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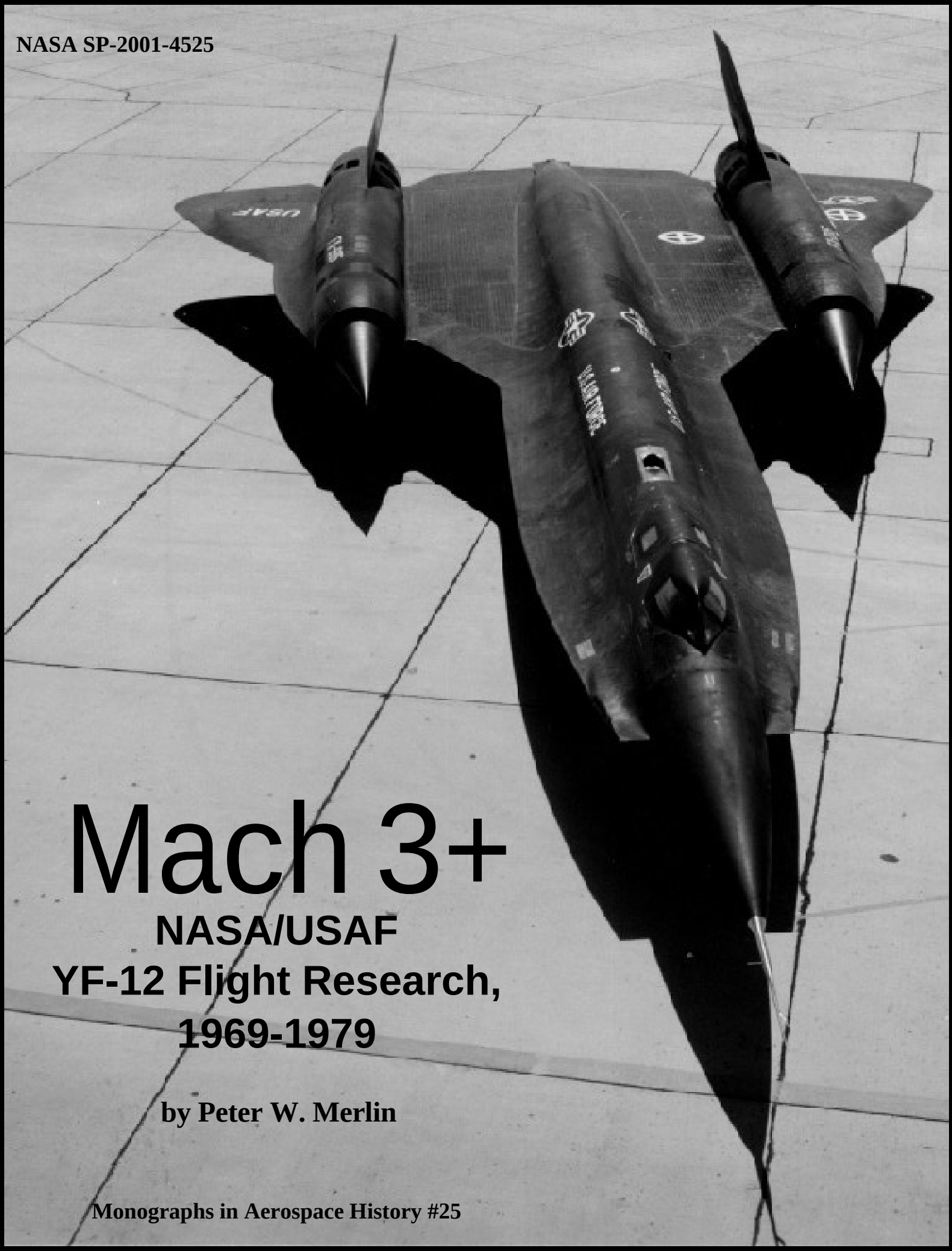

Mach 3+

NASA/USAF YF-12 Flight Research, 1969-1979

by Peter W. Merlin

Monographs in Aerospace History #25

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Mach 3+:
NASA/USAF YF-12 Flight Research, 1969-1979

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YF-12 program personnel. Standing (left to right): Ray Young, Fitz Fulton, Don Mallick, and Vic Horton. Kneeling: Frank Brown, MSgt. Cliff Fenwick, Larry Barnett, Ed Nice, Bud Franklin, Carl Barnes, Joe Misplay, Charlie Grace, and Clayton Threewit. (NASA photo E72-24130)

Front Cover Image:

YF-12A on ramp, seen from above (NASA photo EC71-2679)

Back Cover Image:

YF-12C on ramp, seen from above (NASA photo E72-24985)

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Preface

During the 1950s, American aircraft designers emphasized configurations that flew increasingly high and fast, a trend that continued for nearly two decades. Then, during the 1970s, efficiency, noise reduction, and fuel economy also became important considerations, in part because military analysts no longer deemed speed and altitude the paramount capabilities necessary to ensure national security.

Among the aircraft designs that transitioned from paper to hardware during the high-speed era, the Lockheed Blackbirds hold a unique place. The A-12, YF-12A, M-21, D-21, and SR-71 variants outperformed all other jet airplanes in terms of altitude and speed. To this day, they remain the only production aircraft capable of sustained cruise in excess of Mach 3. Developed in utmost secrecy, they eventually became some of the world's most famous aircraft.

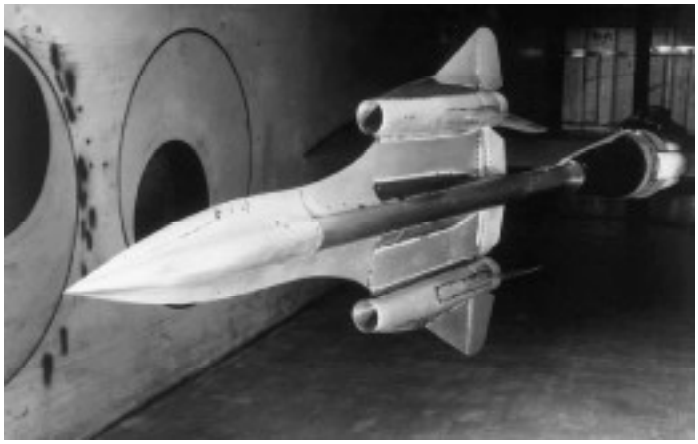
Conceived originally as spyplanes, several Blackbirds saw service with the National Aeronautics and Space Administration (NASA) as research platforms. This monograph describes the first major NASA project involving the Blackbirds. Conducted with the U.S. Air Force (USAF) as a partner, the NASA/USAF YF-12 research lasted 10 years, and produced a wealth of data on materials, structures, loads, heating, aerodynamics, and performance for high-speed aircraft.

More than two decades after the program ended, no comprehensive history of the joint program has yet been written. This monograph is an attempt to rectify that deficiency. Until recently, security restrictions prevented the release of some information relative to the YF-12. Since then, numerous documents have been declassified, and program participants are free to speak about previously restricted aspects of the project. Unfortunately, some who contributed to the NASA/USAF YF-12 investigations have not outlived the blanket of security that covered their work. Those who have must reach back more than 20 years to retrieve anecdotes and historical details. In a sense, the oral history interviews in this monograph amount to a sort of salvage archeology into the fading memories of the remaining YF-12 participants.

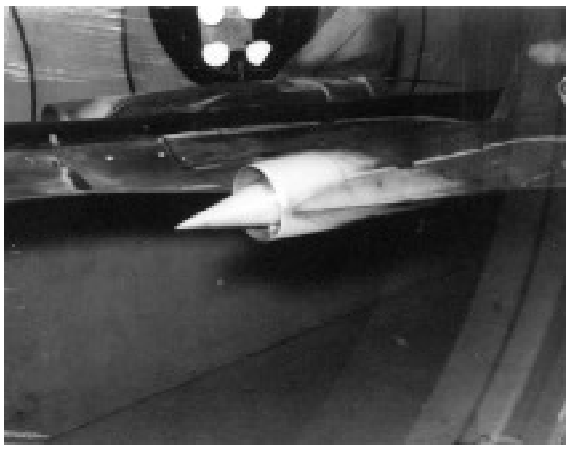
Over the years, numerous books and articles have been written about the Blackbirds, but few give more than a brief description of the YF-12 and its role as a research aircraft. In this monograph, I briefly describe the origins of the Blackbird family of aircraft and how NASA became involved with them. Each of the following chapters then describes a facet of the NASA/USAF YF-12 research program in detail. This monograph would not have been possible without access to numerous technical reports (some recently declassified), briefings, and other source material from the NASA Dryden Historical Reference Collection, as well as the oral interviews that fleshed out the story and provided an insider's view of the project.

Finally, this work rests on the kind assistance of a number of individuals: Dr. Dill Hunley, the DFRC Historian and his successor, Dr. Michael Gorn, both served as editors of the study. Archives Assistant Betty Love provided invaluable aid in identifying individuals in the group photos. Berwin Kock, a Dryden project manager and engineer; Don Mallick, a retired NASA research pilot; Gene Matranga, a former Dryden project manager and engineer; Fitz Fulton, a retired NASA research pilot; Col. Joe Rogers (USAF, Ret.), a former commander of the SR-71/F-12 Test Force; and Col. Hugh Slater (USAF, Ret.), a former commander of the 1129th Special Activities Squadron that flew the early Blackbird variants all provided valuable information about the project. Under a tight schedule, Dryden *X-Press* editor Jay Levine outdid himself in designing the page layout of this monograph. The many photos were printed by Kerrie Paton and scanned by Jay. Further, both Steve Lighthill and Muriel Khachooni helped shepherd the monograph through the process of printing.

Peter W. Merlin
Edwards, California
January 2002



Lockheed engineers tested a scale model of the A-12 (Lockheed Model 204) in the 8'x7' Unitary Plan Wind Tunnel at NASA Ames Research Center on Moffett Field, California, in the early 1960s. Note the absence of the inlet spikes. (Lockheed photo)



In 1962, the NASA Ames wind tunnel simulated speeds up to Mach 3.25 for a scale model of the A-12 (with inlet spikes installed). The white coating aided in flow visualization. (Lockheed photo)

Chapter 1: YF-12 Design and Development

The family of aircraft known collectively as the Lockheed "Blackbirds" includes the A-12, YF-12, and SR-71. Designed by Clarence L. "Kelly" Johnson under Project OXCART, the A-12 resulted from a series of designs for a successor to the U-2 spyplane. The twelfth design in Johnson's series was a sleek aircraft built almost entirely of titanium. With powerful turbo-ramjets, the A-12 was capable of reaching a speed of Mach 3.29 and an altitude of 90,000 feet.[1]

In August 1959, the Central Intelligence Agency (CIA) approved funding for construction of the A-12. In 1960 and 1961, Lockheed engineers conducted tests of a scale model of the A-12 in the NASA Ames Research Center's 8x7-foot Unitary Plan High-Speed Wind Tunnel at Moffett Field, California.[2] Tests included various inlet designs, control of cowl bleed, design performance at Mach 3.2, and off-design performance of an optimum configuration up to Mach 3.5.[3] This marked the beginning of a long relationship between NASA and the Blackbirds.

As a reconnaissance platform, the A-12 was flown exclusively by the CIA. The first airframe was delivered in February 1962. Test flights and operational missions continued until June 1968. The A-12 pilots required full pressure suits, enabling them to fly for extended periods at Mach 3.2 and at operational altitudes of 70,000 to 85,000 feet.

In March 1960, even before delivery of the first A-12 prototype, Lockheed and the U.S. Air Force (USAF) discussed development of an interceptor version of the A-12. Designed as the AF-12 under

---

[1] "OXCART A-12 Aircraft Experience Data and Systems Reliability," BYE-8725-68, formerly classified TOP SECRET-OXCART, Central Intelligence Agency, Washington, D.C., 15 January 1968. Declassified 14 December 1998, p. 2. NASA Dryden Historical Reference Collection.

[2] Jay Miller, *Lockheed's Skunk Works—The First Fifty Years* (Arlington, Texas: Aerofax, Inc., 1993), p. 116.

[3] "Proposed High Speed Wind Tunnel Tests of an Inlet Model 204 in the 8x7 Unitary Plan Wind Tunnel of the NASA at the Ames Research Center," Lockheed Aircraft Company, Burbank, California: LAL 455-IIP by H. H. Shibata, 3 June 1960; LAL 455-IVP by Donald K. Hill, 7 December 1960; LAL 455-VIIP by Donald K. Hill, 1 August 1961. NASA Dryden Historical Reference Collection.

First of the Blackbirds to fly, the A-12 (code-named OXCART) was capable of speeds in excess of Mach 3. The Central Intelligence Agency (CIA) operated the aircraft exclusively from 1962 to 1968. (Lockheed photo)

project KEDLOCK, the interceptor featured a Hughes ASG-18 pulse-Doppler radar system and launch bays for three AIM-47 missiles. A second crew position, located just behind the cockpit, accommodated a Fire Control Officer (FCO) to operate the missile launch system.

With the assistance of the CIA, the Air Force entered an agreement with Lockheed to build three prototypes, now designated YF-12A, for testing. On 7 August 1963, Lockheed test pilot James D. Eastham piloted the maiden flight of the YF-12A (USAF serial number 60-6934). Two other YF-12A aircraft were built: 60-6935 and 60-6936. Early testing of the YF-12A occurred in secret throughout 1963 and early 1964.

The public first became aware of the aircraft on 29 February 1964, when President Lyndon B. Johnson announced its existence. By agreement with Kelly Johnson, the President intentionally misidentified the aircraft as an "A-11."[4] Now public knowledge, the YF-12A flight-test program moved to Edwards Air Force Base (AFB) northeast of Los Angeles in the Mojave Desert. The Air Force soon began testing the aircraft's weapons system and worked on solving troublesome problems with transonic acceleration and various subsystems. On 1 May 1965, the aircraft set several official speed and altitude records, including a closed course speed of 2,070.101 mph and a sustained altitude of 80,257.65 feet.

Lockheed engineers faced unique challenges in designing and building the YF-12. The aircraft's flight profile demanded structural materials able to withstand prolonged exposure to high temperatures from aerodynamic heating,

[4] Miller, *Lockheed's Skunk Works—The First Fifty Years*, pp. 122–125. The President asked Kelly Johnson for advice regarding a proposed public announcement of the Blackbird program. On 25 February 1964, Johnson wrote in his personal log: "Plans going forward for surfacing of AF-12 program. I worked on the draft to be used by President Johnson and proposed the terminology 'A-11' as it was the non-anti-radar-version."

Lockheed test pilot James D. Eastham lands in the first of three YF-12A aircraft on its maiden flight. (Lockheed photo)

in some places exceeding 1,000 degrees Fahrenheit (F). Fully 93 percent of the vehicle's structural weight consisted of titanium alloys. Since all-titanium construction had not yet become common, Lockheed engineers and technicians pioneered new inspection, test, quality control, and manufacturing techniques. Moreover, large sections of the leading and trailing edges, vertical stabilizers, chines, and inlet spikes were made of "plastic" laminates of phenyl silane, silicone-asbestos, and fiberglass. These materials—featured primarily on the A-12 and SR-71 families—helped reduce the aircraft's radar signature. However, the first A-12 and the YF-12A prototypes employed titanium instead of the composite laminates.

The Blackbirds not only incorporated some cutting-edge materials, but also some novel design concepts. The Lockheed team developed a monocoque structure for the fuselage and nacelles, and a multispar/multirib wing structure with cordwise corrugations for stiffness. The presence of fuselage side-fairings, or chines, generated almost 20 percent of the aircraft's total lift. Acting as fixed canards, they also produced a favorable effect on trim drag. Additionally, vortices from the chines improved directional stability of the aircraft as angle of attack increased. The chines also provided a convenient housing for wires and plumbing on either side of the cylindrical center-body fuel tanks.

Propulsion for the Blackbirds consisted of two Pratt & Whitney JTD-11B-20 (J58) afterburning turbojet engines. Each had nine compressor and two turbine stages. A variable geometry inlet diffuser

The large radome (housing a Hughes AN/ASG-18 radar) sets the YF-12A, left, apart from the SR-71. Other differences include ventral fins on the YF-12A's centerline and engine nacelles. Additionally, the leading and trailing edges of the wings and the chines of the SR-71 are largely comprised of fiberglass-asbestos laminates that sandwiched a silicone-filled asbestos honeycomb. (Lockheed photo CC-471)

and a complex bleed bypass system allowed for high engine efficiency in the Mach 2 to Mach 3.2 flight regime by controlling the location of the shockwave inside the inlet and allowing air to bypass the turbine section and go directly to the afterburner.

By contrast with some of its other, more advanced concepts, the aircraft operated with fairly conventional flight controls. Control surfaces included inboard and outboard elevons for pitch and roll and two all-moving vertical fins for lateral control. The vertical control surfaces had to be large to counteract the effect of severe yaw during an inlet unstart or engine failure. (An unstart resulted when the shock wave moved outside the engine inlet).

In addition, inwardly canted fins minimized roll-yaw coupling with vertical tail deflection, and further reduced radar cross section. Internal control linkages included a dual-redundant hydraulic and mechanical system. Stability augmentation was controlled by a triple-redundant fail-operational electronics system.[5] Although the Blackbird designers considered fly-by-wire and adaptive flight controls, they rejected them because of potential unknown problems that might develop in the extreme operational environment of the aircraft. NASA researchers later adopted an experimental digital control system.

Because it operated in an environment of high aerodynamic heating, the Blackbird required a special low-vapor-pressure (high-flash-point) fuel, designated JP-7, one so difficult to ignite that a lit match thrown into a puddle of it is extinguished.[6] Consequently, a catalytic igniter called triethylborane (TEB) had to be injected into the fuel for engine start and afterburner ignition. Fuel for the

[5] Fail-operational is defined as the ability to control the aircraft after any single failure (in the electronics system in this case).

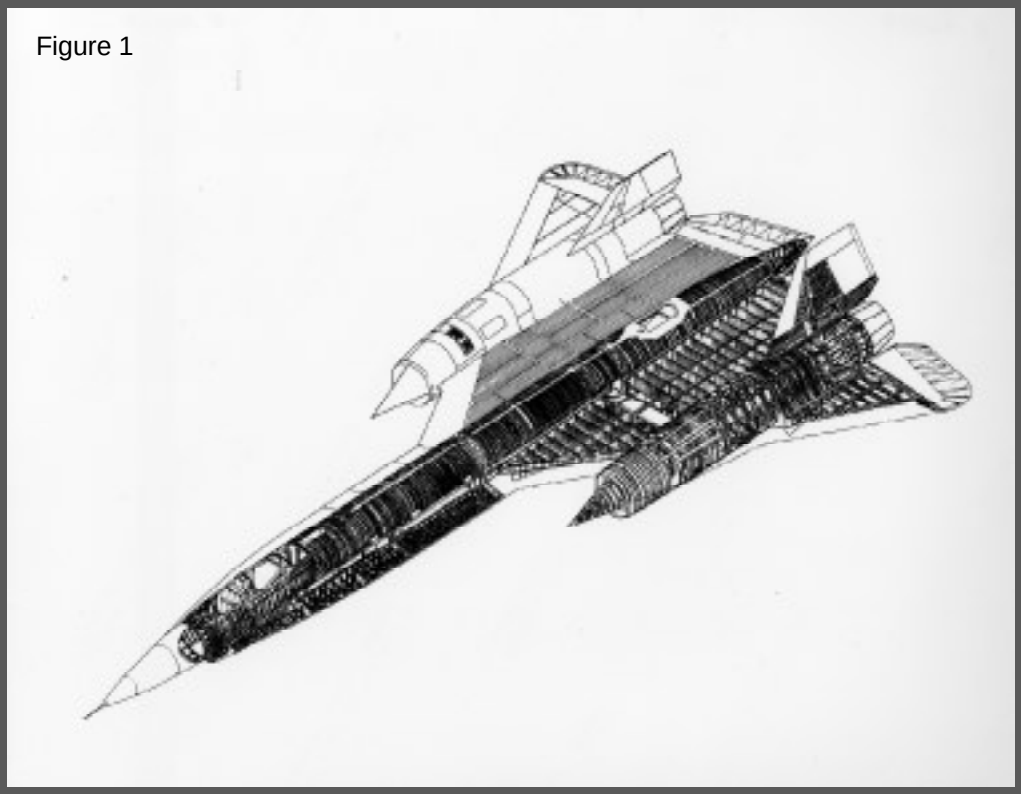
[6] Author's personal experience.

YF-12A (USAF serial number 60-6935), seen in flight just east of Edwards AFB, was the first to join the NASA/USAF research program. The two pointed objects on the underside of the engine nacelles are camera pods. (NASA photo EC76-5086)

SR-71—pressurized and rendered inert with nitrogen—was contained in six integral tanks within the fuselage and wing structure. (The A-12 and YF-12A had no wing tanks). Although they included 10,000 linear feet of sealant, the tanks leaked a considerable amount of fuel as a result of the provisions for expansion and contraction of the tanks with changes in temperature. According to NASA project engineer Gene Matranga, Lockheed designers faced a difficult challenge with the sealant. They needed to find one that would be compatible with titanium, yet "remain elastic enough to move with the expanding and contracting airframe, which grows up to four inches in length when hot, shudders through an unstart, reaches temperatures over 600˚F and bounces through turbulence and taxi loads."[7]

The A-12 fleet operated in secret until June 1968. At that time, all of the A-12 aircraft ended their service lives and went to Lockheed's Palmdale facility for storage. Their operational mission had been assumed by the SR-71A, operated by the Air Force. A planned operational version of the YF-12A interceptor, designated F-12B, failed to materialize as Secretary of Defense Robert McNamara ultimately cancelled the program as a cost-cutting measure. As a consequence, on 29 December

[7] Gene J. Matranga and William J. Fox, "YF-12A Development and Operational Experience", unpublished paper presented at the Supercruiser Conference, Wright-Patterson AFB, Ohio, 17-20 February 1976. NASA Dryden Historical Reference Collection.



This cutaway view illustrates the complex internal structure of the YF-12A. Design and construction of a mostly titanium airframe posed numerous challenges for Lockheed engineers. (NASA photo E76-30059)

1967, the Air Force instructed Kelly Johnson to terminate F-12B development. The YF-12A program ended on 1 February 1968, and the aircraft joined the A-12s in storage. There they remained until NASA reached an agreement with the USAF for a joint research program, beginning in 1969. Subsequent events proved this partnership to be a long and rewarding one.

Chapter 2: Joint USAF/ NASA YF-12 Research

Within a year of the public debut of the YF-12A, NASA expressed an interest in using the aircraft as a research platform. In an overview of active and proposed research programs for 1965, planners at the NASA Flight Research Center (FRC) at Edwards AFB, California, wrote that the YF-12A had "significant features of the configuration and operation of the aircraft that are of vital research interest," and which would complement research being conducted with the XB-70, F-111, and X-15.

NASA engineers regarded the YF-12A, with its capacity to sustain Mach 3 cruise speeds, as a potential source of data for developing advanced supersonic and hypersonic aircraft. Initially, the FRC program consisted of analyzing results of the USAF-Lockheed test program in hopes of a better understanding of:

• High-altitude hypersonic handling qualities.

• Techniques to determine the structural integrity of hypersonic aircraft in flight.

• Performance of hypersonic air-breathing propulsion systems.

• The interrelationships between the aerodynamics of air propulsion systems and the aerodynamics of hypersonic cruise configurations.[8]

In the beginning, NASA failed to obtain any of the YF-12A or SR-71 aircraft for flight research. The first attempt was a request by NASA to R. L. Miller of Lockheed, who in turn submitted a proposal to the company's Director of Flight Test Larry M. Bohanan in June 1968. NASA engineers wanted to obtain SR-71 inlet data by installing instrumentation in the number four SR-71A (USAF serial 61-7953).[9] Miller agreed to include the NASA request as a separate part of a larger proposal for instrumenta-

NASA engineers analyzed propulsion, as well as stability and control data obtained from the number four SR-71A in 1968 and 1969 as it underwent USAF Category II (performance) tests at Edwards AFB, California. (USAF photo)

[8] "Project Programs-Part II," briefing material from the center director's monthly Projects Review meeting, NASA Flight Research Center, Edwards, California, March 1965. NASA Dryden Historical Reference Collection.

[9] A note on serial numbers: Only three YF-12A aircraft were built by Lockheed; they include USAF serial numbers 60-6934 through 60-6936. A-12 aircraft serial numbers include 60-6924 through 60-6933 and 60-6937 through 60-6939. The M-21 variants were 60-6940 and 60-6941. The SR-71 series includes 61-7950 through 61-7981. The SR-71 serial numbers have frequently been published erroneously with a "64" prefix, as in 64-17950. All official documentation bears out the statements above. The best example is a complete list of SR-71 serial numbers in *SR-71 Final Report–Category II Flight Test Program, 1 July 1965 to 30 June 1967*, Volume II, Appendix X, p. X-8, declassified on 5 February 1991. A copy of this report is available in the Air Force Flight Test Center History Office at Edwards AFB, California.

tion in the aircraft. But even though he forwarded the proposal, Miller did not support it. In the first paragraph of the proposal he wrote: "It is probably not advantageous from our standpoint to allow NASA participation since it would require increased maintenance and would interfere with our development tests which are required in support of the fleet. In addition, the measurements would not provide any known benefits to the SR-71 program."[10]

Not surprisingly then, Lockheed turned down NASA's request. However, a second opportunity presented itself when two NASA representatives participated in the USAF Category II tests of the SR-71A. Engineers Gene Matranga and Bill Schweikhard worked with Air Force officials in analyzing propulsion, stability, and control data from the tests conducted in 1968 and 1969.[11]

Although these contacts did not yield an SR-71 for NASA to use, the Air Force finally agreed to make two YF-12A aircraft available to NASA researchers. A Memorandum of Understanding (MOU) for a joint NASA/USAF research program, signed on 5 June 1969, agreed that the Air Force would provide the airplanes, personnel, ground support equipment, and facilities. NASA, in turn, agreed to pay the operational expenses for the program, using funding that became available following termination of the XB-70 and X-15 programs.

The MOU outlined the general provisions of a joint NASA/USAF YF-12 research program, consisting of Phases I and II. The USAF Phase I, conducted to explore the tactical performance and support requirements of an advanced interceptor, included tactical tests of command, control, and communications; test intercepts of flying targets; and tests of the ASG-18 fire control system. The program also involved an examination of post-attack escape maneuvers, a demonstration of a semi-autonomous operational concept for a Mach 3 interceptor, and an assessment of the feasibility of a visual identification maneuver against an Super-Sonic Transport (SST)-type target. The renewed interest of the USAF in Phase I resulted from the recent introduction of the high-performance MiG-25 into the Soviet Air Force inventory. Although Phase I centered on Air Force needs, the MOU also accommodated the objectives of the NASA investigations.[12]

The two partners announced the joint program on 18 July 1969. Gene Matranga headed up the NASA team, which spent the first several months of the project installing instrumentation in the YF-12A. By December, engineers had placed strain gauges and thermocouples in the wing and fuselage to measure dynamic loads and temperatures.

The NASA Phase II program began when Paul F. Bikle, director of the NASA FRC, signed an agreement on 31 March 1970 with the Air Force, loaning YF-12A (60-6935) to NASA. This second round of tests included research into propulsion systems, aerothermoelasticity, and flight-dynamics characteristics of supersonic cruise aircraft.

NASA YF-12 research represented a cooperative effort by researchers from

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[10] Memorandum from R. L. Miller to L. M. Bohanan regarding Proposed Instrumentation for 2004 Follow On Tests, 17 June 1968. NASA Dryden Historical Reference Collection.

[11] Berwin Kock, "Overview of the NASA YF-12 Program," presentation during NASA YF-12 Experiments Symposium held at Hugh L. Dryden Flight Research Center, Edwards, California, 13 September 1978. NASA Dryden Historical Reference Collection.

[12] "Memorandum of Understanding, USAF-NASA Research and Development Program," 5 June 1969. NASA Dryden Historical Reference Collection.

The YF-12A collected aerodynamic data with and without the ventral fin. NASA engineers determined that removing the fin did not seriously affect aircraft stability. The white circles with crosses served as photo calibration marks for ground-based tracking cameras. (NASA photo EC71-2710)

every NASA aeronautical center. Engineers from Langley Research Center in Hampton, Virginia, concentrated primarily on aerodynamics and structures. Lewis Research Center (now Glenn Research Center) in Cleveland, Ohio, had an interest in propulsion aspects. Engineers from Ames Research Center focused on inlet dynamics and the correlation between wind-tunnel and flight data. Researchers at NASA FRC organized these various interests into a single, unified investigation.[13] According to a program overview by NASA FRC engineer Berwin Kock, "the program also had unique, strong, and continuing support from NASA Headquarters, and the USAF was an active partner in the program, providing logistics support and playing an active role in formulating technology experiments."[14]

In spite of its earlier resistance to the project, Lockheed Aircraft Company now provided valuable technical support. Privately, however, YF-12 designer Kelly Johnson made some frank observations about NASA and the YF-12 in his personal log:

> Had a visit from the NASA test organizations [which] discussed their research to date. They haven't come up with anything that is new to us, but it seems to be a good program for them to keep up their technical organizations. I am attaching a letter from Gene Matranga indicating our current relationship, which is excel-

[13] Richard P. Hallion, *On the Frontier: Flight Research at Dryden, 1946-1981* (Washington, D.C.: NASA SP-4303, 1984), p. 191.

[14] Berwin Kock, "Overview of the NASA YF-12 Program."

Personnel associated with YF-12 research included: (standing, left to right) William R. "Ray" Young, Fitzhugh L. Fulton, Jr., Donald L. Mallick, Victor W. Horton, and (kneeling, left to right) Harry R. Childs, William P. Albrecht, Bob Eaton, Jack Mayesh, Gene J. Matranga, William Fox, and Joe D. Watts. (NASA photo EC72-2989)

> lent. I have two objections to the NASA program, the main one is that they will probably publish important data, which the Russians will be happy to receive as they always are with NASA reports. Secondly, they are repeating so many things we pioneered in and I gravely doubt our people will be given any, or sufficient, credit for solving the problems first. We have continued to cooperate to the hilt with NASA in spite of the above.[15]

NASA flight crew members for the YF-12 aircraft included two pilots and two flight-test engineers. The first NASA crew to be checked out in the YF-12A consisted of Fitzhugh L. Fulton, Jr. (research pilot) and Victor W. Horton (flight-test engineer). Fulton, a former Air Force test pilot, joined NASA in 1966. Prior to assignment to the YF-12 program, he had served as project pilot on the XB-70. Aerospace engineer Vic Horton joined NASA in 1959 and became involved in the paraglider and lifting-body programs. He also served as launch panel operator on the NB-52B mothership aircraft. Fulton and Horton underwent a series of three checkout flights in YF-12A (60-6936) in March 1970. The following month, NASA FRC chief research pilot Donald L. Mallick, a former XB-70 project pilot, was checked out in YF-12A (60-6935). At the end of April,

[15] Jay Miller, *Lockheed's Skunk Works–The First Fifty Years*, p. 133.

YF-12A (USAF serial number 60-6936) joined the program in 1970 as the primary USAF test aircraft. White markings near the nose commemorate world speed and altitude records achieved by this aircraft on 1 May 1965. (NASA photo EC70-22047)

aerospace engineer William R. “Ray” Young, associated previously with the X-15, XB-70, Lunar Landing Research Vehicle (LLRV), and F-111 research programs, teamed with Mallick. With the completion of this process, the experiments aboard the Mach 3 Blackbirds could begin.

Detail of the rear fuselage heater assembly under construction around SR-71A (61-7954). When construction was completed, a total of 16,430 radiant quartz lamps enabled researchers to simulate flight temperatures over a 5,000-square-foot area of the aircraft's surface. (NASA photo E71-23782)

Chapter 3: Heating and Loads Research

Originally, NASA researchers planned to concentrate the YF-12 program on propulsion technology, especially inlet performance. Since the YF-12 featured a mixed-compression inlet, engineers planned to investigate drag, compressor face distortion, unstart margins, control parameters, air data requirements, and bleed system effects.

But problems associated with high-temperature instrumentation delayed the propulsion investigation. This postponement gave NASA engineers time to develop a second initiative: a structures research program involving thermal stresses and aerodynamic loads. The overall effort relied on wind-tunnel data, analytical prediction, and flight research.

SR-71A (61-7954) served as a stand-in for the YF-12A during construction of heaters for the structural loads program. (NASA photo E71-23783)

The forebody heater assembly, shown undergoing tests prior to installation around the foreward fuselage of the YF-12A. (NASA photo EC71-2788)

Since supersonic aircraft undergo aerodynamic as well as thermal loads, the NASA team planned a series of experiments at the FRC to measure the two types, both combined and separately. Technicians installed instrumentation in the wing and fuselage of YF-12A (60-6935). Strain gauges placed in several locations measured aerodynamic loads. At the same time, instruments on the left side of the aircraft recorded skin temperatures.

The YF-12 possessed ideal qualities for thermal research. Previous research aircraft, such as the X-15, had experienced high temperatures, but only for short periods of time. The YF-12, however, could sustain high-speed thermal loads for relatively long periods during cruise, enabling temperatures to stabilize. As FRC project manager Gene Matranga noted:

> We recognized that it would take a while to develop instrumentation for the aircraft, and we decided to use this time to investigate steady-state heating effects on the aircraft structure.
>
> In all the X-15 work, everything had been transient. The vehicle went to high speed in a matter of two to three minutes. It slowed down in a matter of three to five minutes. Everything was always transient because the temperature was always increasing or decreasing. The YF-12, on the other hand, could stay at Mach 3 for 15 minutes. We could get steady-state temperature data that would augment the X-15 data immeasurably.[16]

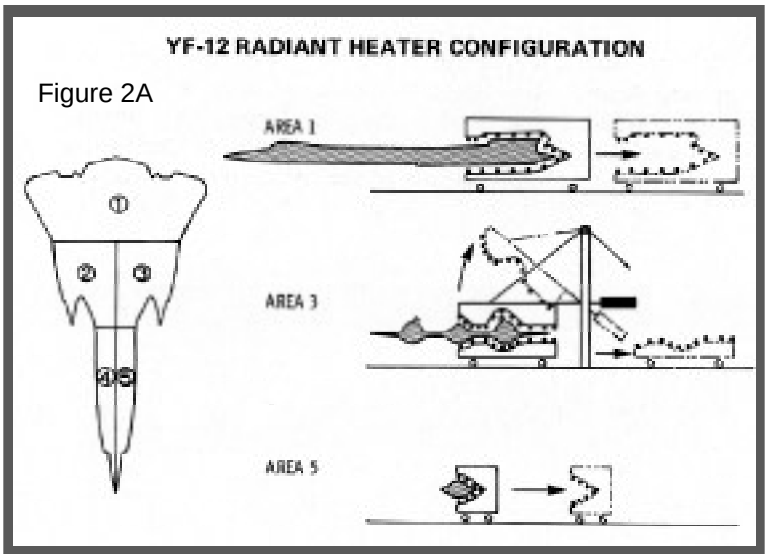
After collecting flight research data over most of the YF-12 performance envelope, researchers compared it to data collected during ground testing in the High Temperature Loads Laboratory (HTLL) at the NASA FRC during 1972-73. The process of comparison involved several steps.

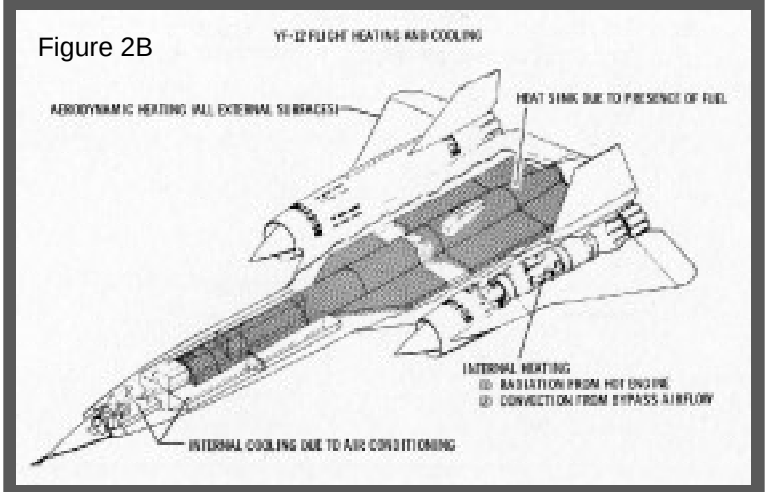
[16] Interview of Gene Matranga by Peter Merlin, Lancaster, California, 30 May 2000. See Appendix 4 for a transcript of this interview. An original copy is in the NASA Dryden Historical Reference Collection.

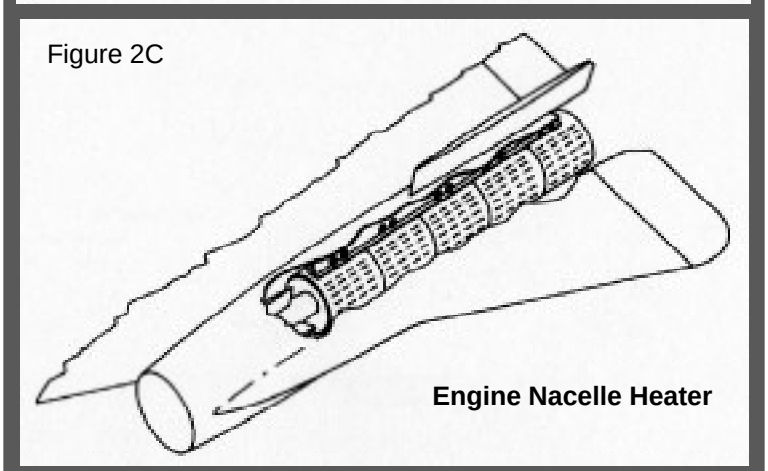
Flight research data provided measurements of the combined effects of temperature and loads. Once this information had been gathered, technicians put the aircraft into the HTLL and heated the entire structure to the same temperatures that it had experienced in flight. By measuring the strain outputs from temperature alone, NASA engineers could then separate the thermal effects from the flight data to obtain accurate measurement of aerodynamic loads.

In the HTLL, a radiant heater provided the necessary heating for the ground simulation. The apparatus consisted of 464 stainless steel reflector panels configured to fit the contours of the aircraft. A total of 16,430 radiant quartz lamps enabled the YF-12 team at the FRC to simulate flight temperatures over a 5,000-square-foot area of the aircraft's surface. The heater units covered five areas: aft fuselage, mid-fuselage and forward nacelles (right and left), and the right and left halves of the forward fuselage. Additionally, another heater fit into the nacelle in place of an engine, allowing researchers to simulate exact three-dimensional engine temperatures inside the nacelle. All of the heaters were subdivided into numerous control zones, each one in turn governed by a surface thermocouple. A data acquisition and control system, a test monitor system, and a test data processing system fulfilled the remaining simulation requirements.[17] By feeding the temperature profiles recorded in flight into a computer, the quartz lamps could generate the same profiles during the ground tests.

To prepare the aircraft for the heating research, technicians removed the aircraft's vertical tails, nose cone, and inlet spikes, parts not considered relevant to the temperature calibration of the aircraft. They also detached the engines, relying on the nacelle heater to simulate







Radiant quartz lamp heaters were fitted around the exterior of the YF-12A and inside the engine nacelles. Thermocouples on the aircraft's skin measured temperatures that simulated those occurring in flight. (The Radiant Heater graphics, Figures 2A-1C, came from NASA FRC Basic Research Review, 23 July 1973.)

[17] Jerald M. Jenkins and Robert D. Quinn, "A Historical Perspective of the YF-12A Thermal Loads and Structures Program," NASA Dryden FRC, Edwards, California, NASA TM (Technical Memorandum) 104317, May 1996, pp. 8-11. NASA Dryden Historical Reference Collection.

engine temperatures. To avoid accidental explosion, FRC technicians also removed fuel-soaked insulation and replaced it with dry material. They flushed and dried the fuel tanks as well and purged them with gaseous nitrogen during the tests.[18]

Results of the heating experiments showed that the predictions largely agreed with the laboratory results. Data obtained during flight, however, indicated temperatures as much as 20 degrees higher than anticipated because of the differences in the process of heat transfer. The rate of radiant heating is lower than that for aerodynamic heating in areas of higher structural mass. Moreover, the dry fuel tanks used in the ground tests also influenced the results. In flight, the aircraft's fuel acted as a heat sink. Given the absence of fuel in the aircraft during ground-based heating tests, the fuel tank skin temperatures exceeded those obtained in flight. The simulation and flight measurements converged as the flight- test aircraft depleted its fuel supply. Once these values converged, researchers established a correction for in-flight strain gauge measurements.[19]

With the resultant data about aerodynamic heating at high speeds recorded, the YF-12 team could turn to its initial interest, propulsion research at high speeds.

