MEETING THE CHALLENGE OF SUPERSONIC FLIGHT

James O. Young
Air Force Flight Test Center
History Office
Edwards AFB, California

Front and back cover captions:

Front--

U.S. Air Force Captains Charles E. "Chuck" Yeager and Jackie L. Ridley beside the cockpit of the No. 1 Bell XS-1 rocket plane --secured in the bomb bay of its B-29 launch aircraft--at Muroc AFB, California.

Back--

The headline in the Los Angeles Times on December 22, 1947, revealed that the "sound barrier" had been broken but the column which accompanied it was rife with misinformation and revealed virtually nothing of any importance about the program. Calling the feat "one of the greatest explorations into the unknown since Columbus," reporter Marvin Miles explained that it would open "a new aerial age of high-speed flights that will rival Buck Rogers." U.S. Air Force Chief of Staff General Hoyt Vandenberg and the NACA's Hugh Dryden did not officially confirm the supersonic breakthrough until June 15, 1948.

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The Problem

The remarkably rapid evolution of aircraft design during the first four decades of this century had brought the state of the art to an apparent impasse by the late 1930s. Designers were beginning to conceive of aircraft capable of speeds in excess of 500 mph. Some truly daunting challenges faced them, however, as they considered the obstacles to be overcome. At 500 mph, they would be probing the lower limits of the transonic region, the little-understood area between Mach* 0.7 and Mach 1.3 where an aircraft would encounter mixed subsonic and supersonic airflow. And, as it approached the speed of sound (Mach 1.0), a virtual "wall" of air would build up in front of it which one prominent aerodynamicist, speaking for many of his colleagues, likened to a "barrier against future progress." [1]

Theoretical calculations seemed to indicate that, as an aircraft approached Mach 1.0, drag would reach infinity. Just how much power would be required to contend with "infinite" drag? And there were other, equally perplexing problems surrounding the phenomenon which aerodynamicists called "compressibility." At transonic speeds, an aircraft would encounter mixed subsonic and supersonic airflow conditions. Airflow accelerates as it passes over an airfoil and thus, while an airplane may only be flying at seven-tenths the speed of sound, the flow over its wings may well be moving at supersonic speeds. In this turbulent region of mixed flow conditions, aerodynamicists knew that shock waves would form on the aircraft and, moving back and forth, violently disrupt the airflow and thereby dramatically change the aerodynamic trim of the vehicle and drastically alter its control response and controllability. Further, many aerodynamicists believed the turbulent flow could result in aircraft oscillations severe enough to cause structural damage.[2]

Theoretical concerns became tragic realities by the early 40s. In the United States, the first aircraft to encounter serious compressibility problems was the Lockheed P-38 *Lightning*. Encountering violent buffeting during high-speed dives, its nose tended to "tuck under" while its tail surfaces shook wildly. The magnitude of the problem was brought home in terrifying fashion one morning in November of 1941, when veteran Lockheed test pilot Ralph Virden pushed over into a steep dive. As he accelerated downward, he lost elevator effectiveness and the P-38's dive angle grew increasingly steep. As the craft continued to pick up speed, ultimately accelerating to an estimated airspeed of 535 mph, the violently disturbed airflow coming off the wings overstressed the tail and literally tore it off. Caught in the grip of compressibility, a skillful test pilot had been reduced to the role of a helpless passenger on a journey toward destruction. A makeshift remedy-dive flaps attached to the front wing spar on the lower surface of the wing--substantially alleviated the problem by, in effect, permitting the wing to retain enough lift at high speeds to provide pilots with sufficient control to pull out of dives at higher Mach numbers. This, however, was just a temporary remedy, not a solution.[3]

Throughout the war, pilots of high-performance fighters continued to encounter the problem. During high-speed dives, they would suddenly discover that their control columns had frozen up or reversed control effectiveness altogether and, even if they were ultimately able to effect dive recoveries, the excessive aerodynamic loads imposed on the tails of their craft all too frequently resulted in catastrophic failures.[4]

* Mach number (in honor of Austrian physicist Ernst Mach, 1838-1916) is the ratio of the speed of an object to the speed of sound in the medium through which it is moving. Thus an object moving at Mach 0.7 is traveling at seven-tenths the speed of sound and, at Mach 1.0, it would be moving at the speed of sound. The speed of sound at sea level, in dry air at 32-degrees F, is approximately 741 mph.

The Lockheed P-38 Lightning was the first U.S. aircraft to fall prey to the effects of compressibility.

All of these very serious problems surfaced while prop-driven fighters still ruled supreme. The development of turbojet technology during the war years made the search for a real solution all the more compelling. By war's end, it was obvious that turbojet engines offered the potential to propel aircraft through the transonic and even, perhaps, into the supersonic region. And, indeed, in *Where We Stand*, the seminal assessment which Dr. Theodore von Karman submitted to General of the U.S. Army Air Forces (AAF) Henry H. “Hap” Arnold in August of 1945, he warned: “We cannot hope to secure air superiority in any future conflict without entering the supersonic speed range.” This, in fact, was presented by Karman as the highest priority requirement confronting the postwar Air Force. The major question remained, however. Could a piloted airplane be designed and built to ***survive*** in that flight environment?[5]

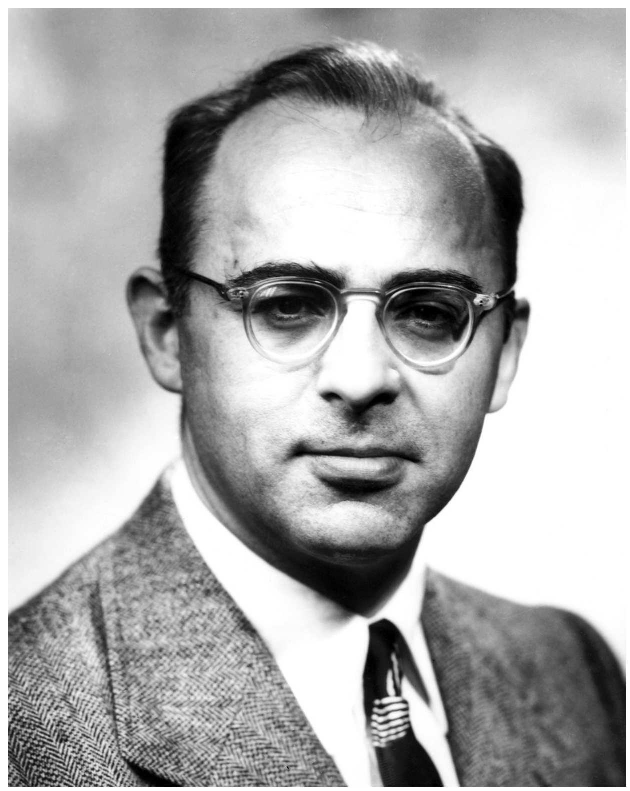
The answers, unfortunately, were not easily forthcoming. First and foremost, designers needed a much more complete knowledge of transonic aerodynamics and their knowledge had to be based on concrete evidence, not theoretical calculations. Throughout the war years, however, wind tunnels remained practically useless in terms of transonic research. At Mach numbers below 0.8 and above 1.2, smooth airflow could be maintained and thus aerodynamicists were able to acquire accurate measurements. But, between those numbers, the tunnels "choked," as shock waves formed off test models and, in turn, reflected off tunnel walls, thereby inhibiting accurate measurement of flow characteristics around the model. The best solution to this problem, the slotted-throat transonic tunnel, would not arrive on the scene until the late 40s.[6]

In the meantime, other methods of data acquisition--rocket-propelled models, free-falling instrumented missile shapes released from high altitudes, and wing-flow tests of airfoil shapes mounted to the upper surface of a P-51's wing--were employed as stopgap alternatives. While some useful data were acquired by these means, it was really of only limited value in terms of the magnitude of the problems to be overcome. These circumstances enhanced the appeal of a far more radical approach: to build and flight test a fully instrumented experimental aircraft.[7]

Such an approach would, indeed, represent a radical departure from standard practice; in essence, a reversal of the time-honored process wherein researchers accumulated and analyzed their data ***before*** the designers built their aircraft. And, while there were legions of experts who scoffed at such an approach, there were a number of individuals who had labored long and hard to promote its merits. Among them, two men would play pivotal roles in the genesis of the experimental research airplane programs of the mid-to-late 40s: Major Ezra Kotcher, from the Engineering Division at Wright Field, and John Stack, director of the Compressibility Research Division at the National Advisory Committee for Aeronautics' (NACA) Langley Memorial Aeronautical Laboratory (LMAL). Both were confident that the sonic "wall" could be breached and both strove to convince their respective organizations that research airplanes offered the best means to demonstrate to the aeronautical community the validity of U.S. Navy Captain Walter S. Diehl's contention that the so-called "sound barrier" was "just a steep hill."[8]

Setting the Stage

More than any other single individual, Ezra Kotcher would be responsible for the design and development of the airplane that would ultimately prove the validity of this observation. After graduating from the University of California in 1928, he had gone to work as a civilian at Wright Field. As senior instructor at the Army Air Corps Engineering School throughout the 30s, he was required to remain abreast of the latest developments in a remarkably wide range of increasingly esoteric aeronautical disciplines and he established a reputation as one of the few truly brilliant engineers who were then working at Wright Field. He first became interested in the subject of transonic aerodynamics in the mid-30s and, very early on, concluded that overcoming all of the problems associated with the sonic barrier was really just a matter of acquiring valid data concerning transonic conditions. Given the wind tunnel limitations of the time, he also concluded that the only way to acquire that knowledge would be by means of specially designed research aircraft and, given the limitations of even the highest performance fighters of the day, he realized that such airplanes would require unconventional propulsion systems. In August of 1939, nearly *two years* before the AAF became aware of turbojet and other reaction propulsion developments abroad, Ezra Kotcher submitted a report to the Kilner-Lindbergh Board in which he recommended the establishment of a comprehensive transonic flight research program which would permit the correlation of wind tunnel and actual flight performance data. He also suggested that gas turbine or rocket propulsion systems would have to be developed to support such an effort because of the compressibility limitations on prop-



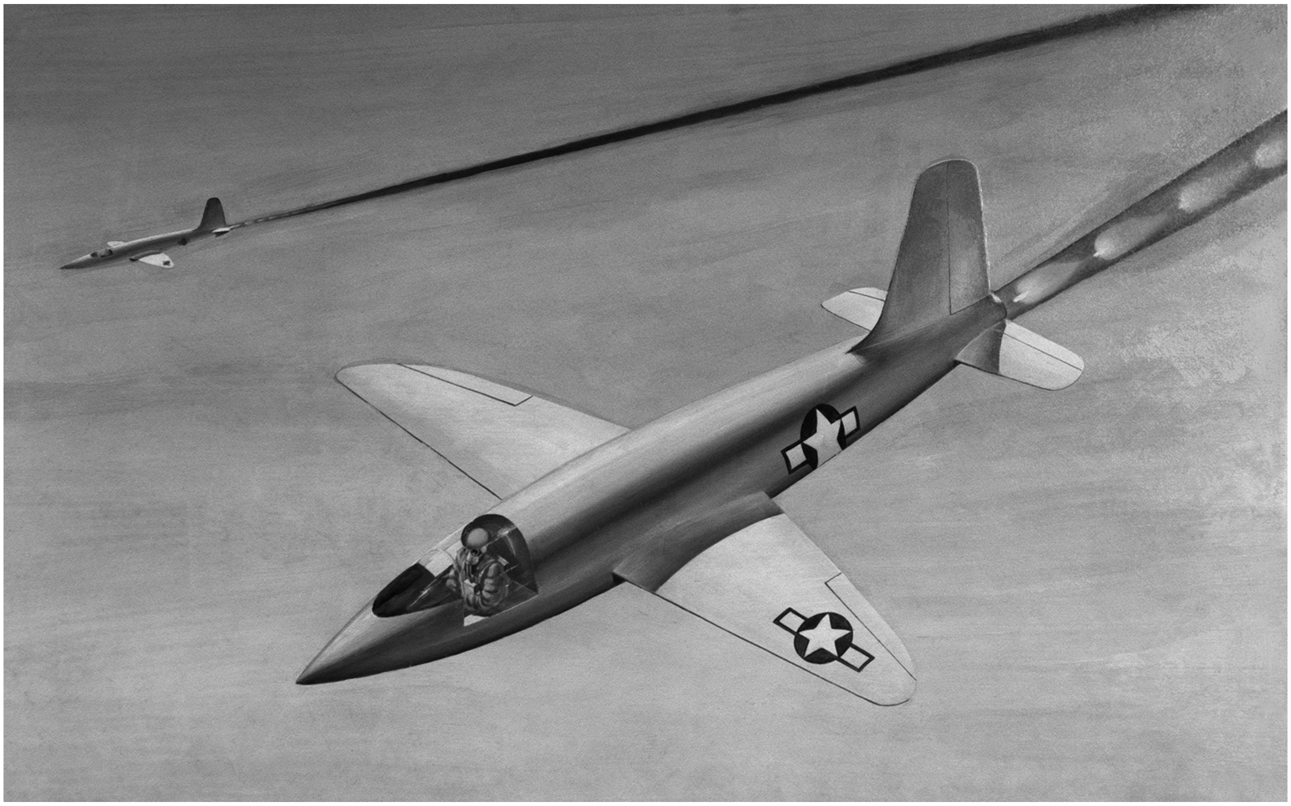
Called to active duty in 1942, Ezra Kotcher initially served as technical executive to the Engineering Division's Air Technical Intelligence Group. Subsequently assigned to the Experimental Aircraft Projects Section, he served as the initial project officer for both the XS-1 and XS-2 rocket plane projects as well as a number of other programs which focused on the development of turbojet and rocket-propelled fighters as well as quided missles.

driven aircraft at high speeds. A truly *bold* proposal but, in 1939, his was a voice in the wilderness. With war imminent, Air Corps leadership was totally focussed on immediate production problems and long-term research proposals such as he was recommending were relegated to the back burner.[9]

Nevertheless, Kotcher was persistent and, called toactive duty and assigned to the Engineering Division at Wright Field after the U.S. entered the war, he continued to press for a dedicated transonic flight research program. He also remained perhaps the staunchest proponent for rocket propulsion within the AAF. His arguments finally began to win converts only after combat pilots started encountering the effects of compressibility in existing prop-driven fighters and the enormous potential of turbojet propulsion finally became apparent. And they became even more compelling after intelligence sources began to reveal that German turbojet and rocket propulsion projects were in advanced stages of development. Against this backdrop, in early 1943, Kotcher's boss and chief of the Engineering Division, Brigadier General Franklin O. Carroll, asked Theodore von Karman if he believed an aircraft capable of flying at Mach 1.5 could actually be built. After pondering the question for a few days, Karman not only replied in the affirmative, he also provided Carroll with very preliminary design data for such a vehicle. Kotcher and other representatives from the Engineering Division conducted a series of conferences with Karman and his colleagues at the California Institute of Technology throughout the remainder of the year and ultimately issued them a contract to develop theoretical methods for predicting pressure and velocity distribution over aerodynamic bodies at subsonic and supersonic speeds as well as a means by which such theoretical predictions could be correlated and compared with real-world experimental data. Kotcher finally had his opening and, over the next couple of years, in addition to serving as project officer for a number of advanced programs which focussed on the development of radical new technologies, he was also assigned the job of shepherding a nascent high-speed research aircraft program for the AAF which, from its very inception, aimed at achieving *supersonic* flight (*i.e.*, flight beyond the so-called "sonic wall").[10]

By early 1944, Kotcher and other representatives of the Engineering Division had already entered into discussions with the Douglas Aircraft Company concerning its interest in submitting a design proposal for a supersonic airplane which could attain speeds of up to *1,500* mph. Douglas design engineers expressed confidence that they could tackle such a project.[11] Meanwhile, Kotcher had also inaugurated an in-house comparative study to examine the merits of rocket versus turbojet propulsion for a transonic research airplane. He asked the Design Branch of the Aircraft Laboratory at Wright Field to prepare design studies for two different configurations. The first was to be designed around a 4,000-pound thrust General Electric TG-180 axial flow turbojet which was then under development and the other around a 6,000-pound thrust liquid-fuel rocket engine which had been proposed for development by the Aerojet Engineering Corporation. Completed in April, the so-called "Mach 0.999" study confirmed Kotcher's predilection for rocket propulsion. The rocket engine would provide more thrust--and, hence, higher speed--and far better high-altitude performance than any turbojet then under development. It would enable test pilots to make their high-speed runs for up to two minutes in level flight at pressure altitudes which would impose lower air load stresses, rather than in risky dives into the dense lower atmosphere which would, at best, afford roughly 20-30 seconds of useful data. Interestingly enough, the general configuration of the "Mach 0.999" rocket airplane bore a striking resemblance to the research aircraft which would ultimately appear on the ramp. Incorporating a 6,000-pound thrust rocket engine, it was a mid-wing design, with conventional tail surfaces, a bullet-shaped fuselage, and a smoothly faired cockpit canopy.[12]

John Stack, along with a number of his colleagues at Langley, had been concerned with compressibility phenomena since the late 1920s and, in the early 30s, he had even conceptualized a modest, prop-driven compressibility research aircraft which he estimated would be capable of achieving more than 560 mph. It was the "choking" problem caused by shock wave formation in the wind tunnels, however, which ultimately drove Stack and his



Artist's conception of the Engineering Division's "Mach 0.999" experimental rocket plane, 1944.

colleagues to the conclusion that, if they were ever going to understand the transonic region, it would be necessary to design and develop a specially instrumented full-scale airplane that would be capable of safe operation in that speed range. By the spring of 1942, Stack had convinced Langley management of the need for such an airplane but, when he proposed the idea to Dr. George W. Lewis, the director of NACA research, he did not get an enthusiastic reception. Nevertheless, Lewis was not averse to some kind of low-priority effort to at least identify the most desirable design features for such an aircraft and, by the early summer of 1943, a small team under Stack's direction had completed a preliminary design study for a small turbojet aircraft which they estimated would be capable of safely probing the region *between* Mach 0.8 and Mach 1.0. By this time, the real-world problems posed by compressibility had become so commonplace that the NACA had established a Compressibility Research Division at Langley under Stack's direction. Even George Lewis was finally convinced of the need for a transonic flight research program when first the military and then the aircraft industry began to show a strong interest in it. In late December 1943, for example, Robert A. Wolf, a Bell Aircraft Corporation engineer who had been involved in the design and development of America's first jet airplane, the XP-59A, explained the urgency of the need for valid transonic data because jet fighters would soon encounter the same compressibility effects in level flight which current fighters were then encountering in max-power dives. A turbojet transonic research airplane, he argued, was both feasible and absolutely essential.[13] Lewis responded that the NACA was giving the matter "our very serious consideration." [14]

In early February 1944, Lewis informed the engineer-in-charge at Langley that he was establishing a special High-Speed Panel which would coordinate transonic research activities at all three of the NACA's laboratories. The panel met

John Stack as Chief of the LMAL's Compressibility Research Division, 1944.

for the first time at Langley on March 2-3. Stack and Eastman Jacobs, another long-time and very articulate proponent for a research airplane program, were among the Langley representatives. Lewis informed them that he wanted the panel to be the most forward thinking group in the NACA and, in the discussions which followed, Jacobs even went so far as to argue the benefits that could be gained from a special *supersonic* research airplane. The panel concluded, however, that such an effort was currently far too ambitious and it shifted its focus toward the development of a more conventional turbojet-powered airplane which would be limited to speeds in the low transonic range. Several of the members argued in favor of procuring a small, fighter-sized aircraft powered by *four* Westinghouse 19XB jet engines (providing a combined 6,440 pounds of thrust) and Lewis suggested that this recommendation be submitted to the AAF for review.[15]

Thus, by early 1944, the dogged persistence of men like Kotcher and Stack within the AAF and the NACA, along with similar efforts by like-minded men such as Captain Diehl within the Navy, had brought their respective agencies to the point where each had independently concluded that the procurement of some kind of research airplane was essential to unraveling the mysteries of transonic flight. Each also knew that the best way to proceed would be by combining forces. The military services realized that the NACA had the charter for conducting flight research in the United States and that they would require the agency's technical expertise. And, for its part, the NACA was painfully aware that it did not have the funding or the authority to procure a research airplane. The presumption was that the military would purchase the airplane based on specifications developed by the NACA and then the NACA would conduct the flight research program and collect and reduce the data. Thus the stage was set for a meeting of the minds.

That meeting occurred at a conference between AAF, Navy and NACA representatives held at Langley on March 16, 1944. During the course of two sessions, one chaired by Captain Diehl and the other by Colonel Carl Greene, the AAF Materiel Command's liaison officer at Langley, the conferees discovered that, although all three organizations agreed on the need for a joint NACA-military transonic research airplane, there was little agreement concerning the basic design features for such a craft or even the specific goals for a flight test program. Basically, Stack made a pitch for the NACA's turbojet-powered airplane and a program aimed at collecting data at speeds *approaching* Mach 1. Although interested in dispelling the myth of an impenetrable sound barrier, the Navy tended to follow Stack's lead and favored a cautious approach utilizing jet propulsion in a gradual, step-by-step program directed toward the acquisition of transonic data. The AAF, however, argued for a much bolder approach: a major developmental effort, employing unconventional propulsion if necessary, directed toward attaining speeds in *excess* of Mach 1. As the discussions proceeded, the prospects for a single, concerted effort evaporated because of a fundamental disagreement over means and ends. In the end, the Army and Navy representatives indicated that they would recommend that their respective services should each furnish a different airplane. The research aircraft program was to be an entirely new type of enterprise and the differing views that were laid on the table at this conference were just the first of many to follow.[16]

An indication of the AAF thinking at this time may be found in a March 29 memo from General Carroll to Major General Oliver P. Echols, the Assistant Chief of the Air Staff for Materiel, Maintenance and Distribution, in which Carroll sought approval to proceed with the development of "a purely experimental airplane" to support the NACA's research efforts. This memo was, in fact, drafted by Kotcher and, after detailing the problems with wind tunnels and the progress of the ongoing Cal Tech and Douglas Aircraft supersonic flight studies, he described an airplane which was obviously based on the Mach 0.999 design study that was then nearing completion:

> At present the experimental airplane is roughly visualized as one where excess strength will be built in for safety since useful load will be of secondary importance. A very heavy skin will be employed to insure against wrinkling distortion of the desired aerodynamic profiles. If necessary to reduce drag, certain privileges might have to be taken in disregarding standard military requirements for cockpit arrangement and pilot's position and vision. Obviously controls and control surfaces will have to be fabricated and instrumented to provide high speed design data. Eventually it might be desirable to fabricate several wing panels with uniform and varying thickness ratios along the span. These wings will be constructed so as to provide both chordwise and spanwise pressure distribution information. One of the most difficult items to evaluate from flight tests is aerodynamic drag due to the uncertainties connected with the evaluation of net propulsive thrust. To date this has not been successfully accomplished on turbo-jet engines. Hence, it might be worthwhile to consider employing a simple stationary jet rocket motor which could be readily mounted to indicate net propulsive thrust. Also in that way the problems connected with high speed air ducting can be avoided while focusing the attention principally on problems of external aerodynamic flow. If the high fuel consumption of a rocket motor precludes its use in a small airplane due to insufficient fuel space for practical endurance, then it might be feasible to consider towing to altitude for tests. In that way it will be possible to eliminate the need for assisted take-off devices and the enormous fuel requirements for acceleration to high climbing speed and climb to altitude.[17]

While he had certain reservations concerning the purchase of an aircraft that did not strictly meet a military requirement, Echols agreed with the proposal "in general" as well as the overall effort "to support the National Advisory Committee for Aeronautics in all high speed investigations." Carroll interpreted this as a "yes" and, on 15 April, the Engineering Division placed the design and development of the airplane within a parcel of projects which were designated "High-Speed Flight Investigations," classified "Confidential" and assigned the project number MX-524.[18]

On April 20 and again on May 15-16, Kotcher and other members of the Engineering Division resumed their discussions with Stack and his NACA colleagues. During the May meetings, Kotcher once again explained that the AAF was interested in the development of a supersonic research airplane and, after presenting the results of the Mach 0.999 design study, he reiterated his contention that only a rocket propulsion system could meet the power requirements for such a vehicle.[19] But caution had always prevailed in NACA flight research and Stack and his colleagues were vehemently opposed to the rocket-propulsion proposal, insisting that the immaturity of the technology made such an approach far too dangerous. Stack informed Kotcher that the majority of NACA Langley test pilots were opposed to the idea of a transonic airplane, in the first place, and they would most certainly be unwilling to fly in a rocket-powered vehicle. Privately, in fact, Melvin Gough, the NACA's chief test pilot at Langley, had issued an edict: "No NACA pilot will ever be permitted to fly an airplane powered by a damned firecracker!"[20] Stack also argued that such a craft would not offer enough endurance (only a couple of minutes of powered flight per mission) to yield either the kind or the volume of data that flight researchers required. Besides, data derived from a turbojet configuration would obviously be more directly applicable to aviation's near-term future. Thus he continued to push for the NACA's four turbojet configuration and promised to submit a full design report on it for AAF review in the near future.[21]

Following the conference, General Carroll reported to the Air Staff that, while at Langley, Kotcher had taken the opportunity to look into the status of NACA research studies on supersonic flight. Based on his conversations with various laboratory personnel, he had decided that "sufficient engineering information was now available from which to conclude that a supersonic airplane appeared to be a feasible project." Furthermore, Kotcher had "encouraged" the NACA " to integrate the existing knowledge on the various components of a supersonic airplane and submit a report to the Army Air Forces on a design proposal."[22] When Stack finally submitted the NACA design study to the Engineering Division on July 10, however, it still incorporated the turbojet engines and it was optimized to fly in the speed range between Mach 0.8 and 1.0 with a typical high-speed dash velocity of Mach 0.85 (approximately 650 mph). Stack had held firm. He wanted an airplane that would collect transonic data, not one that would fly at supersonic speeds.[23]

In early November, General Carroll once again reported to the Air Staff on the status of "the purely experimental supersonic research airplane which the AAF is planning to procure for the NACA." After outlining the studies submitted by Kotcher's Wright Field team and the NACA's turbojet proposal, he certainly did not overstate the circumstances when he reported that "thus far none of the designs has engendered spontaneous approval." He also noted that Kotcher's team would be holding another conference with the NACA in the near future in order to come to some agreement concerning the most suitable configuration for the airplane but that, even if some consensus could be achieved, "it will be a problem to find a competent airplane manufacturer to undertake its fabrication."[24]

Kotcher had, indeed, run into problems in his search for a suitable manufacturer. Douglas had never followed up on his request for a preliminary design proposal and, while both North American and Republic Aviation had expressed some interest in taking on such a project, they were both too busy with wartime production work to dedicate the engineering personnel that would be required for such an effort. By late November, however, both Bell and the McDonnell Aircraft Company had agreed to submit some very preliminary design proposals for review at the upcoming AAF-NACA conference.[25]

That conference was held at Langley on December 13 and 14. After Kotcher reiterated his preference for rocket propulsion and, once again, reminded the conferees that the primary objective of the project was to "attain a Mach number slightly greater than 1," the AAF contingent quickly dismissed the NACA's turbojet proposal as too conservative to achieve that goal. Then they turned to the preliminary proposals from the two contractors. McDonnell's approach was immediately rejected because it required both a vertical dive technique and the use of a mothership to air-launch the test airplane. The NACA was adamantly opposed to the latter. John Stack was not well impressed with Bell's initial design effort, either. Among other things, it incorporated the use of rocket engines mounted beneath the wings. Kotcher, who was predisposed in favor of Bell because of the innovative resourcefulness of its design staff and its substantial experience with highly unconventional projects, reminded him that the proposal was *far* from a final configuration. For all intents and purposes, the issue was settled. Bell had effectively been given the job.[26]

Next, they turned to the task of defining some very basic specifications which would provide the contractor with a starting point for his design efforts. In this regard, they managed to achieve some consensus: the maximum speed had to be well above the critical Mach number*; duration at full power at 35,000 feet had to be at least two minutes; the design had to be flexible enough to permit the use of a variety of wing and tail surfaces; and sufficient space had to be provided

* The speed at which an aircraft is traveling when Mach 1.0 is attained at the maximum thickness point (i.e., point of highest airflow velocity) of its wing.

for approximately 400 pounds of instrumentation (plus roughly 100 pounds of wiring and tubing). Stack continued to argue against a rocket engine and, for the sake of argument at least, Kotcher was at this point still willing to concede that use of a turbojet *might* be necessary for the takeoff and climb to altitude. Thus the conferees tentatively focussed on a design which would combine the use of a General Electric TG-180 (the axial-flow J35 which was ultimately rated at 4,000 pounds of static thrust) with a 6,000-pound thrust liquid fuel rocket booster. In retrospect, it is important to note that it was at this conference that the NACA made, *by far*, its most important contributions to the design criteria for the airplane when Stack and Robert R. Gilruth made several recommendations concerning the tail section. First, they insisted that the horizontal stabilizer should have a lower thickness-chord ratio* than the wings. Thus, if the wings encountered serious compressibility effects at a certain speed, the thinner stabilizer with its higher critical Mach number would not lose its effectiveness by simultaneously encountering the same problems. In the event of serious stability and control problems, this would permit the pilot to maintain adequate control of the airplane until he could decelerate to a lower Mach number. In order to guarantee sufficient longitudinal control in the transonic region, Stack and Gilruth also recommended mounting the elevator on an adjustable horizontal stabilizer *in lieu* of a standard configuration which would have featured a fixed horizontal tail with a movable elevator. At subsonic speeds, the pilot could employ the elevator for adequate control. In the transonic region, however, he could opt to change the entire stabilizer's angle of incidence. Finally, they stipulated that the horizontal stabilizer should be located high on the vertical fin in order to minimize wing wake impingement on it.[27]

As the conference was coming to a close, Kotcher raised a couple of points which would ultimately become major issues as the program evolved. He suggested, for the first time, that ideal conditions and the facilities required to test a highly unconventional, rocket-powered airplane already existed on southern California's high desert at Muroc Army Air Field. Moreover, if NACA pilots were reluctant to fly it, he indicated that the AAF might be willing to hire a civilian pilot for the program. He believed that veteran test pilot Harry Crosby, who had recently completed tests on Northrop's rocket-powered MX-324 at Muroc, might be willing to undertake the job "for suitable compensation."[28]

