Photo EC95 43218-8)

By the same token, flight is an area of research where results are particularly difficult to predict. Simulators and computers have advanced greatly, but they can only model what is known; they cannot yet accurately predict the exact behavior of a new system in actual flight conditions, especially when it involves a human pilot. In addition, while computers have im-

Artist's concepts of the X-33 Reusable Launch vehicles. On the left is the proposed design for the single-stage-to-orbit vehicle by a team headed by Rockwell. This is a Space Shuttle-like vehicle that would take off vertically and land horizontally. In the center is the vehicle being designed by a team including McDonnell Douglas; it would take off and land vertically. The third design, by a Lockheed Martin team is a lifting-body that would be launched vertically and landed horizontally. This is the design that features Rockwell's linear aerospike engine to be tested in supersonic flight by NASA's SR-71 aircraft. (NASA Photo EC95 43320-1)

proved the capabilities of ground facilities, they have also made aircraft more complex. When all the variables of such complex technologies are brought together in a constantly changing flight environment, it is almost impossible to predict or cover every possible contingency.

So despite the advances in technology, flight research is still an exploration into the realm of the unknown. We have learned to function above the Earth and at high speeds, but we still do not fully understand all the dynamics and forces at work there. Yet it is in this margin, on the ragged boundary between what is known and the mysteries that lie beyond, that discovery happens. Discovery is more often than not a quiet process, a puzzled moment when something does not react as expected. But it is in these moments that our understanding of our world expands.

For the past 50 years, the Dryden Flight Research Center has been a place where those moments have been welcomed. The people who work there are trained and encouraged to look for the unexpected and have the passion to pursue the reasons for anomalies that occur. In a way, the people who work at Dryden are no different from Columbus, Lewis and Clark, the Wright brothers, or anyone else who has ever stood at the forward edge of knowledge and ventured into the unknown territory ahead. Their tools are research aircraft and engineering formulas instead of sailing ships or frontier knives. But in a sense, the effort is the same. And as with any exploration, it is not without its risks. The pilots and crew are the only members of the research team who actually put their lives on the line, but every employee of Dryden feels the burden of protecting those lives. The challenge of reaching far enough to learn something new without reaching so far that the risks become too high is one Dryden's researchers face every day. Yet it is their success in continually striking a balance between those two that has allowed Dryden to make the contributions it has.

Over half a century, Dryden has grown from a desert outpost into the nation's premier flight research center. Its priorities and projects have changed; its challenges have evolved. But it has continued to make contributions because at its core, it has always remained a unique place where people could expand the boundaries of what was known or possible. It has been a place where people searched for the unexpected and overlooked and worked to separate the real from the imagined. And discovery by discovery, it has helped shape the world in which we live and expanded our understanding of that place they call the sky.

Chapter Notes

CHAPTER 1

[1] H. H. Arnold, *Global Mission* (New York: Harper & Brothers, 1949), 136.

[2] *On the Edge*, video documentary on Edwards AFB and the Air Force Flight Test Center, prepared by James O. Young, AFFTC Historian, 1991.

[3] Richard P. Hallion, *On the Frontier: Flight Research at Dryden, 1946-1981* (Washington, D.C.: NASA SP-4303, 1984), xvi.

[4] Hallion, *On the Frontier*, 9.

[5] Hans Mark and Arnold Levine, *The Management of Research Institutions: A Look at Government Laboratories* (Washington, D.C.: NASA SP-481, 1984), 265.

[6] James R. Hansen, *Engineer in Charge: A History of the Langley Aeronautical Laboratory, 1917-1958* (Washington, D.C.: NASA SP-4305, 1987), 328.

[7] From untitled publication in Richard Hallion's files, Dryden Flight Research Center Office of External Affairs.

[8] Richard P. Hallion, "American Flight Research and Flight Testing: An Overview from the Wright Brothers to the Space Shuttle," paper from Dryden Flight Research Center Technical Library files, 18 September 1976, 18-19.

[9] Kenneth J. Szalai, interview with author, Dryden Flight Research Center, Edwards, California, 4 August 1995.

[10] Marta Bohn-Meyer, interview with author, Edwards, California, 22 August 1995.

[11] H.W. Withington to John P. Reeder, letter, 6 June 1979, from the files of the Advanced Transport Operating Systems office at the NASA Langley Research Center, Hampton, Virginia.

[12] The Dryden Flight Research Center actually had several names over the years, including the Muroc Flight Test Unit, the High Speed Flight Research Station, and the Flight Research Center. To avoid confusion, however, I simply refer to it as "Dryden" throughout this book, except in Chapter 2 where I specifically discuss the Center's chronological history and name changes.

[13] "Dryden Contributions," collection of charts and viewgraphs, from Dryden Flight Research Center administration files, Kenneth J. Szalai, interview, 4 August 1995; William H. Dana, interview with author, Edwards, California, 14 July 1995; Duane McRuer, interview with author, Hawthorne, California, 31 August 1995; William Burcham, interview with author, Edwards, California, 24 August 1995.

[14] Kenneth J. Szalai and Cal Jarvis, interview with author, Edwards, California, 30 August 1995.

[15] Kenneth J. Szalai, interview, 4 August 1995.

[16] Hallion, *On the Frontier*, 15.

[17] *Public Papers of the Presidents of the United States, John F. Kennedy, 1961* (Washington, D.C.: Government Printing Office, 1962), 396-406.

[18] "Introductory Remarks," *Research-Airplane-Committee Report on Conference on the Progress of the X-15 Project*, NACA Compilation of Papers (Langley Aeronautical Laboratory, Va., Oct. 25-26, 1956), xix; thanks to Ed Saltzman for locating this source.

[19] Kenneth J. Szalai, interview, 4 August 1995.

[20] The pilots and crewmembers whose lives have been lost include: Howard Lilly, killed in a Douglas Skystreak in 1948; two Bell Aircraft Company employees (one pilot, one crewmember) killed in an X-2 explosion in 1953; Capt. Milburn "Mel" Apt, killed in an X-2 research plane in 1956; Air Force pilot Ray Popson, killed in an X-5 stall-spin accident in 1955; Air Force Maj. Carl Cross and NASA pilot Joe Walker, killed in a mid-air collision between an XB-70A and an F-104N in 1966; Air Force Maj. Michael Adams, killed in 1967 when his X-15 went out of control and broke apart in mid-air; and NASA pilot Richard Gray, killed in a T-37 spin accident in 1982.

CHAPTER 2

[1] The phrase, of course, comes from Tom Wolfe, *The Right Stuff* (New York: Ferrar, Straus, Giroux, 1979).

[2] These figures do not include support contractors at the facilities, which at Dryden currently number approximately 450. Information from Kenneth J. Szalai, interview with author, Edwards, California, 4 August 1995; William H. Dana, interview with author, Edwards, California, 14 July 1995; Hallion, *On the Frontier*, Appendix B, 273; and especially *NASA Pocket Statistics* (Washington, D.C.: NASA, [1995]), C-26 to C-27. These statistics are for civil servants on personnel rolls at the ends of fiscal years 1965 (Dryden) and 1966 (Langley, Lewis, and Marshall). The numbers for all of the centers were much smaller in the mid-1990s.

[3] Later redesignated the Langley Aeronautical Laboratory and then the Langley Research Center.

[4] R. Dale Reed, interview with author, Edwards, California, 19 July 1995; Ed Saltzman, interview with author, Edwards, California, 20 July 1995; Jack Russell, interview with author, Lancaster, California, 20 July 1995; Hallion, *On the Frontier*, xvi, xvii, 24.

[5] From Edmond C. Buckley to Hartley A. Soulé, letter, 22 January 1948, as quoted in Hallion, *On the Frontier*, 24.

[6] Information on the early years of Dryden from Hallion, *On the Frontier*, xvii-xix, 23-27; Mary Little Kuhl, interview with author, Lancaster, California, 3 August 1995; Jack Russell, interview, 20 July 1995; Dale Reed, interview, 19 July 1995; Ed Saltzman, interview, 20 July 1995.

[7] Summary report of the House of Representatives Committee on Science and Astronautics recommenda-

tions affecting NASA for FYs 1964, 1965, and 1966, 25 May 1966, from Richard Hallion files in the Dryden Flight Research Center External Affairs Office, Edwards, California.

[8] Hallion, *On the Frontier*, 134-135; Kenneth J. Szalai, interview, 4 August 1995.

[9] On 17 November 1995, Kenneth J. Szalai redesignated the ITF as the Walter C. Williams Research Aircraft Integration Facility during a memorial service for Walt Williams, who had died on 7 October 1995.

[10] Kenneth J. Szalai, interview, 4 August 1995; "Dryden Historical Milestones," fact sheet, Dryden Flight Research Center External Affairs Office files.

[11] Kenneth J. Szalai, interview with author, Edwards, California, 14 July 1995.

[12] R. Dale Reed, interview, 19 July 1995; Kenneth J. Szalai, interview, 4 August 1995.

[13] Information on Dryden's management approach from Kenneth J. Szalai, interviews, 14 July 1995, 4 August 1995, and 30 August 1995; William H. Dana, interview, 14 July 1995; Rogers Smith, interview with author, Edwards, California, 19 July 1995; Dana Purifoy, interview with author, Edwards, California, 7 September 1995.

[14] Information on research pilots is from William H. Dana, interview, 14 July 1995; Rogers Smith, interview with author, 19 July 1995; Fitzhugh "Fitz" Fulton, interview with author, 19 July 1995; Ed Schneider, interview with author, Edwards, California, 24 August 1995; Gordon Fullerton, interview with author, 7 September 1995; Dana Purifoy, interview with author, 7 September 1995, all at Edwards, California.

[15] Gary Trippensee, interview with author, Edwards, California, 24 August 1995.