[18] Ibid., p. 12.

[19] Ibid., p. 13.

Chapter 4: Propulsion Research

Using the YF-12, NASA researchers hoped to establish a technology base for the design of an efficient propulsion system for supersonic cruise aircraft, such as a Supersonic Transport (SST). The main areas under investigation included inlet design analysis, propulsion system steady-state and dynamic performance, inlet engine control systems, and airframe/propulsion interactions. Engineers and scientists from NASA Ames, NASA Langley, NASA Lewis, and the NASA FRC all contributed to the YF-12 propulsion studies.

Since supersonic cruise aircraft required a propulsion system capable of operating efficiently throughout a wide range of flight conditions, designers needed to optimize the inlet system to match engine requirements at varying speeds and altitudes. NASA FRC engineer James A. Albers described the research process inherent in the YF-12 investigation:

> A first step in optimization of the propulsion system is an analytical study of the various inlet geometries that match the engine requirements. This is followed by wind tunnel testing of scaled models prior to flight testing. In general, conditions in the wind tunnel do not exactly duplicate flight conditions. With scaled models, the Reynolds numbers[20] and local flow field do not always correspond to those in flight. In addition, the geometry and the instrumentation location and accu-

Technicians opened the hinged nacelle to gain access to the Pratt & Whitney J58 engine for repair or replacement. Operating in continuous afterburner during cruise, the engine consumed over 11,000 pounds of fuel per hour. (NASA photo E71-23809)

[20] Reynolds number, named after Osborne Reynolds, is a nondimensional parameter equal to the product of the velocity of an object (an airplane in this case) passing through a fluid (air in this case), the density of the fluid and a representative length, divided by the fluid's viscosity. In shorthand, the Reynolds Number represents the inertial forces divided by the viscous forces for the mass of air acted upon by the vehicle. Among other uses, it served to compare data from wind-tunnel models with that from full-sized airplanes or components. The Reynolds number was not determined solely by the viscosity of the air. The YF-12, for example, would have a much larger Reynolds number when flying through air at a given altitude, location, and time than would a small model simply because of the difference in size and the amount of air displaced. Furthermore, the Reynolds number would be much larger at the rear of a flight vehicle than at the front.

A movable cone, or spike, transitioned forward and aft to control the position of the shock wave and the Mach number of airflow into the J58 engine's inlet. Forward bypass doors opened and closed automatically to control airflow depending on pressures measured inside the ducts. (NASA photo E79-36284)

> racy of wind tunnel models are difficult to match to those of the flight hardware. Since the flight hardware and its expected performance are determined from scaled wind tunnel models, scaling techniques that allow the extrapolation of subscale inlet data to full-scale flight are necessary.[21]

Employing two Pratt & Whitney J58 engines, the YF-12's propulsion system included a mixed compression inlet in which air entered at supersonic speeds and slowed down to subsonic speeds before reaching the engine. The air's velocity had to be reduced because no existing engines could run on supersonic flow. Several devices moderated airflow into the engine. A movable cone, or spike, in the inlet transitioned forward and aft to control the position of the shock wave and inlet Mach number. Forward bypass doors opened and closed to maintain the proper position of the shock wave. The doors operated automatically as a function of pressures measured in the ducts. Aft bypass doors, operated by the pilot as a function of Mach number and forward door position, controlled airflow at the engine turbine face. Designers also devised a system to bleed off low-energy boundary-layer air that formed along the surface of the inlet spike. This practice improved inlet efficiency by making the entire main inlet flow passage available to the high-energy, high-velocity airflow.

A CIA report on the Project OXCART A-12 aircraft (predecessor to the YF-12) underscored the pivotal function of the Blackbird's inlet:

> A supersonic inlet or air induction system is designed to provide [the] best possible aerodynamic perfor-

[21] James A. Albers, "Status of the NASA YF-12 Propulsion Research Program," NASA TM X-56039, March 1976, p. 1. NASA Dryden Historical Reference Collection. The FRC became the NASA Dryden Flight Research Center in the month and year this paper appeared, but Albers had been an FRC engineer when he wrote it.

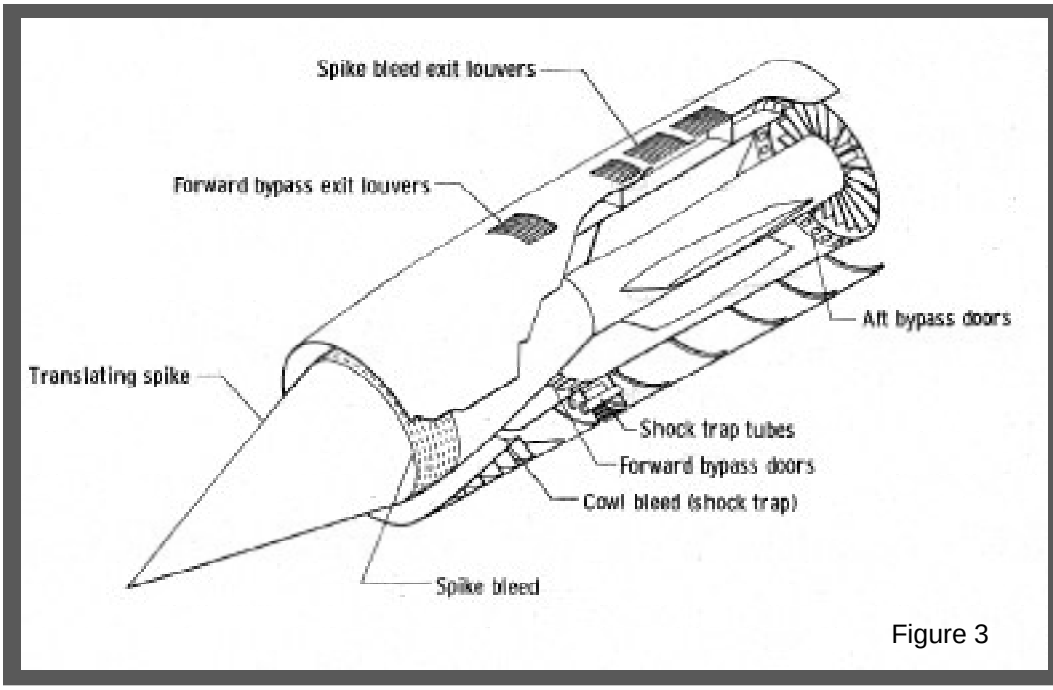


Figure 3

YF-12 inlet diagram showing translating spike and bypass doors and louvers. (Drawing taken from NASA TM X-56039)

mance over a range of supersonic Mach numbers with a stable and steady flow of air to the engine. However, due to constraints imposed by supersonic aerodynamics, truly optimum performance with an ideal shock pattern and an inlet airflow exactly matched to the engine airflow requirement can only be provided at one flight condition. Since the OXCART aircraft must cruise for considerable periods of time at a Mach 3 speed, maximum possible range is realized by providing this optimum inlet performance at the Mach 3 cruise condition. The basic geometry and airflow characteristics of the inlet are then varied to provide a minimum compromise of aerodynamic performance and efficiency at lower flight speeds. Some of this needed flexibility is provided by varying the position of the inlet spike. Since the airflow which can be admitted by the inlet is in excess of that which can be accepted by the engine at other than the design condition, this excess airflow is dumped overboard through a series of forward bypass doors or passed down the nacelle airflow passage around the engine through a series of aft bypass doors.[22]

During high-speed flight in the YF-12, compression of air in the inlets generated most of the vehicle's thrust. The turbojet continued to run, but the inlet provided 70 to 80 percent of the total motive force. A significant percentage of the air entering the inlet bypassed the engine through ducts and traveled directly to the afterburner. At cruise Mach conditions, fuel burned more advantageously in the afterburner than in the main burner section. Hence, engineers described the powerplant as a turbo-ramjet.[23]

The shock waves presented a challenge to the system. If designers failed to properly

[22] "OXCART A-12 Aircraft Experience Data and Systems Reliability," p. 6. (See Chapter 1, footnote 1.)

[23] Gene Matranga and William J. Fox, "YF-12A Development and Operational Experience," unpublished paper presented at the Supercruiser Conference, Wright-Patterson AFB, Ohio, February 17-20, 1976, p. 3. NASA Dryden Historical Reference Collection.

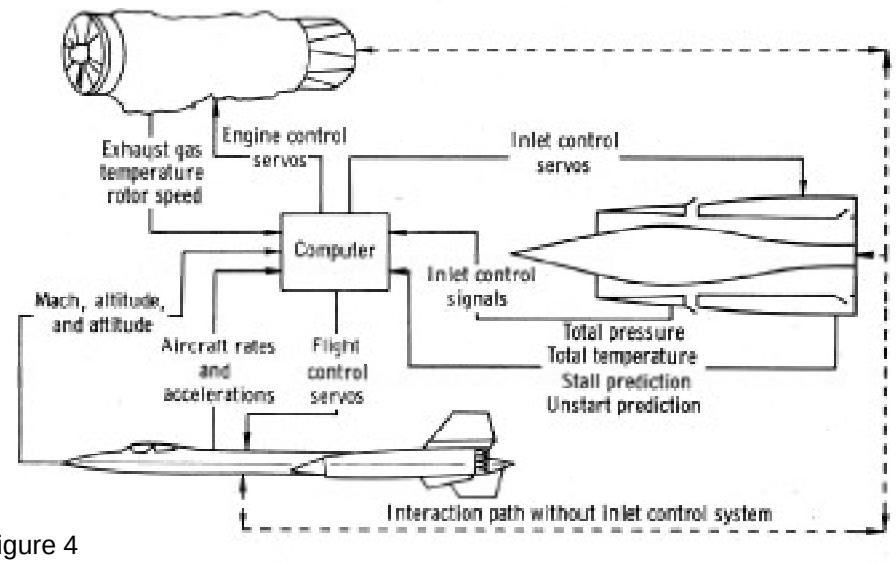
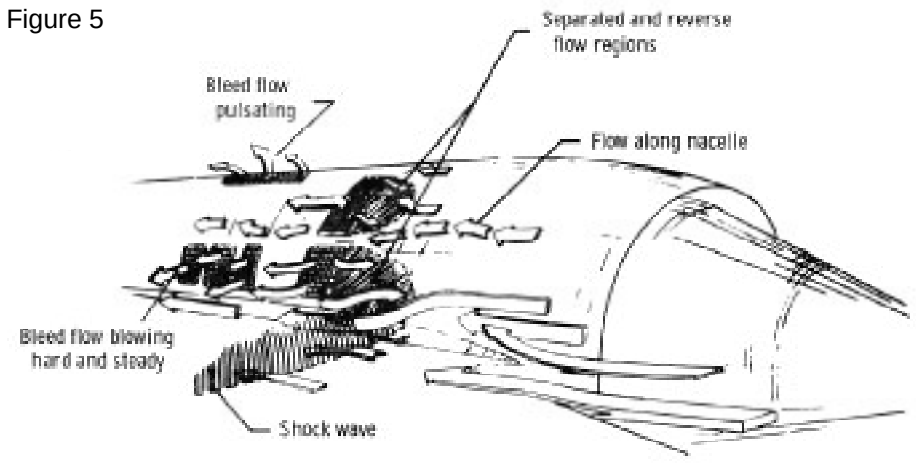


Figure 4

Conceptual schematic drawing of an integrated inlet and airflow control system. (Drawing taken from NASA TM X-56039)

match airflow to the inlet, the shock wave would create drag. Normally the shock wave would be expected to occur slightly behind the inlet throat and supersonic diffuser for stability. But in this case, the spike and bypass doors functioned together to retain the shock wave inside the inlet. Sometimes, however, large airflow disturbances or improper inlet control system operation caused the inlet to expel the shock wave. This resulted in an inlet unstart, the byproduct of insufficient pressure and air for normal engine operation. This sudden loss of thrust produced violent yawing, pitching, and rolling of the airplane. Pilots likened the phenomenon to a train wreck. During the YF-12 research program, unscheduled unstarts were common on any given mission. But as a result of the NASA investigation, spike schedule refinements (coordinating spike position to retain the shock wave in the inlet), and hardware improvements rendered unstarts a rare occurrence.[24]

Figure 5



Airflow into the nacelles with the forward bypass doors open. Note areas of separated and reverse airflow. (Drawing taken from NASA TM X-56039)

[24] Ibid., p.4.

At the same time, NASA did not give up its earlier attempts to acquire an SR-71A for Blackbird flight research. Such efforts did not meet with enthusiasm in Air Force circles. Some USAF officials felt that the sensitive SR-71 technology might not be protected properly in civilian hands. Indeed, the Blackbirds then in service had improved engines[25] as well as inlet spikes[26] less visible to radar than those on earlier models. For security reasons, the Air Force refused to lend NASA an aircraft with either of these advanced features.[27]

Air Force representatives did finally relent, but with conditions. They agreed to loan NASA the second SR-71A (61-7951), but with the earlier model engines, ostensibly to match the inlet behavior of the YF-12A. Additionally, to hide the aircraft's identity, it entered NASA service as the YF-12C and received tail number 06937. The tail number followed in sequence with the other two aircraft—06935 and 06936—and bolstered the assertion that this was a YF-12, and not an SR-71. The SR-71s' tail numbers began at 17950. A classified A-12, with tail number 06937, also existed. Placed in storage at the Lockheed facility in Palmdale, California, its existence remained unknown to the public until 1982. (For purposes of convenience, the YF-12C designation will be used throughout the remainder of this monograph). By May of 1971, Lockheed technicians undertook an inspection of the YF-12C in preparation for its addition to the NASA research program. They completed their work on number 937 by the middle of June, and prepared it to join 935 and 936.[28]

On 24 June 1971, the program suffered a setback. Lt. Col. Ronald J. "Jack" Layton piloted number 936 on its 62nd flight of the joint program, and Maj. Billy A. Curtis served as flight-test engineer. After performing a handling qualities evaluation the crew returned to base. But on the way home, disaster stuck. A fuel line in the right engine failed, causing a fire. As Layton approached Edwards, hoping to make an emergency landing, flames engulfed the right side of the aircraft. The crew ejected safely, but the YF-12A plunged into the desert.[29] The loss of 936 caused

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[25] Two types of engines were used in the SR-71 aircraft. The early type (referred to as the J-engine), also used in the YF-12A, incorporated fixed compressor inlet guide vanes and had a maximum afterburner thrust rating of 32,500 pounds at sea-level standard-day conditions. An improved configuration (the K-engine) incorporated two-position compressor inlet guide vanes. The vanes were automatically positioned axially below Mach 1.9 to provide increased airflow and increased thrust rating. Above Mach 1.9, the vanes moved to a cambered position and the engine provided thrust equivalent to the J-engine. The K-engine had a maximum afterburner thrust rating of 34,000 pounds at sea-level standard-day conditions.

[26] Metal spikes were originally built for the first three SR-71A aircraft and the two SR-71B trainers. This type of spike assembly was also used on the YF-12A. A "plastic" spike was later incorporated into production aircraft to reduce the vehicle's radar cross-section. Both types of spike were primarily constructed of A-100AT titanium alloy. On early models, the conical front section of the spike was comprised of a built-up, ring-skin assembly. On the improved units an asbestos-fiberglass laminate "plastic" assembly replaced the metal cone.

[27] Several years later, the improved (K-type) engines were installed in the YF-12A (60-6935). The first flight of 935 with the K-engines took place on 18 October 1974. No propulsion research was conducted with the K-engines.

[28] "Project Activity Guide (Accomplishments)," dated 2 June 1971 and 17 June 1971, lists all three aircraft (935, 936, and 937) indicating that 937 was not simply a replacement for 936, which crashed on 24 June 1971. NASA Dryden Historical Reference Collection.

[29] YF-12A (60-6936) Mishap Report, "History Of Flight," AF Form 711, Part 11, 16 July 1971. Formerly classified SECRET-Special Access Required-SENIOR CROWN Program. Declassified in 1996 per Freedom Of Information Act request by author. Released 14 May 1998. NASA Dryden Historical Reference Collection.

YF-12A (serial number 60-6936) served as the primary USAF test aircraft during the joint program. It was lost in a non-fatal accident during an Air Force flight on 24 June 1971. (Lockheed photo LA-4087)

delays in the YF-12 propulsion research program. While the remaining YF-12A continued to serve as a loads testbed, the YF-12C arrived at NASA FRC on 16 July 1971. It did not begin propulsion research flights, however, until 6 June 1972.

Propulsion research using the YF-12C included airspeed calibrations, collection of baseline data, and data collection at numerous flight conditions. To gather data on propulsion system performance, research crews performed such tasks as level accelerations and decelerations, constant power turns, and airspeed lag calibration roller-coaster maneuvers. As the crews operated the engine inlet controls in manual and automatic modes, instruments measured oscillations known as phugoids.[30] They also gathered data on engine-bypass-door and inlet-spike performance and established speed-power points. Finally, they performed constant-speed climbs and descents at specific knots estimated airspeed (KEAS) or Mach number and constant-power turns.

For the early USAF tests, Lockheed had equipped a YF-12A with a Honeywell

[30] A phugoid occurs when an aircraft's airspeed or pitch attitude is disturbed from its trimmed equilibrium condition. During flight, the pilot trims the aircraft to a desired angle of attack (pitch attitude) which may then be disturbed by additional pilot input or natural air turbulence. The airplane's tendency to return to its trimmed attitude is so strong that it generally returns too quickly and overshoots. The resultant oscillations tend to die out after a few cycles and the aircraft returns to its trimmed condition. John S. Denker provides an excellent description of phugoids in *See How It Flies* (1996), a book available on the World Wide Web at http://www.monmouth.com/~jsd/how/htm/how.html#contents.

By May 1971, Lockheed technicians were inspecting the number two SR-71A (61-7951) in preparation for its addition to the NASA research program. It was redesignated "YF-12C" for reasons of security and painted in NASA markings with a different tail number, 06937. The YF-12C arrived at the NASA Dryden FRC on 16 July 1971. (NASA photo EC72-3149)

general-purpose computer called the Central Airborne Performance Analyzer (CAPA) Phase I to monitor the aircraft's Air Inlet Control System (AICS). The unique inlet system on the YF-12 made it vulnerable to high stresses, severe environmental conditions, and possible malfunctions. Because the AICS only realized its full operational capabilities at high supersonic speeds, malfunctions—which tended to occur in this regime—proved most difficult to detect. Such malfunctions could not be discovered during static ground tests. But the CAPA provided a central system to continuously monitor and analyze the performance of the AICS during flight and transmitted maintenance messages identifying the faulty components.

Honeywell delivered an improved CAPA Phase II to Lockheed in February 1973. The new CAPA featured a special-purpose computer with an instruction repertoire specifically tailored to the task of in-flight performance monitoring, malfunction detection, and fault isolation. A second remote unit monitored additional signals including fuel and hydraulic systems and engine functions for information purposes rather than fault detection. Lockheed technicians installed the CAPA Phase II prototype in a Functional Mock-Up (FMU), a ground-based model containing all the operational systems of a real YF-12 aircraft. Lockheed delivered the CAPA unit to NASA in March for installation in the YF-12A. By 28 June, NASA technicians had completed the integration of the CAPA Phase II system. Between 12 July 1973 and 6 June 1974, the CAPA system operated during 28 flights. Because of the high reliability associated with AICS, the CAPA made only one valid fault detection/diagnostic in over 71 hours of

operation. The remote unit, however, detected failures in other systems, revealed in later ground-based data processing. If the maintenance software for these systems had been installed into the CAPA, technicians on the ground could have detected the failures in real time.[31]

Once this software had been evaluated, the YF-12 crews conducted a series of tests between 19 November 1976 and 21 July 1977 to correlate specific wind-tunnel data points with flight-test data points. To establish the match points precisely, the pilot had to fly the aircraft within 0.05 Mach number of the recorded wind-tunnel speed. The match points provided flight-test inlet data and verified the earlier wind-tunnel results. Researchers also studied the phenomenon of unstarts by inducing them intentionally and then restarting the engine. NASA technicians installed an inlet override system, called Inlet Recall, to allow manual control of the inlet spike and bypass doors. During a test of the system, the autopilot controlled attitude and altitude. The pilot slowly trimmed the inlets to maximum performance, then went beyond and induced the unstart condition. As the aircraft underwent a sudden, violent loss of altitude and airspeed, the pilot initiated either an automatic or manual restart procedure.

These important investigations were complemented by another phase of NASA Blackbird flight research, involving the landing characteristics of these high-speed vehicles.

[31] "Final Report for the CAPA/YF-12 Central Airborne Performance Analyzer, Phase II: The Study of In-Flight Real Time Diagnostics," Honeywell, Report W8340-FR, 8 November 1974, pp. 1-1 to 4-2.

Chapter 5: Landing Studies

In another facet of YF-12 research, NASA and Lockheed engineers investigated Space Shuttle landing dynamics using the YF-12C. Several flights, conducted in April and June 1973, demonstrated Shuttle-type flight characteristics during low lift-to-drag (L/D) approaches.[32] Specifically, the researchers needed data for L/D ratios of two to three, the range predicted for the Space Shuttle orbiter. This necessitated operating the YF-12C in a high-drag configuration, achieved by reducing power to idle, moving the inlet spikes forward, and opening the bypass doors to the restart position. In addition, the pilots needed to transfer fuel to maintain a forward center-of-gravity and to burn off fuel to allow descent at as light a weight as possible (to avoid flying the aircraft at maximum L/D). The descent profile maximized engine negative thrust-inlet drag and also allowed for the lowest possible lift coefficient.

Three flights, including 26 approaches, resulted in satisfactory pilot ratings for all handling qualities. The flight crews noticed no tendency toward pilot-induced oscillation and suggested that the YF-12C would serve as an acceptable model for Space Shuttle landing characteristics.

In 1974, NASA engineers decided to use the YF-12 aircraft in a somewhat different role: to study the landing dynamics of a low-aspect-ratio[33] supersonic aircraft. The data would be used to validate the Flexible Aircraft Takeoff and Landing Analysis (FATOLA) computer program developed by NASA Langley, one that offered a six-degrees-of-freedom rigid body simulation.[34] Technicians from

Following takeoff, the YF-12C takes on JP-7 fuel from a KC-135Q tanker. In 1973, NASA crews flew the YF-12C to simulate Space Shuttle landing approaches. Satisfactory pilot ratings suggested that the aircraft had acceptable handling qualities to serve as a model for Shuttle landing characteristics. (NASA photo EC72-3146)

[32] Lift-to-drag ratio is the value of the total aerodynamic force acting on a body (such as an aircraft or wing) divided by the retarding force that acts on that body as it moves through a gaseous fluid.

[33] Aspect ratio is the ratio of the square of the span of an airfoil to the total area, or the ratio of its span to its mean chord.

[34] Six-degrees-of-freedom refers to six axes of motion, in this case: up, down, left, right, backward, and forward.

NASA research pilots flew the YF-12A to study landing dynamics of low-aspect-ratio supersonic aircraft. The data validated computer simulation methods developed by NASA Langley. (NASA photo EC76-5110)

McDonnell Douglas Astronautics Corporation programmed FATOLA with the YF-12 structural mode data and computed the airplane response to taxi, landing, and takeoff using a measured runway profile.[35]

Up to this time, aircraft designers lacked a solution to a complex problem affecting transport aircraft. They could not predict adequately the structural and control problems resulting from landing gear and airframe interactions. Runway irregularities routinely affected tire loads. Surface roughness, ground contour elevations and slopes, and airplane-to-ground axis orientation all contributed inputs through tire deflections and unsprung mass excitations.[36] The increased structural flexibility and higher takeoff and landing speeds of proposed Supersonic Transport (SST) designs magnified the problem. Since the YF-12 shared many structural characteristics with SST designs, the Blackbirds assumed a leading role in the landing dynamics research program.

[35] "YF-12 Runway Response," James M. McKay notebook. NASA Dryden Historical Reference Collection. The original program, designed by NASA Langley for use with rigid bodies, was called Takeoff and Landing Analysis (TOLA). After McDonnell Douglas Astronautics Corporation programmers modified it with a flexible-body option, it was renamed Flexible Aircraft Takeoff and Landing Analysis (FATOLA). James M. McKay refers to it simply as TOLA throughout his notes, but it is more properly called FATOLA as used for the YF-12.

[36] Ibid.

Planning for the landing study involved much teamwork inside and outside of NASA. Gene Matranga and Jim McKay represented NASA's Flight Research Center. Bob McGehee and Huey Carden were the primary researchers from NASA Langley. Bill Fox and Gus Dishman of Lockheed Advanced Development Projects provided additional support, particularly regarding the calibration of instrumentation. These calibrations were completed by the end of 1974 and on 31 January 1975 Jim McKay submitted a Request for Project Approval to measure YF-12 response to runway roughness. McKay proposed instrumenting the YF-12A to measure ground loads and dynamic response during landing, taxiing, and takeoff on the Edwards AFB main runway.
The program coordinated the research efforts of the NASA Langley Structures and Dynamics Division in developing an active landing-gear-control system for proposed SST aircraft. NASA FRC researchers obtained experimental response data from flight tests to correlate with the response calculated using the FATOLA program. The validated FATOLA program defined the interactive characteristics of active-control landing gear systems with other aircraft characteristics and systems such as engine thrust, ground effect[37] and crosswind aerodynamics, unsymmetrical touchdown conditions, airframe structural elasticity, and antiskid braking.

During March 1975, Flight Research Center technicians instrumented the YF-12A with strain gauges and accelerometers for the two-phase program. The first phase consisted of consecutive takeoffs and landings in the low-speed flight regime. The second phase included high-speed flight to assess the effect of elevated temperatures on landing gear performance.

Prior to conducting ground-loads and aircraft-response experiments, researchers created a runway profile for the primary paved airstrip at Edwards AFB, California, to better define flight-test conditions. Capt. Thomas Black of the USAF Civil Engineers at Tyndall AFB, Florida, supervised the runway profile measurements. A three-track profile encompassing an area within 18 feet on either side of the runway centerline was then added to the FATOLA program.

The first data flight took place on 27 January 1976. Research pilot Fitz Fulton, accompanied by test engineer Vic Horton, conducted a low-speed taxi test and made a number of touch-and-go landings for high-speed taxi data. Don Mallick and Ray Young made a second flight eight days later. Two other flights failed to gather data; the first due to foam on the runway, and the second because of an unsafe landing gear indication on the YF-12A. Based upon the correlation of the computer simulations and flight data, researchers validated FATOLA as a versatile analytical tool.

A second landing project took place in 1977. This research demonstrated a dual-mode adaptive landing gear system to reduce the dynamic response of an airplane during ground taxi. An airplane's landing gear system absorbs the kinetic energy associated with vertical velocities at touchdown and generally produces maximum efficiency at its maximum sink rate. Designers accomplish this by adjusting the combined shape of the static air-load-stroke curve[38] and the hydraulic damping curve to provide a constant load during a maximum-design sink-rate

[37] Ground effect is an increase in the lift of an aircraft operating close to the ground caused by reaction between high-velocity downwash from its wing and the ground.

[38] The air-load-stroke curve is a function of landing gear strut stroke and strut loads. The stroke (length of extension/compression of the gear strut) is a function of maximum touchdown load, impact velocity, stroking efficiency, and tire deflection.

The YF-12A main landing gear included three nitrogen-filled 32-ply tires. They were coated with a thin film of aluminum to reflect heat while retracted. (NASA photo E71-22968)

landing. For a given kinetic-energy absorption, this yields the shortest gear stroke. Such a design resulted in the lightest practical gear to absorb the landing energy. An adaptive landing gear system can also increase the lifespan of an airframe by reducing vibration stress incurred during taxi, takeoff, and landing.

Such an approach reduced total aircraft weight but did not necessarily result in a static air-load-stroke curve suitable for isolation of runway roughness during taxi. This particular condition had special significance for large flexible aircraft designs such as the YF-12. To remedy the problem, Lockheed engineers designed a dual-mode adaptive landing gear system for the YF-12A. The configuration included a strut with an optimized air-load-stroke curve during landing and an automatic switch-over system to allow for a flatter air-load-stroke curve during taxi.

Lockheed engineers first proposed testing a dual-mode landing gear system in 1976 and installed the prototype system in the YF-12A in January 1977. Pilots then flew three series of test runs,

In 1978, a dual-mode landing gear study with the YF-12A demonstrated reduced dynamic response during taxi, takeoff, and landing operations. The prototype system was installed in the YF-12A in January 1977. (NASA photo EC77-6992)

demonstrating three gear configurations. Don Mallick and Ray Young led off with two baseline landing gear stiffness tests in February. Fitz Fulton and Vic Horton then flew two tests with a large-volume auxiliary air chamber added to the system to modify the air-load-stroke curve. Mallick and Young accomplished the final two tests to demonstrate a mixed-volume configuration. For each of the three configurations tested, the crew performed a series of eight taxi runs, providing constant-speed taxi data at a variety of airplane weights and velocities.

The study demonstrated the effectiveness of a dual-mode adaptive landing gear system in reducing the dynamic response of an airplane during taxi. It also provided a database to aid in determining the degree of correlation between analytically predicted responses and actual test results with a full-scale YF-12A. During the tests, the system reduced dynamic response by 25 percent at the aircraft's center of gravity and as much as 45 percent at the cockpit. The research pilots who flew the aircraft commented that the "degree of ride improvement is quite noticeable, particularly at the higher gross weights."[39]

A final YF-12 landing study took place in March 1978. Dryden engineers scheduled three Space Shuttle orbiter landing-approach simulation flights in the YF-12A. The first occurred on 23 March with Fitz Fulton and Vic Horton as the crew. The last two flights took place on

[39] Max A. Gamon, "Testing and Analysis of Dual-Mode Adaptive Landing Gear, Taxi Mode Test System for YF-12A," Lockheed (Burbank, California: NASA CR-144884, September 1979), pp. 1.

31 March. Einar Enevoldson flew with Ray Young, and Bill Dana flew with Vic Horton. The pilots felt that the aircraft had exceptionally good control characteristics during Shuttle-type approaches, which involved precise maneuvering just prior to touchdown. They did not experience any tendency toward over-control or pilot-induced oscillation (PIO).

Researchers compared data collected from the YF-12 flights with that accumulated by simulated Shuttle approaches flown in the F-8 Digital Fly-By-Wire (DFBW) aircraft and the NC-131H Total In-Flight Simulator (TIFS). These simulations paved the way for approach and landing tests using the Space Shuttle *Enterprise*, which in turn furnished planners with data for the first Space Shuttle Orbital Flight Test (OFT-1). Air-launched from a Boeing 747, *Enterprise* completed five Approach and Landing Tests (ALT) between 12 August and 26 October 1977. The final flight ended with a dramatic PIO as the vehicle settled onto the concrete runway. In a presentation at NASA Dryden on 17 August 1978, Milt Thompson summarized the results of the various Shuttle landing simulation test programs: "The landing characteristics of the orbiter are conditionally acceptable for an OFT-1 Edwards recovery but unacceptable for general operational use."[40]

Under contract to NASA Dryden, Gary Teper, Richard DiMarco, and Irving Ashkenas of Systems Technology, Incorporated (STI), compared data from the YF-12 Shuttle simulations and the ALT tests. They found that the YF-12 pilots could correct the vehicle's flight path quickly and smoothly while maintaining desired altitude. By contrast, orbiter pilots in the *Enterprise* experienced significant oscillations in attitude and altitude. The comparative analysis of the two vehicles identified such critical orbiter flight-control characteristics as excessive time delay in the attitude response to pilot control inputs and degraded flight path response to attitude changes associated with an unfavorable orbiter pilot location in the cockpit. The STI study determined that moving the pilot location forward improved the pilot's ability to control the vehicle's sink rate and landing performance.[41]

Even as the Blackbirds carried out these varied landing tests, they also contributed to aeronautical knowledge in a unique way—as platforms capable of carrying out a wide range of experiments during long-duration Mach 3 flight.

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[40] Milton O. Thompson, "DFRC Orbiter Landing Investigation Team—Final Presentation," briefing at NASA Dryden Flight Research Center, Edwards, California, on 17 August 1978. NASA Dryden Historical Reference Collection.

[41] Gary L. Teper, Richard J. DiMarco, and Irving L. Ashkenas, "Analysis of Shuttle Orbiter Approach and Landing Conditions," Systems Technology, Inc., Hawthorne, California, (Technical Report number TR-1137-1, January 1980), pp. 17–26.

Chapter 6: A Flying Laboratory

The two remaining YF-12 aircraft served NASA as flying laboratories, ideally suited as testbeds for a wide range of experiments: boundary-layer flow effects, digital integrated controls, heat transfer, and drag. Other experiments included the evaluation of a maintenance monitoring and recording system, measurement of engine effluents for pollution studies, noise suppression tests, sonic boom effects, and testing of a series of structural wing panels designed by NASA Langley and fabricated by Lockheed.

Not every potential use of the YF-12 aircraft came to fruition. In 1971, NASA requested a Lockheed Advanced Development Projects (ADP) study on the feasibility of launching a hypersonic drone from the YF-12C. On 30 July 1971, Lockheed's Henry G. Combs and John R. McMaster submitted the results of the study, based on the design of NASA's proposed HT-4 subscale high-speed transport model. After investigating various drone locations (dorsal and ventral), mounting and separation methods, and launch and landing options, the two engineers offered their conclusions. The launch of a dorsally mounted drone could be realized, but only with certain provisions.

Combs and McMaster proposed a series of steps before attempting a drone launch. Predicted aerodynamic and drag data would have to be substantiated with an adequate wind-tunnel program, including the determination of an optimum drone launch angle with respect to the carrier aircraft. Certain areas of the YF-12C structure required rework, such as hard points, for mounting the drone. Modification of the fuel system would be required to maintain the center-of-gravity. Also, engineers had to determine operating restrictions to avoid exceeding the aircraft's structural load limits.

The proposed HT-4, a model of a high-speed transport design, was scaled down to a length of 600 inches. Powered by a Pratt & Whitney RL-10 engine, it was designed for launch at standard YF-12 cruise and altitude conditions.

Although the Lockheed ADP study declared the concept technically feasible, some individuals raised concerns. ADP Senior Vice President Kelly Johnson approved the report, but commented cautiously: "This is a progress report only. I want to talk to NASA about safety aspects before concrete action is taken to implement any construction."[42]

In 1971, at the request of NASA researchers, Lockheed submitted a study on the feasibility of using the YF-12C to launch a hypersonic drone from a dorsal pylon. The Lockheed evaluation incorporated data derived from the then-classified M-21/D-21 project which involved the launch of a dorsally-mounted Mach 3 drone from an early Blackbird variant. (NASA photo E71-23563)

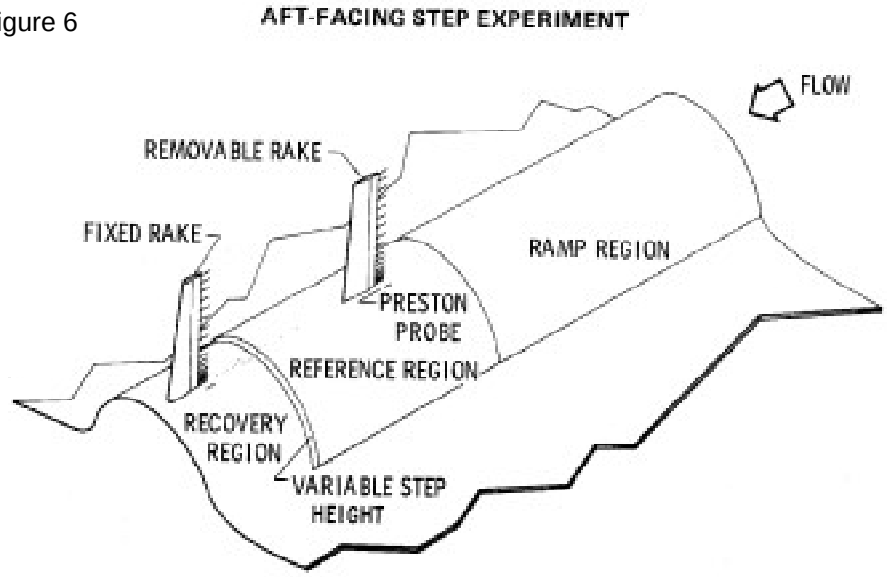
[42] Henry G. Combs and John R. McMaster, "Feasibility Study on Launching a NASA HT-4 Hypersonic Drone from a Lockheed YF-12C Airplane," Lockheed Report No. SP-177930, July 1971. NASA Dryden Historical Reference Collection.

The M-21 variant of the Blackbird carried a D-21 drone on a dorsal pylon. Captive carry tests began in December 1964 and flight tests occurred in 1966. In 1971, NASA pursued the idea of launching a hypersonic test vehicle in a similar manner. (Lockheed photo)

Johnson had reason for concern. Lockheed ADP had already flown a similar configuration, in utmost secrecy, in 1966. Two A-12 type aircraft (designated M-21) had been built expressly as launch aircraft for the secret D-21 reconnaissance drone. Captive flight tests of the dorsally mounted D-21 began in December 1964. Numerous difficulties relative to range and transonic acceleration plagued the M-21/D-21 combination. The first launch took place on 5 March 1966. Kelly Johnson later reported that “mainly, we demon-

The M-21 variant served as a mothership for D-21 drones. Following three successful launches, a fatal accident brought an end to the M-21/D-21 program. NASA personnel were briefed on the D-21 program and initially decided to pursue a similar HT-4 proposal in spite of the difficulties Lockheed had experienced with the D-21. (Lockheed photo)

Figure 6



An aft-facing step experiment determined the drag penalty caused by aft-facing surface discontinuities in a thick boundary layer region. Vertical rakes contained probes to collect data throughout the boundary-layer. (Figure taken from NASA FRC Basic Research Review, 20 October 1975)

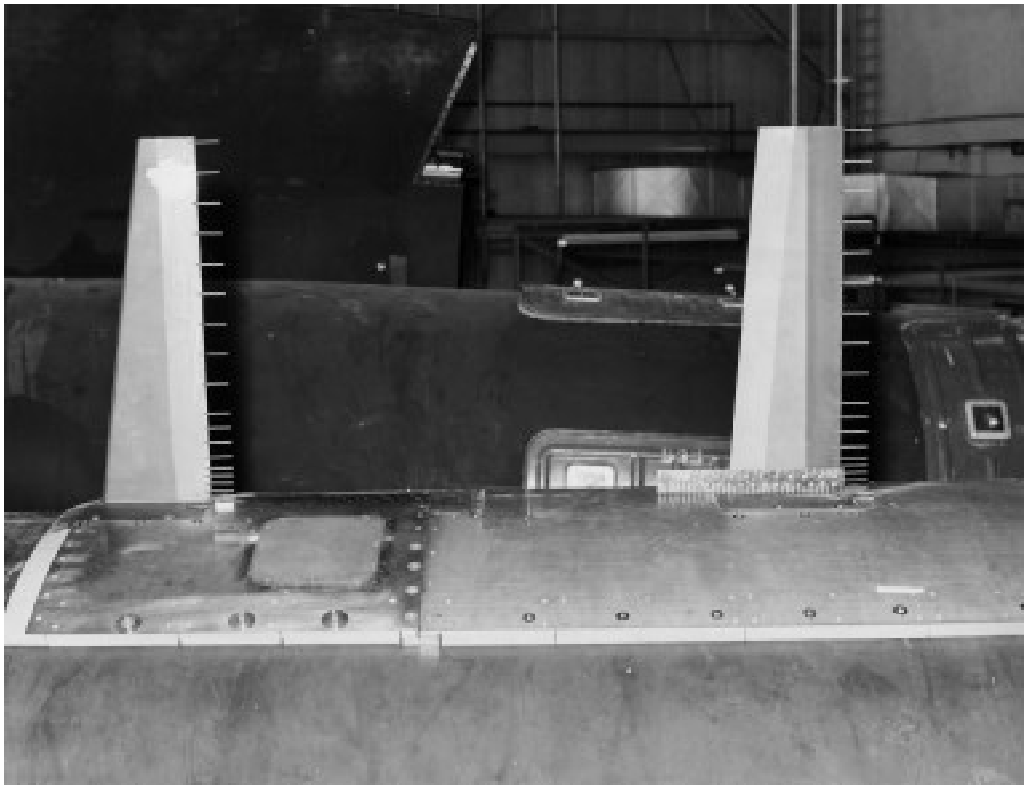
strated the launch technique, which is the most dangerous maneuver . . . [on] any airplane I have worked on."

