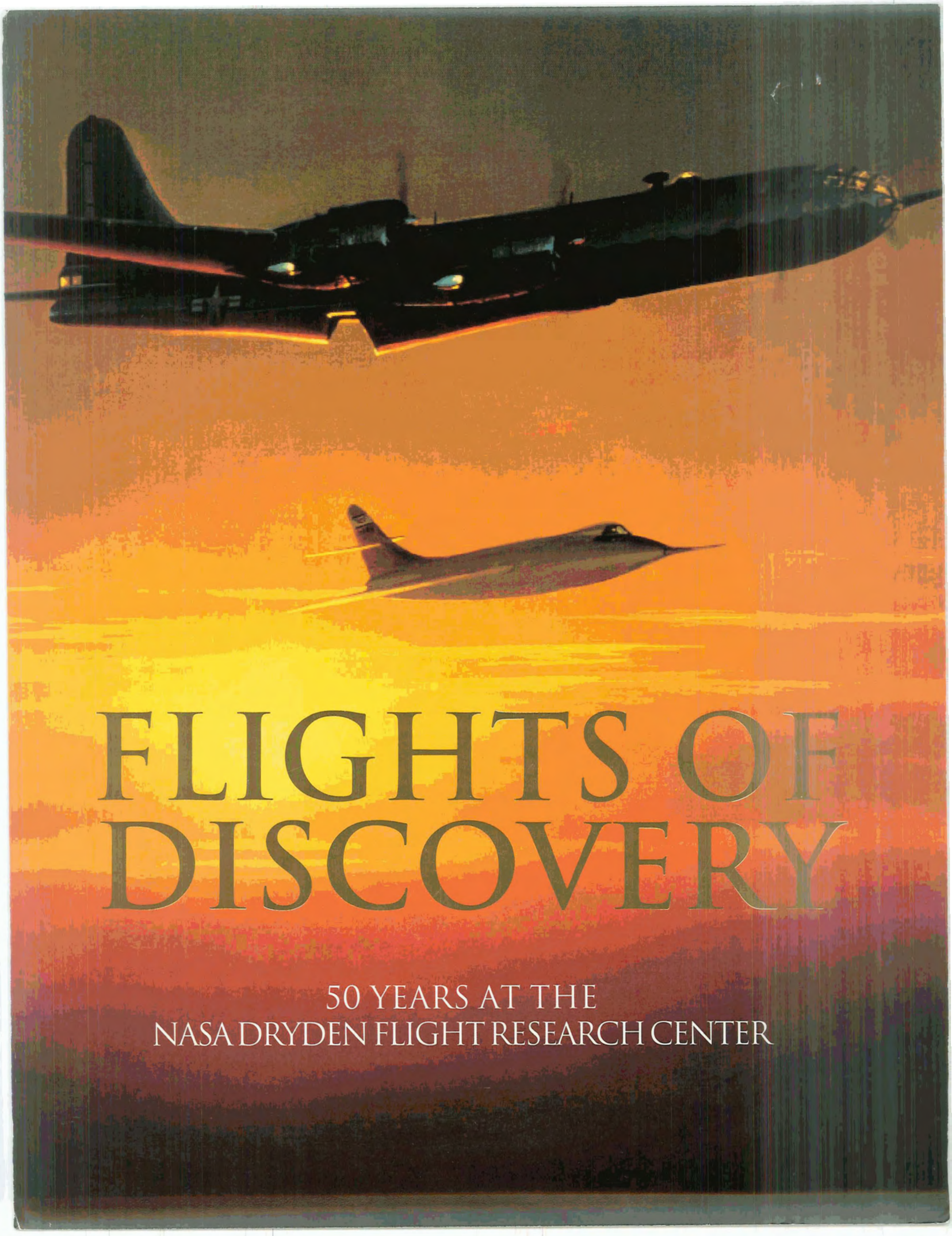
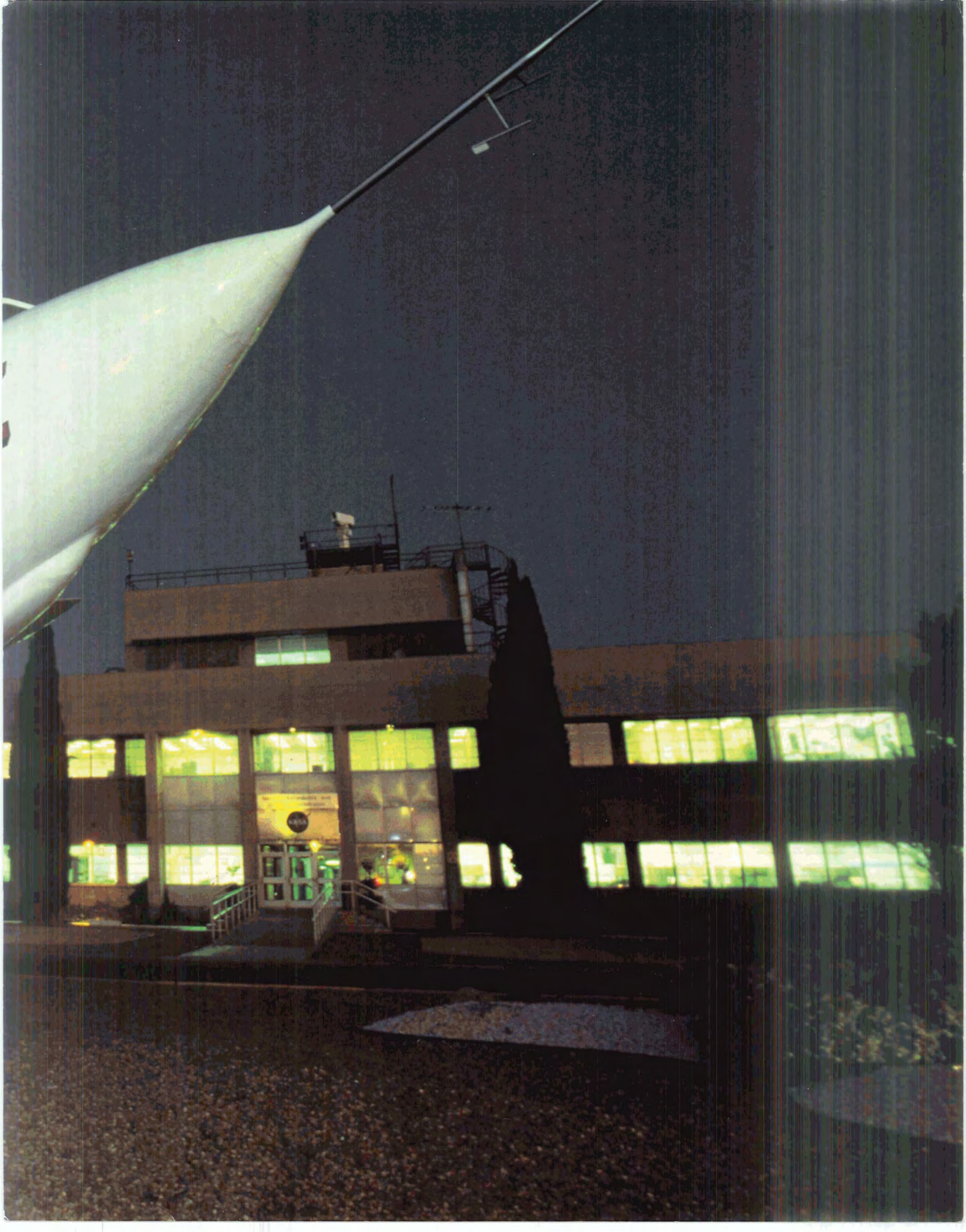


FLIGHTS OF DISCOVERY

50 YEARS AT THE NASA DRYDEN FLIGHT RESEARCH CENTER


X-1



Cover photo:
William S. Phillips' painting of Mach 2 Dawn *from the NASA art program. The painting depicts the first Mach 2 flight, which NACA pilot Scott Crossfield achieved on 20 November 1953. In a D-558-2, he climbed into the heavens under a P2B Superfortress (the Navy designation of the B-29), dropped clear of the bomber at 32,000 feet, and climbed to 72,000 feet before diving to 62,000 feet, where he became the first pilot to attain the Mach 2 milestone.*

Inside front cover:
The X-1E on a pedestal in front of the Dryden Headquarters building (NASA Photo ES96 43421-1)

Inside back cover:
Moonrise over Atlantis. *Following the STS-76 dawn landing at Dryden on 31 March 1996, the orbiter* Atlantis *was prepared for delivery to Kennedy Space Center and placed atop NASA 905, one of two modified Boeing 747 Shuttle Carrier Aircraft the evening of 5 April 1996. (NASA Photo EC96 43493-1)*

FLIGHTS OF DISCOVERY

by Lane E. Wallace



50 YEARS AT THE NASA DRYDEN FLIGHT RESEARCH CENTER

The NASA History Series

NASA SP-4309



National Aeronautics and
Space Administration

NASA History Office
Washington, D.C. 1996

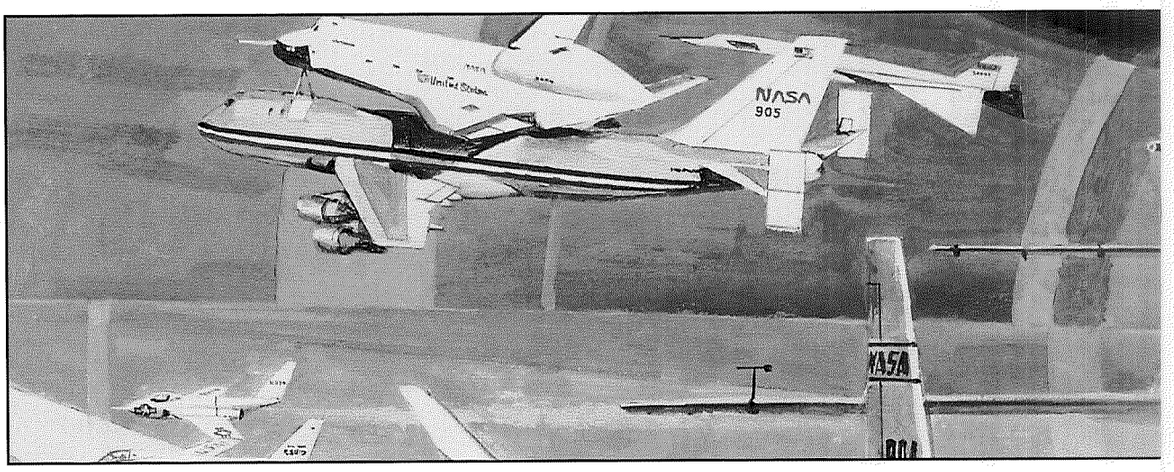
Library of Congress Cataloging-in-Publication Data

Wallace, Lane E., 1961-
Flights of discovery : 50 years at the NASA Dryden Flight Research Center / by Lane E. Wallace.
p. cm. — (The NASA history series) (NASA SP ; 4309)
Includes bibliographical references and index.
1. NASA Dryden Flight Research Center—History. I. Title.
II. Series. III. Series: NASA SP ; 4309.
TL521.312.W354 1996
629.1' 0720794'88—dc20 96-15797
CIP

For sale by the U.S. Government Printing Office
Superintendent of Documents, Mail Stop: SSOP, Washington, DC 20402-9328

To my friend Jim
For believing

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▶ Foreword

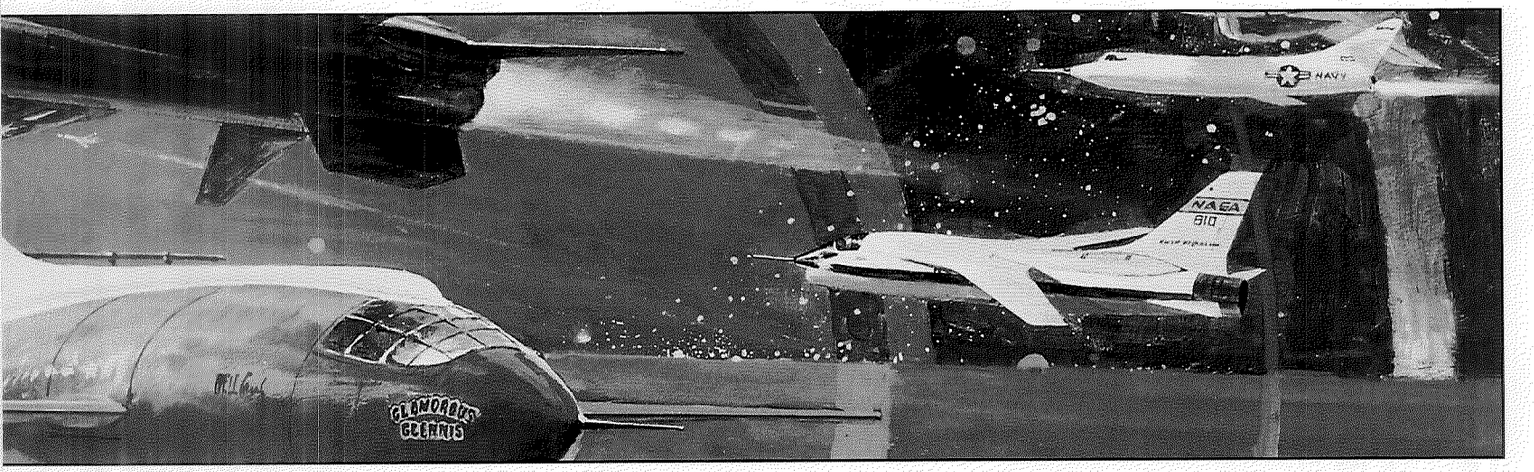


Early members of the Dryden Team, although the organization that became the Dryden Flight Research Center was then called the NACA High Speed Flight Research Station. Left to right, standing: Beverly Smith, Lilly Ann Bajus, unidentified, John Cardon, John Rodgers, unidentified, Hubert "Jake" Drake, Walter C. Williams; seated and kneeling: Mary Little, Harry Claggett, Ed Holleman, Angel Dunn, Roxanah Yancey, De E. Beeler (early 1950s) (NASA Photo E96 43403-12)

This volume adds another dimension to the existing literature about the history of the Hugh L. Dryden Flight Research Center (DFRC). While previous accounts—most notably Dick Hallion's superb *On the Frontier: Flight Research at Dryden, 1946-1981*—cover part of Dryden's history from one perspective or another, this is the first book to provide an overview of the entire 50 years of the Center's history from several perspectives.

In this book, Lane Wallace also provides insights into the process of research engineering. She differentiates between flight testing and flight research, and she describes the "technical agility" of researchers at Dryden—a quality that has been an enormously important ingredient in the process of discovery through flight here in the Mojave Desert. She has also captured the spirit of the role flight research plays in the aeronautics research and development chain.

Lane Wallace has included some "behind-the-scenes" events that provide additional insight into the human side of this highly technical discipline. Dryden frequently puts the innovations and ideas of others to the ultimate test of real flight conditions. The products of theory, wind-tunnel testing, and computational



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"The history of any institution is really the history of its people. The advances in aeronautics and space technology at Dryden were literally bought with blood, sweat and tears."

fluid dynamics—often developed elsewhere—are absolutely critical ingredients in the process of aeronautical discovery. In this book, Lane Wallace has captured very effectively many of the ways in which Dryden has cooperated with its partners over the past half-century to advance the process of aeronautical discovery that has so often begun with Dryden's partners.

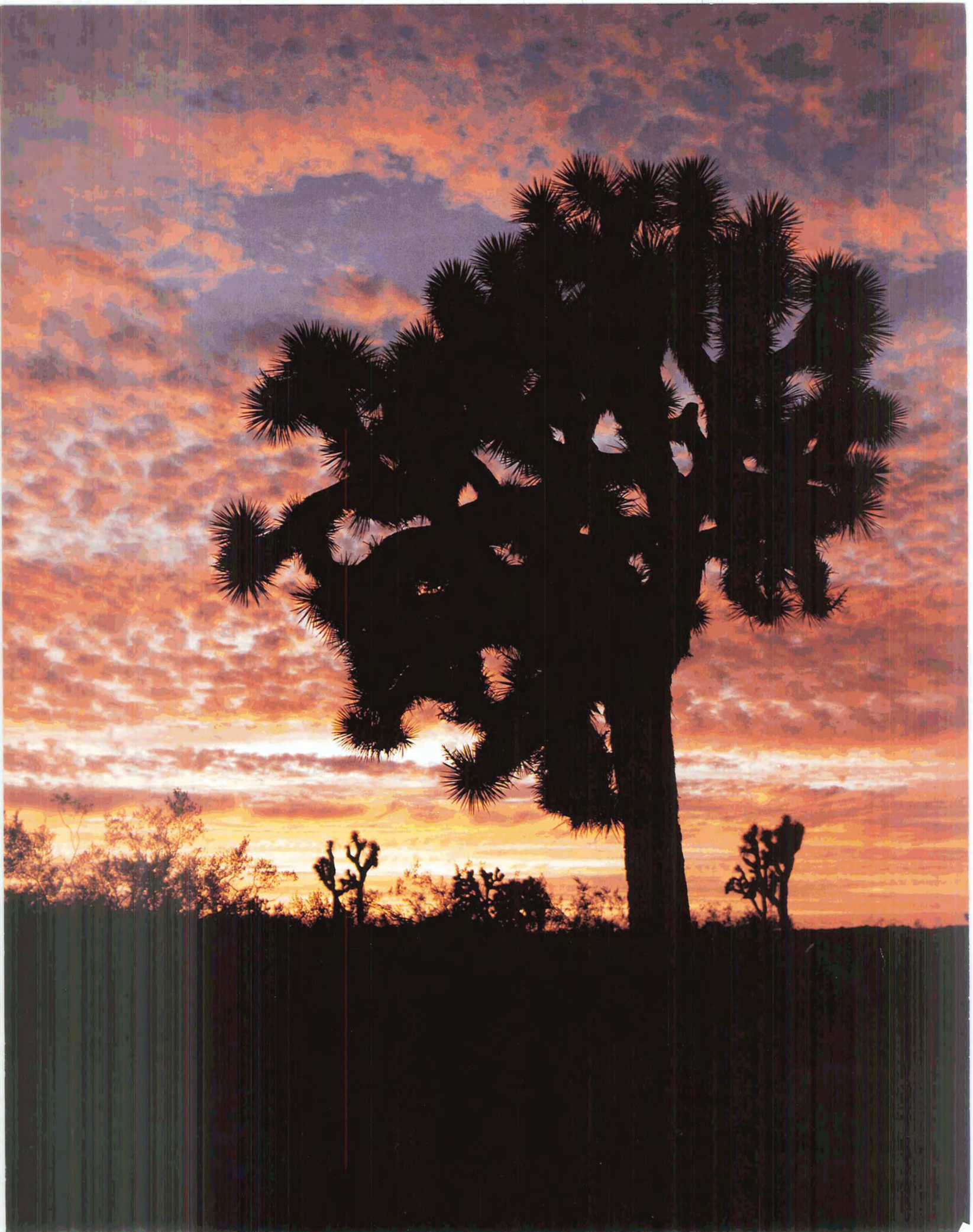
An important part of the Dryden spirit was bequeathed by its first Director, Walter C. Williams. He joined the National Advisory Committee for Aeronautics (NACA) in August of 1940. During World War II, he was a project engineer in the evaluation of several fighter aircraft—the P-47, P-51, and F6F—looking at handling qualities, low- and high-speed flight characteristics. As a member of Hartley A. Soulé's stability and control branch at Langley Memorial Aeronautical Laboratory, he was one of the NACA's foremost research airplane advocates. He led the first NACA team at Muroc and became the first Director of what was to become DFRC

He had tremendous experience in the flight testing of high-performance aircraft. As Dick Hallion noted in *On the Frontier*, Walt "was an inquisitive, take-charge sort of engineer, a man who believed that useful research had to confront actual problems and not be limited to studying theoretical aspects of aeronautical science." This outlook continues to be the basis of our work here at Dryden—the study of aeronautical phenomena and the applications thereof, the solving of practical problems.

It's clear that Dryden owes its heritage to Walt, who died peacefully at his home in Tarzana, California, on 7 October 1995. To him, for example, we owe our emphasis on research instrumentation, on getting the data we need; on safety and quality assurance; on careful flight planning by a small, integrated, and highly competent team. We also got from him our willingness to tackle the most difficult and seemingly impossible tasks. The project structure we use today was really invented in these early years.

History records all of the technical accomplishments in terms of Mach number, altitude, maneuverability, orbits, and the like. For these alone, Walt will be remembered and honored. But historians will never capture in words the zeal and zest that Walt put into his life and work. This same spirit lives on today at NASA Dryden. The history of any institution is really the history of its people. The advances in aeronautics and space technology at Dryden were literally bought with blood, sweat and tears. I therefore dedicate this book to the Dryden Team that has given so much to accomplish the flight research mission for 50 years.