[16] Rogers Smith, interview, 19 July 1995; Ed Schneider, interview, 24 August 1995.

[17] William H. Dana, interview, 14 July 1995.

[18] Ed Schneider, interview, 24 August 1995.

[19] Kenneth J. Szalai, interview, 4 August 1995.

[20] Kenneth J. Szalai and Calvin R. Jarvis, interview, 30 August 1995; Rogers Smith, interview, 19 July 1995.

[21] Hallion, *On the Frontier*, 13-20; Jack Russell, interview, 20 July 1995.

[22] Rogers Smith, interview, 19 July 1995; Dana Purifoy, interview, 7 September 1995; Marta Bohn-Meyer, interview with author, Edwards, California, 22 August 1995; Gary Trippensee, interview, 24 August 1995; Kenneth J. Szalai, interview, 4 August 1995.

[23] Kenneth J. Szalai, interview with author, 4 August 1995; Dana Purifoy, interview with author, 7 September 1995.

CHAPTER 3

[1] Kenneth S. Kleinknecht, "The Rocket Research Airplanes," in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit: Wayne State University Press, 1964), 196; Hallion, *On the Frontier*, 6; Hansen, *Engineer in Charge*, 271-301; Ben Guenther and Jay Miller, *Bell X-1 Variants* (Arlington, TX: Aerofax, Inc., 1988), 1-5.

[2] Richard P. Hallion, "American Rocket Aircraft: Precursors to Manned Flight Beyond the Atmosphere," paper presented at the International Astronautical Federation XXVth Congress in Amsterdam, Holland, 30 September - 5 October 1974, 3.

[3] Walter Williams, interview with Richard P. Hallion, 13 June 1977; Ben Guenther and Jay Miller, *Bell X-1 Variants*, 6-7.

[4] Jack Russell, interview with author, Lancaster, California, 20 July 1995; Hallion, *On the Frontier*, 13-14.

[5] Edwin J. Saltzman and Theodore G. Ayers, *Selected Examples of NACA/NASA Supersonic Flight Research* (Edwards, CA: NASA SP-513, 1995), 9.

[6] Hallion, *On the Frontier*, 11-12, 14-18; Guenther and Miller, *Bell X-1 Variants*, 7-8; Jack Russell, interview, 20 July 1995; Edwin J. Saltzman, interview with author, Edwards, California, 20 July 1995.

[7] Strictly speaking, vortex generators are miniature airfoils rather than "tabs." Their purpose is to produce vortices (whirlpools) in the air flowing in the direction of the wing's chord from leading to trailing edge. This increases the intermixing of layers of air, postponing what is called boundary layer separation and improving lift. See H.D. Taylor, "Summary Report on Vortex Generators," United Aircraft Research Department Report R-05280-9, March 7, 1950; Sighard F. Hoerner with Henry V. Borst, "Fluid-Dynamic Lift: Practical Information on Aerodynamic and Hydrodynamic Lift" (1975), 6-18 to 6-19, both kindly supplied by Ed Saltzman.

[8] Hallion, *On the Frontier*, 19-21, 34-35; written comments of Edwin J. Saltzman, 6 December 1995.

[9] Hallion, *On the Frontier*, 27-29.

[10] Hallion, "American Rocket Aircraft," 6-8.

[11] Kenneth S. Kleinknecht, "The Rocket Research Airplanes," 199-202; Hallion, "American Rocket Aircraft," 7-8; Hallion, *On the Frontier*, 12-13, 47-48.

[12] Melvin Sadoff and A. Scott Crossfield, "A Flight Evaluation of the Stability and Control of the X-4 Swept-Wing Semitailless Airplane," NACA RM-H54G16 (Washington, D.C., 30 August 1954), 14; Ed Saltzman, comments, 6 December 1995.

[13] General James Doolittle from document written in 1958, as quoted in text from untitled, undated transcript of NASA presentation on the X-1 program, from Richard P. Hallion files in NASA External Affairs Office. Parts of this and succeeding paragraphs also based on Saltzman comments, which have been extraordinarily helpful on technical details throughout this chapter.

[14] A "G" force is a way of measuring the effect of gravity on an object. One "G" is the normal gravitational pull of the Earth. A "2 G" force would be equivalent to two times the Earth's normal gravitational pull. Or to put it another way, in an 8 G maneuver, a pilot's arm would feel eight times as heavy as its normal weight.

[15] Saltzman and Ayers, *Selected Examples of NACA/*

NASA Supersonic Flight Research, 10-11. The "Century Series" fighters were all built and first flown in the early-to mid-1950s. They are so called because their designations were F-100, F-101, F-103 and so forth.

[16] William H. Phillips, a researcher at the Langley Laboratory, had predicted the inertial-coupling problem in a technical paper published several years before. But the X-3 provided the first comprehensive data on the problem.

[17] Hallion, *On the Frontier*, 47-62; "Edwards Pioneers High-Speed Research," *Aviation Week & Space Technology*, 3 June 1957, 16-18; D. E. Beeler, interview with Richard P. Hallion, undated.

[18] Information on the derivative X-1 aircraft and the X-2 is from Charles V. Eppley, "The Rocket Research Aircraft Program," Air Force Flight Test Center Technical Documentary Report No. 63-3, February 1963, 6-17; Hallion, "American Rocket Aircraft," 5-6, 9-17; Kleinknecht, "The Rocket Research Airplanes," 199-204; Hallion, *On the Frontier*, 63-85; Edwin J. Saltzman, interview, 20 July 1995.

[19] Eppley, "Rocket Research Aircraft," 18-19, 22; Kleinknecht, "Rocket Research Airplanes," 205-206; Wendell H. Stillwell, *X-15 Research Results* (Washington, D.C.: NASA SP-60, 1965), 6, 11-14.

[20] Stillwell, *X-15 Research Results*, 21; Kleinknecht, "Rocket Research Airplanes," 206-207.

[21] Hallion, "American Rocket Aircraft," 30; William H. Dana, interview with author, Edwards, California, 14 July 1995.

[22] William H. Dana, interview, 14 July 1995; Hallion, *On the Frontier*, 110-111; Eppley, "The Rocket Research Aircraft Program," 19; Edwin J. Saltzman, interview, 20 July 1995.

[23] Jack Russell, interview, 20 July 1995.

[24] Jack Kolf, interview with author, Palmdale, California, 22 August 1995; William H. Dana, interview, 14 July 1995; Edwin J. Saltzman, interview, 20 July 1995.

[25] McKay recovered from his injuries sufficiently to fly the X-15 again, but his injuries were serious enough to force his retirement from NASA almost 10 years after the accident, in 1971.

[26] Jack Russell, interview, 20 July 1995; William H. Dana, interview, 14 July 1995; Ben Guenther, Jay Miller, and Terry Panopalis, *North American X-15/X-15A-2* (Arlington, TX: Aerofax, Inc., 1985), 13-14; Hallion, *On the Frontier*, 122-125.

[27] Overall, according to Richard Hallion, the X-15 had a 92% mission success rate. Hallion, "American Rocket Aircraft," 28, 35.

[28] Milton O. Thompson, *At the Edge of Space* (Washington, D.C.: Smithsonian Institution Press, 1992), 266-267.

[29] Hallion, *On the Frontier*, Appendix M, 329-337.

[30] Guenther et al., *North American X-15/X-15A-2*, 16; Hallion, "American Rocket Aircraft," 30.

[31] Hallion, *On the Frontier*, 115.

[32] William H. Dana, interview, 14 July 1995; Hallion, "American Rocket Aircraft," 35-36; Thompson, *At the Edge of Space*, 270.

[33] Thompson, *At the Edge of Space*, 270-271; Hallion, "American Rocket Aircraft," 37; Hallion, *On the Frontier*, 103.

[34] Hallion, *On the Frontier*, 102.

[35] M2-F1 information from R. Dale Reed, "Wingless Flight," as yet unpublished manuscript, 2-12 - 3-31; R. Dale Reed, interview with author, Edwards, California, 19 July 1995; William H. Dana, interview, 14 July 1995.

[36] Hallion, *On the Frontier*, 155.

[37] "Heavyweight" lifting body information from Reed, "Wingless Flight," 4-2 - 6-17; Reed, interview, 19 July 1995; William H. Dana, interview, 14 July 1995; Milton O. Thompson, interview with author, Edwards, California, 26 February 1992; Hallion, On *the Frontier*, 158-160.

[38] Milton O. Thompson, interview, 26 February 1992; Hallion, *On the Frontier*, 165-167.

[39] Milton O. Thompson, interview, 26 February 1992; William H. Dana, interview, 14 July 1995; Hallion, *On the Frontier*, 167-168.

[40] R. Dale Reed, interview, 19 July 1995; Milton O. Thompson, interview, 26 February 1992; Kenneth Iliff, interview with author, Edwards, California, 1 September 1995.

[41] Hallion, *On the Frontier*, 178-180.

[42] XB-70A information from Fitzhugh Fulton, interview with author, Edwards, California, 19 July 1995; Hallion, *On the Frontier*, 178-189; Ed Saltzman comments, 28 February 1996, based upon Henry H. Arnaiz, John B. Peterson, Jr., and James C. Daugherty, "Wind Tunnel/Flight Correlation Study of Aerodynamic Characteristics of a Large Flexible Supersonic Cruise Airplane (XB-70-1)," NASA Technical Paper 1516 (1980).

[43] Generally, the first test prototypes would be designated with an "X" and the production prototypes would be designated with a "Y." Hence, the "YF" 12A was a production prototype of a fighter (or fighter/interceptor) aircraft.

[44] Fitzhugh Fulton, interview, 19 July 1995.

[45] Information on the YF-12 research program from William H. Dana, interview, 14 July 1995; Fitzhugh Fulton, interview, 19 July 1995; Hallion, On *the Frontier*, 189-199.