Two more successful launches followed, but the fourth flight substantiated Johnson's statement. Moments after separation, the drone collided with the mothership. Both vehicles were destroyed. Lockheed test pilot Bill Park parachuted to safety, but his launch officer, Ray Torick, drowned in the Pacific Ocean. An investigation board concluded that Mach 3 launches of large vehicles from the Blackbird were essentially unsafe.[43] In light of this tragedy, it is apparent why Johnson voiced concern over the YF-12C/HT-4 proposal. Ultimately, the HT-4 project never materialized, possibly as a result of Lockheed's experience with the D-21.

But the Blackbirds did notable work as platforms for many other projects. In July 1973, following ground tests in the High Temperature Loads Laboratory, YF-12A (935) was instrumented for boundary-layer measurements along the lower fuselage. Engineers typically use a number of empirical theories to predict compressible turbulent-boundary-layer parameters. Since these theories produced substantially different values, they required additional data from flight and wind-tunnel experiments. NASA researchers fitted the YF-12A with boundary-layer rakes to collect such data during flight. Each rake consisted of an aerodynamic vertical pylon with hollow tubes arrayed on its leading edge. Each tube collected measurements at a different point within the boundary-layer region of airflow. Instruments also took static pressure and skin surface measurements. In order to provide undisturbed airflow over the lower fuselage, all upstream protrusions and vents needed to be removed or faired over.

The YF-12A also carried an aft-facing step experiment to determine the drag penalty caused by aft-facing surface discontinuities in a thick boundary-layer region. Such discontinuities caused drag and shock-wave propagation at supersonic speeds. The experiment provided designers with data for predicting the drag associated with lap joints and shingle structures on large aircraft at high Mach numbers. A panel on the aft

[43] Jay Miller, *Lockheed's Skunk Works—The First Fifty Years*, pp. 137-138.



Preston probes consisted of rakes with hollow tubes to collect measurements from multiple points within the boundary-layer airflow. This set of probes, on the aft-facing step experiment, included a fixed rake (left) and a movable rake. (NASA photo E73-25764)

fuselage created a small step over which the airflow passed. It consisted of a ramp region, a reference region, the step, a recovery region, and two boundary-layer rakes. Technicians installed pressure orifices along the plane of the surfaces of the reference and recovery regions and the step face. The step height—from 0.125 to 0.500 inches—could be varied between flights. The experiment produced data from incompressible speeds to ones in excess of Mach 3 and for ratios of boundary-layer momentum thickness to step height from 1 to 5. The results had applicability to the prediction of drag penalties for aft-facing discontinuities over a wide speed range for both the forward and aft regions of large airplanes.[44]

NASA technicians glued tufts to the fuselage of the YF-12A for surface flow visualization studies related to the aft-facing step experiment. (NASA photo E76-31377)

[44] *Basic Research Review for the NASA OAST Research Council*: RTOP-761-74-01, Robert D. Quinn, August 1971, p.15; RTOP-501-06-05, RTOP-501-06-08, RTOP-770-18-10, RTOP 501-06-05, Edwin J. Saltzmann, 7 August 1972 and 20 August 1974, pp. 9-10; RTOP-505-06-31, Sheryll Goecke Powers, 20 October 1975, p. 9.

The YF-12A climbs to altitude with the Coldwall heat transfer experiment pod mounted beneath the fuselage. After the aircraft attained Mach 3, the white insulation covering the pod was pyrotechnically removed to expose the nitrogen-cooled stainless steel tube to aerodynamic heating. (NASA photo EC75-4765)

In early November 1974, the YF-12A underwent a Coldwall experiment to study the effects of compressible turbulent boundary-layer and heat transfer coefficient at high speed. Designed and supported by NASA Langley, the apparatus consisted of a 13-foot-long stainless steel tube mounted on a ventral pylon below the forward fuselage. The tube, equipped with thermocouples and pressure sensors, required cooling by liquid nitrogen and a covering with an insulating material. Planners desired the insulator to be pyrotechnically removed at Mach 3, exposing the tube to aerodynamic heating. Researchers also conducted wind-tunnel tests of a similar tube for comparison with data obtained in flight in order to validate ground research methods.

The Coldwall program suffered numerous setbacks. An initial low-speed functional check flight had to be aborted early when the experiment's accelerometer malfunctioned. A second attempt a week later ended the same way. The third flight, on 27 February 1975, took a more dramatic turn. On this day, the crew consisted of Don Mallick and Ray Young. Mallick climbed to 15,000 feet and advanced the throttle until the aircraft was traveling at 0.9 Mach number. At one point, the test card called for an aileron pulse with roll/yaw Stability Augmentation System (SAS) off. As Mallick executed the maneuver, the ventral fin tore off, damaging the right wing and causing a fuel leak. The crew brought the YF-12A back to Edwards for a safe landing. An investigation determined that several factors contributed to the incident:

• Inadequate definition and documentation of aircraft limits.

• Inadequate attention and adherence to existing, published, operating limits for the transonic region.

• A less than conservative approach in the flight qualification of the Coldwall heat transfer experiment in that tests were

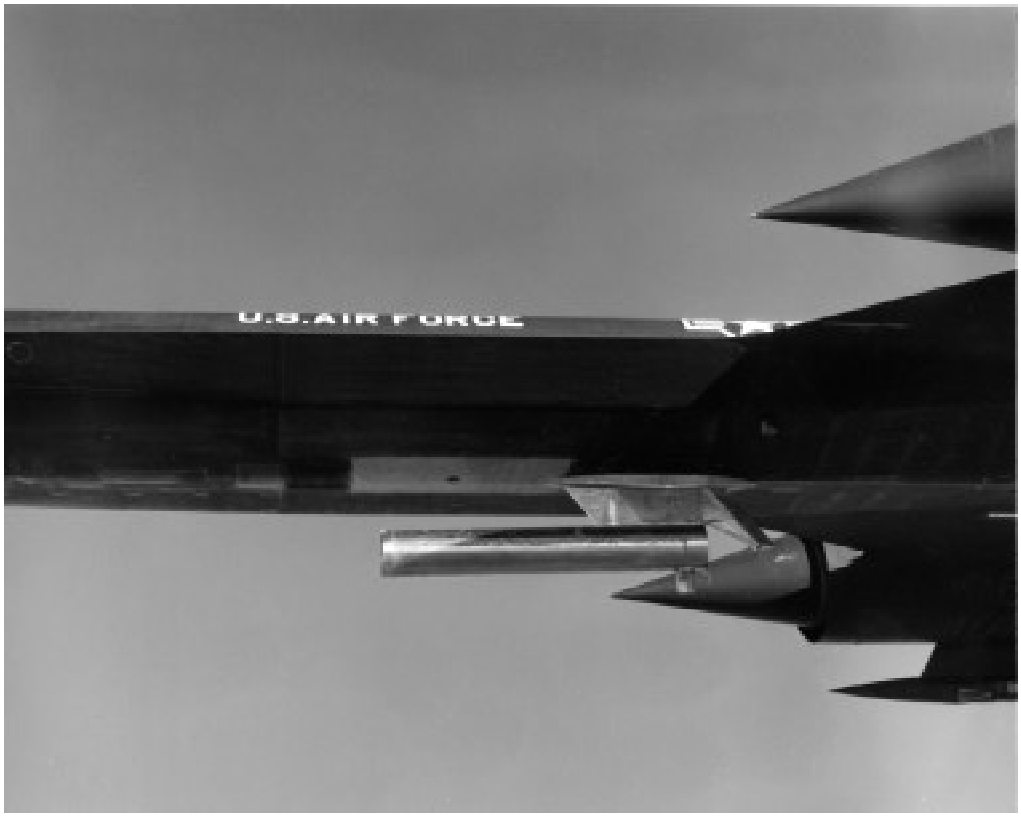
During a low-speed functional check flight of the YF-12A with the Coldwall experiment attached, the aircraft's ventral fin tore off. Although the right wing was damaged, causing a fuel leak, the pilot, Don Mallick, landed safely at Edwards. (NASA photo E75-28266)

conducted at known limit conditions with a new configuration.[45]

Test flights to demonstrate the structural characteristics of the Coldwall fixture resumed in July 1975. An operational check of the insulation removal system followed in August. Actual Coldwall data flights did not begin until August 1976, when a series of baseline "Hotwall" flights occurred without the liquid nitrogen coolant or insulation. The first true Coldwall flight took place on 21 October 1976. The premature loss of the insulation material prevented the collection of data on that flight, however. This problem continued to plague the experiment through 2 June 1977. The first good

Don Mallick holds the ventral fin from the YF-12A. It took searchers nearly a week to locate the fin north of Red Rock Canyon in the Mojave Desert. With Mallick are several members of a search party. (NASA photo E75-28414)

[45] "Report of Investigation," memorandum from YF-12 Ventral Incident Investigation Board to Director of NASA Hugh L. Dryden FRC, 25 April 1975, p. 5. NASA Dryden Historical Reference Collection.



Without insulation, the stainless steel tube of the Coldwall experiment is exposed to aerodynamic heating during high-speed flight. Engineers compared data from flight tests to validate predictive methods for estimating turbulent heat transfer. (NASA photo EC75-4777)

Coldwall data finally began to flow on 23 June when "the insulation removal system was successfully operated at the design test condition of Mach 3.0 and 72,500 feet."[46]

The next Coldwall flight, on 21 July 1977, although less successful, was certainly more dramatic. Insulation material from the experiment became ingested into the left engine of the YF-12A, resulting in an unstart. The right engine also unstarted. As the crew worked to restart the engines, the YF-12C chase aircraft also experienced multiple unstarts. Despite these problems, both aircraft returned safely to Edwards but remained grounded until September for inspection and repair. The last two Coldwall flights occurred successfully on 30 September and 13 October. At the time, several theories existed regarding the nature of turbulent heat transfer, but they yielded conflicting results when compared with wind-tunnel data. The competing schools of thought were represented by Edward R. van Driest's equations for estimating turbulent heat transfer, E. R. G. Eckert's reference enthalpy method, and the Spalding-and-Chi method for determining skin friction coefficients. Researchers used the Coldwall experiment data to validate Van Driest's theory.

Following the Coldwall flights, Don Mallick and Ray Young flew the YF-12A for a lower-surface boundary-layer survey and handling-qualities evaluation. Unfortunately, a malfunction of the wake-visualization water-spray system prevented them from obtaining any subsonic wake vortex flow data.

The incident of the lost ventral fin in February 1975 gave researchers an opportunity to flight-test a new material.

[46] "Aeronautical Projects Update—June 1977," memorandum from Director of Aeronautical Projects and Director of Research to the Director of NASA Hugh L. Dryden Flight Research Center, 5 July 1977. NASA Dryden Historical Reference Collection.

The YF-12C served as a chase aircraft for the YF-12A during Coldwall flights. On one sortie, both aircraft suffered simultaneous multiple engine unstarts. After landing safely at Edwards AFB, they were grounded for inspection and repair. (NASA photo EC75-4775)

Technicians fitted a replacement ventral fin, made of Lockalloy, on the damaged YF-12A. Lockalloy, a metal alloy developed by Lockheed, consisted of 62 percent beryllium and 38 percent aluminum. Aircraft designers considered it a promising material for constructing high-temperature aircraft structures. The Lockalloy fin flew for the first time on 16 January 1976. Envelope expansion flights continued through 20 May. Flight crews gradually exposed the new ventral fin to a variety of low-speed and high-speed flight conditions, eventually exceeding Mach 3. Loads and pressure distribution data closely agreed with predicted results.

The YF-12 also served as a testbed for advanced structural panels. A number

Loss of the titanium ventral fin in February 1975 provided researchers with an opportunity to test a new material. In January 1976, the YF-12A flew with a ventral fin made from a Lockheed-designed beryllium-aluminum alloy called Lockalloy. (NASA photo EC76-5103)

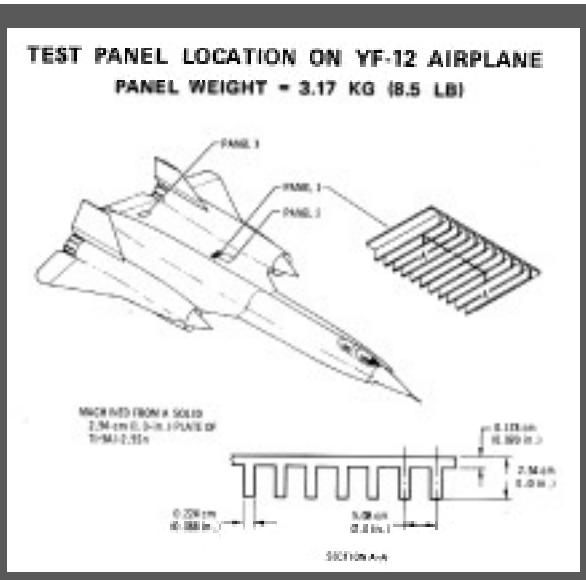


Figure 7A

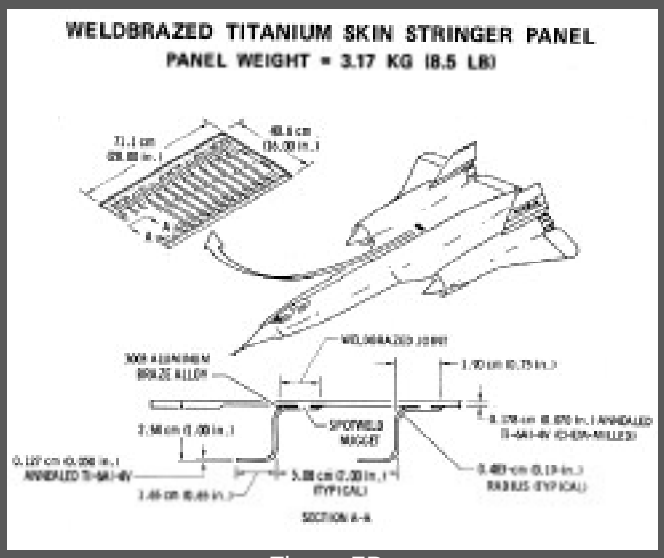


Figure 7B

The YF-12 aircraft served as testbeds for advanced structural panels. NASA Langley sponsored these tests under the Supersonic Cruise Aircraft Research (SCAR) program. (Figures 7A-7D are from the NASA FRC Basic Research Review, 20 August 1974)

of structural-configuration and material concepts showed promise in terms of reducing aircraft structural weight. Initially, a weldbrazed-skin stringer panel (one with stiffeners spot-welded in place) underwent approximately 37 hours of flight, including eight hours at Mach 3, with no adverse effects. Then, in July 1974, an experimental titanium honeycomb panel replaced an existing integrally stiffened primary structural part of the YF-12A upper wing surface, located over the landing gear. Researchers also undertook flights with a composite panel of titanium honeycomb with a boron/aluminum face sheet onboard. NASA Langley Research Center initiated these panel tests under the Supersonic Cruise Aircraft Research (SCAR) program. Each panel type underwent ground testing by Lockheed before the actual flight test.[47]

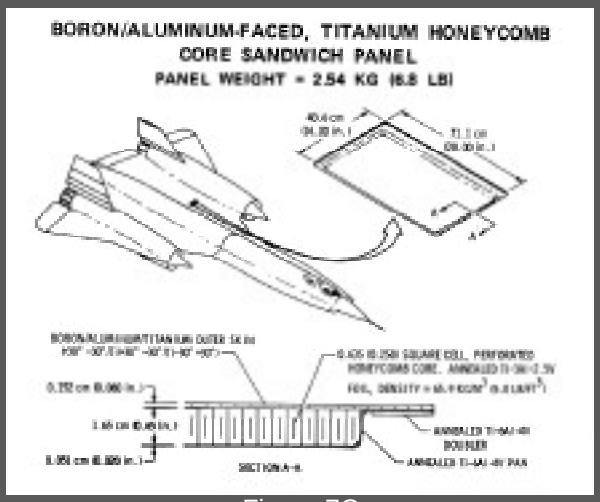


Figure 7C

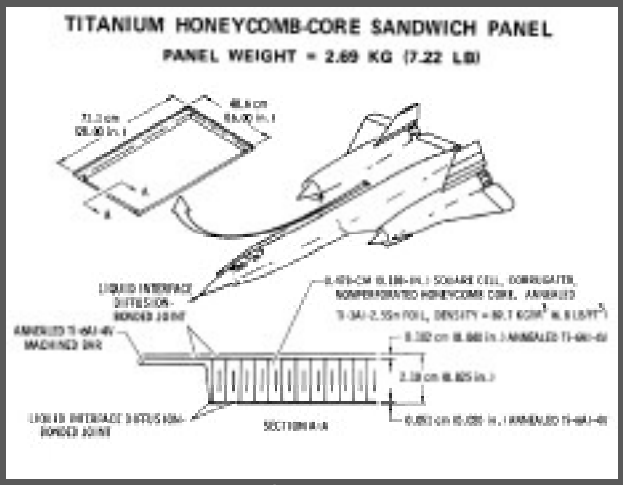
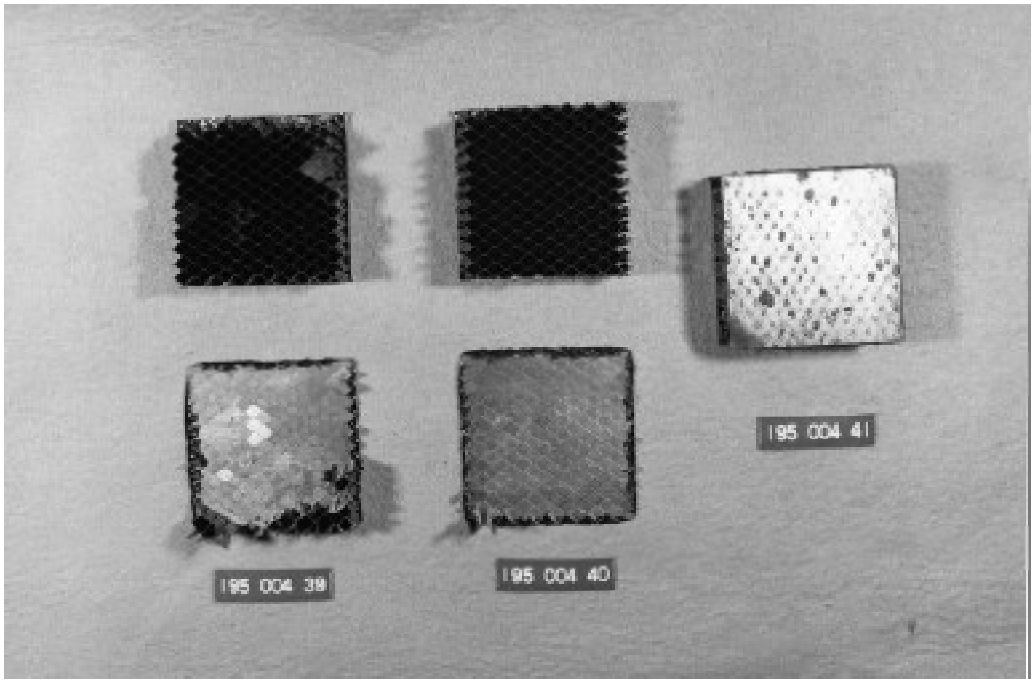


Figure 7D

[47] *Basic Research Review for the NASA OAST Research Council*: RTOP-743-32-23, Alan L. Carter, 20 August 1974, pp. 43-45.



Engineers studied samples of structural materials from the SCAR program to assess their structural integrity with regard to future aircraft construction. (NASA photo E75-28611)

In 1977, a SCAR panel was fitted to the YF-12C wing surface and flown regularly on a non-interference basis. Engineers assessed its structural integrity after each flight.

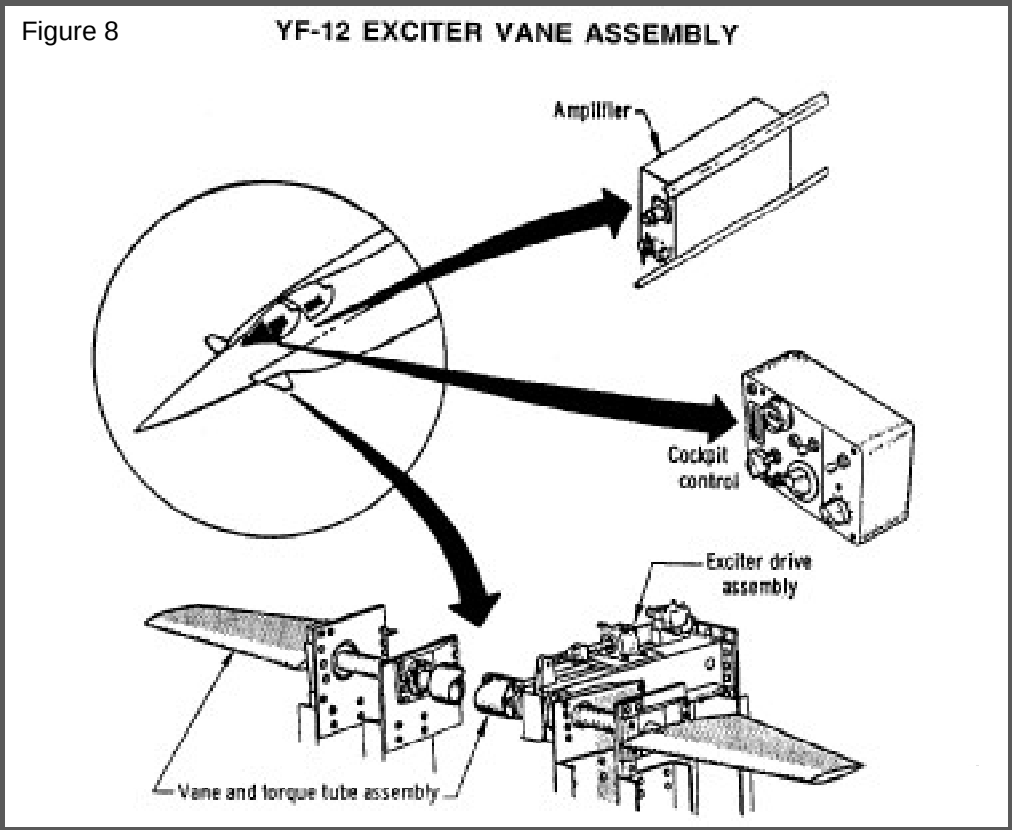
In December 1977, several NASA research pilots who had not yet participated in the YF-12 program had the opportunity to fly the YF-12A. John Manke, Bill Dana, and Tom McMurtry flew familiarization flights with Vic Horton. Gary Krier and Einar Enevoldson made short hops with Ray Young. As noted in Chapter 5, both Dana and Enevoldson then made additional flights as part of the Space Shuttle approach simulation program in March 1978. After that, the aircraft was grounded for installation of a shaker vane system.

As early as 1970, Lockheed had proposed testing a Loads Alleviation and Mode Suppression (LAMS) system on a YF-12A and conducted a feasibility study. The design involved the use of small canards (or shaker vanes) on the aircraft forebody to excite the airplane's structural modes using controlled dynamic inputs at selected flight conditions. Such a system enabled a pilot to use feedback control techniques to suppress the aircraft's aeroelastic contributions to local acceleration and to develop techniques to reduce aircraft damage from air turbulence. The resulting flight-test data could then be compared with calculated aeroelastic response data and thus validate analytical techniques. The YF-12A design did not require LAMS technology itself and was, in fact, not well suited for evaluating rigid-body load alleviation techniques such as direct lift control. However, as a flexible aircraft it could be used to evaluate suppression techniques for aeroelastic modes. According to a study of LAMS for the YF-12, "evaluation of mode suppression techniques on the YF-12A could result in eliminating most of the design risk associated with LAMS technology and, thus, lead to acceptance by airframe manufacturers."[48]

The YF-12 mode suppression effort expanded LAMS research already begun with the NASA/USAF XB-70 and the

[48] Lester D. Edinger, Frederick L. Schenk, and Alan R. Curtis, "Study of Load Alleviation and Mode Suppression System (LAMS) on the YF-12 Airplane" (Washington, D.C.: NASA CR-2158, December 1972), p. 2.

Figure 8



Small canards, called shaker or exciter vanes, were installed on the YF-12A as part of a load alleviation and mode suppression system (LAMS). Engineers compared structural mode data from research flights with computer-generated data to validate analytical models. (Drawing from the NASA DFRC Historical Reference Collection)

Air Force's NB-52E Control Configured Vehicle (CCV) testbed. A Lockheed study in 1972 compared five candidate LAMS systems for the YF-12, evaluating each in terms of performance and mechanization. The Lockheed engineers concluded that a combination of small shaker vanes near the cockpit and inputs to the outboard elevons would provide the most effective LAMS system for the YF-12 aircraft.[49]

While the YF-12A remained in the hangar, the YF-12C returned to service. It had been unavailable since October 1977 in preparation for cooperative controls (Co-Op) research. This program focused on digital integrated control of the aircraft's inlets, autopilot, autothrottle, air data system, and navigation system.

Preparations for the Co-Op project began in early 1977, including tests of the aircraft's autothrottle system designed to control Mach and altitude simultaneously. In March 1977, Gene Matranga observed that "the system provided precision of control significantly better than that attainable by manual control at Mach 3.0 and constitutes a virtual technological breakthrough in flight path control for supersonic cruise aircraft." By June, he felt that "sufficient data had been obtained to verify the operational characteristics of the system, and to define control logic to be implemented in the upcoming Co-Op Digital Control Program." By September, the NASA team had acquired all the baseline propulsion/airframe interaction data necessary to prepare for the Co-Op study.

As a result, a Cooperative Airframe/ Propulsion Control System (CAPCS) digital computer went into the YF-12C. This system incorporated the air data, inlet, and autopilot systems into a single

[49] Ibid., pp. 1-5.

computer to improve overall aircraft flight control. Following installation of the CAPCS, Don Mallick and Ray Young took the aircraft up for a functional check flight on 26 May 1978. Gene Matranga later reported that "all flight objectives were satisfactorily accomplished with air data calculations, inlet control, and autopilot demonstrated." The flight also verified the basic logic flow and system architecture for the CAPCS.

Nine more CAPCS flights followed. Seven of them proved to be successful. The final CAPCS flight, on 28 September 1978, aborted early due to an engine bypass door failure that precluded acquisition of Co-Op control data. It turned out to be NASA's last flight of the YF-12C. On 27 October, the aircraft returned to the Air Force after being ferried to the Lockheed facility in Palmdale. The YF-12C ended its NASA career on a high note. The CAPCS system exceeded the designers' goals. Flight path control precision improved by a factor of 10. Additionally, aircraft range increased by seven percent, and inlet unstarts became almost unknown. Ultimately, Lockheed installed the system in the entire operational SR-71 fleet.[50]

In order to undertake research on the structural design required for a future supersonic transport aircraft, Jim McKay of the NASA FRC Dynamic Analysis Branch submitted a request for shaker-vane project approval on 4 February 1975. With a view toward future SST development, NASA engineers needed accurate structural design calculations for flexible, low-aspect-ratio aircraft in the transonic flight regime. A large body of static and quasi-static test data had been generated during flight and ground YF-12 loads research. Additionally, McKay pointed out that the YF-12 team had "developed one of the most complete finite element [NASA] structural analysis (NASTRAN) programs ever assembled for an aircraft, along with a complete static aeroelastic analysis program (FLEXSTAB)."[51]

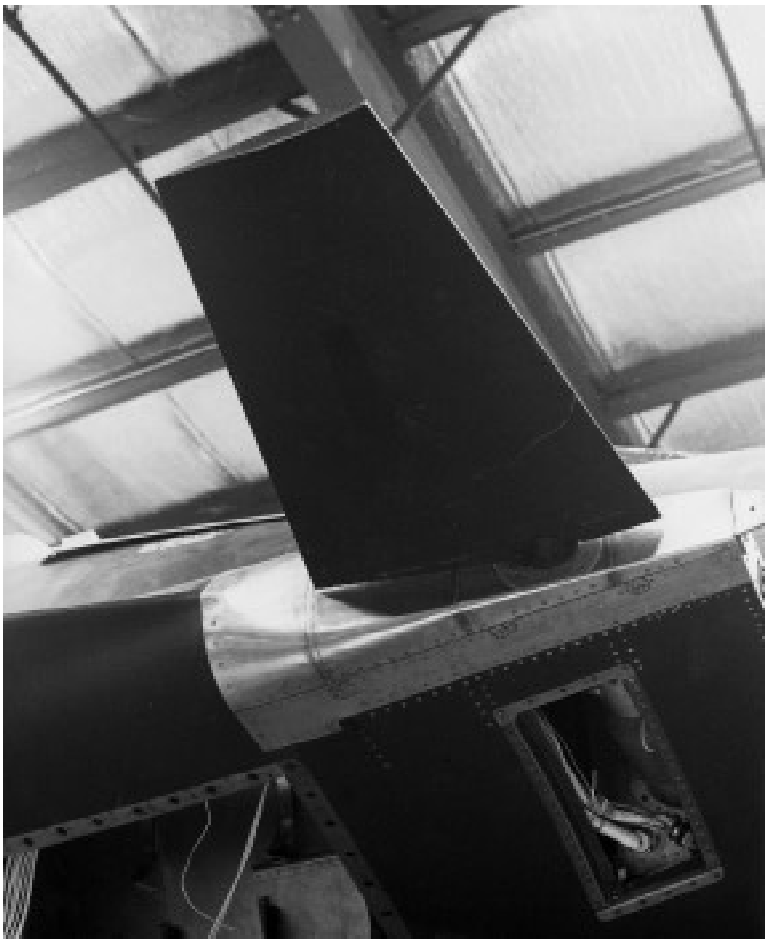
Software engineers at NASA Goddard Space Flight Center in Greenbelt, Maryland, originally designed the NASTRAN program for space vehicles. In its first major application to an airplane, Alan Carter of NASA asked Lockheed's Al Curtis to create a NASTRAN model to support YF-12 loads research. The FLEXSTAB program, developed by Boeing for the SST, allowed researchers to assess the effect of airframe flexibility on stability and control characteristics of a supersonic aircraft. Perry Polentz of NASA Ames also sought out Curtis to model the YF-12 using FLEXSTAB. Although Curtis encountered some problems adapting the program to the YF-12 wing configuration, the extensive analytical database set the stage for the proposed flight research effort. Jim McKay thought the resulting data would have "direct application to low-aspect-ratio vehicles with close dynamic coupling between major components such as fuselage and wing." He also believed that it would "provide data input to the Langley Research Center landing loads/response study in support of the work on actively controlled landing gear."[52]

Finally, in February 1978, Dryden received funding from NASA Langley

[50] "NASA YF-12 Cooperative Control Program," briefing, 1983. NASA Dryden Historical Reference Collection.

[51] James M. McKay, "Request for Project Approval to Measure the YF-12 Structural Response to Aerodynamic Shaker Excitation and to Correlate with Analytical Results," letter to Acting Director, NASA Flight Research Center, Edwards, California, 4 February 1975. NASA Dryden Historical Reference Collection.

[52] Ibid.



Shaker vanes were installed on the YF-12A for a series of six flights between November 1978 and March 1979. Data from these flights were compared with data generated by the NASA Structural Analysis (NASTRAN) computer program. (NASA photo E78-34738)

and the Air Force Flight Dynamics Laboratory to support a structural dynamics program with the remaining YF-12A. Installation of the shaker vanes began in April. The system consisted of a set of oscillating canards attached by a shaft to a driving unit in the nose of the airplane. The shaker vanes supplied controlled dynamic inputs to excite the response of various structural modes at selected flight conditions. On 22 November, the YF-12A made its first flight with the new shaker vanes. Five more flights had occurred by 15 March 1979. The shaker-vane study provided flight data on aeroelastic response, allowed comparison with calculated response data, and thereby validated analytical techniques.[53] With these last missions, the NASA YF-12 flight research program ended.

[53] Ibid.

Chapter 7: Lessons Learned

During a 10-year period, the NASA YF-12 research program produced a wealth of data, derived from flight and ground research, as well as from simulation and modeling. Collectively, these investigations made important contributions to the advancement of aerodynamics and thermodynamics. Among other achievements, the comparison of flight data to wind-tunnel data and predictions helped researchers develop more accurate modeling techniques for flexible, supersonic aircraft designs.

At the start of the undertaking, NASA engineers and technicians faced a difficulty inherent in this type of research. Because the high speeds of the YF-12 generated sustained aerodynamic heating, the YF-12 team needed to devise data recording techniques suited to these conditions. Indeed, NASA project manager Gene Matranga noted that instrumentation for the YF-12 was "very inadequate to begin with, and it cost a lot of money to develop new instrumentation and make it work." Once they resolved this problem, a wide vista of research opportunities became possible.

To begin with, researchers compared heating measurements in the High Temperature Loads Laboratory to in-flight heating. The results allowed them to more accurately calibrate instrumentation for loads measurement on high-speed aircraft by separating thermal loads from aerodynamic loads. They also explored structural configurations relative to the thermal environment, studied the resulting thermal stresses, and demonstrated how a thermal calibration of the aircraft eliminated contaminating heating effects from loads equations. Additionally, Matranga and his colleagues discovered unexpected hot spots and leakage of hot air into the aircraft's internal structure.[54]

The YF-12 aircraft likewise provided a wide range of propulsion data on variable cycle engine operation and mixed-compression inlet operation. The

The YF-12A was equipped with a water spray nozzle on the forward fuselage for flow visualization. The system underwent ground tests prior to flight in 1976. Note the Coldwall pod attached on the lower fuselage. (NASA photo E76-31090)

[54] Matranga interview.

YF-12C and crew. Standing, left to right: unknown USAF officer, Airman Baker, Glenn Gemenhardt, Fitz Fulton, Lorenzo "Larry" Barnett, Thomas C. McDonald, Ralph A. Merkner, Byron D. Gibbs, John W. Louett, James C. Gordon, LeRoy P. Frost, John R. Rifenberry, Victor Horton, unknown, unknown USAF life support technician, LeRoy J. Adelsbach, and Billy Furr. Kneeling: Charles A. Grace, Jr., and John M. Bruno.(NASA photo EC78-9975)

flight research demonstrated that an inlet could be designed using small-scale models and also showed that YF-12 inlet dynamics had a profound effect on stability and control. The dynamics sometimes surprised the researchers. Air from the forward bypass doors, for instance, actually moved forward at least 12 inches before mixing with the boundary layer. "This startled everybody," said Gene Matranga. "We didn't realize there was so much separation just ahead of the bypass area." Ultimately, NASA developed a computer control system for the bypass doors to improve efficiency. It increased aircraft range and performance and eventually became incorporated into the operational SR-71 fleet.[55] Flight-test data also indicated that during Mach 3 flight, air venting through the inlet bypass doors accounted for half of the aircraft's total drag.[56] The inlet control proved to be imprecise due to sensor placement and inaccuracy, making unstarts a frequent occurrence. But NASA's YF-12 research program virtually eliminated unstarts through a combination of inlet spike schedule refinements and hardware improvements.

Wind-tunnel model data provided an opportunity to validate scale and wind-tunnel effects against the flight data. It also enabled engineers to determine more precisely the placement of instruments in the airplane inlet. Inlet-flow-systems interactions studies helped researchers define the inlet operating envelope and yielded information about unstart/restart boundaries. Engineers compared data

[55] Ibid.

[56] Hallion, *On The Frontier*, pp. 195-196.

Life support technician John R. Rifenberry looks on as Fitz Fulton (left) and Vic Horton, the last NASA crew to fly the YF-12A, pose following their flight on 31 October 1979. (NASA photo EC79-11907)

from the NASA Ames and NASA Lewis wind tunnels to data obtained during research flights to better evaluate scaling and tunnel effects. NASA researchers found that testing limitations prevented the attainment of identical test conditions in the mixed-compression inlet mode. To solve this problem, FRC engineers James D. Brownlow, Henry H. Arnaiz, and James A. Albers developed a mathematical model from which comparisons could be made using statistical techniques.[57]

During a series of landing studies, a mixed-volume dual-mode gear system reduced airplane dynamic response during high-speed taxi. The test procedure called for taxiing at constant speed on the same section of runway during each run. In practice, however, the airplane traversed slightly different sections of runway from one test to the next. Aircraft weight differed throughout the test series due to fuel consumption. Although the mix of aircraft weights and velocities used did not represent any one specific aircraft configuration, the results encompassed a wide range of operational conditions. Overall, the dual mode system provided significant dynamic response reductions, yielding a smoother ride. Analytical results generated by a digital computer program provided excellent correlation with the flight-test data at most areas, except the cockpit.

During handling-qualities investigations made during the YF-12 program, researchers concentrated on characteristics associated with longitudinal control during high-speed supersonic cruise, with possible application to the development of a supersonic passenger transport aircraft. Part of the investigation involved altitude hold and Mach hold, important because maximum range performance depended in part on accurate control of altitude and Mach num-

[57] They derived the model from wind-tunnel test data using a multiple regression technique which uses a least-squares method to fit equations to the data. The least-squares method is a statistical technique of fitting a curve close to some given points, which minimizes the sum of the squares of the deviations of the given points from the curve.

ber. In flight tests with a modified altitude and autothrottle hold mode, the YF-12C proved to be the most stable aircraft platform thus far demonstrated at Mach 3 speeds.

Flight research on the YF-12 also included certain propulsion and aerodynamics problems encountered during the Blackbird's operational life. During flight at a constant power setting, for instance, many aircraft experienced a natural oscillation called a phugoid. NASA research pilot Milton O. Thompson described the phugoid effect in the YF-12.

> Automatic engine inlet operation can have a pronounced effect on phugoid characteristics. In fact, under certain conditions, the automatic inlet operation can couple with the autopilot system in a manner to drive the phugoid unstable. Another unanticipated problem is the effect of engine bypass air on stability and control characteristics. At certain flight conditions, engine bypass air being ducted overboard can produce rolling moments comparable to that available with full aileron deflection. Inlet unstarts are not uncommon even under so-called ideal steady state cruise conditions. Atmospheric anomalies may be responsible for some of these inlet unstarts, since we have seen some rather abrupt changes in outside air temperature at these high speeds; however, other unstarts are not readily explained.[58]

The YF-12 team also employed the aircraft as a platform to study human factors in a high-altitude supersonic cruise environment. Researchers first identified sets of aircraft and physiological parameters most sensitive to pilot workload. Next, they isolated and quantified physical and nonphysical workload effects. Finally, they gathered and reduced flight data for comparison with findings from a clinical study to develop a pilot workload model from which predictions could be made.

Cockpit of the YF-12A. The vertical strip instrument to the left of the large attitude indicator (artificial horizon) is the airspeed indicator (measuring in knots and Mach number). The altimeter is on the right. (NASA photo E71-22774)

NASA engineers conducted extensive studies of the boundary layer, using instrumented rakes. They found significant discrepancies between wind-tunnel model data and flight-test results. These apparently resulted from surface imperfections on the full-scale aircraft. "There were lumps, and bumps, and waves," said Gene Matranga. "A wind tunnel model was a nice, smooth, rigid structure." Although researchers developed predictive methods to compensate for these differences,

[58] Letter from Milton O. Thompson to Walter C. Williams, 1 November 1976. NASA Dryden Historical Reference Collection.

The YF-12C (SR-71A) cockpit. The altimeter and airspeed indicators have been merged into the triple display indicator, below and to the left of the attitude indicator. (NASA photo E72-25349)

according to Matranga "it requires interpretation on the part of very skilled people."[59]

Another benefit of the YF-12 program arose from the extreme altitude range at which the aircraft flew. NASA engineers Terry Larsen and Jack Ehernberger—working in support of the SR-71 Category II tests—extensively documented upper atmosphere physics. Such atmospheric modeling proved useful for later designs of high-altitude research aircraft. The YF-12 contributed valuable sonic-boom information and showed that mild turbulence could exist even at the highest altitudes at which the aircraft cruised.[60]

Finally, NASA and USAF researchers gained valuable information concerning loads suppression and mode alleviation for flexible aircraft using a nose-mounted canard (shaker vane) system. This apparatus allowed them to make direct comparisons with calculated aeroelastic response data and thereby validate available analysis techniques.

Once the shaker vane study had been completed, the NASA YF-12 research program essentially ended. Research pilots Stephen Ishmael and Michael Swann each received a familiarization flight in the YF-12A on 29 March 1979. On 31 October, Fitz Fulton and Vic Horton made the final NASA flight of the aircraft and on 7 November 1979, Col. James V. Sullivan and Col. Richard Uppstrom ferried the aircraft to Wright-Patterson AFB, Ohio, for permanent display in the USAF Museum.

Thus, over its long lifespan, the NASA YF-12 program made significant contributions to high-speed aeronautical research. Perhaps most importantly, it left a legacy of structural, aerodynamics, propulsion, and atmospheric-physics data likely to serve as the basis for future high-speed aircraft designs and analytical model evaluation.

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[59] Matranga interview.