This was probably not welcome news to his NACA auditors, for it was the first mention of the possibility that the airplane might be tested at some location other than at Langley and by someone other than an NACA test pilot. Moreover, it fit into a disturbing trend which they had seen unfolding over the preceding months. It centered on the issue of control over the research program and, although they were perhaps not fully conscious of its long-range implications, it reflected a much larger development which was then evolving in AAF research policy. In the prewar era, the NACA had ruled supreme as *the* arbiter of fundamental aeronautical research in this country and, for a variety of reasons, the U.S. Army Air Corps had been quite willing to defer to its wisdom and expertise. The wartime experience, however, had severely tarnished the NACA's image. British and, especially, German development of turbojet technology had taken the U.S. by surprise and forced the AAF into a "catch-up" mode in which it had been forced to depend upon the British. Throughout the war, it became increasingly apparent that the German research establishment had come up with a host of other new systems and concepts-rocket engines, guided missiles, the application of swept wings for high-speed flight, to name a few-which were well in advance of the state of the art in this country. Although the fault certainly did not rest entirely with the NACA (the prewar Army Air Corps was at least equally culpable), there was a perception among senior AAF leadership that the NACA had failed to remain on the cutting edge of aeronautical science. This, coupled with the

* The chord of a wing is essentially the length of a line drawn through the airfoil from its leading edge to its trailing edge. The thickness-chord ratio of the wing is the ratio of its maximum thickness--measured perpendicular to the chord--to the length of its chord.

realization that science and warfare had become inextricably intertwined and advanced technology would be the key to success in future conflicts, set the AAF on a course to establish a comprehensive postwar research and development capability which would be second to none--one which, while still including the NACA, would also encompass industry, the universities *and*, for the first time, a major in-house capability, as well. As it developed this in-house expertise, the AAF would no longer automatically defer to the NACA's judgements and, increasingly, it would vest management control over major research efforts in the hands of its own technical experts. All of this would come into much sharper focus in the postwar era but the trend was certainly evident much earlier on when, for example, the AAF chose to exclude the NACA and team up with industry to develop turbojet technology. It was also certainly evident in the effort to develop a transonic research airplane.[29]

Ezra Kotcher could well have served as the archetype for the kind of technology manager that the AAF would attempt to develop in the future. In addition to his solid technical credentials across a wide spectrum of disciplines, his wartime assignments had given him extensive hands-on experience with an impressive array of radical new cutting-edge technologies. He had played key roles in the development of the top secret XP-59A and XP-80 turbojets, the semi-tailless, rocket-powered MX-324, and the pulsejet powered JB-2 cruise missile (a U.S. copy of the German V-1 "buzz bomb"). Thus he had more than a passing acquaintance with the latest developments in high-speed aerodynamics and reaction propulsion systems and he was not inclined to presume NACA omniscience on either of those subjects. In addition to confidence in his own technical judgements, of course, Kotcher--and Stack--also knew that he held the ultimate trump card; since the AAF was procuring the airplane, the NACA had little choice but to acquiesce and begin preparations for its support of the program. And, though the partnership between the AAF and the NACA was not without discord and Stack and several of his colleagues were not optimistic about the outcome of the project, the NACA's support *would* prove to be critical to the success of the program.[30]

Disappointed and feeling more than a little skepticism concerning the prospects for any airplane employing rocket propulsion, Stack had persisted in his efforts to convince the Navy to build the type of research airplane favored by the NACA. Confiding to officials in the Bureau of Aeronautics that the AAF's airplane probably would not survive many flights, he pushed for a turbojet configuration which would meet the NACA's specifications. Since the Navy was already inclined in that direction and because, compared to the AAF, it had conducted very little of its own research, Navy officials agreed to proceed with construction of an airplane that was very close to the NACA's more conservative design concept. The NACA-Navy collaboration would ultimately result in the development of the Douglas D-558 *Skystreak*. This, recalled one of Stack's close associates, "was the research airplane the NACA wanted" and "we extended ourselves in every way to assist in its development."[31] The *Skystreak* was designed to meet both research *and* military requirements so that the data acquired from its flight test program could be directly applied to a future tactical aircraft. Its maximum speed was *not to exceed* Mach 1. In hindsight, its development was unnecessary. It was essentially a 650 mph airplane. New tactical fighters that were soon to enter the inventory would exceed its performance and, at substantially less cost, could have been employed to collect transonic data. Nevertheless, three airplanes were built and, for many years, they were used by the NACA for extensive flight research at high subsonic speeds.[32]

The Army's transonic airplane represented an entirely new kind of research program and, with it, the AAF and the NACA had entered into a new kind of relationship. Because there were no precedents to guide them, they proceeded without any well-established ground rules and thus each side was still feeling its way. They had entered into the program with roughly similar assumptions; the AAF would procure an airplane and the NACA would oversee the technical aspects of its development and then complete the research program. That assumption had been based on

Marine test pilot Major Marion Carl and Douglas' Gene May posing beside the turbojet-powered D-558-I Skystreak at Muroc AAF. Major Carl established a short-lived World Absolute Speed Record of 650.796 mph in this aircraft on August 20, 1947. The airplane exceeded Mach 1 while in a 35-degree dive on September 28, 1948, which was the first and only time a Skystreak aircraft attained supersonic speed.

long-standing custom. Yet, in part, because the AAF and the NACA personnel who came together in this effort were the progeny of two very different organizational cultures, they entered into the relationship with differing objectives and, therefore, widely disparate views on the best way to approach and solve the problem. Although their labors had certainly resulted in a wide variety of very practical and palpable applications, John Stack and his Langley colleagues were laboratory scientists long accustomed to seeking after truths that were, in some sense, quite abstract. They were accustomed to studying a problem in painstaking depth and detail, pondering over it, and then rendering an unimpeachable verdict. Because they were scientists and seeking "truth," they had always tended, by nature, to be very methodical, very thorough, and very cautious. All of this took time. By contrast, in their recent experience, Ezra Kotcher and his AAF peers had been project officers driven by the exigencies of war to find prompt and pragmatic solutions to immediate problems and this often involved accepting elements of risk. In order to exploit the potential advantages offered by radical new technologies, they had to be able to quickly translate them into practical, fieldable combat systems. This meant they could seldom afford to pursue perfection; their circumstances dictated that they find the most expedient way to get a job done and then press ahead. They were problem solvers, not seekers after truth.

Moreover, though it was not perhaps immediately apparent to any of the participants in this episode, their respective organizations were each undergoing a metamorphosis. During the war, the NACA had largely been relegated to the unfamiliar role performing "clean-up work" in support of the military. As a result of developments during the war, the AAF was in the process of assuming a much more active role in the management of research activities. In hindsight, it would have been to everyone's advantage if, at this juncture, someone could have stepped forward and clearly defined just who was going to actually be in charge. This, apparently, did not happen. Thus, although they knew full well that the AAF held the purse strings, the NACA contingent had entered into the partnership assuming that this would be *their* program and, for the longest time, no one would explicitly disabuse them of this assumption. This was no doubt due, in part, to the fact that the AAF participants were breaking new ground and really did not *know* where the process was heading. In essence, they were playing it by ear. And thus, as the two sides attempted to work their way through this new partnership, they did so with increasingly divergent assumptions and they would have to find their way, more or less, through trial and error. There was, after all, no blueprint for what they were about to attempt.

The Airplane

The genesis of the AAF's research airplane took place in Ezra Kotcher's office at Wright Field, on November 30, 1944, when Robert J. Woods, chief engineer and co-founder of the Bell Aircraft Corporation, dropped by for a chat. Kotcher, of course, had long been searching for a contractor to take on his project and thus what began as a simple dialog on the problems of high-speed flight quickly evolved into a very earnest discussion concerning Bell's interest in building the airplane. The basic requirements, at least as set forth by Kotcher, were certainly straightforward: employing a rocket engine with at least a two-minute high-speed endurance capability, the aircraft would have to be able to attain 800 mph at 35,000 feet; while it would not be encumbered with all of the usual military specifications, it would have to be overstrength for the purposes of safety; and Bell would only have to guarantee its safety and controllability up to a speed of Mach 0.8. Woods was not inclined toward the use of rocket propulsion and, at least at this point, it was not an absolute requirement. Almost without blinking an eye, he committed his company to the project right then and there.[33]

The requirements may have been straightforward but, as Robert M. Stanley assembled a small design team to undertake preliminary studies, they quickly discovered what it felt like to be set adrift on an uncharted sea. Two of them, design engineer Benson Hamlin and aerodynamicist Paul Emmons, traveled to various research facilities around the country in search of useful data and expert advice. They found little of either. Hamlin later recalled commenting to Emmons on the train ride back to the Bell facility in Buffalo, New York, that they were basically free to design the aircraft "any way we please, and no one can criticize us."[34]

The design team's freedom, however, was not absolute. In order to insure that the airplane would not break apart during its turbulent transition from subsonic to supersonic flight, both the AAF and the NACA insisted that it be designed for an ultimate load factor of 18 g's. That represented a figure about 50 percent higher than for any existing fighter aircraft. Ben Hamlin later recalled that this load factor was nothing more than an "ignorance factor." "I protested in vain," he noted, "and lost another battle. It proved to be loads and loads of ignorance, that factor did."[35] To complicate matters further, after much debate within the Langley ranks, the NACA determined that the rugged airframe should be configured with what, for the day, were extremely thin wings. Based on evidence that thin wings, with higher critical Mach numbers, retained more effective lift in the transonic region, the NACA ultimately decreed that Bell should produce two sets of wings which would be interchangeable on each of the test aircraft: one set with an eight-percent and the other with a ten-percent thickness-chord ratio.* Thus the Bell team had to come up with a design for extremely thin wings which would support ***18*** times the weight of the fuselage and its contents without breaking--a *very* formidable task.[36]

Although Kotcher had, most emphatically, expressed a preference for rocket propulsion, Bell was free to employ any type of power plant--or combination of power plants--which would provide the desired performance. During the course of the design team's investigation, a pure turbojet system was quickly ruled out because the highest speed

Key members of the Bell XS-1 design and development team included (from left, front): Joe Marchese, assistant project engineer; Stanley Smith, original project engineer; Benson Hamlin, preliminary design project engineer; (back row) Roy Sandstrom, assistant chief of preliminary design; Jack Strickler, assistant chief engineer; Bill Smith, chief rocket engineer; Robert Woods, initial chief of preliminary design; Paul Emmons, chief aerodynamicist; and Richard H. Frost, second project engineer.

attainable with even the most powerful engines then under near-term development would have only been about Mach 0.9 at sea level and the thrust would have fallen off very substantially from that at altitude. Next, they turned to the jet-rocket combination which would employ a turbojet for takeoff, climb to altitude and return to base, and a four-chamber, 6,000-pound thrust Aerojet liquid-fuel rocket engine for high-speed runs at altitude. This resulted in an excessively large airplane because, as Bob Stanley and Bell design team member Roy J. Sandstrom later reported:

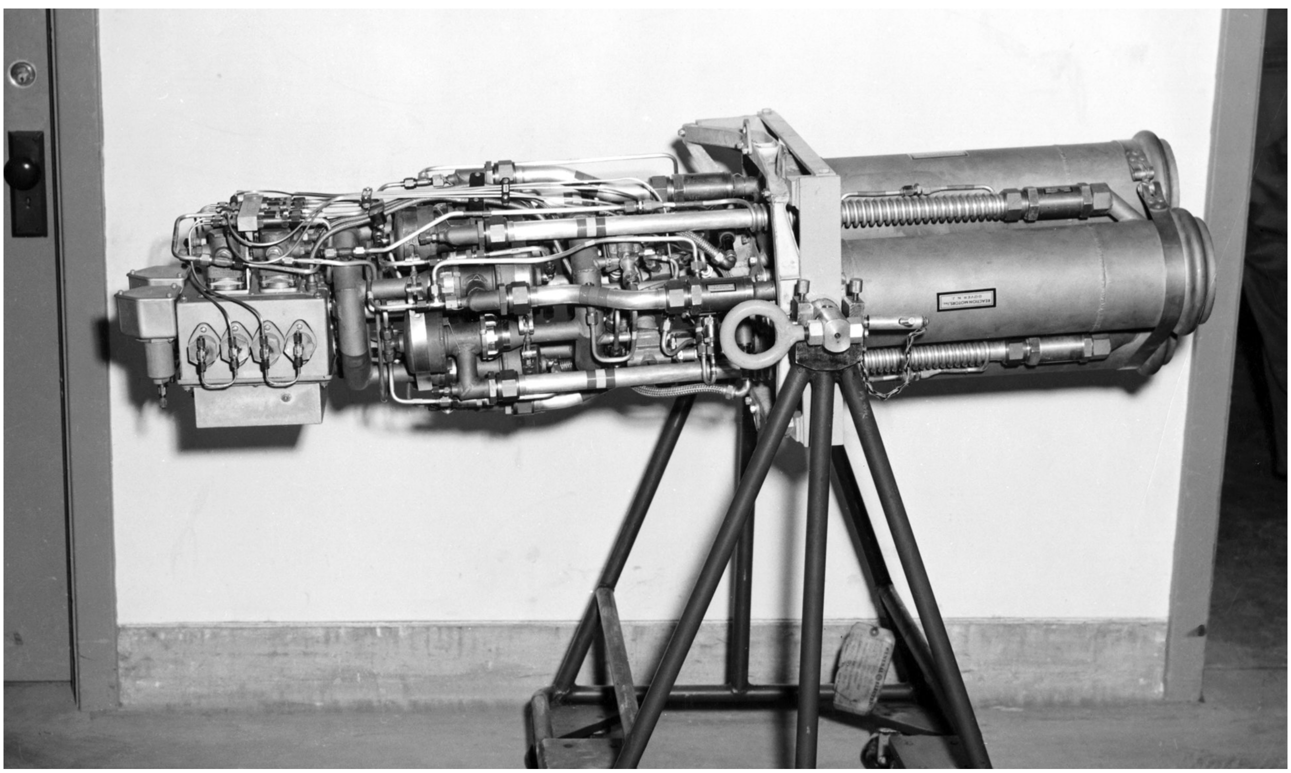
> The turbojet performance fell off at altitude resulting in a poor rate of climb, which in turn called for a large amount of fuel. The speed at which the airplane was flying when the operational altitude was reached was also low, requiring a considerable amount of rocket fuel for acceleration purposes. The use of two such widely different power plants also increased the installation and operational problems.[37]

This left them with only one potentially viable alternative. They determined that, although the fuel consumption of a pure rocket system would be high, the airplane's rate-of-climb would also be high averaging better than 20,000 feet per minute between sea level and 35,000 feet with a climbing speed of 500 mph. Thus, they concluded, the volume of fuel required for the climb phase was relatively low and the amount required to accelerate from climbing speed to the targeted test speed would also be less than with the combined turbojet and rocket system.

Thus, by a process of elimination, they finally arrived at the all-rocket propulsion configuration which Kotcher had advocated all along.[38]

Unfortunately, the system which had long been under development for the AAF, the 6,000-pound thrust Aerojet "Rotojet" rocket engine, employed red fuming nitric acid and aniline as propellants. The two compounds were hypergolic, meaning that violent spontaneous combustion occurred whenever they came into contact with each other, and this raised *very* serious safety concerns among those who were attempting to design a man-rated airplane. Because of this and the fact that development of the Aerojet engine had fallen behind schedule, Kotcher finally settled on a 6,000- pound thrust rocket engine which had originally been under development for the Navy by Reaction Motors, Inc. Fifty-four inches in length and weighing just 208 pounds empty, the XLR-11 was a four-cylinder engine (1,500 pounds of thrust per cylinder) which employed liquid oxygen (the oxidizer) and water-diluted ethyl alcohol (the fuel) as propellants. These propellants were not spontaneously combustible and thus, in comparison with a wide range of other exotic combinations considered, they were relatively safe and easy to work with. The engine was regeneratively cooled by circulating the super-cold propellants through cooling jackets around the combustion cylinders before they were injected into them. According to the original design requirements, a turbine-driven pump system was to be employed to force the propellants through the cooling jackets and into the cylinders. Though the engine was not throttleable, the pilot would have the option to ignite or shut down each cylinder individually so that he could operate at 25-, 50-, 75-, or 100-percent power.[39]

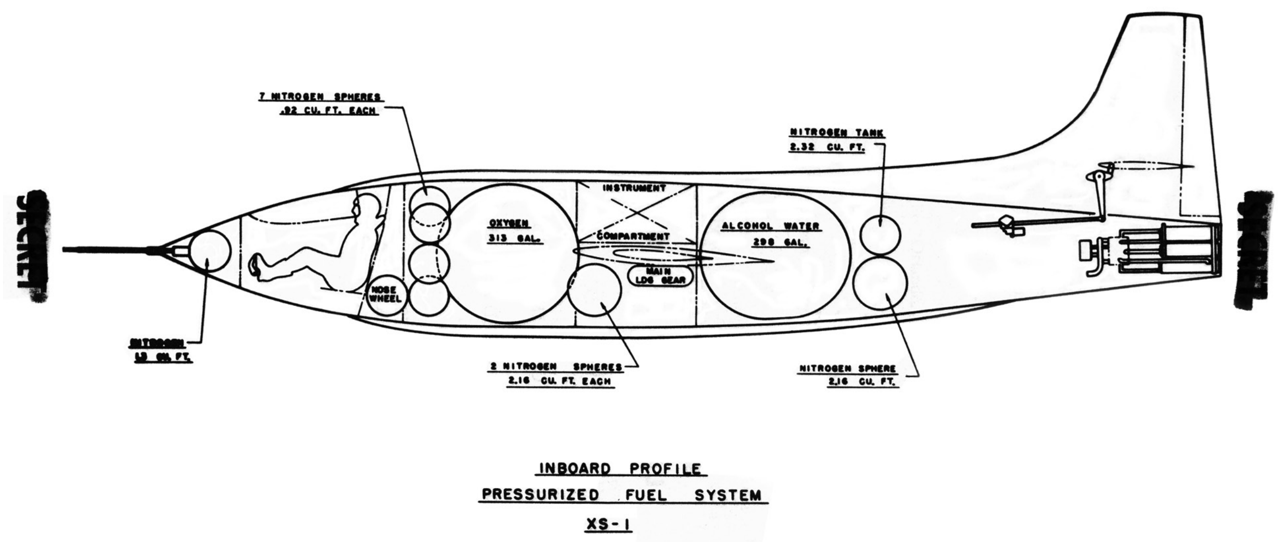
Unfortunately, development of the turbine-driven propellant pump was plagued by so many problems that, at Bob Stanley's insistence and over John Stack's strong objections, it was sidelined in favor of a system in which high-pressure nitrogen gas would be employed to force-feed the liquid oxygen and alcohol into the engine. This meant that the propellant tanks would have to be heavy, high-strength steel containers in order to withstand an internal pressure of 350 psi which would be required to force the liquid oxygen and ethyl alcohol



The Reaction Motors XLR-11 liquid-cooled rocket engine.

into the rocket cylinders against the high pressures produced therein by the combustion of the two liquids. Not only would the tanks be heavier, but the almost spherical shapes which were now required would be far less efficient in terms of volume than the low-pressure cylindrical aluminum tanks which would have been used with a turbine-pump system. Propellant storage capacity was further reduced by the fact that the nitrogen used to pressurize the propellant system would also have to be stored in a group of heavy high-pressure tanks. A total of 12 of these 4,500 psi nitrogen containers, along with three heavy-duty--and a pair of smaller--pressure regulators which would be used to reduce the original nitrogen source pressure to usable levels, would be required to pressurize the propellants, and operate the landing gear and flight controls, as well as to pressurize the cockpit. The impact of all of this on the aircraft's design was critical: the vehicle's landing weight was increased by one ton, while fuel capacity was reduced from 8,160 pounds to an estimated 4,680 pounds and, instead of 4.2 minutes, engine burn time was limited to just 2.5 minutes.[40]

While this created a number of headaches for the design team, it at least served to resolve a very contentious debate over whether the aircraft should be designed for air launch or ground takeoff. The NACA and a number of Bell personnel had argued vehemently in favor of ground takeoffs. Ostensibly, the NACA favored this approach because it would provide useful data on the widest possible range of conventional flight operations. Equally important, however, was the fact that a decision to conduct air-launch operations with a rocket-powered vehicle would virtually guarantee that the airplane could never be tested at a busy flying field such as Langley which was located adjacent to highly populated areas. The prospect of offsite operations at some remote location suggested to NACA managers that they might have difficulty exerting direct control over the test program. Those Bell management personnel, such as Bob Woods, who also argued for ground takeoffs did so because they were looking toward the future development of the craft into a rocket-powered interceptor. Key members of the design team, most notably Bob Stanley and Ben



Cutaway view of the XS-1 airplane detailing the major components of the propulsion and pressurization systems.

Hamlin, countered the ground-takeoff arguments by citing safety considerations and the need to conserve rocket propellants for actual high-speed work at altitude as compelling reasons for air launching the craft. Much to the chagrin of Woods and the NACA, the weight increase and reduction in fuel capacity caused by the high-pressure fuel feed system settled the issue; the research airplane would be air launched at relatively high altitude from the bomb bay of a specially modified B-29.[41]

During their generally disappointing tour of research institutions in the United States, Hamlin and Emmons had made a stop at the AAF Ballistics Laboratory at Wright Field. They knew that bullets traveled at supersonic speeds and wondered, specifically, how and why the shape for .50 cal. bullets (which were known to travel at speeds as high as 2,491 mph) had been determined. They discovered that the ogival shape of the bullet's nose had been selected because, in testing, it had produced the smallest dispersion pattern. Here at least was a configuration which had proven to be stable at supersonic speeds. Feeling that they were on to something, and with a paucity of other useful precedents, they decided to pattern the cylindrical shape of the fuselage after the bullet.[42]

While not unaware of the potential advantages which might be offered by employing swept wings to delay the onset of compressibility, Kotcher had opted, early on, to go with a more conventional straight-wing planform and the Bell design team ultimately elected to go with NACA 65-108 (eight-percent thickness-chord ratio) and 65-110 (ten-percent) airfoil sections. The benefits of swept wings, which had been postulated by NACA aerodynamicist Robert T. Jones in early 1945 and which were soon to be confirmed as German research archives were examined, were still nothing more than theoretical calculations at the time of Kotcher's decision. No one in this country had any experimental data on the characteristics of such airfoils and thus both Kotcher and the NACA concluded that applying them to the design of what was already an extremely unconventional airplane would introduce unnecessary additional risk into the program. Moreover, Bell was already faced with the daunting challenge of designing and fabricating the eight- and ten-percent wings. To overcome the problems inherent in building extremely thin wings capable of sustaining 18g loads, the Bell team eventually decided to employ exceptionally thick wing skins which tapered from one-half inch at the wing roots to a conventional thickness at the tips. The thick, milled aluminum skins were not only designed to add structural integrity and rigidity to the wings, they would also presumably maintain their smooth contours as turbulent flow developed in the transonic flight regime. In response to a NACA instrumentation requirement, Bell cut 240 pressure orifices in the skin of each of the left wings and installed 12 strain gauges within each so that pressure distribution and air loads data could be acquired. Finally, based on Stack's and Gilruth's original suggestions, two different sets of adjustable horizontal stabilizers were fabricated--one sized at a six-percent thickness-chord ratio to be flown with the eight-percent wings and the other, an eight-percent section, which would be flown with the ten-percent wings. If required to overcome rapid trim changes in the transonic flight regime, these adjustable stabilizers could be moved through a 15-degree arc at a rate of one degree per second. Should this rate prove to be inadequate, Bell made provision for it to be increased up to as high as three degrees per second.[43]

In a fashion not unlike that demonstrated by the American aircraft industry throughout the recent war, the Bell team--supported by technical data and advice from the NACA--worked fast and effectively as it solved all of the foregoing as well as a host of other perplexing problems. The official contract for final design and construction of three XS-1 (for Experimental Sonic-1; the designation was later simplified to X-1) airplanes, at a total cost of $4,278,537, had been issued on March 16, 1945. Less than ten months later, on December 27 of that year, the first aircraft (serial number 46-062) was rolled out of the Bell plant in Niagara Falls, New York. As it rested on the ramp that day, the bullet-shaped, saffron-colored airplane's simple, extremely clean lines bespoke its sole mission: speed. According to Bell specifications, it had been designed for an empty weight, including

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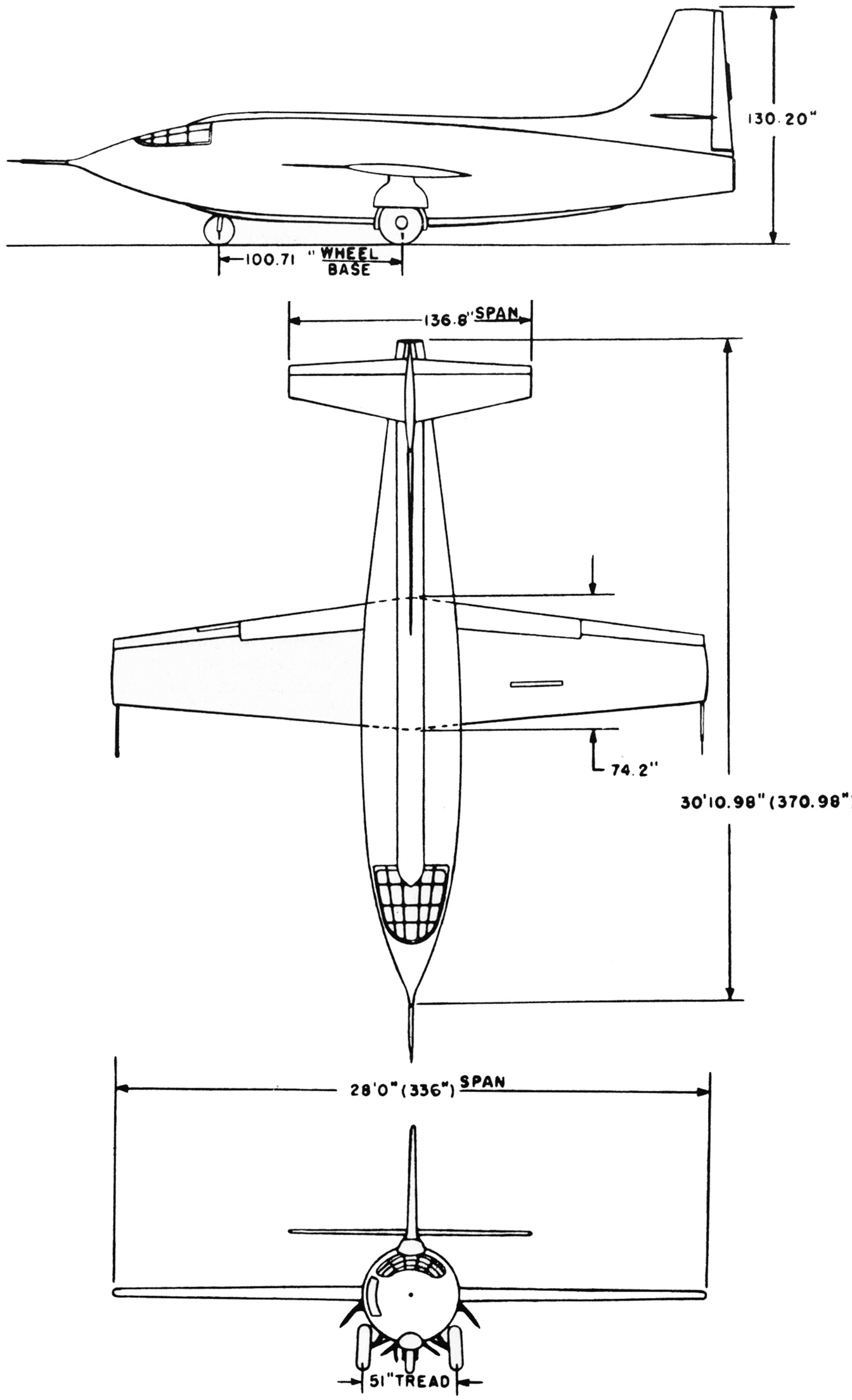

Three View Drawing of XS - 1

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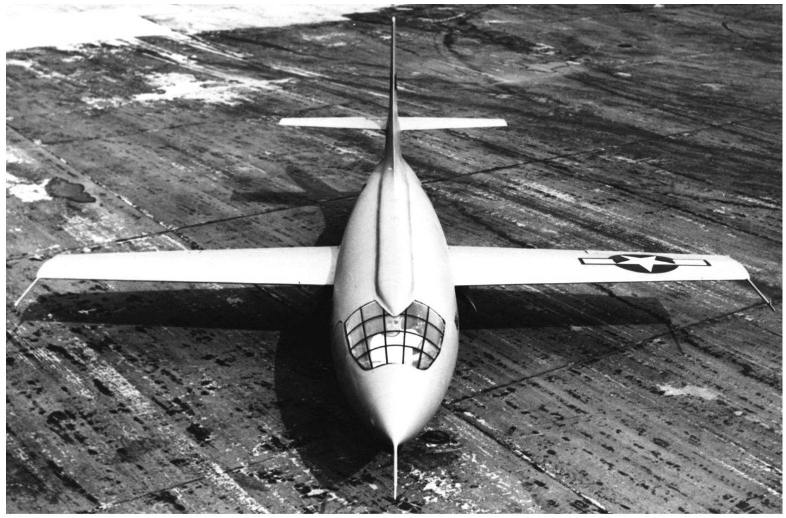
Three-view of the airplane as depicted in Bell's final XS-1 specification report, January 10, 1946.