[46] SR-71 research program information provided by Dave Lux and Steve Schmidt, interview with author, Edwards, California, 22 August 1995; Rogers Smith, interview with author, Edwards, California, 19 July 1995; Kenneth J. Szalai, interview with author, Edwards, California, 4 August 1995.

[47] C. M. Plattner, "NASA to Begin Unmanned Tests of New Type Lifting Shape for Hypersonic Maneuvering," *Aviation Week & Space Technology*, 29 September 1969, 52-58; R. Dale Reed, "Wingless Flight," 8-4 - 8-11; R. Dale Reed, interview, 19 July 1995; Hallion, *On the Frontier*, 210-212.

[48] *Aeronautics and Space Report of the President, Fiscal Year 1994 Activities* (Washington, D.C.: NASA, 1994), 41; Bruce Holmes, interview with author, Oshkosh, Wisconsin, 29 July 1995.

[49] A Boeing 747, by comparison, has a wing loading of approximately 100 pounds per square foot.

[50] John Del Frate, interview with author, Edwards, California, 1 September 1995; R. Dale Reed, interview, 19 July 1995; Michael A. Dornheim, "Solar Powered Aircraft Exceeds 50,000 Ft.," *Aviation Week & Space Technology*, 18 September 1995, 67; William B. Scott, "Technology Transfer Support Wavers," *Aviation Week & Space Technology*, 23 October 1995, 57-60; Stuart F. Brown, "The Eternal Airplane," *Popular Science*, April 1994, 70-75, 100.

CHAPTER 4

[1] This is not to say that engineers at Dryden had not been working on efficiency issues before this point. Indeed, in the early days of turbojet engines, aerodynamic efficiency was of great concern for engineers in part because the engines were not very powerful. Designs like the F-104 had to be extremely efficient aerodynamically in order to achieve the performance desired. But the fuel crisis of the 1970s suddenly made fuel efficiency in and of itself a top priority for the airlines, manufacturers, and national decision-makers, turning attention and funding toward focused research programs to improve aircraft fuel efficiency and reducing the support for some other high-speed efforts such as the SST.

[2] Phil Felleman, phone interview with author, 19 February 1996.

[3] A "gigabyte" is approximately one billion bytes. Other information in this section from Kenneth J. Szalai and Calvin R. Jarvis, interview with author, Edwards, California, 30 August 1995; Marcy Rosenberg and E. Drake Lundell Jr., "IBM and the Compatibles: How They Measure Up," *Computerworld*, 5 January 1979, 382; Kevin Shine, IBM PC Technical Representative, phone interview with author, 2 June 1995.

[4] Dr. Whitcomb's "area rule" concept looked at streamlining the overall frontal area of an aircraft from its nose to its tail. A typical aircraft design would have a sharp increase in its frontal area at the point where the wings joined the fuselage. By indenting the fuselage at that point, and even sometimes adding a "bump" to the nose area ahead of the wing, Whitcomb was able to keep the overall frontal area more consistent. This, in turn, created less drag as the aircraft passed through the difficult transonic speed range. Whitcomb's concept is generally regarded as a critical advance that enabled the design of operational supersonic aircraft.

[5] Boundary layer separation is the point where the air no longer flows along the contour of the wing but "separates" from the wing.

[6] Dr. Richard T. Whitcomb, "Research on Methods for Reducing the Aerodynamic Drag at Transonic Speeds," paper, presented at The Inaugural Eastman Jacobs Lecture, NASA Langley Research Center (Hampton, Virginia, 14 November 1994), 4-8; Weneth D. Painter, interview with Richard Hallion, 8 August 1977; Richard P. Hallion, *On the Frontier*, 201-206.

[7] Louis Steers, phone interview with author, 22 November 1995; Hallion, *On the Frontier*, 209.

[8] The Air Force tanker version of the commercial Boeing 707 jetliner.

[9] Whitcomb, "Methods for Reducing Aerodynamic Drag," 8-9; "KC-135 Program Review," NASA Conference Publication 2211 (Proceedings of Dryden Symposium, Edwards, California, 16 September 1981), 115-117, 128.

[10] Hallion, *On the Frontier*, 250-251; Kenneth J. Szalai and Calvin R. Jarvis, interview with author, Edwards, California, 30 August 1995; "The AD-1 Program, 1976 to 1982," viewgraphs, from the office of Alex Sim, Dryden Flight Research Center.

[11] In the late 1950s, Dryden did conduct some supersonic laminar flow research with an F-104 research plane. See Richard D. Banner, John G. McTigue, and Gilbert Petty, Jr., "Boundary-Layer-Transition Measurements in Full-Scale Flight," NACA Research Memorandum H58E28, (Washington, D.C.: NACA, 28 July 1958).

[12] Marta Bohn-Meyer, interview with author, Edwards, California, 22 August 1995; Bruce A. Smith, "F-16XL Flights Could Aid in HSCT Design," *Aviation Week & Space Technology*, 23 October 1995, 42-44.

[13] Composite construction is a manufacturing approach that combines more than one type of building materials. One common type of composite construction, for example, uses a foam core sandwiched between two fiberglass layers. But composite construction can refer to any multiple-element material.

[14] Hallion, *On the Frontier*, 215-216; HiMAT Fact Sheet from Dryden Research Center External Affairs Office files; Dave Lux, phone interview with author, 20 February 1996; comments of Ed Saltzman, 12 January 1996, a very helpful source throughout this chapter.

[15] "Angle of Attack" is a term used to describe the angle of the relative wind to an aircraft's wing. Or, to put it another way, it is the angle at which the air from the aircraft's flight path hits the wing. An aircraft in stable, level flight would have an angle of attack close to zero. If an aircraft was moving forward at a stable altitude but had its nose pointed up 20 degrees, the angle of attack of the wing would be close to 20 degrees. A 20 degree angle of attack could also be achieved, however, if the aircraft was in a horizontal configuration but was descending at a 20 degree angle. In either case, the air from the aircraft's flight path would be hitting the wing at a 20 degree angle.

[16] Rogers Smith, phone interview with author, 20 February 1996; Steve Ishmael, phone interview with author, 20 February 1996; Bob Clark, phone interview with author, 20 February 1996; Ed Saltzman, comments, 12 January 1996.

[17] Rogers Smith, interview with author, Edwards, California, 19 August 1995; Gary Trippensee, interview with author, Edwards, California, 27 August 1995; Steve Pace, *The Grumman X-29* (Blue Ridge Summit, PA: TAB Books, 1991), 2-15, 22-54; "The X-29," Fact Sheet, from the NASA Dryden Flight Research Center Office of External Affairs files.

[18] The official term for the F-18 is an F/A-18, designating it as a Fighter/Attack aircraft. For simplicity's sake in repeat references, however, I refer to it as simply an F-18.

[19] Ed Schneider, interview with author, Edwards, California, 24 August 1995; "F-18 High Angle of Attack Research Aircraft," Fact Sheet, from NASA Dryden Flight Research Center External Affairs Office Files; Guy Norris, "Breaking the Stall Barrier," *Flight International*, 11-17 November 1992, 34-37.

[20] The company started out as Messerschmidt-Bolkow-Blohm, then became Deutsche Aerospace, and most recently merged with Daimler-Benz.

[21] Carbon-carbon is a very strong composite material.

[22] Redesignated in 1995 as the Walter C. Williams Research Aircraft Integration Facility, after the founding director of Dryden.

[23] A pitot tube is a device used to measure airspeed. Actually, the device on the aircraft at the time of the mishap was a substitute for a conventional pitot called a Kiel probe.

[24] Gary Trippensee, interview, 24 August 1995; Rogers Smith, interview, 19 July 1995; X-31 Program Videotape; "X-31 Enhanced Fighter Maneuverability Demonstrator," Fact Sheet from the NASA Dryden External Affairs Office Files, Guy Norris, "Breaking the Stall Barrier," 34-37.

[25] Verification and validation are both important tasks in flight research that check new technology , components or systems before flight. A very basic differentiation of the two tasks could be described as follows: Verification is making sure you did the thing right. Validation is making sure you did the right thing.

[26] Duane McRuer, "Human Dynamics and Pilot-Induced Oscillations," paper, presented at the Minta Martin Lecture, (MIT, Cambridge, Massachusetts, 2 December 1992), ii, 1-7, 11; Duane McRuer, interview with author, Hawthorne, California, 31 August 1995; Michael A. Dornheim, "Report Pinpoints Factors Leading to YF-22 Crash," *Aviation Week & Space Technology*, 9 November 1992, 53-54; Carole A. Shifrin, "Gripen Likely to Fly Again Soon," *Aviation Week & Space Technology*, 30 August 1989; Michael A. Dornheim, "Boeing Corrects Several 777 PIOs," *Aviation Week & Space Technology*, 8 May 1995; Kenneth J. Szalai and Calvin R. Jarvis, interview with author, Edwards, California, 30 August 1995.

[27] For more information on the F-8 PIO research in support of the Space Shuttle program, see Chapter 5.

[28] Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1979*, (New York: Viking Penguin, 1989), 71-74.

[29] F-8 DFBW Research Information from: Kenneth J. Szalai, interview with author, Edwards, California, 4 August 1995; Kenneth J. Szalai and Calvin R. Jarvis, interview, 30 August 1995; Kenneth J. Szalai et al., "Design and Test Experience with a Triply Redundant Digital Fly-By-Wire Control System," AIAA Paper No. 76-1911, presented at AIAA Guidance and Control Conference (San Diego, California, 16-18 August 1976).

[30] Weneth D. Painter, interview with Richard P. Hallion, 8 August 1977.

[31] Hallion, *On the Frontier*, 220-222; Frank W. Burcham, Jr., Glenn B. Gilyard, and Lawrence P. Myers, "Propulsion System/Flight Control Integration and Optimization," NASA TM 4207, July 1990, 2.