[60] Gene J. Matranga, "The Realities of Manned Supersonic and Hypersonic Flight—Lessons Learned," presentation at NASA Lewis Research Center's Hypersonic Propulsion Symposium, August 1988. NASA Dryden Historical Reference collection.

End of an Era

Air Force security police halt traffic for the arrival of the YF-12A at the USAF Museum at Wright-Patterson AFB, Ohio, on 7 November 1979. The aircraft was piloted by Col. James V. Sullivan with USAF Museum director Col. Richard Uppstrom in the back seat. (Lockheed photo)

Appendices

Appendix 1: Flight Logs

This section includes lists of the aircraft in the YF-12 program, crewmembers, and flight logs for each aircraft.

Aircraft:

YF-12A (60-6935) – Second YF-12A built. Flew 146 times from 1969 to 1979. Retired to USAF Museum at Wright-Patterson Air Force Base near Dayton, Ohio.

YF-12A (60-6936) – Third YF-12A built. Flew 62 times in 1970 and 1971. Destroyed in crash near Boron, California.

SR-71A (61-7951) – Second SR-71A built. Aircraft was given fictitious "YF-12C" designation and borrowed A-12 tail number 06937 during NASA research program. Flew 90 times from 1971 to 1978. Retired to Pima Air Museum at Tucson, Arizona.

Pilots:

Maj. William J. Campbell, USAF: YF-12A (935 and 936)

William H. Dana, NASA: YF-12A (935), one pilot familiarization flight, one research flight

Einar K. Enevoldson, NASA: YF-12A (935), one pilot familiarization flight, one research flight

Maj. Mervin L. Evenson, USAF: YF-12C, delivered aircraft to NASA FRC

Fitzhugh L. Fulton, NASA: YF-12A (935 and 936), YF-12C, USAF test pilot and FRC research pilot

Stephen D. "Steve" Ishmael, NASA: YF-12A (935), one pilot familiarization flight

Lt. Col. Calvin F. "Cal" Jewett, USAF: YF-12C, piloted final flight of aircraft

Gary E. Krier, NASA – YF-12A (935), one pilot familiarization flight

Lt. Col. Ronald J. "Jack" Layton, USAF: YF-12A (935 and 936)

Donald L. Mallick, NASA: YF-12A (935 and 936), YF-12C, FRC research pilot

John A. Manke, NASA: YF-12A (935), one pilot familiarization flight

Thomas C. McMurtry, NASA: YF-12A (935), one pilot familiarization flight

Col. Joseph W. Rogers, USAF: YF-12A (935 and 936), Director of USAF SR-71/F-12 Test Force

Col. Hugh C. "Slip" Slater, USAF: YF-12A (935 and 936)

Col. James V. Sullivan, USAF: YF-12A, YF-12C, transferred 935 and 937 back to USAF

Michael R. Swann, NASA: YF-12A (935), one pilot familiarization flight

Fire Control Officers/Test Engineers/Observers:

Lorenzo C. "Larry" Barnett, NASA: YF-12A (935), one flight, FRC YF-12 crew chief

Maj. Billy A. Curtis, USAF: YF-12A (936)

Maj. William J. Frazier, USAF: YF-12C RSO, transfer to USAF and last flight of aircraft

Maj. Gary I. Heidelbaugh, USAF: YF-12A (935 and 936) FCO

Victor W. Horton, NASA: YF-12A (935 and 936), YF-12C, FRC test engineer

Maj. Charles J. McNeer: YF-12C RSO, delivered aircraft to NASA FRC

Col. Richard Uppstrom, USAF: YF-12A (935), Director of USAF Museum

Maj. Sammel M. Ursini, USAF: YF-12A (935 and 936) FCO

William R. "Ray" Young, NASA: YF-12A (935), YF-12C, FRC test engineer

YF-12A (935) Flight Log:

Flt. 001 / **11 DEC 69**: Rogers/Heidelbaugh. USAF test.

Flt. 002 / **17 DEC 69**: Campbell/Ursini. USAF test.

Flt. 003 / **06 JAN 70**: Rogers/Ursini. USAF test.

Flt. 004 / **14 JAN 70**: Campbell/Heidelbaugh. USAF test.

Flt. 005 / **19 JAN 70**: Slater/Heidelbaugh. USAF test.

Flt. 006 / **21 JAN 70**: Slater/Ursini. USAF test.

Flt. 007 / **27 JAN 70**: Slater/Heidelbaugh. USAF test.

Flt. 008 / **11 FEB 70**: Campbell/Ursini. USAF test. Ventral fin damaged in sideslip.

Flt. 009 / **26 MAR 70**: Campbell/Horton. Functional check flight of data acquisition systems, to clear aircraft to Mach 2.0 without a ventral fin, and to obtain cruise data (Mach 2.0). First flight with a NASA test engineer.

Flt. 010 / **01 APR 70**: Mallick/Ursini. Pilot check-out #1, and FCF for data acquisition systems. First flight with a NASA pilot.

Flt. 011 / **08 APR 70**: Mallick/Ursini. Pilot check-out #2, and to acquire stability and deflection data.

Flt. 012 / **14 APR 70**: Fulton/Horton. Deflection points, stability data, and phugoids (Stability Augmentation System [SAS] off). Biomedical data flight.

Flt. 013 / **17 APR 70**: Fulton/Horton. Deflection points, stability data, and SST flight control design data. Biomedical data flight.

Flt. 014 / **28 APR 70**: Mallick/Young. Deflection points, stability data, phugoids (Mach 2.0, SAS off, auto inlets). Biomedical data flight.

Flt. 015 / **01 MAY 70**: Fulton/Horton. Deflection points, pitch pulse with SAS off, stability data, phugoids (Mach 0.8, Pitch SAS off). Biomedical data flight.

Flt. 016 / **07 MAY 70**: Mallick/Young. Deflection points, stability pitch pulses, and SST flight control design data. Phugoid (Mach 2.0) data and use of 935 as a supersonic target for YF-12A (60-0936) not accomplished. Biomedical data flight.

Flt. 017 / **15 MAY 70**: Fulton/Horton. Deflection points, stability pitch pulses, phugoid (Mach 1.5, manual inlets), stability and control set (Mach 1.5). Biomedical data flight (pilot only).

Flt. 018 / **22 MAY 70**: Mallick/Young. Deflection points, stability pitch pulses, and phugoid (Mach 1.3, Mach trim on and off). Phugoid at Mach 1.5 not accomplished. Biomedical data flight.

Flt. 019 / **27 MAY 70**: Fulton/Horton. Deflection points, stability pitch pulses, phugoid (Mach 2.0), level acceleration at 35,000 feet, and functional check of wing camera. Biomedical data flight.

Flt. 020 / **02 JUN 70**: Mallick/Young. Level accelerations in maximum afterburner at 10,000 and 20,000 feet, and functional check of wing camera. Level accelerations (25,000 to 35,000 feet), deflection data during transonic acceleration, inlet tuft data (Mach 2.0), phugoid (Mach 2.0, autopilot in altitude hold), and constant KEAS supersonic climb not accomplished. Biomedical data flight.

Flt. 021 / **11 JUN 70**: Fulton/Horton. Level acceleration in minimum afterburner (10,000 to 30,000 feet), deflection and tuft data during supersonic acceleration, SST handling qualities

evaluation at Mach 2.0, phugoids (Mach 2.0 in altitude hold and Mach hold), and served as radar target for YF-12A (60-6936). Biomedical data flight. Control room conflict with HL-10 lifting-body flight.

Flt. 022 / **16 JUN 70**: Fulton/Young. SST handling qualities evaluation repeated, constant Mach climbs (M=0.7, 0.8, and 0.9), two phugoids at Mach 2.0 and 60,000 feet (Mach hold, altitude hold, inlets manual), and served as radar target for YF-12A (936). Deflection data at Mach 0.8 not accomplished. Biomedical data flight. Aircraft grounded for instrumentation changes.

Flt. 023 / **22 MAR 71**: Mallick/Horton. Functional check flight with ventral fin on, instrumentation check, and ventral fin loads data during sideslip. Phugoids, deflection data, and temperature time history profile not accomplished. Biomedical data flight.

Flt. 024 / **07 MAR 71**: Fulton/Horton. Ventral fin off.

Flt. 025 / **16 APR 71**: Mallick/Horton. Stability and control points (Mach 2.4 to 2.6), and light-weight PIO data. Deflection data and level deceleration not accomplished. Biomedical data flight.

Flt. 026 / **29 APR 71**: Mallick/Young. Stability and control data (Mach 2.6 and 2.7). Loads and deflection data not accomplished. Biomedical data flight.

Flt. 027 / **05 MAY 71**: Fulton/Horton. Stability and control data (Mach 2.7 and 2.8), loads data (Mach 1.3), tuft data, level deceleration, deflection data, and PIO test. Phugoid not accomplished due to shortage of fuel. Biomedical data flight.

Flt. 028 / **23 JUN 71**: Mallick/Young. Ventral fin on. Refueling practice, deflection data and ventral tuft photos in the transonic region. Temperature profiles and loads data not accomplished. Flight aborted early due to landing gear warning light.

Flt. 029 / **09 JUL 71**: Fulton/Horton. Loads data, level deceleration, wing camera data, and SST handling qualities evaluation (Mach 2.5). Deflection data not collected.

Flt. 030 / **13 JUL 71**: Mallick/Young. Air Force intercepts, loads and deflection data, temperature profiles to Mach 2.65, ventral fin tuft photos in the transonic region, wing camera data, and bypass tests. Biomedical data flight.

Flt. 031 / **20 JUL 71**: Mallick/Horton. Air Force intercepts, loads and deflection data, temperature profiles to Mach 3.0, wing camera data, and SST handling qualities evaluation at cruise (Mach 3.2). Aborted mission early, prior to refueling, due to SAS malfunction. Biomedical data flight.

Flt. 032 / **27 JUL 71**: Mallick/Horton. Air Force intercepts, loads and deflection data, temperature profiles to Mach 2.8, and wing camera data. Unable to hook on to tanker due to pilot error with SAS channel settings. Aborted second leg of the mission. Biomedical data flight.

Flt. 033 / **03 AUG 71**: Layton/Young. Air Force intercepts, loads and deflection data, temperature profiles, wing camera data, and level deceleration. Biomedical data for FCO only. Had to retract landing gear manually. Three unstarts. Had to use manual restart twice.

Flt. 034 / **10 AUG 71**: Fulton/Young. Air Force intercepts, temperature profiles, wing camera data, and level deceleration. Loads and deflection data not collected. Biomedical data flight. Unable to find tanker. Aborted second leg of mission.

Flt. 035 / **17 AUG 71**: Fulton/Horton. Air Force intercepts, loads and deflection data, wing camera data, temperature profiles, stability and control data, and level deceleration. Biomedical data flight.

Flt. 036 / **22 OCT 71**: Mallick/Horton. Low-speed functional check flight (Mach 1.2), PIO tracking investigation, level accelerations, and loads data. Biomedical data flight.

Flt. 037 / **22 OCT 71**: Fulton/Horton. Loads data. Handling qualities, phugoid, and level acceleration not accomplished. Biomedical data flight. Flight aborted early due to hydraulic system failure.

Flt. 038 / **29 OCT 71**: Mallick/Horton. Loads data and level accelerations. Biomedical data flight.

Flt. 039 / **29 OCT 71**: Fulton/Young. Level decelerations, loads data, and level acceleration. High-speed functional check and airframe/propulsion interaction test not accomplished. Biomedical data flight.

Flt. 040 / **02 NOV 71**: Mallick/Horton. Loads data, temperature profile, and constant KEAS climb. Handling qualities evaluation (autopilot Mach hold) not performed. Biomedical data flight.

Flt. 041 / **09 NOV 71**: Fulton/Young. Loads data and temperature profile. Handling qualities evaluation (autopilot Mach hold) not completed. Biomedical data flight.

Flt. 042 / **16 NOV 71**: Mallick/Horton. Loads data, temperature profile, airframe/propulsion interaction test, and handling qualities evaluation.

Flt. 043 / **23 NOV 71**: Fulton/Horton. Loads data and simulated single-engine approach. Airframe/propulsion interaction test not accomplished. Second leg of mission cancelled because tanker aborted. Biomedical data flight.

Flt. 044 / **30 NOV 71**: Mallick/Young. Loads data, handling qualities evaluation, airframe/propulsion interaction test, and level deceleration. Biomedical data flight.

Flt. 045 / **07 DEC 71**: Fulton/Horton. Bypass tests, angle-of-attack lag tests, and wing camera data. Handling qualities evaluation not performed. Biomedical data flight. Aircraft diverted to Palmdale due to Edwards AFB runway closure.

Flt. 046 / **07 DEC 71**: Fulton/Horton. Ferried aircraft from Palmdale to Edwards.

Flt. 047 / **14 DEC 71**: Mallick/Young. Air Force intercepts, loads data, sideslips (rudder doublet), and handling qualities evaluation. Biomedical data flight.

Flt. 048 / **21 DEC 71**: Fulton/Horton. Handling qualities evaluation, loads data, level acceleration, airframe/propulsion interaction, longitudinal static stability, and low-speed phugoids. Stability and control test with auto inlets and manual inlets not attempted. Biomedical data flight.

Flt. 049 / **11 JAN 72**: Mallick/Young. Loads data, longitudinal handling qualities, and lateral-directional handling qualities. Airframe/propulsion interaction tests, inlet doublets, and phugoids not accomplished. INS system failed and the right-hand (R/H) bypass door control knob fell off the panel.

Flt. 050 / **18 JAN 72**: Fulton/Horton. Bypass tests, pitch pulse to evaluate angle-of-attack lag, and airframe/propulsion interaction test. Biomedical data flight. The airplane was unable to turn tightly enough to avoid overflying Death Valley National Monument.

Flt. 051 / **26 JAN 72**: Fulton/Horton. Loads data, level cruise (Mach 3.2). Biomedical data flight.

Flt. 052 / **26 JAN 72**: Fulton/Horton. Loads data and airframe/propulsion interaction test. Biomedical data flight.

Flt. 053 / **23 FEB 72**: Mallick/Young. Refueled near El Paso, Texas for maximum time at Mach 3.2 cruise speed.

Aircraft grounded for studies in the NASA FRC Loads Laboratory.

Flt. 054 / **12 JUL 73**: Fulton/Horton. Low-speed functional check. Nose gear failed to extend during test of emergency gear extension cycle. The remainder of the mission was aborted.

Flt. 055 / **26 JUL 73**: Mallick/Young. Emergency gear extension functional check, autopilot checks, and stabilized cruise points for boundary-layer and aft-facing step experiments.

Flt. 056 / **03 AUG 73**: Fulton/Horton. High-speed functional check, boundary-layer and aft-facing step experiments, and sideslip data.

Flt. 057 / **23 AUG 73**: Fulton/Young. Boundary-layer and aft-facing step experiments, sideslip data, and low L/D landing.

Flt. 058 / **06 SEP 73**: Mallick/Horton. Stabilized points for the aft-facing step and boundary-layer experiments.

Flt. 059 / **13 SEP 73**: Fulton/Horton. SAS-off pitch pulses, boundary-layer and aft-facing step experiments, and phugoids.

Flt. 060 / **11 OCT 73**: Mallick/Barnett. Aft-facing step and boundary-layer data point (Mach 1.1) and functional check of emergency landing gear extension system.

Flt. 061 / **11 OCT 73**: Mallick/Young. Autopilot baseline checks in altitude hold mode (Mach 2.5 to 3.2) and boundary-layer data point (Mach 3.0). Phugoid not accomplished. Tanker cancelled because it was needed to support a project with a higher priority (probably SR-71 coverage of the Arab-Israeli war, which started on 6 October).

Flt. 062 / **23 OCT 73**: Fulton/Horton. Steady-state sideslip (Mach 1.6), boundary-layer, and aft-facing step experiments.

Flt. 063 / **07 NOV 73**: Mallick/Young. Boundary-layer and aft-facing step experiments (Mach 2.2 to 3.2) and phugoid (Mach 3.0, altitude hold).

Flt. 064 / **16 NOV 73**: Fulton/Horton. Boundary-layer and aft-facing step experiments (Mach 0.89 to 2.5) and autopilot baseline data (Mach hold and altitude hold).

Flt. 065 / **03 DEC 73**: Mallick/Young. Boundary-layer and aft-facing step experiments (Mach 2.5 to 3.0) and autopilot baseline data (Mach 3.0, Mach hold and altitude hold).

Flt. 066 / **13 DEC 73**: Fulton/Horton. Boundary-layer and aft-facing step experiments (Mach 0.6 to 2.8) and effect of bypass airflow on the wing boundary-layer rake.

Flt. 067 / **11 JAN 74**: Mallick/Young. Boundary-layer and aft-facing step experiments (Mach 0.8 to 3.2).

Flt. 068 / **17 JAN 74**: Fulton/Horton. Boundary-layer and aft-facing step experiments (Mach 0.6 to 3.2).

Flt. 069 / **25 JAN 74**: Mallick/Young. Boundary-layer and aft-facing step experiments (Mach 0.9 to 3.2).

Flt. 070 / **04 MAR 74**: Fulton/Horton. Boundary-layer, aft-facing step, and boat-tail-drag data (Mach 0.9 to 3.0), modified autopilot tests, and elevator pulses (Mach 3.0, auto inlets and manual inlets).

Flt. 071 / **08 MAR 74**: Mallick/Young. Boundary-layer, aft-facing step, and boat-tail-drag data (Mach 0.8 to 2.5).

Flt. 072 / **15 MAR 74**: Fulton/Horton. Boundary-layer, aft-facing step, and boat-tail-drag data (Mach 1.0 to 3.2).

Flt. 073 / **21 MAR 74**: Mallick/Young. Boundary-layer, aft-facing step, and boat-tail-drag data (Mach 0.6 to 3.2), altitude-hold test in climb.

Flt. 074 / **28 MAR 74**: Fulton/Horton. Boundary-layer, aft-facing step, boat tail drag data (Mach 0.9 to 3.0), constant “G” turns, and modified autopilot tests.

Flt. 075 / **18 APR 74**: Mallick/Young. Boundary-layer, aft-facing step, and boat-tail-drag data

(Mach 0.6 to 3.0). Flight aborted early due to left-hand (L/H) engine oil pressure malfunction.

Flt. 076 / **02 MAY 74**: Fulton/Horton. Boundary-layer, aft-facing step, and boat-tail-drag data (Mach 0.9 to 3.2).

Flt. 077 / **09 MAY 74**: Mallick/Young. Boundary-layer, aft-facing step, and boat-tail-drag data (Mach 0.9 to 2.5).

Flt. 078 / **16 MAY 74**: Fulton/Horton. Boundary-layer, aft-facing step, and boat-tail-drag data (Mach 0.6 to 3.2), modified autopilot tests, and handling-qualities evaluation.

Flt. 079 / **23 MAY 74**: Mallick/Young. Aborted early due to R/H generator malfunction shortly after takeoff. Boundary-layer, aft-facing step, and boat-tail-drag data not collected.

Flt. 080 / **30 MAY 74**: Mallick/Young. Boundary-layer, aft-facing step, and boat-tail-drag data (Mach 2.0 to 3.2).

Flt. 081 / **06 JUN 74**: Fulton/Horton. Boundary-layer, aft-facing step, and boat-tail-drag data (Mach 0.6 to 3.0).

Flt. 082 / **11 SEP 74**: Fulton/Horton. Low-speed functional check, aft-facing step, four-foot flow field survey rake, and boat-tail-drag data (Mach 0.6 to 1.5).

Flt. 083 / **17 SEP 74**: Fulton/Horton. Aft-facing step, four-foot flow field survey rake, and boat-tail-drag data.

Flt. 084 / **03 OCT 74**: Fulton/Horton. Aft-facing step, four-foot flow field survey rake, and boat-tail-drag data (Mach 0.6 to 1.2). Back-up flight profile flown due to crew environmental system malfunction.

Flt. 085 / **18 OCT 74**: Fulton/Horton. Functional check of the Type K engines, aft-facing step, four-foot flow field survey rake, boat-tail-drag data (Mach 0.9 to 3.2), rudder doublet (Mach 3.0), and water dump.

Flt. 086 / **25 OCT 74**: Fulton/Horton. Coldwall track and profile data, aft-facing step, four-foot flow field survey rake, and boat-tail-drag data (Mach 1.05 to 2.0).

Flt. 087 / **01 NOV 74**: Fulton/Horton. Coldwall track and profile data, aft-facing step, four-foot flow field survey rake, and boat-tail-drag data (Mach 1.05 to 3.2).

Aircraft grounded for installation of Coldwall experiment.

Flt. 088 / **07 FEB 75**: Fulton/Horton. Low-speed functional check flight with Coldwall experiment. Aborted early due to Coldwall accelerometer malfunction.

Flt. 089 / **14 FEB 75**: Mallick/Young. Planned functional check flight of Coldwall experiment was aborted due to Coldwall accelerometer malfunction. A subsonic back-up mission profile was flown for stability and control data.

Flt. 090 / **27 FEB 75**: Mallick/Young. Rudder doublets (Mach 0.8 to 3.0). Ventral fin separated from aircraft during flight. Mission ended with emergency landing at Edwards AFB.

Aircraft grounded for repairs. No ventral fin until Flight 097.

Flt. 091 / **11 JUL 75**: Fulton/Horton. Structural demonstration of the Coldwall experiment at supersonic speed, structural demonstration of the flow field survey rake in place of the ventral fin, ventral flow field data, and documentation of the stability of the aircraft with Coldwall and camera pods on and the ventral fin off.

Flt. 092 / **24 JUL 75**: Mallick/Young. Structural demonstration of Coldwall with an insulation blanket installed, flow field data in the ventral region, documentation of aircraft stability, and collection of scanivalve data prior to and following each use of afterburner.

Flt. 093 / **07 AUG 75**: Fulton/Horton. Operational check of the Coldwall insulation removal system at Mach 2.4. Both inlets ingested insulation material and unstarted.

Flt. 094 / **21 AUG 75**: Fulton/Horton. Flow field survey of aircraft with Coldwall experiment removed and camera pods on.

Flt. 095 / **28 AUG 75**: Mallick/Young. Flow field survey and aircraft stability with Coldwall experiment off and camera pods on.

Flt. 096 / **05 SEP 75**: Fulton/Horton. Aircraft stability with Coldwall experiment off, ventral survey rake and camera pods on. Pilot declared an emergency on landing approach due to unsafe R/H landing gear indication. Landing was accomplished without incident.

Aircraft grounded for installation of Lockalloy (62Be-38Al) ventral fin.

Flt. 097 / **16 JAN 76**: Mallick/Young. First flight with new Lockalloy ventral fin; rudder and aileron pulses, and steady-state sideslips.

Flt. 098 / **27 JAN 76**: Fulton/Horton. Touch-and-go landings for high-speed taxi data with instrumented landing gear, low-speed taxi test.

Flt. 099 / **05 FEB 76**: Mallick/Young. Touch-and-go landings for high-speed taxi data with instrumented landing gear, runway roughness tests, and low-speed taxi test.

Flt. 100 / **12 FEB 76**: Fulton/Horton. Envelope expansion and sideslip data with Lockalloy ventral fin. Landing gear data was not obtained due to foam on the runway.

Flt. 101 / **04 MAR 76**: Fulton/Young. Envelope expansion and sideslip data with Lockalloy ventral fin, plus low L/D approach. Landing gear data was not obtained due to unsafe gear indication.

Flt. 102 / 23 MAR 76: Fulton/Horton. Envelope expansion and sideslip data with Lockalloy ventral fin, push-over and pull-up maneuvers, and landing gear.

Flt. 103 / 02 APR 76: Fulton/Young. Envelope expansion and sideslip data with Lockalloy ventral fin.

Flt. 104 / 12 APR 76: Fulton/Young. Ventral tufts (flow-field photos), low landing approach, and landing gear data.

Flt. 105 / 13 MAY 76: Mallick/Young. Envelope expansion with Lockalloy ventral fin; landing gear data.

Flt. 106 / 20 MAY 76: Fulton/Horton. Envelope expansion with Lockalloy ventral fin; landing gear data.

Flt. 107 / 15 JUL 76: Mallick/Young. Stability and control data with Coldwall, camera pods, and Lockalloy ventral fin on.

Flt. 108 / 22 JUL 76: Fulton/Horton. Stability and control data with Coldwall, camera pods, and Lockalloy ventral fin on, Coldwall alignment flight data, and operational test of Coldwall rake guard.

Flt. 109 / 10 AUG 76: Mallick/Young. Coldwall profile and Hotwall data.

Flt. 110 / 31 AUG 76: Fulton/Horton. Coldwall profile, Hotwall data, and landing flare data.

Flt. 111 / 13 SEP 76: Fulton/Horton. Coldwall skin-friction balance-cooling verification and conical probe alignment data.

Flt. 112 / 28 SEP 76: Fulton/Horton. Coldwall profile, Hotwall data and skin friction data.

Flt. 113 / 21 OCT 76: Fulton/Horton. Coldwall data not obtained due to premature loss of Coldwall experiment insulation.

Flt. 114 / 10 NOV 76: Fulton/Horton. Gust-vane calibration, handling-qualities evaluation, vortex flow visualization photos, and autopilot altitude-hold tests.

Flt. 115 / 09 DEC 76: Mallick/Young. Coldwall profile, Hotwall data, and fuselage tuft photos at subsonic speeds.

Flt. 116 / 03 MAR 77 : Fulton/Horton. Coldwall data not obtained due to premature loss of Coldwall experiment insulation.

Flt. 117 / 02 JUN 77: Fulton/Horton. Vortex flow visualization photos. Coldwall data not obtained due to premature loss of Coldwall experiment insulation.

Flt. 118 / **23 JUN 77**: Fulton/Horton. Vortex flow visualization photos and Coldwall data.

Flt. 119 / **21 JUL 77**: Fulton/Horton. Coldwall data not obtained because Coldwall insulation was ingested into the L/H engine inlet, causing an unstart that did not clear correctly. Aircraft made an emergency landing at Edwards. The YF-12C chase aircraft simultaneously experienced a high KEAS condition and compressor stalls. Aircraft grounded for overspeed and overload inspection.

Flt. 120 / **30 SEP 77**: Fulton/Horton. Coldwall data, U-2 intercept, and a fly-by of the NASA Dryden Flight Research Center.

Flt. 121 / **13 OCT 77**: Fulton/Horton. Coldwall data. Final Coldwall flight.

Flt. 122 / **18 NOV 77**: Mallick/Young. Lower surface boundary-layer survey and handling qualities evaluation. Subsonic wake vortex flow visualization data not obtained due to a malfunction of the wake visualization water-spray system.

Flt. 123 / **01 DEC 77**: Manke/Horton. Pilot familiarization.

Flt. 124 / **01 DEC 77**: Dana/Horton. Pilot familiarization.

Flt. 125 / **09 DEC 77**: Krier/Young. Pilot familiarization.

Flt. 126 / **13 DEC 77**: Enevoldson/Young. Pilot familiarization.

Flt. 127 / **14 DEC 77**: McMurtry/Horton. Pilot familiarization.

Flt. 128 / **28 FEB 78**: Mallick/Young. Dual-mode landing gear baseline stiffness tests.

Flt. 129 / **28 FEB 78**: Mallick/Young. Dual-mode landing gear baseline stiffness tests.

Flt. 130 / **07 MAR 78**: Fulton/Horton. Large volume landing gear stiffness tests.

Flt. 131 / **07 MAR 78**: Fulton/Horton. Large volume landing gear stiffness tests.

Flt. 132 / **15 MAR 78**: Mallick/Young. Mixed volume landing gear stiffness tests.

Flt. 134 / **23 MAR 78**: Fulton/Horton. Space Shuttle approach simulations.

Flt. 135 / **31 MAR 78**: Enevoldson/Young. Space Shuttle approach simulations.

Flt. 136 / **31 MAR 78**: Dana/Horton. Space Shuttle approach simulations. Aircraft grounded for installation of shaker vane system.

Flt. 137/ 22 NOV 78: Fulton/Horton. Shaker vane study.

Flt. 138/ 01 DEC 78: Fulton/Horton. Shaker vane study.

Flt. 139/ 24 JAN 79: Mallick/Young. Shaker vane study.

Flt. 140/ 16 FEB 79: Fulton/Horton. Shaker vane study.

Flt. 141/ 08 MAR 79: Mallick/Young. Shaker vane study.

Flt. 142/ 15 MAR 79: Fulton/Horton. Shaker vane study.

Flt. 143/ 29 MAR 79: Ishmael/Horton. Pilot familiarization.

Flt. 144/ 29 MAR 79: Swann/Young. Pilot familiarization.

Flt. 145/ 31 OCT 79: Fulton/Horton. Final NASA flight of 935.

Flt. 146/ 07 NOV 79: Sullivan/Uppstrom. Ferried aircraft to USAF Museum.

YF-12A (936) Flight Log:

Flt. 001 / 03 MAR 70: Slater/Heidelbaugh. USAF test.

Flt. 002 / 05 MAR 70: Fulton/Horton. Pilot check-out #1.

Flt. 003 / 09 MAR 70: Fulton/Horton. Pilot check-out #2.

Flt. 004 / 11 MAR 70: Fulton/Horton. Pilot check-out #3.

Flt. 005 / 24 MAR 70: Slater/Heidelbaugh. Aborted.

Flt. 006 / 31 MAR 70: Slater/Heidelbaugh. Intercepts and turn performance, FCF, fuel tank sealant curing, radar tracked constant KEAS descent.

Flt. 007 / 10 APR 70: Mallick/Ursini. Final check-out (#3) flight for Mallick, fuel tank sealant curing, air-data system calibration (constant KEAS climb and descent), radar intercepts, and NASA Edwards and Ely radar tracking range determination.

Flt. 008 / 16 APR 70: Slater/Ursini. Supersonic controlled intercepts, constant KEAS accelerations, and subsonic controlled intercepts. Other objectives not met due to mechanical malfunctions.

Flt. 009 / 21 APR 70: Slater/Heidelbaugh. Radar intercepts. Other objectives not accomplished due to mechanical malfunctions.

Flt. 010 / **24 APR 70**: Slater/Heidelbaugh. Simulated supersonic target ID intercept, controlled and autonomous intercepts. Air data system calibrations not performed. No research engineers at the USAF radar site to advise expected inbound track for radar acquisition.

Flt. 011 / **30 APR 70**: Slater/Ursini. Mission Control data link check. Other objectives not accomplished due to apparent high fuel consumption.

Flt. 012 / **07 MAY 70**: Slater/Heidelbaugh. Fuel consumption and CG check, pitch trim calibration, air data system calibration (350 KEAS descent), and simulated supersonic ID intercept.

Flt. 013 / **17 MAY 70**: Rogers/Heidelbaugh. Armed Forces Day airshow fly-by at Edwards AFB.

Flt. 014 / **26 MAY 70**: Campbell/Ursini. Supersonic cruise altitude control at Mach numbers of 2.6, 2.8, and 3.0. Unable to attain maximum Mach number (3.2) due to fuel flow variations between engines at high speed.

Flt. 015 / **05 JUN 70**: Slater/ Heidelbaugh. Air data system calibration (400 KEAS descent). Planned airborne early warning (AEW) and B-57 intercepts not accomplished due to not receiving tone for radar time correlation as called for on the flight cards.

Flt. 016 / **11 JUN 70**: Slater/Ursini. Supersonic transport intercept geometry using YF-12A (60-6935) as a target, air data calibration (450 KEAS acceleration). Biomedical data flight. Control room conflict with HL-10 lifting-body flight.

Flt. 017 / **16 JUN 70**: Slater/Heidelbaugh. Supersonic Transport ID intercept, and Air Force documentary photos. Biomedical data flight.

Aircraft grounded for instrumentation changes.

Flt. 018 / **29 AUG 70**: Campbell/Heidelbaugh. Functional check flight, and inlet instrumentation shakedown. Biomedical data flight.

Flt. 019 / **05 SEP 70**: Layton/Heidelbaugh. Pilot check-out #1. Fire control officer (FCO) biomedical data flight.

Flt. 020 / **06 SEP 70**: Layton/Heidelbaugh. Pilot check-out #2. FCO biomedical data flight.

Flt. 021 / **06 SEP 70**: Layton/Heidelbaugh. Pilot check-out #3. FCO biomedical data flight.

Flt. 022 / **11 SEP 70**: Layton/Heidelbaugh. Pilot check-out #4, aerial refueling, and radar cross sections and intercepts. FCO biomedical data flight.

Flt. 023 / **12 SEP 70**: Layton/Heidelbaugh. Final pilot check-out (#5). No biomedical data on this flight.

Flt. 024 / **15 SEP 70**: Layton/Heidelbaugh. F-106 autonomous intercept, B-57 controlled intercept, and turn performance. EC-121 radar intercept not accomplished. Biomedical data for pilot only.

Flt. 025 / **17 SEP 70**: Layton/Heidelbaugh. USAF test.

Flt. 026 / **06 OCT 70**: Layton/Heidelbaugh. High-speed altitude control, and level deceleration (cruise to minimum KEAS). Radar intercepts not accomplished.

Flt. 027 / **09 OCT 70**: Layton/Heidelbaugh. Aborted.

Flt. 028 / **16 OCT 70**: Layton/Heidelbaugh. Air data system calibration. Biomedical data flight.

Flt. 029 / **23 OCT 70**: Layton/Heidelbaugh. F-106 and B-57 controlled intercepts. Biomedical data flight.

Flt. 030 / **27 OCT 70**: Layton/Heidelbaugh. Radar intercepts of B-57 and F-106, and turn performance. Biomedical data flight. Control room conflict with X-24A lifting-body flight.

Flt. 031 / **29 OCT 70**: Layton/Heidelbaugh. F-106 supersonic target ID intercept, F-106 radar intercepts, and lag stair step profile (Mach 3.0). Biomedical data flight. U-2 high-altitude intercept not accomplished.

Flt. 032 / **03 NOV 70**: Mallick/Heidelbaugh. Pilot recurrency, phugoids (Mach 3.0, auto inlets, pitch autopilot off). Biomedical data flight. Radar intercepts not accomplished due to inoperative radar.

Flt. 033 / **03 NOV 70**: Layton/Heidelbaugh. U-2 and F-4 controlled radar intercepts, F-106 autonomous radar intercepts, phugoids (Mach 3.0), and lag stair step (Mach 2.5).

Flt. 034 / **17 NOV 70**: Layton/Curtis. FCO check-out, U-2 and F-106 radar intercepts.

Flt. 035 / **20 NOV 70**: Layton/Curtis. F-106 radar intercepts. Unable to perform B-57 radar intercepts, phugoids, and level deceleration. Mission aborted early due to oil quantity problem.

Flt. 036 / **25 NOV 70**: Campbell/Heidelbaugh. F-106 radar intercepts, cruise sideslip, and level deceleration (cruise to minimum KEAS). B-57 and F-4 radar intercepts not accomplished. Control room conflict with M2-F3 lifting-body flight.

Flt. 037 / **01 DEC 70**: Layton/Heidelbaugh. F-106 and B-52 radar intercepts.
F-106 and F-4 radar intercepts not accomplished. NASA sideslip and lag stair step not accomplished. Environmental test antenna fell off prior to flight. Flight aborted early due to hydraulic system failure.

Flt. 038 / **17 DEC 70**: Layton/Curtis. Flight aborted early due to liquid nitrogen system failure. No data.

Flt. 039 / **19 JAN 71**: Layton/Curtis. Subsonic pulse code modulation (PCM) failed.

Flt. 040 / **22 JAN 71**: Mallick/Heidelbaugh. Pilot recurrency, B-57 radar intercept, sideslip and roller coaster maneuver (Mach 2.75 and 3.0). Biomedical data flight. Landing approaches not accomplished due to precautionary emergency straight-in landing (low oil pressure in R/H engine). NASA PCM failed.

Flt. 041 / **29 JAN 71**: Layton/Curtis. Aborted early due to repeat of problems from Flt. 40. Biomedical data flight. No other data.

Flt. 042 / **02 FEB 71**: Layton/Heidelbaugh. ECM target (B-57), F-106 conversion target, and sideslip (Mach 2.75). Other objectives not accomplished due to engine malfunction (R/H oil pressure fluctuation, shutdown). Biomedical data flight.

Flt. 043 / **10 FEB 71**: Layton/Heidelbaugh. Functional check flight, sideslip (Mach 3.0), cruise bleed and bypass manual inlet, and phugoid. Biomedical data flight. B-57 offset target, F-106 conversion target, and Mach 3.0 roller coaster not accomplished.

Flt. 044 / **18 FEB 71**: Layton/Curtis. F-106 head-on and conversion target, bleed and bypass manual inlet (Mach 3.0), and B-57 conversion target. Biomedical data flight. Other objectives not accomplished. Roller coaster maneuver found to be impractical.

Flt. 045 / **23 FEB 71**: Layton/Curtis. PCM system noise checks, F-106 maneuvering target, B-57 conversion target, phugoid (Mach 3.0, pitch autopilot off), manual forward bypass acceleration, and modified roller coaster maneuver (Mach 3.0). F-106 conversion target not completed.

Flt. 046 / **02 MAR 71**: Layton/Curtis. B-57 maneuvering and conversion target, modified roller coaster (Mach 2.75 and 3.0), bypass manual inlet (Mach 2.75), pitch and yaw pulse (Mach 3.0), and B-57 PCM target.

Flt. 047 / **05 MAR 71**: Mallick/Heidelbaugh. Pilot proficiency check, pitch and yaw pulse (auto and manual inlets, SAS off), and B-57 offset and conversion target. C-130 radar intercept not completed.

Flt. 048 / **09 MAR 71**: Layton/Heidelbaugh. B-57 conversion target, and handling qualities altitude change. F-106 conversion target, C-130 head-on target, and level deceleration not accomplished. Flight aborted early due to low L/H engine oil pressure.

Flt. 049 / **18 MAR 71**: Layton/Curtis. B-57 maneuvering target, and phugoid (autopilot, Mach hold, Mach 3.0). F-105 frontal intercept, B-57 conversion target, and 400 KEAS descent not accomplished. SPORT radar unable to acquire YF-12 during descent.

Flt. 050 / **23 MAR 71**: Layton/Heidelbaugh. B-52 maneuvering target, F-106 head-on target, B-57 conversion target, altitude control handling qualities (Mach 3.0), level deceleration (cruise to minimum KEAS), and 400 KEAS descent. C-130 head-on target not accomplished due to radar malfunction.

Flt. 051 / **25 MAR 71**: Layton/Curtis. B-52 maneuvering target, altitude change handling qualities, and phugoid (Mach 3.0, altitude hold). F-106 and C-130 head-on intercepts not accomplished. Phugoid terminated after one cycle due to excess speed.

Flt. 052 / **30 MAR 71**: Layton/Heidelbaugh. F-106 and B-57 conversion targets, altitude-control handling qualities (Mach 2.75), level deceleration (cruise to minimum KEAS), and 400 KEAS descent. Radar tracking kept breaking lock. SPORT tracking radar unable to re-acquire YF-12 for level deceleration. Severe turbulence at 47,500 feet. Heavy persistent contrails at 65,000 feet.

Flt. 053 / **13 APR 71**: Layton/Curtis. USAF test.

Flt. 054 / **20 APR 71**: Layton/Curtis. C-131 radar target (propeller signatures), F-106 and F-4E frontal intercepts, and speed stability trim point (Mach 3.0). B-57 detection and tracking, phugoid, and ventral lateral accelerations not accomplished.

Flt. 055 / **27 APR 71**: Layton/Heidelbaugh. Speed stability trim point (Mach 3.0).

Flt. 056 / **06 MAY 71**: Layton/Curtis. Speed stability trim point (Mach 3.0). Cruise roller coaster maneuver not accomplished.

Flt. 057 / **13 MAY 71**: Layton/Heidelbaugh. Transonic ventral acceleration and deceleration data, and roller coaster maneuvers (Mach 3.0 and 3.2). Inlet control parameter data and Mach 2.75 roller coaster not accomplished.

Flt. 058 / **04 JUN 71**: Layton/Curtis. Transonic ventral accelerations, inlet cruise data calibration, and auto inlet parameters. NASA bypass door walk instrumentation data and manual inlet parameters not accomplished. Initial flight abort resulted in lakebed takeoff.

Flt. 059 / **10 JUN 71**: Layton/Heidelbaugh. Throttle advance/inlet noise correlation, and intervalometer data quality.

Flt. 060 / **15 JUN 71**: Layton/Curtis. Handling qualities intervalometer data. Steady state inlet data (Mach 2.0) not accomplished.

Flt. 061 / **22 JUN 71**: Layton/Heidelbaugh. Steady-state inlet data (Mach 2.0), and handling qualities mission survey.