17 April 1996 Kenneth J. Szalai
Director
Dryden Flight Research Center



▶ Chapter One:

A Place for Discovery

Less than 100 miles north of the bustling international city of Los Angeles lies a barren, windswept landscape known as the Mojave Desert. It is an unfriendly environment known for blazing summer temperatures and bone-chilling winter winds, a place once described by then-Colonel Henry H. "Hap" Arnold as "not good for anything but rattlesnakes and horned toads."[1]

Yet for all of its desolation, the desert also contains unique gifts. It offers unending days of piercing blue skies; dawns and sunsets that dust its rocky mountain sides with breathtaking hues of color. And while its arid landscape and dry lakebeds support little vegetation, for the past half century they have provided an ideal environment for pilots, researchers and engineers to test and explore new concepts in flight.

Joshua trees in desert at sunrise



X-1 with crew: left to right, Eddie Edwards; Bud Rogers, Dick Payne, crew chief; Henry Gaskins (NASA Photo E-49-00039)

It was above this stark expanse of land that the notorious "sound barrier" was finally broken; that innumerable speed and altitude records were set and quickly surpassed; that the first Space Shuttle proved it could land safely without power. It was here that the X-15 taught researchers valuable lessons about hypersonics and space; that the first fully digital fly-by-wire aircraft was flown; and that a pilot successfully landed a transport aircraft using only thrust for engine control.

Over half a century, this desolate location has allowed innumerable technologies to be explored, improved upon, and given enough credibility for industry to accept and apply them. And what began as a small, temporary detachment to support a single research project has evolved into a substantial National Aeronautics and Space Administration (NASA) facility known today as the Hugh L. Dryden Flight Research Center.

There are three things that made the Mojave Desert so well suited for flight research. The first was the area's flying conditions, which included clear skies and 50 or 100 miles of visibility almost every day of the year. The second was Rogers Dry Lake—a 44-square-mile natural landing site that General Albert Boyd referred to as "God's gift to the Air Force."[2] The third factor was that the lakebed was surrounded by miles and miles of virtually uninhabited desert, providing a buffer zone where rocket and jet aircraft could be operated safely and with far fewer restrictions than a

more populated area would require.

The Army's initial interest in the area around Rogers Dry Lake was as a bombing and gunnery range in the years preceding World War II, and a formal army air base was established near the town of Muroc in July 1942.[3] But it was the advent of jet engines and higher speed aircraft that highlighted the real strengths of the desert location. The new experimental jet aircraft, starting with the Bell XP-59A, required longer runways than most air bases had, and the classified nature of the research required a remote site for flight testing. The Muroc Army Airfield, officials realized, was the perfect choice for this kind of work.


EXTRA

RACE RESULTS

Los Angeles Times

Pictorial

VOL. LXVII — MONDAY MORNING, DECEMBER 22, 1947 — DAILY, FIVE CENTS

U.S. MYSTERY PLANE TOPS SPEED OF SOUND

Suicide Pact Fatal to Man; Wife May Die

Pair Take Sleeping Pills and Write Loving Note to Sea

Test Pilots Pierce Dread Barrier at 70,000 Feet Altitude Above Desert

BY MARVIN MILES

Three Americans have pierced the wall of sound!

The dread barrier to supersonic flight was first conquered at Muroc Air Base early last month when Capt. Charles Yeager, Air Force pilot, hurled the XS-1 rocket plane through the wall at approximately 70,000 feet, The Times learned from reliable sources.

Howard Lilly and Herbert Hoover, test pilots for the National Advisory Committee for Aeronautics, duplicated Yeager's feat in the same batch the experimental ship after being dropped from the belly of a Superfortress over the desert base.

Three Win International Hare

In streaking through the invisible ocean of compressibility the three men won an international race for supersonic honors and an air base like flight the world's aeronautic attitude toward—if like forecasts toppled by the highly unstable first speedster.

Some of the three pilots experienced new ill effects from hurtling through the barrier now as the XS-1 dropped in a 50-degree dive from an altitude of 42,000 feet.

The Air Force has announced the plane can attain a level pace with the winds. "The plane has been designed to reach about 1700 m.p.h. at 36,000 feet altitude."

Just what speed was attained remains a closely guarded military secret, but it is known that the craft was probably powered at about 664 m.p.h. at altitudes ranging from 40,000 to 70,000 feet.

Speed Put Barrier Almost Unlimited

Before the flights were made theorists asserted that any plane that broke through the freezing turbulence could ride on up to almost any speed, depending on the amount of fuel available.

Hence the speed attained by any one of the three XS-1 pilots might have reached anywhere from 664 m.p.h. up to the Air Force estimate of 1700 m.p.h.

But authentic listeners, with the newest rocket power available in the XS-1, up to 3,000 m.p.h., the original Air Force figure of 1500 m.p.h. was based on a super power plant—which probably is not yet available.

While the Air Force originally announced its supersonic exploration plans for the XS-1 and received publicity for the experiment, it recently did an about-face and placed the XS-1 and its personnel under a blanket of military secrecy. Today newspapermen were barred from the base.

It was apparent yesterday that the most breathtaking test lessons public knowledge and The Times, pledged to withhold its information, was then withheld from keeping its pledge.

Air Force officials ignored several test physical challenges in the world of flight, the sound wall was approached with the success of the atomic bomb experiments.

The XS-1, first plane designed to break through the barrier, remained in range roughly from 300 to 700 m.p.h., was locked into the mystery over a long period of months.

Gentle Rate First 20 Flights

Chalmers (Slick) Goodlin, Bell Aircraft test pilot, flew the first ship on five 20 flights, and took it to "Mach number" at .85 (Mach number is actual speed relative to the velocity of sound at any altitude) at 42,000 feet. Then, powered not the XS-1 for the more recent flights.

Test pilots describe the approach as "nibbling at the fringes" of sound, each flight hurling its way a little farther into the mysterious realm.

One of the greatest explorations into the unknown since Columbus, the achievement opens a new aerial age of high-speed flights that will rival Buck Rogers.

The secrecy has been prompted for years and there were many who predicted it could never be conquered. "A plane

Turn to Page 2, Column 4

Eight Killed by Gunfire and Knife in Palestine

INFANT ABANDONED ON PORCH WILL BE MISS CHRISTMAS'

U.S. Strives to Prevent Western Union Strike

Man Struck by Auto Dies

Cold Wave Hits Italy

New White House Dog Received by President

ANNOUNCEMENT

FEATURES INDEX

Red Belt States Line Up to Dominate Europe

Although the NACA and the Air Force would continue until June of 1948 "neither [to] confirm nor deny" the story of Capt. Charles "Chuck" Yeager's breaking the sound barrier on 14 October 1947, the Los Angeles Times was one of a number of publications that reported the story in late December. Apart from the facts that Yeager had exceeded the speed of sound in the XS-1, the reporting was rife with so-called "facts" that were nothing more than sheer speculation. Nearly two years would elapse, for example, before the XS-1 came close to the 70,000 feet the Times reported as already reached. The Times also reported that NACA research pilots Howard Lilly and Herbert Hoover had already "duplicated Yeager's feat." In fact, Hoover became the NACA's first supersonic pilot nearly three months after the article appeared, in early March 1948, followed by Lilly about three weeks later.
(Air Force Photo)

These same reasons led the Army Air Forces, Bell Aircraft, and the National Advisory Committee for Aeronautics (NACA) to choose Muroc as the test site when they undertook the challenge of designing and building a research aircraft to break the notorious "sound barrier." In the fall of 1946, the first NACA contingent of 13 engineers, instrument technicians, and support staff arrived at the Muroc Army Airfield to support the X-1 effort.[4]

The X-1 project was just one of many research efforts the NACA had undertaken to expand the country's knowledge and understanding of aeronautics. Established in 1915, the NACA's mission was to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution."[5] The committee was to help the fledgling aeronautics industry by conducting research that manufacturers could not, either because the work was too expensive, long-range, or required facilities industry lacked.

By 1946, the NACA had already made numerous contributions to aeronautics. But the coming of the high-speed jet age at the close of World War II brought new challenges. Ground facilities did not exist that could adequately simulate the dynamics of the transonic environment, which included speeds above Mach 0.85 but below Mach 1.2. The first slotted-throat transonic wind tunnel, which provided much better data at speeds approaching and surpassing the speed of sound, was not developed until 1950.[6] A large part of the rationale for building the X-1 was because at that time there was no other way to gather reliable information about transonic flight.

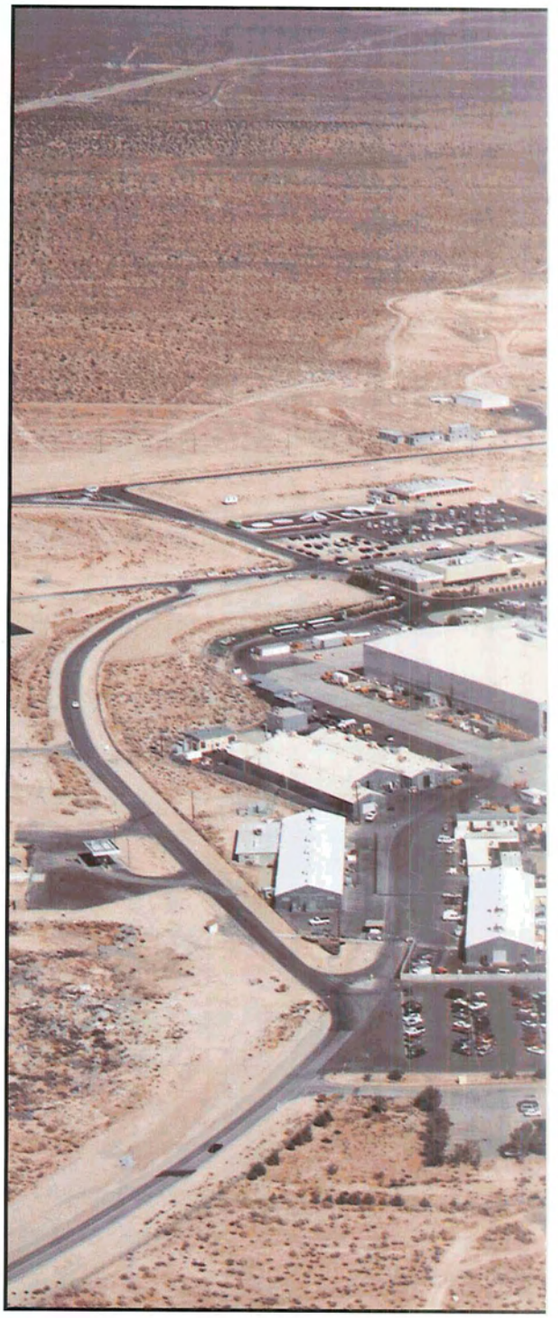
The Role of Flight Research

It was not only the lack of ground facilities that provided the justification for exploring ideas in flight, however. The importance of trying out new concepts and designs in flyable aircraft was understood even by Wilbur Wright, who in 1901 argued that "if you are looking for perfect safety you will do well to sit on a fence and watch the birds, but if you really wish to learn you must mount a machine and become acquainted with its tricks by actual trial."[7]

The NACA shared Wright's belief, and flight research has always played a critical role in the work of both the NACA and its successor agency, NASA. By the mid-1960s, ground facilities were much more capable than they had been in the days of Wilbur Wright or the X-1, but NASA administrator James E. Webb still considered flight research a critical activity. In 1967 he testified before Congress that

> Flight testing of new concepts, designs, and systems is fundamental to aeronautics. Laboratory data alone, and theories based on these data, cannot give all the important answers. . . . Each time a new aircraft flies, a "moment of truth" arrives for the designer as he discovers whether a group of individually satisfactory elements add together to make a satisfactory whole or whether their unexpected interactions result in a major deficiency. Flight research plays the essential role in assuring that all the elements of an aircraft can be integrated into a satisfactory system.[8]

That argument still holds true today. No matter how sophisticated laboratory technology becomes, computers can only simulate what is known. The unknown is always, in a sense, unpredictable. A computer can extrapolate what *should* happen as a logical extension of what has happened up to that point, but the outcome cannot be assured until it is tested in realistic conditions. Flight research is where that testing occurs. It is that unique point where the rubber meets the road, where the aircraft, human, and real-life flight conditions come together for the first time. And because flight research explores that ragged edge between the known and the unknown, it is a place where discovery happens.



Aerial of NASA facility and desert beyond as of 1992 (NASA Photo EC92 10204)

Discovery is that moment of divergence where something other than what was expected occurs. Indeed, researchers say a discovery is marked less often by a shout of "Eureka!" than by a perplexed murmur of "That's odd. . . ." And for all the improvements in ground and laboratory facilities, there has yet to be a flight research project conducted at Dryden that did



not have at least one such moment.[9] Sometimes, the discovery shows only that the computational codes used to predict the performance of the aircraft need to be adjusted. Other times it turns the research in an entirely different direction, opening up a whole new set of questions from those envisioned at the start of the project.

In either case, it is these discoveries that slowly expand our understanding of the world of aeronautics. And it is the pursuit of these discoveries that differentiates flight research from the closely related discipline of flight test.

The Air Force Flight Test Center (AFFTC) is situated just a short hike down the flightline from the Dryden Flight Research Center at what is now Edwards Air Force Base. The flightlines of both centers display an impressive array of high performance aircraft and, to a casual observer, there might seem little difference in the work the two facilities do. Both centers employ highly skilled pilots who fly new and experimental aircraft configurations to precise test points. In both cases, data from those maneuvers is collected by various types of instrumentation and recorded or sent back to the ground, where it is processed by engineers, technicians and analysts.

The difference between flight test and flight research lies not in the mechanics of each operation, but in the questions that drive the work and how unexpected discoveries are viewed. In flight test, the objective is to compare the airplane's performance against set specifications it is supposed to meet. The idea is not to explore new realms of aeronautical knowledge, but simply to make sure that a new aircraft design or configuration performs in an acceptable manner. Unless the anomaly is better-than-predicted performance, unexpected results in a flight test program indicate problems that need to be fixed. The information gained through flight test is also directed toward a specific customer with regard to a specific product.

Flight research, on the other hand, gathers information that can be used by a much wider audience for a wide variety of applications. In addition, flight research involves



much broader questions. The objective is not simply to determine if an airplane performs in a certain way, but to understand why it does and to explore various factors that affect that performance. Discoveries are not problems to be fixed but doors opening into new realms of possibility. They give researchers a glimpse into the world beyond what we know, raise new questions and often lead to entirely new lines of research.

Discovery can and does happen in all types of research settings. But the potential for discovery is particularly great in flight research because it is an arena where so many variables and unknowns come together. For all of our technological advances, there is still much we do not understand.

Supersonic aircraft, for example, have been flying since the late 1940s. Yet although aeronautical engineers have learned how to design aircraft that can function in the supersonic realm, even researchers do not fully understand the dynamics of that environment. As Marta Bohn-Meyer, project manager of Dryden's supersonic laminar flow research program, says, "The more we get into this, the more I realize how little we really know about what happens in the transonic and supersonic

NB-52A (tail number 003) making a pass over one of the X-15s following a lakebed landing. One of only three B-52As produced, 003 was one of a pair of highly modified Stratofortresses—the other being NB-52B number 008—that were used to launch X-15s at speeds of 600 miles per hour and at altitudes of up to 45,000 feet. Scenes such as this typically took place 20 minutes or more after the X-15 had touched down, because the NB-52 returned from a launch point 200 to 300 miles northeast of Edwards. (NASA Photo EC61 0034)



Group airplane photo, X-24B, F-15 Remotely Piloted Vehicle, F-111 Transonic Aircraft Technology, F-8 Digital Fly-By-Wire, F-104s, T-38, PA-30, Jetstar, Aerocommander, R-4D (Gooney Bird), F-111 Integrated Propulsion Control System, and the small remotely-piloted research vehicles in the foreground (6 May 1974). (NASA Photo ECN 4029)

regions."[10]

The problems have also become more complex. In 1946, researchers were simply trying to see if it was possible for an aircraft to surpass the speed of sound. Today, the goals are broader. We want not just supersonic aircraft, but efficient, environment-sensitive supersonic aircraft, or highly maneuverable supersonic aircraft. So despite all the advances in aeronautics, flight research is still operating at the cutting edge of knowledge.

Even elements that are understood individually may interact in an unexpected manner when they are brought together in a realistic flight environment. This is especially true for any aircraft that requires a human pilot. Time after time, for example, computerized flight control systems for aircraft have been tested successfully in simulators, only to exhibit different tendencies in actual flight. One reason for this is that simulators rely on predicted data to model a new aircraft or system's performance. But another cause is the simple fact that pilots react differently in simulators, where even the worst mistake will cause them only embarrassment, than in an aircraft where the stakes are very real and very high. Yet if the end goal of aeronautical research is to improve



products.

Furthermore, there is a measure of credibility that can be achieved, almost instantaneously, from a successful demonstration of a technology on an actual aircraft in realistic flight conditions. As a former vice president of engineering at the Boeing Commercial Airplane Company argued, "laboratory development has great appeal and usually gets substantial government support. However . . . the attainment of credibility is [also] an important national issue. It is during this second phase that a technical concept achieves a state of readiness, validation and credibility such that private industry and financing can assume the attendant risks."[11]

the design of practical, flyable aircraft, it is essential to explore those reactions and discover potential problems with configurations or technology.

Indeed, another important function of flight research is that it forces researchers to focus on those particular problems that are truly critical to developing usable technology. Many interesting questions can arise in the course of laboratory and ground research. But putting a piece of technology on a flyable aircraft quickly differentiates those questions that are low-priority curiosities from those that suggest critical issues to address. Furthermore, a problem identified as critical cannot simply be put aside to be studied later. It has to be solved.

In part because so many operational problems have to be addressed and solved before a concept can be tried on an aircraft, flight research can also play an important role in winning industry's acceptance for new technology. Technology that has been explored in flight is generally more mature than concepts investigated only in laboratory or simulator settings, leaving a smaller gap for industry to bridge in order to incorporate it into commercial

In some cases, laboratory research is sufficient for industry to see the benefits of a concept and invest in it. But especially as technology becomes more complex and expensive, making a commitment to a new technology is an increasingly difficult and risky gamble for industry to make. An idea that has been proven successful in realistic flight conditions is much more convincing, because while it might still be uneconomical or impractical, industry decision-makers at least know it can work.

Giving aerospace manufacturers the confidence to invest in new technology can, in turn, increase their global competitiveness. This has important implications, because aerospace is one of the few remaining fields in which the United States still has a trade surplus. If the



Above left: SR-71 crew members with aircraft. (NASA Photo EC91 056.Fr 16)



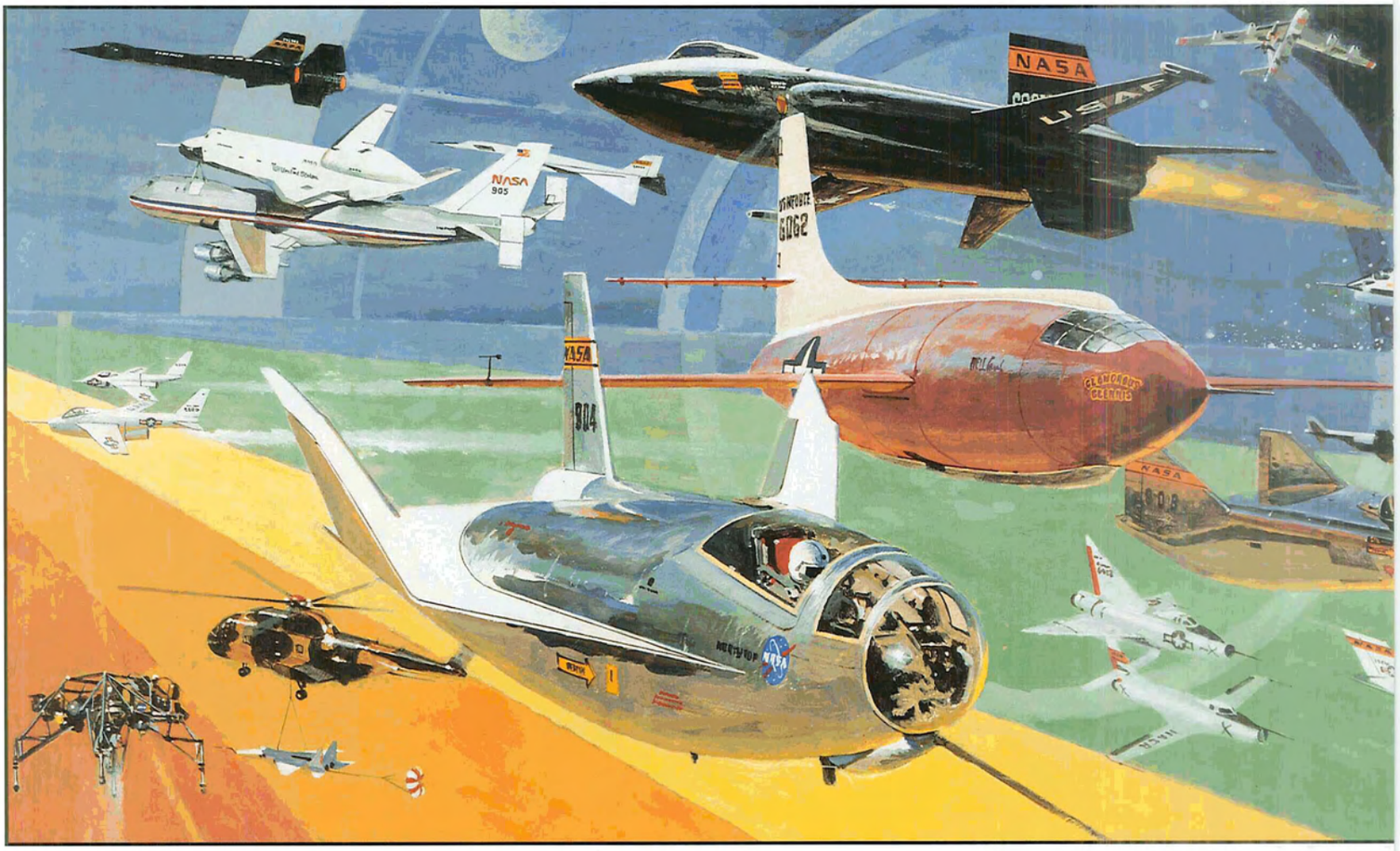
SR-71B Mach 3 trainer at sunset. (NASA Photo EC95 43351-1)

country is to improve its balance of trade and overall economy, the aerospace industry must remain competitive.