[32] Burcham, Gilyard, Myers, "Propulsion System/ Flight Control Integration," 2-5.

[33] Ibid, 6-7; Bill Burcham, interview with author, Edwards, California, 24 August 1995; "Value of NASA Flight Research for Technology Transition," viewgraph from Bill Burcham's office files, Dryden Flight Research Center, Edwards, California.

[34] "F-15 Flight Research Facility," Fact Sheet from Dryden Flight Research Center External Affairs Office files, 3; "NASA F-15 Demonstrates Self-Repairing Flight Control System," Press Release, from NASA Dryden Flight Research Center External Affairs Office Files, 23 March 1990; Bill Burcham, interview, 24 August 1995.

[35] Gordon Fullerton, interview with author, Edwards, California, 7 September 1995; Bill Burcham, interview, 24 August 1995; Bill Burcham, "Cleared for Landing," *Air & Space*, April/May 1995, 20-21; Les Dorr, Jr., "Coming in on Two Engines and a Prayer," *NASA Magazine*, Winter 1994, 14-17; "F-15 Flight Research Facility," Fact Sheet from Dryden Research Center External Affairs Office files, November 1994.

[36] P. Doane, R. Bursey and G. Schkolnik, "F-15 ACTIVE: A Flexible Propulsion Integration Testbed," AIAA Paper 94-3360, Presented at the 30th AIAA/ ASME/ASEE Joint Propulsion Conference, Indianapolis, Indiana, 27-29 June 1994); Roger Bursey, "The F-15 ACTIVE Aircraft 'The Next Step,'" AIAA Paper, 1995; Gerard Schkolnik, phone interview with author, 22 November 1995.

[37] Joel R. Sitz, "F-18 Systems Research Aircraft Facility," SAE Technical Paper 922063, (Anaheim California: Aerotech '92); Joel R. Sitz, phone interviews with author, 20 and 21 November 1995; Michael A. Dornheim, "NASA F/A-18 Tests Components," *Aviation Week & Space Technology*, 5 September 1994, 89-90; Guy Norris, "Test Case," *Flight International*, 8-14 June 1994, 30-31; Systems Research Aircraft Viewgraphs and schedule from Joel R. Sitz files, Dryden Flight Research Center.

CHAPTER 5

[1] Richard P. Hallion, *On the Frontier*, 135-146.

[2] William H. Dana, interview with author, Edwards, California, 14 July 1995; Milton O. Thompson, interview with author, Edwards, California, 26 February 1992; Hallion, *On the Frontier*, 137-140.

[3] A "zero-zero" ejection seat is one that is effective with "zero" altitude and "zero" speed. Other models require a certain amount of altitude and airspeed in order to be effective.

[4] Robert Baron, interview with author, Edwards,

California, 4 August 1995; Hallion, *On the Frontier*, 140-146; William H. Dana, interview, 14 July 1995; "Lunar Landing Research Vehicle, the LLRV," Fact Sheet, from Dryden Flight Research Center External Affairs Office files.

[5] William H. Dana, interview, 14 July 1995.

[6] Neil Armstrong, from a talk given to Dryden staff members soon after the Apollo 11 mission, as quoted in Robert Baron, interview, 4 August 1995.

[7] Hallion, *On the Frontier*, 145.

[8] William H. Dana, interview, 14 July 1995.

[9] Fred Haise had been a research pilot at Dryden before joining the astronaut program and was a member of the ill-fated Apollo 13 crew. Gordon Fullerton would later join Dryden's staff as a research pilot.

[10] Kenneth J. Szalai and Calvin R. Jarvis, interview with author, Edwards, California, 30 August 1995.

[11] Duane McRuer, "Human Dynamics and Pilot-Induced Oscillations," paper presented at the Minta Martin Lecture (MIT, Cambridge, Massachusetts, 2 December 1992), ii, 1-8, 11; William H. Dana, interview, 14 July 1995; Kenneth J. Szalai and Calvin R. Jarvis, interview, 30 August 1995; Duane T. McRuer, interview with author, Hawthorne, California, 31 August 1995; Duane T. McRuer, "Lore and Discoveries from Flight Research at Dryden Flight Research Center," NASA TR-2464-1 (NASA Dryden Flight Research Center, October 1994), 5-15; Gordon Fullerton, interview with author, Edwards, California, 7 September 1995.

[12] Robert R. Meyer, Jr., and Jack Barneburg, "In-Flight Rain Damage Tests of the Shuttle Thermal Protection System," NASA TM 100438, May 1988; Bianca M. Trujillo, Robert R. Meyer, Jr., and Paul M. Sawko, "In-Flight Load Testing of Advanced Shuttle Thermal Protection Systems," NASA TM86024, December 1983.

[13] Robert Baron, interview, 4 August 1995; "Landing Systems Research Aircraft," Fact Sheet from the Dryden Flight Research Center External Affairs Office files; Gordon Fullerton, interview, 7 September 1995.

[14] Roy Bryant, interview with author, Edwards, California, 30 August 1995; "B-52 Launch Aircraft," Fact Sheet from Dryden Flight Research Center External Affairs Office files; Ed Schneider, interview with author, Edwards, California, 24 August 1995.

[15] See Chapter 3 for more information on inertial-coupling research and the X-3.

[16] Walter Bonney, "A Brief History of the High-Speed Flight Station," undated manuscript from Richard Hallion files, Dryden Flight Research Center External Affairs Office; Roy Bryant, interview, 30 August 1995; Hallion, *On the Frontier*, 58-59, 88-97, 229.

[17] Ed Schneider, interview, 24 August 1995; Hallion, *On the Frontier*, 233.

[18] Hallion, *On the Frontier*, 88-89, 213-214.

[19] Ibid., 89.

[20] William H. Dana, interview, 14 July 1995; Hallion, *On the Frontier*, 89, 223; Marvin R. Barber et al., "An Evaluation of the Handling Qualities of Seven General Aviation Aircraft," NASA TN D-3726 (Washington, D.C.: NASA, November 1966); Marvin R. Barber, phone interview with author, 9 January 1996.

[21] Hallion, *On the Frontier*, 223-226; Roy Bryant, phone interview with author, 9 January 1996; Marvin R. Barber, phone interview, 9 January 1996.

[22] Kenneth J. Szalai, interview with author, Edwards, California, 4 August 1995; William H. Dana, interview, 14 July 1995; Marvin R. Barber, phone interview, 9 January 1996.

CHAPTER 6

[1] Thomas C. Muse, "Some Contributions of NASA to Aeronautics," NASA Contractor Report, P.O. # W-14, 122, September 1976, 2.

[2] For more information about Dryden's high-speed research and ERAST programs, see Chapter 3.

[3] For more information on F-15 ACTIVE research, see Chapter 4.

[4] Kenneth J. Szalai, phone interview with author, 12 January 1996; Ken Iliff, phone interview with author, 16 January 1996; Mike Kehoe, phone interview with author, 12 March 1996.

[5] "About the Reusable Launch Vehicle Technology Program," from World Wide Web [http://rlv.msfc.nasa.gov/RLV-HTMLS/RLVOverview.html], 6 December 1995; Steven Ishmael, phone interview with author, 12 January 1996.

[6] For more information on the Aerospike engine tests, see Chapter 3.

[7] "RLV X-33 Concepts," from World Wide Web[http://rlv.msfc.nasa.gov/RLV-HTMLS/RLVX33.html], 6 December 1995; Kenneth J. Szalai, phone interview, 12 January 1996; Steven Ishmael, phone interview, 12 January 1996.

[8] "ACRV-X Project," viewgraphs presented to RLV industry teams, 9 August 1995; "X-35 Phoenix Project Plan," revised date 19 April 1995, from NASA Dryden Flight Research Center External Affairs Office files; Ken Iliff, phone interview, 16 January 1996; Kenneth J. Szalai, phone interview, 12 January 1996; "NASA Studying Lifting-Body/Parafoil Combination for Station ACRV," *Aerospace Daily*, Vol 176, No. 9, 13 October 1995, 73.

[9] Kenneth J. Szalai, interview with author, Edwards, California, 14 July 1995; William H. Dana, interview with author, Edwards, California, 14 July 1995; Kenneth J. Szalai, interview with author, Edwards, California, 4 August 1995; Dana Purifoy, interview with author, Edwards, California, 7 September 1995.

[10] From untitled publication in Richard Hallion's files, Dryden Flight Research Center External Affairs Office.

[11] Executive Office of the President, Office of Science and Technology Policy, "National Aeronautical R&D Goals: Agenda for Achievement," report of the Aeronautical Policy Review Committee, (Washington, D.C., February 1987), 2; Robert S. Ames, "U.S. Must Understand the Link Between R&D and the Economy," *Aviation Week & Space Technology*, 12 October 1987, 149-150; testimony before a House subcommittee on technology and competitiveness, as quoted in Christopher P. Fotos, "Industry Experts Say NASA Must Devote More Resources to Civil Aeronautics," *Aviation Week & Space Technology*, 24 February 1992, 42.

[12] Rogers Smith, interview with author, Edwards, California, 19 July 1995.

[13] Kenneth J. Szalai, interview, 4 August 1995.

Bibliographical Essay

The single most important group of sources for this book consists of numerous interviews with managers and engineers at Dryden and other NASA centers, plus documents they provided from their files. A great deal of information and insight also came from Richard P. Hallion's authoritative *On the Frontier: Flight Research at Dryden, 1946-1981* (Washington, DC: NASA SP-4303,1984) and the collection of interviews, documents, and papers upon which it is based. This collection currently resides at the External Affairs Office of the Dryden Flight Research Center, which has furnished a number of fact sheets, news releases, and other documents that were useful in providing an overview of Dryden's first fifty years.