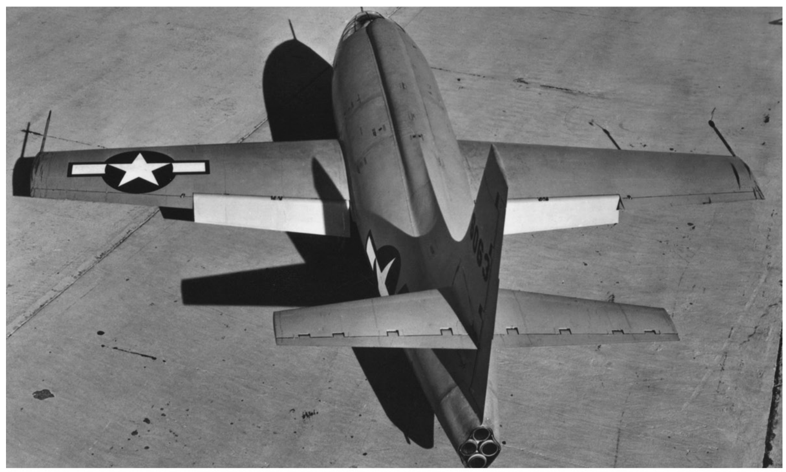
instrumentation, of 6,511 pounds and a maximum gross weight--with 5,120 pounds of propellants and 301 pounds of pressurized nitrogen--of 12,050 pounds. Minus its nose-mounted pitot boom, the fuselage was 30 feet 11 inches long and the wingspan was 28 feet, providing a net wing area of 102.5 square feet. Bell predicted that, due to current fuel storage limitations, the airplane could achieve a top speed of 916 mph at an altitude of 50,000 feet. The recently redesignated Project MX-653 was poised to enter a new phase.[44]

It should be noted, however, that the Bell XS-1 had *already* achieved one of the fundamental purposes of the research program. Its design had stimulated the development of new wind-tunnel techniques at Langley which enabled researchers to begin to circumvent the choking problem. Thus, even before the XS-1 commenced its transonic flight research program, the NACA was able to acquire reliable transonic flow data up to about Mach 0.9 and make reasonably confident wing-flow predictions up to a Mach number of 0.93. Beyond that Mach number, of course, the flight researchers who were about to engage in the test program would be on their own.[45]

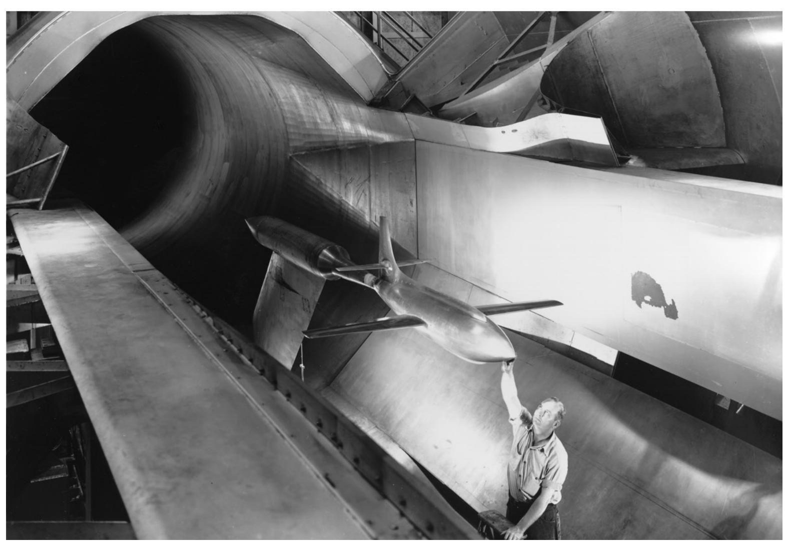
Initial Glide Tests

Under the terms of its contract, Bell was only required to demonstrate satisfactory operation of the airplane up to a Mach number of 0.8. Specifically, this meant that the XS-1 had to demonstrate an endurance of 2.5 minutes at full thrust, satisfactory controllability





Above: Front and rear views of the XS-1 which illustrate its bullet-like shape, the arrangement of its flight controls and the relatively small size of the exhaust nozzles for each of the chambers of its 6,000-pound thrust engine. Below: Model of the XS-1 in the Langley Memorial Aeronautical Laboratory high-speed wind tunnel.



up to Mach 0.8 and structural integrity during 8g accelerations at both minimum airspeed and at a speed not to exceed 500 mph. Though the XLR-11 rocket engine would not be ready for installation on the airplane for several months, the AAF was eager to proceed with flight tests in order to verify the feasibility of air-launch operations and to determine whether or not an exotic research aircraft could be safely operated out of a conventional airfield--albeit one at an isolated location. The previous May, the NACA had already been informed by Colonel George F. "Pooh" Smith, Kotcher's boss and chief of the Experimental Aircraft Projects Section at Wright Field, that the airplane would not be tested at Langley. Though he and Kotcher envisioned a location such as Muroc AAF or possibly even Wendover Field in Utah, the final decision on where to conduct the contractor's acceptance tests was left up to Bell.[46]

Bob Stanley tasked Jack Woolams, Bell's chief test pilot, to conduct a survey of all potentially suitable landing fields across the country. The 28-year old Woolams, renowned for his skills as a test pilot and for his fun-loving exploits as Bell's prankster *par excellence*, had flown all of the most hazardous tests on the jet-powered Bell XP-59A--including the spin and compressibility dive tests--and he had been selected as the company's project pilot for the XS-1 acceptance tests. Indeed, the airplane's cockpit had been designed around his 6'1" frame. Having spent eight months as Bell's chief of test operations on the jet program at Muroc in 1943, he was well acquainted with the tremendous natural advantages afforded by the base--its isolation, unsurpassed flying weather and the tremendous margin of safety afforded by the world's largest natural landing field, the vast 44-square mile expanse of Rogers Dry Lake. Winter was already upon them, however, and he was also aware that the high desert's short rainy season was imminent and that would mean the lake bed might well be flooded, making flight operations impossible for an indeterminate length of time. Both the AAF and Bell wanted to get the flight program underway *post haste* and, based on Woolams' report,

Bell chief test pilot Jack Woolams with the No. 2 XS-1 shortly after it was completed.

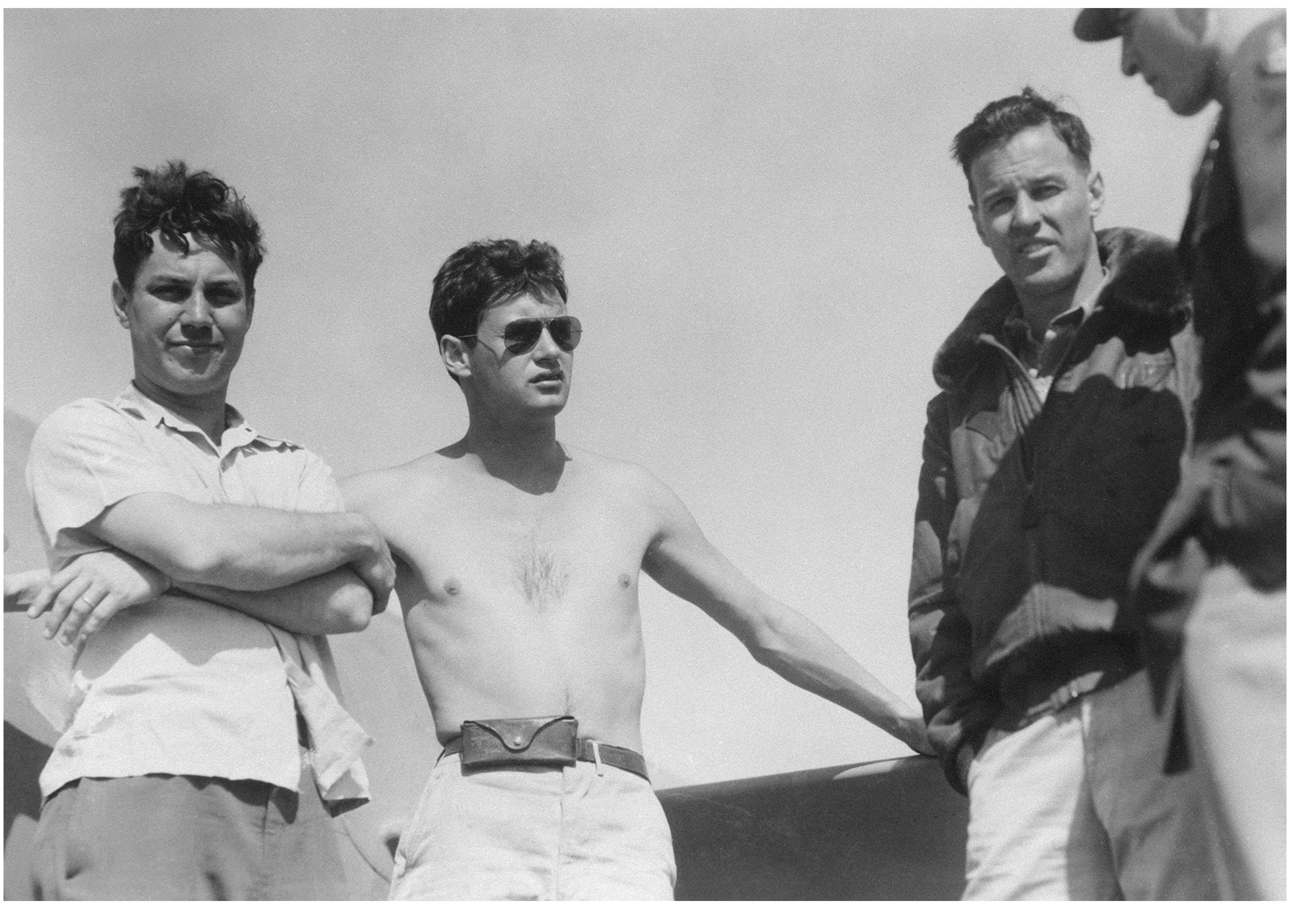
The No. 1 XS-1 in its loading pit at Pinecastle Field, Florida. B-29 launch aircraft in background.

Stanley recommended Pinecastle Army Air Field, near Orlando, Florida, as the most suitable place to commence unpowered glide-flight test operations. The field was relatively isolated, it had a 10,000-foot runway, adequate military security and, of course, the winter weather in Florida promised to be much better than it would be at most other locations in the U.S. Despite the NACA's continued desire to conduct the flight program at Langley, Colonel Smith approved Bell's selection.[47]

Configured with the ten-percent wings and eight-percent horizontal stabilizer which would be employed for the initial glide test program, the No. 1 XS-1 was carried aloft by the modified B-29 (serial number 45-21800) for its first captive test while still at Bell's Nigara Falls facility on January 10, 1946. This test was conducted to evaluate the mated airplanes' flight characteristics and to collect pressure distribution data from the XS-1's wing in order to determine if adequate separation forces existed to insure safe launch operations. Satisfied with the results, Bell used the B-29 to transport the rocket plane to Pinecastle Field on the 18th.[48]

The AAF had requested that the NACA take responsibility for radar tracking, telemetry and data acquisition and analysis for the glide test program and, the following day, Walter C. Williams and a small contingent of NACA engineers and technicians arrived from Langley. The 27-year old Williams had graduated from Louisiana State University in 1939 and, the following year, had gone to work for the NACA at Langley where he specialized in aircraft stability and control. He had worked with Stack on the NACA's original design concept for a transonic airplane and was subsequently placed in charge of the XS-1 flight test program. He was young, ambitious, very bright and, given an opportunity and responsibility which he took very seriously, he could be stubborn and very headstrong. In this regard, he would more than meet his match in Bob Stanley. A skilled aviator with a degree in aeronautical engineering from Cal Tech, Stanley had been Bell's chief test pilot on the XP-59A program. A brilliant engineer--brilliant to the point of arrogance, he was a relentlessly hard-driving and impatient man who was not inclined to tolerate opinions contrary to his own. The phrase "my way or the highway" would very aptly define his approach to interpersonal relations. Williams received his first lesson on this at the outset when, prior to the second captive test flight, his team's efforts to instrument the XS-1 fell behind schedule. The AAF and the NACA had sent the Langley contingent to Pinecastle to acquire data and, indeed, Williams could justifiably argue that data collection was *the* purpose of the test program. But,

Bell Aircraft Corporation president Larry Bell (left) and, captured in a lighter moment, chief engineer Bob Stanley (right).



From left to right, Walt Williams, Joel Baker (the NACA's test pilot-observer), and Jack Woolams conferring with XS-1 project officer Captain David Pearsall at Pinecastle Field, early February 1946.

from Bob Stanley's point of view, he was running a contractor test program which was solely aimed at meeting contractual obligations concerning air-launch operations and the airworthiness of the airplane up to a specified Mach number. For Stanley, time was money and the sooner the test program could be completed the better. Whether the instrumentation was ready or not, the flight *would* go off on schedule and Stanley informed Williams that his technicians had until 2:30 p.m. on January 21 to complete the job. They managed to meet the deadline and the second and final captive carrry flight test was completed that day without the issue erupting into a major *contretemps* between Stanley and Williams. But this seemingly minor incident was indicative of events in the future.[49]

Four days later, on January 25th, Jack Woolams was seated in the cockpit of the XS-1 as, at an airspeed of 180 mph and an altitude of 22,600 feet, it was released for the first time. He reported a clean break from the B-29--which was obviously the first major objective of this test--and, ultimately attaining a top speed of approximately 275 mph, thoroughly enjoyed himself as he completed a series of maneuvers and stalls during the ten-minute glide toward the field below. The final moments of the flight were not quite so enjoyable, however. Approaching the field, he suddenly realized that he had miscalculated the steepness of the airplane's rapid descent and, while he managed to coax the XS-1 over a row of trees that lined the edge of the field, he undershot the landing as he touched down on a hard grass shoulder 400 feet short of the end of the runway. Apart from his pride, Woolams suffered no injuries and the aircraft was undamaged. His miscue notwithstanding, Woolams was extremely pleased with the airplane. Reporting that it felt "solid as a rock" and yet "light as a feather during maneuvers" because of the lightness, effectiveness, and nice balance between the controls, he found the sleek experimental aircraft extremely easy to fly.[50] The final paragraph of his flight report summed up his admiration for what Bell had wrought:

> Of all the airplanes the writer has flown, only the XP-77 and Heinkel 162 compare with the XS-1 for maneuverability, control relationship, response to control movements, and lightness of control forces. Although these impressions were rather hastily gained during a flight which lasted only 10 minutes, it is the writer's opinion that due to these factors and adding to them the security which the pilot feels due to the ruggedness, noiselessness, and smoothness of response of this airplane, it is the most delightful one to fly of them all.[51]

Woolams completed a total of ten glide flights at Pinecastle between January and early March 1946. The XS-1 was launched at speeds of up to 240 mph and from 25,000 feet altitude, and Woolams had evaluated its handling qualities at air speeds as high as 400 mph. The concept of air-launch operations was successfully demonstrated and the XS-1, based on the data acquired and Woolams' assessment, had exhibited excellent flying qualities. The program, however, had not been without incident. At the end of one flight, the left main landing gear had retracted as the airplane touched down and the left wing had been damaged. As he was rolling out on landing after another flight, the nose gear had retracted and, during yet another flight, the XS-1's windscreen had fogged up and then Woolams' vision was further obscured when glycol syphoned out of the windshield de-icing system. Combined with long delays that had been encountered because of poor weather conditions, these incidents settled one very important issue, once and for all. The powered flight program would not be conducted at Pinecastle...and *certainly* not at Langley Field. Indeed, based upon his recent experiences in the XS-1, Woolams recommended Muroc. It had everything going for it that Pinecastle did *plus* better--and more predictable--weather, more isolation, *and* the vast, pilot-friendly expanse of Rogers Dry Lake.[52]

Extremely pleased with the results of the glide-test program, Bell ferried the No. 1 XS-1 back to New York for installation of its engine and propellant tanks as well as to replace the wings and horizontal tail with the thinner airfoils which would be employed on it for the high-speed portion of the research test program. This airplane, however, would not fly again for more than a year. The No. 2 ship (serial number 46-063), configured with ten-percent wings and an eight-percent tail, was being

The XS-1 suffered a number of landing mishaps during the Pinecastle tests. Jack Woolams (second from left) surveyed the damage following the fourth flight on February 8, 1946. Following touchdown, the left landing gear had retracted and, when the left wing hit a runway boundary light, the aircraft had careened off the runway.

prepped to complete the initial powered flights at Muroc. Jack Woolams had expected to make those flights and, indeed, was fully confident that he would ultimately become the first man to exceed the speed of sound. Tragically, however, on August 30, he was killed in an accident while preparing to fly a highly modified P-39 in the Thompson Trophy Air Race near Cleveland.[53]

The tragic death of the popular Woolams was a serious blow to the whole Bell team and, in light of subsequent events, it might well be considered as one of the major turning points in the XS-1 program. Bell was already negotiating with the AAF for a contract to make the attempt on the speed of sound and, if negotiations proceeded in Bell's favor, Woolams was slated to make those flights. Contractor pilots typically received substantial bonuses for flying hazardous test programs. Indeed, Woolams had been promised a $10,000 bonus for flying the initial acceptance test program. But, shortly before his death, he had confided to his wife that Bob Stanley knew he had him "over a barrel." "He knows I'm so eager to make those [supersonic] flights," he explained, "that I'll do it for nothing if I have to."[54] One can only speculate about where all of this may have led but certainly the personal loss, for all involved, was tremendous. A few days after the accident, Larry Bell confided to Brigadier General Laurence C. "Bill" Craigie, the chief of the Engineering Division at Wright Field: "Jack's death was a great loss to aviation; one of the most capable test pilots I have ever seen and a fine boy of great charm and personality to whom we were all deeply devoted. I felt closer to Jack than to any pilot we ever had. His willingness to explore the unknown was a great inspiration to me."[55]

Bell's Powered Flight Test Program

With resumption of the flight test program close at hand, Bell selected 23-year old Chalmers H. "Slick" Goodlin to replace Woolams as the XS-1 pilot. Handsome and engaging, Goodlin had enlisted in the Royal Canadian Air Force in 1941 and, after completing a combat tour flying *Spitfires* with the RCAF, he had subsequently served as a test and ferry pilot for the U.S. Navy. He had flown as a test pilot for Bell since January of 1944. By the time he was assigned to the XS-1 project, Goodlin had already acquired vast experience in high-performance aircraft and he had earned a reputation as an outstanding "stick-and-rudder man." During the acceptance test program, Bell was contractually obligated only to test the craft and prove its flight worthiness out to 0.8 Mach. However, since it was common practice for contractor pilots to fly all of the early, hazardous envelope-expansion phases of test programs on new aircraft, there was at least reason to believe that, if he and the XS-1 survived, Goodlin might well proceed to fly the rest of the program up to, and including, the assault on Mach 1.[56]

But first things first. The whole issue of who would make those flights--whether it would be a pilot from Bell, the NACA or some other organization--would not be settled for many months. For the present, Bell still had to complete the acceptance program. The company was under pressure from the AAF to complete the tests as quickly as possible so that the research program could get underway. In addition, Bell had its own motives for proceeding with haste. Like many other aircraft manufacturers caught up in the postwar drawdown, the company was facing a serious financial crisis and could ill afford the costs of conducting a long, drawn-out test program.[57]

While the Pinecastle tests were still underway, Bell had designated Richard H. "Dick" Frost as its project engineer for the XS-1 program. The 28-year old Frost had graduated with a degree in aeronautical engineering from Rensselaer Polytechnic Institute in 1940 and had joined Bell as a test pilot in July of 1943. Serious injuries incurred while bailing out of a burning P-63 in February of 1945 had curtailed his test piloting career and he had transitioned into the company's experimental engineering programs. In late August, he outlined the remainder of Bell's planned acceptance test program for the Engineering Division. Given the fact that the XS-1 was a highly experimental aircraft employing an exotic propulsion system, he explained, it was impossible to provide a detailed, flight-by-flight plan. Decisions concerning the planned events for each flight would necessarily be based on what was encountered in previous flights. However, Bell was just as eager as the AAF to complete the program as quickly as possible and hence it would "make every effort to limit our flight tests at Muroc." On the issue of the controllability of the XS-1, for example, the company did not "envision any lengthy series of scientific tests to investigate all the byroads of stability in its various forms." It would, instead, accept its pilot's judgement on the issue. While Bell wanted to cooperate with the NACA in its efforts to collect data, Frost reminded the AAF that the company's engineering funds for the program were extremely constrained. Bell's responsibility was to complete the acceptance tests as expeditiously as possible, not to engage in flight research. Thus, he explained:

> We do not foresee the need for delaying any flight test, for instance, to permit detailed analysis of numerous data which the automatic instrumentation may have recorded the previous flight, nor delaying a flight because radar or telemetering, or say, a multiple manometer were not functioning 100 percent since none of those items have any bearing on our contractual commitments.[58]


Dick Frost shortly after he joined Bell as a test pilot in 1943.

While this was acceptable to the AAF and certainly consistent with the approach already taken by Bell during the Pinecastle tests, it was certainly *not* in keeping with the kind of program the NACA had envisioned. The agency viewed the acceptance tests as the first phase of a detailed flight research program which, at this point, it still intended to conduct. Moreover, before it would be willing to proceed with the high-speed tests, the NACA wanted complete data--especially on air loads and stability and control. Always very guarded and deliberate in its approach to research projects, the NACA was especially sensitive to the risks involved in this program. Thus, in early June, Walt Williams had planned a very comprehensive and deliberately cautious flight research program for the XS-1 which was predicated upon obtaining complete data from a fully instrumented airplane during the contractor's acceptance tests.[59] And, in his memo transmitting that plan to NACA headquarters later that month, Henry J.E. Reid, the Engineer-in-Charge at Langley, had cautioned that "the tentative nature of this program should be stressed, as the progress is contingent on the findings of estimates which may be off several hundred percent."[60] Williams reiterated both the NACA's concerns and its requirements in meetings with Frost and Stanley at Bell's Niagara Falls facility in mid-September. He was informed that, while Bell would attempt to assist the NACA in meeting its data requirements, the company would be satisfied with Goodlin's judgements concerning stability and control and that no special data gathering flights would be scheduled nor would any delays in the flight test program be tolerated.[61]

While conceding that it met the legal requirements of Bell's contract with the AAF, this response was totally unacceptable to Reid. Thus, in late September, he informed NACA headquarters that Langley's requirements for the acceptance test program included "systematic exploration of the stability and control characteristics and structural loading at successively higher speeds up to a Mach number of 0.8. This program," he continued, "is based on the understanding that before asking anyone to proceed with the extremely hazardous flying above a Mach number of 0.8 everything would be done to make certain that the airplane was satisfactory in all aspects in the speed range up to Mach 0.8." Bell's proposed program fell far short of meeting these requirements. "The mere flying of the airplane to a Mach number of 0.8 and making an 8 g pull-out," he explained, "is not considered suitable preparation for the research flying... Langley cannot operate and maintain the XS-1 and other airplanes needed for research testing and does not want its pilots to undertake the research flying on the XS-1 following such limited acceptance tests as Bell proposes." Under the circumstances, Reid recommended that the Army immediately start proceedings for a contract with the Bell Corporation for the operation, maintenance, repair and modification of the XS-1 airplane, as well as "for the research flying under NACA supervision."[62] NACA headquarters rejected this proposal outright; it was not consistent with smart politics at a time when the NACA was campaigning for additional congressional funding for a proposed National Supersonic Research Center.[63]

Nevertheless, flight researchers at Langley had cause to be concerned about safety. The transonic flight program would venture into a completely uncharted area. The potential risks were tragically highlighted less than a month after Jack Woolams' fatal accident when, on September 27, English test pilot Geoffrey de Havilland was killed during a practice flight in preparation for an attempt to set a new world speed record in the D.H. 108 *Swallow*. The experimental jet was flying in the dense lower atmosphere at only 7,500 feet when, as de Havilland attained a speed of 0.875 Mach, the airplane was subjected to a violent longitudinal pitching oscillation and literally disintegrated. The news was sobering, indeed. By that time, in fact, Great Britain had already abandoned its attempts to develop piloted supersonic research vehicles.[64] Britain's director of Scientific Research for Air had noted at a press conference the preceding July that flying at speeds greater than sound "introduces new problems" and he conceded: "We do not yet know how serious they are. The impression that supersonic aircraft are just around the corner is quite erroneous. But the difficulties will be tackled by the use of rocket-driven models. We have not the heart to ask pilots to fly the high-speed models, so we shall make them radio-controlled." [65]

Three days after de Havilland's accident, on September 30, Walt Williams and the initial cadre of NACA engineers and technicians arrived at Muroc and, although they did not realize it at the time, they were the first component of what would become a permanent NACA/NASA establishment at the base. Once again, as at Pinecastle, his unit would be responsible for instrumenting the airplanes, gathering and analyzing the data, and exerting

Muroc Army Air Field on October 10, 1946--the day prior to Slick Goodlin's first flight. The village of Muroc appears near the top left-hand corner of this photo. A portion of the immense 44-square mile dry lake bed, where the XS-1 would complete so many of its landings, is visible at top. The giant Northrop XB-35 Flying Wing bomber prototype can be seen taxiing toward the west main hangar where the XS-1 would be serviced. The rocket plane's loading pit and fueling area were located at the extreme west (left) end of the adjacent ramp.

as much influence as they could on the planning and conduct of the flight test program. That issue returned to the forefront almost immediately after the B-29 and XS-1 arrived, along with Bob Stanley, on the evening of October 7. The next day, Stanley announced that Bell planned to complete Goodlin's first unpowered checkout flight on the morning of October 9. When Williams informed him that it would be impossible to instrument the aircraft because most of his technicians were not even scheduled to arrive until later that day, Stanley was anything but sympathetic. Finally, they took the issue to Major Clarence A. Shoop, who was the Air Materiel Command's (AMC) representative for the XS-1 project at Muroc. Williams reported back to Mel Gough at Langley:

> At first Major Shoop said that he didn't want to get into the argument because he was just a third party and the difficulty was between Bell and NACA. However, it was pointed out that the AMC which he represents was the mediator and so he was in it. This resulted in a phone call to Wright Field. A conference call was made with me, Stanley and Major Shoop on this end and Jim Voyles and Charles Hall [both of the Experimental Aircraft Projects Section] on the Wright Field end. The results were rather inconsequential. I told them that we were not ready and could not possibly be ready by tomorrow. Stanley emphasized that it was not just the matter of delaying the first flight but also a matter of policy for the entire flight test program. I told them we needed to get started right or we would always be behind Bell.[66]

Voyles more or less attempted to pacify both sides, stating that the AMC agreed with the flight test program as defined by Bell while reminding Stanley of the importance of having an adequately instrumented airplane. The bottom line, as Williams reported to the Chief of Research at Langley was that "the Wright Field personnel would not...make a definite statement as to the policy on this test program." [67]

Part of the Bell XS-1 team at Muroc (from left to right): Dick Frost (project engineer), Harold "Pappy" Dow (B-29 launch pilot), Mark Heaney (B-29 co-pilot), Al Bindig (instrumentation technician and B-29 scanner), Frank Nichols (mechanic and B-29 scanner), Bill Miller (B-29 flight engineer), Slick Goodlin (XS-1 pilot), Charles "Mac" Hamilton (XS-1 crew chief).

Three key members of the NACA's XS-1 team at Muroc: De E. Beeler (front), Hubert M. "Jake" Drake (left), and Walt Williams (right). Drake was the team's stability and control engineer. Beeler served both as Williams' deputy and as the project engineer in charge of the aircraft loads program.

Ezra Kotcher had long since moved on to other projects and, unfortunately, instead of taking a stand and settling the issue, the AMC would continue to equivocate. In meetings with the principals, it continued to emphasize that time was of the essence. Funding was short and thus Bell was encouraged to proceed with all due speed. On the other hand, because the AMC still planned to transfer management control of the research program over to the NACA, it wanted the agency to be satisfied with the airplane before it was accepted--and this meant that Williams' crew should be given adequate opportunity to instrument the XS-1 and to acquire sufficient data. While the AMC never did stipulate who should be in charge of the program, a very *informal* compromise was eventually hammered out. NACA and AMC officials ultimately settled on a total of approximately 20 contractor demonstration flights, during which both the No. 1 and 2 aircraft would be evaluated, as adequate for the NACA's data-gathering purposes. Privately, Dick Frost informed Williams that "he would see that things worked out better for us" once Stanley departed for Buffalo. Indeed, even Stanley himself acknowledged as much when he conceded that "he was pushing the project faster than normal because his time [at Muroc] was limited." [68]

Bell's attempt to fly on October 9 came to naught. The launch had to be aborted when Goodlin was forced to jettison the cabin door because of a malfunctioning cabin pressure relief valve. Never one to stand idly by, Stanley himself pitched in and fixed the damaged door with a sledge hammer and Goodlin was able to complete his first unpowered checkout flight on October 11. After an uneventful flight, his first landing demonstrated the wisdom of selecting Muroc for the tests. He touched down about half-way down the 6,500-foot concrete runway and the brakes failed. The aircraft rolled out across the runway overrun onto the lake bed and continued to roll until it finally came to a stop nearly 8,000 feet from where it had touched down. Although pleased with the XS-1, in general, Goodlin reported that he had "considerably" over controlled the airplane because of the lightness of its controls and he recommended that the friction in the control system should be increased. He completed another pair of glide flights over the following week during which he continued to encounter problems with the brakes as well as with the pressure regulators and various other systems. Stanley then called a halt to flight operations so these problems could be rectified and the B-29 could undergo a 100-hour maintenance checkout.[69]

The hiatus gave Williams an opportunity to search, without much luck, for some decent housing for the NACA employees as well as to conduct some NACA business. He traveled to the Douglas facility in El Segundo, California, for example, to check on the D-558 and was able to report that it was progressing well. Since his arrival at Muroc, he had been very much impressed by the extraordinary variety of new experimental prototypes which were undergoing tests at the base from AAF prototypes, such as the XB-35, XB-43A, and XP-84 to a surprisingly large array of U.S. Navy aircraft, including the XFJ-1, XF6U, XF2R-1 and the gargantuan Lockheed XR6O-1 *Constitution*. He reported that he had heard rumors--which proved to be accurate--that the AAF had a master plan to transform the ramshackle base into a major modern test installation and, after just a few weeks at the location, he could see why. The flying conditions were incomparable and the lake bed had already proven its value. In this out-of-the way, almost primeval location, he had caught a glimpse of the future. While the NACA had strongly resisted the idea of testing the XS-1 at Muroc, he predicted that the agency would probably "have a large group out here for a very long time." There were "no two ways about it," he explained to Mel Gough back at Langley, "this is the place to test experimental airplanes or, for that matter, any sort of airplane."[70] He proved to be a prophet.

Top: XS-1 as it dropped away from the B-29 launch aircraft, October 1946.

Middle: just prior to touchdown following one of its early glide flights at Muroc, October 1946.

Bottom: Slick Goodlin emerging from the cockpit of the XS-1 following one of its early flights. Bell mechanic and aircrew member, Jack Russell (to the left), would subsequently go to work for the AAF and serve as the XS-1 crew chief for the supersonic flight program.

The B-29 taxiing out with the XS-1 loaded in its bomb bay. Note the extremely small space between the ramp and the XS 1's ventral surface.

The B-29 returned to Muroc on November 20 and Bob Stanley returned seven days later with news that Larry Bell was coming out to spend the first week of December. He was hell-bent to complete the first powered flight during Bell's visit and, ignoring Dick Frost's reservations about the readiness of the XS-1 for powered flight, he once again accelerated preparations into a frenzied, "hurry up" mode. "Stanley," Williams observed, "is a hard man to understand." Wryly, he noted that "'The Great White Father' as the Bell boys call him, from his performance Friday, you would expect to find him floating face down in the lake any morning if there was water in the lake."[71] A humorous observation; however, the events which followed were anything but.