Flt. 062 / **24 JUN 71**: Layton/Curtis. Handling qualities intervalometer. Fire in R/H engine resulted in crash. Crew ejected safely.

YF-12C (937) Flight Log:

Flt. 001 / **16 JUL 71**: Evenson/McNeer. Delivery to NASA FRC. Aircraft grounded for installation of NASA instrumentation.

Flt. 002 / **24 MAY 72**: Fulton/Horton. First NASA flight of 937. Functional check flight, phugoid, airspeed calibration, and stability and control pulses. Biomedical data flight.

Flt. 003 / **06 JUN 72**: Mallick/Young. Airspeed calibration. Level acceleration and deceleration, and constant KEAS climb. Biomedical data flight.

Flt. 004 / **14 JUN 72**: Fulton/Horton. Airspeed calibration and propulsion. Level decelerations, constant KEAS descent, roller coaster maneuvers, and sideslips. Biomedical data flight.

Flt. 005 / **21 JUN 72**: Mallick/Young. Propulsion performance baseline data, and stability and control data. Forward engine bypass tests, roller coaster maneuvers, sideslip, level deceleration, constant KEAS descent, and phugoids. Biomedical data flight.

Flt. 006 / **18 JUL 72**: Fulton/Young. Performance baseline and airspeed calibration data. Functional check of engine revolutions-per-minute trim and SAS recall, roller coaster maneuvers, sideslip, engine bypass tests (Mach 2.5 to 3.2), level deceleration, and constant KEAS descent. Biomedical data flight.

Flt. 007 / **26 JUL 72**: Mallick/Young. Propulsion baseline data, stability and control (Mach 2.9, manual and auto inlets), and phugoids. Biomedical data flight.

Flt. 008 / **01 AUG 72**: Fulton/Horton. Served as target for Navy F-14 radar intercept, propulsion performance (roller coaster maneuvers, sideslip, and bypass tests), and stability and control data. Biomedical data flight.

Flt. 009 / **15 AUG 72**: Mallick/Young. Airspeed lag calibration roller coaster maneuvers, and stability and control interactions. Biomedical data flight.

Flt. 010 / **22 AUG 72**: Fulton/Horton. Propulsion baseline data, stability and control data, and phugoid. Biomedical data flight.

Flt. 011 / **29 AUG 72**: Mallick/Young. Performance baseline data, airspeed calibration, and phugoids. Biomedical data flight.

Aircraft grounded for installation of Inlet Recall system.

Flt. 012 / **15 NOV 72**: Fulton/Horton. RPM trim test (Mach 3.0), functional test of Inlet Recall (intentional unstart), bypass tests, and roller coaster maneuvers. Biomedical data flight.

Flt. 013 / **22 NOV 72**: Mallick/Young. Phase II propulsion tests. Biomedical data flight.

Flt. 014 / **05 DEC 72**: Fulton/Horton. Phase II propulsion tests. Biomedical data flight.

Flt. 015 / **12 DEC 72**: Mallick/Young. Phase II propulsion tests. Biomedical data flight.

Flt. 016 / **11 JAN 73**: Fulton/Horton. Phase II propulsion tests. Biomedical data flight.

Flt. 017 / 18 JAN 73: Mallick/Young. Performance tests. Level accelerations, speed-power points, roller coaster maneuvers, constant KEAS climb and descent, and constant power turns. Biomedical data flight.

Flt. 018 / 24 JAN 73: Fulton/Horton. Performance tests. Level accelerations, speed power points, roller coaster maneuvers, constant KEAS climb and descent, and constant power turns. Biomedical data flight.

Flt. 019 / 01 FEB 73: Fulton/Young. Phase II propulsion tests. Biomedical data flight.

Flt. 020 / 08 FEB 73: Mallick/Horton. Propulsion and handling qualities tests. Biomedical data flight.

Flt. 021 / 15 FEB 73: Fulton/Young. Performance tests. Constant KEAS climb, speed-power points, roller coaster maneuvers, and constant 400 KEAS descent. Biomedical data flight.

Flt. 022 / 22 FEB 73: Mallick/Horton. Performance tests. Level accelerations, speed-power points, roller coaster maneuvers, and constant 400 KEAS climb and descent. Biomedical data flight.

Flt. 023 / 22 MAR 73: Fulton/Horton. Functional check flight and Phase II propulsion tests. Biomedical data flight.

Flt. 024 / 05 APR 73: Mallick/Horton. Support U-2A (56-6692) target radiation intensity measurement tests, Phase II propulsion tests, and radar targeting for Navy F-14. Biomedical data flight.

Flt. 025 / 12 APR 73: Fulton/Young. Phase II propulsion tests. Biomedical data flight.

Flt. 026 / 20 APR 73: Mallick/Young. Phase II propulsion tests, low L/D approach. Biomedical data flight.

Flt. 027 / 26 APR 73: Fulton/Horton. Phase II propulsion tests, low L/D approach. Biomedical data flight.

Flt. 028 / 02 MAY 73: Mallick/Young. No objectives completed. Aborted to Naval Air Station (NAS) Fallon, Nevada, due to R/H spike failure and subsequent high fuel consumption. Biomedical data flight.

Flt. 029 / 03 MAY 73: Mallick/Young. Subsonic ferry flight from NAS Fallon, Nevada, to Edwards AFB.

Flt. 030 / 10 MAY 73: Fulton/Horton. Phase II propulsion tests. Biomedical data flight.

Flt. 031 / 17 MAY 73: Mallick/Young. Phase II propulsion tests. Biomedical data flight.

Flt. 032 / **31 MAY 73**: Fulton/Horton. Stability and control, handling qualities, and phugoids. Biomedical data flight.

Flt. 033 / **08 JUN 73**: Mallick/Young. Constant 450 KEAS climb, constant Mach climb (maximum KEAS to minimum KEAS), speed-power point (Mach 2.5), constant 450 KEAS descent, and low L/D approach to lakebed. Biomedical data flight.

Aircraft grounded for 13 months.

Flt. 034 / **11 JUL 74**: Fulton/Horton. Aircraft functional check flight, Data Acquisition System check-out for Phase III propulsion test program. Biomedical data flight.

Flt. 035 / **26 JUL 74**: Mallick/Young. Aircraft performance data. Level accelerations, constant Mach climb, speed-power points, and roller coaster maneuvers. Biomedical data flight.

Flt. 036 / **13 SEP 74**: Mallick/Young. Phase III propulsion tests. Fixed inlet study, inlet Reynolds number tests, Mach 2.48 wind-tunnel match point, aft bypass frequency generator test, and angle-of-attack tests (Mach 2.1). Biomedical data flight.

Flt. 037 / **25 SEP 74**: Mallick/Young. Phase IIIa propulsion tests. Real-time match tests, Reynolds number tests, aft bypass function generator test, and inlet angle-of-attack tests. Biomedical data flight.

Flt. 038 / **07 NOV 74**: Fulton/Horton. Performance data. Level accelerations, constant KEAS climb, constant Mach climb, level cruise, constant KEAS descent, and constant Mach descent. Biomedical data flight.

Flt. 039 / **19 DEC 74**: Mallick/Young. Low-speed functional check flight and inlet transducer lag checks. Biomedical data flight.

Flt. 040 / **19 DEC 74**: Mallick/Young. High-speed functional check flight and performance modeling data. Constant Mach climbs, level accelerations, constant KEAS climb and descent, and speed-power points. Biomedical data flight.

Flt. 041 / **17 JAN 75**: Fulton/Horton. Performance modeling data and Turbine Inlet Gas Temperature (TIGT) system check. Biomedical data flight.

Flt. 042 / **24 JAN 75**: Mallick/Horton. Performance modeling data and TIGT system check. Biomedical data flight.

Flt. 043 / **24 APR 75**: Fulton/Horton. Performance modeling data and TIGT system check. Biomedical data flight.

Flt. 044 / **05 JUN 75**: Mallick/Young. TIGT system check, TIGT control tests in climb and descent, and phugoids (Mach 2.9, auto inlets and manual inlets). Aft bypass door generator data not accomplished. Biomedical data flight.

Flt. 045 / **12 JUN 75**: Fulton/Horton. TIGT system transient tests (Mach 3.0), TIGT control tests during a standard climb profile, and spike tip data (Mach 1.6 to 3.2). Biomedical data flight.

Flt. 046 / **20 JUN 75**: Mallick/Young. Performance modeling data and TIGT system check. Biomedical data flight.

Flt. 047 / **26 JUN 75**: Fulton/Horton. TIGT transient tests, TIGT control test during a standard descent, and baseline co-op control data (Mach 3.0) Aft bypass function generator tests not accomplished. Biomedical data flight.

Flt. 048 / **03 JUL 75**: Mallick/Young. Propulsion data. Mach tests, spike tests, sideslip tests, and angle-of-attack tests (Mach 2.8 to 3.2). Biomedical data flight.

Flt. 049 / **07 AUG 75**: Mallick/Young. Chase for YF-12A (935) Coldwall flight, and spike tip tests (Mach 2.1 to 3.2). Biomedical data flight

Flt. 050 / **14 AUG 75**: Mallick/Young. Propulsion data. Mach tests, spike tests, sideslip tests, and angle-of-attack tests (Mach 2.8 to 3.2). Biomedical data flight. Repeat of Flight 048 test card. Sine/step generator functional check not accomplished.

Flt. 051 / **11 SEP 75**: Mallick/Young. Propulsion data at Mach 3.2 (Mach test, spike test, side-slip test, Duct Pressure Ratio (DPR) test, and angle-of-attack) and TIGT tests. Aft bypass function generator tests (Mach 3.0, manual inlets and auto inlets) not accomplished. Biomedical data flight.

Flt. 052 / **24 SEP 75**: Fulton/Horton. TIGT tests, and stability and control data. Subsonic TIGT transient tests, co-op control interaction tests, autopilot altitude hold tests, and sine/step function generator test. Biomedical data flight.

Flt. 053 / **16 OCT 75**: Mallick/Young. Engine compressor stall tests (engines did not stall at any of the test conditions), aft bypass function generator tests (Mach 3.0), and phugoid. Interaction test series not performed. At end of flight, cockpit air temperature was 110 degrees and there was no suit cooling. Biomedical data flight.

Flt. 054 / **30 OCT 75**: Fulton/Horton. Engine compressor stall tests, interactions data, and autopilot tests. Biomedical data flight. Aircraft grounded for 11 months.

Flt. 055 / **16 SEP 76**: Mallick/Young. Low-speed functional check flight (FCF) and boattail drag study. High-speed FCF and inlet DPR test not accomplished. The airplane was limited to Mach 1.6 due to a pitch SAS problem. Biomedical data flight.

Flt. 056 / **30 SEP 76**: Mallick/Young. High-speed FCF, boattail drag study, and autothrottle data (DPR tests). Biomedical data flight.

Flt. 057 / **21 OCT 76**: Mallick/Young. Chase for YF-12A (935) Coldwall flight and subsonic boattail drag data. Dynamic inlet data (DPR tests) not accomplished due to power supply failure. Biomedical data flight.

Flt. 058 / **09 NOV 76**: Mallick/Horton. Propulsion DPR tests and handling qualities evaluation with pitch SAS in recall. Biomedical data flight.

Flt. 059 / **19 NOV 76**: Mallick/Young. Inlet wind-tunnel dynamic match point tests, boattail drag data, and handling qualities evaluation. Biomedical data flight.

Flt. 060 / **02 DEC 76**: Mallick/Young. Inlet wind-tunnel dynamic match point tests, inlet DPR tests, inlet variation tests, boattail drag data, and handling qualities evaluation. Biomedical data flight.

Flt. 061 / **03 MAR 77**: Mallick/Young. Chase for YF-12A (935) Coldwall flight, inlet wind-tunnel dynamic match point tests, boattail drag data, and bypass door data. Biomedical data flight.

Flt. 062 / **18 MAR 77**: Fulton/Horton. Propulsion match point data (Mach 2.44) and autothrottle tests (Mach 3.0). Biomedical data flight.

Flt. 063 / **24 MAR 77**: Fulton/Young. Propulsion match points, autothrottle tests, and gust vane experiment. Boattail drag data not accomplished. Biomedical data flight.

Flt. 064 / **01 APR 77**: Mallick/Horton. Propulsion match points, sine/step function generator data, and gust vane experiment. Autothrottle tests not accomplished. Biomedical data flight.

Flt. 065 / **12 MAY 77**: Fulton/Horton. Autothrottle tests (Mach 2.8). Propulsion match points and gust vane experiment not accomplished.

Flt. 066 / **19 MAY 77**: Mallick/Young. Propulsion match points, autothrottle tests, and gust vane experiment.

Flt. 067 / **26 MAY 77**: Fulton/Horton. Autothrottle tests, propulsion match points, and gust vane experiment.

Flt. 068 / **02 JUN 77**: Mallick/Young. Chase for YF-12A (935) Coldwall flight and propulsion match points. Autothrottle test not accomplished.

Flt. 069 / **15 JUN 77**: Mallick/Young. Propulsion match points and autothrottle test.

Flt. 070 / **16 JUN 77**: Fulton/Horton. Steady-state and dynamic interactions (Mach 2.8), autothrotle tests, and handling qualities evaluation.

Flt. 071 / **23 JUN 77**: Mallick/Young. Chase for YF-12A (935) Coldwall flight and boattail drag data. Propulsion match points not accomplished.

Flt. 072 / **14 JUL 77**: Fulton/Horton. Propulsion match points, autothrottle tests, and airframe/ propulsion dynamic interactions.

Flt. 073 / **21 JUL 77**: Mallick/Young. Chase for YF-12A (935) Coldwall flight. Propulsion match points, autothrottle tests, and interaction tests not accomplished due to high KEAS condition and compressor stalls during chase mission. The YF-12A simultaneously experienced inlet unstarts and compressor stalls.

Aircraft grounded for overspeed and overload inspection.

Flt. 074 / **08 SEP 77**: Mallick/Young. Propulsion transients, sine/step generator, steady-state interactions, and autothrottle test. Chase for YF-12A (935) Coldwall flight not completed because YF-12A aborted takeoff due to nosewheel shimmy.

Flt. 075 / **16 SEP 77**: Fulton/Horton. Airframe/propulsion interactions, propulsion transients, and autothrottle tests. Aborted early due to SAS caution light.

Flt. 076 / **22 SEP 77**: Mallick/Young. Airframe/propulsion interactions and propulsion transients.

Flt. 077 / **30 SEP 77**: Mallick/Young. Chase for YF-12A (935) Coldwall flight, U-2 intercept, and a fly-by of NASA Dryden Flight Research Center.

Flt. 078 / **13 OCT 77**: Mallick/Young. Chase for YF-12A (935) Coldwall flight, airframe/ propulsion interactions, aft bypass door tests, afterburner transients, and autothrottle tests. Aircraft grounded for co-op control program modifications.

Flt. 079 / **26 MAY 78**: Mallick/Young. Functional check of Cooperative Airframe/Propulsion Control System (CAPCS) digital computer system (Mach 1.8).

Flt. 080 / **16 JUN 78**: Fulton/Horton. CAPCS digital computer system envelope expansion (Mach 2.8).

Flt. 081 / **17 JUL 78**: Mallick/Young. CAPCS digital computer system test not accomplished. Aborted early due to air data transducer failure.

Flt. 082 / **03 AUG 78**: Fulton/Horton. CAPCS digital computer system test.

Flt. 083 / **18 AUG 78**: Mallick/Young. CAPCS digital computer system test.

Flt. 084 / **31 AUG 78**: Fulton/Horton. CAPCS digital computer system test.

Flt. 085 / **07 SEP 78**: Mallick/Young. CAPCS digital computer system test, co-op control test.

Flt. 086 / **13 SEP 78**: Fulton/Horton. CAPCS digital computer system test, co-op control test.

Flt. 087 / **25 SEP 78**: Fulton/Horton. CAPCS digital computer system test, co-op control test.

Flt. 088 / **28 SEP 78**: Mallick/Young. CAPCS digital computer system test. Co-op control test not accomplished. Aborted early due to R/H forward bypass door failure. Last NASA flight of YF-12C.

Flt. 089 / **27 OCT 78**: Sullivan/Frazier. Transferred aircraft to USAF, ferry flight to Lockheed facility in Palmdale, California.

Flt. 090 / **22 DEC 78**: Jewett/Frazier. Last flight. Aircraft placed in storage at Palmdale.

Sources: Richard P. Hallion, *On The Frontier: Flight Research at Dryden, 1946-1981* (Washington, DC: NASA SP-4303, 1984), pp. 189-199; YF-12 Research Flight Reports in the NASA DFRC Historical Reference Collection (donated by Richard E. Klein); YF-12 Flight Requests in the NASA DFRC Historical Reference Collection; NASA FRC Daily Logs in the NASA DFRC Flight Operations Office.

Appendix 2: Bibliography

The below list includes a number of books and technical papers describing the development and operational history of the Blackbird family of aircraft. Many, but not all, of these publications served as sources for this monograph. Two invaluable bibliographies are Gene Matranga's list of 91 technical reports and papers related to the YF-12 research program and *Fifty Years of Flight Research: An Annotated Bibliography of Technical Publications of NASA Dryden Flight Research Center, 1946-1996* by David F. Fisher (NASA TP-1999-206568).

Books:

Byrnes, Donn A. and Kenneth D. Hurley. *Blackbird Rising: Birth of an Aviation Legend*. Los Lunas, New Mexico: Sage Mesa Publications, 1999.

Crickmore, Paul F. *Lockheed SR-71 Blackbird.* London, England: Osprey Publishing Ltd., 1986.

Crickmore, Paul F. *Lockheed SR-71, The Secret Missions Exposed.* London, England: Osprey Aerospace, 1993.

Drendel, Lou. *SR-71 Blackbird In Action.* Carrollton, Texas: Squadron/Signal Publications, 1982.

Goodall, James. *SR-71 Blackbird.* Carrollton, Texas: Squadron/Signal Publications, 1995.

Hallion, Richard P. *On The Frontier: Flight Research at Dryden, 1946-1981.* Washington, DC: NASA SP-4303, 1984.

Hallion, Richard P. *Test Pilots: The Frontiersmen of Flight*. Washington, DC: Smithsonian Institution Press, 1988.

Jenkins, Dennis R. *Lockheed SR-71/YF-12 Blackbirds.* North Branch, Minnesota: Specialty Press, 1997.

Kommisarov, D. S. and K. G. Udalov. *SR-71 Aircraft.* Moscow, Russia: Aviko Press, 1993.

Miller, Jay. *Lockheed SR-71*. Arlington, Texas: Aerofax, Inc., 1985.

Miller, Jay. *Lockheed's Skunk Works: The First Fifty Years*. Arlington, TX: Aerofax, Inc., 1993.

Peebles, Curtis. *Dark Eagles*. Novato, CA: Presidio Press, 1995.

Studies In Intelligence. Langley, VA: Central Intelligence Agency, 1982. This volume contains McIninch, Thomas P. (pseud. of John Parangosky), "The OXCART Story."

Technical Papers:

Albers, James A. "Inlet Operating Flow Field of the YF-12 Aircraft and Effects of this Flow Field on Inlet Performance." NASA Lewis Research Center Inlet Workshop, 1977

Albers, James A. "Status of the YF-12 Propulsion Research Program." NASA TM X-56039, March 1976.

Albers, James A. and Frank V. Olinger. "YF-12 Research Program and Results." NASA CP-001. *Proceedings of the SCAR Conference*, 1976.

Anderson, D. L.; G. F. Conolly; F. M. Mauro; Paul J. Reukauf; and R. Marks "YF-12 Cooperative Airframe/Propulsion Control System Program," Vol. 1. NASA CR-163099, November 1980.

Anderson, J. Thomas; Robert K. Martin; and Harry H. Shibata. "1/3 Scale Inlet Model Test Results," Vols. I-III. NASA CR-114702 through CR-114704, 8 March 1974.

Arnaiz, Henry H.; James D. Brownlow; and James A. Albers. "A Comparison of Steady-State Performance Among a Flight Inlet on a YF-12C Airplane and Two Wind-Tunnel Models Using Statistical Techniques." NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978

Bales, T. T.; E. L. Hoffman; L. Payne; and A. L. Carter. "Fabrication and Evaluation of Advanced Titanium and Composite Structural Panels." NASA CP-001. *Proceedings of the SCAR Conference*, 1976.

Bangert, L. H.; Frank W. Burcham, Jr.; and Karen G. Mackall. "YF-12 Inlet Suppression of Compressor Noise – First Results." AIAA Paper No. 80-0099, January 1980.

Bangert, L. H.; E. P. Feltz; L. A. Godby; and L. D. Miller. "Aerodynamic and Acoustic Behavior of a YF-12 Inlet at Static Conditions." NASA CR-163106, January 1981.

Bauer, Carol A.; Karen G. Mackall; Frederick Stoll; and Jeffrey W. Tremback. "Comparison of Flight and Wind-Tunnel Model Instantaneous Distortion Data from a Mixed-Compression Inlet." NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Bennett, Donald L. "Evaluation of a Hemispherical Head Flow Direction Sensor for Inlet Duct Measurements." NASA TM X-3232, May 1975.

Bentley, J. H.; S. M. Dent; and W. L. Kruse. "Final Report for the CAPA/YF-12 Central Airborne Performance Analyzer." Honeywell Report W8340-FR.

Berry, Donald T. "A Summary of YF-12 Handling Qualities." NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Berry, Donald T. “Flight Experience with Longitudinal Long-Period Airframe/Propulsion Interactions of a Mach 3 Cruise Vehicle.” AIAA Atmospheric Flight Mechanics Conference Open Session, Palo Alto, California, 13 September 1972.

Berry, Donald T. and Glenn B. Gilyard. *A Review of Supersonic Cruise Flight Path Control Experience with the YF-12 Aircraft.* NASA SP-416, 1976.

Berry, Donald T. and Glenn B. Gilyard. “Airframe/Propulsion System Interactions – An Important Factor in Supersonic Aircraft Flight Control.” AIAA Paper No. 73-831, August 1973.

Berry, Donald T. and Glenn B. Gilyard. “Some Stability and Control Aspects of Airframe/ Propulsion System Interactions on the YF-12 Airplane.” ASME Paper No. 73-WA/Aero. 4, November 1973.

Berry, Donald T.; Donald L. Mallick; and Glenn B. Gilyard. “Handling Qualities Aspects of NASA YF-12 Flight Experience.” NASA CP-001. *Proceedings of the SCAR Conference*, 1976.

Berry, Donald T. and William G. Schweikhard. “Potential Benefits of Propulsion and Flight Control Integration for Supersonic Cruise Vehicles.” NASA TM X-3409, August 1976.

Brilliant, Howard M. and Carol A. Bauer. “Comparison of Estimated with Measured Maximum Instantaneous Distortion Using Flight Data from an Axisymmetric Mixed Compression Inlet.” AIAA Paper No. 77-876, July 1977.

Brilliant, Howard M.; Carol A. Bauer; and Robert A. Davis. “Predicted and Measured Maximum Instantaneous Distortion for Flight and Wind-Tunnel Model Data for Mixed-Compression Inlet.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Brooks, William A., Jr. and Marvin B. Dow. “Service Evaluation of Aircraft Composite Structural Components.” NASA TM X-71994, October 1973.

Brown, Stuart C. “Computer Simulation of Aircraft Motions and Propulsion System Dynamics for the YF-12 Aircraft at Supersonic Cruise Conditions.” NASA TM X-62245, August 1973.

Brownlow, James D.; Henry H. Arnaiz; and James A. Albers. “Mathematical Modeling of the Performance of a YF-12C Mixed-Compression Inlet by Using Multiple Regression Techniques.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Burcham, Frank W., Jr. and Donald R. Bellman. “A Flight Investigation of Steady State and Dynamic Pressure Phenomena in the Air Inlets of Supersonic Aircraft.” NASA TM X-67495, December 1971.

Burcham, Frank W., Jr.; Glenn B. Gilyard and Lawrence P. Myers. “Propulsion System-Flight Control Integration and Optimization: Flight Evaluation and Technology Transition.” NASA TM-4207, July 1990.

Burcham, Frank W., Jr.; Jon K. Holzman; and Paul J. Reukauf. “Preliminary Results of Flight Tests of the Propulsion System of a YF-12 Airplane at Mach Numbers up to 3.0.” AIAA Paper No. 73-1314, November 1973.

Burcham, Frank W., Jr.; Earl J. Montoya; and Phillip J. Lutschg. “Description of YF-12C Airplane, Propulsion System, and Instrumentation for Propulsion Research Flight Tests.” NASA TM X-3099, September 1974.

Campbell, David H. “F-12 Inlet Development.” SAE Paper No. 740831, October 1974.

Campbell, David H. “F-12 Series Aircraft Propulsion System Performance and Development.” AIAA Paper No. 73-821, August 1973

Campbell, David H. *YF-12 Inlet Flight Test Experience.* NASA SP-1655, 12 August 1970.

Campbell, David H. *YF-12 Inlet Performance Data Package.* NASA SP-1612, 4 May 1970.

Campbell, David H. *YF-12 Inlet Performance Data Package.* NASA SP-1635, 16 June 1970.

Cole, Gary L.; David S. Cwynar; and Lucille C. Geyser. “Wind-Tunnel Evaluation of the Response of a YF-12 Aircraft Flight Inlet to Internal Airflow Perturbations by Frequency-Response Testing.” NASA TM X-3141, December 1974.

Cole, Gary L.; Miles O. Dustin; and George H. Neiner. “Wind-Tunnel Performance of a Throat-Bypass Stability System for the YF-12 Inlet.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium,* August 1978.

Cole, Gary L.; George H. Neiner; and Miles O. Dustin. “Wind-Tunnel Evaluation of YF-12 Inlet Response to Internal Airflow Disturbances With and Without Control.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium,* August 1978.

Cole, Gary L.; Bobby W. Sanders; and George H. Neiner. “Wind-Tunnel Performance of a YF-12 Aircraft Flight Inlet Modified by various Stability Bypass Porous-Bleed Configurations.” NASA TM-73801.

Combs, Henry G. and John R. McMaster. “Feasibility Study on Launching a NASA HT-4 Hypersonic Drone from a Lockheed YF-12C Airplane.” Lockheed report No. SP-1779, 30 July 1971.

Cooper, Paul A. and Richard R. Heldenfels. “NASA Research on Structure and Materials for Supersonic Cruise Aircraft.” NASA TM X-72790.

Cubbison, Robert W. “Wind-Tunnel Performance of an Isolated, Full-Scale, YF-12 Aircraft Inlet at Mach Numbers Above 2.1.” NASA TM X-3139, December 1974.

Cubbison, Robert W. and Bobby W. Sanders. “Comparison of the One-Third and Full-Scale YF-12 Isolated Inlet Performance.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Cubbison, Robert W. and Bobby W. Sanders. “Full-Scale YF-12 Inlet Calibration and Flow System Interactions.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

DeAngelis, V. Michael. “A Historical Overview of High-Temperature Structural Testing at the NASA Dryden Flight Research Facility.” Structural Testing Technology at High Temperature Conference, Dayton, Ohio, November 1991.

DeAngelis, V. Michael and Karl F. Anderson. “Thermal-Structural Test Facilities at NASA Dryden.” NASA TM-104249, August 1992.

DeMarco, D. M. “A Dynamic Pressure Generator for Checking Complete Pressure Sensing Systems Installed on an Airplane.” NASA TM X-56026, September 1974.

Duba, R. J.; A. C. Haramis; R. F. Marks; Payme; R. C. Sessing, *YF-12 Lockalloy Ventral Fin Program: Design Analysis, fabrication, and Manufacturing of Aircraft Structures Using Aluminum and Beryllium Alloys for the YF-12 Aircraft.* Vol. 1 (NASA CR-144971) and Vol. 2 (NASA CR-144972), January 1976.

Dustin, Miles O.; Gary L. Cole; and George H. Neiner. “Continuous-Output Terminal-Shock-Position Sensor for Mixed-Compression Inlets Evaluated in Wind-Tunnel Tests of YF-12 Aircraft Inlet.” NASA TM X-3144, December 1974.

Dustin, Miles O. and George H. Neiner. “Evaluation by Step Response Tests of Prototype Relief Valves Designed for YF-12 Inlet Stability Bleed System.” NASA TM X-3262.

Edinger, Lester D.; Alan R. Curtis; and Frederick L. Schenk. “YF-12A LAMS Feasibility Study,” Vols. I through III, July 1970.

Edinger, Lester D.; Frederick L. Schenk; and Alan R. Curtis. “Study of Load Alleviation and Mode Suppression (LAMS) on the YF-12A Airplane.” NASA CR-2158, December 1972.

Ehernberger, L. Jack. “High-Altitude Turbulence Encountered by the Supersonic YF-12A Airplane. AMS Sixth Conference on Aerospace and Aeronautical Meteorology, El Paso, Texas, November 1974.

Ehernberger, L. Jack. “High-Altitude Turbulence for Supersonic Cruise Vehicles.” NASA TM-88285, May 1987.

Ehernberger, L. Jack. “High-Altitude Turbulence Investigation.” NASA Working Paper FWP-19, August 1970.

Ehernberger, L. Jack. “The YF-12 Gust Velocity Measuring System.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Ehernberger, L. Jack and Betty J. Love. “High-Altitude Gust Acceleration Environment as Experienced by a Supersonic Airplane.” NASA TN D-7868, January 1975.

Falkner, Victor L.; Robert Clarke; and Frederick L. Schenk. “Cooperative Aircraft/Propulsion Control System (CAPCS) for the YF-12A Aircraft.” NASA Flight Research Center Working Paper.

Farlow, N. H.; V. R. Watson; M. Lowenstein; K. L. Chan; H. Hoshizaki; R. J. Conti; and J. W. Meyer. “Measurements of Supersonic Jet Aircraft Wakes in the Stratosphere.”

Fields, Roger A. “A Study of the Accuracy of a Flight Heating Simulation and its Effect on Load Measurements.” NASA TN D-5741.

Fields, Roger A. “Flight Vehicle Thermal Testing With Infrared Lamps.” NASA TM-4336, January 1992.

Fisher, David F. “Boundary Layer, Skin Friction, and Boattail Pressure Measurements from the YF-12 Airplane at Mach Numbers up to 3.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Flight Research Center staff, “NASA YF-12 Flight Loads Program.” Proceedings from symposium held at NASA Flight Research Center, Edwards, California. .NASA TM X-3061, 5-6 June 1974

Flight Research Center staff, “YF-12 Research Airplane Project Management Report.” NASA FRC Working Paper.

Gamon, Max A. “Testing and Analysis of Dual-Mode Adaptive Landing Gear, Taxi Mode Test System for YF-12A.” NASA CR-144884, September 1979.

Gilyard, Glenn B. “Determination of Propulsion-System-Induced Forces and Moments of a Mach 3 Cruise Aircraft.” NASA TN D-7647, April 1974.

Gilyard, Glenn B.; Donald T. Berry; and Daumants Belte. “Analysis of a Lateral-Directional Airframe/Propulsion System Interaction.” NASA TM X-2829, 1973.

Gilyard, Glenn B. and John J. Burken. “Development and Flight Test Results of an Autothrottle Control System at Mach 3 Cruise.” NASA TP-1621, July 1980.

Gilyard, Glenn B. and Daumants Belte. “Flight-Determined Lag of Angle-of-Attack and Angle-of-Sideslip Sensors in the YF-12A Airplane from Analysis of Dynamic Maneuvers.” NASA TN D-7819, October 1974.

Gilyard, Glenn B.; Donald T. Berry; and Daumants Belte. “Analysis of a Lateral-Directional Airframe/Propulsion System Interaction of a Mach 3 Cruise Aircraft.” AIAA Paper No. 72-961, September 1972.

Gilyard, Glenn B. and John W. Smith. “Flight Evaluation of a Mach 3 Cruise Longitudinal Autopilot.” AIAA Paper No. 74-910, August 1974.

Gilyard, Glenn B. and John W. Smith. “Flight Experience with Altiutude Hold and Mach Hold Autopilots on the YF-12 Aircraft at Mach 3.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Gilyard, Glenn B. and John W. Smith. “Results from a Flight and Simulator Studies of a Mach 3 Cruise Longitudinal Autopilot.” NASA TP-1180, April 1978.

Gilyard, Glenn B.; John W. Smith; and Victor L. Falkner. “Flight Evaluation of a Mach 3 Cruise Longitudinal Autopilot.” AIAA Paper No. 74-910, August 1974.

Goforth, E. A.; R. C. Murphy; J. A. Beranek; and R. A. Davis. “Flight and Analytical Investigations of a Structural Mode Excitation System on the YF-12A Airplane.” NASA CR-166623, April 1987.

Hauser, Daniel. “Investigation of the Effects of Brazing on the Properties of Fiber-Reinforced, Aluminum-Matrix Composites.” NASA CR-145096.

Henry, John and Griffin Anderson. “Design Considerations for the Airframe – Integrated Scramjet.” NASA TM X-2895.

Herrick, Paul W. “J58/YF-12 Ejector Nozzle Performance.” SAE Paper 740832, October 1974.

Hoffman, E. L.; L. Payne; and Alan L. Carter. “Fabrication Methods for YF-12 Wing Panels for the Supersonic Cruise Aircraft Research Program.” Materials Review ‘ 75, Seventh National Technical Conference, Albuquerque, New Mexico, October 1975.

Hoffman, Sherwood. “Supersonic Cruise Aircraft Research (SCAR) Program Bibliography: July 1972 through June 1976.” NASA TM X-73950.

Holdeman, James D. “Dispersion and Dilution of Jet Aircraft Exhaust at High-Altitude Flight Conditions.” AIAA Paper No. 74-41, published in the *AIAA Journal of Aircraft*, Vol. II, No. 8, August 1974.

Holdeman, James D. “Dispersion of Turbojet Engine Exhaust in Flight.” NASA TN D-7382, August 1973.

Holdeman, James D. “Emission Calibration of a J58 Afterburning Turbojet Engine at Simulated Stratospheric Flight Conditions.” NASA TM X-71571, July 1974.

Holdeman, James D. “Measuremnt of Exhaust Emission fromTtwo J58 Afterburning Turbojet Engines at Simulated Supersonic Cruise Flight Conditions.” NASA TM X-71826.

Holdeman, James D. “Gaseous Exhaust Emissions form a J58 Engine at Simulated Supersonic Flight Conditions.” NASA TM X-71532, April 1974.

Holmes, H. R. “Investigation of the Effect of Internal Forced Convection on F-12 Type Aircraft Wing Temperatures.” Lockheed ADP Working Paper.

Houbolt, John C.; Roy Steiner; and Pratt. “Dynamic response of Airplanes to Atmospheric Turbulence Including Flight Data on Impact and Response.” NASA TR R-199.

Jenkins, Jerald M. “Correlation of Predicted and Measured Thermal Stresses on an Advanced Aircraft Structure with Dissimilar Material.” NASA TM-72865, June 1979.

Jenkins, Jerald M. “Problems Associated with Attaching Strain Gages to Titanium Alloy Ti-6Al-4V.” NASA TM X-56044, February 1977.

Jenkins, Jerald M.; Roger A. Fields; and Walter J. Sefic. “Elevated-Temperature Effects on Strain Gages on the YF-12A Wing.” *Experimental Mechanics*, Volume 19, March 1979.

Jenkins, Jerald M. and Albert E. Kuhl. “Recent Load Calibration Experiences with the YF-12 Airplane.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Jenkins, Jerald M.; Albert E. Kuhl; and Alan L. Carter. “Strain Gage Calibrations of a Complex Wing.” *Journal of Aircraft*, Volume 14, December 1977.

Jenkins, Jerald M. and Robert D. Quinn. “A Historical Perspective of the YF-12A Thermal Loads and Structures Program.” NASA TM-104317, May 1996.

Johnson, Clarence L. “Some Development Aspects of the YF-12A Interceptor Aircraft.” AIAA Paper No. 69-757, July 1969.

Johnson, Clarence L. “Some Development Aspects of the YF-12A Interceptor Aircraft.” *AIAA Journal of Aircraft*, Vol. VII, No. 4, July-August 1970.

Johnson, Harold J. and Earl J. Montoya. “Local Flow Measurements at the Inlet Spike Tip of a Mach 3 Supersonic Cruise Aircraft.” NASA TN D-6987, May 1973.

Kock, Berwin M. “Overview of the YF-12 Program.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Kordes, Eldon E. and Alan R. Curtis. “Results of NASTRAN Modal Analyses and Ground Vibration Tests on the YF-12A Airplane.” ASME Paper 75-WA/Aero-8, December 1975.

Ladd, J. M. “Airflow Calibration of a J58 Engine at Simulated Supersonic Conditions.” NASA TM X-71797.

Lamb, Milton; Robert L. Stallings, Jr.; and Ceilia S. Richardson. “Aerodynamic Characteristics of 1/25 Scale Model of YF-12 Airplane at Mach 1.80 to 2.96 With and Without External Instrument Packages and Flow Surveys at Mach 2.96.” NASA TM X-2524, 1972.

Larson, Terry J. “Compensated and Uncompensated Nose Boom Static Pressures Measured from Two Air data Systems on a Supersonic Airplane.” NASA TM X-3132, November 1974.

Lewis Research Center staff. “Wind-Tunnel Installation of Full-Scale Flight Inlet of YF-12 Aircraft for Steady-State and Dynamic Evaluation.” NASA TM X-3138, November 1974.

Loftin, Laurence K., Jr. “Toward a Second-Generation Supersonic Transport.” AIAA Paper No. 73-15, 1973.

Love, James E. “Flight Test Results of an Automatic Support System on Board a YF-12 Airplane.” Automatic Support Systems for Advanced Maintainability Symposium, San Diego, California, October 1974.

Love, James E.; William J. Fox; and Edward J. Wicklund. “Flight Study of a Vehicle Operational Status and Monitoring System.” NASA Flight Research Center. NASA TN D-7546, 1974.

Maglieri, Domenic J.; Vera Huckel and Herbert R. Henderson. “Sonic Boom Measurements for SR-71 Aircraft Operating at Mach Numbers to 3.0 and Altitudes to 24,384 Meters.” NASA TN D-6823, September 1972.

Matranga, Gene J. “Material, Systems, and Maintenance Problems Associated with Supersonic Cruise Aircraft. NASA FRC Working Paper.

Matranga, Gene J. and William J. Fox. “YF-12A Development and Operational Experience.” Paper Presented at the Supercruiser Conference, Wright-Patterson AFB, Ohio, 17-20 February 1976.

Matranga, Gene J.; William G. Schweikhard; and Donald T. Berry. “Operating Problems of High-Altitude Supersonic Cruise Aircraft.” NASA Safety and Operating Problems Conference at NASA Langley Research Center. Published as NASA SP-270, May 1971.

McGehee, John R. and Huey D. Carden. “A Mathematical Model of an Active Control Landing Gear for Load Control During Impact and Roll-out. NASA TN-8080.

McMaster, John R.; and Frederick L. Schenk. “Development of the F-12 Series Aircraft Manual and Automatic Flight Control System. AIAA Paper No. 73-822, August 1973.

Meyer, Robert R. and V. Michael DeAngelis. “Flight-Measured Aerodynamic Loads on a 0.92 Aspect Ratio Lifting Surface.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Miller, Richmond L., Jr. “Flight Testing the F-12 Series Aircraft.” AIAA Paper No. 73-823, August 1973.

Montoya, Earl J. “Wind-Tunnel Calibration and Requirements for In-Flight Use of Fixed Hemispherical Head Angle-of-Attack and Angle-of-Sideslip Sensors.” NASA TN D-6986, March 1973.

Morris, Foss, and Russell. “Assessment of Variable Cycle Engines for Mach 2.7 Supersonic Transports: A Status Report.” NASA TM X-73977.

Muckler, Fred; Richard W. Obermayer; and Douglass R. Nicklass. “Pilot Performance Measurement Study.” NASA CR-143842, December 1977.

Neiner, George H.; Dale J. Arpasi; and Miles O. Dustin. “Wind-Tunnel Evaluation of YF-12 Aircraft Inlet Control System by Frequency-Response and Transient Testing.” NASA TM X-3142, December 1974.

Neiner, George H.; Miles O. Dustin; and Gary L. Cole. A Throat-Bypass Stability-Bleed System Using Relief Valves to Increase the Transient Stability of a Mixed-Compression Inlet. NASA TP-1083.

Neiner, George H.; Miles O. Dustin; and Gary L. Cole. “Mechanical Characteristics of Stability-Bleed Valves for a Supersonic Inlet.” NASA TM X-3483.

Neiner, George H.; Robert C. Siedel; and Dale J. Arpasi. “Wind-Tunnel Evaluation of Experimental Controls on YF-12 Aircraft Flight Inlet by Frequency-Response and Transient Testing.” NASA TM X-3143, December 1974.

