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Introduction

In December 1903, man first experienced the thrill of powered flight--the excursions were of small duration, using today's standards of measurement (Figure 1) but without question these were flights that marked a major milestone in the history of mankind. This was truly the birth of a new machine which would mature and become both a military weapon and a vehicle for public conveyance--it was the first step towards man's exploration of space. Through perseverance, ingenuity, dedication, and with superlative craftsmanship, the Wright Brothers had mastered control of powered flight.

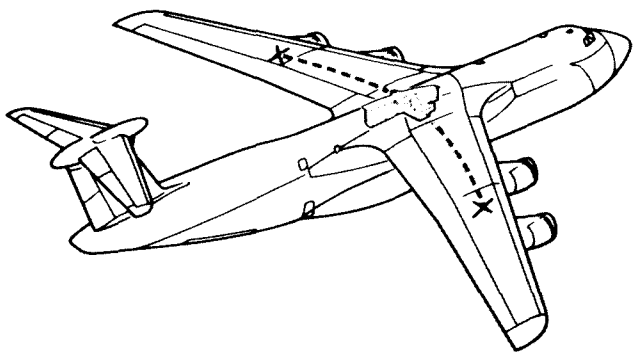


Fig. 1. The Wright Flyer and the C-5A

As we look back and study their design philosophy and techniques of development, we realize that almost all significant advancements in aviation have followed in their footsteps. In a lecture in Chicago in September 1901, Wilbur Wright made the observation that there were two ways to learn to ride a horse. One way is to sit on top of the horse, experience the pitching and plunging of the animal, and learn how to get control. The other way is to sit on the fence post and watch the animal and in one's leisure reflect how one might someday best master the animal. Wilbur observed that the latter was probably the safest, but for him the first was the only productive way.

And so it was, in the years 1900 to 1902, the Wright Brothers learned by flying their kites and gliders, and by trial and error, solving the problems of control so they could maneuver and land where they wanted to. They learned by running experiments in their primitive wind tunnel, and by conducting methodical ground tests in their bicycle shop in Dayton. They masterfully perfected both an engine and a propeller. Then in 1903, they were ready. And for the first time, man's oldest dream came true--man had learned to fly like a bird--aviation was a reality.

Years later other aviators like Charles Lindburgh and Wiley Post and many, many others, some not so famous, helped to develop the airplane through similar dedication and participation, with an eager willingness to take the next step even though this direction lead into unknown areas. The unbelievable progress made in the 75 years since the first epic flight is clear testimony to the success that was achieved in this way.

New Fighter Aircraft Needs

A major step into the aeronautical unknown began in the late 1930s, precipitated by the Spanish Civil War which revealed to the world new potential for the armed airplane. The threat of large-scale aerial bombing and the need for fast, high-flying fighter aircraft were emerging. And further to the east the belligerent military threat of Nazi Germany was looming greater and greater. The quest for newer and better performance aircraft was becoming more justified and soon aircraft were to encounter new flight phenomenon, and airplane designers would be confronted with new challenges related to performance prediction, handling qualities, and propulsion systems.

In the United States these military affairs in Spain were being observed very carefully, as were new aircraft developments taking place in France, England, and Germany. The need for a new U.S. high-altitude bomber crystalized--leading to the Flying Fortress development. The U.S. Army Air Corps began to see the urgency for new, faster, high-flying fighters (Figure 2). Requirements and plans began to appear from the Wright Development Center, guided in large measure by Lt. Benjamin Kelsey. He was among the few who saw the pressing need for new aircraft with better rates of climb and ability to pursue high-flying bombers equipped with heavy caliber shell firing armament.

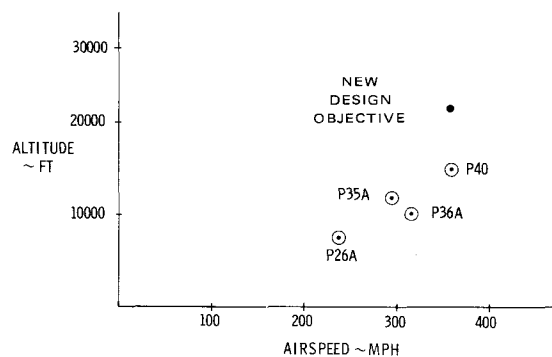


Fig. 2. Air Corps Fighter Performance - 1937

The need led to the development first of the Bell XM-1 Airacuda, a twin-engine design powered by two Allison engines and manned with a pilot and aft-facing gunner. Unfortunately performance goals were not met and a new requirement and proposal request was soon in the making. Lt. Kelsey was convinced that this next fighter design should be single-place to minimize size and weight and to best take advantage of available engines and power ratings.