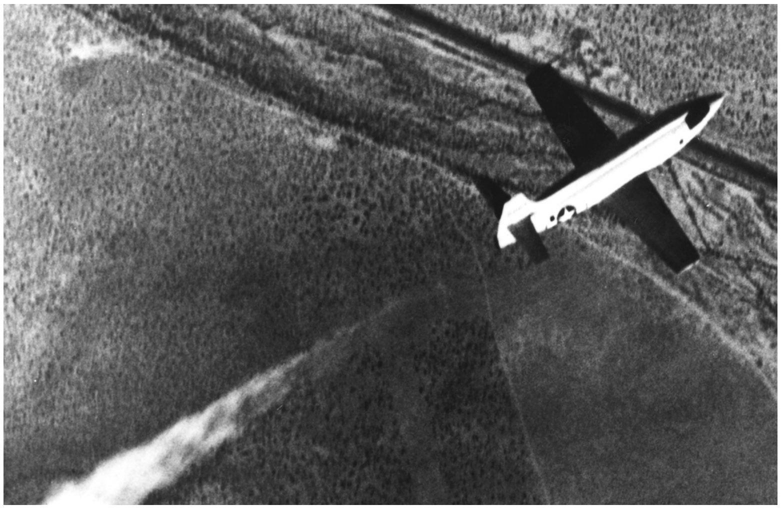
Stanley decided that only one more glide test was necessary in order to prepare for the first powered flight. This was to be a "ballast test." Bell technicians filled the fuel and liquid oxygen (lox) tanks with a water-alcohol solution to about 40-percent of their capacity. This increased the gross weight of the aircraft to about 8,700 pounds and it would permit Goodlin to test the fuel and lox jettison valves.[72]

With Larry Bell, Stanley and a number of other dignitaries stationed in the control tower and Dick Frost flying chase in an FP-51, the B-29 took off from the main runway on December 2. During a preflight inspection, the ground crew had noticed that the XS-1's nosewheel would not lock in the up position. When mated to the B-29 with the XS-1's nose gear retracted, the clearance between the rocket plane and the ground during takeoff was less than one foot. If, for any reason, the B-29 had to land while still carrying the XS-1 and the gear should extend, it could well mean disaster. No one anticipated this, however, and Stanley gave orders to proceed with the flight. Well, the unanticipated did happen. As the B-29 was climbing toward launch altitude, a nitrogen pressure valve in the XS-1 malfunctioned. The lox tank could not be pressurized and thus its contents could not be jettisoned. The XS-1's landing gear was not designed to support a landing with the equivalent of 1,000 pounds of lox on board. All of the sudden, the nose gear ground clearance issue got *everybody's* attention. There were only two alternatives, neither of which was very attractive: either jettison the XS-1 or attempt to land the B-29 with its cargo. Loss of the rocket plane would have dealt a devastating blow to the whole program and thus Stanley ultimately decided to proceed with the attempt to make the dangerous landing. Frost radioed Goodlin and recommended that he retract the nose gear just before the B-29 touched down. It would slowly return to the down position but, by the time it had completed its cycle, the B-29 would be safely on the ground on final rollout. Stanley, however, had difficulty visualizing Frost's proposal and he ordered him to come down and explain it in person. All the while, the B-29 had been burning up fuel and its supply was running low. Fuming with rage, Frost landed his airplane, taxied to Base Ops, hopped out and, after he had carefully--and rather heatedly--explained the procedure, Stanley gave it his blessing. Frost then had to jump back into his airplane, climb back up to the B 29, and repeat his instructions to Goodlin. With Frost "talking him down" as he approached the runway, the young test pilot managed to retract the gear just as the B-29 was about to touch down and the XS-1 was saved to fly, believe it or not,.....*yet again that very same day*![73]

Remarkably, Stanley decided to reattempt the final glide flight that afternoon. The valve problem had been fixed...but nothing had been done to remedy the nosewheel uplock problem! Just prior to launch, Frost reported that the nose gear was once again inching its way downward. Undeterred, the Bell crew proceeded with the launch. There was a maxim, which has since become famous as "Murphy's Law," which was just then entering the vernacular of flight testers at

The No. 2 XS-1 on the ramp adjacent to the loading pit (lower left) and the lox and fuel loading facility, December 1946.

Muroc: "If anything can go wrong, it will." And, in this instance, it did. When the launch mechanism was activated, nothing happened. After further attempts from the B-29's cockpit had failed, XS-1 crew chief Mac Hamilton crawled back into the bomb bay and manually operated the release mechanism. Good fortune smiled and, after achieving a clean separation, Goodlin jettisoned the contents of the tanks and made a safe landing. It had been a *most* eventful day for Slick Goodlin but, eager to get on with the program, he recommended that the next mission should be a powered flight.[74]



The No. 2 XS-1 just after engine ignition during its first powered flight on December 9, 1946.

Colonel Signa Gilkey, Muroc AAF commander, congratulating Slick Goodlin following the first powered flight. Looking on (from l to r): Jim Voyles, XS-1 project officer from Wright Field, Bob Stanley and Bell vice president D. Roy Shoults.

That moment of truth occurred on December 9, when Goodlin and the rocket plane dropped away from the B-29 at 27,000 feet. As the craft plummeted with its full load of fuel, Goodlin waited about ten seconds to ignite the first cylinder of his engine. Never employing more than two of the cylinders, he climbed to 35,000 feet and effortlessly achieved a top speed of Mach 0.795. Then he cut off all power and dove to 15,000 feet where, pulling up into a climb, he momentarily ignited all four chambers of the engine and instantaneously felt a "terrific acceleration." He also heard what he later described as an “ungodly howl.” Correctly assuming this to be the result of a lean fuel mix entering the engine, he immediately shut down all four chambers. Then he noticed a fire-warning light on his instrument panel. Dick Frost was too far behind to give him a visual confirmation of any evidence of fire and, from his position on the ground, Stanley told Goodlin to jettison all of his remaining propellants and come on down. There had, indeed, been a small engine fire which burned some wiring and instrumentation. But, apart from that and a slight lateral snaking motion caused by fuel sloshing, Bell considered the first powered flight to be quite successful and Goodlin judged the handling characteristics of the XS-1 to be very good.[75]

Immediately after this flight, Bob Stanley returned to Buffalo and, following repairs to the XS-1's engine bay, the testing proceeded at a steady but somewhat less accelerated pace. The purpose of the contractor program was to develop the airplane and its systems to a level of performance and reliability which would be acceptable to the AAF and the NACA. Thus Bell engineers and technicians were forced to spend a considerable amount of time isolating the causes of problems encountered during each flight and then devising workable engineering solutions to remedy them. And, good as his word, Dick Frost made every attempt to satisfy the NACA’s data requirements as Goodlin flew most of the data points requested by Williams. All of this required painstaking effort and it took time. Nevertheless, by the end of February 1947, Goodlin had completed 12 powered flights in the No. 2 aircraft and, meeting Bell's contractual requirements, he had attained a top speed of Mach 0.828 and had demonstrated the structural ruggedness of the craft by completing pullups in excess of 8g’s at speeds ranging from 0.4 to 0.8 Mach. Although engine and fuel pressurization problems had plagued the program, and would continue to cause problems, Bell had also satisfactorily demonstrated the full-power performance of the rocket engine. In order to fulfill all of its requirements, however, the company had to complete a total of 20 powered flights, including at least five flights in each airplane. The No. 1 airplane, with its thin eight-percent wings and six-percent tail, arrived at Muroc in early April and, after a single glide flight, Goodlin completed its first powered flight on April 11. Between that date and June 5, he completed six additional flights in this airplane and the No. 2 vehicle was launched two more times, including a single familiarization flight which was made by Bell’s new chief test pilot, Alvin M. “Tex” Johnston. Altogether, Bell completed a total 15 glide and 22 powered flights in order to bring the company's airworthiness demonstration to a satisfactory conclusion.[76]

Although he had not been able to acquire all of the data he had hoped for, even Walt Williams was satisfied that the NACA had sufficient information on the two airplanes to proceed with the research program. And even though NACA test pilot Joel Baker, who had been assigned to thoroughly inspect the rocket plane and observe the Bell tests, had a long list of reservations about various features of the XS-1, he had concluded that it “could be used in its present configuration as a transonic research vehicle.”[77] Everything appeared to be in readiness for the onset of the research program and the assault on Mach 1. There was one major issue, however, which still had to be resolved: who was going to fly the airplane?

A Turning Point

The issue of who was going to attempt to exceed the speed of sound had remained in doubt almost from the inception of the XS-1 program. Initially, the program had been predicated on the assumption that, after Bell had completed the acceptance flights, the airplanes would be turned over to the NACA for the research phase of the testing.

Early on, however, Bob Stanley had started lobbying for Bell to receive a contract to fly the supersonic program and, as early as May 1945, Colonel George Smith had informed NACA headquarters that it was the "intention" of the Engineering Division to place a separate contract with Bell to complete those flights.[78] Whether this information was ever relayed to flight researchers at Langley remains in doubt, however, because they proceeded with plans to conduct their own kind of transonic flight research program. The major issue for them, however, was never really who would fly the airplane so much as it was who would exercise *control over* the program. Thus, the following October, Mel Gough informed Bob Stanley that the NACA planned to take over control of the research program and it would fly the XS-1 "until such time as the aircraft evidenced characteristics that made it uncontrollable and extremely hazardous to fly. At that time a contract may be negotiated to fly the airplane at higher speeds."[79] While Colonel Smith basically concurred with this, he subsequently imposed at least one very noteworthy condition. In April 1946, he informed NACA headquarters that the agency would conduct the high-speed flight research program and that it would be expected to fly beyond the range of safety. If the NACA was unwilling to fly in that regime, however, the aircraft would be returned to AAF jurisdiction. That final stipulation was, no doubt, somewhat troubling to the NACA for it at least implied loss of control over the research program.[80]

Col George F. Smith, Chief of the Engineering Division's Experimental Aircraft Projects Section, faced some very tough decisions regarding conduct of the XS-1 research program.

While most NACA researchers had been less than enthusiastic about the XS-1--and its primary objective as defined by the AAF--and, while the agency had repeatedly gone on record that it did not want its pilots to perform any of the "extra hazardous" flights, it did want its pilots to fly the airplanes within safe limits and it *most certainly* wanted to maintain control over the planning and conduct of the transonic research program. Looking toward this eventuality, in June of 1946, Walt Williams drafted a proposed research flight program. In keeping with NACA practice, it was designed to gather extremely detailed data on stability and control, aerodynamic loads, drag and performance. This was to be accomplished in two phases. During the first, which would define what Williams called the "operational limits of the airplane," the NACA would "progress in definite Mach number increments such as 0.83, 0.86, 0.89" to acquire complete data on the stability and control characteristics of the airplane as well as sufficient data from strain-gauge instrumentation to establish an adequate level of confidence concerning aerodynamic loads. The second phase would focus on a detailed investigation of spanwise and chordwise aerodynamic loads on the wings and tail through the use of very precise pressure-distribution instruments (manometers). Because the "operational limits" of the airplane would be defined during the initial phase, it was really the most critical. Concerning it, he explained:

> It is estimated that eight successful flights will be required to complete the tests...at each speed increment. It is possible, therefore, that as many as 48 successful flights will be required. If the configuration of the airplane is changed, it will probably be necessary to go through an entire series of tests as outlined above at speeds below a Mach number of 0.8 as well as at

> speeds above 0.8. If difficulties in control are manifested, it may be necessary to expand the test program and investigate the difficulties in detail and the number of flights will, of course, be increased.[81]

Forty-eight flights with a highly experimental research airplane was a very sizeable number in and of itself. However, a "successful flight" would be one in which all systems on board the aircraft functioned properly, the pilot was able to fly the prescribed profile precisely as planned, and all of the data acquisition, transmission and recording equipment functioned as designed. Historically, the chances for all of these variables to fall into place according to plan were about 50-50. Thus, 48 successful flights might well require over 100 missions. On top of this, Williams had suggested that, if they ran into difficulties, it might "be necessary to expand the test program and investigate the difficulties in detail and the number of flights will, of course, be increased." He had outlined a flight test program that might well require a year or more to complete and yet, not once in this very detailed test plan, did he specifically address the issue of attempting to exceed the speed of sound. When this plan was passed along to the Engineering Division at Wright Field, it must have raised more than a few eyebrows.[82]

The No.1 (foreground) and -2 (loading pit) XS-1s with the B-29 launch aircraft on the ramp at Muroc shortly after the conclusion of the Bell test program in June of 1947.

Meanwhile, Bob Stanley proceeded with Bell plans to take over the high-speed program. In mid-September, he met with Goodlin to discuss compensation for an extended series of flights which would ultimately carry the XS-1 through the sound barrier. They ultimately came to a "handshake agreement" that Bell would issue him--or a corporation formed in his name--a contract which would pay Goodlin a total of $150,000 spread out over a period of five years.[83] At this point in time, although no one in the NACA or certainly the AMC knew anything about this agreement, it appeared that all sides might be inclined to let Bell take on the job. On October 14, 1946, NACA and AMC officials gathered at Wright Field to discuss the research program and, as Hartley Soule reported to the LMAL Chief of Research: "it was agreed that the flying of the XS-1 airplane for the research tests is extra hazardous and probably that it could be done most fairly by contracting for the pilot's services." There was one very important drawback to this approach, however. When the AMC proposed that the NACA undertake the negotiation of a contract for the research flights, both sides learned that *neither* had the funding to pay for it.[84]

In the postwar drawdown, AAF budgets had been slashed and much of the ambitious research and development program the service had planned, in order to capitalize on technological revolution spawned by the recent war, had to be shelved. Thus the AMC's research and development budget was severely limited. The budget for the entire XS-1 program, for example, totaled only $4,371,560 (as of December 1947) and its funding for fiscal 1948 was limited to $192,000 (indeed, the AMC's entire R&D budget for all of the many programs it would manage in 1948 came to only $29,175,000).[85] For the time being, at least, this circumstance also shelved any plan to hire a contractor to conduct the XS-1 research program. Indeed, it appeared to have taken the program back to square one. On February 6, 1947, AAF, AMC and NACA officials formally agreed that the NACA would furnish the flight and maintenance crews for the XS-1 and, indeed, all upcoming X plane programs. While he had been a party to this agreement, Colonel Smith was none too comfortable with it. Indeed, he had other concerns on his mind in addition to the issue of funding as he prepared for an upcoming meeting with Bob Stanley and NACA officials to discuss the current status and future direction of the program.[86]

That conference was held at Wright Field, on March 5, and Stanley was none too pleased with the proceedings. The whole issue of whether Bell had satisfactorily met its contractual requirements for the initial acceptance program--and, more critically, whether or not the NACA would accept the airplane--was still unresolved. The NACA had expressed reservations about the XS-1 since the original design concept meetings and, while the current flight test program had revealed no serious flaws, it soon became apparent that Mel Gough was still not eager to have his pilots fly the airplane. Stanley reported back to Bell officials, afterwards, that "Mr. Gough was as timorous as an old maid as regards 'putting his stamp of approval' on the airplane by accepting it...He finally reluctantly admitted that it complied with the specification but...he thought that the specification was loosely written." Stanley was equally skeptical about the NACA's approach to the research program:

> I was rather disturbed in the conference by a statement made by [Hartley] Soule [of the LMAL] that they weren't interested in the third airplane (with the turbine pump) because they could get all they wanted out of the present airplane. This, of course, means that they have taken a defeatist attitude in ever going to sonic or supersonic speed and hence are not interested in the additional 800 m.p.h. which the turbine pump will give them. I have heard from several sources that they are more or less marking time until they can get hold of the Douglas D-558 and they are only slightly interested in the XS-1. This may be an extreme view but I believe it is partially true. As far as I can determine from several pointed questions which I asked yesterday, they will use the XS-1 no more effectively than they could the P-80 or P 84 since they are going to fly it at low altitudes up until they encounter trim change and/or buffeting and then they will stop. At these low altitudes, they could do the same with a P-84 since it reaches Mach No. trouble at part throttle.[87]

Stanley had not given up hope that Bell would be issued a follow-on contract and he argued, apparently in vain, that his company should be permitted to fly one of the airplanes in an accelerated program to "run interference" for the NACA and define the envelope "in advance of their detailed research." This suggestion, he reported, "was not well received by NACA and the Army politely murmured 'We don't have the funds.'"[88] Nevertheless, for the first time, Stanley's proposal introduced the notion that the best way to proceed might be by breaking the XS-1 program up into two roughly parallel phases, one aimed at achieving supersonic flight as quickly as possible and the other at collecting detailed transonic data.

After the conference broke up, Stanley continued to press his case in a private meeting with Colonel Smith and his deputy, Colonel Osmond J. "Ozzie" Ritland. "I explained in some detail my views concerning the public relations situation," he reported, "the general tempo of the program under NACA, our company reputation as probably handled by the press when they learn that Goodlin was no longer going to fly the XS-1, and the probable wrath of General Spaatz as to the arrangement that had been decided upon." He reported that he "found Colonel Smith most attentive, very courteous, and quite agreeable but also quite troubled." In Ritland, however, he found an apparent ally. He had served as a test pilot at Wright Field throughout most of the war and "was quite familiar with the NACA flight test personnel and methods." Stanley reported that Ritland said: "There is no doubt that NACA will do a thorough flight test job but they will take forever." After much discussion, Stanley reported, "Colonel Smith finally intimated that the question of funds was not the real question but it was one involving the danger of offending NACA and the political repercussions of same."[89] Smith was facing quite a dilemma. In point of fact, funding *was* a critical issue. Moreover, the NACA still held the charter for the conduct of fundamental aeronautical research activities in this country and, despite the recent damage to its reputation, the agency still had very powerful allies in Washington. Smith also realized, however, that Larry Bell also had top-level connections in Washington, among them the Commanding General of the USAAF, General Carl Spaatz, and that Stanley's mention of his name was not just an idle threat. As he had in the past, Larry Bell could be expected to go over everyone's head and take the issue all the way to the top.[90] Ultimately, Smith reopened the door for Bell by offering Stanley some off-the-record advice. "He felt that the AAF was powerless to sponsor such a program," Stanley reported, "unless initiated by the NACA and suggested that unofficially and without his sponsorship we approach Dr. Lewis [NACA Director of Aeronautical Research] on the basis of our willingness to perform this very hazardous function with the goal of beating a safe path for their research."[91]

With General Craigie, Larry Bell and Stanley in attendance, the proposed meeting was held in George Lewis' office on March 21. Intent on selling his proposal, Stanley understated the scope of the Bell plan considerably when he indicated that the company's "program would be brief with only a few flights culminating in an attempt to fly through Mach number one." General Craigie indicated that the AMC would attempt to find a way to fund such an effort *if* the NACA would continue to support the program and provide Bell with instrumentation and engineering assistance. Placed in an awkward position, Lewis apparently felt he had little choice but to agree with the proposal. It appeared that the program had taken yet another 180-degree turn.[92]

Stanley may have sold the Bell program on the basis of its being "brief" and requiring only "a few flights" prior to the assault on Mach 1 but that was not the program that he would formally submit to AMC for approval. Back at Muroc, Walt Williams reported that, when Dick Frost informed them of the decision to give Bell the program, he "stated that unofficially Stanley had said that the program would last a minimum of thirty weeks and possibly sixty weeks with a program entailing probably fifty or sixth [sixty] flights." Such a program, Williams wryly observed, seemed "quite lengthy." If Bell could get past Mach 1 in 10-15 flights, then its program would serve a useful purpose but, if the company was going to take 50 or 60 flights to do it, "then their program is unnecessary since the NACA in fifty flights or so will have proved whether or not XS-1 can fly faster than the speed of sound, if the original program which I wrote last year is followed."[93]

Williams was not alone in this observation. Back at Wright Field, George Smith had come to a similar conclusion. When Bell submitted its formal proposal, it called for a cost-plus-fixed-fee contract with no specifics regarding the length of the program nor any guarantee of results. The potential length of the program, General Smith later recalled, was "excessive" and the cost was "exorbitant." Moreover, a tight-fisted fiscal conservative, he was absolutely outraged when he saw a graph depicting Stanley's proposed payment schedule to Slick Goodlin. The AAF could not and, so far as Smith was concerned, absolutely would not provide the funds to underwrite such an enormous pilot bonus contract. Thus the AMC responded with a proposal for a fixed price contract which would carefully stipulate, in advance, what Bell would accomplish during the tests. In essence, Smith offered Bell a contract which he was fairly confident the company could not accept. Thus the program appeared to have taken yet another turn. The obvious answer would have been to return the whole program back to the NACA. Yet Smith had some misgivings.[94]

Bob Stanley's arguments concerning the NACA at the March 5 meeting had not fallen on deaf ears. Smith and Ritland had already conducted meetings with NACA personnel and they were not comfortable with what they were hearing. They, too, had detected a certain skepticism on the NACA's part, particularly in the comments of Hartley Soule who repeatedly expressed doubts about the XS-1's ability to transit the transonic region en route to Mach 1. At the very least, it seemed apparent to them that the NACA would proceed with extreme caution and probably consume a lot of time before it attempted to make an actual assault on Mach 1. After all, the test plan submitted by Williams would take at least a year to complete and it had never directly addressed the issue of breaching the sonic wall. From the Army Air Force's point of view, however, achieving Mach 1 in the shortest possible time was--as it had always been--***the*** primary objective of the XS-1 program. It appeared to Smith and Ritland that the NACA did not have much enthusiasm for that specific goal--or, at best, had put it somewhere on the back burner. For the AAF, however, the issue was more than academic...or even economic. The AMC had fighter aircraft in near-term development, such as the sweptwing XF 86, which promised to nudge precariously close to the supersonic region. Thus the AAF had an immediate and very critical requirement to determine whether or not supersonic flight would pose unacceptable risks.[95]

The more they discussed the matter between themselves, the more they began to consider what, at the time, was a truly unusual alternative: to permit the AMC's Flight Test Division to take over responsibility for the accelerated research program. Though this represented a radical departure from long-established custom, it offered the benefits of avoiding the cost of a program conducted by Bell and, by giving AMC personnel day-to-day, hands-on control of the operation, it would insure that the AAF's primary objective would be pursued in earnest and without delay. Moreover, based on his first-hand experience, Ozzie Ritland had a great deal of confidence in the capabilities of the Flight Test Division and the pilots assigned to it. Having served as deputy chief of flight test at Wright Field in 1943-44, he was intimately familiar with a pair of developments which had come to fruition late in the war years.[96]

To understand them, it is necessary to look at what had transpired over the previous two decades. The Army had once boasted a truly impressive flight test capability. Back in the early 20s, the Army test pilots who flew at old McCook Field, in Dayton, Ohio, were regarded as true professionals--indeed, as among the very best in the business. Aviation pioneers such as Lieutenants James H. "Jimmy" Doolittle and John A. Macready regularly engaged in the full range of flight test activities, from major flight research projects to the extensive developmental testing of new prototypes. All of this changed after Congress passed the Air Corps Act of 1926. The act expressly forbade the Air Corps' involvement in the design and development of its own airplanes and, at the same time, Congress noted that fundamental flight research was a part of the NACA's charter and that military efforts in that realm would constitute an unnecessary and wasteful duplication of capabilities which would no longer be tolerated. From that point through the early years of World War II, Army test pilots found their role increasingly restricted as NACA pilots gained a virtual monopoly on research flying while contractor pilots increasingly performed the lion's share of envelope expansion and other developmental tests on new aircraft proposed for the military inventory. Under these circumstances, Army test pilots were essentially relegated to performing brief acceptance flight test programs which were confined to little more than spot-checking a contractor's data in order to confirm its integrity. No longer regarded as true professionals, they were more or less consigned to a second-class status. While this system had functioned adequately during the prewar years, such complete dependence on the NACA and the contractors proved to be an Achilles' heel during the crisis of war as the AAF found itself unable to acquire the kind and volume of data it needed to make timely and well-informed decisions regarding major weapons systems. As deputy chief of flight test, Ozzie Ritland had been among those who had lobbied long and hard within the AAF for the establishment of a legitimate high-speed flight research capability within the Flight Section (the forerunner of the Flight Test Division which would be constituted in early 1945). This effort finally bore fruit when a Flight Research Branch, with its own dedicated engineers and test pilots, was established in late 1944.[97]

The viability of this new capability was based, to a considerable extent, upon the implementation of yet another initiative with which Ritland was equally familiar. For he had also been among those who were involved in the effort to establish a formal test pilots' school at Wright Field. This institution, initially established as the Air Technical Service Command Flight Test Training Unit in September of 1944, was the forerunner of the present-day U.S. Air Force Test Pilot School. Its purpose, from the outset, was to insure the implementation of standardized flight test methodologies and to transform outstanding stick-and-rudder men into professional engineering test pilots--pilots who would have both the talents and the knowledge necessary to engage in *any* type of flight test program. And, by the spring of 1947, as he and Smith were discussing the future of the XS-1 program, Ozzie Ritland was confident that it had already achieved that purpose. Army Air Forces test pilots were, in his view, more than capable of meeting the challenge and he recommended that Colonel Smith turn the accelerated supersonic program over to the AMC's Flight Test Division.[98]

In an age when the research and development business was conducted a lot more "informally" than it is today, Colonel Smith was remarkably free to make the decision himself without having to go through a lengthy chain of command to higher Army Air Forces headquarters. Thus, not long after the March 5th conference with Bell and NACA officials, he simply called Colonel Albert Boyd, the indomitable chief of the Flight Test Division at Wright Field, and asked him if his

Colonel Albert Boyd, Chief of the Flight Test Division at Wright Field, on the ramp at Muroc AAF in June 1947.

people could conduct the accelerated test program. Enthusiastically, he replied: "You bet!" Boyd was eager to prove that the military--and especially his test pilots--could successfully conduct a highly experimental research program.[99]

Born in Rankin, Tennessee, in 1906, Boyd has justifiably been called "the father" of modern Air Force flight testing. Tough and absolutely unyielding in his demand for excellence, he had assumed command of the Flight Test Division in October of 1945. From the outset, he had energetically pursued the expansion of the flight research mission and, more than any other individual, he had transformed the new test pilot school into an institution which would set industry-wide standards for the profession. Under his always stern and reportedly "omniscient" glare, only the very best pilots--those who had already convincingly demonstrated their discipline, objectivity, precision flying skills, and love for the job--were even permitted to enter the school in the first place. But this was only a part of the winnowing process. After graduation, those who did not continue to meet those standards were unceremoniously weeded out. By 1947, he was confident that he had built up his cadre of professionals and he was just waiting for the opportunity for them to prove their worth. The XS-1 program seemed to offer the best of all possible opportunities.[100]

However, while the offer had been made and the Flight Test Division commenced its planning, the final decision on whether or not it would actually get the program hung in the balance for more than two months. As Colonel Smith had expected, Bell was unwilling to take on a fixed-price contract and, on May 1, 1947, he sent the following message to headquarters USAAF:

> The Bell Aircraft Corporation has formally notified the Air Materiel Command that they consider it inadvisable to accept the highly experimental transonic flight test program on the XS-1 airplane on a fixed cost basis. As a result of this notification, discussion is now underway with [the] view of having this program taken over by AMC Flight Test Division. [101]

The issue, however, was still not settled. Larry Bell had not given up and, employing his very considerable connections in Washington, he challenged the AMC proposal. And, although Colonel Smith had been free to make the original decision without any interference, he suddenly found himself forced to defend it all the way up to the highest levels at AAF headquarters. The issue was ultimately placed before General Spaatz who weighed the pros and cons of the AMC decision for more than three weeks. Finally, on June 24, the AMC commander was officially directed by AAF headquarters to terminate negotiations with Bell and assume responsibility for the transonic flight test program.[102]

Meeting the Challenge of Mach 1

The official go-ahead only served to give formal sanction to an effort which was already well underway. By April, preliminary planning had progressed to the point where the following, very tentative program--based largely upon the conservative Bell proposal--had been outlined by the AMC:

> a. Because of the shortage of telemetering equipment and the desirability of completing these tests in the shortest possible time, no elaborate instrumentation will be installed. The instrumentation will be the minimum required to adequately measure the speeds and altitudes obtained during the tests. Recording equipment will be used which will have some chance of remaining intact if the aircraft is destroyed.
>
> b. The flights to be made may be broken down into several phases. Each flight will be launched from the B-29 airplane at about 30,000 feet.
> 1. Approximately five glide and power familiarization flights may be required in which speeds of up to a Mach number of .8 may be attained.
> 2. Several flights may be required to investigate the flying qualities up to [and] including the critical Mach number of approximately .87.
> 3. A series of flights will then be made to increasingly higher altitudes up to the maximum possible altitude (perhaps

100,000 feet) using the best climbing speed of the XS-1. In the course of these flights speeds up to a Mach number of 1.1 may be reached. The speeds will be attained in a steep climb at high altitude which appears to be the safest and most practical manner of entering the transonic speed range.

4. The high speed of the XS-1 may then be approached in steps by making a series of flights in which the aircraft is leveled off at approximately 70,000 feet and allowed to accelerate. A high speed of possibly 800 mph may be reached at this altitude. Additional flights will then be made in which the aircraft will be leveled off at 60,000 feet, 50,000 feet, 40,000 feet and 30,000 feet and allowed to accelerate to the highest practical speed. In each case the maximum speed will be reached before a stabilized speed has been obtained because of stability difficulties or shortage of fuel.