Supporting National Priorities

Of course, global competitiveness has not always been the driving national concern that it has become in recent years. But the flight research conducted at Dryden[12] over the past half century has played an important role in furthering the country's priorities, whatever they were.

In the post-World War II era and the Cold War of the 1950s, the drive was to develop aircraft that could go higher and faster, exploiting speed and power to maintain superiority over Soviet aircraft and defense systems. Dryden's work reflected this theme with its X-



planes and its efforts to improve a variety of military jet aircraft designs. After the launch of Sputnik in 1957, the space race also became a high national priority, culminating in the Apollo effort throughout the 1960s. At Dryden, those priorities were paralleled by its X-15 and lifting bodies research, as well as efforts such as the Paresev and the Lunar Landing Research Vehicles.

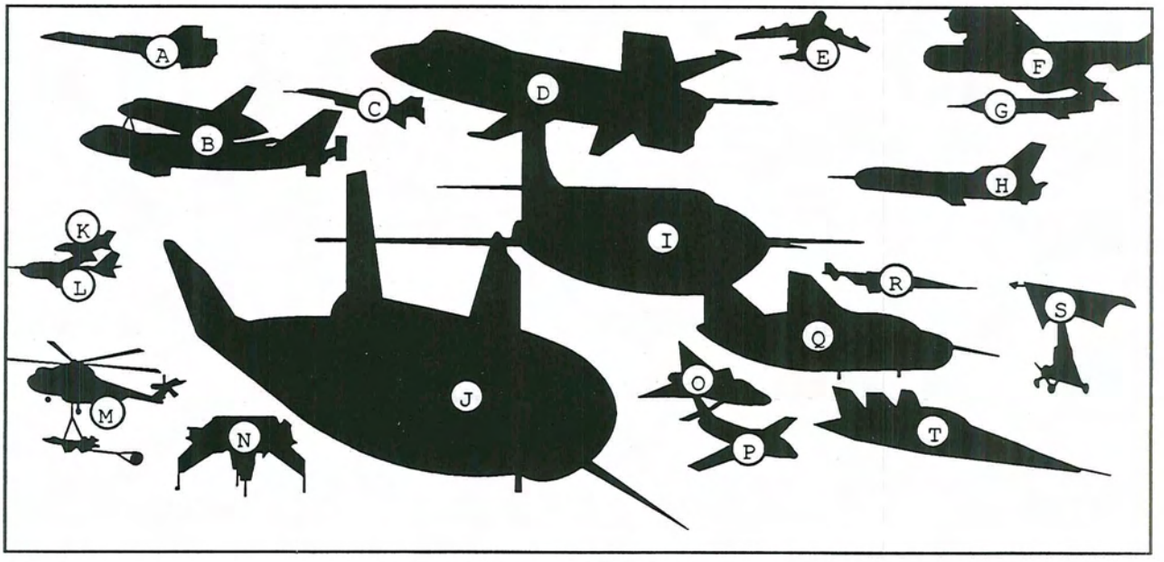
Another national priority in the 1960s was the development of a civil Supersonic Transport (SST). This goal spawned a number of high-speed research projects at Dryden, including work with the Mach 3 XB-70 and YF-12 aircraft. But environmental concerns, an economic recession and a burgeoning fuel crisis in the 1970s shifted the country's priorities to improving the fuel efficiency and internal systems of aircraft. Dryden's focus shifted with the nation's, leading to projects such as the Supercritical Wing and winglets, which made aircraft more aerodynamically efficient, and to the world's first purely digital fly-by-wire airplane, which opened a whole new realm of efficient and capable aircraft design.

The country's need for higher performance aircraft continued into the 1980s, leading to research at Dryden that focused on understanding the dynamics associated with more maneuverable and capable configurations. The X-29, the HiMAT, the F/A-18 High Alpha Research Vehicle (HARV) and the X-31 research planes all reflected this priority in one way or another.

Interestingly enough, the 1990s have brought a renewed national interest in higher

Robert McCall's famous mural entitled The Spirit of Flight Research *depicts the aircraft flown during Dryden Flight Research Center's first 30 years. McCall completed the painting the year after the renaming of the Center in honor of Hugh Latimer Dryden. (NASA Photo EC96 43416-3)*





Key to Aircraft

A. YF-12: Predecessor to the SR-71, flew at Dryden in a high speed research program from 1969-79.

B. 747/Orbiter *Enterprise*: 747 shuttle carrier aircraft carried *Enterprise*, prototype orbiter, aloft during 1977 approach and landing tests at Dryden.

C. XB-70: flown from 1967-69 in a high speed research program.

D. X-15: Rocket-powered research aircraft flew 199 missions from 1959 to 1968. The X-15 still holds the world's absolute speed (4520 mph) and altitude (345,200 ft) records for winged aircraft.

E. B-52: Pictured carrying the X-15, NASA's B-52 air launch aircraft, NASA 008 has been used since the late 1950s to air launch a variety of piloted and unpiloted vehicles.

F. B-50: A modified B-50, and an earlier B-29, were used to air drop research and experimental aircraft in the 1940s and 1950s.

G. D-558-2: The D-588-2 Skyrocket, dropped from the B-50 launch aircraft, flew from 1948-56 to investigate the swept-wing configuration at supersonic speeds. First aircraft to fly twice the speed of sound.

H. F-8SCW: Supercritical wing research was carried out at Dryden on a modified F-8 from 1971-73. Concept now used on many transport and fighter aircraft.

I. X-1: The X-1 became the first aircraft to fly faster than sound on October 14, 1947. Pilot was then-Captain Charles E. Yeager, one of the several project pilots assigned to the joint NACA/Army Air Corps project. History of Dryden dates to 1946 and the X-1 project.

J. HL-10: Fastest and highest flying of the five lifting body designs flown at Dryden form 1966-75. Research aided space shuttle program. HL-10 now displayed at Dryden entrance.

K. X-4: Semi-tailless vehicle flown from 1948-54 in studies of stability and control at transonic speeds.

L. X-5: First aircraft capable of sweeping wings in flight, flew from 1950-54.

M. HH-53: HH-53 aerial recovery helicopter carries NASA's F-15 3/8 scale remotely-piloted research vehicle used in stall-spin research program.

N. LLRV: Lunar Landing Research Vehicle, flown in mid -1960s, developed control system used on the Apollo lunar module to land astronauts on the moon's surface and on the Apollo astronauts' training vehicle.

O. XF-92: First delta-wing aircraft flew at Dryden from 1951-1953.

P. D-558-1: D-588-1 Skystreak was flown from 1947-53 in a program to investigate safety of flight at transonic speeds.

Q. M2-F2: First heavyweight lifting body was the M2-F2, flown from 1966-67. Damaged in a landing accident and rebuilt as M2-F3 with a third vertical tail and flown from 1970-72. Now displayed at the Smithsonian National Air and Space Museum.

R. X-3: Dubbed the Flying Stiletto, X-3 flew from 1952-55 to gather data on supersonic flight and use of titanium and stainless steel in aircraft construction.

S. PARESEV: Between 1962-64 the PARESEV 1A vehicle (paraglider research vehicle) studied wing configurations as possible methods of returning vehicles through the atmosphere from space.

T. X-24B: Last of the lifting bodies, the X-24B flew from 1973-75 in a program aiding in development of the space shuttle. It was developed from the X-24A airframe.



Shuttle mate/demate facility with Space Shuttle Endeavour in it. Endeavour had just completed its first flight (STS-49) from 7 May 1992 to 16 May 1992, when this photo was taken. (NASA Photo EC92 05169-1)

and/or faster aircraft—but with a twist. The impetus for high flying aircraft is fueled largely by the need to gather information on the Earth's atmosphere, and that avenue of research is focusing primarily on small, remotely piloted vehicles. NASA's initiative for a High Speed Civil Transport (HSCT) differs significantly from the 1960s goal of a Supersonic Transport in that it now must be economical and environmentally sensitive as well as fast. Not surprisingly, therefore, the work Dryden is conducting to support NASA's High Speed Research program is looking not just at speed, but at technologies such as achieving supersonic laminar flow and mapping the parameters of sonic booms. A national concern with making access to space more economical is also driving Dryden's current research into reusable launch vehicles such as the X-33.

Not all of the research conducted at Dryden fits neatly into these chronological national themes. Efficiency, for example, is an important issue in any aircraft design and has always been a concern for aerodynamicists working on furthering the basic research and technology knowledge base. Layered on top of those basic research efforts, however, are more focused research programs such as the X-15, the Aircraft Energy Efficiency (ACEE) program, or the Space Shuttle, which are more closely tied to shifts in national concerns. And on this level, there have always been inescapable parallels between the focus of Dryden's research and the nation's technological and economic priorities. This is hardly surprising, of course, given that NACA/NASA has always been funded by the national government. Congress is unlikely to approve funding for research that is totally irrelevant to national concerns. Yet it is not just funding that drives the type of research Dryden performs.

The managers and researchers at the Dryden Flight Research Center understand that their mission is not only to advance their own ideas but also to provide support to other NASA centers, government agencies, the military, industry and, in the end, the American public. Consequently, only perhaps 50 percent of the work the Center does is "exploratory" research stemming from long-term objectives developed with its various research partners. The other half of its work comes from requests by other centers, government agencies, the military, or industry for help on other programs or efforts. Programs on stall-spin characteristics of small airplanes, tests of an experimental anti-misting fuel, and research on shuttle thermal tiles and tires are just a few of the many such projects Dryden has undertaken over the years.

Dryden Contributions

Yet whether the research was initiated by Dryden, industry, or by another center or agency, the work conducted by the Center and its research partners over the past 50 years has made some very important contributions to the aerospace efforts of both government and industry. In some cases, the impact of the research has been clear and direct. The flight experience with the X-15 and the lifting bodies, for example, provided the space program with critical information about the use of reaction controls and gave the designers of the Space Shuttle the confidence to have it land without power. Research with the X-3 led to the identification of both the cause and a cure for a lethal inertial roll coupling problem that had plagued the F-100 jet fighter and other aircraft of the 1950s. The Supercritical Wing has been applied

to numerous aircraft, including all new large commercial transports and the AV-8B Harrier, and winglets tested at Dryden have been used on many corporate jets as well as on the Boeing 747-400 and McDonnell Douglas MD-11 airliners.

After a potentially dangerous pilot-induced oscillation (PIO) was discovered in the final pre-launch landing test of the first Space Shuttle, Dryden engineers were able to design a suppression filter that fixed the problem without forcing a redesign of the Shuttle's entire flight control system. Research into a Digital Electronic Engine Control (DEEC) system with a Pratt & Whitney F100 turbofan engine resulted in a DEEC system being incorporated into the company's production model engines. A problem with compressor stalls in an upper corner of the F100's operating envelope was also successfully analyzed and solved as a result of the research.

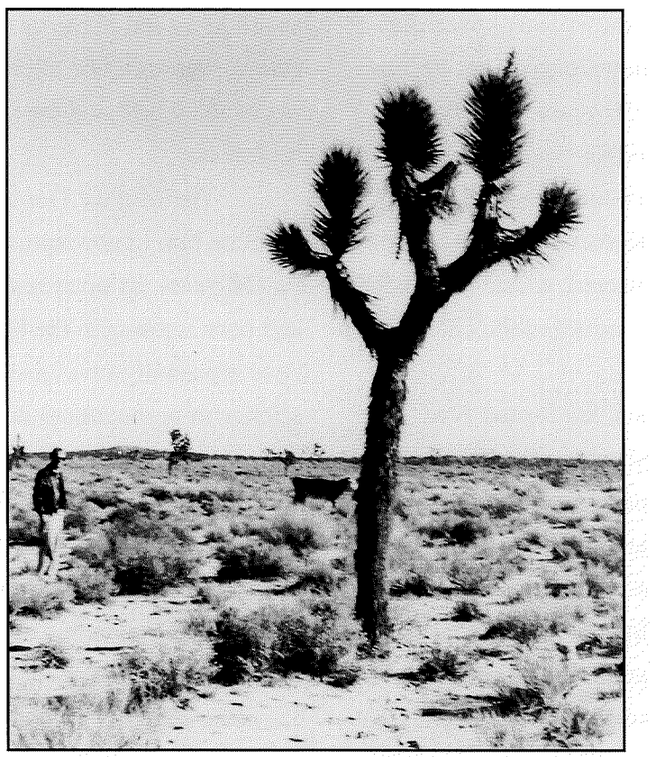
In other cases, the Center's research has advanced technology or understanding in areas that have yet to be applied. The X-29, for example, demonstrated the feasibility of a composite, forward-swept-wing design. There is currently no production aircraft that incorporates this particular technology, but that does not mean that there won't be one some time in the future. The variable-camber, supercritical, variable-sweep wing Dryden investigated on an F-111 proved the validity of the technology, although it has yet to be used. Dryden researchers, in partnership with industry, also developed an integrated, computerized flight and engine control system that allowed a NASA pilot to successfully land both an F-15 fighter jet and an MD-11 transport airliner using only throttle controls. This technology is too recent a development to have spurred any commercial applications yet, but several tragic airline accidents have been caused by partial or complete loss of hydraulic power that rendered the flight controls useless. Since a propulsion control system could help prevent this kind of accident, it might be incorporated into airliners before too long.[13]

Harder to trace, but no less important, are the less direct contributions made by research conducted at Dryden. There are many instances where, although the technology was not applied directly, the Center's research expanded the knowledge base of aeronautical engineers or changed people's thinking on what was possible. In addition to the direct technology that was developed and transferred to industry through the Digital Fly-By-Wire program, for example, the research created an important element of confidence in the basic concept. The fact that Dryden research pilots had flown the fly-by-wire research aircraft without any mechanical back-up controls was a factor in determining how decision-makers' viewed the technology's reliability. That, in turn, led to the design of pure digital fly-by-wire systems for the F-16 C/D and the F/A-18 Hornet fighters, and eventually the Boeing 777 airliner.[14]

By the same token, Dryden's structural flutter research with a Remotely Piloted Vehicle (RPV) led to improved real-time flutter analysis algorithms for designers to use. The F/A-18 HARV is exploring actual airflow dynamics at extremely high angles of attack in order to make the formulas used to predict this flow more accurate. This information, in turn, can allow engineers to design aircraft that will perform better in that flight regime. And a series of mathematical procedures developed by Dryden researchers to extract previously unob-

tainable aerodynamic values from actual aircraft responses in flight, a process known as parameter identification, has become an international standard. This definitive contribution allowed flight researchers for the first time to compare certain flight results with predictions.

In short, the contributions Dryden has made over its 50-year history have been as varied as the aircraft its pilots have flown. Sometimes the contribution was a small piece of technology, a design approach, or a new element or degree of accuracy in the basic aeronautical knowledge base. And sometimes, like the faint traces of pioneer wagon wheels that might still be found decades later, Dryden's contribution was simply to have gone into new territory first, exploring a new configuration or concept that was too advanced, risky, or expensive for industry to pursue on its own.



Joshua tree with cow and unidentified person (NASA Photo E96 43403-5)

Conclusion

The road to discovery is not an easy one. In order to make contributions to technology or to our understanding of aeronautics and aerospace, research has to be working on the cutting edge of knowledge. There is a constant tension in flight research that is characterized as "risk versus reach."[15] To take too small a step is to discover nothing new. To take one too large is to invite catastrophe. And the burden of constantly walking the thin line between those two extremes is one that every researcher at Dryden carries.

Walt Williams, head of the small NACA contingent that arrived at Muroc to support the X-1 program, recalled that the engineers "developed a very lonely feeling as we began to run out of data" near the speed of sound.[16] It is a feeling well understood by anyone who has ever stood on the brink of the unknown. The designers of the Northrop B-2 must have felt it the morning of the Flying Wing's first flight. The managers at the Johnson and Kennedy Space Centers undoubtedly grappled with it as they gave the go-ahead for the first Shuttle mission. At Dryden, it is a feeling researchers confront almost every time they approve new configurations and modifications for flight.

For no matter how well engineers and analysts try to anticipate every possible problem and reaction, physical exploration of the unknown is never without risk. There is always a moment when someone has to make the decision that "enough" has been done and it is time to go fly, knowing that if a mistake has been

made, someone can die. Yet it is the willingness of people to step into that lonely abyss of the unknown—whether it was Lewis and Clark exploring the western wilderness, Wilbur and Orville Wright launching the first powered aircraft, Charles Lindbergh setting off across the Atlantic, or Captain Charles "Chuck" Yeager pushing the X-1 through the speed of sound—that has allowed progress to occur.

"We do these things," President John F. Kennedy said in his famous 1961 space challenge, "not because they are easy, but because they are hard."[17] For 50 years, the Dryden Flight Research Center has been a place where "hard" problems have been welcomed. It is a place where people are encouraged to question and look for the unexpected, where it is understood that the answers exist and the challenge is to find them.

Hugh L. Dryden, the former NACA director of research for whom the NASA flight research center is named, once said that flight research separates "the real from the imagined."[18] His statement is true in more ways than one. In many cases, flight is that critical element in the interdependent disciplines of laboratory, wind tunnel and simulator research that finally turns an idea into hard, tangible reality. In every case, however, it forces researchers to go beyond imagined difficulties and grapple with those very real, critical problems that will make or break a technology or design.[19]

It is an effort not without risks or cost. Out of the original "X-series" and Douglas D-558 research airplanes, for example, four exploded while still attached to the launch aircraft, one crashed in a stall-spin accident, one came apart in mid-air, and one crashed after a catastrophic engine failure on take-off. Over the years, no fewer than nine aircraft have been lost and a number of pilots and crew members have given up their lives in the course of flight research projects associated with Dryden.[20] But the research conducted at the Center has also resulted in innumerable advances that have saved lives, led to the design of better and more capable aircraft, and expanded our understanding of the world and the atmosphere that surrounds it.

The Mojave Desert may be windy and desolate but, in retrospect, it is far from barren. For 50 years, its open spaces have contributed and been witness to the birth of discoveries that have repeatedly revolutionized the art and science of aeronautical design.

Cradled in the midst of that desert world, the Dryden Flight Research Center has grown from a small, temporary detachment to the premier flight research center in the country. And while Dryden has undergone a number of changes over the past half century, one thing has never varied. No matter what its size or research focus, the Center has always been a unique place where people work at the cutting edge of knowledge, where theoretical principle and real life come together, where discovery happens and where the imagined becomes real.





Brig. Gen. Albert Boyd, Commander of Muroc Army Airfield (which became Edwards Air Force Base on 5 December 1949) from September 1949 until February 1952, and Walter C. Williams, Director of the NACA High Speed Flight Research Station during the same period, examining a model of the Northrop X-4 research aircraft, which flew at Dryden from August 1950 through September 1953 (NASA Photo E95 43116-7)

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Chapter Two:

The Right Stuff[1]

The Dryden Flight Research Center is not a large facility. At its largest it employed 669 people, and as of 1995 its government staff complement was approximately 450. (By way of comparison, the civil service staff of the Langley Research Center in Hampton, Virginia, has numbered as high as 4,485; the Lewis Research Center in Cleveland, Ohio, 5,047; and the Marshall Space Flight Center in Huntsville, Alabama, 7,740.[2]) Yet this small desert facility has managed to make a tremendous number of contributions to NACA/NASA, the military, and the aerospace industry over the past 50 years. What made those contributions possible is a combination of facilities, people, partnerships, and a unique approach to management and problem solving that has characterized Dryden since its earliest days.