Many individual details and some perspective on Dryden's accomplishments over this period also came from such sources as Hans Mark and Arnold Levine, T*he Management of Research Institutions: A Look at Government Laboratories* (Washington, DC: NASA SP-481, 1984), Gen. H. H. Arnold's *Global Mission* (New York: Harper & Brothers, 1949), Kenneth S. Kleinknecht's article "The Rocket Research Airplanes" in Eugene M. Emme's *History of Rocket Technology* (Detroit: Wayne State University Press, 1964), the book on *Bell X-1 Variants* (Arlington, TX: Aerofax, Inc., 1988) by Ben Guenther and Jay Miller, Wendell H. Stillwell's *X-15 Research Results* (Washington, DC: NASA SP-60, 1965), and Steve Pace's *The Grumman X-29* (Blue Ridge Summit, PA: TAB Books, 1991). More technical treatments like Edwin J. Saltzman and Theodore G. Ayers' *Selected Examples of NACA/NASA Supersonic Flight Research* (Edwards, CA: NASA SP-513, 1995) as well as other accounts by authors who worked at Dryden for many years, such as Milton O. Thompson's *At the Edge of Space* (Washington, DC: Smithsonian Institution Press, 1992) and R. Dale Reed's as yet unpublished manuscript, "Wingless Flight," were likewise extremely useful in the research for this book.

Further sources of information included technical papers such as Henry H. Arnaiz, John B. Peterson, Jr., and James C. Daugherty's "Wind Tunnel/Flight Correlation Study of Aerodynamic Characteristics of a Large Flexible Supersonic Cruise Airplane (XB-70-1)," NASA Technical Paper 1516 (1980) and Charles V. Eppley's "The Rocket Research Aircraft Program," Air Force Flight Test Center Technical Documentary Report No. 63-3 (1963).

A final group of sources consisted of aviation journals such as *Aviation Week & Space Technology* and *Flight International.* In conjunction with the other sources listed above, these provided helpful background and useful information on many of Dryden's programs and projects over the years. Valuable perspective was also provided by such scholarly works as Thomas P. Hughes' *American Genesis* (New York: Viking Penguin, 1989) and James R. Hansen's *Engineer in Charge* (Washington, DC: NASA SP-4305, 1987).

Glossary of Acronyms

AAF	Army Air Forces
ACTIVE	Advanced Controls Technology for Integrated Vehicles
ADECS	Adaptive Engine Control System
AF	Air Force
AFFTC	Air Force Flight Test Center
AFTI	Advanced Fighter Technology Integration
ALT	Approach and Landing Test
AoA	Angle of Attack
ARC	Ames Research Center
ARPA	Advanced Research Projects Agency
ATF	Advanced Tactical Fighter
CAA	Civil Aeronautics Administration
CID	Controlled Impact Demonstration
DARPA	Defense Advanced Research Projects Agency
DAST	Drones for Aerodynamic and Structural Testing
DEEC	Digital Electronic Engine Control
DEFCS	Digital Electronic Flight Control System
DFBW	Digital Fly-By-Wire
DFRC	Dryden Flight Research Center
EPAD	Electrically Powered Actuator Design
ERAST	Environmental Research Aircraft and Sensor Technology
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FBW	Fly-By-Wire
FCS	Flight Control System
FOCSI	Fiber-Optic Control System Integration
FRC	Flight Research Center
FSW	Forward Swept Wing
GA	General Aviation
GPAS	General Purpose Airborne Simulator
HARV	High Angle-of-Attack Research Vehicle
HIDEC	Highly Integrated Digital Electronic Control
HiMAT	Highly Maneuverable Aircraft Technology
HISTEC	High Stability Engine Control
HSCT	High Speed Civil Transport
HSFRS	High Speed Flight Research Station
HSFS	High Speed Flight Station
HSR	High Speed Research
IBM	International Business Machines
IPCS	Integrated Propulsion Control System
ITF	Integrated Test Facility (now RAIF)
ITO	International Test Organization
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
LeRC	Lewis Research Center
LEX	Leading Edge Extension
LLRV	Lunar Landing Research Vehicle
LLTV	Lunar Landing Training Vehicle
LM	Lunar Module
MAW	Mission Adaptive Wing
MSFC	Marshall Space Flight Center
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NLF	Natural Laminar Flow
OPEC	Organization of Petroleum Exporting Countries
PCA	Propulsion Controlled Aircraft
PIO	Pilot Induced Oscillation
PSC	Performance Seeking Control
RAIF	Research Aircraft Integration Facility
REBUS	Resident Back-Up Software
RLV	Reusable Launch Vehicle
RPRV	Remotely Piloted Research Vehicle
RPV	Remotely Piloted Vehicle
RTLS	Return to Launch Site
SCA	Shuttle Carrier Aircraft
SCW	Supercritical wing
SLFC	Supersonic Laminar Flow Control
SRA	Systems Research Aircraft
SRFCS	Self-Repairing Flight Control System
SST	Supersonic Transport
SSTO	Single-Stage-to-Orbit
STOL	Short Take-Off and Landing
TACT	Transonic Aircraft Technology
VTOL	Vertical Take-Off and Landing
X-CRV	Experimental Crew Return Vehicle

Appendix

Concepts and Innovations to which the Dryden Flight Research Center has Contributed

In the course of its fifty year history, Dryden has evaluated—in the demanding and realistic environment of actual flight—a great many concepts and configurations developed by its own researchers or those from other NASA centers, other agencies, or industry. Evaluating, improving or correcting otherwise promising concepts has provided a stimulating environment for the genesis of other new concepts and solutions. The following tabulation provides a partial list of major contributions to aeronautics made by Dryden personnel either in conjunction with partners or on their own initiative.

YEAR(S)	**CONTRIBUTIONS:**	**SIGNIFICANCE:**
1946-1958	Completed "Round One" flight investigations of the early X-Series and D-558 series of aircraft	Performed subsonic, transonic, and supersonic research to help evaluate and interpret wind tunnel data (special emphasis on transonic nonlinear characteristics). This research used an entire stable of new configurations with which flight loads, buffet, aeroelastic effects, pitch-up, directional instability, longitudinal control, and the effects of wing sweep were investigated. This research contributed to design principles leading to reliable and routine flight of production aircraft at transonic and supersonic speeds.
1947	Provided technical guidance and data analysis for the first flight through Mach 1.0 on the XS-1 (X-1 No. 1) airplane	This was the first time that a piloted airplane was flown through the speed of sound. In addition to overcoming the sound barrier, this flight demonstrated that an airplane could be controlled through the transonic region where very non-linear aerodynamic characteristics occur.
1947-1967	Analyzed and documented flight results obtained from first-time supersonic and hypersonic speeds	Though the sonic barrier (Mach one) was by far the most intimidating hurdle, Mach numbers of 2.0 to 6.0 were also noteworthy because of other challenges, such as diminished stability, aerodynamic heating, and energy management. Flights at Edwards achieved the following records: Mach 2.005 on 20 Nov. 1953 (D-558-2); Mach 3.2 on 27 Sept. 1956 (X-2); Mach 4.43 on 7 March 1961 (X-15); Mach 5.27 on 23 June 1961 (X-15); Mach 6.04 on 9 Nov. 1961 (X-15); and Mach 6.7 on 3 Oct. 1967 (X-15).
1947-1962	Developed generalized energy management algorithms for flight planning and safe flight of low lift-to-drag ratio, unpowered aircraft	Led to the concept of determining a potential landing "footprint" for such aircraft, with variations in scale during the different stages of a mission. Such algorithms have been applied to the Space Shuttle. Will be used for future unpowered space vehicles, providing multiple landing

YEAR(S)	CONTRIBUTIONS:	SIGNIFICANCE:
		trajectories that account for uncertainty in spacecraft characteristics and atmospheric conditions. Allowed for unexpected or emergency conditions and failures.
1954-1957	Identified, in flight, previously predicted inertial coupling and conducted follow-on research	Provided corrective measures for inertial coupling in the F-100 aircraft and all subsequent interceptor/ fighter aircraft.
1956-1962	Conceived and developed side-control stick concept and reaction control piloting techniques	Provided the technology for the first in-flight demonstration of flight control using a reaction control system on an F-104 airplane. Used a ground-based analog computer simulation and a reaction-controlled mechanical simulator, which enabled movement about three axes.
1956-1957	Demonstrated the influence of the "area rule" concept on the YF-102 and F-102A	Verified the area-rule concept and the equivalent body concept in flight using two airplanes that had the same airfoil and planform, but were designed with and without the area-rule. Also, through this effort established the eight-foot slotted-throat wind tunnel (then newly modified) as a credible transonic research facility. The area-rule subsequently became a fundamental design concept for all supersonic cruise aircraft.
1957-1958	Conceived and flew wing-glove boundary layer transition experiment on the F-104	Pioneering demonstration showing that extensive areas of laminar flow can be obtained naturally at supersonic speeds for practical wing surface conditions.
1958	Conceived and developed high-speed power-off landing techniques for low lift/drag vehicles	Flight development of safe technique for landing the X-15. Later applied to lifting bodies and Space Shuttle.
1959-1968	Demonstrated blending of reaction controls with aerodynamic controls for reentry from high-altitude rarified-atmospheric flight using the X-15 airplane	Provided methodology and demonstration of reentry control concept that was later used for the Space Shuttle.
1959-1968	Demonstrated servo-actuated ball nose on the X-15	Accurate measurement of air speed and flow angle at supersonic and hypersonic speeds.
1961-1962	Developed and evaluated piloted, unpowered paragliders as a potential method of landing spacecraft	Resulted in a practical application of the Rogallo wing concept, and enabled the birth of the modern sport of hang gliding. Evolved to proposed application for space station crew return vehicle.
1961-1963	Flew the first airplane to the edge of space — the X-15	The X-15 demonstrated reentry flight from up to sixty miles, encountering phenomena that were important in designing the Space Shuttle reentry flight profile. The following records were achieved by the X-15; 217,000 ft. on 11 Oct. 1961: 314,750 ft. on 17 July 1962; and 354,200 ft. on 22 Aug. 1963.
1961-1965	Provided high-quality flight data to better understand hypersonic aerodynamic and heating theory along with comparable wind tunnel predictions on the X-15	Discovered that hypersonically: 1) boundary layer is turbulent, 2) boundary layer heating is lower than predicted, 3) skin friction is lower than