5. Several flights may then be made to determine the characteristics of the XS-1 when taking off under its own power. If sufficient fuel is available to reach an altitude of at least 60,000 feet under these conditions, an attempt to set a new altitude record may be made.

c. Such a program would have to be coordinated closely with the NACA tests. The number of flights, the increments in which speeds and altitudes would be increased and the actual speeds and altitudes attained will depend upon the pilot and the nature of the difficulties encountered at Mach numbers over .87. It is estimated that such a program would require approximately 30 flights and would take nine months to complete.[103]

Though it bore but faint resemblance to the much more aggressive program which the Flight Test Division would ultimately conduct, it is noteworthy that a key consideration throughout this early planning was that the flights should be made at as high an altitude as possible. Air Materiel Command engineers were awaiting more detailed flight and wind tunnel data from the NACA but they feared that it was possible "that pitching, buffeting or longitudinal oscillations may develop at a rate or in such a manner that they are difficult to control [and] which may result in large accelerations being applied to the airplane." In order to minimize the impact of those oscillations, they concluded, "the flights should be made at the highest practical altitude so that the dynamic pressure of the air (indicated airspeed) will be low."[104]

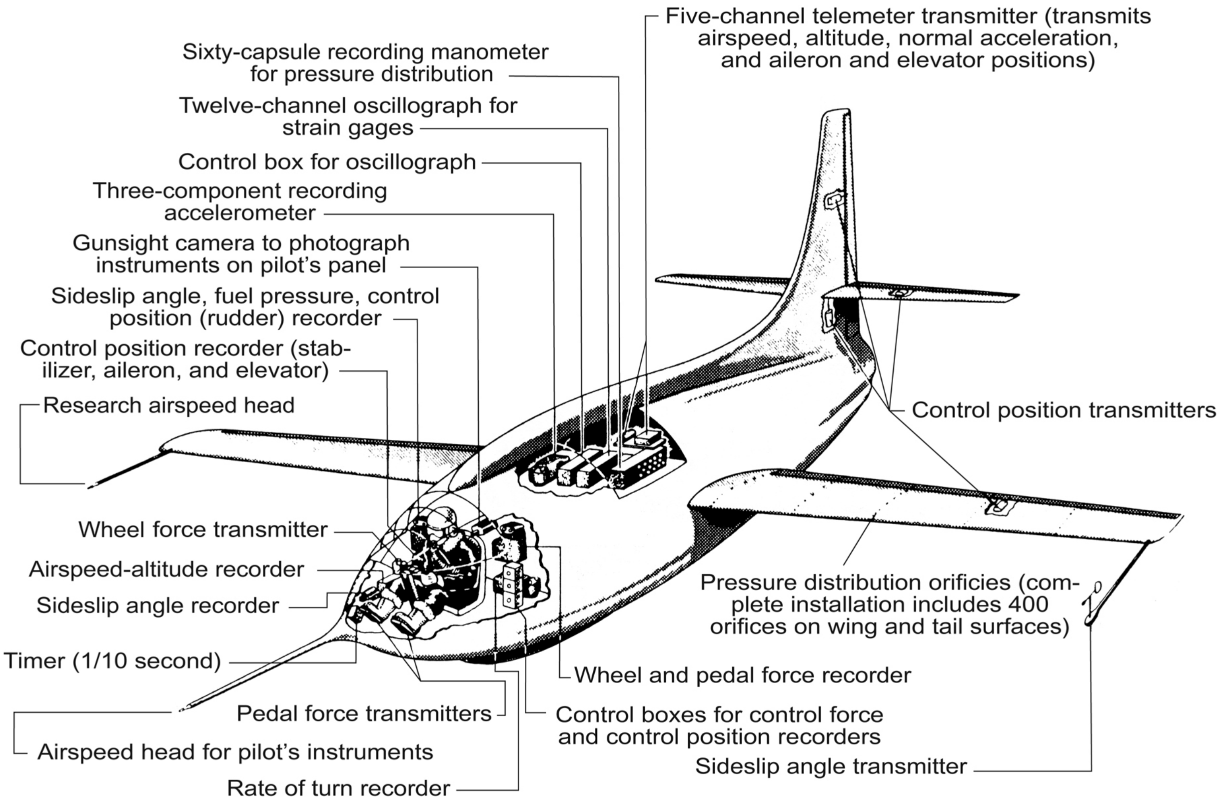
By May, the Flight Test Division was confident enough that it would get the accelerated research program to begin the selection process for the AMC crew that would be responsible for flying the airplane. As chief of the division, Colonel Boyd had the ultimate responsibility for making the choice from a long list of volunteers. He later recalled:

> Selecting the X-1 pilot was one of the most difficult decisions of my life. If the pilot had an accident, he could set back our supersonic program by a couple of years. Looking back, I'm amazed at the freedom given me to select the crew. I had full authority and didn't have to defend my decision to anyone. And I was well aware that the decision could be historic, so I asked my deputy, [Lt] Col Fred Ascani, to sit down with me and review all of the 125 pilots in the flight test division and see what kind of list we could compile. We informed each pilot we interviewed that this was definitely a high-risk project, that most scientists believed that at Mach 1 shock waves would be so severe that the airplane would break up in flight. Our own Air Corps engineers thought it could be done, but at a very high risk.[105]

Boyd wanted a pilot with extremely precise--or, as he called it, "scientific"--flying capabilities and, above all, one who was "rock-solid in stability"--someone who could remain cool under pressure. As he agonized over the selection, he kept coming back to a very junior test pilot, Captain Charles E. "Chuck" Yeager. The 24-year old West Virginian had been a combat ace in the recent war and, though he lacked a college education, Boyd considered him the best instinctive pilot he had ever seen. He had demonstrated an uncanny ability to ferret out and understand any airplane's flaws and he was quickly becoming the test pilot of choice among engineers because he flew with such extraordinary precision that his data points were always right on target. As Ascani recalled in later years, Yeager flew an airplane as though he was "welded to it"--as if he was an "integral part of it." His "feel" for any new or unusual aircraft was "instinctive, intuitive and as natural as if he had flown it for 100 or more hours." Ultimately, this proved to be the decisive factor. Yeager was selected to be the primary XS-1 pilot. First Lieutenant Robert A. "Bob" Hoover, another exceptional "stick-and-rudder man" whose piloting exploits were already becoming legendary around Wright Field, was designated the back-up pilot. Finally, from his Flight Research Branch, Boyd selected a 32-year old Oklahoman, Captain Jackie L. Ridley, as engineer-in-charge of the project. A test pilot with an M.S. in aeronautical engineering from the California Institute of Technology (1946), Ridley's Oklahoma drawl and laid back demeanor masked a highly disciplined, razor sharp mind. Boyd believed that, with his background in test flying and his unique ability to translate esoteric concepts into everyday terms, Ridley would be able to provide the pilots with all of the engineering expertise they would need.[106]

On June 25, the day after the official go-ahead to proceed with the program was given, Yeager, Ridley and Hoover joined with other key personnel from the Flight Test Division and the Aircraft Projects Section in order to further define how the AMC program should be conducted and how it would interact with the NACA test program. The Flight Test Division's program would parallel the NACA's program but, avoiding duplication wherever possible, it would proceed at a much more accelerated pace in order to attain a Mach number of 1.1 in the shortest possible time.[107]

The Air Materiel Command XS-1 test team at Muroc (from left): Lt. Edward L. Swindell (B-29 flight engineer); 1st Lt. Bob Hoover (XS-1 backup and chase pilot); Maj. Robert L. "Bob" Cardenas (officer-in-charge and B-29 launch pilot); Capt. Chuck Yeager (XS-1 pilot); and Capt. Jackie Ridley (AMC XS-1 project engineer).

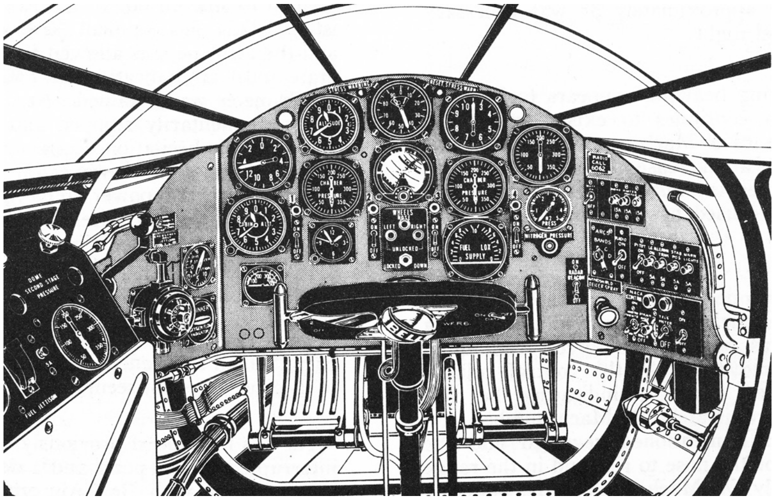


Though rudimentary by latter-day standards, the XS-1 was the most thoroughly instrumented aircraft of its day. The complete NACA instrumentation package weighed nearly 500 pounds and required approximately nine cubic feet of space.

To facilitate this effort, the Flight Test Division planned to employ the No. 1 aircraft with its thinner wings and horizontal stabilizer. Its higher speed capabilities were obviously more compatible with the Army Air Forces' immediate objective, while the No. 2 vehicle, with its thicker airfoils, would have a lower critical Mach number and, hence, be better suited to the NACA's desire to systematically collect detailed transonic data. This would be the Army Air Forces' first foray into experimental research flying and, while not wishing to go it alone, the Flight Test Division wanted to have as many of its own personnel involved as was practicable. Thus it insisted that its own crew should fly the B-29 launch aircraft for all of the accelerated tests with the No. 1 XS-1. It also wanted to provide its own maintenance crew for the B-29 and at least four personnel to assist in the maintenance and servicing of the XS-1. Further, while the Flight Test Division agreed that responsibility for the instrumentation and telemetry should be in the hands of the NACA, it also wanted its people involved in these activities. It was obvious that, by these means, Colonel Boyd expected the Flight Test Division to gain the type of corporate knowledge which would permit it to expand its role in any future experimental programs. The XS-1 program would be more than just an attempt to achieve a major milestone in aviation; it would also be an invaluable learning experience upon which to base a nascent military capability.[108]

While the conferees apparently wanted to maximize the AAF's role, they realized that it was both prudent and necessary to take advantage of the NACA's acknowledged technical expertise. Thus, although the Flight Test Division would be directly in charge of its own--accelerated--phase of the flight test program, the AMC test team was expected to coordinate all activities with Walt Williams who would continue to serve as the NACA's on-site engineer-in-charge. And, while AMC personnel would be involved in maintenance and servicing activities on the experimental aircraft, the NACA was also supposed to retain supervisory control over this activity. The conferees also conceded that the NACA should have first priority on the use of the launch aircraft. Finally, in deference to the NACA's well-established capability in this area, they agreed that the civilian agency would be the first to receive all test data for reduction and analysis.[109]

This meeting was held in preparation for an upcoming conference with NACA officials. When Colonel Smith had first informed the NACA of his intention to hand the accelerated tests over to the Flight Test Division, Langley Engineer-in-Charge Henry Reid had responded that, while the agency had no objections to the AAF’s involvement, it did not agree with the accelerated program. Thus, at the conference, which took place



The XS-1 cockpit was anything but spacious. The H-shaped control yoke was designed to provide the pilot with sufficient leverage if additional effort was required for control in the transonic region. Data recorder and engine ignition switches were also located on the yoke so that the pilot would not have to release it in order to trigger them. The instruments on the main panel were kept to a minimum and they were frequently reconfigured. In the illustrated drawing (above), the airspeed indicator is located at the top-center position on the panel and the machmeter is located immediately to its right. Moving to the left along the top row from the airspeed indicator are the altimeter and the g-meter. Lox and fuel tank pressure gages are in the second row on either side of the bank and turn indicators.

at Wright Field on June 30 and July 1, the AMC representatives were very careful to emphasize that the overall XS-1 program would be a team effort and, on this basis, the two agencies managed to reach a formal agreement on the conduct of concurrent test programs which was very compatible with the Flight Test Division's concept of operations. It would exercise control over the accelerated AAF test program but would "coordinate all activities with the NACA" and the civilian agency would "furnish technical supervision and assistance wherever possible." Colonel Boyd made a special point of emphasizing that the Flight Test Division would "appreciate all of the assistance the NACA personnel could give them in conducting this program." Air Materiel Command officials also explained that they had made a by-name request for the services of Bell's Dick Frost who would be able to provide very detailed technical advice throughout the first six months of the program. The AMC was "well pleased" with his exceptional performance during the acceptance tests and all parties were strongly urged "to cooperate with and give attention to Mr. Frost's recommendations."[110]

Much of the rest of the conference was given over to a presentation of what the NACA had learned thus far in the program and its recommendations concerning how the accelerated program should be conducted. Scarcely concealing what may well have been construed as a certain amount of impatience with the AMC program, Hartley Soule made the presentation for the NACA. He was the chief of the Stability Research Division as well as project manager for the research aircraft program at Langley and his attitude toward the AMC's program was reflected in a memo outlining his presentation to the NACA's chief of research. "The NACA, of course," he explained, "considers its somewhat longer but more systematic approach to supersonic flight the more suitable means of obtaining basic knowledge and design data regarding transonic flight. It is, however, proposed to cooperate with the Army on the Army proposal."[111] At the conference, one of his AMC auditors reported:

> Mr. Soule read very rapidly, from a summary report he had compiled, some of the flight characteristics which are expected to be encountered in flights of the XS-1. His reading of excerpts from this summary was so rapid that it was practically impossible to take notes... Permission was requested to run off a copy of this report but Mr. Soule said it was the one and only copy and needed some revisions but that he would have a revised copy made and sent to the Flight Test Division.[112]

Soule noted that no significant compressibility (i.e., shock-wave) effects had been observed at the top speed thus far attained (0.82 Mach) but that laboratory tests had indicated that conditions would become critical above 0.85 Mach:

> It is apparent from the flight and wind-tunnel data that above M = 0.85 large changes in stability and control and vibration characteristics are to be expected. These have been anticipated in the Langley flights, which will be made at an altitude of 30,000 feet, and plans have been made to increase speed cautiously in small increments and to explore conditions at each increment thoroughly before proceeding to a higher speed.[113]

His assumption, at that point, was that the Flight Test Division would follow Bell's original plan to conduct the accelerated high-speed tests at altitudes somewhere between 50,000 and 60,000 feet. The NACA had some serious concerns about flights at such altitudes, particularly with regard to the potential risks of high-speed stalls and pilot safety in the event of loss of pressurization. Nevertheless, Soule conceded that high altitude flights would reduce the risk of structural problems. In the flights thus far completed, the dynamic pressure had reached approximately 250 pounds per square foot at Mach 0.8 and an altitude of 30,000 feet. "At 60,000 feet for the same Mach number of 0.8," he explained, "the dynamic pressure would be about 65 pounds per square foot." "It appears doubtful, therefore," he concluded, "that any inadvertent attitude to which the airplane might go as a result of stability and control changes could result in any structural failures at 60,000 feet." He cautioned, however, that "the pilot should avoid prolonged glides to lower altitudes where the density is higher because conditions may change critically between the acceleration and deceleration phases of the flight, and consequently such glides may be extremely dangerous."[114]

All of this discussion, however, was still somewhat academic. When the NACA representatives requested a copy of the Flight Test Division's detailed flight test plan, they were informed that no plan had yet been formulated concerning specific altitudes or Mach numbers. Indeed, it must have appeared to them that the AMC had *no* plan at all when Flight Test Division representatives explained that decisions concerning such issues would be made while the tests were underway and would be based upon ongoing analyses of the data and Captain Yeager's recommendations following each flight. Colonel Boyd summed up the Flight Test Division's approach by stating that common sense, sound engineering experience, and a focus on safety would be the guideposts for its efforts. He emphasized, however, that the AMC program would be progressive and it *would* be brief. The objective was to achieve supersonic flight in the shortest possible time and the Flight Test Division would not be distracted from this goal.[115]

Meanwhile, Yeager, Ridley and Hoover had gone to the Bell facility in Niagara Falls for briefings on the program and to get their first close-up look at one of the XS-1s and its XLR-11 power plant. Larry Bell made a big impression. As Yeager recalled, "by the time he got through selling us on the beauty of his orange beast, we were ready to believe that the X[S]-1 could punch its way through the Pearly Gates and make it back covered with angel's feathers."[116] But it was the XLR-11 rocket engine which made, by *far*, the biggest impression.

All four chambers of the XS-1's XLR-11 engine ignited during ground tests in a hangar at the Bell plant in Niagara Falls, New York.

As Bob Hoover later recalled:

> Chuck and I saw the plane for the first time up at Bell and...it was a pretty awesome experience for the two of us. They made an engine run for us. And, first of all, they had to show us exactly what liquid oxygen was like. They took a rubber ball, had it on a string, put it in the liquid oxygen and then dropped it on the floor and it shattered. And, then, they did the same thing with a frog and, I'll tell you, that got our attention! Then,...the airplane was log-chained in this building and, when the rockets were fired, the ceiling started cracking and breaking loose and falling on us and I'd never been so scared in my life. It was just absolutely deafening. And I think Pard [Yeager] was having the same problem. He was sitting there thinking the same thing I was.[117]

They were, indeed, thinking the same thing. "We didn't walk too steady when we left that hangar," Yeager later recalled. "Pard, I don't know about you," he admitted to Hoover, "but that sumbitch scares me to death."[118]

After this sobering experience, the three of them proceeded to Muroc in late July. Major Robert L. "Bob" Cardenas, an experienced multi-engine test pilot, had been selected as officer-in-charge of the AMC XS-1 test unit at Muroc. He would also pilot the B 29 launch aircraft with Lieutenant Edward L. Swindell serving as his flight engineer. By July 27, the whole team had assembled at Muroc and was in the process of establishing office and maintenance facilities. Two days later, Dick Frost started providing XS-1 "familiarization schooling" for Yeager, Hoover and Ridley and, for the next four days, he tried to teach them everything he had learned about the airplane and its rocket engine.[119] Having been a test pilot himself, Frost was well qualified to assess the capabilities of the young military pilot who was preparing to fly the rocket plane. He later recalled that he had known a lot of great stick-and-rudder men but, while most of them were only interested in flying, what set Yeager apart was his keen interest in learning everything he possibly could about the airplane and all of its systems. "Chuck didn't say much," he recalled. "He sat in class listening, and I could tell from his eyes that he understood everything. When he asked a question, it was always to the point...He used Ridley and me as his professors and wound up knowing nearly as much as we did."[120] Or, as Ridley later observed: "He never studied engineering, but he blots the stuff up as fast as it's poured."[121]

A few of the questions Yeager asked were "uncomfortable" but Frost tried to respond as honestly as he could: "¬He asked whether I thought he could survive a bailout. I told him, no way ...But he never did ask me if I believed in an impregnable sound barrier. At best, I was ambivalent about it."[122] "It's easy to read inevitability into past events," Frost recalled many years later. "In hindsight, people may well say that the so-called 'sound barrier' really didn't prove to be a barrier at all. Hindsight is 20-20 but, let me assure you, the conditions Chuck was facing going into those flights were *very much* a barrier in our minds at the time." In 1947, there were no supercomputers or sophisticated simulators to help predict the behavior of the XS-1 in the transonic flight regime; indeed, not even any reliable data beyond 0.92 Mach upon which to base such predictions. And the aircraft itself posed some truly daunting hazards. There were no redundant systems and, at high speeds, absolutely no means by which the pilot could safely egress the airplane should something go wrong. "It wasn't within our power," Frost concluded, "to give Chuck any real assurances about what might happen in any one of a multitude of different circumstances."[123]

As a fellow test pilot, Bob Hoover's biggest concerns were with the rocket engine. Many years later, he explained:

> I'd like you to know what Chuck was really faced with. It wasn't just the aerody-namics of going faster than sound. But it was the handling of the rocket engines and keeping the dome pressures [the XS-1 was configured with dome pressure regulators] exactly where they had to be. I had been assigned to the Me. 163 [a German rocket-powered interceptor] project... and I had worked with the German scientists there at Wright Field and I was supposed to make the powered flights. They got canceled because of the risk that was involved and they didn't feel they could capture enough data to

> make it worthwhile to be exposed to the risk. But those engines were enough to have scared me to death and so...my biggest concern was the engine...Because you know how many fatalities the Germans had with the Me. 163. So Chuck was faced with not just flying the airplane but... if you could just think about all of the dials and valves that he had in the cockpit and that he had to address himself to continuously. And, if he got those pressures out of kilter, he could have blown himself to kingdom come. It was not a matter of just flying the airplane, but it was keeping everything from going overboard, if you will.[124]

Frost's training program was completed by August 1 and the test team turned toward preparations for Yeager's first unpowered familiarization flight. Installation of the engine was delayed because of a shortage of parts and thus the XS-1 carried ballast instead of an engine when Bob Cardenas lifted off from the main runway at Muroc on August 6. As the B-29 climbed through 7,000 feet, Yeager prepared to descend into the cockpit of the XS-1. "Climbing down into the X[S] 1," he later recalled, "was never my favorite moment":

Yeager on lift device just prior to entering the XS-1's cockpit.

> The ladder was on the right side of the X[S]-1. The wind blast from the four bomber prop engines was deafening, and the wind-chill was way below zero. I wore a leather jacket and my flight suit, but no gloves so I could grip the rungs. I had to bounce on the ladder to get it going, and be lowered into the slipstream. There was a metal panel to protect against the wind blast, but it was rather primitive, and that bitch of a wind took your breath away and chilled you to the bone. I would slide into the X[S]-1 feet first, wearing a seat-type parachute, primarily to sit on, because, once you were in, the only way out was to land safely.[125]

Once he was inside the rocket plane, a crew member lowered the door to Ridley, who had followed him down the ladder, and he held it in place while Yeager locked it. Some time later, as Yeager was going through his preflight preparations, Bob Hoover and Dick Frost joined up with the B-29 in their FP-80 chase jets. Hoover, as would become his custom, rather irreverently announced their arrival by passing just feet below the XS-1 and pulling up right in front of the B-29's nose! He got everyone's attention. As Yeager later recalled: "The XS-1 was hooked under the B-29 with just a B7 bomb shackle and that's *all* it was! And I was sittin' there in the dark tryin' to get ready for my launch...and then ol' Hoover came by about ten feet under the XS-1 and pulled up right under the nose and the whole B-29 shook and that shackle rattled. We exchanged a few words."[126]

At 26,000 feet Cardenas nosed the B-29 over into a shallow dive to pick up speed and, at 25,000 feet and a speed of 250 mph, Yeager and the XS-1 dropped from the darkness of the B-29's bomb bay into the blinding sunlight and, almost without thinking, he performed a brief series of slow rolls. Gliding downward, he later recalled that the XS-1 was "graceful, responsive, and beautiful to handle." The whole eight-minute flight, all the way to touchdown and rollout on Rogers Dry Lake, went flawlessly and, from Yeager's point of view, almost effortlessly. The same was true of his second flight the next day and, on his final glide flight on August

The B-29 carrying the XS-1 to launch altitude.

8, he actually engaged Hoover's chase FP-80 in a mock dogfight as they spiraled downward. These three brief flights left Yeager with a high level of confidence concerning his ability to fly the airplane; he felt more than ready to begin the powered-flight program.[127] And, while somewhat dismayed by Yeager's aerial antics, NACA Langley test pilot Herb Hoover was also impressed, as he reported back to Mel Gough: "This guy Yeager is pretty much of a wild one but believe he'll be good on the Army ship from our standpoint. On first drop, he did a couple of rolls right after leaving the B-29! On 3rd flight, he did [a] 2-turn spin! But still believe he'll be good! He has given us a good...story of his 3 flights."[128]

Unfortunately, Yeager had to wait three weeks before attempting a powered flight because a shortage of parts and tools delayed installation of the engine. Colonel Boyd took advantage of the hiatus to fly out to Muroc to confer with his team and urge caution. There was a lot riding on the XS-1 program and, while the objective was to exceed the speed of sound as soon as possible, that did *not* mean they should exceed the bounds of prudence and common sense. "Don't stretch the program by getting too eager on this thing," he cautioned. "Find out what the hell is going on with the airplane." Yeager and Ridley assured him that they did not intend to exceed Mach 0.82 on the first powered flight. The ground tests with the engine installed on the airplane

The XS-1 shortly after engine ignition as it was beginning to accelerate away from the launch and chase aircraft.

finally got underway on August 27. Two days later, the young pilot's wait was finally over as the B-29 carried the rocket plane aloft for the first powered flight in the accelerated research program. Based on his meeting with Colonel Boyd, Yeager knew that this flight was supposed to be for familiarization purposes only; in other words, within the envelope already defined by Slick Goodlin. He was also aware, however, that a good many of the brass from Wright Field had flown in to witness the event.[129]

As the bomber climbed through 7,000 feet, Yeager once again slipped into the cockpit and, chilled to the bone by the liquid oxygen (lox) stored in the tank directly behind the cockpit, he methodically completed all of his preflight checklist procedures. When Cardenas notified him they were five minutes to drop, he started dome-loading the pressure regulators and then pressurizing the fuel and lox tanks. This was a very critical procedure and after, taking great care to insure proper pressure, he asked Dick Frost who was flying low chase to confirm emergency jettison. He provided confirmation as Bob Cardenas announced one minute to launch. At 25,000 feet, Cardenas once again nosed over into a shallow dive and, at 21,000 feet and a speed of 255 mph, the XS-1 was released. Approximately ten seconds later, Yeager ignited the first chamber of his engine and was slammed back in his seat. Following the preflight plan, after five seconds, he ignited the No. 2 chamber while shutting down No. 1. Then, after repeating this procedure for chamber No. 3, he suddenly--and to Frost’s utter amazement and displeasure--deviated from the flight plan and executed a slow roll. As the craft attained zero "g," the engine shut down because of a drop in lox tank pressure. Much to his good fortune, if not foresight, he was able to successfully relight the engine and, rocketing upward at 0.7 Mach, he finally leveled off at about 45,000 feet.[130]

Yeager was a pro and, after one such lapse, he would have been well advised to have left good enough alone. But, all of a sudden, he became a young fighter jock and this was “one helluv’an airplane.” He really wanted to find out what it was all about.

After shutting off the engine, he rolled over into a dive and sped downward. This was not in the flight plan either and, when Frost asked him where he was going, he announced his intent to "show the brass down there a real airplane." Ultimately attaining a top speed of approximately 0.8 Mach during his unpowered descent, he recovered from the dive and leveled out just 2,700 feet above the runway. At this point, he ignited chamber No. 1 and initiated a shallow climb. Then, in rapid sequence, he lit each of the remaining chambers and, as he later recalled:

> ...the impact nearly knocks you back into last week. That nose is pointed so straight up that you can't see the blue sky out the windshield! We are no longer an airplane: we're a skyrocket. You're not flying. You're holding on to a tiger's tail. Straight up, you're going .75 Mach! In one minute the fuel is gone. By then you're at 35,000 feet, traveling at .85 Mach.[131]

Writing to Major Clarence E. "Andy" Anderson, his best friend and fellow combat ace during the war, he tried to convey his feelings at the time: "No kidding, Andy, I was so darned excited, scared, and thrilled (you know that first kill in Germany feeling), I couldn't say a word until the next day."[132]

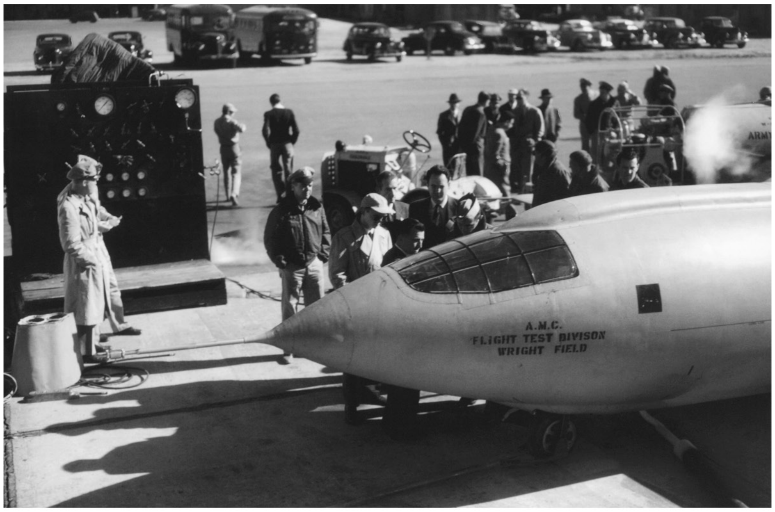
But, as he later recalled, "others said plenty." Per agreement with Colonel Boyd, the flight plan had stipulated that he should not exceed Mach 0.82 on this flight and, as a professional test pilot, he was expected to abide by its requirements. Walt Williams and the NACA team questioned Yeager's sense of discipline. Even Jack Ridley was more than a little perplexed by the deviation from the flight plan. "Any spectators down there knew damned well that wasn't Slick [Goodlin] rattling those dishes," he scolded. "Okay, son, you got it all out of your system, but now you're gonna hang tough."[133] His sternest critic, however, was Colonel Boyd who, as Yeager later recalled, "fired a rocket of his own." He was not about to see the whole program jeopardized by a reckless disregard for discipline. "Reply by endorsement," he wrote, "about why you exceeded .82 Mach in violation of my direct orders." Boyd had grounded many a pilot for far lesser infractions and Yeager, with Ridley's assistance, drafted a very carefully worded reply. He explained that any deviations were "due to the excited condition of the undersigned" and he assured Colonel Boyd that the AMC test team considered safety-related matters to be of utmost importance. Nevertheless, per Colonel Boyd's original instructions, he *ha*d found out "what the hell was going on with the airplane." Dick Frost had not been too pleased with Yeager's performance either but, later, he confided that, after one flight, Yeager "already knew the airplane almost as well as I did."[134]

Walt Williams and his team had been sent to Muroc to acquire data and to provide technical guidance on the conduct of the program. They recommended that the second flight be limited to the Mach 0.80 to -0.85 range in order to collect stability data. The telemetering equipment had failed to function and the photopanel film had been overexposed on the first flight. Thus the NACA team was anxious to acquire some useful data in the region it would be exploring more thoroughly in subsequent tests with the No. 2 aircraft.[135] The AMC team, on the other hand, was eager to proceed to higher speeds. Yeager later recalled:

> They [the NACA engineers and technicians] were there as advisers, with high-speed wind tunnel experience, and were performing the data reduction collected on the X-1 flights, so they tried to dictate the speed in our flight plans. Ridley, Frost, and I always wanted to go faster than they did. They would recommend a Mach number, then the three of us would sit down and decide whether or not we wanted to stick with their recommendation. They were so conservative that it would've taken me six months to get to the [sound] barrier.[136]

To a remarkable degree, the young men who comprised the AMC test team were on their own. In accordance with the agreement with the NACA, they consulted with Williams and the NACA team but, in conjunction with Dick Frost, they invariably made all the final decisions concerning the pace of the program and the specific objectives for each flight. They were not well disposed toward what they perceived to be the condescending attitude of Walt Williams and some of the other NACA personnel and academicians who were attempting to make their own inputs into the program. For his part, Williams apparently made no effort to conceal the fact that he did not regard them as his peers--that is, as professional flight researchers.[137] Yeager later explained: "I'd attend these highly technical NACA preflight planning sessions...and not know what the hell they were talking about. But Jack always took me aside and translated the engineers' technical jargon into layman's terms. There was no way I could communicate with Walt Williams...He had a reputation for being pompous."[138] Williams later cast the relationship in a somewhat different light: "We were enthusiastic, there is little question. The Air Force group--Yeager, Ridley--were very, very enthusiastic. We were just beginning to know each other, to work together. There had to be a balance between complete enthusiasm and the hard cold facts."[139]

Despite their "enthusiasm," the AMC team was well aware of the importance of acquiring the data and Yeager tried to accommodate the NACA's requirement for stability data between Mach 0.80-0.85 on his second



Top: Fueling operations prior to engine ground tests. Yeager (in cap, standing next to the hatch) inspects the cockpit. XS-1 crew chief Jack Russell (to the right and behind Yeager overseeing the operation.

Middle: Static onboard testing of the propulsion system underway. Modern-day concerns about safety were quite obviously not yet a consideration.