X-1E aircraft in front of the headquarters building at the Dryden Flight Research Center (NASA Photo EC96 43434-7)



Aerial view of Muroc Army Airfield, 10 October 1946, just ten days after Walt Williams and his small team had arrived and one day before the XS-1 (later redesignated the X-1) test program got underway with Bell test pilot Chalmers "Slick" Goodlin's first glide flight in the experimental rocket plane. The village of Muroc appears near the top-left corner of this photo with the tracks of the Atchison, Topeka & Santa Fe Railroad extending eastward across Rogers Dry Lake. (They would continue to bisect the lakebed until they were removed in late 1953.) The XS-1 fueling area and loading pit were located at the corner of the far west (left) end of the flightline, and a giant Northrop XB-35 Flying Wing prototype bomber may be seen taxiing across from the West Main Hangar. Williams' NACA team shared space, next door, in the East Main Hangar. Two smaller hangars are visible in a recessed area to the right of the main hangars. The one on the far right would be transferred to Williams' Muroc Flight Test Unit in April of 1948 and it would serve as "home" for NACA flight research operations for the next six years. (Air Force Photo)



The Place

The NACA engineers, technicians and support personnel from the Langley Memorial Aeronautical Laboratory [3] who arrived at the Muroc Army Airfield in September 1946 were faced with conditions that could only be described as primitive. Muroc had been divided into two areas: a South Base, where all training activities took place, and a more remote North Base, which was used for the Army Air Corps flight test work. At first, South Base had been little more than a tent encampment. Barracks, a control tower, a concrete runway and a sewage system had been added in 1943, but the conditions were still appallingly rough.

For work space, the NACA personnel were given part of one of two main hangars at South Base, and two small rooms for offices. The hangars were unheated and the desert sand and dirt blew through them constantly, creating an ongoing problem for technicians working with delicate instrumentation. Engineers would frequently have to sweep a layer of dirt off their desks in the morning before starting work. Flight test equipment was also rudimentary, especially by today's standards. The "control room" for the X-1 flights, for example, consisted of a small, mobile van with a radar antenna on top of it and a radio in the office of the Chief of Operations.[4]

Living quarters for the NACA employ-



Early "computers" at work, summer 1949. In the terminology of that period, computers were employees—typically females—who performed the arduous task of transcribing raw data from roles of celluloid film and strips of oscillograph paper and then, using slide rules and electric calculators, reducing it to standard engineering units. Clockwise from desk in center: Gertrude (Trudy) Valentine, Dorothy Clift Hughes, Roxanah Yancey, Geraldine Mayer, Mary (Tut) Hedgepeth, John Mayer.
(NASA Photo EC49 00053)

ees were even more problematic. Initially, the mechanics and engineers lived in a small, ramshackle shantytown halfway between the South and North Bases. The cluster of firetrap buildings there was known as "Kerosene Flats" because all heating and cooking had to be done with kerosene. An appalled visitor from the Langley Laboratory reported that the NACA employees at Muroc had "the choice of working or going to bed to keep warm. Reading or writing in your quarters is impracticable because of facilities and temperature."[5]

In late 1946, the Marine Corps closed its air station in the town of Mojave, some 25 miles away from the Muroc Army Airfield. As a result, Walt Williams, the head of the NACA contingent, was able to obtain permission for the married NACA personnel to move into the former base housing there. The single NACA employees, however, had to remain at Kerosene Flats until Williams finally won the battle to build new barracks for his staff at Muroc.

The battle over the barracks was actually part of Williams' effort to improve all of the NACA's facilities at Muroc. In addition to better housing, Williams wanted more hangar space and permission to build lean-to offices off the hangar. Somewhat ironically, the difficulty in getting permission to upgrade facilities stemmed from the fact that Muroc's base commander, a Col. Signa Gilkey, had a grander scheme of facility improvement in mind. Gilkey had created a "master plan" for the base that included expanding its property, building a new runway, and constructing new, permanent facilities halfway between the South and North bases. He apparently thought that if he allowed the NACA to build better facilities in its present

location, it might hurt his chances of getting approval for his master plan.

In the end, it took intervention by members of the National Advisory Committee for Aeronautics (NACA) itself to gain approval for new facilities. But in 1948, with the assistance of personnel from the NACA Ames Aeronautical Laboratory near San Francisco, lean-to offices and new men's and women's dormitories were finally constructed. Even then, the facilities were far from plush. The single men's and women's dormitories were wooden buildings with shared bathrooms, living room, and kitchen. Unlike the women, the men were not allowed to eat at the base officers club, but they did have their own cook.



Walt Williams in 1949. He began the year as Director of the NACA Muroc Flight Test Unit and remained the director on 14 November 1949 when the roughly 100 people working there became employees of the NACA High-Speed Flight Research Station. (NASA Photo E49 00170)

There were not many women who came out to work at Muroc, but those who did fulfilled an important role in the research program. A couple of them served as secretary/clerks, but in those pre-automation days, someone with a strong mathematics background had to take the raw data from flight instrumentation and convert it into a format the engineers could process. The women who did that were known, even then, as "computers," and they were a respected and essential part of the research team.

Interestingly enough, both the women and men who worked at the Muroc station seemed to take the inconveniences imposed by their harsh surroundings largely in stride. In part, they knew they were going to a remote outpost and hardly expected the lush green surroundings that existed at Langley. But there was also an acute awareness among the staff members that they were being given the chance to witness and help create history, and that that privilege was worth some sacrifices.

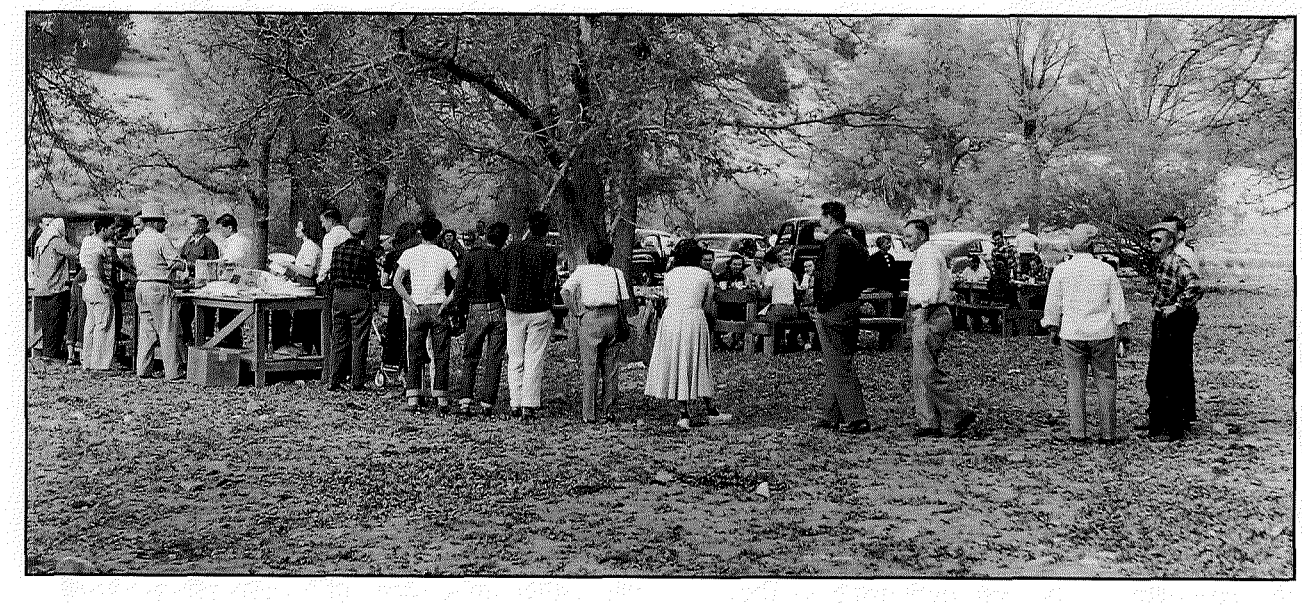
Muroc's isolation also helped the NACA staff become a close-knit group that both worked and socialized together. Group picnics, ski trips, and outings to local desert sites such as Willow Springs, the Tehachapi Mountains or even Los Angeles on the weekends helped mitigate the lack of entertainment on the base itself. Not surprisingly, more than a few marriages developed between the single women and men assigned to the NACA station.

The initial cadre of NACA personnel went to Muroc on a temporary duty status from the Langley Laboratory. By the fall of 1947, however, it had become clear to NACA managers that the group was going to be there awhile. In early 1947, the Army Air Forces and NACA had signed an agreement for joint cooperation on a complete series of X-planes from the X-1 to the X-5, all of which would be flown at Muroc. Consequently, the NACA contingent was made a permanent facility, still under Langley management, known as the NACA Muroc Flight Test Unit.

In 1949, Muroc was renamed Edwards Air Force Base, in memory of Captain Glen W. Edwards, an Air Force test pilot who had been killed in the crash of a YB-49 Flying Wing. That same year, the name of the NACA facility was changed to the NACA High Speed Flight Research Station (HSFRS), underscoring the emphasis of the work the group was conduct-







Top left. Workers constructing NACA building, December 1949 (NASA Photo E49 00234)
Top right. NACA Muroc personnel with snowman (1949). Standing (viewer's left to right): Mary (Tut) Hedgepeth, Lilly Ann Bajus, Roxanah Yancey, snowman, Emily Stephens, Jane Collons, Leona Corbett, Angel Dunn. Kneeling (left to right): Dorothy Crawford Roth, Dorothy Clift Hughes, and Gertrude (Trudy) Wilken Valentine. (NASA Photo E49 00212)

Left. NACA Muroc unit staff barbecue, 1949 (NASA Photo E49 00236)

ing. Yet it remained a division of Langley until 1954, when it was redesignated the NACA High Speed Flight Station (HSFS) and made an autonomous facility reporting directly to NACA headquarters. That same year, the Station's employees, who now numbered 250, moved into new facilities halfway between the South and North Bases. Those facilities have been expanded since that time, but they are still in use today.[6]

To many people who worked at the HSFS, the 1950s were their golden years. Jet noise, rocket sounds, and sonic booms shattered the desert air throughout the day, and NACA's "stable" was filled with exotic X-planes and new configuration fighters. Speed and altitude records were being set on a regular basis, and there was a tremendous public fascination with the activities at Edwards that grew as the X-planes reached higher and higher altitudes and speeds. The Station's fame, prestige and priority status at the NACA probably reached its peak with the X-15 program, which made its first flight in 1959, just after the NACA became the National Aeronautics and Space Administration (NASA) and the space race began. That same year, NASA renamed the Edwards station once again, redesignating it as the NASA Flight



Paresev and crew with one of its tow aircraft, a Stearman biplane, on lakebed; Milt Thompson seated in Paresev and, to his right, a motorcycle with driver who served as the chase observer during lift-off and low-level flights. (NASA Photo E 8713)

Research Center (FRC).

In terms of size, the era of the X-15 was the high-water mark for the Flight Research Center. The X-15 was a joint project with the Air Force and Navy, but it still required a tremendous number of support personnel. The FRC staff during that time grew to over 600, and the NASA facilities at Edwards were expanded in 1963 to accommodate the larger staff. The X-15 also received a tremendous amount of public attention, since its pilots were flying much faster and higher than anyone had ever gone before. Slowly, however, the X-15 began to be eclipsed by the Mercury, Gemini and Apollo space programs. A craft that could fly back from space had been put on the back burner in favor of a simpler ballistic capsule design and, with the Mercury missions, more of NASA's resources and the nation's focus turned toward the space centers of Johnson and Kennedy.

In an effort to keep the concept of a flyable space vehicle alive, FRC engineers began flight research of lifting body shapes and concepts. That work later contributed valuable information to the Space Shuttle program, but its worth was not universally recognized at the time. In fact, as the X-15 program wound down in the mid-1960s, the House Committee on Science and Astronautics recommended the closing of the Flight Research Center, as "no future activity beyond the X-15 would require the existence of the center."[7]

This evaluation was proven wrong, but it pointed out to FRC Director Paul Bikle the danger of having the Center dependent on a single research project. In 1963, Bikle's staff compiled a 5-year plan for the Center that outlined a number of projects the Center could pursue that would support both the space



SR-71 being worked on at night on ramp. The aircraft was one of three SR-71s loaned to NASA by the Air Force for use as high-speed, high-altitude testbeds for research in such areas as aerodynamics, propulsion, structures, thermal protection materials, and instrumentation. Data from the SR-71 research program could aid designers of future supersonic/ hypersonic aircraft and propulsion systems. (NASA Photo EC92 3103-8)

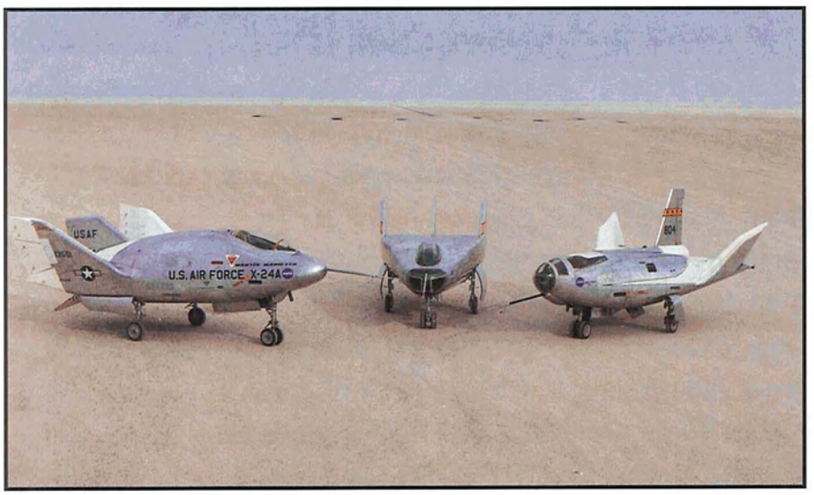
program and the development of a Supersonic Transport (SST). Fortunately, both of those programs were high national priorities in the late 1960s, and congressional funding for the Center was kept intact.[8]

The late 1960s and 1970s, then, saw the Center diversifying into several different research areas—not only because Bikle wanted to develop a broader base of research, but also because the Center was receiving a growing number of external requests for joint research efforts. In addition to lifting body and Lunar Module research to support the space program, the FRC conducted high-speed research with the XB-70A and the YF-12 supersonic aircraft. At the same time, the Center delved into digital fly-by-wire, supercritical wing and winglet research, wingtip vortex analysis and a number of other research programs. It was during this time that the Center was renamed once again, in honor of Hugh L. Dryden, the internationally renowned aerodynamicist who had been the NACA's Director in the FRC's early days. On March 26, 1976, the Center became the Hugh L. Dryden Flight Research Center.



This painting by Stan Stokes of the X-15 rocket aircraft is part of the NASA Art Program. First flown in 1959 from the NASA High Speed Flight Station (renamed the NASA Flight Research Center that year and the Dryden Flight Research Center in 1976), the rocket-powered X-15 was developed to provide data on aerodynamics, structures, reentry characteristics, heating, reaction and other flight controls, instrumentation, and the physiological aspects of high speed, high altitude flight. Three were built by North American Aviation for NASA, the Navy and the Air Force. They made a total of 199 flights during a highly successful research program lasting almost ten years. Their speed and altitude records for winged aircraft remained unbroken until the Space Shuttle first returned from Earth orbit in 1981. (NASA Photo EC94 42909-1)

Despite its efforts to diversify, Dryden once again faced a challenge when the YF-12 program ended in 1979. The number of employees was scaled back, and the Center was forced to reevaluate its future direction. Then, while it was still in the process of redefining itself for the needs of the 1980s and beyond, the Center was hit with another rough adjustment. Its status as an independent NASA center was taken away, and it was redesignated as a Flight Research Facility under the administration of the Ames Research Center near San Francisco.



These wingless, lifting-body aircraft sitting on Rogers Dry Lakebed are, from left to right, the X-24A, M2-F3, and HL-10. The lifting-body aircraft studied the feasibility of maneuvering and landing an aerodynamic craft designed for reentry from space. Launched by a B-52 mothership, the lifting bodies flew, powered by their own rocket engines, before making an unpowered approach and landing. They helped validate the concept that a Space Shuttle could make safe, accurate, landings without power. (NASA Photo ECN 2359)



The No. 2 X-29 technology demonstrator aircraft, flown by NASA's Dryden Flight Research Center in a joint NASA-Air Force program to investigate the unique design's high angle-of-attack characteristics and its military utility. Angle of attack is the angle of an aircraft's body and wings relative to its actual flight path. This aircraft was flown at Dryden from May 1989 until August 1992. (NASA Photo EC90 0039-4)

Putting Dryden under the auspices of Ames was actually one of several consolidation moves NASA made in 1981 in an effort to conserve money and resources. Combining Dryden and Ames, it was reasoned, would eliminate duplication of many administrative functions. Yet regardless of the reason, going from an autonomous facility to one that required Ames' approval for its activities was a difficult change for the independently-minded Dryden employees to accept. Part of the problem was that having to obtain approval from managers over 300 miles away, who often went months without ever seeing the people they were supervising, slowed down the speed with which projects could proceed. The Ames directors did attempt to maintain the flexible and exploratory communication style that managers and employees at Dryden had developed over the years, and they remained strong supporters of the flight research Dryden was conducting. But it was sometimes difficult for off-site managers to understand the need or importance of some of Dryden's activities or requests, and both communication and management relations were hampered by the 300 mile distance between the two facilities.

Nevertheless, the merger was the way of the world, at least for the time being, and the

work at Dryden continued. In fact, the 1980s saw the development of the first significant X-plane since the X-15. In 1984, the radical forward-swept wing X-29 made its first flight. And if speed was perhaps less of a driver than it had been, especially in military aircraft design, there was a great deal still to be learned about improving systems and making aircraft more maneuverable and efficient.

Dryden's work in the 1980s included the beginning of the High Alpha (Angle of Attack) Research Vehicle (HARV) F/A-18 program, the Highly Integrated Digital Electronic Control (HIDEC) F-15 program, the Advanced Fighter Technology Integration (AFTI) F-16 project, and the AFTI F-111/Mission Adaptive Wing (MAW) effort, as well as the Highly Maneuverable Aircraft Technology (HiMAT) remotely piloted vehicle research. The facility also broke ground in 1987 for a new $16.1 million Integrated Test Facility (ITF).[9] The new building would include not only office space, but hangar space designed for working on modern, computerized aircraft; simulator facilities that could even be connected to the actual aircraft cockpits; and facilities for rapid aircraft systems check-out and troubleshooting. With the ITF, Dryden would be better prepared for the computer-driven information age, both in aircraft and on the ground.

By 1990, NASA headquarters had come to the conclusion that Dryden's dependence on Ames for all its decision-making was causing more difficulties than it was solving, and a number of administrative functions were relegated back to Dryden. The head position of Dryden was upgraded from a "site manager" to a "director" level, reflecting the increase in control over the facility's activities. Over the next four years, Dryden moved slowly back toward independent operation, and in March 1994, Dryden was officially redesignated as an autonomous NASA Center.[10]

The move in part reflected NASA's recognition of the continuing importance of flight research and the invaluable resources that Dryden's clear skies and open-desert surroundings provided. In fact, soon after Dryden was redesignated as a center, senior staff at NASA began investigating the idea of moving all of the agency's aircraft and flight research activities to Dryden.

But more than anything else, Dryden's shift back to the status of an autonomous center reflected NASA's recognition of the fact that bigger was not always better. Left on its own, the small, sometimes irreverent center in the desert could operate much like the innovative and effective "Skunk Works" that Kelly Johnson had created for the Lockheed Corporation in 1943. Dryden's particular mission, location, personnel and circumstances had created what Center Director Kenneth J. Szalai described as "a unique way of doing business" that operated more effectively than anything outside managers could impose.[11]

A Unique Approach

Dryden's "unique way of doing business" was a result of a number of factors that have characterized the Center throughout its 50-year history. First, the Center has always been small, remote, and independent. From the early days, there were never quite enough people for the tasks at hand, so employees got used to being flexible and performing whatever job had to be done. The fact that it was small and not easily accessible also meant that it had to contend with less bureaucracy and politics than

many other NACA/NASA centers. Even today, managers are likely to simply "run into" anyone they need to consult several times in the normal course of their day, either in the halls or the center's small cafeteria. This allows an informal, face-to-face management and problem-solving style that is low on paperwork and still highly efficient and effective.

Dryden's small size also meant that it often had to draw on the expertise and cooperation of other NASA centers, research facilities, and industry in order to accomplish its research. As a result, the Center has developed strong ties with external sources that have led to many important joint research efforts and have helped transfer new technology back to others who could use it.

Furthermore, Dryden's single mission of flight research has given the Center a very practical focus around which all activities and efforts revolve. Although it retains a nominal organizational structure based on research disciplines, such as aerodynamics, structures, etc., Dryden has always relied on matrix management to operate its flight research programs. A matrix structure creates a team of people from various disciplines to work on a particular project, led by a program manager. At the center of each team is not any particular discipline of research, but an aircraft. This "real world" tie requires people to work as a team and forces everyone to remain focused on practical applications and solutions.

This practical mind-set is reinforced by the fact that many of Dryden's employees have worked there a long time. Much of their expertise, therefore, comes not from a textbook or procedure manual but from the numerous projects they have worked on before. In fact, Dryden's official operating manual still consists of a mere two pages of policies. The rest of its five volumes are simply procedures that offer guidelines based on what has worked with previous Center projects.