Nicklas, Douglass R. “Pilot Performance Measurement Study I: YF-12 Mission Evaluation and Task Analysis.” Paper written for Manned System Sciences, June 1973.

Obermayer, Richard W. “Pilot Performance Measurement Study II: Data Collecting and Processing.” Paper written for Manned System Sciences, February 1973.

Obermayer, Richard W. “Pilot Performance Measurement Study III: Measurement Development.” Paper written for Manned System Sciences, May 1973.

Obermayer, Richard W. and Douglass R. Nicklas. “Pilot Performance Measurement Study: Final Technical Report.” Written for Manned System Sciences, June 1973.

Ochieano, Mario and Russell S. Kaneko. “Survey of Titanium Structural Shapes Fabrication Concepts.” NASA CR-132384.

Olinger, Frank V.; Walter J. Sefic; and Richard Rosecrans. “Laboratoiry Heating Tests of the YF-12 Aircraft.” NASA Flight Research Center Working Paper.

Olinger, Frank V.; Harry Shibata; and James A. Albers. “Local Flow Measurement at the Inlet Plane of a 1/12-Scale Model of the YF-12C Airplane.” NASA TM X-3435.

Powers, Bruce G. “Phugoid Characteristics of a YF-12 Airplane with Variable-Geometry Inlets Obtained in Flight Tests at a Mach Number of 2.9.” NASA TP-1107, December 1977.

Powers, Sheryll Goecke. “Flight-Measured Pressure Characteristics of Aft-Facing Steps in Thick Boundary Layer Flow for Transonic and Supersonic Mach Numbers.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Powers, Sheryll Goecke. “Flight-Measured Pressure Characteristics of Aft-Facing Steps in High Reynolds Number Flow at Mach Numbers of 2.20, 2.50, and 2.80 and Comparison with Other Data.” NASA TM-72855, May 1978.

Presley, L.; P. Cutler; and R. Sorenson. “Predicted and Measured Flow Fields Upstream of the YF-12 Inlet and Inlet Internal Flow Solutions.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Quinn, Robert D. and Leslie Gong. “In-Flight Compressible Turbulent Boundary Layer Measurements on a Hollow Cylinder at a Mach Number of 3.0.” NASA TP-1764, November 1980.

Quinn, Robert D. and Frank V. Olinger. “Flight Temperatures and Thermal Simulation Requirements.” NASA Preliminary Paper H-828.

Redin, Paul C. “A Performance Model of the YF-12C Airplane.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Redin, Paul C. “Optimization of Transonic Acceleration Performance for the YF-12C Airplane Using the Climb-Dive Maneuver.” NASA TM X-2694, 1972.

Reukauf, Paul J. “Flight Test Experience with a Digital Airframe/Propulsion Control System on a YF-12 Airplane.” NASA CP-2054, Vol. 1 *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Reukauf, Paul J. “Preliminary Flight Investigation of a YF-12A Mixed Compression Inlet.” NASA Working Paper FWP-33, 1972.

Reukauf, Paul J. and Frank W. Burcham. “Propulsion-System/Flight-Control Integration for Supersonic Aircraft.” NASA CP-001. *Proceedings of the SCAR Conference*, Part I, 1976.

Reukauf, Paul J.; Frank W. Burcham, Jr.; and Jon K. Holzman. “Status of a Digital Integrated Propulsion/Flight Control System for the YF-12A Airplane.” AIAA Paper No. 75-1180, October 1975.

Ruekauf, Paul J.; Frank V. Olinger; L. Jack Ehernberger; and Craig Yanagidate. “Flight-Measured Transients Related to Inlet Performance on the YF-12 Airplane.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Reukauf, Paul J.; William G. Schweikhard; and Henry Arnaiz. “Flight-Test Techniques for Obtaining Valid Comparisons of Wind-Tunnel and Flight Results from Tests on a YF-12 Mixed-Compression Inlet.” AIAA Paper No. 74-1195, October 1974.

Rezek, Terry W. “Human Factors Opportunities on High-Speed Aircraft.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Rezek, Terry W. “Pilot Workload Measurement and Experience on Supersonic Cruise Aircraft.” NASA CP-2054, Vol. 1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Rich, Ben R. “The F-12 Series Aircraft Aerodynamic and Thermodynamic Design in Retrospect.” AIAA Paper No. 73-820, August 1973.

Rich, Ben R. “The F-12 Series Aircraft Aerodynamic and Thermodynamic Design in Retrospect.” *AIAA Journal of Aircraft*, Vol. II, No. 7, July 1974.

Rosser, R. W. and J. A. Parker. “Chemical Research Projects Office Fuel Tank Sealants Review.” NASA TM X-62401.

Schweikhard, William G. “Operating Problems that Relate to Aircraft and Propulsion Systems Performance of High-Altitude Supersonic Cruise Aircraft.” NASA FRC Working Paper.

Schweikhard, William G. “Test Techniques, Instrumentation, and Data Processing.” AGARD Lecture Series on Distortion-Induced Engine Instability. AGARD-LS-72, October 1974.

Schweikhard, William G. and Donald T. Berry. “Cooperative Airframe/Propulsion Control for Supersonic Cruise Aircraft.” SAE Paper No. 740478, May 1974.

Schweikhard, William G. and David H. Campbell. “An Introduction and Summary of the YF-12 propulsion Research Program.” NASA CP-2054, Vol.-1. *Proceedings of the YF-12 Experiments Symposium*, August 1978.

Schweikard, William G. and Robert W. Cubbison. “Preliminary Flight and Wind-Tunnel Results of the YF-12 Propulsion System Test Program.” NASA TM X-56016, 1973.

Schweikhard, William G. and Earl J. Montoya. “Research Instrumentation Requirements for Flight/Wind-Tunnel Tests of the YF-12 Propulsion System and Related Flight Experience.” In *Instrumentation for Airbreathing Propulsion*, edited by Allen E. Fuhs and Marshall Kingery. Cambridge, Massachussetts: The MIT Press, 1974.

Scoggins, James R.; Terry L. Clarks, and Norman C. Passiel. “Relationship Between Stratospheric Clear Air Turbulence and Synoptic Meteorological Parameters Over the Western United States between 12-20 KM Altitude.” NASA CR-143837, December 1975.

Simcox, Craig D. “Jet Noise Suppression Systems for High-Speed Aircraft.” SAE Paper No. 730896.

Smeltzer, Donald B.; Ronald H. Smith; and Robert W. Cubbison. “Wind-Tunnel and Flight Performance of the YF-12 Inlet System.” AIAA Paper No. 74-621, July 1974.

Smith, John W. and Donald T. Berry. “Analysis of Longitudinal Pilot-Induced Oscillation Tendencies of YF-12 Aircraft.” NASA TN D-7900, February 1975.

Smith, Ronald H. and Carol A. Bauer. “Atmospheric Effects on the Inlet System of the YF-12 Aircraft.” Presented at the Eleventh National Conference on Environmental Effects of Aircraft and Propulsion Systems, Trenton, New Jersey, May 1974

Smith, Ronald H. and Frank W. Burcham, Jr. “Instrumentation for In-Flight Determination of Steady-State and Dynamic Inlet Performance in Supersonic Aircraft.” *Instrumentation for Airbreathing Propulsion*, edited by Allen E. Fuhs and Marshall Kingery. Cambridge Massachussetts: The MIT Press, 1974.

Spearman, Leroy and Wallace Sawyer. “External Store Effects on the Stability of Fighter and Interceptor Airplanes.” NASA TM X-71935.

Stewart, James F.; Frank W. Burcham, Jr.; and Donald H. Gatlin. “Flight-Determined Benefits of Integrated Flight-Propulsion Control Systems.” NASA TM-4393, June 1992.

Stoll, F.; J. W. Tremback and Henry H. Arnaiz. “Effect of Number of Probes and Their Orientation on the Calculation of Several Compressor Face Distortion Descriptors.” NASA TM-72859, May 1979.

Webb, William L. “Turbine Inlet Gas Temperature Measurement and Control System.” USAF AFAPL-TR-73-116, December 1973.

Webb, William L. and Paul J. Reukauf. “Development of a Turbine Inlet Gas Temperature Measurement and Control System Using a Fluidic Temperature Sensor.” AIAA Paper No. 73-1251, November 1973.

Webb, William L. and G. J. Zewski. “J58 Cooperative Control System Study,” Vols. I, II, and III. NASA CR-121195, June 1973.

Wilson, Earl J. “Installation and Testing of Strain Gages for High-Temperature Aircraft Application.” Western Regional Strain Gage Committee Meeting, Tempe, Arizona, 20-21 September 1971.

Wilson, Earl J. “Strain Gage and Thermocouple Installation on a Research Airplane.” Western Regional Strain Gage Committee Meeting, Tempe, Arizona, 20-21 September 1971.

Wilson, Earl J. “Strain Gage Installation on the YF-12 Aircraft.” Society for Experimental Stress Analysis, Spring Meeting, Los Angeles, California, 13-18 May 1973.

Wilson, Ronald J.; Frank W. Cazier; Jr.; and Richard R. Larson. “Results of Ground Vibration Tests on a YF-12 Airplane.” NASA TM X-2880, August 1973.

Appendix 3: Interview transcripts

These interviews are edited for readability, with titles and other information provided in square brackets, but the substance of the interviews remains unchanged.

Gene J. Matranga, interviewed by Peter Merlin on 30 May 2000:

Merlin: To get started, why don't you give me a little background on how you became involved in the YF-12 research program?

Matranga: It was the fall of 1967, on a late Friday afternoon. [Flight Research Center Director] Paul Bikle called me into his office and he and [head of the Research Division] Joe Weil were sitting around his desk. They asked me the question: Would I be willing to go do a three-month program with the Air Force on the SR-71? Bikle made the qualifier that we probably wouldn't be able to publish anything that we learned, because of the classified nature of the program, but he wanted to try to get NASA involved with the SR-71. He said to go home and think about it over the weekend and give him an answer on Monday morning.

At the time, I was doing the general aviation program, and we had a coordinated small scale/full scale analytical prediction of the flying qualities of the Piper PA-30. So, it was an interesting challenge. I thought about it, not very long, over the weekend. On Monday, I came back and said sure, I would be willing to do anything they needed me to do.

So Bikle made the arrangements for me to go over and talk to the Air Force people and get briefed into the program. What they were looking for was technical assistance to do the Category II evaluation of the SR-71. That's the basic evaluation of the plane's stability and control, and performance. So, I went over and got briefed and talked to Col. Robert "Fox" Stephens, the commander of the SR-71/F-12 Test Force, and three or four of his technical people. Bob Sudderth, a civilian with the Air Force was doing the stability and control work. Dick Abrams, also a civilian with the Air Force, was doing the performance work. There were military people working in parallel with them. They were just starting into the Category II program, so I was really getting in on the ground floor.

I asked if I could bring any additional help with me, and they were eager to have all the help we could provide. So, I made arrangements for Bill Schweikhard to help with the performance work. I did the stability and control work. As we got involved in it, we realized we needed some additional help. We brought in Terry Larsen and Jack Ehernberger to do meteorological work and basic upper atmosphere physics work to support the stability and control, and performance studies.

One of the things we learned very early in the game was that we were seeing some strange effects as the airplane banked at high speed, and Schweikhard suspected that we were seeing erroneous instrument readings as a result of sideslip on the airplane. He asked if the airspeed boom had ever been calibrated in the wind tunnel, and the answer was "no." So, we talked to the people at NASA Ames Research Center and made arrangements to calibrate the boom in their Mach 3 wind

tunnel.

When we went up there to do that, we talked with Lloyd Jones who was in charge of their high-speed wind tunnel. Lloyd explained to us how we really got involved in the program. He had been very instrumental in getting NASA involved again. Lockheed had done the basic wind-tunnel work at Ames, and packed up all the data and brought it back to their Burbank facility. Lloyd wanted access to that data, and we were just the tools to help him do that. It was fine with us. So, as we went along, we documented the fact that the airspeed boom now had the corrections that nobody had done until that time. We went off into the program and got the wind-tunnel data for Mr. Jones, and made it available to him. He was cleared for the program, so that was not a problem. And, off we went.

We started off with the longitudinal stability and the performance work. Sudderth and I worked very well together. We had to do most of the analysis using oscillograph records from the Air Force instruments, and hand plotting the data. It was not nearly as automated as the NASA system was at the time. Bill Schweikhard did the same sort of thing from the performance standpoint. Sudderth usually rode in the back seat of the airplane for the tests of stability and control, and Abrams sat in the back seat for performance work.

The Air Force had about four pilots involved at the time. “Fox” Stephens, the squadron commander, did his share of the flying. Bill Skliar did a share of the flying. We later got Bill Campbell involved in it. It seems there were a couple of other pilots that I don’t remember.

One of the other people involved in this was Maj. Sam Ursini. He had been the back seat guy for a good chunk of the YF-12 testing. He was involved with missile launch, and evaluation of the tracking system and missile system in the YF-12A. Early in the game, Sam took me over to see the F-12 airplanes, which were in storage in Building 1810, halfway between the control tower and the NASA facility. The two airplanes had been sitting there for almost two years. They periodically ran the systems to keep them operational, but there was no flight activity, and Sam was basically the only Air Defense Command troop that was involved in the program at the time.

So, as we went along, we identified things we from NASA would be interested in doing that the Air Force had no interest in at all. At the same time, there was the competition among Boeing, Douglas, and Lockheed for the Supersonic Transport, the SST. So, we made the proposal to NASA Headquarters that we would try to be the filter for data out of the SR-71 program to Douglas and Boeing, since Lockheed already had access to the data. It was pretty well agreed to. The Air Force said, “yeah, we can do that.” They wanted to sit in on all the discussions and make sure that we didn’t tell them anything that we shouldn’t be telling, but they were generally agreeable to that sort of arrangement.

We plodded along in the program for the better part of a year, and the Air Force had pretty well completed the Category II testing. So, we recommended that for the subsequent series of tests, we put a NASA instrumentation system on the airplane. We proposed to instrument the airplane more completely, and use the automatic data reduction capability in the much more modern NASA instrumentation. The Air Force wasn’t terribly thrilled with the idea. We went back and talked to Col. Ben Bellis, who was head of the SR-71 System Program Office at the

time. He was not really interested at all, but he suggested that he had the two YF-12 airplanes in storage. He wasn't doing anything with them, and didn't expect to do anything with them. Bellis asked us to put together a proposal for what we wanted to do. So, we did it. Bill Schweikhard and I put the plan together. We talked with Joe Weil and Paul Bikle, and got their agreement. Then, we went back to Bellis with the proposal, and he said it looked reasonable.

So, the question then was "how does this arrangement work?" Typically, the way NASA had done business was to have the Air Force provide the airplane and funding for the program, and NASA would do all the technical work. Well, the Air Force said, "we're not going to fund anything." They were hard pressed enough just to keep the SR-71 program alive, without being able to fund anything else. So, we went back and talked with Bill Aiken at NASA Headquarters. We told Bill that this was the kind of program we could do, and that we guessed it would cost about three to four million dollars a year to conduct the program. We advised Bill that the YF-12 data would be available to the winner of the SST competition, and NASA would be a big hero for being able to provide this data that otherwise was not available. Bill said he would see if he could find money to fund the program, and he did.

We worked out an arrangement, and put together a Memorandum of Understanding between NASA and the Air Force. The agreement basically was that the Air Force would provide the airplanes for us, and that we would share the flying activity. There would be Air Force flight crews and NASA flight crews, but NASA would foot the bill for operating the airplanes.

At that stage of the game, we decided that there was something else we needed to do. We figured that we had better talk to Kelly Johnson at the Lockheed Skunk Works and find out if he would be amenable to all this. So, I was invited to go down and talk to Kelly, and explain what we wanted to do with the airplane. The way Kelly operated was that he had one representative from the government, and he had a few of his people from the Lockheed side sit in and listen to the presentation. He was in no way tolerant of a gaggle of government people coming down and overwhelming his organization, which was relatively small.

I went down to Burbank and talked to Kelly. When I walked into his conference room, he had about a dozen people there. He proceeded to berate me for about a half-hour, telling me what a dumb thing it was that NASA wanted to do. He just thought it was a gross waste of government money that would be better spent doing other things. He essentially concluded by asking, "well, what do you have to say for yourself?" And, I said: "Kelly, answer me a question. What is the angle of attack at the engine face? Because that affects the distortion, and we know there are problems with unstart." He thought for a couple of minutes, and he said, "if you can answer that, you have a program." We had a program.

I went back to Lockheed later with Bill Schweikhard. We sat down with Burt McMaster, who was head of aeronautics; Dave Campbell, head of propulsion; Ben Rich, chief thermodynamicist; and Kelly Johnson. So, two people from NASA and four people from Lockheed, and we laid out a program. We recognized that it would take a while to develop propulsion system instrumentation for the aircraft, and we decided to use this time to investigate steady-state heating ef-

fects on the aircraft structure.

In all the X-15 work, flight conditions always were transient. The vehicle went to high speed in a matter of two to three minutes. It slowed down in a matter of three to five minutes. Everything was always transient because the temperature was always increasing or decreasing. The YF-12, on the other hand, could stay at Mach 3 for 15 minutes. We could get steady-state temperature data, which would augment the X-15 data immeasurably. It would answer many questions about the theories for predicting high-speed temperatures, so Kelly agreed that we should look into that. He was interested because he didn't know the actual conditions in the airplane either. All he knew was that it worked. We were going to fill in a lot of information that would be useful for future things, such as the SST.

So, that was basically the first thing we set out to do while we tried to develop instrumentation for the propulsion work. We needed to have instrumentation that would survive temperatures of about 1,000 degrees Fahrenheit, and be able to provide frequency response up to 100 cycles, 100 Hertz, something like that. There was no instrumentation small enough scale to fit in the engine inlet. Sensors to do that sort of thing were probably about an inch and a half to two inches in diameter, and maybe six inches long. We wanted something that was a quarter inch in diameter, and maybe an inch long, in order to fit in a rake that would sit in the inlet. We went on to a program to develop the sensor, and it was recognized that it was going to take a year or so. We instrumented the first YF-12 with strain gauges and thermocouples, and we started flying the airplanes.

The Air Force got the Air Defense Command involved in the program because the F-12 was built for air defense purposes to launch missiles as an interceptor. A very interesting political game was being played by the Air Force. The Air Defense Command sent in a full bird colonel named Hugh "Slip" Slater, and he was the senior colonel in the Air Force part of the program. So, even though "Fox" Stephens was a colonel, and was commander of the Test Force, Slater came in and he was senior to Stephens. He had rank on him in the Air Force hierarchy.

Merlin: Slater had also commanded the A-12 unit, the 1129th Special Activities Squadron.

Matranga: Yes. He had commanded the A-12 unit when it was in development. He brought Ronald "Jack" Layton with him. Layton had been the senior A-12 pilot, with 300 hours of Mach 3 flight time. He also brought along a couple of backseaters, Maj. Gary Heidelbaugh and Maj. Sam Ursini. They were all from Air Defense Command. We also had "Fox" Stephens and some of his backseaters from Air Force Systems Command. Bill Campbell came into the Test Force about this time, because Stephens was scheduled to rotate out. Campbell was going to take over from him.

I recall that Joe Rogers made the first flight in the YF-12 after they had been in storage for over two years. The first flight worked like a dream. It was really remarkable that the airplane, after sitting that long, had no problems on the first flight. It had been well checked out. We had brought Larry Barnett, and a number of other NASA people, to work along with the Air Force crew. The Air Force officer who was in charge of maintenance on the airplane was astounded at the abilities of our NASA mechanics. We had wonderful working relations with the Air Force.

On one of the early flights, we asked Bill Campbell to do some sideslips for us in the transonic region, and he bent the ventral fin. The leading edge of the ventral bent around double,

and everybody was much taken aback over that.

Merlin: That would have been flight number eight of YF-12A #935 (11 February 1970).

Matranga: Yes. I knew it was sometime early in the game. So, we flew a series of flights without the ventral on 935 [3 March 1970 to 22 March 1971]. This limited us to something on the order of Mach 2.5 instead of Mach 3. Lockheed began analysis of the problem. They had their ideas and [Flight Research Center (FRC) engineer] Don Kordes had his ideas, and Kelly Johnson, in his own way, always prevailed, so they refurbished things his way. I don't remember the exact sequence of it, but we put the Lockheed modified ventral on, did a sideslip in the transonic region, and the whole thing came off [27 February 1975]. Don Kordes said "I think it's time to give my idea a try." This was way down the road, because it took time to do all this, but the beefed up ventral with the Kordes fixes on it worked fine.

We went into the structures program, and did a limited stability and control program. Don Berry and Glenn Gilyard [from the FRC] got some fundamental stability and control data, and we did the flying with all the strain gauges and thermocouples. We put some deflection devices on the YF-12 so we could measure how much the structure deformed. Then we heated the airplane. We had Lockheed build this big oven that we put around the airplane. Controlling the heat lamps in the oven, we heated the airplane to the same kinds of conditions that it was experiencing in flight. We measured the deflections, temperatures, and loads so that we could separate the aerodynamic loads from the thermal loads.

At about that time, we got the instrumentation and started testing it in YF-12 #935. We had planned on putting it in #936, but the Air Force lost that airplane in June 1971. Jack Layton and Billy Curtis were returning to Edwards at the end of a test flight when they had an indication of fire in one of the nacelles. They did a fly-by, and the control tower confirmed that there was a lot of flame coming out of the back end of the airplane. Layton was concerned that the fire had weakened the structure to the point where the wing might come off at touchdown. He made the judgement that he and Curtis had to get out of the airplane. They punched out over the lakebed, and the airplane crashed. In retrospect, we looked at the nacelles and temperatures were up in the neighborhood of 2,500 degrees. The metal was distorted, and it was kind of marginal as to whether he could have made a successful landing. I can't recall anybody faulting Layton for the judgement that he made. The cause of the fire was determined to be a broken fuel line.

Now, we only had one airplane. At that stage of the game, we wondered what to do about it. I was aware that there were ten A-12 airplanes sitting in a hangar in Palmdale. But, Kelly Johnson wanted no part of us operating the A-12. He felt that it had been designed quickly, and not as thoroughly as either the YF-12 or SR-71. He recommended that we use the number two SR-71. It was non-standard, and therefore couldn't go into operational service.

So, we got together with the Air Force and talked about that, and there was a question because we were only authorized to have YF-12 airplanes and not SR-71 airplanes. We suggested that if we put the older "J" engines in the airplane instead of the newer "K" engines, it would reduce the performance. Since the inlets on the YF-12 and SR-71 were the same, we would still have the inlet conditions of the YF-12. The nose flow was slightly different, but what went on

inside the inlet would be the same. We could, therefore, consider that this was YF-12 information. We agreed to give the airplane a new designation, a new tail number, and that we would always use the "J" engines so there would be no question of us giving away SR-71 data.

We called the airplane a "YF-12C" and gave it the number 937. That was the game that was played. We instrumented that airplane and did all the performance work that Bill Schweikhard wanted to do. We wanted the extra Mach 3 time that the SR-71 could provide, contrasted with the YF-12. The SR-71 would go an extra five minutes at Mach 3. It increased our capability by a third.

About that time, the Air Force was ready to move to Palmdale with the supporting activities. The Category II, Category IV, and Category VI tests had all been accomplished, so it was just developmental operational testing that was moved to Palmdale. At that stage of the game, we moved to a hangar up in the NASA area. We had previously operated out of Hangar 1414. I don't think #937 ever operated out of 1414.

At one point, we took a salvaged nacelle, and sent it back to NASA Lewis Research Center. The Lewis people put it in their Mach 3 wind tunnel and ran a test of the full-scale inlet. The people at Ames ran a 1/3-scale model at Mach 3. So, we had a full-scale "model", a 1/3-scale model, and flight test data from the airplane. We had ideal conditions for making a comparison between wind-tunnel testing and flight testing. That program went off very, very well. The instrumentation worked, and we got what we wanted out of it.

We went from there into a whole series of aerodynamics experiments. We put boundary layer rakes on the airplane. [FRC engineers] Ed Saltzman and Sheryll Powers came up with what they called an aft step experiment, looking at the drag behind a rise on the back of the airplane. We built a new ventral fin made of Lockalloy. The Langley people came up with a new landing gear mechanism that we tested. The airplane really became an aerodynamic testbed for a whole variety of things.

We developed computer programs for aerodynamics, and for loads and structures. We contracted with Lockheed to create a NASTRAN computer program for structures work to match what we did in the flight heating conditions. Across the board, we developed the capability of analysis, model testing, and flight testing to answer the questions of how to predict all of this stuff. I think we laid a foundation for future work. I can't think of any program that had the equivalence of complete analytical, flight and wind-tunnel comparisons. It's textbook stuff that I think will be used for the foreseeable future.

Let's talk about people. As I said, we really had no conflicts with the Air Force on what we wanted to do. We had good relations with "Fox" Stephens, Bill Campbell, and Joe Rogers. "Slip" Slater was very, very easy going in his own way. If you knew how to give him the right deference, you got the answer without much trouble. All the working-level people were fine.

Lockheed was very helpful. We developed a wonderful relationship with Kelly Johnson. I think we established our technical credibility with him. He came up with ideas for us. We gave him revelations that he found very intriguing. Burt McMaster in the stability and control area was

great. Ben Rich became a very close personal friend. Dave Campbell was an excellent engineer. Henry Combs did all the coordinating for us in the Lockheed hierarchy. Bill Fox, who was our interface in the flight test world, was my equivalent at Lockheed. They were all wonderful people.

Merlin: Was it difficult to transfer the YF-12 data to other agencies due to the security classification issues?

Matranga: No. I think we understood the sensitivity on the part of the Air Force and worked that issue fairly well. The only ones we really had to interface with were the Boeing people. The decision had been made that Boeing would build the SST, so we had made arrangements with the Air Force to give Boeing a briefing. We put together what we thought were the pertinent facts that would be of use to them in the design of the SST. We cleared that with the Air Force, and we had a two-day briefing for Boeing. We gave them a rundown on all the theories that seemed to apply, the problems that we had encountered, and the problems that we thought they should be looking for. We were disappointed because the Boeing people seemed to be bored silly. I got the impression that they were told by their management to go down and listen to this but that they were not particularly interested.

About two years later, we had some of those same people come back to us with questions. So, we went through it all over again. Once they had experienced the problems, then they were receptive and ready to listen to us. Interestingly enough, Bob Sudderth, who had worked with me on stability and control for the SR-71, went to work for Boeing on the SST program. He transferred that information in his head, so we had fewer questions from them in the stability and control area.

Merlin: What would you say are some of the lessons learned during the YF-12 program?

Matranga: Instrumentation, first of all. The instrumentation was very inadequate to begin with, and it cost a lot of money to develop new instrumentation and make it work. We had to cool instrumentation that supposedly would have withstood the temperatures. There was a lot of development necessary.

Stability and control. The effects of the inlet on the stability of the airplane turned out to be much more profound than Lockheed had originally thought. The air that was dumped out of the forward bypass doors moved forward for about a foot or so before it mixed with the boundary layer. This startled everybody. We didn't realize that there was that much separation just ahead of the bypass areas. We put control over the bypass doors under a computer program. The Air Force found that useful enough that they implemented it on all the operational airplanes. It increased the range of the airplane.

Atmospheric science. We documented the upper atmosphere conditions better than anyone had done previously. In fact, we had a remarkable flight once when we had a very cold day at altitude. Bill Campbell was able to fly at Mach 3 without afterburner. That was a remarkable accomplishment in my book, but it was strictly a function of temperature at altitude.

Boundary layer studies. The boundary layer work documented the differences between

small-scale wind-tunnel models and what was really happening in flight. We confirmed the fact that the airplane grew about a foot at high Mach number. I just look back at the design that Kelly did in the late 1950s to build the original airplanes. He designed everything with his great intuition, based on his gut feel. That's remarkable. Kelly was one of the remarkable people that I have had the very good fortune to be involved with. He was a dictator. It had to be his way, but he was a remarkable fellow.

Merlin: What contributions did the YF-12 research make to later aircraft development?

Matranga: It would have helped the SST. The SST program was cancelled before a prototype was built. The YF-12 answered some questions about the inlets. We did some design work after I went to work at Lockheed, and we certainly used the lessons learned from the YF-12 in the design of those inlets. We went to square inlets, rather than round inlets, because the round inlets leaked like a sieve. There was no way to keep the air from leaking out of them, and we determined that we could seal much better by going to square inlets. We certainly had the advantage of being able to schedule the geometry of the inlets better and to apply the bleed off the inlet to keep a better boundary layer. So, the lessons learned about the inlet were applied to those designs, and it would have made a significant difference.

It was the same situation with the boundary layer work. Prior to the YF-12, all we had to work with was small-scale model data. We found significant discrepancies between the small-scale model and the full-scale airplane. We theorized that it was probably due to imperfections on the airplane's surfaces. It certainly wasn't a smooth surface. There were lumps and bumps and waves that obviously had an effect on it. A wind-tunnel model was a nice smooth, rigid structure. The airplane certainly was not that.

Merlin: Were predictive methods developed to compensate for that?

Matranga: Well, . . . the answer to the question is "yes," but that is still an art at this stage of the game. It requires interpretation on the part of very skilled people like Ed Saltzman to make sense out of that.

Merlin: What would you say was the most rewarding thing about working on the YF-12 program?

Matranga: From my standpoint, the most rewarding thing was the freedom of activity that Paul Bikle gave me. I was the dictator for NASA on the YF-12 program. Bikle essentially gave me free reign to run the program as I saw fit, and to make sure we didn't run afoul of the Air Force or other NASA centers.

It was tremendously rewarding for me to have the people at Ames, Lewis, and Langley cooperate so well in the program. Bill Aiken gave me the money to run the program. It turned out to cost about five million dollars a year, rather than the three million we had estimated, at the height of the development. It backed down to about three million when we were just flying the airplane as it was. I can recall the Lewis people especially, when they did the full-scale inlet and I provided them with something on the order of a million dollars to do the test. They said: "we've

never had this kind of cooperation from anybody before."

From my standpoint, this was an Agency program, and I had the responsibility to use that Agency money the best way I saw fit. If it didn't go to the Flight Research Center, if it went to Lewis instead, then so be it. It created a working relationship that I've never seen anywhere else with the other centers. We had that relationship with everybody. It was great. They supported us, too. Toward the end of the program, times got kind of lean, and there were people with knives out looking to slice things away. It was kind of nice to have someone from Lewis stand up and say: "Wait a minute, wait a minute, we have an interest in that. Let's make sure that money is there." It was very rewarding.

Berwin Kock, interviewed by Peter Merlin on 14 June 2000

Merlin: How did you became involved in the YF-12 program?

Kock: Well, about late 1975 or '76, I was managing the DAST [Drones for Aerodynamic and Structural Testing] program and Gene Matranga, the first YF-12 program manager, had been promoted up to Director of Projects. Ming Tang had succeeded him. For some reason, they needed to make a change, and Gene asked me if I would like to manage the YF-12 program. I said "great, wonderful," so I really didn't lobby for it or anything like that. A few years earlier, I had done a brief study about launching a Mach 8 hypersonic research vehicle off the back of a YF-12, so I had some familiarity with the program.

Merlin: Was that the HT-4?

Kock: Yes, that's what it was. So, Gene Matranga made the decision to put me in charge.

Merlin: Whatever happened to the HT-4 proposal?

Kock: It didn't go anywhere. I think it was a combination of things. One is that launching things off the back of a Mach 3 airplane was dangerous. There was some previous history that said there was some difficulty doing that sort of thing. In fact, Lockheed crashed an airplane when they were doing that kind of thing earlier with the D-21. I just don't think NASA was ready to step up to that kind of risk at the time.

Merlin: At the time when you were working with the YF-12, was the Air Force still involved in the program?

Kock: Yes. The Air Force had an active role. We used a lot of their assets to implement our program. We had some Air Force people assigned to the program. They also had a security office at Norton Air Force Base that supported us. They did a lot of our contracting for us with Lockheed, Pratt & Whitney, and the other companies that were involved. We funneled money to them, and shared in the contracting exercise. Also, they provided logistics and support, such as tankers for aerial refueling. They had their own program, and we had ours. We joined together in these spe-

cific areas.

Merlin: What were some of the areas of research you worked with involving the YF-12 aircraft?

Kock: The first one I worked on when I came onboard involved the ventral fin. We had broken the fin off in flight and were just in the process of installing a new one made of Lockalloy. We did integrated inlet, autothrottle, autopilot, control work, and the Coldwall experiment. I don't know if you are familiar with that.

Merlin: I am. There was some trouble with the insulation blowing off prematurely quite often. Ultimately, some data was collected. Do you consider the Coldwall to have been a successful project?

Kock: Well, I'll quote Ed Saltzman, who is one of our premier aerodynamicists here. He says it's "probably the best pure science program" we had ever done up to that time. We got good data for him. It worked very well at the end. In terms of getting data, it was painful to get there, but it was a good experiment. We got good data.

But, to continue the other theme, we also did a landing gear dynamics study. Typically, the spring constant damping in landing gear is designed for handling the touchdown maneuver. When you taxi, you want a different set of spring constants and damping to reduce fatigue loads on the airplane. So, we varied the landing gear dynamics somewhat on the YF-12.

At one point, we did a structural dynamics test. The B-1 bomber has these little vanes, or canards, underneath the cockpit area to smooth out the ride. We wanted to do a science experiment to understand the interaction of aerodynamics and structural dynamics. So, we put similar vanes on the YF-12. Ming Tang was the principal investigator on that. It was about the last thing we did in the program.

Merlin: What happened to the program then?

Kock: Basically, Center Director Dave Scott decided that he would rather we do integrated controls research on the F-15, as opposed to spending more money on YF-12 high-speed aircraft technology. At the same time, it was getting harder and harder to sell in Washington. This was in 1978. Bill Aiken was the Director of Aeronautics at that time. Ron Smith was the person in his office who worked on the YF-12 program. They concluded that there was just not enough support to keep it at its previous funding level. So, the two of them, together, kind of spelled a death knell for the program.

Merlin: Were researchers at Dryden anxious to continue with it if they could have?

Kock: Yes, they were, but there were two problems. We didn't have a long list of experiments to do on the airplane. Our researchers had kind of exhausted their options, I guess. The other problem was that the whole Supersonic Transport technology program was running into some

difficulties. There was soft support for high-speed kinds of research in the country. That kind of airplane is expensive to operate. All of that kind of came together, and indicated that it was time to end it.

Merlin: What would you say were some of the lessons learned from the YF-12?

Kock: Well, first of all, exotic airplanes generate a lot of enthusiasm on their own, regardless of the technology involved. The YF-12 was an intriguing, exciting airplane to be associated with. So, that's the first lesson.

The second lesson, I guess, is that if you are going to do quality research, it takes a lot of money. So, fund it right.

The third lesson is that contractor and government teams can work together very well. We had a great relationship with the Air Force. You've got to strive to get that kind of relationship.

I guess the fourth thing is that classified programs limit your ability to garner supporters and advocates. It was a special access program. Much of what we did, we could talk about, but there was a lot we could not talk about. It never got fully integrated into the Supersonic Transport research program because the people working on that could not gain total access to the YF-12 program. That boundary complicated our efforts to formulate experiments, conduct experiments, and keep money flowing into the program.

There was a process set up whereby we could write reports. There were a lot of things about performance, how experiments were integrated, and such, that we could not write about. It was hard, but we managed to produce an incredible amount of reports.

Merlin: How did YF-12 research contribute to programs that came along later?

Kock: The program did a lot of fundamental science work on things like boundary layer behavior, heat transfer, and skin friction. All of that is generically applicable to a lot of airplanes. We did autopilot work that is applicable to planes that fly fast, and I think that benefited many of them. The biggest effort in the whole program was the heating test that was done before I came onboard. Obviously, that has relevance to aircraft and spacecraft that get hot. I think that generations of aircraft benefited from our providing a fundamental understanding of that sort of thing. We also developed the NASTRAN program that I think was an industry standard for structural analysis. There was a lot of good work that I think was applied in areas we are not even aware of.

Merlin: Can you tell me anything about the other people you worked with?

Kock: I got to know Ben Rich personally. The people down at the Skunk Works were the best of the best in the industry at the time. Gene Matranga was one of the most dynamic individuals on the NASA side. Fitz Fulton, premier test pilot, and Don Mallick, and Vic Horton did a lot to help the program. Bill Aiken at Headquarters was widely respected. There were lots of good people involved.

Merlin: Was the Center management at Dryden helpful?

Kock: We had a good relationship with Center management, but things were changing about that time. It was a period of transition. Paul Bikle left about 1973, and we were going through Center Directors rapidly. Each of them brought a different perspective. Some of them didn't understand the flight research mission of this center. They came from a different world. They were good managers, but they didn't quite grasp what we were about.

Merlin: What would you say, for yourself, was the most rewarding aspect of the YF-12 program?

Kock: There were several things. First of all, that airplane was, and is, a magnificent engineering accomplishment. Just to be associated with the YF-12 was a reward in itself. Another thing it let me do was get an insight into the Lockheed Skunk Works. At the time, the Skunk Works was "The Place." They did all these exotic and challenging things, with great people, so that was immensely rewarding. Also, the YF-12 project had an esprit de corps that was truly unique. Everybody was enthused, and wanted to come to work. It was great.

Personally, it marked a transition in my career growth from more routine kinds of work to something that was on the forefront of technology. It was the largest project on the Center at the time. It brought in 40 percent of the total money that the Center had. It was the project that kept the Center going.

The hardest part of the whole thing was when it ended. I had stretched the program as far as I could with the money that was available. I had a great team of contractors and civil servants. It was really hard to take care of these people, to find places for them to go as we were winding down. That was really hard.

And, the ending didn't work out terribly well with some of the folks at the Skunk Works. They were of the opinion that NASA didn't work hard enough to keep it alive, so there were some strained relationships that developed out of that.

All in all, a great experience. A great program. Good work. Good people. That's about it.

Appendix 4: Don Mallick describes YF-12 flight operations

This material has been excerpted from Mallick's unpublished manuscript "The Smell of Kerosene." It has been edited, out of its original order, to preserve the narrative flow. He read the edited version and enthusiastically endorsed it.

On the morning of a test flight, I would set the alarm for about 3:00 a.m. and get on the road to Edwards by 3:30 a.m. Usually, I would meet Fitz Fulton at his home in Lancaster and we would car-pool together.

Flight planning and briefings were intense and thorough before each flight. It was standard procedure to have a set of "back up" test cards to be conducted at lower altitude and slower speeds in the event that some malfunction prevented us from flying the high-speed flight. This gave a little fall-back and allowed us to gather some flight data even on a flight that could not get to high speed. Actually, we did not have to fall back on these cards too often, and usually our mishaps or problems in flight required that we return for landing ASAP without a lot of delay.

There would be a meeting of the research engineers and operational people, which included the pilots and flight test engineers. The research engineers would present a briefing on what test data they would like to gather in the upcoming flight. There was interchange between the research engineers and operational people even before this meeting to ensure that the data requested was reasonable and achievable. The flight test engineer and flight test pilot would suggest what type of maneuver would be used to gather the required data. At this meeting, entitled the Technical or Tech Brief, the initial flight test cards were already made up. These cards presented the test maneuvers required and their sequence during the flight.

The Tech Briefing would normally occur a minimum of three days before the flight to allow all concerned parties to study the test points and cards and make inputs for changes prior to the test flight. As the pilot, I began a comprehensive review of the test cards with all of the planned test points. At this point, a simulator could have been used to practice the test flight, but there was not a Blackbird simulator available at Dryden. The flight test cards were cardboard 5-by-7-inch cards that were inserted in a checklist-type book that was attached to the right leg of my pressure suit with Velcro material. The fact that the Blackbirds had their own checklists, one normal and one for emergencies, added to the problem for the pilot keeping this material ready in the cockpit. The aircraft's normal checklist was attached to the top left thigh of the pressure suit. I referred continually during the flight to both of these checklists to make sure that the normal aircraft functions were completed along with the test points. The aircraft emergency checklist was placed in a side console pocket for reference if needed. In an emergency situation, the test card and normal checklist were put aside in favor of the emergency check list.

Because of the lack of a simulator and the fact that each flight was busy and time-critical, I had designed a substitute for the simulator at my desk at home. I had pictures of the aircraft cockpit and consoles laid out in photos and, prior to each flight, I sat at this desk or pseudo-

simulator and mentally ran through the aircraft's normal checklist and the test cards while reaching for and visually noting the positions of each switch that would be activated during the flight. Depending on the complexity of the flight, I would go through this practice a number of times until I was familiar with the test flight procedures and sequences.