Bottom: Jackie Ridley (to the left) and Yeager conferring with Dick Frost who was "on loan" to the AAF to serve as the AMC team's technical expert on the airplane and all it's systems. Because of this expertise, Frost flew "low chase" to provide any information or advice that Yeager might require during launch operations.

Yeager and Ridley (top left and right) with the AMC XS-1 ground crew, from left to right: Merle Woods, Jack Russell (crew chief), and Garth Dill. The "Glamorous Glennis" legend, in honor of Yeager's wife, was painted on the nose of the XS-1 by Russell shortly before Yeager's eighth powered flight on October 10, 1947.

flight on September 4. Leveling off at about 30,000 feet he accelerated slowly to 0.84 Mach. With only a single chamber burning, he maintained that speed for about a minute without encountering any indications of trim change or buffeting. Then, following the flight plan, he lit the No. 2 chamber and, as he reported, "an indicated Mach no. of .865 was reached very fast." He quickly shut down one of the chambers so he would not exceed this number. Post-flight data analysis revealed that he had actually attained a top speed of approximately Mach 0.89.[140] Yeager subsequently reported that very little change in trim was noticeable from the cockpit until he reached a Mach number of 0.87, at which time he encountered light buffeting which became more severe as his speed increased. The buffeting was accompanied by a nose-down trim change and the right wing became "noticeably heavy." Stick forces were light, however, and the airplane remained completely controllable.[141]

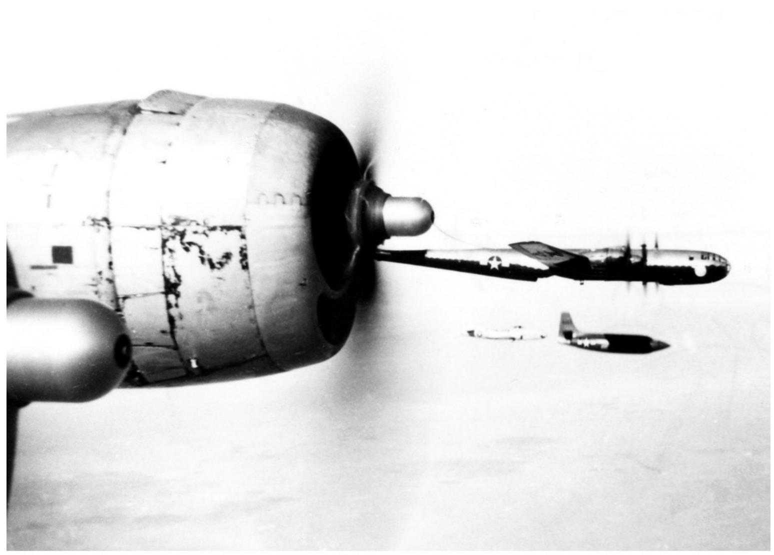
The fact that Yeager had encountered no truly major surprises up to Mach 0.89 was the good news. The bad news was that the NACA's telemetering equipment had once again failed to function. Thus he was required to repeat essentially the same profile during his third flight on September 8.[142] Nevertheless, even though flying within this restriction, he was still able to gain some insight into what he was likely to encounter at slightly higher speeds by employing a technique he had learned while testing the P-84. While flying straight and level, the P-84 started buffeting and porpoising at about Mach 0.82. He had discovered that, if he slowed it up to about 0.76 Mach--where it flew very smooth--and then rolled over and pulled about 3 g's at the slower airspeed, he would encounter the same effects he had while flying straight and level at 0.82 Mach. "So I was using this knowledge, in reverse, with the X[S]-1," he later explained. "Meaning, when I hit the maximum Mach number that I was aiming for, I'd roll over and pull about 3 g's at that Mach number. Then this'd show me what I'd run into at a higher Mach number, straight and level."[143] On this particular flight, as he hit an indicated Mach number of 0.88, he pulled the airplane into an accelerated stall, employing full up elevator, into the buffet boundary at 2.5 g's. From his perspective in the cockpit, he reported the buffeting appeared normal with the XS-1 exhibiting good lateral control throughout the stall. Postflight analysis of telemetered data, however, indicated that heavier than predicted buffeting seemed to appear above 2 g's and aerodynamic trim was reversing as the airplane exhibited a tendency to nose up. No one was quite sure what this data meant--whether it pointed toward an easily controllable trim change requirement or rapid nose-up-and-then-down trim changes which would throw the airplane completely out of control. All agreed it was worth further investigation and that Yeager should spend the next couple of flights carefully probing the region around Mach 0.90.[144]

He accelerated to Mach 0.91 at 36,000 feet during his fourth flight, on September 10, when his static flight instruments malfunctioned and he was forced to shut down the engine and terminate the flight early. Two days later, during his fifth flight, he continued to explore the region around Mach 0.9 in order to evaluate elevator and stabilizer effectiveness as he accelerated out to 0.92 Mach. These two flights confirmed what the data had suggested. At Mach 0.90, the airplane nosed up and, at Mach 0.92, the buffeting became quite severe. After the fifth flight, the airplane was grounded so that the one-degree per second stabilizer actuator could be replaced with a faster--three-degrees per second--actuator which the test team hoped would provide greater control authority as they reached for higher speeds. Per previous agreement, on September 25, Yeager completed the government's acceptance flight on the No. 2 ship for the NACA.[145]

After a series of delays, caused by problems encountered during installation of the new actuator, Yeager finally returned to the air for his sixth powered flight in the No. 1 XS-1 on October 3. During his first run, he accelerated to an indicated Mach number of 0.86, at which point he reported that the airframe shook from light shock-wave buffeting. So far, no surprises. After completing an accelerated stall to give him some idea of what he would encounter at slightly higher speeds, he slowed down to 0.82 indicated Mach number and reset the stabilizer to the 2-degrees nose-down position in preparation for his next speed run. The effect of this input took him very *much* by surprise, as he later reported: "The trim change occurred so rapidly with the reworked actuator...that approximately 4 negative G's resulted and the desired setting was exceeded by ½ deg. The negative acceleration caused loss of chamber pressure, so the remaining cylinder was turned off immediately, after which the stabilizer was reset to the 2 deg. position."[146] Reigniting chambers 2 and 4, he completed another stabilized run at 25,000 feet. Once again, he noted shock-wave buffeting commencing at about Mach 0.86 indicated airspeed and increasing in severity as he accelerated to a top speed of Mach 0.88 indicated (true airspeed was about 0.92 Mach). The airplane also, once again, began to feel right-wing heavy and, at top speed, he was required to employ about 50 percent available aileron in order to remain in wings-level flight.[147]

On his next flight, five days later, Yeager attained a top airspeed of Mach 0.925 indicated (recorded data revealed that his true airspeed was actually Mach 0.945) at approximately 40,000 feet. During climb out after launch, as on the previous flight, he noted extremely rapid stabilizer travel which, once again, caused a momentary negative acceleration. He also reported essentially the same phenomena between 0.86 and 0.88 indicated Mach numbers, noting that they were the same whether accelerating or decelerating through this range. He further reported that the buffeting diminished noticeably after he exceeded an indicated Mach number of 0.90 and, at that point, the acceleration of the aircraft increased without any apparent increase in engine performance. There was one event during this flight, however, which seemed to bode ill for the future. While flying at an indicated Mach number of 0.88 at 40,000 feet, Yeager attempted to perform an accelerated stall. But, as he reported, "despite full back stick it was impossible to achieve a stall." It was obvious that he had entered into the speed range where shock waves were probably forming right along the hinge-line of his elevators. There was further sobering news when the NACA team's postflight data analysis indicated that, at about Mach 0.94, the trim change *again* reversed to a nose-down tendency.[148]

His eighth powered flight, on October 10, proved to be an eventful one, indeed. After attaining an indicated top speed of 0.94 Mach at 40,000 feet, he pulled back on the control column...and virtually nothing happened! The control wheel felt as if the cables had snapped. He had, indeed, lost elevator effectiveness and, with it, pitch control of the aircraft. Though the craft still seemed to be quite stable at this speed, he shut down his engine, jettisoned his remaining fuel and prepared to land. As he descended toward the lake bed, however, a solid layer of frost formed on his windshield and, despite repeated efforts, he was unable to clear it. He radioed Dick Frost, who was flying low chase, about the problem and, with Yeager flying on instruments, Frost talked him down to a safe landing on the dry lake bed.



Top: An extremely rare photo of the XS-1 just after release from the B-29 launch aircraft with photo-recon FP-80 flying chase.

Middle: Captain Chuck Yeager seated in the cockpit of the XS-1.

Bottom: Yeager (hatless at center of group) greeted by program personnel and observers after landing on Rogers Dry Lake.

He had to have felt a certain amount of gratitude for the foresight of those who had decided to test the rocket plane over its vast, friendly expanse. Nevertheless, he rolled out on the lake bed with a feeling of dread. Aerodynamicists had predicted that, at the speed of sound, the XS-1's nose would either pitch up or down and, without effective pitch control, he would be "in a helluva bind." [149]

Postflight data analysis, which included corrections for errors in the XS-1's onboard instruments, initially indicated that Yeager had attained a true Mach number of 0.957. Postflight analysis also confirmed that, as he approached that speed, a shock wave had, indeed, formed right along the hinge-line of the elevator on the XS-1's horizontal tail. Fortunately, at the NACA's insistence, Bell designers had provided the airplane with the moving tail which could, they hoped, be employed to serve as an auxiliary elevator. Up to this point in time, however, the stabilizer's angle of incidence had only been changed at lower speeds, primarily while climbing out after launches. In theory, Jack Ridley believed that, dispensing with the elevator altogether as he reached the higher Mach numbers, Yeager could probably control the craft by making very small adjustments to the stabilizer's angle of incidence. They ground tested the stabilizer system that afternoon and decided that, by moving the horizontal tail in increments of 1/4- to 1/3-degree, he would probably be able to maintain control without having to rely on the elevator.[150] "It may not be much, and it may feel ragged to you up there," Ridley explained, "but it will keep you flying." [151] Yeager had supreme confidence in Ridley's judgement. As he later explained: "I trusted Jack with my life. He was the only person on earth who could have kept me from flying the X[S]-1." [152] Nevertheless, writing to Andy Anderson that night, he confided: "I'm sure it's o.k. and very effective but I've never changed it [at] that high a Mach No." [153]

Meanwhile, NACA personnel had worked tirelessly, round-the-clock further refining the data over the weekend and their subsequent analysis revealed a stunning surprise. On the 10 October flight, Yeager had actually achieved a top speed of *Mach 0.997* at 37,000 feet! He had gotten tantalizingly close and, indeed, there were many within the AMC and NACA contingent who believed that he had, in fact, *already* exceeded the speed of sound. At this point, everyone--with Yeager foremost among them--was eager to put the "sound barrier" myth to rest, once and for all. For this upcoming flight, however, NACA engineers warned him not to exceed an indicated Mach number of 0.96 unless he was unequivocally certain he could do so safely.[154]

On the morning of Tuesday, October 14, ground crews completed their final preparations for the flight. The night before, they had backed the airplane down into its cross-shaped loading pit, towed the B-29 into position over it, hoisted the XS-1 up into the bomb bay and shackled it into place. Now, a white layer of frost formed around the rocket plane's midsection as they injected the super-cold lox into the tank just aft of the cockpit. To prevent a recurrence of frosting on the interior surface of the windscreen, crew chief Jack Russell applied a thin coating of Drene shampoo an ingeniously simple and inexpensive solution to a potentially dangerous problem. With the ground crew's preparations completed by mid-morning, Yeager and the launch crew boarded the B-29 and, at 10:00 am, took off from Muroc's main 8,000-foot runway.[155]

About midway through the B-29's long, slow ascent to launch altitude, Yeager made his way painfully down through the hatch on the right side of the XS-1's cockpit. Over the weekend, he had suffered a pair of broken ribs in a riding accident at Pancho Barnes' nearby Rancho Oro Verde Fly-Inn Dude Ranch (a gathering place and watering hole for Muroc pilots which is better known to posterity as the "Happy Bottom Riding Club"). Fearing that he would be grounded by the flight surgeon, he had gone to a civilian doctor off base and had himself taped up. He had confided this only to Ridley and now, with Ridley's assistance and the aid of a ten-inch length of broom stick which provided him with enough leverage to lock the door, he held his breath and secured the hatch. [156]

As Bob Cardenas continued his climb in the B-29, Bob Hoover and Dick Frost joined up for chase in their FP-80s. As usual, Hoover pulled up under the nose of the B-29 and started climbing to position himself about ten miles ahead of the B-29 at an altitude of 40,000 feet. From his high chase

Photo shot by Bob Hoover from his FP-80 as the XS-1 accelerated past him on October 14, 1947. A copy of this photo was on President Truman's desk the very next morning.

position, he would provide Yeager with an aiming point during his climb and, if his timing was perfect, he might be able to get a photo of the XS-1 as it shot past him. Dick Frost positioned himself just behind and to the right of the B-29 so he could confirm lox and fuel jettison. Then he would climb about 500 feet so he could increase his speed in a dive as the countdown approached "drop." Meanwhile, Yeager pressurized the propellant tanks, checked the jettison system, completed his checklist and then waited. One minute prior to launch time, Ridley asked if he was ready. "Hell, yes," he replied, "let's get it over with." [157]

With that, Cardenas pushed over into a shallow dive and initiated the countdown. "10-9-8-7-6-5-3-2-1" (throughout the flights, he had consistently skipped a number) and, at 20,000 feet, Ridley pulled the release mechanism. At 10:26, the XS-1 dropped free into the bright desert sky. The drop, at an indicated airspeed of 250 mph, was "slower than desired" and the XS-1 started to stall. As soon as he was able to get the nose down and pick up speed, he fired all four of his rocket chambers in rapid sequence and left Frost and Cardenas far behind as he began his climb. Accelerating upward rapidly, he shut down two cylinders and, anticipating loss of elevator effectiveness, he tested the stabilizer control system as his Machmeter registered numbers of 0.83, 0.88, and 0.92. Moved in small increments of 1/4- to 1/3-degree, he reported that the stabilizer proved to be "very effective."[158]

He reached the 0.92 indicated Mach number as he leveled out at about 42,000 feet. With perhaps 50 percent of his propellants left, he ignited a third cylinder and, as he tersely explained in his pilot's report: "Acceleration was rapid and speed increased to .98 Mach [indicated]. The needle of the machmeter fluctuated at this reading momentarily, then passed off the scale. Assuming that the off-scale reading remained linear, it is estimated that 1.05 Mach was attained at this time."[159] He had felt no violent buffeting or any other indication that he had just passed through a dreaded "barrier." Surprised and, as he later recalled, somewhat disappointed that "it took a damned instrument meter to tell me what I'd done," he remained supersonic for approximately 20 seconds before shutting down his engine. He coasted up to 45,000 feet, performed a 1g stall and then descended in a quiet glide toward Rogers Dry Lake where he joined up with Hoover and Frost before touching down on the lake bed just 14 minutes after launch from the B-29. Postflight

Reproduction of painting, "Hey Pard, You'll Get a Free Steak at Pancho's Tonight!," commissioned by General Yeager and produced by famed aviation artist Mike Machat to commemorate the 50th anniversary of supersonic flight. The image recreates the moment on final approach to Rogers Dry Lake when chase pilot Bob Hoover keyed his mike and acknowledged Yeager's accomplishment that morning by reminding him that he would be able to collect on Pancho Barnes' promise of a free steak dinner to the first pilot to exceed the speed of sound (reproduced here by permission of General Yeager and the artist).

analysis revealed that Yeager had attained a top speed of Mach 1.06, approximately 700 mph, at 43,000 feet that morning.[160]

Epilogue

Less than a month earlier, on September 18, 1947, the United States Air Force had come into being as a separate military service and one could convincingly claim that its birth was heralded by the sharp double crack of the sonic boom that was heard in the clear blue skies above the Mojave Desert that October morning as Captain Chuck Yeager nudged the XS-1 through the "sonic wall" and aviation science crossed the invisible threshold to flight faster than sound. The words accompanying the citation for the Collier Trophy for that year aptly summarized the magnitude of the accomplishment: "This is an epochal achievement in the history of world aviation--the greatest since the first successful flight of the original Wright Brothers' airplane, forty five years ago."[161]

Remarkably, this major milestone had been accomplished within a span of just over two months. In the days before pilots could prefly aircraft in simulators, and after only three glide and nine powered flights, Yeager had pierced a "barrier" which many experts had long predicted would be impenetrable. In hindsight, the speed with which this goal was accomplished seems all the more remarkable in light of the circumstances under which the program was conducted. By latter-day standards, the accelerated XS-1 test program was a model of simplicity. The total test team at Muroc never numbered more than 25 people. Less than 15 years later, by contrast, the X-15 test program would require the efforts of more than 300 highly trained personnel. Management of the program at Muroc

was also remarkably uncomplicated--in fact, almost informal by today's standards--and left in the hands of young men, all in their twenties or early thirties, who were given a wide degree of latitude by their Wright Field superiors. In consultation with Dick Frost, Bob Cardenas and Walt Williams, Yeager and Ridley had the final say about when to proceed and how far to proceed on each flight. In the complex flight test environment of today, just the safety review process for a hazardous mission can involve scores of people and require months and literally dozens of meetings to accomplish. Lacking a formal safety review process and the encumbrances of a large bureaucracy, the key members of the XS-1 test team simply sat down and, based upon the evidence at hand from previous flights, decided amongst themselves what the parameters for the next flight should be--and they did so with an alacrity which belied the magnitude of their decisions. At one point during the accelerated program, for example, Yeager completed three flights within the brief span of just six days. In the end, the speed with which the program was conducted was, to a large extent, the product of its simplified personnel and management structure. A small number of men had been given an important job to do and they had been guided by a philosophy based upon the conventional wisdom that the shortest distance between two points is a straight line.[162]

Yeager's flight through the "sound barrier" that morning had borne out Captain Diehl's prophecy that it was "just a steep hill" and, though few people could fully comprehend its implications at the time, the young pilot had just taken the first step in a chain of events which would ultimately vault man beyond the atmosphere and into space. But it had other implications, as well. The XS-1 convincingly proved the feasibility of employing experimental aircraft to conduct basic research and, in doing so, it spawned a whole series of subsequent X-series designs. In its successful conduct of the XS-1 program, from Ezra Kotcher's original conceptualization[163] through Yeager's milestone flight, the U.S. Air Force had demonstrated that the military services could, indeed, play a very meaningful role in experimental flight research. It would build on this experience and continue to expand its capabilities across the whole spectrum of research disciplines. And, more specifically, Yeager's success in the XS-1 fulfilled Colonel Albert Boyd's expectations and legitimatized the role that military test pilots would play in a wide range of future experimental programs. As Yeager explained with pride many years later: "We had never been able or allowed to do research flying as Air Force officers...and, when we got that airplane above Mach 1,...it said we hacked the program and it opened up a whole new era for us."[164] Nearly a decade after the flight, Yeager's contemporary, then-Lieutenant Colonel Frank K. "Pete" Everest concurred with this assessment when he observed:

> The future of military flight testing was riding with him that morning in the little X[S]-1. Colonel Boyd...was aware that many people felt we were too inexperienced for the assignment, one which no civilian pilot had yet accomplished. Had Yeager failed it would have confirmed the warnings of our worst critics...But Chuck's successful flight did much more than silence criticism. It opened the way for the military test pilot to accept more responsibility and participate as an equal in the future development of aviation.[165]

Finally, although the two organizations had not always operated in total agreement, they were, as Walt Williams had observed, just learning to work together and the partnership established between the Air Force and the NACA during the XS-1 program formed the basis for a number of important and fruitful collaborative efforts in the future.

The XS-1 program also helped establish the destiny of an out-of-the-way place on the Mojave Desert where the new breed of exotic research aircraft would continue to carry men into the future. The skies above would become a one-of-a-kind laboratory. A laboratory where, after Yeager's epic flight, men would continue to fly into unexplored regions--where, for the first time, they would pilot their craft past Mach 2, -3, -4, -5, and -6, and up above 100-, 200-, and even 300,000 feet. Man's first supersonic flight transformed an obscure, almost primitive place called "Muroc" into one of the major landmarks of aerospace history. Renamed Edwards AFB in 1949, and designated the U.S. Air Force Flight Test Center two years later, it would become synonymous in the public mind with man's boldest adventures in flight.

ENDNOTES

1. Richard P. Hallion, *Test Pilots: The Frontiersmen of Flight* (Garden City, NY: Doubleday & Company, Inc., 1981), 184-7; James R. Hansen, *Engineer in Charge: A History of the Langley Aeronautical Laboratory, 1917-1958* (Washington, DC: NASA, 1987), 249-59; Richard P. Hallion, *On the Frontier: Flight Research at Dryden, 1946-81* (Washington, DC: NASA, 1984), 4; Richard P. Hallion, *Supersonic Flight: The Story of the Bell X-1 and Douglas D 558* (New York: The Macmillian Company, 1972), xi-xxii and 8-12; Louis Rotundo, *Into the Unknown: The X-1 Story* (Washington, DC: Smithsonian Institution Press, 1994), 5-6; Ben Guenther and Jay Miller, *Bell X-1 Variants* (Arlington, TX: Aerofax, 1988), 1-2; Theodore von Karman with Lee Edson, *The Wind and Beyond: Theodore von Karman--Pioneer in Aviation and Pathfinder in Space* (Boston: Little, Brown, 1967), 216-31. The term "sound barrier" was apparently an invention of the British press. The statement quoted here was attributed to British aerodynamicist W. F. Hilton. In 1966, Hilton himself recalled that, in a 1935 interview with a newsman, he had pointed to an airfoil drag plot and commented: "See how the resistance of a wing shoots up like a barrier against higher speed as we approach the speed of sound." On the following day, he recalled, all of the English dailies had misrepresented his statement and transformed it into "the sound barrier." See W. F. Hilton, "British Aeronautical Research Facilities," *Journal of the Royal Aeronautical Society 70*, Centenary Issue (1966), 103-4.

2. Karman and Edson, *The Wind and Beyond*, 220-21, 232-3; Hallion, *Test Pilots*, 185-8; Hansen, *Engineer in Charge*, 249, 253-6; Guenther and Miller, *X-1 Variants*, 2.

3. Karman and Edson, *The Wind and Beyond*, 231-2; Hallion, *Supersonic Flight*, 14-15; Hallion, *Test Pilots*, 185-6; Clarence L. "Kelly" Johnson with Maggie Smith, *Kelly: More than My Share of It All*, (Washington, DC: Smithsonian Institution Press, 1985), 71-6; Hansen, *Engineer in Charge*, 249-51; Tony LeVier and John Guenther, *Pilot* (New York: Harper & Row, 1954), 142-8. The failure of the P-38's tail section may have also resulted from Virden's attempts to pull out of the high-speed dive in the denser lower atmosphere where the air loads could have exceeded its structural strength.

4. Brig. Gen. E.L. Eubank, U.S. Army, President, Army Air Forces (AAF) Board, AAF Board Project No. (M-1) 82: Effects of Compressibility Dives on Fighter Aircraft, 19 June 1944, Box RD 3735, Records of the USAF Engineering Division, 1917-1951, Washington National Records Center, Suitland MD (documents from this collection have recently been transferred to the National Archives II in College Park, MD; hereafter cited as "RD" plus digits); memo, Col. Frank N. Moyers, Director, Aerodynamics Br., Aircraft Laboratory, Wright Field, to Chief, Technical Staff, Engineering Division, AAF Report Entitled "Effects of Compressibility Dives on Fighter Aircraft," 7 August 1944, RD 3735; Hallion, *Supersonic Flight*, 17-18; Edward H. Heinemann and Rosario Rausa, *Ed Heinemann: Combat Aircraft Designer*, (Annapolis, Maryland: Naval Institute Press, 1980), 142. For an excellent discussion of compressibility and the experiences of World War II fighter pilots who encountered it, see Robert V. Brulle, "Don't Panic: It's Just a Compressibility Dive," *Air Power History* (Spring 1996), 41-53.

5. Karman as quoted in "Where We Stand," in *Prophecy Fulfilled: "Toward New Horizons"* and *Its Legacy*, ed. Michael H. Gorn (Washington, DC: Air Force History and Museums Program, 1994), 26. See also Theodore von Karman, "Science, the Key to Air Supremacy," in same volume, 101-15; Hsue-shen Tsien, "High-Speed Aerodynamics," in *Toward New Horizons*, Vol. III-1, December 1945, 1-34; William R. Sears and Irving L. Ashkenas, "The Airplane: Prospects and Problems," in *Toward New Horizons*, Vol. III-2, 12-15; Frank L. Wattendorf, "Gas Turbine Propulsion," in *Toward New Horizons*, Vol. IV-1, 21-2; Brig. Gen. Laurence C. Craigie, Chief, Engineering Division, Air Technical Service Command (ATSC), briefing to a NACA-Industry Conference, "High-Speed Research Program," 6 September 1945, Lt. Gen. Laurence C. Craigie papers, AFFTC Historical Archives (HA), hereafter Craigie papers and, unless otherwise stipulated, all primary documentation on file in the AFFTC/HA; Brig. Gen. Laurence C. Craigie, Chief, Engineering Division, ATSC, speech to General Electric Swampscott Conference, 2 June 1945, Craigie papers; Brig. Gen. Laurence C. Craigie, Chief, Engineering Division, ATSC, "Research and the Army Air Forces," *Aeronautical Engineering Review*, Vol. 4, No. 10 (October 1945), 3, Craigie papers; Michael H. Gorn, *Harnessing the Genie: Science and Technology Forecasting for the Air Force 1944-1986* (Washington, DC: Government Printing Office, 1988), 27-9; Michael H. Gorn, *The Universal Man: Theodore von Karman's Life in Aeronautics* (Washington and London: Smithsonian Institution Press, 1992), 108-109; Johnson, *Kelly*, 75-6, 95; Hallion, *Supersonic Flight*, 15-16, 19, 27. For a detailed analysis of the efforts of General Arnold and Karman to implement a process for long-range technology forecasting, see Major Dik A. Daso, "Architects of Air Supremacy: General Hap Arnold and Dr. Theodore von Karman" (doctoral dissertation, University of South Carolina, 1996).

6. Craigie briefing to NACA-Industry Conference on "High-Speed Research Program"; Walter C. Williams and Hubert M. Drake, "The Research Airplane--Past, Present, and Future," reprint of lecture presented to the Institute of the Aeronautical Sciences, 17-20 June 1957, 2; George W. Gray, *Frontiers of Flight: The Story of NACA Research* (New York: Alfred A. Knopf, 1948), 333-4; Hansen, *Engineer in Charge*, 257-9; Hallion, *Supersonic Flight*, 13; Heinemann and Rausa, *Ed Heinemann*, 142. For an excellent analysis of transonic wind tunnel developments during the 1940s, see John V. Becker, *The High-Speed Frontier: Case Histories of Four NACA Programs, 1920-1950* (Washington, DC: NASA, 1980), 61-118.

7. Hansen, *Engineer in Charge*, 261-70; Hallion, *Supersonic Flight*, 19-22; Gray, *Frontiers of Flight*, 334-7.

8. Craigie briefing to NACA-Industry Conference on "High-Speed Research Program"; Craigie comments to press at Swampscott Conference; Hallion, *Supersonic Flight*, 10-14, 16-23; Hansen, *Engineer in Charge*, 253, 256-61, 270-74; Guenther and Miller, *X-1 Variants*, 2-3, 5.

9. Ezra Kotcher, Air Corps Materiel Division Engineering Section Memorandum Report No. 50-461-351: Future Aeronautical Research and Development Problems, 18 August 1939; Lois E. Walker and Shelby Wickam, *From Huffman Prairie to the Moon: The History of Wright-Patterson Air Force Base* (Washington, DC: Government Printing Office, 1984), 406; Lt. Gen. Ralph P. Swofford, Jr., USAF (Ret), interview by Lt. Col. Arthur W. McCants, Jr., 24-25 April 1971, Oral History No. K239.0512-1120, USAF Historical Research Agency, Maxwell AFB, AL, 36-7; Lt. Gen. Laurence C. Craigie, USAF (Ret), interview by author, Riverside, CA, 14 May 1992; Hallion, *Supersonic Flight*, 12-13; Martin P. Claussen, *Materiel Research and Development in the Army Air Arm, 1914-1945*, Army Air Forces Historical Studies No. 50 (Washington, DC: AAF Historical Office, 1946), 98-102; Wesley Frank Craven and James Lea Cates, eds., *The Army Air Forces in World War II*, Vol. 6, *Men and Planes* (Chicago: University of Chicago Press, 1953), 228-9.

10. Memo, Col. R.C. Wilson, Chief, Developmental Engineering Br. (hereafter DEB), Assistant Chief of Air Staff, Materiel, Maintenance & Distribution (hereafter AC/AS MMD), to Technical Executive, AAF Materiel Command, Study of High Performance Jet Propelled Fighter Type Aircraft, 17 January 1944, RD 2306; Karman and Edson, *The Wind and Beyond*, 233-4; memo, Col. Donald L. Putt for Brig. Gen. F. O. Carroll, Chief, Engineering Division, AAF Materiel Command, to Development Engineering Br., AC/AS MMD, Study of High-Performance Jet-Propelled Fighter Type Aircraft, 27 January 1944, RD 2306; Hallion, *Supersonic Flight*, 13, 19-21; Rotundo, *Into the Unknown*, 9, 11.

11. Putt for Carroll to DEB AC/AS MMD, 17 January 1944; memo, Brig. Gen. F. O. Carroll, Chief, Engineering Division, AAF Material Command, to DEB AC/AS MMD, Study of High Performance Jet Propelled Fighter Type Aircraft, 29 March 1944 (this memo, like most of others concerning the experimental supersonic aircraft project, was drafted by Ezra Kotcher), RD 2306; memo Col. M.S. Roth, Chief, Aircraft Projects, Engineering Division, AAF Materiel Command, to Douglas Aircraft Company, Supersonic Airplane Development, 27 November 1944, RD 2306.

12. Hallion, *Supersonic Flight*, 20-21. With tongue in cheek, Kotcher titled the study "Mach 0.999" so the brass in Washington would not become unduly alarmed about the fearful prospect of attempting to penetrate the "sonic barrier" (Mrs. Ezra Kotcher interview by Frederick A. Johnsen, Oakland, CA, 9 June 1997). See also memo, Ezra Kotcher to Mr. [William] Lundgren, 4 November 1953.

13. Hansen, *Engineer in Charge*, 253-60; Becker, *The High-Speed Frontier*, 88-90; Hallion, *Supersonic Flight*, 13-19.

14. As quoted in Hallion, *Supersonic Flight*, 19.

15. Rotundo, *Into the Unknown*, 10-11.

16. *Ibid*., 11-13; Becker, *The High-Speed Frontier*, 91; Hansen, *Engineer in Charge*, 260-61.