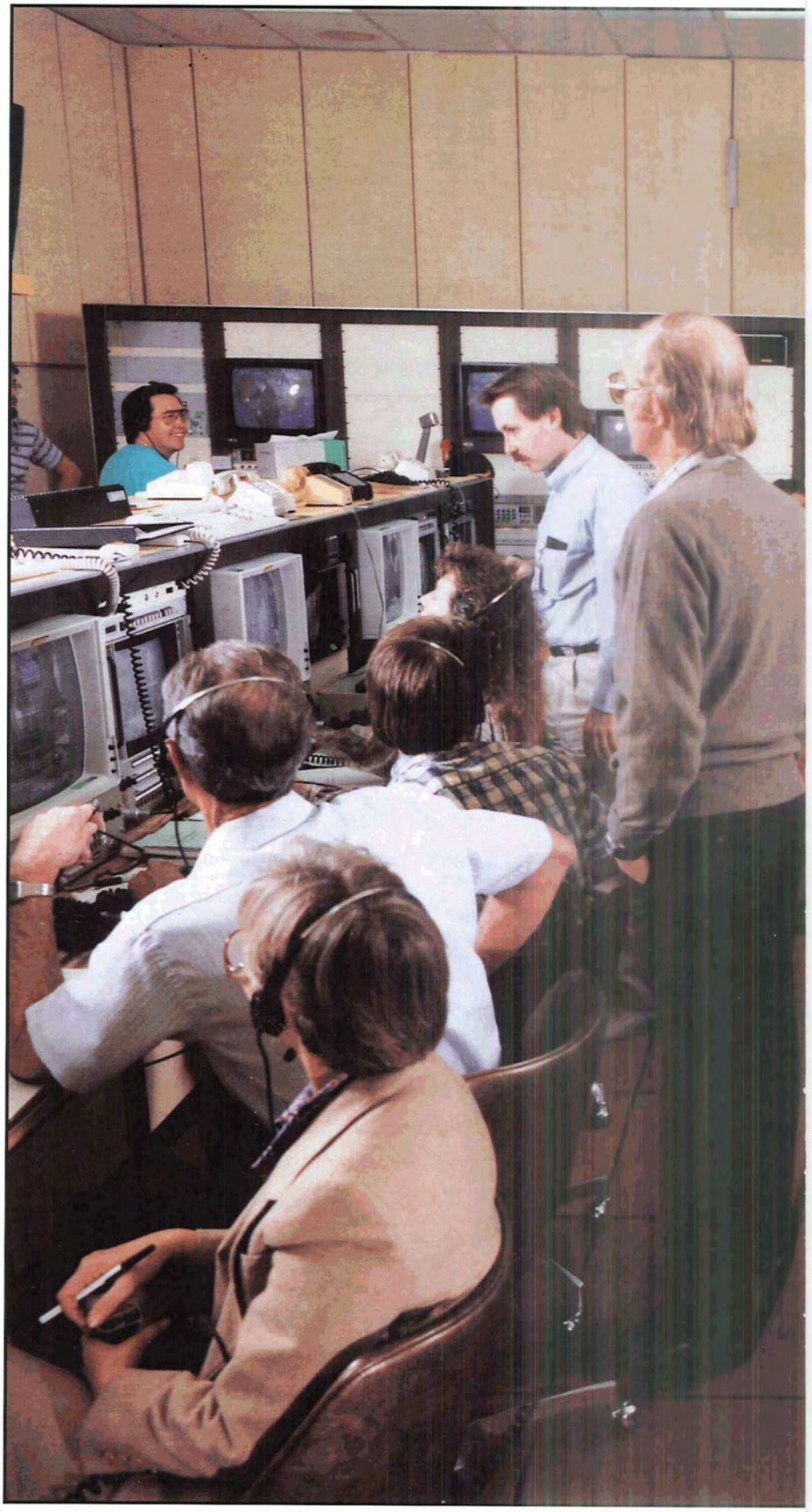
The structure of Dryden's operating manual reflects not only a reliance on a human corporate memory, but also a belief on the part of Center management in empowering its employees to simply "get the job done." If a problem arises at 8:00 at night and the airplane is scheduled to fly at 8:00 in the morning, the most important goal is to find a solution that works. In the minds of Dryden's managers, a thousand procedures cannot cover the myriad of contingencies encountered in flight research as well as the resourcefulness of employees challenged and empowered to find creative solutions.

This attitude also creates an environment where innovation and experimentation are more likely to occur. The lifting body research, for example, started as a "backyard" project by several researchers who believed a craft could be flown back from space. Knowing it would be difficult to get approval for a formal program through accepted channels, they went about proving the concept themselves first, with a small amount of FRC money, a steel-tube-and-plywood wingless aircraft, and a souped up Pontiac tow vehicle. The success of their design led to a formal research program which, in turn, significantly influenced the design of the Space Shuttle. But without feeling that they had the freedom to innovate; to venture ever so slightly beyond the lines imposed by formal procedures and programs, the researchers who instigated the lifting body effort would never even have attempted the project.

This kind of support for individual innovation at Dryden has endured over the

years. And NASA supports this kind of grass roots effort by including a small "director's discretionary fund" in centers' budgets to allow researchers to explore concepts that might be outside the scope of existing formal research programs, but which still might generate important results.[12]

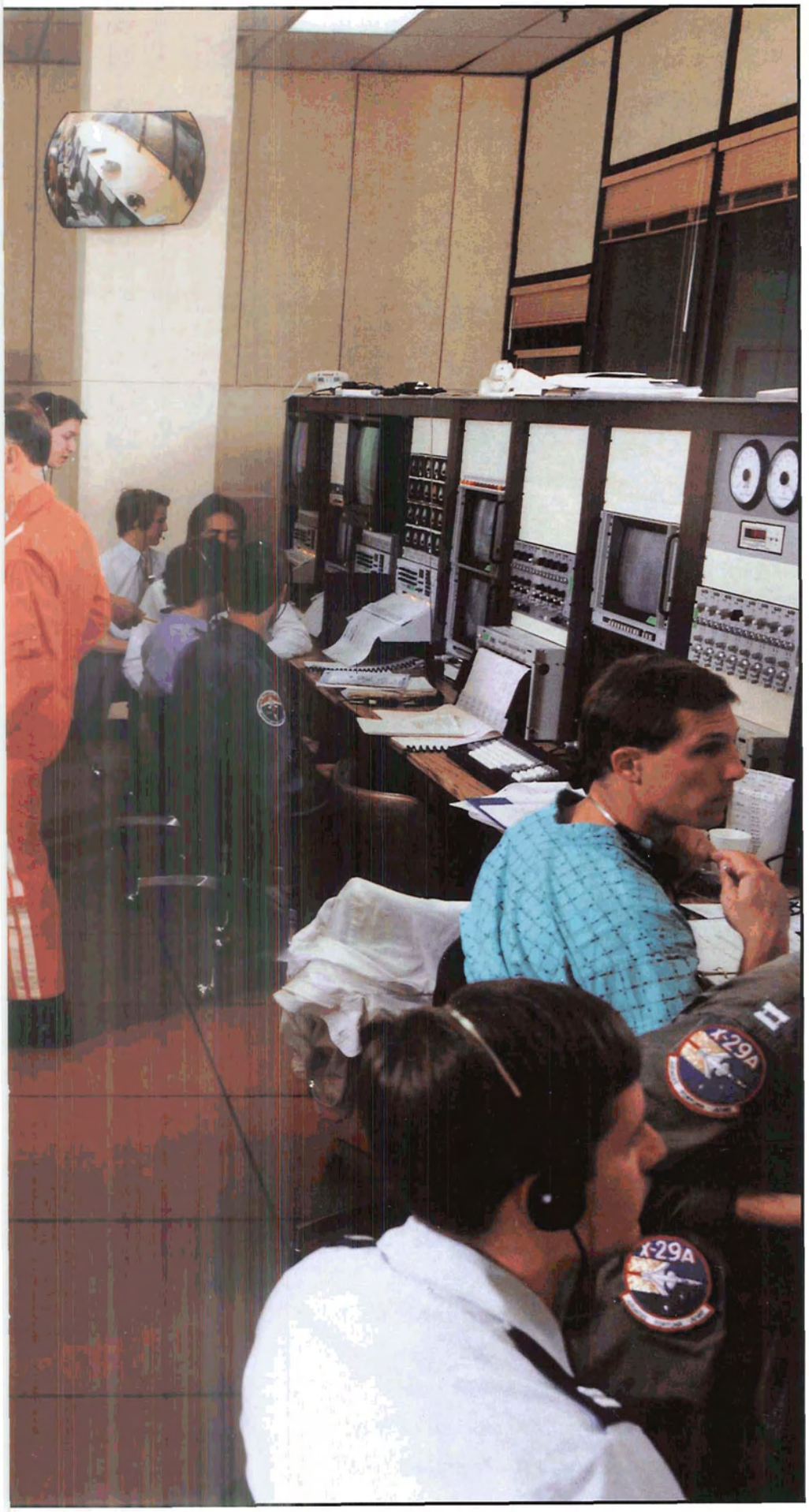
All of these elements—this individual empowerment, a freedom to innovate, a staff accustomed to being flexible and working on several projects at once, a long corporate memory, the informal management style allowed by the center's small size, and an ever-present focus on practical solutions—have created a unique atmosphere at Dryden that is particularly well suited for flight research. These same elements have also given the center a capability described as "technical agility," or the ability to adapt and adjust resources to meet constantly changing needs. It is this quality that has allowed Dryden to accommodate not only changing national research goals, but also the estimated 50 percent of its research projects that are requests for help from other sources.[13]



The People

Without question, the facilities themselves and the Center's unique environment have played a big role in the contributions Dryden has made over the years. But another of the Center's most valuable resources has always been its people.

From its very earliest days, it took a special kind of individual to work at the desert station. Even today, with all the growth that has come to the Palmdale and Lancaster communities south of Edwards Air Force Base, a prospective employee is unlikely to choose Dryden



Gold control room during X-29 flight.
(NASA Photo EC89 0300-1)

because of its location. For the past 50 years, most of those who have come to work at the Center have done so for one reason: they love airplanes, and they want to do flight research badly enough that they are willing to live in the Mojave desert in order to do it. The advantage of this fact, of course, is that Dryden's employees have always tended to be very dedicated to their work.

The most visible of those employees have always been the pilots. They are the ones whose pictures appear next to the airplanes, the "Iron Men" of the rocket era who became heroes to millions of American children. One reason pilots have always had such a high profile is simply that they perform the most visible piece of the many elements involved in any research project. For all the sketches, calculations, wiring, and measurements that are completed ahead of each flight, the pilots are the ones who actually climb into the hardware and take it up in the air. But by the same token, the flight crews are also the only members of the research team who actually risk their lives to gain new knowledge or understanding.

Some features of NACA/NASA pilots have changed over the years. In the early days, although Dryden research pilots had Bachelor of Science degrees, they were more likely to be "stick and rudder" men who knew more about flying than they did about systems and who taught themselves the observation and reporting skills necessary for flight test or flight research. Today, NASA research pilots typically possess

not only Bachelor of Science degrees, but also quite possibly Masters degrees, and have formal test pilot school training or some equivalent experience. The few pilots hired in recent history at Dryden who had not already completed test pilot training were sent through the Air Force school at Edwards Air Force Base. As a result, current NASA pilots tend to be more knowledgeable about systems and systems safety than their predecessors were.

Yet many aspects of the research pilot's job have not changed. The job has always required excellent, almost faultless, flying skills. For researchers to get the data they needed, the pilots need to be extremely precise in all of their maneuvers, because at the edges of an aircraft's performance envelope or at speeds of Mach 3 or Mach 6, there is little margin for error. In addition, no matter how they got their training, the pilots have to be able to observe and report the nuances and peculiarities of an aircraft's performance in clear, specific terms.

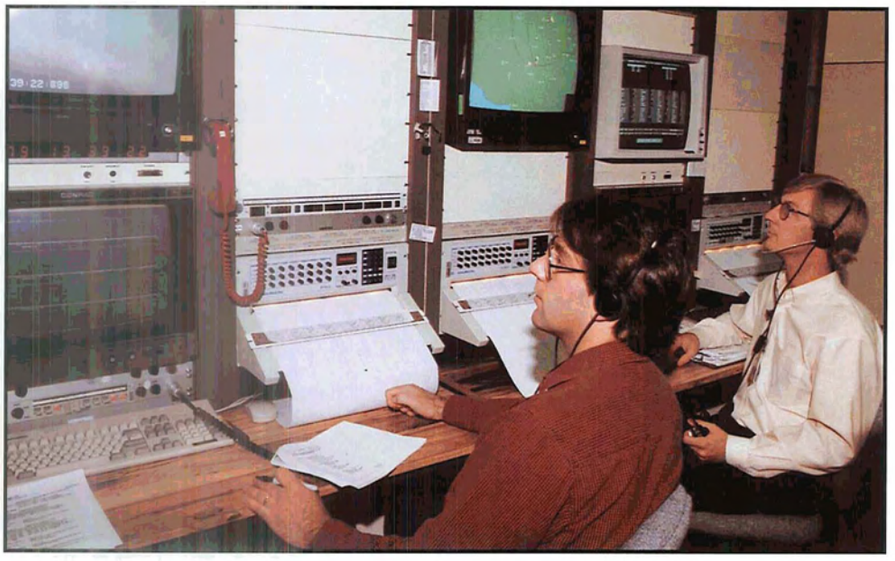
Being a research pilot also has always entailed a certain degree of risk. Street names at Edwards Air Force Base that memorialize pilots who didn't come back are a constant reminder of the price sometimes exacted for progress in knowledge or aircraft designs. Pilots rarely talk of danger or fear, but they do acknowledge risk. "If we're doing something new, then by its very nature, we are stepping into arenas where we use all of these capabilities, all of these tools, to minimize the risks and maximize the chance of success, but there are still elements there that are unknown," says NASA research pilot Rogers Smith.[14]

Thirty or forty years ago, the risks were higher because computer ground test and simulation technology was not nearly as advanced. The X-15 pilots, for example, were exploring altitudes and speeds far beyond anything that was known. No amount of wind tunnel model testing could really predict what an actual aircraft would do at Mach 6 or 50



F-18 simulator with Martha Evans, simulation group leader, at the controls (NASA Photo EC93 3171-1)

miles above the Earth's surface. Not surprisingly, the accident and pilot loss rate was also much higher thirty years ago than it is today. Yet the risk is always there. Despite all the advances in technology and simulation, an X-31 research plane was still lost in January 1995. The pilot managed to eject safely, but he only had approximately two seconds to identify that a problem existed, gauge its severity, make a decision and punch out of the aircraft.[15]



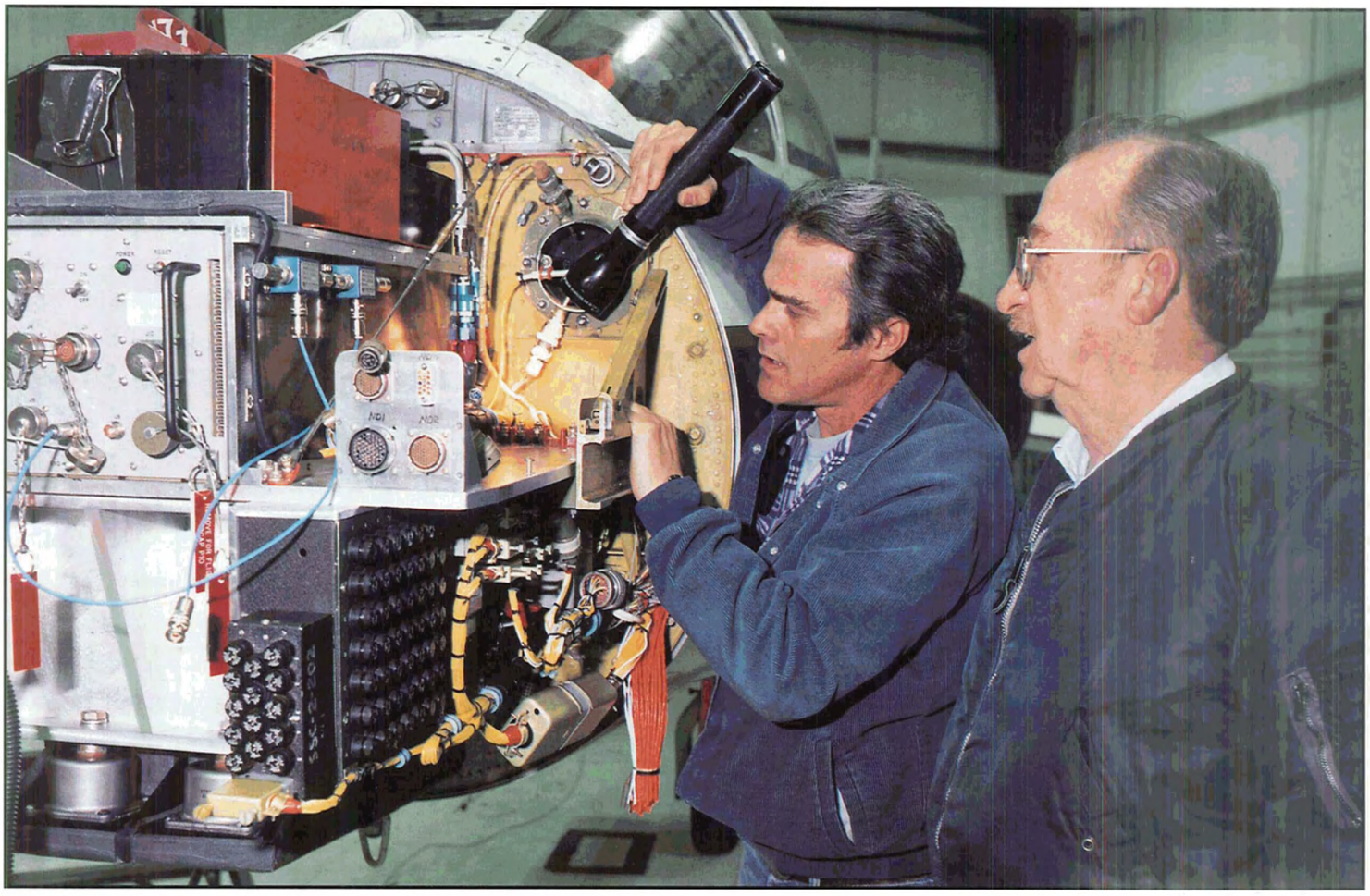
Close-up of researchers in control room for the F-15 HIDEC flight research; John Orme, (on right) and Gerard Schkolnik (center) (NASA Photo EC93 42219-5)

Even normal operating circumstances in research flying can be extremely challenging, both physically and mentally. One of NASA's SR-71 pilots reported that he could tell how proficient he was in the Mach 3 airplane by how long into the flight it took him to uncurl his toes. Some of the maneuvers required for test purposes would be more uncomfortable than most people could stand. A textbook definition of an F-18 spin, for example, might describe it as having "a medium yaw rate mode, oscilliatory in all three axes," with a note that "a post-stall gyration may occur." What this means for the research pilot, however, is that he will be thrown about as if he were inside a washing machine, and after he stops the spin, the aircraft is likely to snap upside down suddenly and hang motionless in the air.[16]

It takes a special kind of person to be both able and eager to take on these kinds of challenges. Certainly, many different types of pilots have climbed into Dryden's cockpits over the years, but they seem to share several important traits. Beyond simply being highly capable, confident, and observant, good research pilots possess a driving curiosity for new challenges and knowledge that could be described as "technical passion." They want to learn what is



Electronics technician Bill Clark making a cannon plug as Jim Lewis looks on (NASA Photo EC91 134-29)



F-104 nose instrumentation and technicians Keith Wright (holding flashlight) and Gaston Moore (NASA Photo EC91 134-4)

beyond the limits of our current knowledge—badly enough that they are willing to take the calculated risks and discomfort the journey may entail. And while they all have undoubtedly had moments of anxiety or high tension, they focus on preparing well for each new challenge and handling any contingencies in a professional manner. As veteran research pilot William H. Dana said, "I've been scared a few times flying research missions, but my real fear was screwing up."[17]

This fear of not measuring up reflects a pride in their profession that NASA's research pilots all seem to share. "The flying we do is a craft," explains pilot Ed Schneider. "Your hands, your brain, and your artistic talent literally are combined together . . . and, like the guilds in the middle ages, we pass that knowledge down to new pilots."[18]

Yet despite the visibility of their position, the research pilots are very aware that they constitute only one element of the project team. A typical project will include research engineers, operations engineers, and a project manager, in addition to data systems engineers, technical and support staff. Research engineers work on designing the experiments and analyzing the results, while operations engineers make sure the modifications will not compromise the integrity or safety of the aircraft. The project manager is responsible for keeping the project on schedule and budget and coordinates the various efforts and work tasks. These three forces clearly have slightly different agendas,



Gold control room during F-15 flight. (NASA Photo EC93 42219-Fr.2)

but they are designed to balance each other to keep research efforts both on track and safe. Indeed, staff members are so acutely aware of the real-life consequences of any mistakes that they tend to be very outspoken about their views. As Dryden employees say, "there are no secrets in flight research." There cannot afford to be. And any project team member, from research engineer to the pilot himself, has the power to stop a flight if he or she feels there is a safety-of-flight issue left unresolved.[19]

In addition, Dryden is such a small facility that most employees can see, within one or two steps, the direct impact of their efforts on a flyable aircraft. This helps maintain the high morale and enthusiasm that, in turn, make the Center's "technical agility" possible. Delaying an ongoing project to incorporate a new research effort can be frustrating; yet it is the ability to reassign personnel according to need that allows Dryden to conduct such a wide range of research with its relatively small staff. Seeing the tangible results of their efforts helps staff members cope with these kinds of frustrations. It also makes employees more aware of the fact that the efforts of many other people may hinge on successful completion of their particular task. Consequently, when a problem occurs that could stop a scheduled flight the next day, it is not unheard of for researchers and technicians to work through the night to find a solution.[20]

The Partnerships

Dryden's own employees are not the only people whose dedication has been essential to the Center's contributions, however. Since the first group of engineers came to Muroc with Walt Williams to support the Army/Bell Aircraft/NACA X-1 effort, Dryden's research has been characterized by partnerships. Some were fairly simple pairings, involving only Dryden and a single contractor, or Dryden and another NASA center. Others—such as the X-1, X-15 and X-29 projects—have involved one or more contractors, several NACA/NASA centers, and one or more branches of the military. And the X-31 program involved not only U.S. contractors, the U.S. Navy, the U.S. Air Force, the Advanced Research Projects Agency (ARPA) and NASA, but the German Air Force and a German contractor as well.