YEAR(S)	CONTRIBUTIONS:	SIGNIFICANCE:
		predicted, and 4) surface irregularities cause local hot spots—all of which led to improved design tools for future hypersonic vehicles, including the Space Shuttle.
1962-1967	Conceived, developed, and flew the Lunar Landing Research Vehicle	Provided the basis for realistic training vehicle for Apollo astronauts and the controls design data base for the lunar module.
1963	Simulated supersonic transport operations with A-5A aircraft	Developed FAA air traffic control procedures for future supersonic transports.
1963-1966	Developed and evaluated the lightweight lifting body, the M2-F1	Demonstrated feasibility of piloted lifting body and the controllability and landability of the lifting-body shape.
1963 to present	Developed and utilized the Flight Test Fixture Experimental Facility concept	Provided efficient, cost effective method to expose a wide variety of experiments to a real flight environment.
1965-1972	Determined responses to high-altitude gust inputs and control usage in supersonic flight on the XB-70 and YF-12	Established baseline information for large, flexible aircraft on operational handling qualities, pilot ratings, and gust (turbulence) variations with altitude for future supersonic passenger aircraft.
1965-1972	Determined atmospheric features associated with high cruise altitude turbulence	Provided high-altitude clear-air-turbulence prediction techniques for supersonic passenger transport operation.
1966 to present	Pioneered developmental work in Parameter Identification	Provided powerful analytical tools for analysis of aerodynamic characteristics of aircraft from flight response; useful in other dynamic systems analysis.
1966-1968	Performed an in-depth lift-drag project for correlation of flight and wind tunnel data on the XB-70	Most comprehensive drag correlation ever achieved; revealed sources of major inaccuracies with wind-tunnel data at transonic speeds.
1967	First in-flight experience in severe shock interaction aeroheating on the X-15 Inconel-X pylon	Elevated the shock-interaction problem to its being recognized as a key temperature constraint on future hypersonic aircraft. The knowledge gained from this was first applied to the Space Shuttle.
1967	Developed the constant angle-of-attack test technique for in-flight ground-effect measurement on the XB-70 and F-104	Provided an efficient approach to obtain aerodynamics ground-effects data. Obtained evidence that aerodynamic ground effect is influenced by sink rate.
1968-1972	Identified the effect of dynamic pressure fluctuations on engine stall using the F-111A	Verified that high-frequency pressure fluctuations cause engine stalls and improved design methodology for F-15, F-16, and F-18 airplanes.
1970 to present	Developed highly flexible flight simulation methodology	This methodology was applied to flight testing of most complex envelope-expansion efforts and also to pilot training, mission planning, and ultimately to aircraft system flight qualification. Flexible, friendly user interface allows productive operation by the individual user with little or no support.

YEAR(S)	CONTRIBUTIONS:	SIGNIFICANCE:
1971-1986	Developed Remotely Piloted Research Vehicle concept using ground-based FORTRAN programmable computers to emulate crucial flight control systems and to provide ground-based cockpit and displays	Allowed the pilot to demonstrate concepts in flight from ground cockpit, and enabled rapid idea-to-flight demonstration of advanced control and display concepts without extensive validation and verification. Unpiloted 3/8 scale F-15 was able to quickly emulate full-scale F-15 and provide flight data in hazardous high angle-of-attack regime prior to exposing full-scale piloted airplane to those conditions. Also unpiloted HiMAT took advanced aerodynamic design concept and structural materials to flight much earlier than piloted aircraft could have.
1971- 1988	Evaluated the supercritical airfoil concept on the F-8 SCW, F-111 TACT, HiMAT, AFTI/F-111, and X-29	F-8 Supercritical Wing (SCW) research provided early and thorough demonstration and analysis of the supercritical airfoil in flight. Later applications demonstrated the affects of various planforms and sweep. Supercritical airfoils are now widely used throughout the world.
1972-1973	Conducted a pioneering thermal calibration and separation of aero- loads for Mach 3 YF-12 airplane	Demonstrated that thermal loads can be separated from flight loads by a combination of laboratory and flight results.
1972	Flew first aircraft with full digital flight control system with no mechanical backup on the F-8 DFBW (Digital-Fly-By-Wire)	Laid the groundwork for and proved the concept of digital fly-by-wire application that later flew operationally in the Space Shuttle, F/A-18, B-2, and the current generation of commercial transports.
1973-1978	Developed sensor system for precise measurement of true gust velocity and demonstrated it at high supersonic cruise altitudes on the YF-12	Provided highly improved reference measurement methods for load alleviation and propulsion system evaluations in high-altitude turbulence.
YF-12: 1973-1974 T-37: 1981	Demonstrated light-bar artificial horizon (peripheral vision display), tested on the YF-12 and T-37	Concept incorporated in operational SR-71 fleet as improved indicator of horizon through laser projection.
1974-1981	Applied aerodynamic lessons learned in flight to ground vehicle (truck or motor home) drag reduction	Verified effectiveness of air deflectors and defined the benefits of full streamlining. Results contributed to fuel savings estimated at 15 million barrels per year.
1974-1976	Flight tested an integrated digital propulsion control system on the F-111	Demonstrated performance and stability improvements with digital inlet/engine control systems, technology applicable to the F-22 and High Speed Civil Transport.
1974-1978	Performed in-depth mixed compression inlet research on the YF-12	Interpreted and documented pressure recovery, distortion, unstart and stall dynamics, and control for engine inlets; compared results to full scale and subscale wind tunnel test results. This technology was intended for the supersonic transport concept.
1975-1977	Conducted power-off landings to measure airframe noise on the Jetstar and AeroCommander airplanes.	Basic airframe noise "floor" documented for establishing engine noise reduction goals.

YEAR(S)	CONTRIBUTIONS:	SIGNIFICANCE:
1975-1977	Conceived and flew the YF-12 hollow-cylinder "Cold Wall" experiment	Benchmark, laboratory-quality fluid-mechanics experiment. A major contribution to predicting aerodynamic heating.
1975-1977	Flew the redundant computer systems with the associated algorithms in the F-8 DFBW	Tests provided confidence for flight-worthiness in the digital control concepts. They revealed many modifications that had to be made before being flown in the Space Shuttle.
1975-1978	Developed and demonstrated a Mach 3 cruise autopilot on the YF-12	Accuracy of altitude control and ride quality was greatly improved.
1975-1981	Investigated wing tip vortices behind bombers and transports with probe airplanes	Assessed vortex strength on trailing aircraft to evaluate separation distance and evaluated flap configurations for hazard attenuation.
1976	Demonstrated agility and turn capability at elevated load factors as well as overall flying qualities of the YF-17 Aircraft	Extended the agility and performance standards for the next generation of fighter aircraft.
1976 to present	Pioneered research efforts in unpiloted, non-airbreathing, high-altitude loiter aircraft technology	This technology provided a capability for high altitude atmospheric study of the ozone layer and greenhouse effects. Also has the potential for use in studying and surveying within the atmosphere of Mars.
1977-1980	Studied the effects of time delay for digital flight control systems on the F-8 DFBW	This flight research quantified the effect of pure time delayed response occurring in digital systems. These delays can cause serious safety problems for aircraft and spacecraft.
1977-1981	Conceived, developed and tested a pilot-induced-oscillation suppression system for the Space Shuttle	Developed flight control system modifications to reduce pilot induced oscillations during landing of the Space Shuttle.
1977-1986	Performed theoretical and experimental buckling research	Enabled determination of design guidelines and buckling characteristics for hypersonic wing panel without destroying the test part.
1978	Performed benchmark flight research using the 10-Degree-Cone boundary-layer transition experiment on the F-15	Provided benchmark reference of flow quality for transonic and supersonic wind tunnels, and a rational means for rating the various tunnels for flow quality.
1978	Developed and flew a cooperative integrated propulsion/flight control system on the YF-12	Improved flight control precision and reduced the occurrence of inlet unstarts. Incorporated in the operational SR-71 fleet.
1978-1980	Conducted comprehensive study of variable-geometry external compression inlet on the F-15	External compression inlet pressure recovery, steady state and dynamic distortion, drag, and lift were measured in flight and compared to wind-tunnel and analytical methods; also documented effects of scale and Reynold's number.
1978-1985	Demonstrated in flight and improved a NASA aileron/rudder interconnect concept on the F-14	Improved departure spin resistance for the F-14 aircraft. Final product to be incorporated into fleet for F-14 models A, B and D.