17. Carroll memo to DEB AC/AS MMD, 29 March 1944.

18. Memo, Maj. Gen. O.P. Echols, AC/AS MMD, to Chief, Engineering Division, Materiel Command, Study of High Performance Jet Propelled Fighter Type Aircraft, 15 April 1944, RD 2306; memo, Col. M.S. Roth, Acting Chief, Technical Staff, Engineering Division, to Chief, Engineering Division, Request for Classified Project Number, 7 April 1944, RD 2306; memo, Brig. Gen. F.O. Carroll, Chief, Engineering Division, to Chief, Technical Staff, Request for Classified Project Number, 15 April 1944, RD 2306; memo, Brig. Gen. F.O. Carroll, Chief, Engineering Division, to Chief, Aircraft Laboratory, Request for Classification of Project, 24 April 1944, RD 2306.

19. Memo, Brig. Gen. F.O. Carroll, Chief, Engineering Division, Materiel Command, to AC/AS MMD, Study of High Performance Jet Propelled Fighter Type Aircraft - Progress Report, 26 June 1944, RD 2306; Rotundo, *Into the Unknown*, 16; Hansen, *Engineer in Charge*, 271-2; Hallion, *Supersonic Flight*, 24.

20. Gough as quoted by Becker in *The High-Speed Frontier*, 92. See also Hallion, *Supersonic Flight*, 23-4.

21. Carroll memo to AC/AS MMD, 26 June 1944; Hansen, *Engineer in Charge*, 272.

22. Carroll memo to AC/AS MMD, 26 June 1944.

23. Hansen, *Engineer in Charge*, 272; Becker, *The High-Speed Frontier*, 91.

24. Memo, Brig. Gen. F.O. Carroll, Chief, Engineering Division, Air Technical Service Command (ATSC), to AC/AS Development & Engineering Br. (M&S), Study of High Performance Jet Propelled Fighter Type Aircraft, 8 November 1944, RD 2306.

25. Memo, Col. M.S. Roth, Chief, Aircraft Projects, Service Engineering Section, Engineering Division, ATSC, to Douglas Aircraft Company, Supersonic Airplane Development, 27 November 1944, RD 2306; Rotundo, *Into the Unknown*, 17.

26. Memo, J.A. Roche for Col. Carl Greene, ATSC Liaison, NASA Langley, to Director, ATSC, MX-524: Conference on Development of Specification on 13 and 14 December 1944, 26 December 1944, RD 2306; Hansen, *Engineer in Charge*, 272; Rotundo, *Into the Unknown*, 19.

27. Roche for Greene memo to Director, ATSC, 26 December 1944; memo, John W. Crowley, Jr., Acting Engineer-in-Charge, Langley Memorial

Aeronautical Laboratory, to ATSC-NACA Liaison Officer, Langley Field, Project MX-524 - Suggested Revision to Report of Conference at Langley on December 13-14, 1944, 5 February 1945, RD 2306; Hallion, *Supersonic Flight*, 42-3; Hansen, *Engineer in Charge*, 278-9; Williams and Drake, "The Research Airplane--Past, Present, and Future," 3. It is interesting to note that the concept of employing a movable stabilizer was already beginning to enter into design thought within the industry even before the XS-1 was completed. In October 1945, for example, Management and Research, Inc., of Upper Darby, PA, proposed a 592 mph sweptwing penetration fighter-bomber design to the AAF which employed a pair of three-bladed contrarotating props and an LR-11 rocket booster. The proposed design also incorporated a movable stablizer (5-degrees up and 10-degrees down) which could be controlled by the pilot in flight. See Management and Research, Inc., AAF Proposal #P-4A, Model H-92A: Penetration Type Fighter-Bomber Specification and Description 29 October 1945, RD 1338.

28. Roche for Greene memo to Director ATSC, 26 December 1944. Crosby was subsequently killed at Muroc during the first flight of the Northrop XP-79B *Flying Ram* on September 12, 1945.

29. For analyses of demise of the NACA's influence, see Alex Roland, *Model Research: The National Advisory Committee for Aeronautics, 1915-1958*, vol. 1 (Washington, DC: NASA, 1985), 191-3, 202-5; Roland, "The Impact of War Upon Aeronautical Progress: The Experience of the NACA," in *Airpower and Warfare: Proceeding of the Eighth Military History Symposium, USAF Academy 1978* (Washington, DC: 1979), 376-80; Daso, "Architects of Air Supremacy," 62-3, 70-74, 140-44, 154-57; Virginia Dawson, *Engines and Innovation: Lewis Laboratory and American Propulsion Technology* (Washington, DC: NASA, 1991), 56-7; Hansen, *Engineer in Charge*, 223-4, 231, 241-2, 245-6, 289; Rotundo, *Into the Unknown*, 90-94. For an analysis of the Army Air Forces' efforts to develop jet propulsion, see James O. Young, "Riding England's Coattails: The U.S. Army Air Forces and the Turbojet Revolution," paper presented to symposium, "Technology and the Air Force: A Retrospective Assessment," Air Force History and Museum Program, Andrews AFB, MD, 23 October 97; and I. B. Holley, Jr., "Jet Lag in the Army Air Corps," in *Military Planning in the Twentieth Century: Proceedings of the Eleventh Military History Symposium, USAF Academy 1984* (Washington, DC: Office of Air Force History, 1986), 123-53. While acknowledging the NACA's failure to keep abreast of the new technology, Young and Holley also examine impediments within the prewar Air Corps, including its lack of an adequate research organization and the scarcity of command-level personnel with first-rate technical backgrounds. These and other factors, in their view, contributed to its failure to fully comprehend the vital interaction between fundamental and applied research. In a 1971 interview, Lt. Gen. Laurence C. Craigie, USAF (Ret), who spent several tours at Wright Field during the 1930s and 40s, recalled that, in 1934, no more than a dozen individuals, out of 1,100 personnel working there, could be referred to as "real scientists." Even after World War II, he noted that, while "somewhere between 62 and 68 percent of all regular officers in the Army and Navy had bachelor degrees," only 32 percent of their Air Force counterparts had graduated from colleges. He concluded: "We couldn't begin to compare with the Navy in this area of technical competence and knowhow" and this also put the Air Force at a tremendous disadvantage when dealing with anyone in the scientific community. Looking back, he observed: "I think you are going to have to have enough competence in-house so that you can not only contribute to research, but deal effectively with the agencies outside, also." See Lt. Gen. Laurence C. Craigie, USAF (Ret), interview by Maj. Paul Clark and Capt. Donald Baucom, 24 September 1971, US Air Force Academy, U. S. Air Force Oral History Program Interview No. 637, 70-71. The Craigie papers in the AFFTC Historical Archives offer a wealth of material on efforts to develop a first-rate research capability. See, for example, memo, [Col. Theodore B.] Holliday, Equipment Laboratory, Engineering Division, to Brig. Gen. Laurence C. Craigie, Deputy Chief, Engineering Division, ATSC, Memo Regarding Colonel Tobiason's Comments on German Facilities [with attachment], 20 July 1945; Brig. Gen. L. C. Craigie, Deputy Chief, Engineering Division, Wright Field, to Col. H. Z. Bogert, HQ AAFSC/MTO, Air Maintenance Division, A. P. O. 528, New York City, Greatly Expanded Research and Development, 14 August 1945; Craigie, "Research and the Army Air Forces," 1-4; Gen. H. H. Arnold, Commanding General, Army Air Forces, Statement at Joint Hearings of Subcommittee on War Mobilization, Senate Military Affairs Committee, and Two Subcommittees of Senate Commerce Committee, Washington, DC, 18 October 1945, 1-9; Maj. Gen. L. C. Craigie, Chief, Engineering Division, AMC, Army Air Forces Research and Development Program: On-the-Record Remarks before the Congressional Appropriations Committee, Washington, DC, 10 March 1947.

30. Becker, *The High-Speed Frontier*, 91-2; Hansen, *Engineer in Charge*, 272-3; Hallion, *Supersonic Flight*, 24.

31. Becker, *The High-Speed Frontier*, 92, 96.

32. Becker, *The High-Speed Frontier*, 92, 96; Hansen, *Engineer in Charge*, 273-4; Hallion, *Supersonic Flight*, 24-7. For detailed discussions of the development of the D-558-I and -II, see Hallion, *Supersonic Flight*, 56-84; and Heinemann and Rausa, *Ed Heinemann*, 141-61.

33. R.M. Stanley and R.J. Sandstrom, "Development of the XS-1 Airplane," in *Air Force Supersonic Research Airplane XS-1 Report No. 1*, 9 January 1948, 7; Hallion, *Supersonic Flight*, 34-5; Donald J. Norton, Larry: *A Biography of Lawrence D. Bell* (Chicago: Nelson-Hall, 1981), 171.

34. Memo, B. Hamlin for R.M. Stanley, Chief Engineer, Bell Aircraft Corp., to Maj. E. Kotcher, Chief, Pilotless Aircraft Branch, Experimental Engineering Section, ATSC, MX-524 Conference, 8 February 1945, RD 2306; Hallion, *Supersonic Flight*, 34-7; Benson Hamlin, "The Design Conception of Supersonic Flight," unpublished manuscript, *ca*. late 1970s.

35. Hamlin, "The Design Conception of Supersonic Flight"; Hallion, *Supersonic Flight*, 36.

36. Hallion, *Supersonic Flight*, 38-9; Hansen, *Engineer in Charge*, 275-7; Hamlin, "The Design Conception of Supersonic Flight."

37. Stanley and Sandstrom, "Development of the XS-1 Airplane," 7-8. See also memo, J.A. Roche for Col Carl F. Greene, ATSC Liaison Officer NACA-Langley, to Director, ATSC, MX-524 Conference at L.M.A.L. on 24 January 1945, 26 January 1945, RD 2306; Hallion, *Supersonic Flight*, 37-8.

38. Stanley and Sandstrom, "Development of the XS-1 Airplane," 8.

39. Stanley and Sandstrom, "Development of the XS-1 Airplane," 10-11; memo, Andrew G. Haley, President, Aerojet Engineering Corporation, to Director, ATSC, "Conference on Alternate Propellants for Project MX-524, 26 February 1945, RD 2306; Bell Aircraft Corporation Technical Data Report No. 44-947-001 (Final Corrected): Model Specification for Rocket-Propelled High Speed Research Airplane Model No. XS-1, 1 October 1946; Robert L. Perry, "The Antecedents of the X-1," unpublished paper for the RAND Corp., June 1965, 20-25; Notes on the XS-1, 16 May 1947 [this document was one of a series of unsigned notes on meetings and program status concerning the XS-1 which were maintained in the files of Louis H. "Si" Sibilsky, Deputy Chief of the Test Engineering Subdivision, Flight Test Division, AMC]; Hallion, *Supersonic Flight*, 40-1; Hamlin, "The Design Conception of Supersonic Flight." For more details on the XLR-11 and Reaction Motors, see Frank Winter, "Bringing Up Betsy," *Air & Space* (December 1988/January 1989), 76-84; and, especially, Frederick I. Ordway and Frank H. Winter, "Pioneering Commercial Rocketry in the United States of America, Reaction Motors, Inc., 1941-1972," Parts 1-4, *Journal of British Interplanetary Science* (December 1983, April 1985, 1987), 542-51, 155-68, 389-400, 405-16.

40. Stanley and Sandstrom, "Development of the XS-1 Airplane," 11; Hallion, *Supersonic Flight*, 46-9; Hamlin, "The Design Conception of Supersonic Flight"; Richard H. Frost interview by author, 7 September 1990; Frost interview by author, 12 September 1990; Hansen, *Engineer in Charge*, 287-88.

41. Becker, *The High-Speed Frontier*, 93; Hallion, *Supersonic Flight*, 44-7, 85-6; Hamlin, "The Design Conception of Supersonic Flight"; Hansen, *Engineer in Charge*, 286-8, 554; Rotundo, *Into the Unknown*, 31, 37, 39, 50.

42. Hamlin, "The Design Conception of Supersonic Flight"; Hallion, *Supersonic Flight*, 37, 43; Guenther and Miller, *X-1 Variants*, 6.

43. Stanley and Sandstrom, "Development of the XS-1 Airplane," 7, 14; Bell Aircraft Corporation Technical Data Report No. 44-947-001; Kotcher to Lundgren; Hansen, *Engineer in Charge*, 279-86, 289-90; Hallion, *Supersonic Flight*, 41-2, 44, 49; Rotundo, *Into the Known*, 32-3. The decision to employ extremely thick skins on the wings was based on the results of dive tests--particularly a series of tests with the XP-51 conducted by the NACA and flown by Wright Field test pilot Major Gus Lunquist--which revealed that the wing skins deformed at high speeds causing chord-wise pressure distribution to vary considerably. See Notes on the Status of High-Speed Aerodynamic Research which were prepared *ca*. April 1944 and maintained in Exra Kotcher's personal files (copy on file AFFTC/HA).

44. Bell Aircraft Corporation Technical Data Report No. 44-947-001; Hallion, *Supersonic Flight*, 41, 50; Rotundo, *Into the Unknown*, 26. Completion of the No. 3 aircraft (serial number 46-064) would await the development of an acceptable propellant turbopump which, by eliminating the high-pressure fuel system employed on the first two craft, would permit it to fly to higher altitudes and speeds. Unfortunately, the development of this system and completion of the aircraft would require more than three years and it only completed a single unpowered glide flight before it was destroyed in an explosion on the ground in 1951.

45. Becker, *The High-Speed Frontier*, 75-95; Hallion, *Supersonic Fligh*t, 45; Hansen, *Engineer in Charge*, 289.

46. Bell Aircraft Corporation Technical Data Report No. 44-947-001; Hallion, *Supersonic Flight*, 86; Rotundo, *Into the Unknown*, 30.

47. Rotundo, *Into the Unknown*, 35-6, 38, 41-3; Jack Woolams, "Autobiography," a brief unpublished manuscript, 20 March 1946.

48. Rotundo, *Into the Known*, 51-2; Hallion, *Supersonic Flight*, 87.

49. Rotundo, *Into the Unknown*, 53-9; Hallion, *Supersonic Flight*, 86; Robert M. Stanley, "My Thirty Years in Aviation," *Stanley Capsule*, an autobiography which was published in eleven installments in the Stanley Aviation Corporation's monthly newsletter in 1962; Richard H. Frost telephone interview by author, 14 August 1990; Jack Russell telephone interview by author, 17 July 1992.

50. Jack Woolams, Bell Aircraft Corporation Pilot's Report: XS-1 Flight No. 1, 25 January 1946; Rotundo, *Into the Unknown*, 63-69, 289.

51. Pilot's Report: XS-1 Flight No. 1.

52. Rotundo, *Into the Unknown*, 70-89, 95. Rotundo's book provides, by far, the most detailed account of these tests.

53. Hallion, *Supersonic Flight*, 88-9; Hallion, *Test Pilots*, 195; A.M. "Tex" with Charles Barton, *Tex Johnston: Jet-Age Test Pilot* (Washington, DC, and London: Smithsonian Institution Press, 1991), 89-96; Rotundo, Into the Unknown, 115; Frost interview by author, 7 September 1990.

54. Mary Margaret Woolams interview by author, Tonawanda, NY, 22 May 1991. Dick Frost confirmed Woolams' extreme eagerness to fly the airplane and indicated that Woolams' statement about flying it for nothing was entirely in character with his whole attitude toward the XS-1 program, Frost telecon interview by author, 24 June 1992.

55. Lawrence D. Bell, President, Bell Aircraft Corp., to Brig. Gen. Laurence C. Craigie, Chief, Engineering Division, 6 September 1946, Craigie Papers.

56. Transcript of speech delivered by Chalmers H. Goodlin to the Dallas/Fort Worth Section of the Society of Experimental Test Pilots, the Society of Flight Test Engineers, the American Helicopter Society and the American Institute of Aeronautics and Astronautics, Dallas, TX, 13 March 1986; Hallion, *Supersonic Flight*, 89-90; Hallion, *Test Pilots*, 195; Rotundo, *Into the Unknown*, 116-17.

57. Rotundo, *Into the Unknown*, 120.

58. Memo, R.H. Frost, Bell Aircraft Corporation, to Commanding General, Air Materiel Command (AMC), "Contract W33-038 AC-9183 XS-1 Flight Test Program," 28 August 1946. See also Rotundo, *Into the Unknown*, 103; Frost interview by author, 7 September 1990.

59. Memo, Walter C. Williams, LMAL, to NACA Chief of Research, Research Test Program, XS-1 Airplane, 7 June 1946.

60. Memo, H.J.E. Reid, Engineer-in-Charge, LMAL, to NASA HQ, Transmittal of Memorandum Regarding Research Test Program, XS-1 Airplane, 24 June 1946.

61. Memo, Walter C. Williams, LMAL, to Chief of Research, Visit to Bell Aircraft Corporation, 20 September 1946; Rotundo, *Into the Unknown*, 103, 118-19.

62. Memo, H.J.E. Reid, Engineer-in-Charge, LMAL, to NACA HQ, Langley Form Let Sept. 25, 1946 B.M. FIT JTC Enc., 26 September 1946.

63. Rotundo, *Into the Unknown*, 122.

64. Hallion, *Test Pilots*, 196-7; Melvyn Smith, *Space Shuttle: An Illustrated History of US Winged Spacecraft--X-15 to Orbiter* (Newbury Park, CA: Haynes Publications, Inc.,1985), 8-9.

65. Sir Ben Lockspeiser as quoted by Lt Col Gene Gurney (USAF) in *A Chronology of World Aviation* (New York: Franklin Watts, Inc., 1965), 132. Famed British test pilot Roland Beaumont later called the decision to resort to rocket-driven models "a misjudgement of monumental proportions, doomed to rapid failure, and it put Britain six years behind America in the race to achieve practical supersonic level flight and to acquire the technology necessary for the inevitable requirement for military supersonic aircraft." See *Testing Early Jets: Compressibility and the Supersonic Era* (Shrewsbury, England: Airlife Publishing, Ltd., 1990), 61-2.

66. Williams to Gough, 8 October 1946. See also Walt Williams to Mel Gough, 1 October 1946; memo, Walter C. Williams to LMAL Chief of Research, Telephone Call to Wright Field, 10 October 1946.

67. Williams to Chief of Research, 10 October 1946.

68. Williams to Gough, 8 October 1946; memo, Walter C. Williams, NACA - Muroc, to LMAL Chief of Research, Visit of Col. R.S. Garman and Mr. J.H. Voyles to Muroc Army Air Field, 21 October 1946. See also memo, Hartley A. Soule, Chief, Stability Research Division, LMAL, to LMAL Chief of Research, XS-1 Airplane - Discussion of Policy Regarding Acceptance and Research Flights between Army and NACA Personnel at Wright Field on October 14, 1946, 15 October 1946; Rotundo, *Into the Unknown*, 136.

69. Walter C. Williams, NACA - Muroc, to Melvin N. Gough, LMAL, 9 October 1946; Bob Baker, NACA - Muroc, to Herbert Hoover, LMAL, 10 October 1946; memo, Walter C. Williams, NACA - Muroc, to LMAL Chief of Research, Progress Report for the Week Ending Oct. 11, 1946, XS-1 Project, 11 October 1946; Walter C. Williams, NACA - Muroc, to Melvin N. Gough, LMAL, 11 October 1946; Rotundo, *Into the Unknown*, 129-30, 133-5.

70. Williams to Melvin N. Gough, LMAL, 9 November 1946. See also, Williams to Gough, 4 October 1946; Walter C. Williams, NACA - Muroc, to Melvin N. Gough, LMAL, 23 October 1946; Walter C. Williams, NACA - Muroc, to Melvin N. Gough, LMAL, 25 October 1946; memo, Walter C. Williams, NACA - Muroc, to LMAL Chief of Research, Visit to Douglas Aircraft Corporation, El Segundo Plant, 29 October 1946; Walter C. Williams, NACA - Muroc, to Melvin N. Gough, LMAL, 1 November 1946.

71. Williams to Gough, 1 December 1946.

72. Williams to Gough, 1 December 1946; Rotundo, *Into the Unknown*, 142.

73. Frost to author, 7 September 1990; Walter C. Williams, NACA - Muroc, to Hartley Soule, Research Department, LMAL, 3 December 1946; Rotundo, *Into the Unknown*, 143-4.

74. Williams to Soule, 3 December 1946; Rotundo, *Into the Unknown*, 144-5.

75. Frost to author, 7 September 1990; Historical Report, Muroc Army Air Field, 1 October 1946 - 31 December 1946, 12; Goodlin speech to Dallas/ Fort Worth Section of Society of Experimental Test Pilots, et al; Rotundo, *Into the Unknown*, 147-9; Hallion, *Supersonic Flight*, 94.

76. "Notes on the XS-1," 16 May 1947; Hallion, *Supersonic Flight*, 95-96; Rotundo, *Into the Unknown*, 157-78, 198-207, 212-22, 289-90.

77. Walter C. Williams, NACA - Muroc, to Hartley Soule, Research Department, LMAL, 14 February 1947; memo, Joel R. Baker, Jr., NACA - Muroc, to Chief of Research, LMAL, Pilot Evaluation of the XS-1 Aircraft, 25 February 1947.

78. Rotundo, *Into the Unknown*, 25, 30, 37, 106.

79. As quoted in Rotundo, *Into the Unknown*, 38.

80. *Ibid*., 105.

81. Williams to Chief of Research, 7 June 1946.

82. See Rotundo, *Into the Unknown*, 108-9.

83. Goodlin speech to Dallas/Fort Worth Society of Experimental Test Pilots, et al. See also Rotundo, *Into the Unknown*, 125-6.

84. Soule memo to Chief of Research, 14 October 1946.

85. Maj. Gen. Osmond J. Ritland, USAF (Ret), to author, 13 September 1990; Maj. Gen. George F. Smith, USAF (Ret), to author, 14 September 1990; Maj. Gen. Osmond J. Ritland, interview by Lt. Col. Lyn R. Officer, Solano Beach, Calif., 19-21 March 1974, Interview No. k239.0512-722, USAF Historical Research Agency, Maxwell AFB, 67-8; Maj. Gen. Osmond J. Ritland, USAF (Ret), interview by author, Rancho Santa Fe, CA, 25 September 1990; report, "Aircraft Projects Section F.Y. 1948 R&D Program as of 12 May 1947 (Project 611-1)," this was one of roughly a hundred restricted R&D program documents which were kept up to date and maintained in a loose-leaf binder, known as "the Green Book" and distributed to each of the senior personnel in the AMC Engineering Division (Maj. Gen. Osmond J. Ritland Papers, AFFTC HA).

86. Memo, J.W. Crowley, Acting Director of Aeronautical Research, NACA, to Commanding General, AAF, "AAF-AMC-NACA Conference on Research Airplane Program, 19 February 1946; memo, Hartley A. Soule, LMAL, to Chief of Research, LMAL, Proposed Actions Regarding the XS-1 Airplane Project, 24 February 1947.

87. Memo, Robert M. Stanley, Chief Engineer, Bell Aircraft Corporation, to D. Roy Shoults, Vice President, Engineering, *et al*, Bell Aircraft Corporation, Report of Meeting at Wright Field on March 5, 1947, 6 March 1947.

88. *Ibid*. For AMC record of this meeting, see memo (drafted by James H. Voyles of the Aircraft Projects Section), Brig. Gen. Samuel R. Brentnall, Chief, Engineering Operations, Engineering Division, to J.W. Crowley, Acting Director of Aeronautical Research, HQ NACA, 18 March 1947.

89. Stanley memo to Shoults, *et al*, 6 March 1947.

90. Rotundo, *Into the Unknown*, 193-4.

91. Stanley memo to Shoults, *et al*, 6 March 1947.

92. Walter C. Williams, NACA - Muroc, to Hartley A. Soule, Research Department, LMAL, 9 April 1947; Rotundo, *Into the Unknown*, 195-6.

93. Williams to Soule, 9 April 1947.

94. Smith to author, 14 September 1990; Lt. Gen. Laurence C. Craigie, USAF (Ret.), interview by author, Riverside, CA, 11 September 1990; Rotundo, 210-11; Rotundo, *Into the Unknown*, 208.

95. Ritland to author, 13 September 1990; Ritland interview by Officer, 67. See also Rotundo, *Into the Unknown*, 187-8. In his 1974 interview, General Ritland commented: "I want to go on record to the fact that [the] NACA and a guy by the name of Hartley Soule...would not accept the fact that the X[S]-1 could go supersonic. And, if it did, it would break up." In fairness to Soule, it appears that his skepticism principally centered around proposals to attempt supersonic flight in the denser atmosphere at altitudes below 60,000 feet. Though not a supersonic fighter, the XF-86 would exceed the speed of sound in a dive in March of 1948. As early as 1945, virtually all of the major aircraft manufacturers had submitted preliminary design specifications to the AAF for advanced fighter-interceptors, employing rocket boosters, which promised speeds in excess of 700 mph at 50,000 feet. See, for example, Consolidated Vultee, AAF Proposal #I-2A Rev., Interceptor Fighter: Addendum to Report No. DEVF 368-10, 16 November 1945; North American Aviation, Inc., AAF Proposal #I-3B, Report No. NA-8756, Design Specification for an Interceptor Fighter Airplane with External Climb Rocket: NAA Model No. RD-1381-B, 10 October 1945; Bell Aircraft Corp., AAF Proposal #I-1, Model D 35: Interceptor Fighter, 26 October 1945, all RD 1338.

96. Ritland to author, 13 September 1990; Ritland interview by Officer, 68; Smith to author, 14 September 1990.

97. Memo, Col. Mark E. Bradley, Chief, Flying Section, to Commander, ATSC, Formation of Jet Research Unit or Branch of the Flight Section, 20

October 1944; memo, Lt. Col. Richard E. Horner, Chief, Flight Test Engineering and Research Branch, to Chief, Flight Section, Status of Flight Research on Jet Propulsion, 1 January 1945. This whole subject is treated in much greater depth and detail in a manuscript, entitled "Before Edwards: The Antecedents of U.S. Air Force Flight Testing," currently under preparation by the author.

98. Ritland to author, 13 September 1990; James O. Young, text manuscript for *The USAF Test Pilot School: 1944-1994* (to be published by the USAF TPS Alumni Association in 1997), 31-40. For an excellent description of the training provided at the new Test Pilots' School, see Donald S. Lopez, *Fighter Pilot's Heaven: Flight Testing the Early Jets* (Washington, DC: Smithsonian Institution Press, 1995), 125-43.

99. Smith to author, 14 September 1990; Ritland to author, 13 September 1990. Looking back, Smith and Ritland both maintained that giving the accelerated program to the NACA was never a really serious consideration. Lt Gen Laurence C. Craigie, USAF (Ret), who was then the two-star chief of the Engineering Division at Wright Field, frequently commented to the author over the years about the uncomplicated, "informal" manner in which research and development business was conducted up through the mid-1940s (confirmed in a telecon, Craigie to author, September 17, 1990).

100. Memo, Col. Paul H. Kemmer, Deputy Chief, Engineering Division, to All Subdivision Chiefs, Flight Research Program, 13 September 1945, RD 3735; General Chuck Yeager and Leo Janos, *Yeager: An Autobiography* (Toronto, New York, London, Sydney, Auckland: Bantam Books, 1985), 89-96; Brig. Gen. Robert L. Cardenas, USAF (Ret), to author, 9 August 1990; transcript of speech, Brig. Gen. Charles E. Yeager, USAF (Ret), to guests attending the dedication of Boyd Hall at the USAF Test Pilot School, 18 May 1979; Frank K. Everest and John Guenther, *The Fastest Man Alive*, 2nd ed. (New York: Berkley Books, 1986), 82-91.

101. Memo, Col. George F. Smith, Chief, Aircraft Projects Section, AMC, to Commanding General, AAF, Project MX-653, 1 May 1947.

102. Smith to author, 14 September 1990; Rotundo, *Into the Unknown*, 219, 222; memo, Brig. Gen. Alden R. Crawford, Chief, Research and Engineering Division, HQ USAAF, to Commanding General, AMC, XS-1 Transonic Flight Test Program, 24 June 1947.

103. Notes on the XS-1 [unsigned notes maintained on file by Louis H. "Si" Sibilsky, Flight Test Division, AMC], 20 April 1947. See also Notes on the XS-1, 16 May 1947. It is interesting to compare some of these projections with what would actually occur during the program. Throughout the early phases of the program, for example, the XS-1 would be launched from approximately 20,000 feet. Yeager would make only three glide flights in the No. 1 XS-1 before accelerating all the way out to Mach 0.85 on his first powered flight and to Mach 0.89 on the next flight. The emphasis during the first phase of the program would not be on climbing to successively higher altitudes but accelerating to higher speeds at altitudes of around 40,000 feet. The XS-1s would never come close to 100,000 feet; the highest altitude attained would be 71,902 feet on August 8, 1949. The XS-1 would make only one powered takeoff from the ground and that would occur on January 5, 1949 when Yeager climbed to about 25,000 feet.

104. Notes on the XS-1, 16 May 1947.

105. As quoted in Yeager and Janos, *Yeager*, 98.

106. See Boyd and Ascani interviews as quoted in Yeager and Janos, *Yeager*, 98-101; "The Reminiscences of Major General Albert Boyd," Aviation Project, Oral History Research Office, Columbia University, 1960, 18; Maj Gen Fred J. Ascani, USAF (Ret), to author, 21 Jan 1995; memo, Col P. B. Klein, Chief, Fighter Branch, Aircraft Projects Section, Engineering Division, AMC, Conference, Accelerated Transonic Program XS-1 Airplane, 25 June 1947; R.A. "Bob" Hoover with Mark Shaw, *Forever Flying: Fifty Years of High-Flying Adventures, from Barnstorming in Prop Planes to Dogfighting Germans to Testing Supersonic Jets* (New York, London, Toronto, Sydney, Tokyo, Singapore: Pocket Books, 1996), 109; Hallion, *Supersonic Flight*, 100-102.

107. Klein, Accelerated Transonic Program XS-1 Airplane; Hansen, *Engineer in Charge*, 297.

108. Klein, Accelerated Transonic Program XS-1 Airplane.

109. *Ibid*. See also agenda, NACA-AAF Conference: Operation of Concurrent Flight Test Program, XS-1 Airplane, Wright Field, 30 June 1947 and Rotundo, *Into the Unknown*, 238-9. NACA priority on the B-29 would, in fact, become a rather moot point once the Flight Test Division's accelerated flight test program actually got underway. The NACA's first flight in the program would not come until October 21, 1947--exactly one week *after* Yeager's supersonic flight.