In a sense, the type of work Dryden does requires partnerships. In many cases, Dryden has been the last stop on an idea's journey from

someone's mind to a flyable system. That idea might have originated in a researcher's mind at the Ames Research Center, as in the case of the M2 lifting bodies, or in the mind of an engineer at the Langley Research Center, as was the case with the supercritical wing. It might have come from the Defense Advanced Research Projects Agency (DARPA), like the X-29, or from an individual contractor's shop, as the Pegasus project did. The ideas may have been run through computational fluid dynamics analysis and wind-tunnel tests elsewhere. They come to Dryden to be explored in a real-world environment, but that work requires a partnership between flight research specialists and the people who have developed the original idea.

Dryden's partnerships also stem from the fact that flight research requires hardware, which NASA is not usually in the business of building. As a result, Dryden has always had ongoing partnerships and relationships with the aircraft manufacturing industry. Furthermore, the fact that Dryden is located on Edwards Air Force Base and uses Air Force facilities on a regular basis has required an ongoing partnership between the Center and the Air Force.

Although all of these relationships have had their advantages and have allowed Dryden to accomplish the work it has over the past half century, maintaining partnerships can be a challenging task. NASA and the Air Force, for example, have not only different agendas and missions but different operating cultures as well. Over the years, both the Air Force Flight Test Center and Dryden have learned a lot about working together, but creating and maintaining a smooth working relationship still requires effort.

In some ways, the success of a partnership depends on the dynamics of the particular project. On the X-1, for example, the Army Air Forces and the NACA had different objectives. The NACA wanted to proceed methodically and gather as much data as possible, while the Army wanted to forge ahead and conquer the sound barrier as soon as possible.[21] With the X-15, on the other hand, the two organizations had more compatible goals, which helped the partnership work more smoothly. In general, partnerships have seemed to work best when there were clear, common objectives. If members began to feel that the program was moving away from their area of interest or expertise, however, problems were more likely to occur.

Yet even when there are common objectives, there are still challenges to be overcome for a partnership to be successful. Lines of authority in joint efforts are not always clear, and different organizations' procedures and requirements do not always mesh. Successful partnerships, therefore, require skillful negotiation, cooperation, and team-building efforts. Individual relationships are critical, and many partnerships evolve from a rocky beginning to a point where the members have developed enough of a rapport and trust among themselves to develop procedures and approaches that are agreeable to everyone. Team cooperation is so important that, as one Dryden manager said, "You draw up an organizational chart, but if you ever have to pull it out of the drawer and actually look at it, you're in trouble." With a partnership as complex as the X-31, some of the potential turf issues were diffused by consciously downplaying all individual identities in favor of an "X-31 team" identity. The partnership was also aided by the fact that the new Integrated Test Facility (ITF) at Dryden could house all the different team members in the same place. That close proxim-

ity encouraged both individual interaction and informal problem solving, which helped the team overcome its significant organizational challenges.[22]

Clearly, successful partnerships require a lot of work. But they also offer benefits that make the effort worthwhile. One obvious benefit is that partnerships can support projects that are beyond the capabilities of any one organization. But there are other advantages as well. Through some of its industry partnerships, for example, Dryden has found itself simultaneously in the position of both teacher and student, learning about the practical applications of technology as it shares its expertise in developing and testing new concepts. Partnerships also give Dryden's researchers a real-world anchor and a "customer" orientation, helping them understand the needs, pressures, and concerns of those who will actually apply new technology. In addition, joint efforts help transfer new technology by strengthening individual relationships between NASA and industry or military personnel and creating champions for new concepts within organizations or companies.



Walter C. Williams Research Aircraft Integration Facility (formerly, Integrated Test Facility) soon after the dedication of the facility to the first director of what became the Dryden Flight Research Center (NASA Photo EC96 43393-1)

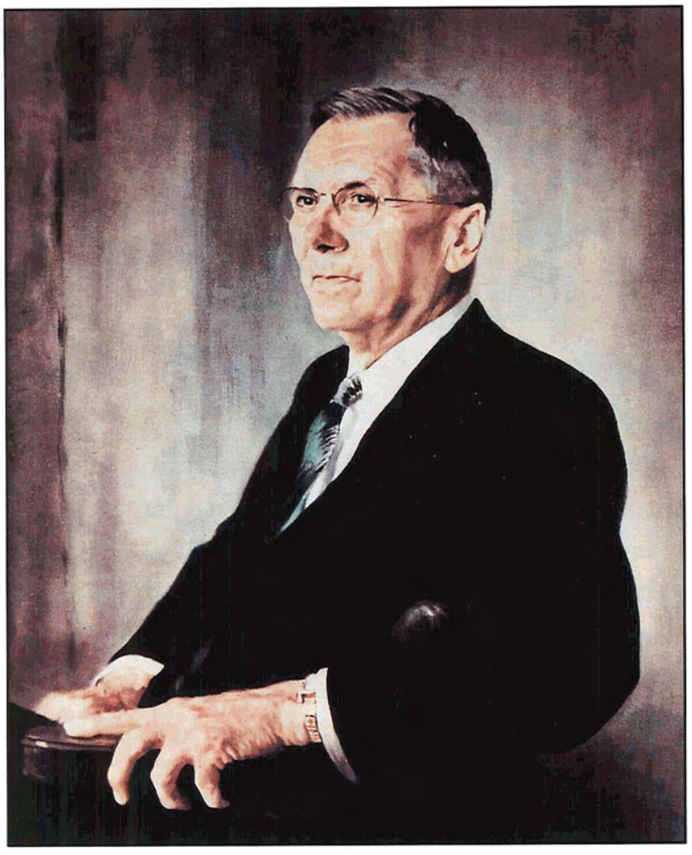
Furthermore, if budgets continue to decrease and pressures to "downsize" increase, partnerships will undoubtedly become even more common. In 1995, for example, the Dryden Flight Research Center and the Air Force Flight Test Center signed an Alliance agreement seeking to develop any and every opportunity to cooperate and share resources, from aircraft flight time and laboratory space to on-site child-care facilities.[23]

Conclusion

The contributions the Dryden Flight Research Center has made to aeronautics and aerospace technology over the past half century have been the result of many people's efforts and many factors that have helped make those efforts possible. Since its origins as a small desert outpost of the Langley Laboratory, Dryden has been a unique place. Certainly its physical environment is unlike that at any other NASA center. But its desert location and single-minded mission have also attracted a certain type of person and encouraged the development of a particular management style well-suited to flight research.

Without question, the physical surroundings at Dryden are very important for its flight research activities. But the most valuable assets at Dryden are not its open skies or even its aircraft, but its people. Without all the individual research team members, the pilots, and a set of pragmatically minded managers, and without the ideas and efforts of its many partners, no flight research would have occurred. It was the unique combination of these factors—the Center, its people, its particular management style, and its partnerships—that gave Dryden "the right stuff" to make its many contributions possible.

Reprinting of an article from the Dryden newspaper, the X-Press, summarizing the life of Hugh L. Dryden on the occasion of the renaming of the NASA Flight Research Center in his honor on 26 March 1976.



Painting of Hugh L. Dryden, for whom the Dryden Flight Research Center was named, by Albert Murray of New York. (NASA Photo EC94 42724-1)

50 Years of Flight Research

Dryden Flight Research Center Dedication Ceremonies, March 26, 1976

This year we celebrate Dryden's anniversary year. In recognition of this event, the X-Press will reprint historical articles, features and photos of events in the past 50 years.

The following is a reprint of an article from the March 26, 1976 edition of the X-Press, commemorating the occasion of the dedication and renaming of the NASA Flight Research Center in honor of Hugh Dryden, with slight corrections for accuracy.

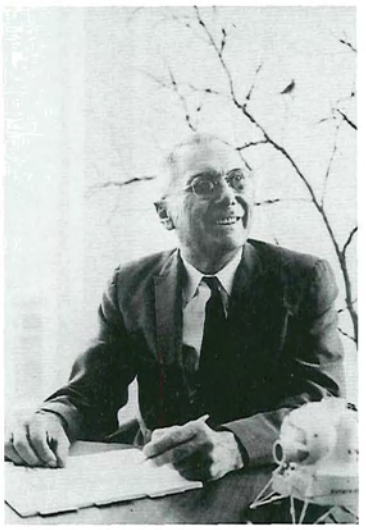
Hugh Latimer Dryden knew Orville Wright and he knew John Glenn.

Dr. Dryden was born in Pocomoke City, Maryland, on July 2, 1898. He was five years old when the Wrights first flew off the dunes at Kill Devil Hill, North Carolina, in 1903. Years later he was fond of remarking, "the airplane and I grew up together."

In 1907 the Dryden family moved to Baltimore where young Dryden saw his first airplane. He was fascinated by the birdlike silhouette of the craft, but he was not much impressed by its performance.

In 1913, at the age of 14, he graduated from Baltimore City College, which in that day was a high school. He went to Johns Hopkins University to receive his bachelor's degree in three years, which he took with honors in 1916. He went on to graduate school to receive his master's degree in 1918. The title of his master's thesis was *Airplanes: An Introduction to the Physical Principles Embodied in Their Use.*

In June of 1918, Dryden joined the staff of the National Bureau of Standards as an inspector of gauges. With the encouragement of Dr. Joseph S. Ames, who at that time was head of the Department of Physics at Johns Hopkins, and a member of the newly created National Advisory Committee for Aeronautics (NACA), Dryden obtained a transfer to the Bureau's recently created wind tunnel section. At the same time Dr. Ames arranged to give advanced courses for a number of Hopkins graduates. This allowed Dryden to complete his doctoral requirements while being employed full time.



HUGH L. DRYDEN - ***NASA Flight Research Center photo #29389***

Youngest Ph.D.

Dryden received his Ph.D. in physics and mathematics in the spring of 1919. He was only 20 years old and he remains the youngest student ever to have received a Ph.D. from Johns Hopkins. The title of his thesis was *Air Forces on Circular Cylinders*; in it he described experiments on the drag and distribution of air flowing around cylinders perpendicular to the wind.

It was also in Baltimore that Dryden met Mary Libbie Travers. On Jan. 29, 1920 they were married.

In the same year Dryden became the head of the Bureau's Aerodynamics section, and continued his researches on turbulence.

In 1924, collaborating with Lyman J. Briggs, his mentor and friend and later director of the Bureau, he made some of the earliest scientific investigations of airfoil characteristics at flows up to the speed of sound -- and even slightly beyond. In a day when the fastest racing planes did well to fly at 280 mph, Dryden was already probing the transonic range of supersonic flight.

Since 1931 Dryden had been a member of the NACA's Committee on Aerodynamics, and in 1934 he became Chief of the Bureau of Standards' Division of Mechanics and Sound.

When the National Defense Research Committee and later the Office of Scientific Research and Development (OSRD) were created in 1940, Dryden took charge of one of the OSRD's guided missile sections. He was specifically charged with the development of a radar guided missile of aerodynamic characteristics, or a glide bomb. For his work on the BAT (glide bomb) he received the Presidential Certificate of Merit.

Dryden's work with OSRD marks his first experience in managing a large research and development project from concept to hardware; and it marks the beginning of the end of his original, creative scientific career and the start of his administrative career. Concurrently with his work for the Bureau of Standards, OSRD and NACA, he was also the Deputy Director, Scientific, of the U.S. Army Air Forces Scientific Advisory Group headed by Dr. Theodore von Karman.

Medal of Freedom

Von Karman's group produced a series of reports, titled collectively *Where We Stand*, and *Toward New Horizons*. For his contributions to these reports and by the direction of General Henry H. "Hap" Arnold, Chief of the U.S. Army Air Forces, Dryden was awarded the Medal of Freedom. Years later, after many other awards had been received, Dryden remarked that he prized this award above all others.

In 1946 Dryden became Assistant Director of the Bureau of Standards, and six months later he became the Bureau's Associate Director. Then in 1947 a new horizon of his own suddenly appeared. Dr. George W. Lewis, Director of Aeronautical Research of the NACA, was in failing health, and Dryden was asked to succeed him. In 1949 he was named to the newly created post of Director of the NACA.

At the NACA Dryden worked with others to find a solution to what might be called "The Great National Wind Tunnel Problem." The result was the Unitary Wind Tunnel Plan, which saved millions of dollars and millions of man-hours of duplicating effort.

In these same years he played a key role in guiding policy and development of a great series of high speed research airplanes which culminated in the X-15, an aircraft that almost became a spacecraft by reaching the very limits of the Earth's atmosphere. As missiles pierced the atmosphere to hurtle out into space, Dryden pushed for solutions to the critical re-entry problem.

On Oct. 4, 1957 the Soviet Union launched into orbit the world's first artificial Earth satellite, *Sputnik 1*.

Congress and the White House immediately made plans of their own to compete with the Russians. These plans included the creation of a civilian agency to conduct the exploration of space. The NACA was to be the nucleus of this new National Aeronautics and Space Administration (NASA).

NASA formed

T. Keith Glennan, president of the Case Institute of Technology was selected to be the new agency's Administrator. Glennan insisted that Dryden be NASA's Deputy Administrator. Together they worked through the new agency's most difficult years.

Dryden brought with him to NASA not only the loyalty of the NACA employees, but also the high regard in which he was held throughout the aeronautical world.

When the White House finally chose James E. Webb to become NASA's second Administrator, Webb replied that he would accept the position only on the condition that Dryden remain as his deputy. And so Dryden remained until his death in 1965.

Methodist Minister

A powerful factor in Dryden's life was his devotion to the Methodist Church. He originally wanted to become a minister, but when he graduated from high school at the age of 14 he was regarded as too young for acceptance in any divinity school. Although he found a second calling in the realms of physics and mathematics his faith experienced no erosion; indeed it broadened and deepened over the years. He became a licensed local preacher of the Methodist Church.

While many scientists and philosophers have whined and cried about "contradiction" between science and religion, Dryden found no difficulty in achieving a durable synthesis of the two. And when he spoke on the subject his auditors were inclined to agree with him. He realized that we live in an imperfect world populated by imperfect men; and although it might be impossible to achieve perfection in this world, it was incumbent upon everyone to strive for the best.

The honors, offices and awards bestowed upon Dryden were great in their significance and in number. A sampling might include the President's Award for Distinguished Civilian Service, the Langley Gold Medal of the Smithsonian Institution, the Daniel Guggenheim Medal, the Wright Brothers Memorial Trophy, the Elliot Cresson Medal of the Franklin Institute, the Rockefeller Public Service Award, the John Fritz Medal, and the Robert A. Goddard Memorial Trophy. He was honored by election to honored foreign member status in the National Academies of France and Germany, and to the aeronautical societies of Great Britain and Canada. His honorary degrees, awarded in the United States and overseas, numbered 16.

Layman of the Year

In 1962 the Methodist Union named Dryden the Methodist Layman of the Year. It was a distinction that he cherished every bit as much as the many scientific prizes and awards and all of the honorary degrees that were bestowed upon him in his lifetime.

Dryden was hospitalized in October of 1961 for some weeks and exploratory surgery determined that he had an incurable malignancy.

Before he entered the hospital for the last time, he kept busy with conferences, meetings, and lectures. Dryden conceded nothing to his illness. He packed each day with more commitments and accelerated his schedule.

At 7:46 p.m. of Thursday, Dec. 2, 1965 High L. Dryden was no longer of this world.

Dryden's career was devoted to solving problems of turbulence -- in the realm of aeronautics and in the affairs of men. As far as many one man's influence can be felt, he was incredibly successful on both accounts.

The legacy of Dryden is described here in one of his sermons: "None of us knows what the final destiny of many may be, or if there is any end to his capacity for growth and adaptation. Wherever this venture leads us, I am convinced that the power to leave the earth - to travel where we will in space and to return at will - marks the opening of a brilliant new stage in man's evolution."



UNVEILING THE BUST - During a Center dedication ceremony on March 26, 1976, Mrs. Hugh L. Dryden unveils the bust of her husband which is now in the lobby of Bldg. 4800. ***NASA photo ECN 5137.***

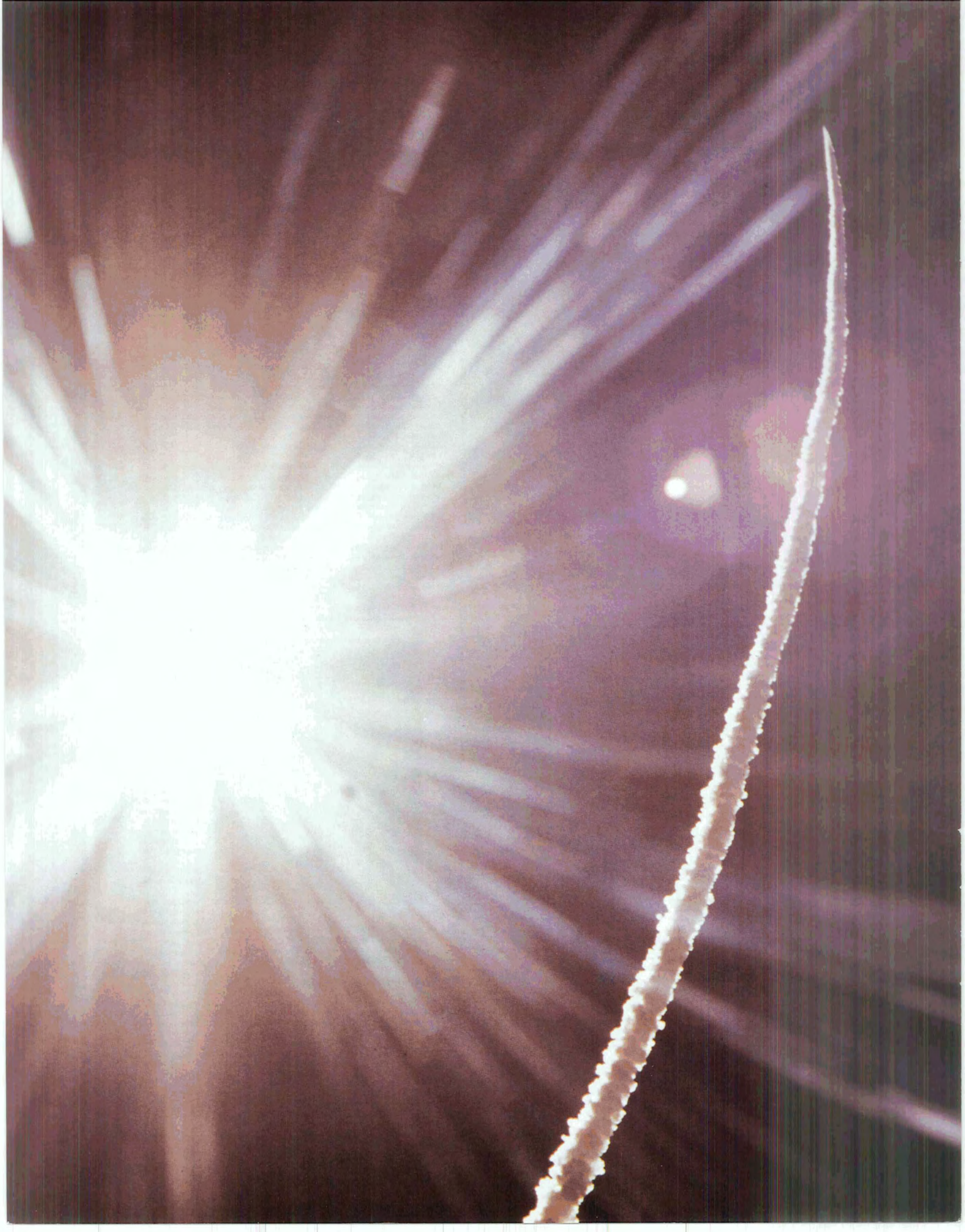
Today's Events (March 26, 1976)

Formal activities today will begin with a ceremony in the calibration hangar. Music will be provided by the Antelope Valley High School Symphonic Band, under the direction of Mr. Joseph Acciani.

Among those addressing the gathering will be Center Director Dr. David Scott, NASA Administrator Dr. James C. Fletcher, Senator Frank Moss, and T. Keith Glennan, first Administrator of NASA. Mrs. Hugh L. Dryden, guest of honor, will unveil a bust of her husband, which will eventually be placed in the Center's lobby.