YEAR(S)	CONTRIBUTIONS:	SIGNIFICANCE:
1978-1992	Evaluated and improved an in-flight wing deflection measurement system used on F-111/ TACT, HiMAT, X-29 airplanes	Applied an electrical-optical system that provides digital data more precisely and with greater ease than photographic methods.
1979-1981	Evaluated the winglet concept on the KC-135 airplane	Defined the potential for drag reduction and increase in range for large transport-type aircraft for various aero load conditions. Concept now applied to many transport and business aircraft.
1979-1981	Evaluated oblique wing concept using the AD-1 airplane	Evaluated low-speed oblique-wing flying qualities, stability, and control at asymmetric sweep angles up to 60 degrees. The concept was proposed for supersonic transport and military applications.
1979-1995	Evaluated non-intrusive air data pressure source arrays on the KC-135, F-14, and F-18	Related applications followed on atmospheric research aircraft, military derivative systems, high angle-of-attack (AoA) research aircraft, and potentially for reentry vehicles. Concepts were extended through the transonic region and to extremely high AoA.
1980	Pioneered the development of fiberglass wing glove technique for high performance airfoil flight research	Provided a low cost method to evaluate innovative high-speed airfoil concepts at full-scale flight conditions.
1980-1983	Conceived and tested flight test trajectory guidance algorithms	Integration of flight-test parameters into single display allowed pilots to fly different flight-test maneuvers more accurately and get higher quality data.
1981	Conceived and tested the flight test maneuver autopilot	Automated the flight test trajectory guidance system to fly flight research maneuvers to produce more repeatable and more accurate data.
1981-1987	Performed in-flight testing of Shuttle tiles for air-load endurance and rain damage	Established criteria for orbiter tile erosion in moisture. Altered launch criteria in rain, and restricted ferrying the Shuttle cross country in bad weather.
1981-1984	Evaluated Digital Electronic Engine Control on the F-15	Flew contractor Digital Electronic Engine Control in flight and suggested and tested improvements.
1981 & 1987	Pioneered in-flight boundary layer transition experiments for effects of wing sweep on the F-111 and F-14	Provided empirical understanding of the effects of sweep on boundary layer transition. Established that extensive lengths of natural laminar flow can occur on a lifting surface (wing).
Hidden Line: 1982 Silhouette: 1986	Developed generalized and practical solution to the hidden-line problem and the silhouette problem	A powerful addition to computer graphics which resolved the problem of perspective and silhouettes in computerized designs, now commonly used in all types of applications and disciplines.
1985-1990	Conceived and developed the half-cycle theory	Provided very practical fatigue theory for life-cycle prediction of aerospace structures.
1986-1987	Conceived and tested active engine stall margin control on the F-15 Highly Integrated Digital Electronic Control flight test	Provided engine and airplane performance improvements without adding weight, used on F-15E and F-22 airplanes.

YEAR(S)	CONTRIBUTIONS:	SIGNIFICANCE:
1987-1988	Quantified the effects of engine control system delays on flying qualities on the F-104	Provided criteria for digital engine control design for use in precise formation flying.
1991-1996	Evaluated propulsive control (thrust vectoring) on HARV and X-31	Significant enhancement of high angle-of-attack agility and maneuverability. Made significant contribution to applicability of computational fluid dynamics (CFD) to high angle-of-attack flows by providing comparison of CFD, wind-tunnel and flight data at the same scale.
1992	Invented the Anderson Current Loop for evaluating signals from sensors	Potential major improvement over the classical Wheatstone Bridge circuit used in applications such as stress measurement.
1993	Demonstrated the Smart Actuator controlled with an optical data link on the F-18 Systems Research Aircraft	Electronics that close the flight control loop are built into the control surface actuator rather than in the flight control computer. Reduced the many wires that normally connect an actuator with the primary flight control computer to four fiber optic cables. Reduced aircraft weight and vulnerability to electro-magnetic interference.
1993-1994	Conducted inlet research at extremely high angle of attack on F-18 HARV	Inlet high frequency pressure recovery and distortion measured at angles of attack up to 100 degrees and in spins, providing data for vertical short take-off and landing (VSTOL) and agile fighter airplanes.
1993-1995	Conceived and tested emergency flight control using computer-controlled engine thrust in the F-15 & MD-11	Provided safe landing for an airplane with failed flight controls—may be implemented with only software changes.
1993-1995	Conceived, and developed the Landing Systems Research Aircraft on the CV-990	Provided unique capability to test Space Shuttle tires, wheels, brakes, blow-outs, and subsystems under severe loading and landing conditions. Allowed Shuttle cross-wind landing limits to be raised by 33 percent.
1993-1995	Completely characterized the sonic boom propagation from airplane to ground	Multi-altitude measurements by probe aircraft permitted assessment of prediction techniques of sonic boom propagation characteristics in the real atmosphere.
1994	Demonstrated flow visualization in-flight of planar laser-induced fluorescence for high Reynolds number at subsonic through supersonic speeds on the F-104 Flight Test Fixture	Collected previously unavailable data for sonic transverse gas injection into crossflows from Mach numbers 0.8 to 2.0, including at Mach 1.0, that provided validation of analytical models of the same flow conditions.
1994	Demonstrated in-flight indirect optical technique for high glide-slope approaches with no direct view of the airfield on the two-seat F-104	Validated indirect optics (non-TV) as a viable concept for piloted landings without direct view of the ground. Important for hypersonic vehicles and possibly for the High Speed Civil Transport.

Photo Credits

Photo archives at the Dryden Flight Research Center do not reveal the names of the photographers for all the photographs used in this volume, but the following photographers are credited with the photographs listed next to their names:

J. Bean: pp. 26 top, 30-31, 81 top; J. Brohmer: pp. 77, 97; B. Brown: pp. 33 bottom, 34, 101, 168; Dutch Flager: p. 164 top; Hinson: p. 137 top; D. Howard: pp. 142, 151: Mary Little Kuhl: pp viii, 22, 24 top right and left: T. Landis: pp. 83 top, 109, 112, 138 top, 162, 165, 167; R Meyer: pp. 8-9, 147 bottom, 160; J. Ross: pp. 8, 33 top, 35, 37, 76, 89, 95, 102, 103,104, 105, 106, 107, 125, 144, 153, 159, 161, 166, 170, inside back cover; L. Sammons: pp. 27, 99 bottom, 156, 169; M. Smith: p. 100; D. Taylor: pp. 86, 114 top and bottom, 115, 143, 146, 154; L. Teal: inside front cover and pp. 18, 128, 163; C. Thomas: pp. 4-5, 12, 32, 83 bottom, 93, 96, 113, 138 bottom: K. Wiersema: p. 83 center; B. Wood: facing p. 1, pp. 81, 146.

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Lane E. Wallace
Los Angeles, CA
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NASA History Series

Reference Works, NASA SP-4000:

Grimwood, James M. *Project Mercury: A Chronology.* (NASA SP-4001, 1963).

Grimwood, James M., and Hacker, Barton C., with Vorzimmer, Peter J. *Project Gemini Technology and Operations: A Chronology.* (NASA SP-4002, 1969).

Link, Mae Mills. *Space Medicine in Project Mercury.* (NASA SP-4003, 1965).

Astronautics and Aeronautics, 1963: Chronology of Science, Technology, and Policy. (NASA SP-4004, 1964).

Astronautics and Aeronautics, 1964: Chronology of Science, Technology, and Policy. (NASA SP-4005, 1965).

Astronautics and Aeronautics, 1965: Chronology of Science, Technology, and Policy. (NASA SP-4006, 1966).

Astronautics and Aeronautics, 1966: Chronology of Science, Technology, and Policy. (NASA SP-4007, 1967).

Astronautics and Aeronautics, 1967: Chronology of Science, Technology, and Policy. (NASA SP-4008, 1968).

Ertel, Ivan D., and Morse, Mary Louise. *The Apollo Spacecraft: A Chronology, Volume I, Through November 7, 1962.* (NASA SP-4009, 1969).

Morse, Mary Louise, and Bays, Jean Kernahan. *The Apollo Spacecraft: A Chronology, Volume II, November 8, 1962-September 30, 1964.* (NASA SP-4009, 1973).

Brooks, Courtney G., and Ertel, Ivan D. *The Apollo Spacecraft: A Chronology, Volume III, October 1, 1964-January 20, 1966.* (NASA SP-4009, 1973).

Ertel, Ivan D., and Newkirk, Roland W., with Brooks, Courtney G. *The Apollo Spacecraft: A Chronology, Volume IV, January 21, 1966-July 13, 1974.* (NASA SP-4009, 1978).

Astronautics and Aeronautics, 1968: Chronology of Science, Technology, and Policy. (NASA SP-4010, 1969).

Newkirk, Roland W., and Ertel, Ivan D., with Brooks, Courtney G. *Skylab: A Chronology.* (NASA SP-4011, 1977).

Van Nimmen, Jane, and Bruno, Leonard C., with Rosholt, Robert L. *NASA Historical Data Book, Vol. I: NASA Resources, 1958-1968.* (NASA SP-4012, 1976, rep. ed. 1988).

Ezell, Linda Neuman. *NASA Historical Data Book, Vol II: Programs and Projects, 1958-1968.* (NASA SP-4012, 1988).

Ezell, Linda Neuman. *NASA Historical Data Book, Vol. III: Programs and Projects, 1969-1978.* (NASA SP-4012, 1988).

Astronautics and Aeronautics, 1969: Chronology of Science, Technology, and Policy. (NASA SP-4014, 1970).

Astronautics and Aeronautics, 1970: Chronology of Science, Technology, and Policy. (NASA SP-4015, 1972).

Astronautics and Aeronautics, 1971: Chronology of Science, Technology, and Policy. (NASA SP-4016, 1972).

Astronautics and Aeronautics, 1972: Chronology of Science, Technology, and Policy. (NASA SP-4017, 1974).

Astronautics and Aeronautics, 1973: Chronology of Science, Technology, and Policy. (NASA SP-4018, 1975).

Astronautics and Aeronautics, 1974: Chronology of Science, Technology, and Policy. (NASA SP-4019, 1977).

Astronautics and Aeronautics, 1975: Chronology of Science, Technology, and Policy. (NASA SP-4020, 1979).

Astronautics and Aeronautics, 1976: Chronology of Science, Technology, and Policy. (NASA SP-4021, 1984).

Astronautics and Aeronautics, 1977: Chronology of Science, Technology, and Policy. (NASA SP-4022, 1986).

Astronautics and Aeronautics, 1978: Chronology of Science, Technology, and Policy. (NASA SP-4023, 1986).