110. Memo, Col. Fred R. Dent, Jr., Chief, Aircraft Projects Section, Engineering Division, Wright Field, to AMC Engineering Liaison Offices at the NACA Laboratory, Langley Field, attn: Mr. H. A. Soule, Contract W33-038 AC-9183, NACA-AAF Conference on Concurrent Flight Test Program for XS-1 Airplane, undated; Smith to Bell Aircraft Corporation, Contract W33-038-AC-9183, XS-1 Airplane, Services of Engineering Representative; Rotundo, *Into the Unknown*, 211, 230-31, 239; Hansen, *Engineer in Charge*, 299; Hallion, *Supersonic Flight*, 97. Those present at this conference included: Clotaire Wood from NACA headquarters; Hartley A. Soule, Walt Williams, Herbert Hoover, all from NACA-Langley; Col. P. B. Klein and Mr. James H. Voyles, representing the AMC; and Col. Albert Boyd, Lt. Col. Robert G. Ruegg, Ridley, Yeager, and Hoover, all from the AMC Flight Test Division.

111. As quoted in memo, Hartley A. Soule, LMAL, to Chief of Research, NACA, Army Proposal for Accelerated Tests of the XS-1 to a Mach Number of 1.1, 21 July 1947.

112. As quoted from unsigned meeting notes [maintained in the Sibilsky files], Meeting with NACA Personnel, 1 July 1947.

113. *Ibid*. See also Soule memo to Chief of Research.

114. Soule to Chief of Research. See also, Rotundo, *Into the Unknown*, 240.

115. Dent memo to AMC Engineering Liaison Offices at the NACA Laboratory; Rotundo, *Into the Unknown*, 240-41.

116. As quoted in Yeager and Janos, *Yeager*, 97.

117. As quoted in Young, *Supersonic Symposium*, 134.

118. As quoted in Yeager and Janos, *Yeager*, 97-8.

119. Report, Maj R. L. Cardenas, Officer-in-Charge, XS-1 Project, Muroc AAF, to Commanding General, AMC, Attn: TSFLT, XS-1 Project, 28 July 1947; report, Maj R. L. Cardenas, Officer-in-Charge, XS-1 Project, Muroc AAF, to Commanding General, AMC, Attn: TSFLT, XS-1 Project, 29 July 1947.

120. As quoted in Yeager and Janos, *Yeager*, 105-106. In 1948, Frost observed: "Charlie Yeager is completely nerveless...He's the coolest guy I've ever seen, and it's been my business to see a lot of pilots preparing for flights of doubtful outcome. He is a perfectly natural airman, if there is such a thing. He flies a plane as if it were part of him. In his test work he does exactly what the aeronautical engineers request, and he brings back the answers (*Collier's Magazine*, 25 December 1948, 30-31).

121. As quoted in *Saturday Evening Post*, 1 July 1950, 27.

122. As quoted in Yeager and Janos, *Yeager*, 107.

123. Frost to author, 29 January 1995.

124. As quoted in Young, *Supersonic Symposium*, 107-107.

125. As quoted in Yeager and Janos, *Yeager*, 111.

126. Yeager as quoted in *Supersonic Symposium*, 122.

127. Reports, Maj R. L. Cardenas, Officer-in-Charge, XS-1 Project, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, XS-1 Project, 1, 4, 5, 6, 7 August 1947; msg, Col Signa A. Gilkey, Commander, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, First XS Dash 1 Glide Flight, 6 Aug 1947; msg, Gilkey, Commander, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, Third and Final Glide Flight, 8 August 1947; Yeager and Janos, *Yeager*, 112-13; Hallion, *Supersonic Flight*, 103.

128. Memo, Herbert A. Hoover, NACA - Muroc, to Chief of Flight Research Division, LMAL, 22 August 1947.

129. Report, 1st Lt Edward L. Swindell, Acting Officer-in-Charge, XS-1 Project, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, XS-1 Project, 15 August 1947; reports, Maj R. L. Cardenas, Officer-in-Charge, XS-1 Project, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, XS-1 Project, 22, 25, 26, 27 August 1947; Yeager and Janos, *Yeager*, 113, 119; Hallion, *Supersonic Flight*, 104.

130. Msg, Col Signa A. Gilkey, Commander, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, First XS-1 No 1 Dash Powered Flight, 29 August 1947; Capt Charles E. Yeager, Pilot's Report: No. 1 Powered Flight, 29 August 1947; Yeager and Janos, *Yeager*, 118-21; Hallion, *Supersonic Flight*, 104; Frost to author, 7 September 1990.

131. As quoted in Yeager and Janos, *Yeager*, 121. See also Pilot's Report: No. 1 Powered Flight. Yeager's climb angle steepened as he fired each chamber until, after the fourth chamber was ignited, he was climbing at an angle of almost 90 degrees. He actually attained top speed on this flight at 30,000 feet after he had dropped the nose and was rolling out into a normal attitude.

132. As quoted from letter, dated 6 October 1947, and reprinted in Col. Clarence E. "Bud" Anderson with Joseph P. Hamelin, *To Fly and Fight: Memoirs of a Triple Ace* (New York: St. Martin's Press, 1990), 167.

133.As quoted in Yeager and Janos, *Yeager*, 121.

134. Yeager and Janos, *Yeager*, 121-2; Pilot's Report: No. 1 Powered Flight; Hallion, *Supersonic Flight*, 104; Frost telecon interview by author, 26 June 1990 .

135. Report, Maj. R. L. Cardenas, Officer-in-Charge, XS-1 Project, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, XS-1 Project, 2 September 1947; Capt. Charles E. Yeager, Pilot's Report: No. 2 Powered Flight undated [sent to HQ AMC on 9 September 1947].

136. As quoted in Yeager and Janos, *Yeager*, 122. For more details on Yeager's impatience with the NACA, see Yeager and Janos, *Yeager*, 129-31, 180-83.

137. Frost to author, 26 June 1990; Richard Frost to author, 8 August 1990; Brig. Gen. Robert L. Cardenas, USAF (Ret), to author, 9 August 1990; Yeager interview by author, 31 August 1990; De E. Beeler to author, 16 January 1997; Hoover, *Forever Flying*, 118, 120; Hansen, *Engineer in Charge*, 301-303.

138. As quoted in Yeager and Janos, *Yeager*, 108.

139. Williams, "The X-1 Story," *NACA High-Speed Flight Station X-Press: 10th Anniversary--Supersonic Flight* (14 October 1957), 3.

140. Pilot's Report: No. 2 Powered Flight; msg, Col. Signa A. Gilkey, Commander, Muroc AAF, to Commanding General, AMC, ATTN: Col. George F. Smith (TSEOA) and Col. Albert Boyd (TSFLT), XS-1 Second Army Powered Flight, 4 September 1947; msg, Gilkey to Commanding General, AMC, ATTN: Col. George F. Smith (TSEOA) and Col. Albert Boyd (TSFLT), XS-1 No. 1 Second Army Flt Analysis of NACA Instrumentation, undated.

141. Capt. Charles E. Yeager, "The Operation of the XS-1 Airplane," in *Air Force Supersonic Research Airplane: XS-1 Report No. 1*, 19.

142. Report, Maj. R.L. Cardenas, Officer-in-Charge, XS-1 Project, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, XS-1 Report, 5 September 1947; Capt. Charles E. Yeager, Pilot's Report: No. 3 Powered Flight, undated.

143. Yeager as quoted in *Supersonic Symposium*, 107-109.

144. Yeager, Pilot's Report: No. 3 Powered Flight; Yeager, "Operation of the XS-1 Airplane," 19; Rotundo, *Into the Unknown*, 261; Hallion, *Supersonic Flight*, 105.

145. Reports, Maj. R.L. Cardenas, Officer-in-Charge, XS-1 Project, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, XS-1 Report, 9, 11, and 15 September 1947; msg, Col. Signa A. Gilkey, Commander, Muroc AAF, to CG [Commanding General], AMC, ATTN: Col. Boyd (TSFLT), XS-1 No 1 Dash Fourth Army Powered Flight, 10 Sept 1947; Capt. Charles E. Yeager, Pilot's Report: 4th Powered Flight, undated; msg, Col. Signa A. Gilkey, Commander, Muroc AAF, to CG, ATTN: Col. George F. Smith (TSEOA) and Col. Albert Boyd (TSFLT), Examination of NACA Recorded Data, 11 Sept 1947; reports, Lt. Col. William K. Phingst, Projects Officer, Flight Test Division, AMC, Muroc AAF, to Commanding General, AMC, ATTN: TSFLT, XS-1 Project, 23, 25, 29 September and 1 October 1947; Yeager, "Operation of the XS-1 Airplane," 19.

146. Capt. Charles E. Yeager, Pilot's Report: 6th Powered Flight, 5 October 1947. See also Yeager and Janos, *Yeager*, 123.

147. Pilot's Report: 6th Powered Flight.

148. Capt. Charles E. Yeager, Pilot's Report: #7 Powered Flight 8 October 1947; msg, Col. Signa A. Gilkey, Commander, Muroc Field, to Commanding General, AMC, ATTN: Col. George F. Smith (TSEOA) and Col. Albert Boyd (TSFLT), Seventh Powered Flight, 10 October 1947; Yeager, "Operation of the XS-1 Airplane," 19.

149. Yeager and Janos, *Yeager*, 123, 125-7; Capt. Charles E. Yeager, Pilot's Report: #8 Powered Flight, 10 October 1947; msg, Col. Signa A. Gilkey, Commander, Muroc Field, to Commanding General, AMC, ATTN: TSFLT and TSEOA, 10 Oct Flt, 13 October 1947; Capt. Charles E. Yeager to Maj. C.E. Anderson, 10 October 1947 (part of which is reprinted in Anderson's *To Fly and Fight*, 167-8); Hallion, *Supersonic Flight*, 106-107. In his autobiography, Yeager recalls that complete loss of pitch control occurred on his seventh powered flight. His own pilot's report, Colonel Gilkey's message to HQ AMC (which was drafted by Jackie Ridley), and his 10 October letter to Andy Anderson, however, all suggest that this occurred during his eighth flight.

150. Hallion, *Supersonic Flight*, 107; Yeager and Janos, *Yeager*, 124-5.

151. Ridley as quoted in Yeager and Janos, *Yeager*, 125.

152. As quoted in Yeager and Janos, *Yeager*, 108.

153. Yeager to Anderson, 10 October 1947.

154. De E. Beeler to author, 16 January 1997; Yeager and Janos, *Yeager*, 124-5; Hallion, *Supersonic Flight*, 107-108.

155. Yeager and Janos, *Yeager*, 110, 119, 127; Hallion, *Supersonic Flight*, 109; Guenther and Miller, *X-1 Variants*, 9, 56, 63.

156. Yeager and Janos, *Yeager*, 127-9; Hallion, *Supersonic Flight*, 107.

157. As quoted in Janos and Yeager, *Yeager*, 129. See also Hallion, *Supersonic Flight*, 108.

158. Capt. Charles E. Yeager, Pilot's Report: 9th Powered Flight, 28 October 1947; Rotundo, *Into the Unknown*, 277. When Yeager later went to Okinawa to test a MiG-15, he said he could immediately spot one of the major reasons why American F-86 pilots enjoyed such a remarkable kill ratio over the Russian fighter; the MiG did not have an all-moving horizontal stabilizer, while later versions of the F-86 did. This, he has always maintained, was one of the most important discoveries made during the XS-1 program. Interestingly enough, although Yeager found the moving tail effective during his tests up to 0.92 indicated Mach number, he apparently did not--according to his pilot's report--use it thereafter during the rest of the flight. In fact, he regained elevator effectiveness when he got beyond Mach 0.96 indicated.

159. Yeager, Pilot's Report: 9th Powered Flight.

160. *Ibid*.; Hallion, *Supersonic Flight*, 109; Yeager and Janos, *Yeager*, 130.

161. As quoted in Hallion, *Supersonic Flight*, 114.

162. Frost interview by author, 26 June 1990; Yeager interview by author, 31 August 1990; Brig. Gen. Charles E. Yeager, USAF (Ret), interview by author, Lancaster, Calif., 22 September 1990; Johnnie G. Armstrong, AFFTC X-30 Program Manager, Office of Research Projects, 6510th Test Wing, to author, 9 August 1990 (Mr. Armstrong was one of the Flight Test Center's key project engineers on the X-15 program).

163. Though Ezra Kotcher never received the public acclaim he so justly deserved--ironically John Stack shared the Collier Trophy with Chuck Yeager and Larry Bell, he never let it bother him. It must, however, have given him some satisfaction when, in 1960, Emerson Conlon, the Assistant Director of Research at NASA headquarters, wrote to him and recalled "the first research airplanes, when you had the X-1 and I had the D-558." "At the time," he recalled, "I was sure that our more conservative approach would prove desirable but experience proved that your approach was the right one. I have a feeling that your 'batting average' was far higher than most aeronautical engineers." Conlon to Kotcher, 23 December 1960.

164. As quoted in *Supersonic Symposium*, 174.

165.As quoted in Everest and Guenther, *The Fastest Man Alive*, 70-71.

Appendix I

Transcript of Air and Ground Crew Communications: XS-1, 14 October 1947

Cardenas: Muroc Tower, Air Force Eight Zero Zero taxi instructions.

Tower: B-twenty-nine Eight Zero Zero cleared Runway Six. Winds out of East, seven miles an hour.

Cardenas: We cleared to roll?

Tower: Roger, cleared to line up and roll.

Swindell (B-29 flight engineer): She's all yours, Major.

Cardenas: All right, Swindell?

Swindell: Roger, she is all yours.

Cardenas: Rolling.

B-29 left side scanner: Left gear full up, left flap full up. One and two [engines] look clean on the take-off, sir.

B-29 right side scanner: Right gear full up, right flap full up. Three and four look good on the take-off.

Swindell: Roger.

Cardenas: B-twenty-nine Eight Zero Zero to Muroc Tower. How do you read me, over?

Tower: Loud and clear.

Swindell: Scanners from engineer, five thousand feet.

Yeager: Check list completed, everything okay.

Ridley: Roger.

Cardenas: B-twenty-nine Eight Zero Zero. Air Force Two Zero One. Hoover, are you guys on the way up?

Hoover: Yeah, boy.

Cardenas: Okay, we're just closing fifteen thousand feet. About twenty south of the lake Rogers Dry Lake). Making a right turn now and heading south.

Hoover: Roger.

Frost: You over El Mirage [Dry Lake], Cardenas?

Cardenas: Coming to the southern end of the lake at sixteen thousand feet.

Frost: I'll be with you soon.

Hoover: Air Force Two Zero One, where are you B-twenty nine?

Cardenas: I am coming around--

Hoover: Okay, I see you now, buddy; coming up to you.

Cardenas: Eight Zero Zero, five-minute warning.

Yeager: Okay, Cardenas, loading first stage now. Ridley? Clear to disconnect nitrogen hose and pilot's breathing oxygen?

Ridley: Roger.

Cardenas: Four minutes.

Yeager: Roger, Cardenas; pressurizing fuel tank.

Ridley: Nitrogen hose disconnected. Pilot's breathing oxygen disconnected.

Yeager: Roger, Jack.

NACA Muroc: NACA radar to Air Force Eight Zero Zero, how do you read?

Cardenas: Loud and clear. Three minutes.

Yeager: Pressurizing lox tank. All pressurized.

Frost: Yeager, this is Frost. I'm in position now to check your jettison.

Yeager: Roger. Fuel jettison is on.

Frost: Fuel jettison okay.

Yeager: Switch off.

Frost: Shut-off okay.

Cardenas: Two minutes.

Yeager: Lox jettison switch on. Switch off.

Frost: Lox jettison and shut-off are okay.

NACA Muroc: Was that two minutes, B-twenty-nine?

Cardenas: Roger, that was two minutes.

Tower: Muroc Air Force Base to all aircraft. All aircraft stay clear of Muroc Dry Lake area. Test in progress. All aircraft on ground return to parking positions. Repeat: all aircraft stay clear.

Cardenas: B-twenty-nine Eight Zero Zero to NACA radar, Muroc Tower, chase aircraft: one minute warning.

NACA Muroc: NACA radar to Air Force B-twenty-nine Eight Zero Zero. You are clear to drop.

Cardenas: Roger.

Tower: Muroc Tower to Air Force Eight Zero Zero, clear to drop.

Cardenas: Roger, Muroc.

Ridley: Yeager, this is Ridley. You all set?

Yeager: Hell, yes, let's get it over with.

Ridley: Remember those stabilizer settings.

Yeager: Roger.

Cardenas: Eight Zero Zero. Here is your countdown: 10--9--8--7--6--5--3--2--1--Drop [note: Cardenas omitted "4" in the drop count; launch occurred at 10:26 A.M. as the B-29 was flying at 20,000 feet and an indicated airspeed of 250 mph].

Yeager: Firing Four [rocket chamber #4]. . . Four fired okay . . . will fire Two . . . Two on . . . will cut off Four . . . Four off . . . will fire Three . . . Three burning now . . . will shut off Two and fire One . . . One on . . . will fire Two again . . . Two on . . . will fire Four.

Ridley: How much of a drop [in chamber pressure]?

Yeager: About forty psi . . . got a rich mixture . . . chamber pressures down . . . now going up again . . . pressures all normal . . . will fire Three again . . . Three on . . . acceleration good . . . have had mild buffet . . . usual instability. Say, Ridley, make a note here. Elevator effectiveness regained [as he passed an indicated Mach number of 0.96].

Ridley: Roger. Noted.

Yeager: Ridley! Make another note. There's something wrong with this Machmeter. It's gone screwy!

Ridley: If it is, we'll fix it. Personally, I think you're seeing things.

Yeager: I guess I am, Jack . . . will shut down again . . . am shutting off . . . shut off . . . still going upstairs like a bat . . . have jettisoned fuel and lox . . . about thirty percent of each remaining . . . still going up . . . have shut off now.

Source: X-1 file, National Air & Space Museum.

Date: 28 October 1947

Pilot: Capt. Charles E. Yeager

[redacted]

Time: 14 Minutes

9th Powered Flight

1. After normal pilot entry and the subsequent climb, the XS-1 was dropped from the B-29 at 20,000' and at 250 MPH IAS. This was slower than desired.

2. Immediately after drop, all four cylinders were turned on in rapid sequence, their operation stabilizing at the chamber and line pressures reported in the last flight. The ensuing climb was made at .85-.88 Mach$_i$, and, as usual, it was necessary to change the stabilizer setting to 2 degrees nose down from its pre-drop setting of 1 degree nose down. Two cylinders were turned off between 35,000' and 40,000', but speed had increased to .92 Mach$_i$ as the airplane was leveled off at 42,000'. Incidentally, during the slight push-over at this altitude, the lox line pressure dropped perhaps 40 psi and the resultant rich mixture caused the chamber pressures to decrease slightly. The effect was only momentary, occurring at .6 G's, and all pressures returned to normal at 1 G.

3. In anticipation of the decrease in elevator effectiveness at speeds above .93 Mach$_i$, longitudinal control by means of the stabilizer was tried during the climb at .83, .88, and .92 Mach$_i$. The stabilizer was moved in increments of 1/4 - 1/3 degree and proved to be very effective; also, no change in effectiveness was noticed at the different speeds.

4. At 42,000' in approximately level flight, a third cylinder was turned on. Acceleration was rapid and speed increased to .98 Mach$_i$. The needle of the machmeter fluctuated at this reading momentarily, then passed off the scale. Assuming that the off-scale reading remained linear, it is estimated that 1.05 Mach$_i$ was attained at this time. Approximately 30% of fuel and lox remained when this speed was reached and the motor was turned off.

5. While the usual light buffet and instability characteristics were encountered in the .88-90 Mach$_i$ range and elevator effectiveness was very greatly decreased at .94 Mach$_i$, stability about all three axes was good as speed increased and elevator effectiveness was regained above .97 Mach$_i$. As speed decreased after turning off the motor, the various phenomena occurred in reverse sequence at the usual speeds, and in addition, a slight longitudinal porpoising was noticed from 198-96 Mach$_i$ which controllable by the elevators alone. Incidentally, the stabilizer setting was not changed from its 2 degrees nose down position after trial at .92 Mach$_i$.

6. After jettisoning the remaining fuel and lox a 1 G stall was performed at 45,000'. The flight was concluded by the subsequent glide and a normal landing on the lake bed.

CLASSIFICATION CHANGED TO Uncl
By Authority of WADC TWX WCIPP-10-25 dtd 29 Oct 58, By L Hamill 7 Nov 58

Charles E. Yeager
CHARLES E. YEAGER
Capt., Air Corps

[redacted]

EXTRA

RACE RESULTS

Los Angeles Times

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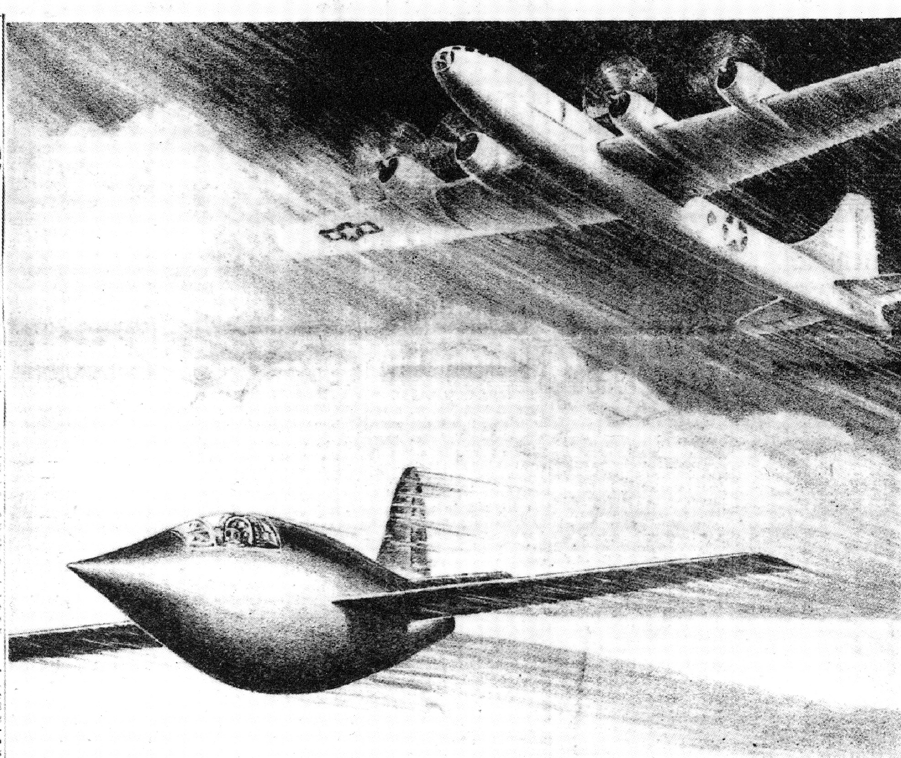
Pictorial

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

U.S. MYSTERY PLANE TOPS SPEED OF SOUND



CRACKS SOUND WALL—The mystery American rocket plane XS-1 which pierced the wall of sound for the first time is depicted above by Times Staff Artist Harlan Kirby as it might have looked when dropped from the belly of a Superfortress over desert for its historic flight.

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

BY MARVIN MILES

Three Americans have pierced the wall of sound!

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

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

Three Win International Race

In cracking through the invisible ocean of compressibility the three men won an international race for supersonic honors and on at least one flight the world's aircraft altitude record—56,156 feet—was toppled by the bright orange Bell speedster.

None of the three pilots experienced any ill effects from hurtling through the barrier nor was the XS-1 damaged in any way from the gargantuan pounding, it was learned.

The Air Force first announced the experimental ship last year with the words: "The plane has been designed to reach about 1700 m.p.h. at 80,000 feet altitude."

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

Speed Past Barrier Almost Unlimited

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

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

Best estimate, however, with the present rocket power available in the XS-1, is 900 to 1000 m.p.h. The original Air Force figure of 1700 m.p.h. was based on a super power plant, which probably is not yet available.

While the Air Force originally announced its supersonic exploration plans for the XS-1 and courted publicity for the experiments, it recently did an about-face and asked all publications to refrain from printing any results of the almost daily flights at Muroc . . . "unless the story gets out of hand."

Knowledge of Event Leaks Out

It was apparent yesterday that the sonic breakthrough had become public knowledge and The Times, pledged to withhold its information, was thus absolved from keeping the secret any longer.

Long one of the greatest mental and physical challenges to the world of flight, the sonic wall was approached with all the caution of the atomic bomb experiments.

The XS-1, first plane designed to break through the barrier, estimated to range roughly from 600 to 900 m.p.h., was inched into the mystery over a long period of months.

Goodlin Made First 30 Flights

Chalmers (Slick) Goodlin, Bell Aircraft test pilot, flew the tiny ship on its first 30 flights, and took it to "Mach number" of .85 (Mach number is actual speed relative to the velocity of sound at any altitude) at 12,000 feet. These tests proved out the XS-1 for the more recent flights.

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

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

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

Turn to Page 2, Column 6

Suicide Pact Fatal to Man; Wife May Die

Pair Take Sleeping Pills and Write Loving Note to Son

With an expression of love for their son, an elderly couple yesterday sought death in their Hollywood apartment.

When police arrived, Wiley Mills, 65, a salesman of 1753½ N. Berendo St., was dead and his wife, Zella, also 65, was unconscious and in a critical condition as a result of swallowing sleeping tablets.

Will Left

On a small table near a couch on which the woman was lying, police found partly filled containers of the tablets, a will and notes indicating despondency. One, addressed to their son, Francis, of Berkeley, read:

"We are sorry to have to do this now. But it is the only thing left. Dad and I talked it out and there would be no use of my trying to go on alone. We love you very much. Mother."

Cambern Cottrell, son-in-law of the couple, of 1025 S. Westmoreland Ave., discovered the tragedy. He had been unable to reach the couple by telephone and called at the house.

Grieved for Daughter

Police Officers L. T. Napier and J. H. Stein investigated. They reported that the couple were despondent over financial matters and continued to grieve over the death of their daughter, Marjorie Mills Cottrell, who died of pneumonia four years ago.

Mrs. Mills was taken to the General Hospital.

The Coroner's office said that an autopsy would be performed today to determine the cause of Mills' death.

Man Struck by Auto Dies

Frank M. Andre, 57, of Buena Park, died at the Rancho Los Amigos Hospital yesterday of injuries received when he was struck by an automobile at Del Amo St. and Pioneer Blvd., Artesia.

California Highway Patrol officers reported that the machine was driven by Curtis L. Harmon, 21, 326 Houghton Park Village, Long Beach, who was not held.

The death raised the total of traffic fatalities since Jan. 1 to 832.

FEATURES INDEX

Red Belt States Line Up to Dominate Europe

Countries under Russian direction acting to forge economic and political links in Danube Basin. See Page 2, Part I.

On Other Pages

Eight Killed by Gunfire and Knife in Palestine

JERUSALEM, Dec. 21. (AP)—Eight persons died in gun and knife attacks today as communal fighting flared along the roads of Palestine and in the Upper Galilee area near the borders of Syria and Lebanon.

Haganah, the Jewish militia, called on Arabs to help bring order back to the Holy Land, and also minimized Arab claims that thousands of volunteers are training for guerrilla warfare against Zionists. A state of "complete anarchy" exists in Arab areas of the Holy Land, Haganah contended.

Total Now 298

Shooting continued for the third straight day in Upper Galilee where Arabs and Jews fought in the town of Safad. One Arab was killed and three Arabs and two Jews were wounded there. The town, which has a mixed Arab-Jewish population, was placed under a curfew until further notice. An official report said "prepared gun positions" were found in both the Arab and Jewish sectors.

Since the United Nations voted for Palestine partition on Nov. 29 a total of 298 persons have been killed in Palestine and 419 throughout the Middle East, an Associated Press count showed.

Fighting today occurred in various trouble spots throughout the length of Palestine. In the south two Jews were stabbed to death near the village of Yazur. An official account said an oil truck in which they were riding was stopped "by a number of men alleged to be Arabs and set on fire."

Arab Bus Riddled

Between 15 and 20 men wearing the uniforms of temporary constables of the Palestine police force riddled an Arab bus with gunfire on the Ramallah-Er Ramle road northwest of Jerusalem. The three occupants of the bus were killed.

Four youths wounded a British lieutenant and a sergeant major on King George St. in the center of Jerusalem. The attackers escaped. The Britons were members of the Lifeguards, an English Royal Household calvary regiment.

Cold Wave Hits Italy

ROME, Dec. 21. (AP)—Italy is having the coldest weather of the winter. Turin thermometers touched 1 above zero Fahrenheit. It was 28 in Rome.

INFANT ABANDONED ON PORCH WILL BE 'MISS CHRISTMAS'

MISSOULA (Mont.) Dec. 21. (AP)—Someone presented the David Ogles with an unusual Christmas present here last night.

Ogle, who has four grown children, answered the doorbell to find a month-old baby girl wrapped in blankets, two paper sacks containing baby clothes, some canned baby food and a book of instructions on infant care on his porch.

Police were called and the infant was brought to St. Patrick's Hospital, where physicians said the baby is in good health.

Catholic Sisters at the hospital already have a name for the latest addition to the nursery—Yvonne Noel Christmas.

New White House Dog Received by President

WASHINGTON, Dec. 21. (AP)—Feller, a five-week-old silver buff cocker spaniel, arrived here today to become the nation's "first dog." Feller was given to President Truman by Mrs. Peter Joseph Marsden of Galena, Ill., formerly a nurse for the President's mother, the late Mrs. Martha E. Truman.

U.S. Strives to Prevent Western Union Strike

WASHINGTON, Dec. 21. (AP) Government conciliators today pressed last-minute efforts to prevent a nation-wide strike of 50,000 Western Union employees, which union leaders said might come at any time before the announced Tuesday deadline.

Wage negotiations have been in progress since Sept. 16, but all attempts to iron out the differences between the company and three A.F.L. unions have met with failure thus far.

Ask 15-Cent Boost

The unions are asking a 15-cent-an-hour wage boost, claiming that average rate is now 96 cents an hour. The company calculates the present hourly wage at $1.234 and takes the position that the union demands far exceed ability to pay and are designed to force Western Union into government ownership.

Cyrus S. Ching, head of the Federal Mediation and Conciliation Service, called representatives of both sides back into conference after no progress was achieved at the latest session which recessed shortly before midnight last night.

Meanwhile across the country, the union locals called strategy mass meetings to map plans for the threatened walkout.

Adolph Brungs, head of the western division of the A.F.L. Commercial Telegraphers Union, told reporters that "the company has offered us nothing." His union, along with the A.F.L. Telegraph Workers Union and the Telegraph Employees Union, advanced the strike deadline from the original union deadline of Tuesday but refused to disclose it in advance.

ANNOUNCEMENT