On the morning of the flight, we would have our final briefing. This was named the Crew Briefing, and it included any last-minute changes in the test cards. Note: The pilots tried to encourage everyone to keep their last-minute changes to a minimum because any late changes could screw up prior planning. The crew briefing also included current weather, tanker information and a review of certain emergency procedures, including planned alternate landing fields in the event of a problem that would not allow us to return to Edwards AFB. After the Crew Brief, as we called it, the flight crew would proceed to the pressure suit van and "suit up" for the flight. The pilot and flight test engineer quickly became very attached to his pressure suit, in that it was their key to survival. Even though it was bulky, cumbersome, and reduced the pilot's visibility, it was comforting to wear the suit while flying in this hostile environment. Vic Horton and Ray Young were two flight test engineers assigned in the pilots office who served as our "backseaters." Although Fitz and I flew with both Ray and Vic, we gravitated into two teams for the Blackbirds: Fitz/Vic and Don/Ray. We flew the majority of our flights with these two teams.

Following the crew briefing, the pilot and flight test engineer would proceed to the pressure suit van, which would drive out to the parked Blackbird. On the drive out, the personal equipment people would help us into the pressure suits and run a pressure check on the test equipment in the van. When the aircraft crew chief reported ready for pilot entry, the personal equipment men, two per crewmember, would accompany us to the aircraft, assist us into the aircraft and hook us up to the radio, oxygen, and ejection seat. An oxygen flow check and suit pressure check were also performed in the aircraft. When the "suit people" left, you were completely tied in, hooked up, and ready to go.

The next step was to complete the pre-start checklist, which was rather long for the Blackbird. Once that was complete and the ground crew ready, the engines were started. Following engine start, another series of post-start checks was performed on the aircraft systems, including the all-important flight controls, auto-pilot, and SAS systems. About 40 minutes from the time you entered the aircraft, you were ready for taxi, barring any problems. The Blackbird, unlike the XB-70, had an adequate nose-steering system. The visibility for taxi was good and the aircraft was of such a size that it was no problem on ground handling. The canopies were closed prior to leaving the chocks.

We normally conducted our test flights early in the morning for several reasons. Takeoff temperatures were of concern to us, especially in the summer. We were taking off with full fuel, which meant a heavy aircraft in a long takeoff run with higher runway temperatures. Edwards has a 15,000-foot runway, a plus. We did, however, like to take off with the ambient temperatures below 70 degrees in that it provided a margin of safety in the event of an engine loss after takeoff. This was a NASA operational decision and all involved agreed that it was reasonable and livable. We did have an Air Force tanker for the mission, but we liked to apply that tanker support after the first long flight-test leg. In that way, we were able to get two full flights for the price of one.

The onboard air-data recorders on the NASA Blackbirds were good for a little over two hours of data, and if we put our tanker in the middle of the mission, it permitted us to fill our data tapes.

Line-up for takeoff was made squarely on the runway centerline. With the before-takeoff checklist completed and the engines increased to military power, the engines were checked for proper operation and the brakes released. Almost immediately, both throttles were lifted slightly and advanced to minimum afterburner; the afterburners would light very close together but seldom simultaneously. As each one lit, the nose of the aircraft would swing in the opposite direction, even with the nose steering engaged. When both afterburners were lit in the minimum setting, they were immediately advanced to maximum afterburner for takeoff. At full fuel, the aircraft accelerated at a moderate rate. Nose rotation was started about 175 knots and was held about ten degrees above the horizon; the aircraft became airborne around 210 knots. The landing gear was retracted and the throttles reduced to military power for a climb at 250 knots. Once past 10,000 feet, the aircraft was again accelerated to about 400 knots for the climb to altitude. The climb was made in military power, switching over to a Mach 0.9 climb to about 22,000 feet and the afterburners were selected. The climb continued at 0.9 Mach to about 34,000 feet where a gentle nose down attitude was introduced with about a 3,500-foot-per-minute rate of descent. The acceleration continued in this descent, and the aircraft was flown at around 29 to 30 thousand feet as it accelerated to 450 KEAS (about 1.2 Mach at this altitude). Once on the 450 KEAS, the Blackbird was allowed to start its climb and continue accelerating to cruise altitude and Mach number, about 75,000 feet and 3.2 Mach. The reason for this descending acceleration was to keep the aircraft's angle of attack as low as possible during the transition through this critical, high-drag region. The complete process from takeoff to cruise took between 20 and 30 minutes, depending on the day and atmospheric temperatures. The Blackbird, like all jet aircraft, liked very cold days at altitude, where the accelerations went much faster and used less gas. On a hot day at altitude, it took the old girl a lot longer to get up and go. Even before level-off at the test conditions, I would be reviewing the first test point and completing any steps that were possible in preparation for it.

The first leg was north toward the Canadian border and the second leg was south to rendezvous with the tanker near Tonopah, Nevada. I flew a lot of Blackbird refuelings during my ten years with NASA. I found it a demanding task, one that required a lot of concentration. It usually took about 12 to 14 minutes on the boom to top off the Blackbird tanks, and I can say that I was usually ready to go back into the climb-accelerate mode and on to other things when that time was up. The YF-12 Blackbird had poor visibility during refueling. The pilot's seat would not lower enough to allow the pilot to see the tanker by looking upward. Therefore, the pilot had to bend his torso forward and arch his head back to view the tanker, no easy task with the pressure suit helmet. The flight control response and damping of the Blackbird were satisfactory in this lower speed area, especially at the lighter gross weights. When the Blackbird fuel load was between a half and a full load, a new characteristic appeared that was structural. If too large a pitch input was made, a small but discernible bending wave was felt to go through the fuselage structure. The pilot had to be careful and not fight this with large stick inputs, but to reduce his inputs and allow it to dampen. During the time on the boom taking gas, you would occasionally feel this structural wave activate and then dampen. The effect would also be aggravated by turbulence in the air. The increasing inertia with increasing fuel load would decrease the aircraft's

response to throttle movement. A weight change of 55 to 60 thousand pounds was not unusual for a refueling. When you were nearing a full load of fuel and the Blackbird had drifted back in the normal refueling envelope, you would push both throttles to full military and then wait and watch as the power application slowed the drift back and slowly started the aircraft forward to its proper position.

If I was flying the Blackbird, Fitz would be a primary chase in the F-104, and the opposite if Fitz was flying the Blackbird. Early in the program, NASA management suggested that the Blackbird pilot not flying the Blackbird that day should be in the control room, but Fitz and I both believed that we could support each other more by being in the air in another aircraft, and our desires were granted. The primary chase would be in an F-104, and would take off right behind the Blackbird. After takeoff, the F-104 would join up and look the Blackbird over for all gear doors closed and all other portions of the aircraft looking normal. As the Blackbird began its acceleration through Mach 1, the F-104 chase would slowly drop behind to conserve fuel, keeping the Blackbird in sight visually for miles by watching the contrail left behind it. If a problem had developed in this area, the F-104 would rejoin the Blackbird and provide chase support to escort it home. As the Blackbird climbed higher and faster, it would go above contrail level and the chase would normally call out the fact that no more contrails were visible. The Blackbird pilot would call back his altitude to mark the level at which the contrails disappeared. This was usually around 60 to 65 thousand feet. From this point, the F-104 chase would set his engine power for maximum endurance and he would hold just west of Beatty, Nevada, the refueling area for the Blackbird.

Once the Air Force KC-135 tanker was spotted entering the refuel track, the chase would make radio contact and join up with the tanker in a loose formation. This arrangement, allowed the chase to watch for the returning Blackbird coming southbound into the refueling track, and there were occasions when the chase assisted the Blackbird pilot by calling out the tanker's clock angle and range to assist the Blackbird pilot in getting a visual on the tanker. Both Fitz and I appreciated this because at times after a descent in the Blackbird with a little moisture on the pressure suit visor, long-range visibility from the Blackbird was not that great. As the Blackbird joined the tanker formation, the chase again looked him over for general integrity and that there were no fluids leaking from the aircraft. After the Blackbird received its fuel and broke away from the tanker, the chase pilot gave the Blackbird one final look over, checked that the refueling door was closed and wished him a good second leg. At this point, the F-104 was low on gas and ready to return to Edwards. Sometimes the primary chase pilot would park his empty F-104 and get immediately into another F-104 waiting for him, take off to greet the Blackbird as it entered the Edwards area for landing after its second flight test leg.

Once off the tanker and cleared to climb, we lit the afterburners and started our climb acceleration from the tanker altitude of around 22,000 feet. This test leg would be a little longer than the first after takeoff, because we did not have to burn the takeoff and climb fuel to get us to 22,000 feet. Normally in the turn at the north end of the track, we did not do any unique test maneuvers because the primary desire was to get the nose pointed south. That sometimes took a 70-mile turn at the Mach 3.2. During the turn, I finally had a little time to look around outside the aircraft. Up to that point, I had been busy establishing test conditions and taking data, and practi-

cally everything was flown on instruments. The outside or real horizon was used as a back-up to the instrument horizon that I was flying in the cockpit. On lower, slower-flying airplanes, the pilot could do a pretty good job of flying just with the visual reference to the outside world. Not so on the Blackbird; the speed was too great and fractions of a degree in pitch would result in large altitude excursions. This aircraft was operated on instruments regardless of the weather.

The aircraft had a good autopilot, and it was used whenever possible to relieve the pilot workload. The turn was usually on autopilot, but the majority of the flight was flown manually by the pilot due to the requirements of the various test points. The view outside was spectacular, especially if the weather was nice and there was not too much cloud cover. It was amazing just how far you could see, the slight curvature of the earth at high altitude and the beautiful shades of blue in the sky. The sky color ran from a light to a very dark blue, almost black as you looked upward. But the turn seemed to end quickly and it was back to work on the test points. In fact, prior to rolling out of the turn, the next test point was being set up. It was the same procedure southbound, getting as many test points completed as possible. The start of decent point was critical in that we had to be on altitude and in a certain location prior to meeting our tanker. The descent and slowdown to the tanker covered about 250 miles, and that time was busy working with clearances with the Federal Aviation Administration (FAA), sometimes accomplished through communications through our own control room and sometimes with direct communications with the FAA. Our problem was that we had to descend through a major east-west jet airway and coordinate the crossing with other traffic. Once we dropped below about 25,000 feet, we were clear of the traffic and we shortly entered the Air Force test area which was void of commercial air traffic. We operated on a see-and-be-seen basis but were provided Edwards Approach Control Radar advisories.

The cockpit on the Blackbird was relatively large, designed for a pilot in a full pressure suit. It was possible to reach all of the switches and buttons with little effort with the exception of those on the consoles alongside and slightly behind the pilot. The pressure suit made these a little tough, but possible to reach. The flight instruments were of the tape or vertical variety. I had experience with these in the XB-70, and although I preferred the round dials, I had no problem flying the tapes. The visibility outside the aircraft was good looking forward and up, but it was limited looking back or down. There was a small periscope in the top of the canopy that could be extended to allow the pilot to check his engine nacelles and verticals. It was difficult to use, but again, it was possible. The periscope was to be retracted at high Mach numbers, but I forgot it on several occasions and it didn’t slow the aircraft down a bit. (It was only an inch in diameter and extended only an inch or two outward). The forward canopy was angular and had thick glass and a thin dark splitter plate to prevent reflections. I thought that this combination along with the pressure suit helmet visor might give problems with visibility during takeoff and landings, but I was wrong. There was no problem. I was never sure if my left eye looked out the left of the splitter plate and my right eye looked out the right, but I had no problem with judging heights during landings.

The pilot scans numerous instruments in the cockpit in order to assimilate and react to the information presented. This information relates to what the aircraft is doing with changes in attitudes, altitudes, and velocities. In addition, he must monitor the performance of all the aircraft

systems, including flight controls, fuel, hydraulic, electric and propulsion systems. It seems like almost an impossible task, but it is possible by setting a priority in the pilot's scan.

The description of the scan is pilot's eye movement over all these instruments as his mind sees and digests the information. The scan is a continuing situation, providing the pilot's mind with updated information. The way the pilot prioritizes this is to give the most critical factors, such as aircraft attitude and speed, a first priority, aircraft propulsion a second priority, and other aircraft systems such as fuel and electrical a third priority, and so on. In addition to the instruments, there is a series of warning lights to alert the pilot to any problems. The scan is continuous as is the pilot's response to it in controlling the aircraft by making inputs to the flight controls, throttles and other systems switches. Fortunately, the Blackbirds had a very good autopilot. On autopilot, the pilot's task is reduced to monitoring the aircraft's position and motions, and fine-tuning the autopilot with small inputs. The climb acceleration was one area that I was able to utilize the autopilot in the NASA mission, and I was quite happy to have the help. During the test points on the heat-loads program, the aircraft was hand-flown because of the unique inputs required for the data points.

The low-speed handling qualities of the Blackbird were fine, and the approach and landing speeds were much like the F-104's. Control response in the landing configuration was excellent and stability was very good. There was no angle-of-attack indicator in the Blackbird; the primary approach reference was the airspeed indicator. It did not seem difficult to set a desired airspeed and control the glide path with throttle. If you could fly a good pattern in an F-104, you could fly an excellent one in the Blackbird. The flare and touchdown were similar to those of other delta-wing-configured aircraft. It had good ground-effect and feel, and smooth landings were the norm with this aircraft. The high-speed flight characteristics were good. The control systems design provided a feel and response to the pilot that was quite normal over the complete flight range.

Appendix 5: Don Mallick describes unstarts

Excerpted from Mallick's unpublished manuscript "The Smell of Kerosene"

On my second flight to high Mach number in ship 60-6936, I experienced a series of unstarts and restarts in the Mach range that rattled my head and other parts. The fact that the Blackbird can operate in a low sub-sonic to Mach 3.2 speed range is impressive. One of the systems that makes this possible is the inlet computer and control that automatically positions the spike and controls the shock wave's location, and the by-pass doors that control the air pressure and flow in the inlet. (Both of these are critical to provide the engine with "prepared" air with a high static-pressure and a subsonic Mach number.) The pilot has manual controls to do this function manually, but it requires a great deal of time and attention. The function of these engine inlets and controls is very much like a wind tunnel in front of the engine. (What occurs in the inlet affects the engine, and also, things that occur in the engine can reflect forward to the function of the inlet.) At supersonic speeds, when everything is running smoothly with the inlet and engine, the inlet is said to be "started" and running not unlike a wind tunnel. When something occurs that upsets the inlet flow to a point that the position of the normal shock wave moves forward from its optimum position, the inlet is said to be "unstarted." The normal shock wave is located in the smallest area of the inlet, and it is the last shock wave prior to the airflow going subsonic and entering the engine. There are numerous other shock waves involved, starting with the outer or Mach shock controlled by the spike position.

The unstart condition is not a gradual thing; it happens immediately with a bang. When the inlet unstarts and loses its smooth flow, there is a large directional input to the aircraft and also some pitch-up moment. At certain Mach numbers around 2.3 to 2.6, the input to the aircraft is so violent that it can snap the pilots head and helmet against the inside of the canopy. The flight control stabilization is quite an aid to the pilot, in that it has a great deal of directional power and input to counter the initial directional divergence that accompanies an unstart. In addition, a special "cross tie" feature is included in the inlet controls to automatically unstart the other inlet to reduce aircraft directional divergence. The cross-tie is active above Mach 2.3, and even with this feature, unstarts can only be described as violent under certain flight conditions. In other supersonic flight conditions, they are less violent, but still disconcerting. As a comparison, an inlet unstart in the XB-70 was less violent. On the XB-70, in fact, a failure of one engine out of the three might not unstart the inlet; it would just alter the position of the throat and bypass doors. The XB-70s engines were also located near the centerline as compared to the Blackbird's mid-wing location. The Blackbird unstarts were unique and, at times, a little scary. The inlet control system also had a feature that was called auto re-start. When the inlet unstarted, the computer control automatically retracted the spikes and opened the bypass doors to a position associated with a lower Mach number. The spike would then move forward slowly and the bypass doors closed down as the shocks were re-positioned. If the original cause of the unstart was gone, the inlet would restart with the airflow re-established to the engine. The Pratt & Whitney engines were quite forgiving to all of these goings on in the inlet, and they had a special feature on the fuel control to reduce the fuel flow to the engines during unstart. The natural tendency of the engine during a reduction in airflow during unstart was to exceed the design temperature limit and cause damage to the engine. This feature was called "de-rich."

On one occasion, the aircraft went through the automatic restart, but the problem that caused the unstart was still present. The inlets unstarted again. After several cycles, I selected a manual restart position and held the inlets in this "safe" condition while the aircraft slowed. About this time, poor old Sam [Ursini, in the back seat], who couldn't hold it back any longer, said, "Mallick, what in the hell is going on up there?" I calmly said, "Sam, as soon as I find out, I'll tell you." As it turned out, I released the inlets out of manual and the next restart worked; we were back in business. One of the disconcerting things about the inlet unstarts was that after a flight, ground checks would sometimes reveal nothing wrong with the inlet controls or computers. The problem was dismissed with the belief that the computer was controlling the inlets too close to the unstart boundary.

On one exciting ride for me, I was close into Edwards before I reached my 30-minute soak-time at Mach 3. I decided, however, that I had airspace enough to complete the maneuver and still slow down for landing at Edwards. As I pulled up to the 1.5g pull-up and the aircraft's nose came up through the horizon, the inlets unstarted and the engines went into a partial stall condition. The cabin pressure dropped to a point where our pressure suits began inflating. The nose of the aircraft continued upward for a period much too long to be comfortable to me, considering I had immediately applied full-forward stick. As the nose finally started to come down, the inlets automatically made an attempt at restart, which failed. After several more attempts, the inlets restarted, the engines cleared their stall and I was able to commence a turn back to Edwards.

Unfortunately, as all of this was going on I was heading out of the Edwards test area toward the Los Angeles Control area, which had many airliners operating at any given time of day. One of our operating rules (a very good one), was to have an FAA representative in our control room during the flights. He was in contact with the various FAA centers that controlled the airspace we operated in and around. This really paid off on this mission, in that the FAA coordinator integrated my intrusion into Los Angeles Center airspace and indicated that I should stay above 45,000 feet until I returned to the Edwards Airspace if possible. It was possible, and that alleviated the situation. I turned back toward Edwards from over Pasadena, California, still humming along at 50,000 feet altitude and well over Mach 2. After the flight, I went over the flight control data traces with the engineers to determine how long I had held full-forward stick until the aircraft nose attitude had started down. It turned out only about eight to ten seconds. With both inlets unstarted, the pressure suit inflated, and a lot of "shakin'" going on, it had seemed like ten minutes to me at the time. For a moment or two, I wasn't really sure the aircraft was responding to my input and I was concerned about who was in control.

Several hours after landing and debriefing at NASA, I learned of a phone call that indicated that we had not escaped all notice with our flight that day. As I completed the 180-degree turn back toward Edwards, our shock wave had broken a large plate glass window in a bar in Pasadena. Fortunately, no one was injured by flying glass and NASA picked up the repair check because we knew the abnormal flight path projected a pretty strong sonic boom on the ground. We were happy that there was only one window broken, or perhaps just one reported.

Documents

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
FLIGHT RESEARCH CENTER
BOX 273, EDWARDS, CALIFORNIA 93523
CL.(805) 9-3111 TWX: 805-281-5055

IN REPLY REFER TO R

September 11, 1969

TO : NASA Headquarters
Attn: Mr. L. Sternfield, Code RAS

FROM : Eldon E. Kordes, Chairman
YF-12 Structural Dynamics Group

SUBJECT: NASA Research and Development Program related to YF-12

In response to your letter of June 20, 1969, and reference to your action plan to implement the YF-12 program, the Structural Dynamics Group of the NASA Intercenter YF-12 Research Planning Team has prepared the enclosed program plan of potential areas of research. The attachment to the program plan contains internal information that was used in preparing the plan and may aid in evaluating some of the research areas.

A number of research areas proposed in the program have been strongly recommended by the NASA Research and Technology Advisory Subcommittee on Aircraft Structures. Particular attention is called to resolutions passed at the May 1968 and the May 1969 meetings of the Subcommittee.

Eldon E. Kordes

Enclosures: (10)
Program Plan

DOCUMENT 1 – Letter, Eldon E. Kordes, [Flight Research Center] Chairman, YF-12 Structural Dynamics Group, to L. Sternfield, Code RAS, NASA Headquarters, subj: NASA Research and Development Program related to YF-12, 11 September 1969.

YF-12 RESEARCH PROGRAM

A. Structural Dynamics

I. Justification - The performance characteristics and structural reliability of large flexible aircraft are significantly influenced by the aeroelastic and thermoelastic properties of the configuration. The design of new aircraft rely on wind-tunnel data obtained from small-scale rigid models for basic information on load distribution and stability derivatives. This data is then corrected for aeroelastic effects by theoretical methods of analysis. This approach to design requires accurate and reliable methods for analyzing structural deformation due to combined effects of external loads and temperature gradients in order to predict the effects of structural deformation on aircraft stability and control, lift distribution and control surface effectiveness. The aeroelastic response characteristics, both static and dynamic, have a major effect on the loads and acceleration resulting from turbulence encounters which in turn influence the fatigue life and flight safety of the aircraft. Limited results obtained from the XB-70 program demonstrated that a mode damper system is effective in reducing the total airplane response during flight through turbulence, but the design requires careful attention to the aircraft's vibration response to assure desired performance without vehicle-systems interaction or instabilities. Additional analytical and flight studies are required to provide a better understanding of the many parameters that control system performance and effectiveness since many of the operational problems, caused by nonlinear effects, cannot be predicted.

The economic and operational success of supersonic-cruise vehicles of the future depend strongly on the accuracy of including the structural dynamic effects into all phases of vehicle design. The YF-12 program provides the means for combining the results of analysis, laboratory tests, wind-tunnel tests with rigid and elastic models, and flight tests into a significant assessment of present state-of-the-art. This assessment is essential for directing research and development activities of future supersonic-cruise vehicles.

II. Objectives - The objectives of the program on structural dynamics are the following:

(a) Develop and demonstrate the accuracy of high-temperature load calibration techniques and measure the loads and structural deformations resulting from combined maneuver loads and aerodynamic heating. Evaluate methods for design analyses and predictions.

(b) Evaluate by direct correlation with flight-test results, methods of predicting the frequency response functions for large elastic aircraft to atmospheric turbulence.

(c) Define the role of modal suppression systems for controlling the response of large flexible aircraft to in-flight disturbances such as atmospheric turbulence and evaluate the design process for the control system and performance estimates.

(d) Evaluate by correlation with flight-test results, both analytical and experimental methods of predicting longitudinal and lateral-directional stability and control derivatives.

III. Requirements - The successful completion of the program on Structural Dynamics will require that basic information be made available by the contractor and that the required NASA facilities be utilized as needed to support the program. The requirements can be summarized as follows:

(a) Lockheed Aircraft Corporation: Description of the structural stiffness and mass distribution of the airplane in a form suitable for calculations of the mode shapes and frequencies of the complete aircraft. Detailed information of the complete airplane structure sufficient to calculate the structural influence coefficients and to define thermal and stress paths throughout the aircraft.

(b) Langley Research Center: Analytical effort and computer time required to calculate aircraft vibration modes and stability and control characteristics. Transonic dynamic tunnel utilization for tests of aeroelastically scaled model.

(c) Ames Research Center: Analytical effort and computer time using NASTRAN to calculate influence coefficients and thermal effects. Wind-tunnel test time for measuring force data, pressure distributions, and stability derivatives on scaled models.

(4) Flight Research Center: Utilization of the high temperature loads calibration facility to measure influence coefficients, thermal deformation and to calibrate aircraft instrumentation for flight-loads measurement. Provide support and conduct the flight-test program.

IV. Approach - The approach used in conducting the Structural Dynamics program will be a combination of analytical calculations, experimental investigations using ground facilities and flight tests. Areas of investigation and the primary responsibilities of each participating center are shown in Table I. Initial studies are aimed at a complete definition of the aerothermoelastic properties of the actual aircraft structure. Experimentally determined thermal response, structural influence coefficients and vibration modes of the complete airplane will be used to assess and improve the analysis methods. Once the properties of the airframe are well in hand, the information will be used to define and construct wind-tunnel models, determine the aeroelastic effects on stability and control, predict flight loads and define the airplane response to turbulence. The properties will also be used to design a model suppression system and determine system effectiveness throughout the flight envelope.

The final phase of the program will bring together the results of the analysis, laboratory and flight tests for a complete evaluation of the state-of-the-art in structural dynamics of supersonic-cruise aircraft.

V. Resources and Schedules - In-house manpower and R. & D. funds required for the Structural Dynamics program are shown in Table II. Table III shows that the R. & D. funds for this program are to be expanded over three fiscal years starting in FY 1970. The time schedule for the various center efforts and the relationship to the flight program is shown in Table IV.

TABLE I

Program Breakdown

	FRC	LaRC	ARC
I. Airplane Structural Characteristics			
1. Room temperature influence coefficients	1. Experimental measurements during ground tests on airplane.		1, 2. Calculations using NASTRAN and updated mass and structural data.
2. Mode shapes and frequencies	2. Experimental measurements during ground tests on airplane.	2. Calculations using Lockheed mass and stiffness data.	
3. Thermal Effects	3. Experimental measurements of deformation during heating tests on airplane, check case for influence coefficients of hot structure.		3. Calculate thermal deformation and influence coefficients of hot structure using NASTRAN.
II. Gust Response			
1. High Altitude Turbulence Experience	1. VGH recorder on all flights.		
2. Airplane Transfer Functions	2. Flight measurements of gust input and airplane response. Develop high-temperature α and β sensors for measurement of gust veloci-	2. Calculate transfer functions from data developed in I.	

TABLE I

(CONTINUED)

	FRC	LaRC	ARC
3. Modal Suppression	3. Contract for design, fabrication and installation of damper system. Evaluate system performance in flight.		
III. Flight Loads and Deformation			
1. Flight Loads	1. Calibrate strain gage for both loads and thermal response. Conduct test program to measure flight loads.		1. Calculate loads from theoretical pressure distribution. Construct pressure model and determine loads from wind-tunnel test data.
2. Structural Deformation	2. Develop instruments to measure structural deformation in flight.		2. Calculate deformation due to thermal and flight loads using NASTRAN.

TABLE I

(CONCLUDED)

	FRC	LaRC	ARC
IV. Aeroelastic Effects 1. Stability and Control	1. Conduct flight tests to measure derivatives at various conditions throughout flight envelope.	1. Construct an elastic model and measure derivatives in the transonic range. Calculate the aeroelastic effect on derivatives for subsonic and supersonic conditions.	1. Construct force model and measure derivatives on rigid deformed model. Calculate aeroelastic corrections for derivatives at other conditions.

TABLE II

R. & D. Cost and Manpower Summary

	FRC		LaRC		ARC	
	Cost, dollars	Man-years	Cost, dollars	Man-years	Cost, dollars	Man-years
I. Airplane Structural Characteristics						
1. Test support	150K					
2. Tests and data analysis		6		1/2		1
3. Update mass and stiffness data					280K	1/2
II. Gust Response						
1. Develop high temperature α, β sensors	50K	2				
2. Calculate airplane transfer functions and response				1		
3. Modal suppression development and installation	2,000K	2				
III. Flight Loads and Deformations						
1. Flight temperature monitor and deformation measuring systems	400K	1				
2. Loads and thermal calibration		5				
3. Pressure model and loads definition					250K	2
4. Calculate deformation					15K	1
IV. Aeroelastic Effects of Stability and Control						
1. Flight analysis		2				
2. Modify pressure model for force tests					50K	
3. Construct elastic model			200K			
4. Calculate aeroelastic effects				2	25K	1

TABLE III

Funding Schedule

	Fiscal Year			
	70	71	72	73
I. Airplane Structural Characteristics				
1. Test support	150K			
2. Tests and data analysis				
3. Update mass and stiffness data	280K			
II. Gust Response				
1. Develop high temperature α, β sensors	50K			
2. Calculate airplane transfer functions and response				
3. Modal suppression development and installation	250K	1,000K	750K	
III. Flight Loads and Deformations				
1. Flight temperature monitor and deformation measuring systems	400K			
2. Loads and thermal calibration				
3. Pressure model and loads definition		250K		
4. Calculate deformation	15K			
IV. Aeroelastic Effects on Stability and Control				
1. Flight analysis				
2. Modify pressure model for force tests			50K	
3. Construct elastic model		200K		
4. Calculate aeroelastic effects			25K	
Total	1,145K	1,450K	825K	

TABLE IV

Schedule

	NASA Center	Fiscal Year 70	71	72	73	74	75
I. Airplane Structural Characteristics							
1. Room-temperature influence coefficients	FRC						
	ARC						
2. Mode shapes and frequencies	FRC						
	ARC						
	LRC						
3. Thermal effects	FRC						
	ARC						
II. Gust Response							
1. High altitude turbulence experience	FRC						
2. Airplane transfer functions	LRC						
	FRC						
3. Modal Suppression							
(a) Development	FRC						
(b) Flight tests	FRC						
III. Flight Loads and Deformation							
1. Flight loads							
(a) Calibration	FRC						
(b) Flight tests	FRC						
(c) Pressure model	ARC						
(d) Wind-tunnel tests	ARC						

TABLE IV
(CONCLUDED)
Schedule

	NASA Center	Fiscal Year 70	71	72	73	74	75
III. Flight Loads and Deformation (Continued)							
2. Structural Deformations							
(a) Develop flight instrumentation	FRC						
(b) Flight tests	FRC						
(c) Calculate deformations	ARC						
IV. Aeroelastic Effects on Stability and Control							
1. Flight tests	FRC						
2. Elastic model construction and test	LRC						
3. Force model tests	ARC						
4. Calculated characteristics	LRC ARC						
V. Results, Summary and Reports	ALL						

Attachment

1a.

DEFORMATION AND LOADS

Objectives:

1. Obtain accurate flight-aerodynamic-loads measurements for evaluation of current prediction methods for hot-structure aircraft.

2. Obtained laboratory and flight measurements of structural deformation for evaluation of current prediction methods and definition of cruise shape.

Approach:

Loads Measurements

1. Complete structural-temperature survey.

2. Completion of current laboratory equipment expansion including 500 channels of direct digital control and increase to 20 megawatts total power available.

3. Design and fabrication of YF-12A structural heating and loading systems.

4. Complete instrumentation of No. 2 airplane with thermocouples and strain gages.

5. Exploratory flight sufficient to obtain structural-temperature survey prior to laboratory tests.

6. Calibration of all strain gages with room temperature loading.

7. Thermal calibration of strain gages at loads-maneuver-temperature conditions.

8. Twenty flights with loads maneuvers.

Deflection Measurements

1. Development of a mechanical deflection measurement system for use in determining hot and cold influence coefficients in the laboratory.

2. Development of an optical system for checking selected point deflections in flight during loads maneuvers.

Instrumentation:

1. Temperatures

Sensors - 800 bonded thermocouples.

Frequency - 1 sample per second with continuous data from take-off through cruise.

Installation - to be done by Loads Laboratory personnel. Time required, approximately 3 months.

Data Requirement - design cruise conditions as early in the program as possible. Equilibrium temperatures at several Mach numbers.

2. Strain

Sensors - 46 strain-gage bridges.

Frequency - bending and shear, 50 samples per second; hinge moments, 200 samples per second.

Installation - to be done by Loads Laboratory personnel. Time required, approximately 1 to 2 months.

Data Requirement - 20 flights with loads maneuvers to be performed after all calibrations are accomplished.

3. In-Flight Deflections

Sensors - an optical system is planned.

Frequency - camera system speed not yet determined.

Installation - system to be procured and installed by FRC.

Data Requirement - data will be taken during all loads maneuvers.

4. Hot-Spot Deflection

Sensor - infrared television system.

Recording - the system will be a self-contained package with a separate tape recording system.

Installation - system to be procured and installed by FRC.

HIGH ALTITUDE TURBULENCE

Objective:

Enlarge scope of data on extent and magnitude of clear air turbulence at altitudes above 40,000 feet.

Approach:

This program would require installation of a NASA VGH recorder on both aircraft during the flight phase of each and as early as possible. The greatest value of the data will be obtained during routine missions and pilot checkout flights and will require no special flights.

The available VGH recorder will be required to record two accelerations, one at airplane center of gravity and one at pilot's station. In addition, a signal correlating film-time with other system timer, will be required.

AIRPLANE DYNAMIC RESPONSE

Objective:

Determine the flexible airplane structural-dynamic characteristics throughout the flight envelope by (a) ground vibration tests and (b) in-flight vibration tests.

Approach:

Ground vibration tests will be conducted to establish the basic aircraft vibration modes and frequencies including the generalized mass of each mode. These tests will be conducted using external vibration exciters and response measuring instruments. The results of these tests will be used to define the locations and requirements of components for the flight measurements. A vibration exciter or shaker system will be designed and installed on the aircraft to provide controlled inputs for the study of airplane symmetric modes throughout the flight envelope.

Although most of the flight-test data can be obtained during flights for other program objectives, it is anticipated that two special flights will be required to complete the test program.

Results from this program will be used to define system requirements for the loads alleviation and elastic mode suppression system that will be designed and installed for flight-test evaluation on the aircraft.

ELASTIC MODE CONTROL

Objectives:

The objectives of the elastic mode control investigation are as follows:

1. Demonstrate elastic mode control on a supersonic configuration at both subsonic and supersonic conditions using the vibration exciter to supply mode damping.

2. Demonstrate elastic mode control on a supersonic configuration at both subsonic and supersonic conditions using an optimum designed control system that will provide mode damping operation over the entire flight envelope.

Approach:

Initially, analytical studies will be made to evaluate control effectiveness, select sensor locations, determine servoactuator response, and estimate hydraulic power requirements. Data from the ground vibration test will be used to update the analytical studies. Signal conditioning and electrical power equipment would also be defined and selected.

Flight tests will be conducted in turbulence where possible to determine the associated aircraft response, and in the absence of turbulence tests will be conducted with the vibration exciter. The mode shapes and frequencies obtained in flight will be used to update the analytical model for the design of the elastic mode control system. This information will be used for the analysis and design of the optimum elastic mode control system and to predict flight results when employing such a system. Testing of the elastic mode control system will be accomplished at several flight conditions by exciting the structural modes with the vibration exciter and with the system engaged, measuring the vehicle response. These tests will be compared to the basic airplane data obtained by utilizing the vibration exciter for the same flight conditions under test. Investigation of the elastic

mode control system in turbulence is desired whenever sufficient data samples can be obtained, again the system response will be compared to the basic airplane response.

In order to accomplish the objectives of this program, the test aircraft would require special modifications. These modifications may include installation of irreversible, high response servoactuators for increased control response and structural beef-ups for increased safety. Accelerometers will be required to monitor and record vehicle response at several selected locations on the aircraft.

MEMORANDUM OF UNDERSTANDING

USAF-NASA YF-12 RESEARCH AND DEVELOPMENT PROGRAM

I. GENERAL

The recent conclusion of the XB-70 and X-15 programs has left both the USAF and NASA without a suitable vehicle, capable of sustained Mach 3 flight, to continue aeronautical research and development objectives. To alleviate this situation, it is agreed that two YF-12A aircraft now in storage at Edwards Air Force Base, will be made available for a joint program of aeronautical research, development, test and operational evaluation. This program will consist of two phases: Phase I is oriented primarily toward Air Force interests, but will also accommodate NASA investigations; Phase II is oriented primarily toward NASA objectives, with provision for Air Force participation. To implement the working relationships between the USAF and NASA, detailed sub-agreements to this Memorandum of Understanding will be written to cover the areas of test management, operations, security and specific loan arrangements.

II. OBJECTIVES

a. The USAF Phase I program will more fully define the tactical performance and support requirements of an advanced interceptor, as applied to the Aerospace Defense Force concept. This will include, but not be limited to, the following major areas of interest: (1) tactical tests of command, control and communications; (2) test intercepts of a variety of modern aircraft at all altitudes; (3) tests of the ASG-18 fire control system in an up-to-date ECM environment; (4) examination of post attack escape maneuvers and development of optimum re-attack techniques; (5) demonstration of the semi-autonomous operation concept of a Mach 3 interceptor; and (6) determination of the feasibility/desirability of a visual identification maneuver against an SST type target.

b. The NASA Phase II program will include investigations of the following general type: (1) assessment of the adequacy of current analytical and simulation techniques to predict propulsion system dynamic characteristics when the system is perturbed by changes in the atmospheric environment, aircraft maneuvers and engine transients; (2) investigation of aerothermoelastic effects on aircraft stability, control and handling qualities; (3) verification of modal suppression techniques and studies of the effects of the combined effects of flight loads and structural deformations resulting from maneuvers, turbulence, and/or aerodynamic heating; (4) investigation of airframe-propulsion system interactions involving the effects of inlet unstart on the aircraft's transient motions; and (5) other investigations such as altitude-hold at supersonic speeds and boundary layer noise and heat transfer characteristics under high speed flight conditions.

DOCUMENT 2 – Memorandum of Understanding, USAF-NASA YF-12 Research and Development Program, 5 June 1969.

These and other research objectives will be supported by NASA personnel and laboratory facilities to develop new knowledge for use in both military and commercial aircraft of the future.

III. DESCRIPTION

a. Phase I will be initiated with the approval of this Memorandum of Understanding and the issuance of appropriate directives and funding authorizations. The primary Phase I aircraft will be flown against Air Force objectives for approximately 125 missions over a two and one half year period. This aircraft will contain aircraft performance-type instrumentation, to be maintained by NASA, which will normally be utilized on all flights. NASA objectives will have priority on about one fourth of the Phase I flights. The second aircraft, which NASA will instrument for the Phase II program, will be flown by the USAF for the first six months of Phase I.

b. Phase II will be initiated with the transfer of an aircraft on a loan basis to NASA for instrumentation six months after the initiation of Phase I. The period of the loan will be as required to accomplish the NASA objectives, except the aircraft will be returned at any time in case of an overriding priority need by the USAF.

IV. MANAGEMENT CRITERIA

Because of the unique procedures which cover certain aspects of the YF-12A program, it is mutually agreed that the following criteria will apply to the conduct of this joint test program:

a. Special management procedures will apply for both phases and will continue as USAF responsibilities.

b. Until a new YF-12A Security Plan is written, the present Senior Crown Security Plan will continue in force.

c. The Phase I test program will be under the operational control of the SR-71/F-12 Joint Test Force, AFFTC, augmented by NASA personnel. The Phase II test program will be under the operational control of NASA, augmented by personnel from the SR-71/F-12 Joint Test Force, as available.

d. Contractor support will be required for both phases.

e. A precedence rating of 1-7 is currently assigned the YF-12A and will continue for the duration of the test program.

f. Key NASA maintenance personnel will receive on-the-job training and will participate as part of the maintenance crews, with the intent of assuming the maintenance of the Phase II aircraft.

g. USAF will furnish maintenance and air crew personnel for both aircraft for the first six months of Phase I, and for one aircraft for the remainder of the Air Force program.

h. Flight crews will be furnished by the USAF for Phase I and by NASA for Phase II. Prior to the beginning of active Phase II flying, two NASA flight crews will be checked out. It is anticipated that such checkout will begin approximately one month prior to active Phase II flying.

i. NASA will provide, install, checkout, maintain and operate all aircraft R&D instrumentation (not to include fire control/missile system instrumentation), with the assistance of the SR-71/F-12 Joint Test Force, as available.

V. SECURITY

a. The security requirements affecting the YF-12A program were designed to protect the sensitive aspects of the SR-71. These aspects differ appreciably from the scientific and technical data expected to be generated by both phases of this test program. It is mutually agreed that every effort will be made to classify all aspects of the YF-12A to as low a security level as possible, without the constraints of Special Access. Until the security plan is revised, however, the existing Senior Crown Security Plan will remain in effect.

b. To this end, an Air Force-NASA security revision group will be formed to advise the YF-12/SR-71 Program Director and enable him to issue a mutually agreeable security plan that will not only protect the sensitive aspects related to the SR-71, but will also allow the distribution of both classified and unclassified technical data generated on this program to the scientific and industrial communities on a normal security basis as provided by AFR 205-1 and NHB 1620.3, July 1966.

c. Access by NASA personnel to YF-12A hardware and data will require the maintenance of a Senior Crown Access Roster, in accordance with existing security requirements. The F-12/SR-71 Program Director will designate NASA focal points for the maintenance and control of the NASA Senior Crown Rosters.