Astronautics and Aeronautics, 1979-1984: Chronology of Science, Technology, and Policy. (NASA SP-4024, 1988).

Astronautics and Aeronautics, 1985: Chronology of Science, Technology, and Policy. (NASA SP-4025, 1990).

Gawdiak, Ihor Y. Compiler. *NASA Historical Data Book, Vol. IV: NASA Resources, 1969-1978.* (NASA SP-4012, 1994).

Noordung, Hermann. *The Problem of Space Travel: The Rocket Motor.* Ernst Stuhlinger, and J.D. Hunley, with Jennifer Garland. Editors. (NASA SP-4026, 1995).

Management Histories, NASA SP-4100:

Rosholt, Robert L. *An Administrative History of NASA, 1958-1963.* (NASA SP-4101, 1966).

Levine, Arnold S. *Managing NASA in the Apollo Era.* (NASA SP-4102, 1982).

Roland, Alex. *Model Research: The National Advisory Committee for Aeronautics, 1915-1958.* (NASA SP-4103, 1985).

Fries, Sylvia D. *NASA Engineers and the Age of Apollo* (NASA SP-4104, 1992).

Glennan, T. Keith. *The Birth of NASA:* The Diary of T. Keith Glennan, edited by J.D. Hunley. (NASA SP-4105, 1993).

Project Histories, NASA SP-4200:

Swenson, Loyd S., Jr., Grimwood, James M., and Alexander, Charles C. *This New Ocean: A History of Project Mercury.* (NASA SP-4201, 1966).

Green, Constance McL., and Lomask, Milton. *Vanguard: A History.* (NASA SP-4202, 1970; rep. ed. Smithsonian Institution Press, 1971).

Hacker, Barton C., and Grimwood, James M. *On Shoulders of Titans:* A History of Project Gemini. (NASA SP-4203, 1977).

Benson, Charles D. and Faherty, William Barnaby. *Moonport: A History of Apollo Launch Facilities and Operations.* (NASA SP-4204, 1978).

Brooks, Courtney G., Grimwood, James M., and Swenson, Loyd S., Jr. *Chariots for Apollo: A History of Manned Lunar Spacecraft.* (NASA SP-4205, 1979).

Bilstein, Roger E. *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles.* (NASA SP-4206, 1980).

Compton, W. David, and Benson, Charles D. *Living and Working in Space: A History of Skylab.* (NASA SP-4208, 1983).

Ezell, Edward Clinton, and Ezell, Linda Neuman. *The Partnership: A History of the Apollo-Soyuz Test Project.* (NASA SP-4209, 1978).

Hall, R. Cargill. *Lunar Impact: A History of Project Ranger.* (NASA SP-4210, 1977).

Newell, Homer E. Beyond the Atmosphere: Early Years of Space Science. (NASA SP-4211, 1980).

Ezell, Edward Clinton, and Ezell, Linda Neuman. *On Mars: Exploration of the Red Planet, 1958-1978.* (NASA SP-4212, 1984).

Pitts, John A. *The Human Factor: Biomedicine in the Manned Space Program to 1980.* (NASA SP-4213, 1985).

Compton, W. David. *Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions.* (NASA SP-4214, 1989).

Naugle, John E. *First Among Equals: The Selection of NASA Space Science Experiments* (NASA SP-4215, 1991).

Wallace, Lane E. *Airborne Trailblazer: Two Decades with NASA Langley's Boeing 737 Flying Laboratory.* (NASA SP-4216, 1994).

Center Histories, NASA SP-4300:

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Hartman, Edwin, *P. Adventures in Research: A History of Ames Research Center, 1940-1965.* (NASA SP-4302, 1970)

Hallion, Richard P. *On the Frontier: Flight Research at Dryden, 1946-1981.* (NASA SP-4303, 1984).

Muenger, Elizabeth A. *Searching the Horizon: A History of Ames Research Center, 1940-1976.* (NASA SP-4304, 1985).

Hansen, James R. Engineer in Charge: A History of the Langley Aeronautical Laboratory, 1917-1958. (NASA SP-4305, 1987).

Dawson, Virginia P. *Engines and Innovation: Lewis Laboratory and American Propulsion Technology.* (NASA SP-4306, 1991).

Dethloff, Henry C. *"Suddenly Tomorrow Came . . .": A History of the Johnson Space Center, 1957-1990.* (NASA SP-4307, 1993).

Hansen, James R. *Spaceflight Revolution: NASA Langley Research Center from Sputnik to Apollo* (NASA SP-4308, 1995).

General Histories, NASA SP-4400:

Corliss, William R. *NASA Sounding Rockets, 1958-1968: A Historical Summary.* (NASA SP-4401, 1971).

Wells, Helen T., Whiteley, Susan H., and Karegeannes, Carrie. *Origins of NASA Names.* (NASA SP-4402, 1976).

Anderson, Frank W., Jr., *Orders of Magnitude: A History of NACA and NASA, 1915-1980.* (NASA SP-4403, 1981).

Sloop, John L. *Liquid Hydrogen as a Propulsion Fuel, 1945-1959.* (NASA SP-4404, 1978).

Roland, Alex. *A Spacefaring People: Perspectives on Early Spaceflight.* (NASA SP-4405, 1985).

Bilstein, Roger E. *Orders of Magnitude: A History of the NACA and NASA, 1915-1990.* (NASA SP-4406, 1989).

Logsdon, John M., with Lear, Linda J., Warren-Findley, Jannelle, Williamson, Ray A., and Day, Dwayne A. *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume I: Organizing for Exploration.* (NASA SP-4407, 1995).

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Lane E. Wallace is a professional aviation writer who lives in Los Angeles, California. She is the author of two previous books and has contributed to a third book about NASA Collier Trophy winners that is due out soon. In addition, she has published over 200 articles on a wide variety of aviation and aerospace topics ranging from biplanes and air racing to new developments in NASA research and military aircraft technology. Her writing has appeared in a number of national and international magazines, including *AOPA Pilot, Flight International*, and *JP-4 Aeronautica.*

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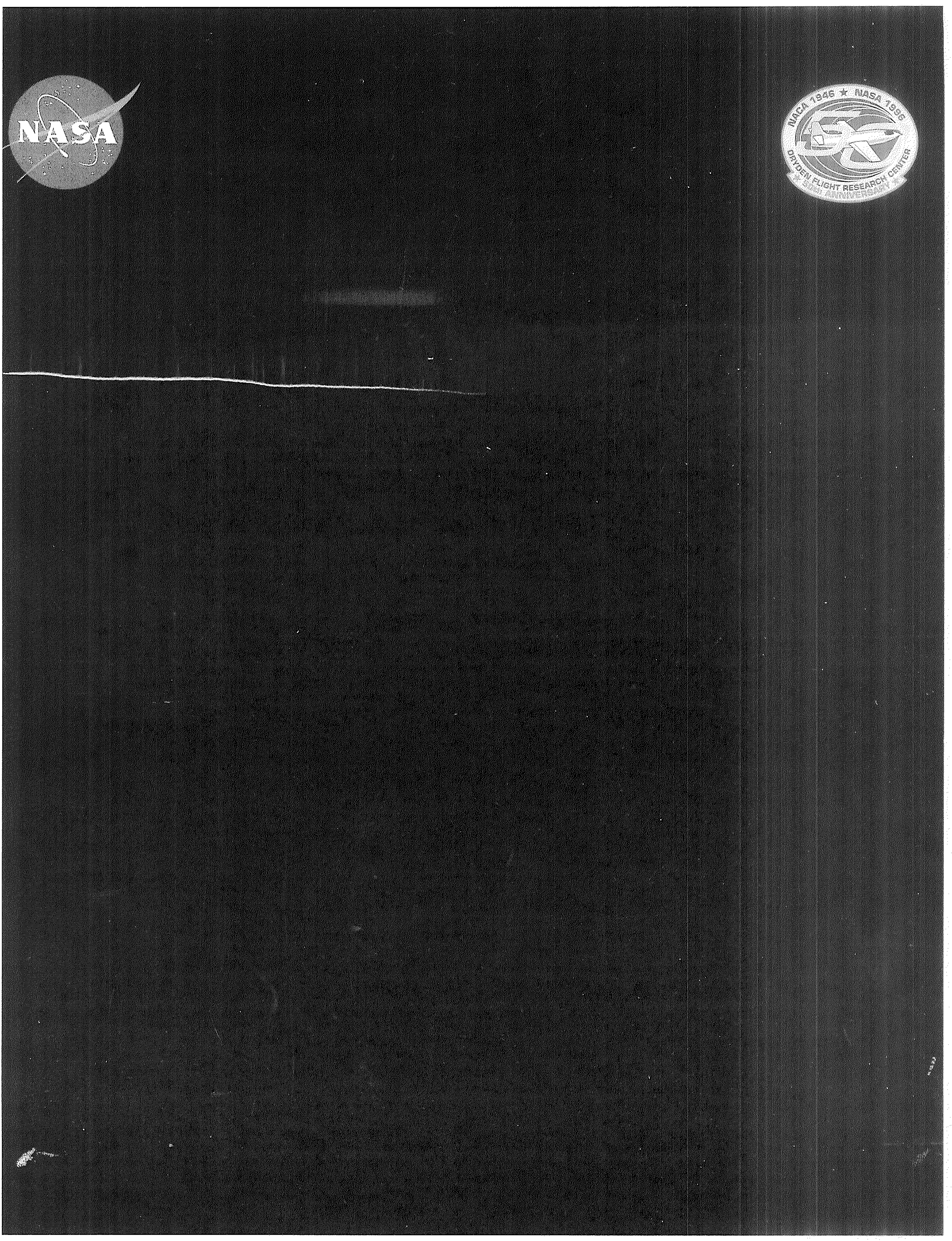
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