In February of 1937, The Army Air Corps issued a Circular Proposal for Project X608. The request outlined the Air Corps' need for a fighter that would have a level flight speed of 360 mph or more. As a pursuit aircraft, it must have rapid climb capability--sea level to 20,000 feet within 6 minutes. Critical altitude must be at least 20,000 feet. Rapid-fire cannon armament was stipulated.

To meet high-altitude performance requirements, existing reciprocating engine designs would have to be modified. With increasing altitude, air density reduces and a conventional reciprocating engine experiences unacceptable decreases in horsepower. To restore the power, air entering the engine must be compressed by means of a supercharger.

Fortunately for the Air Corps (and their desires expressed in Project X608) work on these mechanical and exhaust-driven superchargers had been in the process of development since the early 1930s. The most powerful supercharged engine available in the 1937 time period was the Allison V-1710 liquid-cooled, 12-cylinder engine (Figure 3). This engine had been under development since 1931 and was first flown as a 750-horsepower engine. It used Prestone as a coolant, a new material developed by the Air Corps Materiel Division. By 1937, this engine was equipped with General Electrical turbo superchargers and had a rating of 1150 horsepower.

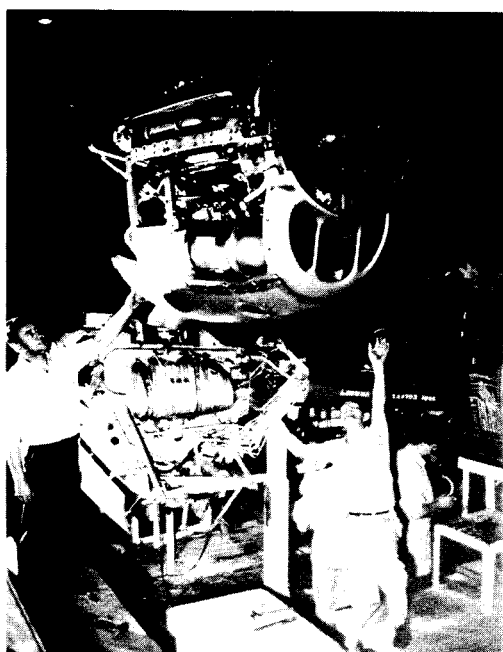


Fig. 3. The Liquid-Cooled Allison V-1710 12-Cylinder Engine

Operation of aircraft and supercharged engines at high altitude was also being pioneered during the 1930 time period. On May 7, 1937, the Lockheed XC-35 made its first flight as part of an Air Corps program to explore the upper atmosphere. The XC-35 was a modified version of the Lockheed Electra twin-engine transport (Figure 4). Two 550-horsepower Wasp engines with exhaust-driven superchargers powered this airplane, dubbed "The Boiler." To provide for the cabin pressurization, a new fuselage of circular cross section had been designed. New design concepts regarding the windshield, structure seals around the doors, and means of fabrication that would minimize leakage had been incorporated.

The XC-35 was the first successful supercharged cabin transport. It provided much useful information regarding problems of high-altitude flight, including study of performance of hydraulic oil at low temperature, design and operation of automatic pressurization controls, and operating characteristics of supercharged engines.