VI. SUPPORT RESPONSIBILITIES

With respect to support of this program, it is agreed that the parties involved will provide the following support throughout the test program:

a. The USAF will provide two YF-12 aircraft, maintenance and operations support, hangar and office space, base services, engine and aircraft AGE, other required support equipment, POL, tanker support and other related functions and services normal to this kind of program.

b. NASA will budget for and fund this test program in accordance with present USAF estimates, for the period FY 69 through FY 74, inclusive of $9.9M (plus Lockheed Phase II costs) allocated as follows:

($ in Millions)

FY 69	FY 70	FY 71	FY 72	FY 73	FY 74
$1.06	$3.595	$2.916	$.827	$.827	$.664

It is understood that the pricing information above does not reflect an input from Lockheed (ADP) for Phase II. The associated costs for ADP support of Phase II must be negotiated at a later date. NASA will fund by issuance of an O/A to Headquarters AFSC for authorization of procurement by the F-12/SR-71 SPO, WPAFB, Ohio, of the necessary YF-12 support effort. NASA will reimburse the Air Force for fuel, material, supply items and such other goods and services required to support this test program, as agreed upon by the F-12/SR-71 SPO and the Director, NASA Flight Research Center.

c. ~~USAF~~ NASA will ~~jointly~~ provide the following support: mission planning, data reduction, and distribution, reporting, test operations, range and chase aircraft support as required.

VII. PUBLIC RELEASE OF INFORMATION

It is specifically agreed that all materials, regardless of nature, proposed for public release in any form will be submitted to the Director of Information, Office of the Secretary of the Air Force (SAFOI) for approval prior to release. General policy supervision of the public information program and authority to resolve information differences will be exercised jointly by the Assistant Administrator for Public Affairs, NASA, and the Director of Information, Office of the Secretary of the Air Force.

VIII. RENEGOTIATION CRITERIA

a. This Memorandum of Understanding is based upon the premise that the SR-71 test activity will continue at Edwards AFB for the duration of this test program. In the event that such SR-71 activity either ceases, or moves to an alternate operating location, this memorandum will be renegotiated for continued NASA support.

b. In the event that an F-12B program receives a go-ahead during this test program, all YF-12A assets must be reviewed for differing flight objectives and flight rates and may require the renegotiation of this Memorandum of Understanding.

IX. TERMINATION CRITERIA

This Memorandum of Understanding will remain in effect until the end of CY 73, unless modified, extended by mutual agreement, or terminated earlier by written request of either party.

UNITED STATES AIR FORCE:

Approved: Grant L. Hansen
ASSISTANT SECRETARY OF THE AIR FORCE
(RESEARCH AND DEVELOPMENT)

Date: JUN 5 1969

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION:

Approved: Charles W. Harper
DEPUTY ASSOCIATE ADMINISTRATOR (AERONAUTICS)
FOR ADVANCED RESEARCH AND TECHNOLOGY

Date: JUN 5 1969

NASA ISSUANCE TRANSMITTAL SHEET	DATE April 20, 1970	ISSUANCE NO. NMI 1052.134

MATERIAL TRANSMITTED

1. NMI 1052.134 "USAF-NASA Agreement--Loan of YF-12A Aircraft, Serial No. 60-6935," effective March 31, 1970.

FILING INSTRUCTIONS

1. File in standard 3-ring binder in numerical sequence, without regard to the alphabetic prefix which identifies the type of issuance.

NASA FORM 1182a (MAR 1965)

DOCUMENT 3 – NASA Management Instruction, USAF-NASA Agreement—Loan of YF-12A Aircraft, Serial Number 60-6935.

NMI 1052.134

March 31, 1970
Effective date

Management Instruction

SUBJECT: USAF-NASA AGREEMENT--LOAN OF YF-12A AIRCRAFT, SERIAL NUMBER 60-6935

1. PURPOSE

This Instruction incorporates in the NASA Issuance System as Attachment A the USAF-NASA Loan Agreement for YF-12A Aircraft, Serial No. 60-6935.

Eleanor G. Borella
Chief, Management Issuances and Information Branch
Administrative Services Division

DISTRIBUTION:
SDL 1

1

ATTACHMENT A
NMI 1052.134

USAF/NASA LOAN AGREEMENT
FOR
YF-12A AIRCRAFT - SERIAL NUMBER 60-6935

I. Purpose:

The purpose of this Agreement is to authorize the loan of YF-12A aircraft, Serial Number 60-6935, and to establish and define the division of responsibilities between the Air Force and the National Aeronautics and Space Administration (NASA) for providing operational and logistic support for this aircraft.

II. Authority:

Authority for this Loan Agreement is established by the USAF/NASA Memorandum of Understanding, dated June 5, 1969, concerning the use of two YF-12A aircraft in a jointly sponsored USAF/NASA Research and Development Program.* The USAF/NASA Memorandum outlines general provisions by which both agencies can continue aeronautical research and development objectives using vehicles capable of sustained Mach 3 flight. Major provisions include the conduct of a USAF Phase I program which will more fully define the tactical performance and support requirements of an advanced interceptor; and, following loan of one of the aircraft and associated equipment to NASA, the conduct of a NASA Phase II program principally directed towards the better understanding of propulsion system, aerothermoelastic, and flight dynamics characteristics related to supersonic cruise aircraft. Additionally, the Memorandum provides for the participation in and support of both phases of the program by both agencies.

III. Property to be Loaned:

The YF-12A aircraft Serial Number 60-6935, and associated engines, engine spares, vehicle spares, supporting material, AGE, and other equipment or facilities, as further delineated in the DD-1149 documents, and in SR-71/F-12 Joint Test Force/NASA FRC Operating Agreement, will be loaned or otherwise made available, as appropriate, by the USAF to NASA, as required for conduct of the NASA Phase II program.

IV. Period of Loan:

The period of loan will commence about March 1, 1970, or later, depending upon satisfactory operational status of the aircraft, and will terminate at the end of CY 1973, unless otherwise changed by agreement between the Air Force and NASA, subject to provisions of the termination clause. SR-71 common items are subject to recall at anytime by the AFLC (ASPO) when required to support operational commitments.

*For official use only.

V. Point of Delivery and Base of Operation:

The Point of Delivery and Base of Operation will be Edwards Air Force Base, California.

VI. Use of Aircraft:

The YF-12A provided in this Agreement will be used by the NASA for aeronautical research. The Air Force will participate in this effort as described in the Memorandum of Understanding.

VII. Support of Loaned Aircraft:

a. The Air Force is currently providing and within its capabilities, will continue to provide, on an as required basis, the following support: contractor services, maintenance and operations support, hangar and office space, engine and aircraft AGE, other required support equipment, POL, tanker support, and other related functions and services normal to this kind of program.

b. Special management procedures, as appropriate, will apply to the support of this program and will continue as USAF responsibilities.

c. NASA will reimburse the Air Force for contractor support, fuel, supply items, and such other material and services required to support this program, as agreed upon by the F-12/SR-71 SPO, its successor, or AFLC (ASPO), and the Director, NASA FRC.

d. Adequate property records will be maintained to satisfy requirements of NASA or Air Force, as appropriate, and the account will be maintained in an auditable status at all times.

e. Supply precedence rating will be the same as that provided for the overall Joint USAF/NASA Research and Development Program.

VIII. Maintenance of Aircraft:

a. NASA shall keep the loaned aircraft in safe mechanical condition and shall be responsible for the safe handling of the loaned aircraft.

b. NASA will be responsible for maintaining adequate aircraft and engine maintenance records.

c. NASA, in coordination with the Air Force, will schedule the loaned aircraft for maintenance and aircraft down time for the purpose of major repairs and/or aircraft changes.

d. NASA, in coordination with the Air Force, may modify the loaned aircraft or AGE, if required, to attain NASA Phase II research objectives. Any modifications of such a character as to preclude the economical restoration of the aircraft or AGE to its original configuration, will be made only with Air Force approval.

IX. Operation of Aircraft:

NASA shall be responsible for the safe operation of the loaned aircraft. The Phase II test program will be under the operational control of NASA, augmented by personnel from the SR-71/F-12 Joint Test Force, as available. The aircraft will be operated within the constraints of the flight manual and the approved joint test plan (to include addendums). Any deviation of such must be approved by the SR-71/F-12 SPO or its successor.

X. Training:

The Air Force will be responsible for providing adequate preflight training and for the checkout of two NASA flight crews prior to active Phase II flying. The selection of the NASA YF-12A pilots will be NASA's responsibility. The specific training to meet NASA's requirements will also be NASA's responsibility; however, it will be coordinated with the Air Force.

XI. Security:

A joint USAF/NASA Security Plan for YF-12 Research and Development Program, as required by the Memorandum of Understanding, has been developed and provides necessary guidance and procedures for conduct of the program.

XII. Public Media, Data and Reports:

a. All materials, regardless of nature, proposed for public media (press, radio, TV release) in any form will be submitted to the Director of Information, Office of the Secretary of the Air Force (SAFOI) for approval prior to release. General policy supervision of the public information program and authority to resolve information differences will be exercised jointly by the Assistant Administrator for Public Affairs, NASA, and the Director of Information, Office of the Secretary of the Air Force.

b. All technical and operational data and reports generated in the NASA Phase II program will be available to the Air Force.

c. Security classification of data and reports will be in accordance with the YF-12A Security Plan and appropriate directives.

XIII. Edwards Air Force Base Assistance:

Program assistance, within the capability/resources of the AFFTC, will be provided to NASA FRC through the SR-71/YF-12 Joint Test Force. Detailed program requirements will be identified in appropriate documentation between AFFTC and NASA FRC.

XIV. Liability:

a. Liability for damage to the aircraft or other property loaned hereunder shall be the responsibility of NASA; provided, however, that in the event of substantial damage to the aircraft or other property so loaned, there must be a joint USAF/NASA decision to repair or not to repair. In arriving at the decision consideration must be given to such factors as the availability of funds and the value of such expenditure in light of accomplished tests and other programmatic considerations extant at the time of the incident. If a decision to repair is made, NASA will bear the cost.

b. If the aircraft, while in the custody and under the control of either NASA or the Air Force, is damaged beyond economical repair, NASA shall not be required to reimburse the Air Force for the aircraft.

c. With respect to third party claims, NASA shall undertake responsibility for the investigation, adjudication, settlement, and payment of any claim asserted against the United States which arises from the use or operation of the loaned property, including all such claims resulting from flight operations without regard to the fact that the pilots and other crew members may be Air Force personnel. This shall also apply to a claim which arises at a time when the loaned property is in the sole custody and under the exclusive operational control of the Air Force, except that NASA may request the assistance of the Air Force in the investigation of such a claim.

XV. Termination:

Unless preempted by provisions of the Memorandum of Understanding, this agreement will be terminated by mutual consent. Upon termination, the provisions of the "Return of Loaned Property" clause in this agreement shall control.

XVI. Return of Loaned Property:

Upon termination of the loan period either by conclusion of the Joint USAF/NASA Research and Development Program, or action by

the parties, NASA will return the loaned property at no cost to the Air Force at a mutually agreeable location and in a mutually acceptable condition.

XVII. Accident/Incident Investigation and Reporting (Safety):

In the event of an accident or incident, as defined in Air Force Regulation 127-4, involving the loaned aircraft or other loaned property, NASA is responsible for investigating and reporting the accident or incident in accordance with the USAF/NASA Agreement for Joint Aircraft Accident Investigations dated March 1968, as affected by the provisions of the USAF/NASA Memorandum of Understanding dated 5 June 1969 and the USAF/NASA Security Plan signed 6 Jan 1970. All such accidents or incidents will be reported by NASA FRC immediately to the Director of Aerospace Safety (AFIAS-F), Norton Air Force Base, California; Headquarters AFSC (SCSA2), Andrews Air Force Base, Washington, D. C.; and to the YF-12/SR-71 Program Director, Headquarters, ASD, Wright-Patterson Air Force Base, Ohio. NASA agrees to cooperate fully with the Air Force in fulfilling the purposes of Air Force Regulation 127-4.

XVIII. Agreement Review:

This agreement shall be reviewed as required for the purpose of updating any portions requiring changes, or for determining need for continuance.

XVIV. Agreement Approval:

UNITED STATES AIR FORCE

CONCUR
YF-12/SR-71 System Program Office
Wright-Patterson AFB, Ohio 45433

APPROVE
Deputy Chief of Staff/Systems
HQ Air Force Systems Command
Andrews AFB, Washington, D.C. 20331

Date: March 26, 1970

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONCUR
NASA Flight Research Center
Edwards, California 93523

APPROVE
Assistant Administrator for DOD and Interagency Affairs
National Aeronautics and Space Administration
Washington, D.C. 20546

Date: March 31, 1970

AIR INLET SYSTEM

The inlet system includes the cowl structure, a moving spike to help provide optimum internal airflow characteristics, a spike porous centerbody bleed, forward and aft bypass openings, and an internal cowl shock trap bleed for internal shock wave positioning and boundary layer flow control. The air inlets for each nacelle are canted inboard and downward to align with the local airflow pattern. (See figures 1-3 and 1-4.) The forward and aft bypass openings control airflow characteristics within the inlet and mass flow to the engine. Normally, the spike and forward bypass opening is operated automatically by the air inlet control system and the aft bypass opening is scheduled manually. Overriding manual controls are provided for the spike and forward bypass. The forward bypass can be operated manually with the spike in automatic operation; however, when the spike is controlled manually the forward bypass must also be in manual control if variable bypass opening is desired. Manual operation of the spike alone while the forward bypass control is in the AUTO position will cause the forward bypass to open fully.

Inlet Control Parameters

Inlet airflow is controlled automatically at supersonic airspeed by the forward bypass and spike positioning so that the locations of shock waves ahead of the inlet and at the inlet throat produce maximum practicable ram (pressure recovery) at the engine face and supply the proper amount of air to the engine.

Manually operated controls provide incremental operation of the aft bypass for those conditions where additional bypass area is required or where a reduction in forward bypass flow is desired. The forward and aft bypass openings and the spikes for the left and right inlets are operated by the L and R hydraulic systems, respectively.

The parameters used to control automatic forward bypass and spike positioning include Mach number, angle of attack, and angle of sideslip. The inlet control also includes a load factor (g) bias to the spike and forward bypass schedules, and a shock expulsion sensor and restart system.

Load Factor Bias

The g-bias function of the air inlet control computer causes the spike to schedule forward and the forward bypass to schedule more open when load factors greater than 1.12 g or less than 0.88 g are experienced during automatic inlet scheduling. The spike biasing is approximately 2 1/2 inches forward per 1-g variation in normal acceleration. This action reduces the possibility of inlet unstarts occurring during turns or other maneuvers which affect angle of attack at the inlets. A noticeable decrease in CIP results from operation of the g-bias. The g-bias feature does not override a manually operated spike or forward bypass.

INLET SPIKES

Each spike is automatically locked in the forward position for ground operation and for flight below 30,000 feet. They are unlocked automatically above this altitude, but remain approximately full forward until Mach 1.6 is reached. During automatic operation above Mach 1.6, the spikes begin to retract to increase the inlet capture area and to de-

DOCUMENT 4 – Extract from YF-12A flight manual (declassified), concerning the air inlet system.

AIRFLOW PATTERNS

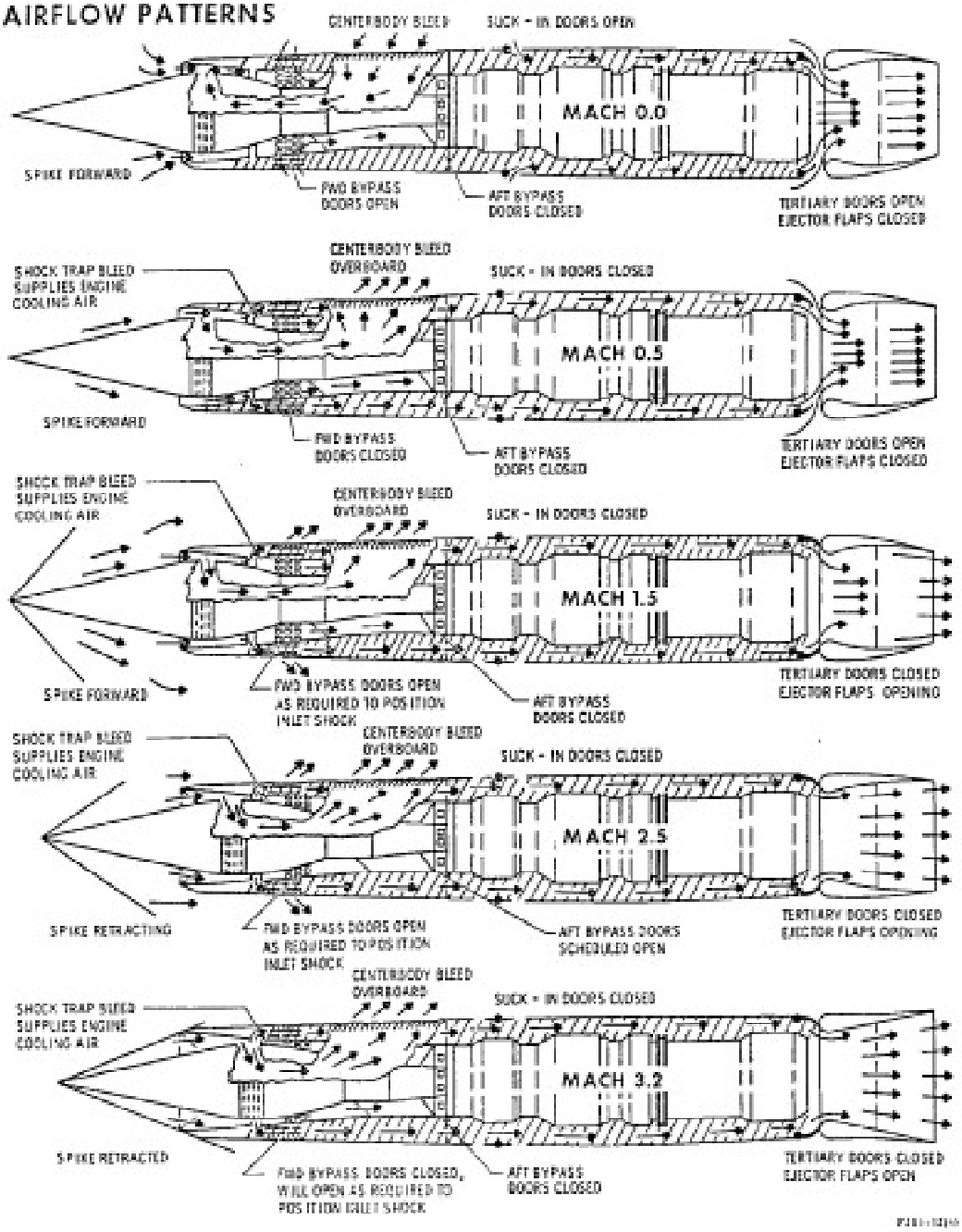

Figure 1-3

crease the inlet throat area which is the narrowest portion of the duct.

Spike position is scheduled primarily as a function of Mach number during automatic operation, with biasing for angle of attack, angle of sideslip, and normal g's. The spike moves aft approximately 26 inches during the transition from Mach 1.6 to Mach 3.2. Total and static pressures for Mach number control of spike position are sensed by the pitot-static head. Angle of attack and angle of sideslip are sensed by the attitude sensor probe located on the left side of the pitot mast. Normal g's are sensed by the inlet control normal accelerometer.

Spike position can also be set manually in accordance with a Mach schedule by use of cockpit controls unless hydraulic pressure is not available for the respective inlet. In this event, use of the appropriate emergency spike-forward switch provides one-shot pneumatic pressure to move and lock the affected inlet spike forward and open its forward bypass. A complete loss of the L and/or R system hydraulic pressure should exist prior to using the emergency system. If system hydraulic pressure for the affected inlet has not failed completely but is low or fluctuating, it is possible for the spike to become unlocked after gas pressure released by the emergency spike switch has been depleted. (SPIKE FWD should also be selected with the inlet spike control as a precaution.)

The spike centerbody is equipped with small slots which remove spike boundary layer air from the inlet throat. This porous construction prevents flow separation. The air is ducted overboard through the nacelle louvers after passing through the spike and its supporting struts.

INLET FORWARD BYPASS

The forward bypass openings in each inlet provide overboard exhausts for that portion of the inlet air which is not required by the engine. The amount of opening is automatically scheduled by the inlet computer to control inlet diffuser pressure and position the normal (internal) shock properly. The bypass consists of a rotating basket which opens duct exhaust ports located a short distance aft of the inlet throat. The excess air exits through louvers located forward of the spike centerbody bleed louvers. When the landing gear is down, the forward bypass is held open by application of an electrical override signal from a landing gear door switch. Control of the bypass openings reverts to the manual or automatic mode of operation, as selected by the pilot, after gear retraction. In automatic operation, the forward bypass remains closed until speed is above Mach 1.4. Then it is released to modulate in accordance with the air inlet control system schedules. The inlet usually "starts" in the speed range from Mach 1.6 to Mach 1.8; that is, the normal shock is made to move from a position in front of the inlet to a position near the cowl shock trap bleed in the inlet throat area. As Mach number increases, the forward bypass opening is scheduled as required to maintain the normal shock at the throat position.

In automatic operation, the amount of forward bypass opening is controlled by the inlet computer, which senses the ratio of inlet duct static pressure (P_sD8) to a reference total pressure (P_pLM). There are four inlet duct static pressure taps which act as shock position sensors. These taps are located circumferentially on the inlet duct wall aft of the shock trap bleed. The reference

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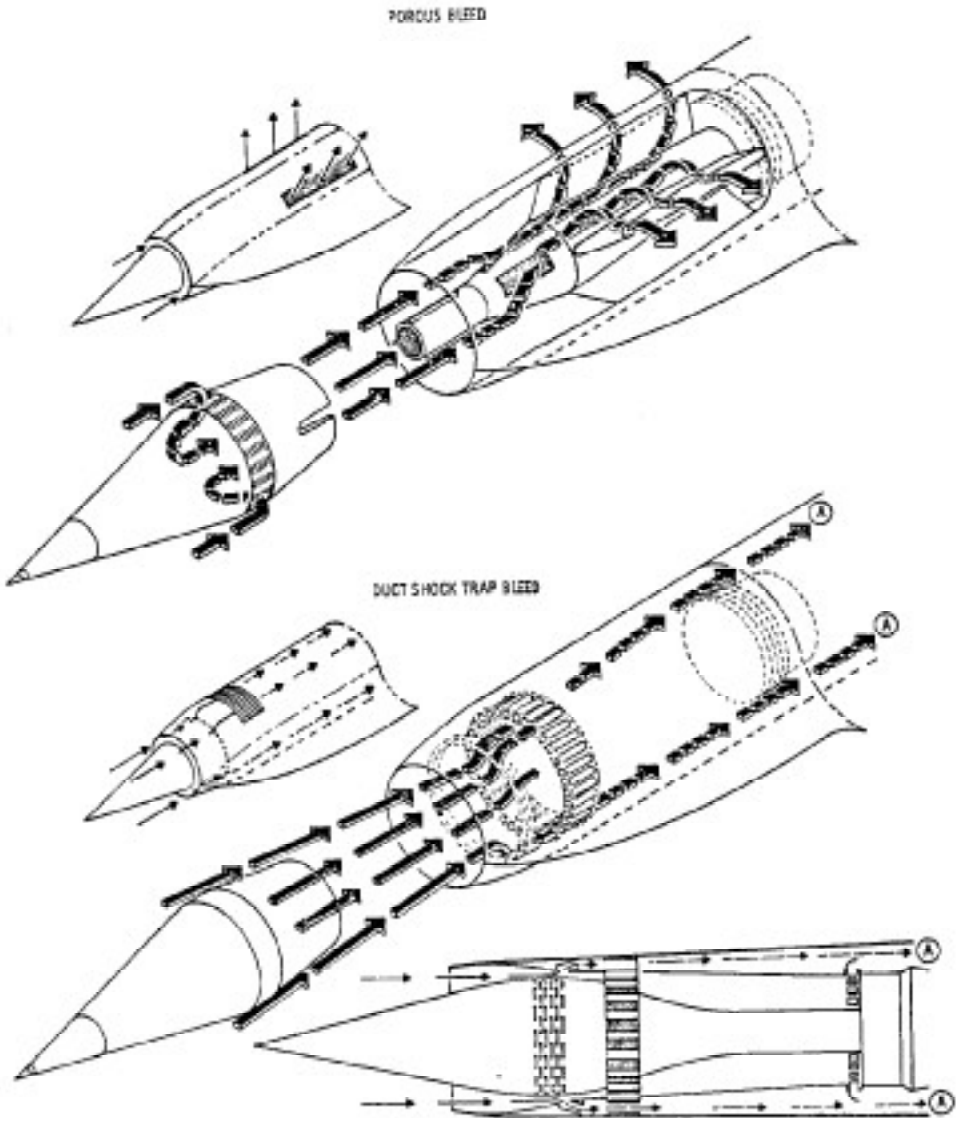

(A) Duct boundary layer air is removed at the shock trap. It passes through tubes in the bypass door, becomes secondary nacelle air and exhausts through the ejector nozzle.

Boundary Layer Control

Figure 1-4 (Sheet 1 of 2)

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total pressure is sensed by two external probes located on the outside of each nacelle. The amount of forward bypass opening can also be set manually in accordance with a Mach schedule by use of cockpit controls unless hydraulic pressure is not available. (See figure 1-5).

INLET AFT BYPASS

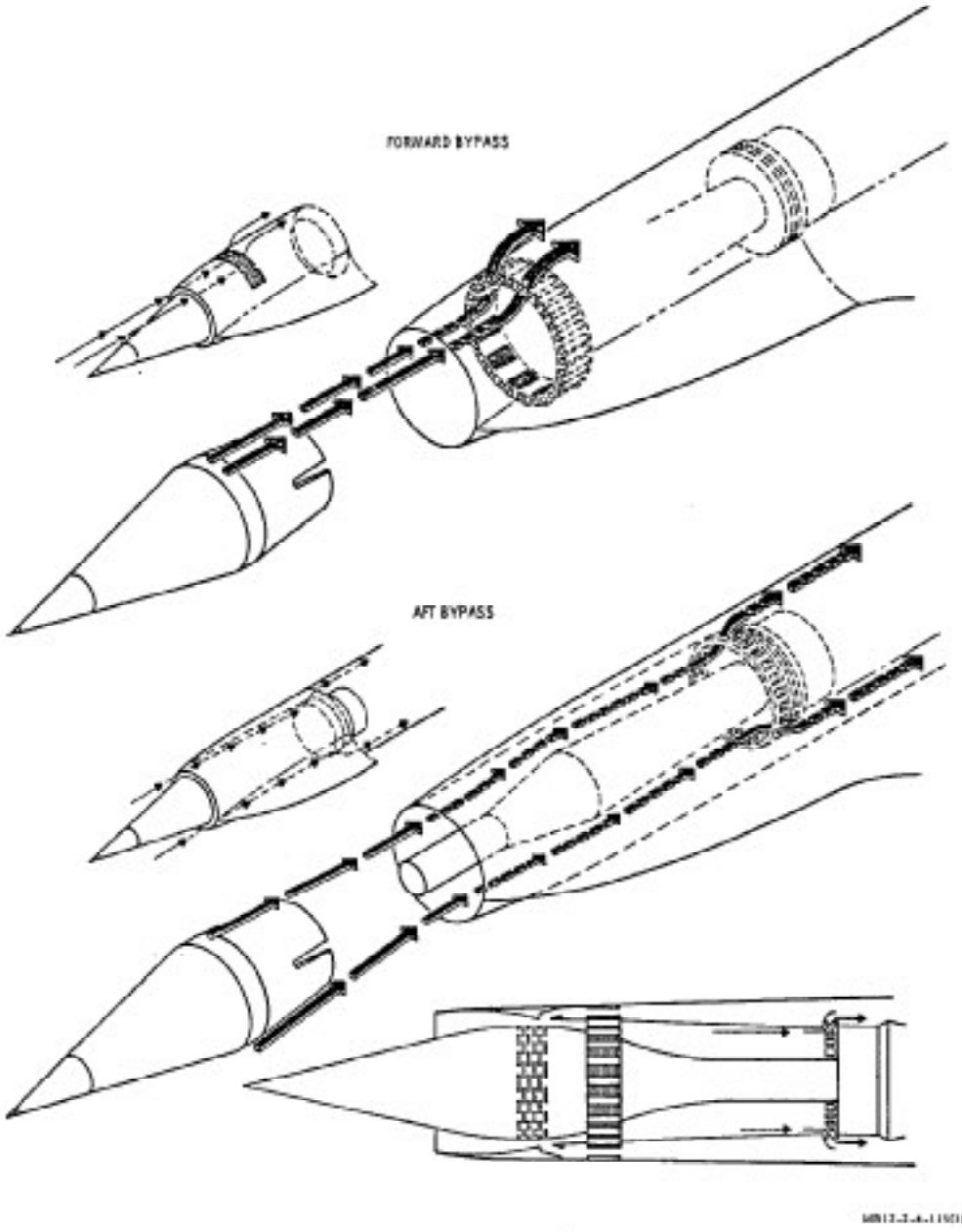
The air inlet aft bypass consists of a ring of adjustable, peripheral openings located just forward of the engine face. These openings allow inlet air to be bypassed around the engine. The bypassed air joins cowl shock trap bleed air and passes through the space between the outside of the engine and afterburner and the inside of the nacelle. This flow augments the exhaust gas flow in the ejector area. The aft bypass ring in each nacelle is positioned by a hydraulic actuator powered by the respective L or R hydraulic system, and controlled by a rotary switch in the cockpit. While the gear is down, the aft bypass is held closed by an electrical override signal from the nose gear downlock.

AUTOMATIC RESTART

The inlet control also includes a shock expulsion sensor (SES) and an auto restart feature which operates automatically when speeds above the minimum for inlet scheduling are reached. (Normally, SES is effective above Mach 2.0). If the inlet normal shock is expelled, the SES for that inlet overrides the auto spike and forward bypass schedules for both inlets. This "cross tie" feature keeps the other inlet from unstarting during attitude variations which might occur immediately after the original unstart occurs, reduces the asymmetric thrust which could otherwise result and minimizes undesirable sideslip angles. During the automatic restart cycle, the forward bypasses open fully and the spikes move forward as much as 15 inches. Spike retraction is started 3.75 seconds after the expulsion is sensed. Then, after the spikes return to their scheduled position, the forward bypasses are returned to automatic operation. The "cross tie" function is locked out below Mach 2.3 so that only the inlet which has unstarted will perform the automatic restart cycle.

Compressor inlet pressure (CIP) is the SES reference. Shock expulsion is sensed and the system actuated when a momentary CIP decrease of more than 23% occurs. Rapid CIP decrease is a characteristic indication of inlet unstart; however, the SES can also be actuated by compressor stalls if CIP fluctuates rapidly to more than 23% below the previously normal condition. Successive unstarts or compressor stalls may cause the SES reference pressure (CIP) to decay. The SES cannot operate if the momentary pressure drop is less than 23% of the existing reference pressure. The autorestart function is not activated in this event, and manual restart procedures will then be necessary.

The SES feature does not override a manually operated spike or forward bypass control and, if an unstart occurs on a side which is being operated manually, neither that inlet nor the opposite inlet will respond. Also, manual operation of the air inlet restart switch for an inlet which has unstarted while in automatic operation overrides the SES automatic restart cycle for that inlet.



Forward and Aft Bypass Door Airflow

Figure 1-4 (Sheet 2 of 2)

List of Acronyms

ADP	Advanced Development Projects
AEW	Airborne Early Warning
AFB	Air Force Base
AICS	Automatic Inlet Control System
ALT	Approach and Landing Tests
CAPA	Central Airborne Performance Analyzer
CAPCS	Cooperative Airframe/Propulsion Control System
CCV	Control Configured Vehicle
CIA	Central Intelligence Agency
Co-Op	Cooperative Controls
DFBW	Digital Fly-By-Wire
DFRC	Dryden Flight Research Center
DPR	Duct Pressure Ratio
F	Fahrenheit
FATOLA	Flexible Aircraft Takeoff and Landing Analysis
FCF	Functional Check Flight
FCO	Fire Control Officer
FLEXSTAB	Computer program to appraise effect of flexibility on stability and control characteristics of a supersonic airplane
FMU	Functional Mock-Up
FRC	Flight Research Center, earlier name for DFRC
HTLL	High Temperature Loads Laboratory
KEAS	Knots Equivalent Air Speed
LAMS	Loads Alleviation and Mode Control System
L/D	Lift over Drag
LLRV	Lunar Landing Research Vehicle
MOU	Memorandum Of Understanding
NAS	Naval Air Station
NASTRAN	NASA Structural Analysis computer program
OFT	Orbital Flight Test
PCM	Pulse Code Modulation
PIO	Pilot-Induced Oscillation
RSO	Reconnaissance Systems Officer
SAS	Stability Augmentation System
SCAR	Supersonic Cruise Aircraft Research
SST	Supersonic Transport
STI	Systems Technology, Incorporated
TEB	Tri-ethyl borane
TIFS	Total In-Flight Simulator
TIGT	Turbine Inlet Gas Temperature
USAF	United States Air Force

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About the Author

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Monographs in Aerospace History

Launius, Roger D., and Gillette, Aaron K. Compilers. *The Space Shuttle: An Annotated Bibliography*. (Monographs in Aerospace History, No. 1, 1992).

Launius, Roger D., and Hunley, J.D. Compilers. *An Annotated Bibliography of the Apollo Program*. (Monographs in Aerospace History, No. 2, 1994).

Launius, Roger D. *Apollo: A Retrospective Analysis*. (Monographs in Aerospace History, No. 3, 1994).

Hansen, James R. *Enchanted Rendezvous: John C. Houbolt and the Genesis of the Lunar-Orbit Rendezvous Concept*. (Monographs in Aerospace History, No. 4, 1995).

Gorn, Michael H. *Hugh L. Dryden's Career in Aviation and Space*. (Monographs in Aerospace History, No. 5, 1996).

Powers, Sheryll Goecke. *Women in Flight Research at the Dryden Flight Research Center, 1946-1995* (Monographs in Aerospace History, No. 6, 1997).

Portree, David S.F. and Trevino, Robert C. Compilers. *Walking to Olympus: A Chronology of Extravehicular Activity (EVA)*. (Monographs in Aerospace History, No. 7, 1997).

Logsdon, John M. Moderator. *The Legislative Origins of the National Aeronautics and Space Act of 1958: Proceedings of an Oral History Workshop* (Monographs in Aerospace History, No. 8, 1998).

Rumerman, Judy A. Compiler. *U.S. Human Spaceflight: A Record of Achievement, 1961-1998* (Monographs in Aerospace History, No. 9, 1998).

Portree, David S.F. *NASA's Origins and the Dawn of the Space Age* (Monographs in Aerospace History, No. 10, 1998).

Logsdon, John M. *Together in Orbit: The Origins of International Cooperation in the Space Station Program* (Monographs in Aerospace History, No. 11, 1998).

Phillips, W. Hewitt. *Journey in Aeronautical Research: A Career at NASA Langley Research Center* (Monographs in Aerospace History, No. 12, 1998).

Braslow, Albert L. *A History of Suction-Type Laminar-Flow Control with Emphasis on Flight Research* (Monographs in Aerospace History, No. 13, 1999).

Logsdon, John M. Moderator. *Managing the Moon Program: Lessons Learned from Project Apollo* (Monographs in Aerospace History, No. 14, 1999).

Perminov, V.G. *The Difficult Road to Mars: A Brief History of Mars Exploration in the Soviet Union* (Monographs in Aerospace History, No. 15, 1999).

Tucker, Tom. *Touchdown: The Development of Propulsion Controlled Aircraft at NASA Dryden* (Monographs in Aerospace History, No. 16, 1999).

Maisel, Martin D.; Demo J. Giulianetti; and Daniel C. Dugan. *The History of the XV-15 Tilt Rotor Research Aircraft: From Concept to Flight*. (Monographs in Aerospace History #17, NASA SP-2000-4517, 2000).

Jenkins, Dennis R. *Hypersonics Before the Shuttle: A History of the X-15 Research Airplane*. (Monographs in Aerospace History #18, NASA SP-2000-4518, 2000).

Chambers, Joseph R. *Partners in Freedom: Contributions of the Langley Research Center to U.S. Military Aircraft in the 1990s.* (Monographs in Aerospace History #19, NASA SP-2000-4519, 2000).

Waltman, Gene L. *Black Magic and Gremlins: Analog Flight Simulations at NASA's Flight Research Center.* (Monographs in Aerospace History #20, NASA SP-2000-4520, 2000).

Portree, David S.F. *Humans to Mars: Fifty Years of Mission Planning, 1950-2000*. (Monographs in Aerospace History #21, NASA SP-2001-4521, 2001).

Thompson, Milton O. *Flight Research: Problems Encountered and What They Should Teach Us.* (Monographs in Aerospace History #22, NASA SP-2001-4522, 2001).

Tucker, Tom. *The Eclipse Project* (Monographs in Aerospace History #23, NASA SP-2000-4523, 2000).

Siddiqi, Asif A. *Deep Space Chronicle: Robotic Exploration Missions to the Planets* (Monographs in Aerospace History #24, NASA SP-2001-4524, 2001).

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The NASA History Series

Reference Works, NASA SP-4000:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Gawdiak, Ihor Y., with Fedor, Helen. Compilers. *NASA Historical Data Book, Volume IV: NASA Resources, 1969-1978*. (NASA SP-4012, 1994).

Rumerman, Judy A. Compiler. *NASA Historical Data Book, 1979-1988: Volume V, NASA Launch Systems, Space Transportation, Human Spaceflight, and Space Science.* (NASA SP-4012, 1999).

Rumerman, Judy A. Compiler. *NASA Historical Data Book, Volume VI: NASA Space Applications, Aeronautics and Space Research and Technology, Tracking and Data Acquisition/Space Operations, Commercial Programs, and Resources, 1979-1988* (NASA SP-2000-4012, 2000).

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

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

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

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

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

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

Astronautics and Aeronautics, 1986-1990: A Chronology. (NASA SP-4027, 1997).

Astronautics and Aeronautics, 1990-1995: A Chronology. (NASA SP-2000-4028, 2000).

Management Histories, NASA SP-4100:

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

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

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

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

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

Seamans, Robert C., Jr. *Aiming at Targets: The Autobiography of Robert C. Seamans, Jr*. (NASA SP-4106, 1996)

Project Histories, NASA SP-4200:

Swenson, Loyd S., Jr., Grimwood, James M., and Alexander, Charles C. *This New Ocean: A History of Project Mercury*. (NASA SP-4201, 1966; rep. ed. 1998).

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

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

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

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

Bilstein, Roger E. *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles.* (NASA SP-4206, 1980, rep. ed. 1997).

SP-4207 not published.

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

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

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

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

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

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

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

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Swanson, Glen E. Editor. "*Before this Decade is Out…": Personal Reflections on the Apollo Program* (NASA SP-4223, 1999).

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Center Histories, NASA SP-4300:

Rosenthal, Alfred. *Venture into Space: Early Years of Goddard Space Flight Center*. (NASA SP-4301, 1985).

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

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

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

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

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

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

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Herring, Mack R. *Way Station to Space: A History of the John C. Stennis Space Center*. (NASA SP-4310, 1997).

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Wallace, Lane E. *Dreams, Hopes, Realities: NASA's Goddard Space Flight Center, The First Forty Years* (NASA SP-4312, 1999).

Dunar, Andrew J., and Stephen P. Waring. *Power to Explore: A History of the Marshall Space Flight Center* (NASA SP-4313, 1999).

Bugos, Glenn E. *Atmosphere of Freedom: Sixty Years at the NASA Ames Research Center Astronautics and Aeronautics, 1986-1990: A Chronology*. (NASA SP-2000-4314, 2000).

General Histories, NASA SP-4400:

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

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

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

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

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

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

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

Logsdon, John M. Editor. With Day, Dwayne A., and Launius, Roger D. *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume II, Relations with Other Organizations*. (NASA SP-4407, 1996).

Logsdon, John M. Editor. With Launius, Roger D., Onkst, David H., and Garber, Stephen E. *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume III, Using Space*. (NASA SP-4407, 1998).

Logsdon, John M. General Editor. With Ray A. Williamson, Roger D. Launius, Russell J. Acker, Stephen J. Garber, and Jonathan L. Friedman. *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume IV, Accessing Space*. (NASA SP-4407, 1999).

Logsdon, John M. General Editor. With Amy Paige Snyder, Roger D. Launius, Stephen J. Garber, and Regan Anne Neuport. *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume V, Exploring the Cosmos*. (NASA SP-2001-4407, 2001).

Siddiqi, Asif A. *Challenge to Apollo: The Soviet Union and the Space Race, 1945-1974.* (NASA SP-2000-4408, 2000).

Mach 3+: NASA/USAF YF-12 Flight Research, 1969-1979 by Peter W. Merlin Monographs in Aerospace History #25