After the ceremony, visitors will be invited to view a static display of aircraft in the main hangar. As of press date, aircraft scheduled to be on display included the YF-12, YC-15, F-16 and F-17, X-24B and HL-10 lifting body, F-111 TACT and IPCS aircraft, Firebee and F-15 Remotely Piloted Research Vehicles, the two F-8 Digital Fly-By-Wire and Supercritical Wing aircraft, the full-size F-15, the Mini-

continued on page 5



▶ Chapter Three:

Higher, Faster

Of the planned "exploratory" research conducted at the Dryden Flight Research Center over the past half century, a good portion was devoted to exploring ways for aircraft to fly higher and faster—especially in the Center's early years. After all, the whole reason for the establishment of the Muroc Station was the development of faster jet and rocket aircraft that could not be tested safely at other NACA locations. Furthermore, the driving thrust of aircraft design from the late 1940s through the 1960s was primarily for increasingly faster and higher-flying airplanes. So it was hardly surprising that the research at NACA's "High Speed Flight Station" during that time focused on technology and advances to help make these goals possible. More surprising, perhaps, is the renewed emphasis on high and fast flight in recent years, although the latest focus is significantly different from the initial work. Today, aircraft such as the proposed High Speed Civil Transport (HSCT) must meet new criteria for fuel efficiency and environmental impact as well as speed and performance. In the early days, the goals were less complex, and the focus was on paving the way to supersonic flight and space.

X-15 contrail after launch (NASA Photo EC65 884)

Breaking the Sound Barrier

The most famous of all the research projects conducted at Dryden and its predecessor NACA/NASA facilities in the Mojave Desert is probably the X-1—the rocket plane that first broke the infamous "sound barrier" in October 1947.

The X-1, a joint effort of the Army Air Forces, NACA, and the Bell Aircraft Corporation, was built to get answers about flight in the transonic region (approaching and immediately surpassing the speed of sound) that researchers were unable to get through conventional ground and wind tunnel tests. Aircraft design had progressed rapidly during World War II, but as high-performance fighters such as the Lockheed P-38 Lightning developed the capability of dive speeds approaching Mach 1, they began to encounter difficulties. Shock-wave, or "compressibility," effects could cause severe stability and control problems and had led to the in-flight break-up of numerous aircraft. Many people began to believe that supersonic flight was an impossibility.

Clearly, more information about flight dynamics at these higher speeds was needed, but that information was proving difficult to obtain. In the 1940s, no effective transonic wind tunnels existed. The NACA Langley Laboratory



X-1 being loaded under mothership, B-50 Superfortress. The aircraft had originally been lowered into a loading pit and the launch aircraft towed over the pit, where the rocket plane was hoisted into the bomb bay. By the early 1950s, a hydraulic lift had been installed on the ramp to elevate the launch aircraft and then lower it over the rocket plane for mating. On 9 November 1951, however, after a so-called "captive" flight in which this particular X-1 (tail number 6-064) remained attached to the launch airplane, both aircraft were destroyed by a postflight explosion and fire that also injured Bell test pilot Joseph Cannon. (NASA Photo E51 593)


ATES AIR FORCE

was conducting research with small airfoil models mounted on the wings of P-51 fighters, which could experience local transonic and low supersonic air flow even if the aircraft speed was subsonic, as well as with rocket models fired from its Wallops Island, Virginia, facility, but neither approach was really satisfactory. Several researchers, including John Stack of the Langley Laboratory, began arguing the need for a research aircraft to explore the transonic region and determine if, in fact, supersonic flight was possible.



NACA pilots Bob Champine and Herb Hoover with X-1 (tail number 6-063), in which both pilots first flew supersonic (NASA Photo E 005)

Although numerous researchers across the country agreed on the need for such an aircraft, they did not all agree on its design. Stack and other NACA engineers, along with the U.S. Navy, favored a jet-powered plane, while the Army Air Forces (AAF) wanted to pursue a rocket-powered design. As a compromise, the researchers decided on a two-pronged approach to their research plane. The AAF and NACA teamed up with Bell Aircraft to build three models of the X-1 rocket aircraft, while the Navy and NACA worked with the Douglas Aircraft Company to create the D-558-1 jet-powered Skystreak. The Skystreak's performance would not be as great as the X-1 design, but a rocket-powered aircraft was seen as a much riskier proposition. The dual approach, therefore, was thought to provide a greater assurance of success in a transonic research program.[1]

The X-1 was modeled after the shape of a bullet, which was the only shape that had been proven capable of stable transonic or supersonic flight. Its four-chamber, 6,000-pound thrust rocket engine would give it a mere 150 seconds of powered flight, which led to the decision to air-launch the aircraft from a specially modified Boeing B-29 Superfortress. In December 1945, only nine months after Bell Aircraft received an Army contract to build the plane, the first X-1 rolled out of the factory.[2] A test group, including a NACA contingent led by Walt Williams, took the airplane a month later for its initial glide tests to Pinecastle Field near Orlando, Florida. Pinecastle had one of the country's very few 10,000-foot-long runways, but the



X-1E being loaded under mothership, with a technician servicing the rocket plane (NASA Photo E 2509)

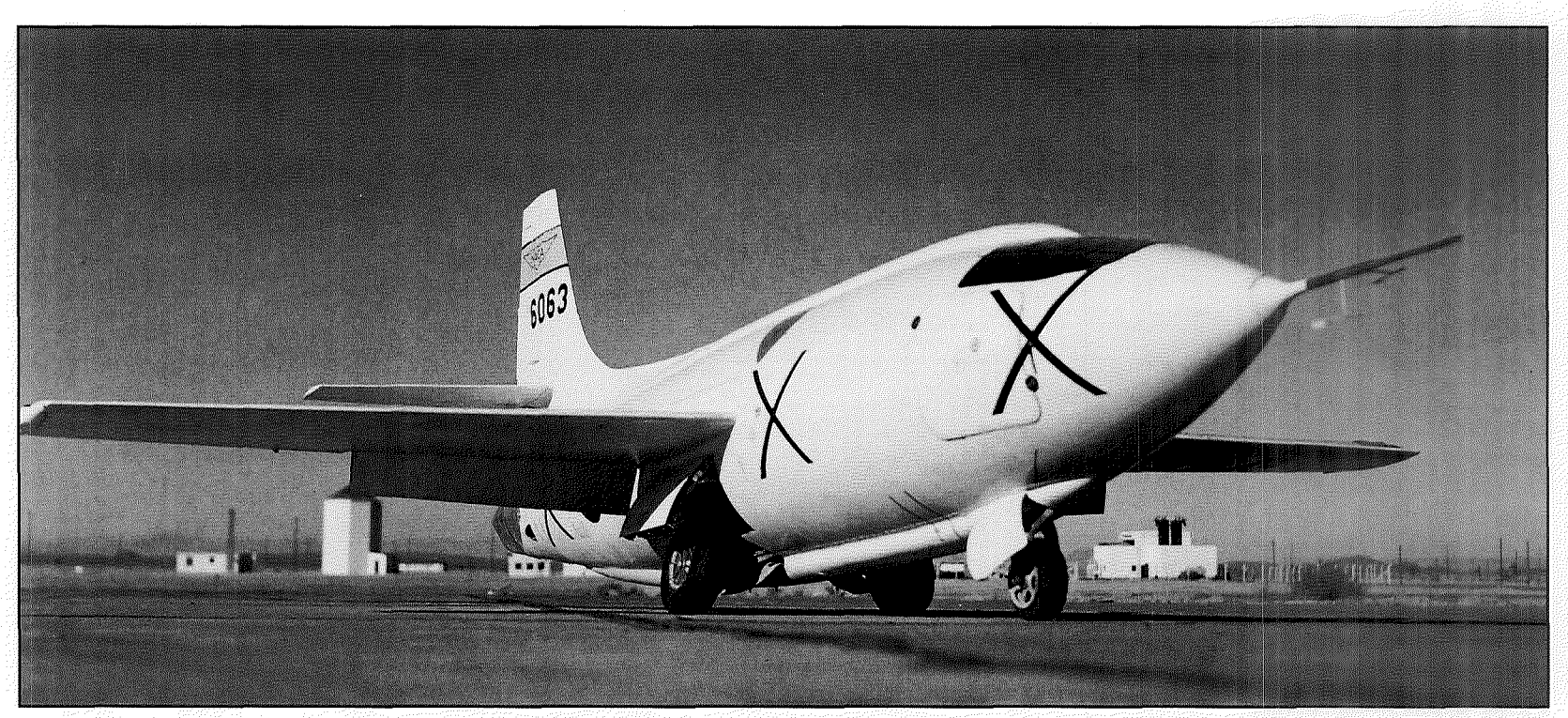
by the AAF to make a more focused, aggressive assault on the sound barrier and to explore the maximum speed and altitude capabilities of the aircraft. The NACA was responsible for providing technical supervision for all the test flights and the instrumentation for both aircraft, however. This created some degree of tension between the AAF and NACA personnel. First of all, the AAF wanted to push ahead and get past the magic "Mach 1" mark as quickly as possible, while the NACA wanted to make sure it got all possible data from every flight. The two goals were often in direct conflict, as instrumentation issues often slowed the pace of the research flights.

area proved less than ideal for the X-1 flights. Among other things, scattered cloud decks and the landscape surrounding Pinecastle could make it difficult for a pilot to keep the airport in sight. On the X-1's very first flight, in fact, Bell's test pilot Jack Woolams did not quite make the runway, touching down on the hard grass beside it. Woolams and the test team recommended that the powered flight tests be conducted at Muroc, where they would have the advantage of clear skies, open landscape and dry lake landing sites.[3]

The NACA team, still headed by Williams, arrived at Muroc on 30 September 1946, and the second X-1 aircraft arrived a week later. This second X-1, which had a thicker wing than the first model, had been designated for the more thorough transonic research NACA wished to conduct. The first X-1 was to be used

This problem was intensified by the fact that although NACA's instrumentation was state-of-the-art for its time, it was still fairly rudimentary and temperamental. Aside from the fact it weighed 500 pounds, the equipment was susceptible to frequent failures, and some flights failed to return much data.[4]

Yet despite the conflicts created by the different approaches and agendas of the two organizations, nobody on the team lost sight of the common goal. Almost 50 years later, with supersonic flight a standard capability of most military and even some transport aircraft, it is difficult to fully appreciate the enormity of the



X-1-2, later rebuilt as the X-1E (NASA Photo E 668)

challenge the X-1 team faced. Many scientists and researchers, even within NACA, thought the X-1 would blow up or break apart in flight. (In fact, one of the X-1's four engine combustion chambers did explode on a flight in May 1948, but the aircraft was landed safely.) The researchers and pilots involved with the project were convinced supersonic flight was possible, but they knew how many things could go wrong. Just a year earlier, for example, Geoffrey DeHavilland had been killed in a British D.H. 108 Swallow while attempting to break the sound barrier.

Even without catastrophic failures, the road to that October flight was not an easy one. On a flight in early October 1947, for example, the Air Force's primary X-1 pilot, Captain Charles "Chuck" Yeager, achieved an indicated airspeed of Mach 0.94 but found that when he pulled back on the control stick, nothing happened. The speed had created a shock wave on the surface of the elevator, rendering it useless and leaving him with no pitch control. Yeager recovered by shutting down the engines and reducing his speed, but the incident taught the researchers the value of a movable horizontal stabilizer. From then on, Yeager used the elevator to control the X-1's pitch at subsonic speeds but relied on small trim adjustments of the entire stabilizer at speeds near or past Mach 1. An all-movable stabilizer proved to be such a critical component for transonic and supersonic flight, in fact, that virtually every transonic/supersonic aircraft since then has had one.[5]

On another flight just four days before the sound barrier was broken, the X-1's canopy frosted over during Yeager's descent and chase pilots had to talk him down to a blind landing. To prevent a recurrence of the problem on future flights, crew members coated the X-1's windscreen with Drene shampoo—illustrating the desert team's ability to find creative and effective solutions to unexpected problems. Finally, however, success was theirs. On 14 October 1947, flying with two broken ribs, Captain Yeager took the X-1 to a speed of Mach 1.06 at 43,000 feet, proving for the first time that a piloted aircraft could successfully



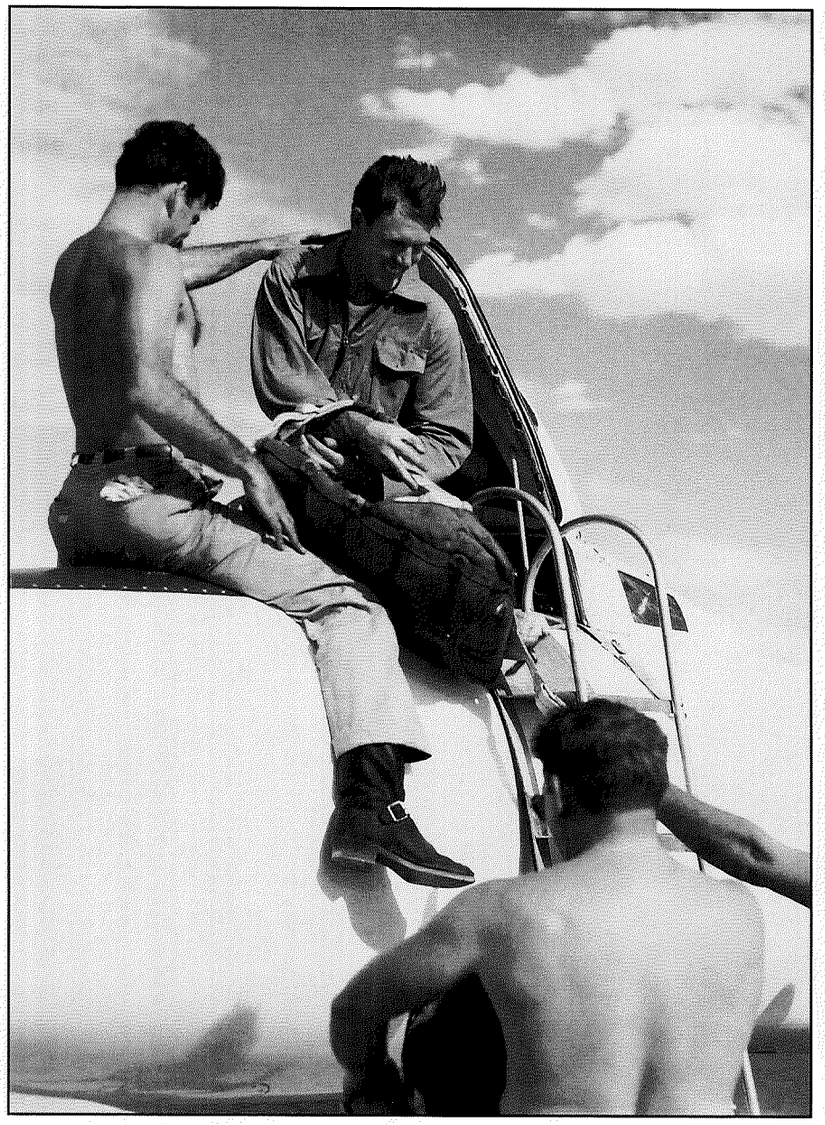
Technicians servicing X-1 attached to B-29 mothership (NASA Photo E 595)

surpass the speed of sound and making the sound "barrier" a myth of the past.[6]

The X-Planes

While the breaking of the sound barrier is the landmark the world remembers, it was actually just one research mark of many for the NACA unit at Muroc. NACA began flight research with the second X-1 just one week after Yeager's Mach 1 flight, and NACA pilot Herbert H. Hoover became the second man to fly supersonically on 10 March 1948. The NACA also received the first of its two jet-powered Douglas D-558-1 Skystreaks in November 1947.

The lower-performance D-558-1 took backseat to the X-1 aircraft, but it did achieve some useful research on flight in the transonic region approaching Mach 1. The Skystreak showed that adding vortex generators, or small vertical tabs, to the wing of an aircraft could reduce buffeting and wing-dropping tendencies.[7] John Stack of the Langley Laboratory came up with the idea and, in a typical example of the Muroc unit's independent, nonbureaucratic management style, Walt Williams simply instructed his technicians to try it out. The small tabs they glued on the Skystreak's wing allowed its speed in level flight to increase by .05



D-558-1 on ramp with NACA pilot (Bob Champine) and crew (NASA Photo E49 00204)

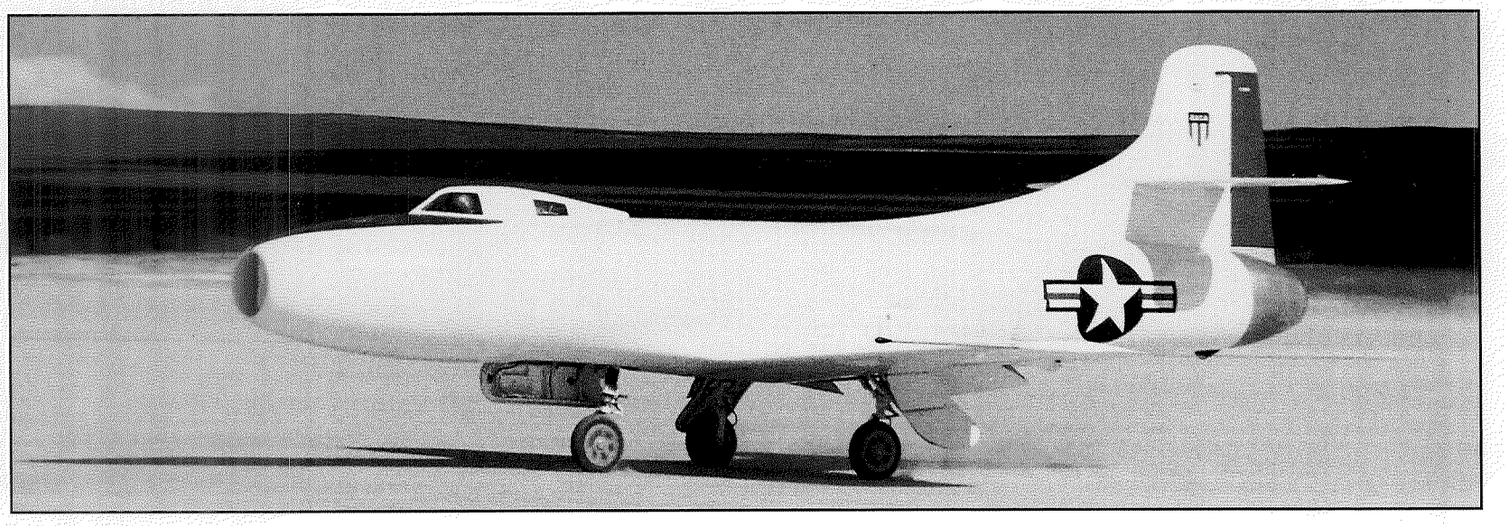
Mach—and proved effective enough that vortex generators were subsequently incorporated into Boeing's B-47 bomber design. Since then, vortex generators have been used to improve the performance of air flow over the external surfaces and even through the engine inlets of a great many production aircraft.[8]

Unfortunately, one of the Skystreaks also claimed the life of NACA research pilot Howard "Tick" Lilly in May 1948, when its jet engine compressor suffered a catastrophic failure on take-off. Lilly, who had been the third person to fly an aircraft past the speed of sound, became the first NACA pilot at Muroc to give his life in pursuit of research.[9]

The three X-1s and the D-558-1 were, in a sense, the first generation of research aircraft planned by NACA and the military. The second generation was not far behind—in fact, follow-on aircraft were already in the planning stages before the X-1 even reached powered flight. The first D-558-1 had not yet been delivered when the Douglas design team came up with a more advanced version of the aircraft, incorporating a swept wing and both a jet and a rocket engine. The new model, designated the D-558-2 "Skyrocket," entered the line-up of research aircraft in 1948. To increase the D-558-2's performance further, Douglas removed the jet engine from one of the three Skyrockets, using the extra space and weight for extra rocket fuel, and configured the airplane for air-launch instead of ground take-off.[10] The Army Air Forces and NACA also signed an agreement in February 1947 detailing a joint effort for additional research aircraft, designated the X-2, the X-3, the X-4 and the X-5. And while the first X-1s were still conducting flight research, an order was put in for three updated versions called the X-1A, the X-1B, and the X-1D. An

X-1C was designed, but its funding and resources were reallocated to the other "X" aircraft and it was never built.

The goals of this multi-aircraft flight research effort were twofold. The derivative versions of the X-1, as well as the X-2 and the D-558-2, were built to explore higher speeds and altitudes, both to help manufacturers build aircraft that could operate in that realm and to provide information useful for future space flight. The X-3, X-4, and X-5, as well as the delta-wing XF-92A, explored the behavior of various configurations in the transonic range.[11]



Turbojet-powered D-558-1 taking off from lakebed (NASA Photo E49-226)

The X-4, for example, was a semi-tailless design similar to the D.H. 108 Swallow that had broken apart while trying to reach supersonic flight in 1946. The X-4 was a twin jet, swept wing aircraft built by Northrop, which had also designed a "flying wing" bomber prototype for the Air Force. Not surprisingly, the X-4, which had a vertical but no horizontal stabilizer, used the flying wing's concept of a combination elevator/aileron called an "elevon" to control its pitch and roll.