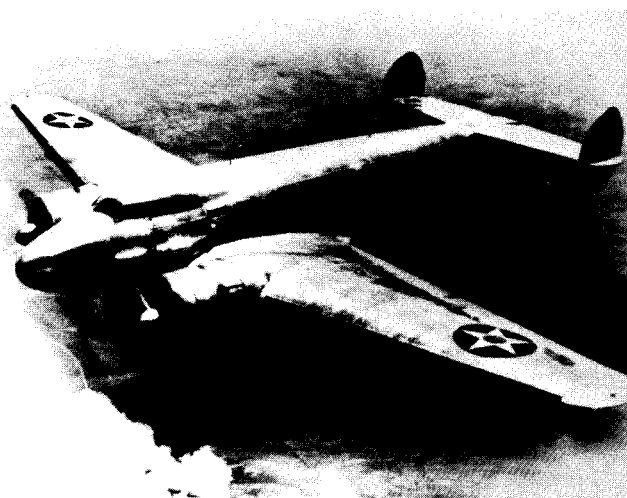


Fig. 4. The Lockheed XC-35 High Altitude Research Airplane

Design of the Model 22

The experience and knowledge which Lockheed design engineers had gained regarding high-altitude aircraft and supercharged engine operation helped provide first-hand data that could be used in evaluating designs that met the requirements of Project X608. The preliminary design experience of the Lockheed-proposed XFM-2 in response to an Air Corps fighter proposal request in 1935 (awarded to Bell and the Airacuda designers) also provided engineering expertise that helped stimulate interest in this new fighter proposal request.

Studies of the new Air Corps fighter aircraft requirements quickly led the Lockheed designers to a decision that the best airplane would be a single-place, twin-engine airplane using two Allison V-1710 engines. They were convinced that the extra power of a multiengine design would provide greater aircraft capability and give added assurance that the airplane would meet performance goals.

A number of two-engine configurations were conceived by the Lockheed design team (Figure 5). The most conventional arrangement placed each of the engines in wing-mounted nacelles, concept 1. Layouts indicated that the internal placement of the many

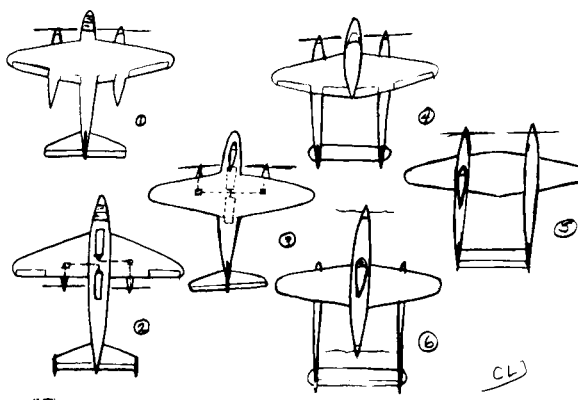


Fig. 5. Model 22 Design Concepts

elements of the propulsion, gear, and armament systems could not be arranged in a manner that used the airplane internal volume to best advantage.

Placement of the two engines in the fuselage along with the pilot led to three other configurations, concepts 2, 3 and 6. Two of these designs used gear boxes and drive shafts so that the propellers were mounted on the wing, either in a tractor or pusher propeller arrangement. Complexities of gearing and shafting and anticipated problems of engine cooling eliminated these ideas. Concept 6 provided for a tractor propeller in the forward fuselage combined with a pusher propeller at the rear of the fuselage. Complementing this arrangement were two tail booms spanned at the rear by the horizontal tail. Problems with rear-engine cooling and the propeller strike hazards related to pilot escape gave reason to discard this design.

The twin-boom arrangement had attractive advantages, so two other alternatives, concepts 4 and 5, were laid out for study. The design which placed the pilot in a fuselage pod along the airplane centerline was found to be the more preferred of these two designs (Figure 6).

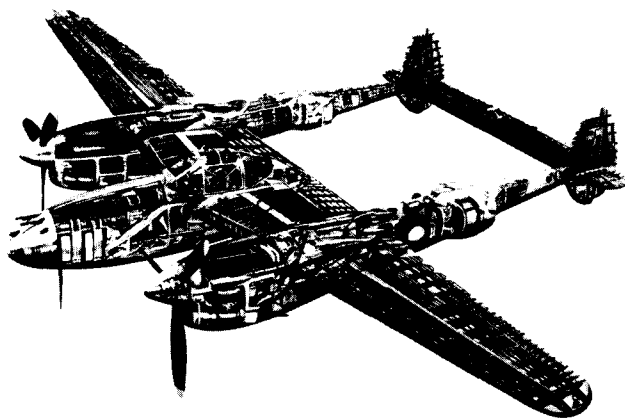


Fig. 6. Cutaway View of the P-38

Concept 4 became the final, most logical choice mainly because the boom arrangement nicely accommodated all the elements of each power plant, allowed room for gear stowage, and at the same time provided proper aircraft balance. Behind the counter-rotating Curtiss 3-bladed propellers and V-1710 Allison engine there was room for the inlet scoops and General Electric turbo superchargers and cooling scoops. A main landing gear wheel fit behind the superchargers, as did the Prestone radiators. In addition, there was space for air induction and cooling ducts, as well as room for other aircraft systems components.