The X-4 was something of a maintenance nightmare, but it did accomplish some useful research. For one thing, flights using the X-4's large speed brakes were able to gather data about the flight characteristics of an aircraft with a low lift/drag ratio that helped the X-15 research program. The airplane also made it clear to designers that the X-4 configuration, which was modeled after not only the Swallow but also the Messerschmidt Me-163 rocket plane, was totally unsuitable for transonic or supersonic flight. Like the Swallow, the X-4 experienced severe oscillations about all three axes as it approached Mach 0.9. Increasing the thickness of the elevon trailing edges helped somewhat, but the problem could not be completely alleviated.[12] Nevertheless, the X-4 supported General Jimmy Doolittle's assertion that "in the business of learning how to fly faster, higher, and farther, it is sometimes very important to learn what won't work."[13]

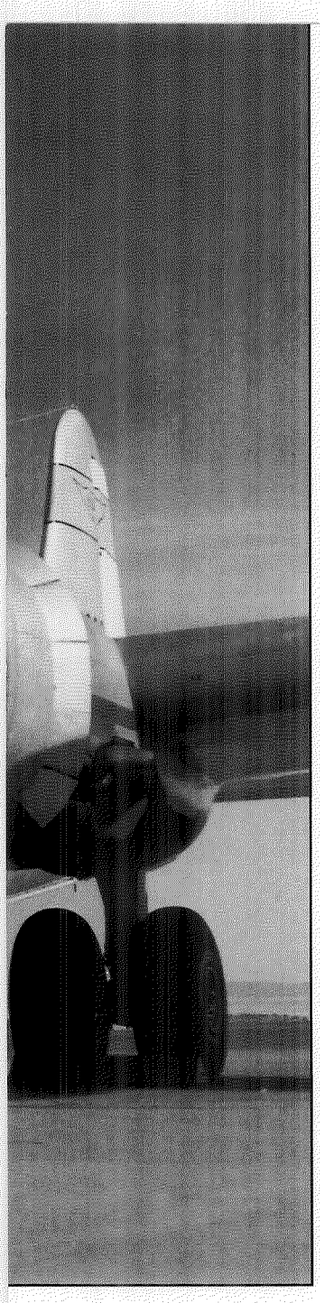
The X-5, which was a variable-sweep wing design built by Bell, arrived at Edwards in 1952. It had vicious stall/spin characteristics that caused NACA pilot Joe Walker to lose 18,000 feet recovering from a stall during one flight and eventually killed Air Force test pilot Ray Popson. But its problems were determined



Two B-29s, one with X-1E attached. The silhouettes on the side of the mothership indicate it had completed 31 launches.
(NASA Photo E-2082)

to be design flaws of the X-5, not the concept of variable sweep. In fact, the aircraft proved the feasibility of the concept and allowed researchers to learn a lot about the dynamics involved with that configuration throughout the transonic range.

Likewise, the Convair XF-92A proved the suitability of the delta-wing design for transonic flight. Yet it, too, had some unpleasant flight characteristics, the most problematic of which was a tendency to pitch up violently during maneuvering, resulting in positive forces as high as 8 Gs and, even more alarmingly, negative forces as high as -4.5 during recovery.[14] "Pitch up" was, in fact, a problem inherent in any swept-wing design at transonic speeds, but research with the X-planes gave engineers an opportunity to examine it in various configurations. One of the major research contributions of the D-558-2 Skyrocket, in fact, was its investigation into the dynamics and possible solutions to the pitch-up problem. Over a 27-month flight program with the Skyrocket, NACA researchers examined the use of wing fences (vertical strips running from the leading edge to the trailing edge of the wing), a sawtooth-shaped leading edge, and retractable leading edge slats to control pitch-up.



Judging from their experience with these aircraft, the NACA researchers determined that the best solution to the pitch-up problem actually was to place the aircraft's tail low and far back on the fuselage, to keep it out of the wing's disturbed airflow and downwash. A delta wing design like the XF-92A, of course, would require another solution because it lacked a horizontal tail. The NACA engineers therefore tried a series of wing fences on the XF-92A, including a combination planned for the follow-on F-102 delta-wing interceptor that Convair was in the process of building. The results were sent to Convair, although the F-102 was subsequently changed quite significantly to take advantage of the "area rule" design concept developed by a Langley Laboratory research engineer named Richard Whitcomb.

Yet the problem swept wing aircraft had with pitch-up almost paled in comparison with another difficulty NACA researchers, and a few unfortunate F-100 fighter pilots, were discovering with aircraft designed for supersonic speeds. The technical term for it was "inertial coupling" or "roll divergence," but to the pilot it meant that the airplane had a tendency to go suddenly and violently out of control during rolling maneuvers. The F-100 jet was the nation's first fighter designed to fly past Mach 1 in level flight, and it had just gone into full production in 1954 when the inertial coupling problem surfaced. It was already a suspected cause in several accidents that had claimed the lives of F-100 pilots when NACA pilot Joe Walker experienced it in the Douglas X-3 research aircraft later that same year.

The X-3 was actually designed for sustained Mach 2 jet-powered research, but the aircraft's engines were so underpowered that it could not go supersonic in level flight. The fastest it ever went was Mach 1.2 in a powered dive. Yet it was still susceptible to inertial coupling because, like the supersonic "Century Series" fighters, it had a thin, short wing and most of its mass was concentrated along its fuselage.[15] The highly instrumented X-3 was able to give engineers their first detailed data and analysis of the dynamics, and therefore the cause, of the inertial coupling problem.[16] As a result, NACA advised North American Aviation to extend the wingspan and increase the vertical tail surface of the F-100 design. The modifications turned the F-100A into a highly effective supersonic fighter, and the knowledge gained through the X-3 flights and the F-100 experience has been applied in one form or another to virtually every supersonic fighter built since then.[17]

The configuration research conducted by NACA and the Air Force from 1950 to 1956 was particularly important to manufacturers because they were at the cutting edge of a revolution in aircraft design and performance that was taking them into realms they knew very little about. They could not have predicted the surprises that Joe Walker found in the X-3 and the X-5 any better than NACA or the Air Force. Furthermore, the work with the D-558-1, the X-3, the X-4, the X-5 and the XF-92A was in the same speed range, and in most cases used the same types of materials and powerplants, that the manufacturers were beginning to incorporate. So even if the aircraft did not always measure up in performance to NACA's hopes or expectations, the research was of great interest to industry designers and engineers. The information provided could mean the difference between the success or failure of an aircraft design. And in the case of the F-100A, the flight research at Dryden prevented the death not only

of the aircraft program but of numerous pilots as well.

This is not to say that Dryden had neglected work in the high-speed arena while it explored various transonic configurations. Indeed, it was the high-altitude and high-speed achievements at Edwards Air Force Base that garnered the biggest headlines during the early 1950s.

The X-1A, X-1B, and X-1D derivatives of the X-1 design were designed to have greatly expanded capabilities. They had larger tanks for rocket propellant and were designed to use a turbine-driven pump instead of the X-1's more cumbersome nitrogen pressure-feed system. They also had, for the first time, an ejection seat for the pilot. Unfortunately, the follow-on X-1s were plagued with accidents and problems.

The X-1D was the first new-generation X-1 to arrive at Edwards, delivered by Bell in mid-1951. On its very first powered flight attempt, however, the aircraft exploded while still attached to the B-50 mother ship. The Air Force pilot, Major Frank K. Everest, managed to get back into the B-50 safely, but the stricken X-1D had to be jettisoned. Thus the X-1D program ended before it began, and the accident set the X-1A and X-1B programs back almost two years.

The X-1A joined the Air Force/NACA research fleet in 1953. It was designed for speeds in excess of Mach 2, but it encountered serious stability problems as it approached its design speed. On one flight at the end of 1953, Chuck Yeager set a new speed record of Mach 2.44, or approximately 1,650 miles per hour, only to lose control of the airplane immediately thereafter. The X-1A gyrated wildly for 70



Early NACA aircraft in front of the South Base hangar used by the NACA unit from the late 1940s to 1954. From viewer's left: D-558-2, D-558-1, X-5, X-1, XF-92, X-4
(NASA Photo EC 145)

seconds, losing 10 miles in altitude before it slowed to a subsonic speed and went into an inverted spin, from which Yeager was able to recover. As was the case with many X-plane partnerships between NACA and the Air Force, the X-1A was flown first by the Air Force and then turned over to the NACA for more in-depth research. Unfortunately, NACA's time with the X-1A was brief. On its second NACA flight attempt, the X-1A experienced a minor explosion while still attached to the B-29 mother ship, just as the X-1D had. NACA pilot Joe Walker managed to get out, but the X-1A had to be jettisoned, ending the X-1A program.

The X-1A had given researchers an unpleasant taste of some of the surprises that still awaited them as they reached for higher speeds. In fact, although both the X-1B and the X-1E that followed were designed for faster speeds, neither one was ever flown above Mach 2.3 because of the stability problems encountered with the X-1A. The X-1E was not in the original plans for research aircraft, but the destruction of the X-1D and X-1A left a need for a back-up aircraft. To fill that need, the X-1E was created by modifying one of the existing X-1 research aircraft and the modified plane flew with the X-1B from 1955 until 1958. Both aircraft were used to gather data about the forces on an aircraft at high speeds and altitudes, including the effects of aerodynamic heating. Aircraft that could fly hypersonically, or above Mach 5, and potential spacecraft were already in the planning stages, and researchers needed information on the flight environment and forces with which those craft would have to contend.

The X-2 was, in a sense, a third genera-

X-4 in flight
(NASA Photo E 17350)



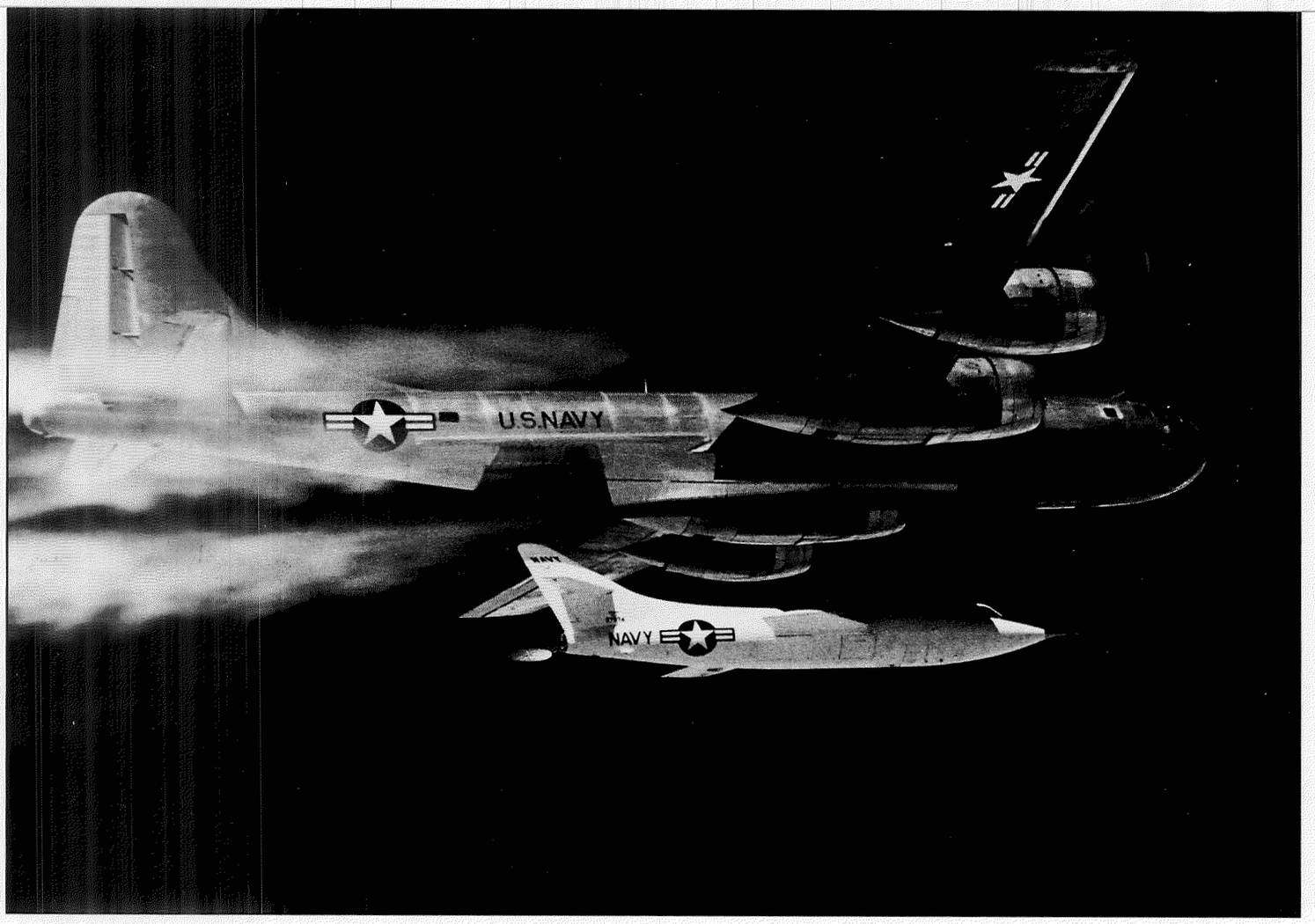


Research aircraft from viewer's left to right: X-1E, D-558-2, X-1B on lakebed (1955) (NASA Photo E 1914)

tion research aircraft, designed to go further in investigating problems of aerodynamic heating as well as stability and control by operating at speeds of Mach 3 and at altitudes between 100,000 and 130,000 feet. To make the plane more heat-resistant, the X-2 was made of stainless steel and a nickel alloy. Its 15,000-pound-thrust Curtiss-Wright rocket engine also had more than twice the thrust of the X-1 family engine.

Unfortunately, the X-2's research career was destined to be short. The first X-2 exploded during Bell Aircraft's initial flight testing of the airplane. The explosion occurred while the X-2 was attached to its B-50 launch plane, resulting in the death of not only the X-2 pilot but one of the B-50 crew members as well. The second X-2 made its first Air Force powered flight in November 1955. Its performance was, in fact, impressive, and on its 12th powered flight, Air Force Captain Iven C. Kincheloe took it higher than anyone had ever flown. His flight to approximately 126,000 feet prompted *Popular Science* to dub Kincheloe "First of the Spacemen." Yet on its very next flight, the last Air Force flight before turning the plane over to NACA for its more thorough research program, tragedy struck. Captain Milburn G. Apt, flying his very first rocket flight, took the X-2 to a record speed of Mach 3.2, or 2,094 miles per hour. But as he turned back to the base, the X-2 went out of control and began spinning. The X-2 had been designed with a jettisonable nose, which was supposed to protect the pilot until he reached a speed slow enough for a normal bail out. But when Apt jettisoned the nose cone, the shock knocked him unconscious. He came to in time to jettison the canopy but was unable to bail out before the cockpit section crashed into the desert.

The accident ended the X-2 research program, but it did lead to a couple of changes in the X-15 program that followed. First, the idea of a jettisonable cockpit was abandoned in favor of an ejection seat. Second, a possible factor in the X-2 accident was thought to be Apt's cockpit instruments. Some researchers thought Apt might have believed he was going slower than he really was, leading him to initiate a turn sooner than he should have. As a



D-558-2 dropping at launch from B-29 mothership (Navy designation: P2B) (NASA Photo E 2478)

result, the X-15 was equipped with a gyro-stabilized inertial navigation system (INS) and flight instrumentation that would give the pilot much more precise and accurate flight information.

The second and third generation rocket planes had produced some valuable information about flight at high speeds and altitudes. But it had come at a cost. So it was against a mixed background of triumphant records and tragic failures that the NACA flight research team at Dryden began working on the X-15—a program that aimed to achieve not only what the early rocket planes had left undone but also goals two or three times as high. [18]

The X-15

The X-15 program actually started in 1952, when several prominent researchers began lobbying for a research vehicle that could begin investigating some of the basic problems that human space flight would entail. At that time, however, NACA had its hands full with the problems of Mach 2 flight, so it was 1954 before serious studies began on an aircraft design for the ambitious goal of flight at speeds from Mach 4 to Mach 10 and altitudes 12-50 miles above the Earth. In December 1954, NACA, the Air Force and the Navy signed an agreement for the research plane that gave the Air Force responsibility for administering its design and construction and NACA responsibility for technical supervision. The Air Force and the Navy would share responsibility for the program's cost. This partnership proved smoother in many ways than the X-1 project, due in large part to the fact that although it was



Right: X-15 in flight. Once the X-15 flew, researchers at Dryden used the data collected during flight to understand better the relationship of theory, wind-tunnel data, and the realities of actual flight. During the early years of the X-15 program, comparisons of flight data with those from wind tunnels had to be done by traditional methods that were time-consuming and not fully consistent. Moreover, the methods in use at that time were unable to provide values for many dynamic aircraft responses in flight. In 1966 Dryden researchers Lawrence W. Taylor, Jr., and Kenneth W. Iliff began developing a more automated technique for obtaining numerical values for aircraft behavior. This involved theoretical contributions resulting in computer programs (later improved by Richard E. Maine) for manipulating multiple differential equations to

X-15 with Neil Armstrong next to nose. The future astronaut and first human to walk on the Moon completed seven flights in the X-15. (Air Force Photo)

obtain the unknown values of the parameters that define aircraft behavior. Called ***parameter identification****, this technique allowed researchers to determine precisely the differences between values predicted from wind tunnel data and those actually encountered in flight. Such precision is essential for understanding and fixing undesirable or dangerous flight characteristics. This significant flight test and flight research technique has been used on over 50 other aircraft at Dryden, including all of the lifting bodies, the XB-70, the SR-71, the Space Shuttles, and the X-29. This technique has spread to virtually all flight test organizations throughout the world and has been used to enhance the safety, flight procedures, and control system designs of most current supersonic aircraft as well as to improve flight simulators, submarines, economic models, and even biomedical models. (Air Force Photo)*



a joint military/NACA program, the goals of the participants were similar. The X-15 was far enough beyond any operational aircraft the military had that it was seen as a pure research aircraft by all three participants. In November 1955, North American Aviation was awarded a contract for three X-15 aircraft, which were to be capable of going 6,600 feet-per-second and reaching an altitude of 250,000 feet.

Despite the huge leap in performance that those figures represented, scientists and engineers knew the foundations upon which the X-15 was based were sound. By the same token, however, they knew that they couldn't wait to have all questions answered before going ahead with the program. When the contract for the X-15's airframe was awarded, for example, the technology for its 57,000-pound-thrust rocket engine (representing 608,000 horsepower at 4,000 miles per hour) did not yet exist. A contract for the powerplant went to Reaction Motors in September 1956, but the engine was still not built when the first X-15 was delivered in 1958. In fact, the first XLR-99 motor was not installed in an X-15 until 1960. In the interim, the X-15s were equipped with two XLR-11 engines from the X-1 program.[19]

North American was also forging new ground with the X-15 airframe. The structure of the X-15 had to withstand forces up to 7 Gs, and the friction generated by its high speed was expected to create temperatures on the airframe as high as 1,200 degrees Fahrenheit. That was beyond the tolerance of any aircraft material used up until that time, including stainless steel. So North American built the X-15 out of a new, heat-resistant nickel alloy called Inconel X. The X-15 also incorporated rocket engine-powered reaction controls and was outfitted with 1,300 pounds of instrumentation, including no fewer than 1,100 sensors.[20]

The main research goals of the X-15 were to investigate aerodynamic forces, heating, stability and control (including reaction controls), reentry characteristics, and human physiology at extremely high speeds and altitudes.

Accomplishing this research was particularly difficult, not only because it required flying far beyond any condition or speed anyone had attempted before, but also because it required operating an aircraft throughout an incredibly wide envelope. The X-15 was air-launched at approximately 45,000 feet, would accelerate to anywhere between Mach 2 and Mach 6 while climbing as high as 350,000 feet, execute a successful hypersonic reentry through Earth's atmosphere and then glide back to a 200-miles-per-hour, unpowered landing on a dry lakebed. This created a real challenge for the X-15's designers. Just as an example, the broad speed range of the X-15 led them to put three control sticks in the cockpit. A conventional center stick was used at slower speeds, and a right-hand side stick was used for high-G maneuvering when it was critical not to over-control the plane. A left-hand side stick operated the reaction controls when the aircraft was outside the Earth's denser atmosphere.[21]

The complexity of the X-15 program also required special ground and air support. The B-29 and B-50 launch planes were replaced by a B-52 with a special pylon for the X-15 mounted under one wing. A formal control room replaced the portable van and radio used to control previous test programs, in order to better monitor and respond to the many pieces of information the X-15 would be transmitting to engineers during each flight. The control room later made famous at the Johnson Space Center was based on the Dryden facility.

X-15 after Jack McKay's mishap. In November 1962 McKay was forced by an engine failure to land at Mud Lake, Nevada. The X-15's landing gear collapsed, flipping the aircraft on its back. McKay was injured but recovered sufficiently to fly again. This aircraft was later restored and is on display at the Air Force Museum near Dayton, Ohio. (NASA Photo E 9149)