In this arrangement, the propeller slip stream would provide ram air for cooling, and increase air flow over the two rudders so as to enhance directional control. The hot Prestone coolant was removed from the cockpit area. All the internal fuel was contained within the wing. Maximum efficiency in the use of airplane volume was achieved and favorable airplane fineness ratio and low frontal area offered minimized parasite drag.

The armament and pilot as well as the nose landing gear were housed in a small fuselage pod mounted on the wing centerline.

Armament was to consist of a shell-firing cannon and four 50-caliber machine guns. All the fire power was concentrated directly forward of the pilot and close to the airplane centerline to increase gun effectiveness and concentrate the firepower (Figure 7). Visibility was enhanced by using a glass enclosure with a hatch-type access. The cockpit layout was spacious and a control wheel rather than a stick was proposed as the control for pitch and roll.

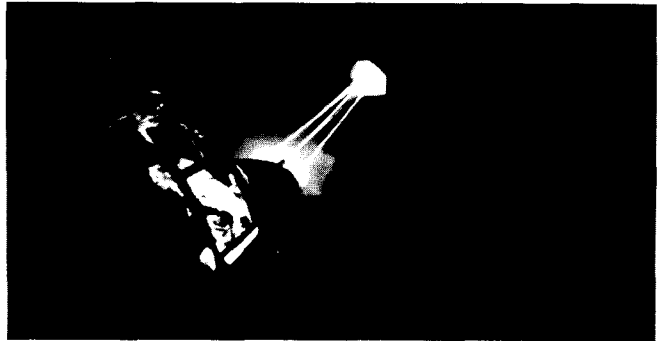


Fig. 7. P-38 Firepower

A unique feature of the new airplane proposal was the tricycle landing gear. This concept was not new to the Air Corps, having been demonstrated earlier by several modified aircraft. Among these was a C-40 military version of the Lockheed Model 12, which featured a fixed tricycle gear to demonstrate the features of the new arrangement. Lt. Kelsey was very favorably influenced, and had stipulated a tricycle gear as a desired feature for the Project X608 fighter design.

To study the problems of the tricycle gear arrangement, Lockheed fabricated a towable test rig that could examine shimmy, side loads, brakes, and steering characteristics (Figure 8). The device was towed at speeds up to a mile a minute, over various runway surfaces, with operations directed by a technician who rode on the rig. One can't help but note that here was a typical example of aircraft design engineers, not sitting on the fence post, but riding their mount made in their "bicycle shop," and solving their problems by doing, following the steps and philosophy of the Wright Brothers.



Fig. 8. Test Rig for the P-38 Tricycle Landing Gear

The Lockheed proposal for their Model 22 twin-boom fighter was submitted to the Air Corps in April 1937. "It was designed to operate at a critical altitude of 20,000 feet and at speeds up to 400 mph." The proposal notes that the "airplane is to be not only flush riveted, but painted and polished as well." A very lengthy discussion of the relationship between skin friction drag and aircraft surface condition was included in the proposal. Reference

was made and data used from an article in the April 1936 issue of *Aircraft Engineering*, titled "Skin Drag of High Speed Aircraft," by S. Hoerner. Flight experience with drag measurements made on the model Electra was also mentioned. The author of this proposal document was Clarence "Kelly" Johnson.

In June 1937, the Air Corps announced two winners, Bell and Lockheed. Bell was to build and test a single-engine, single-seater prototype to be designated the XP-39 Aircobra. Lockheed was to build and test the XP-38.

The XP-38 was to have the following characteristics:

Take-off Gross Weight	10,500 lb
Wing Area	327.5 sq ft
Wing Aspect Ratio	8.25
Wing Loading	32 lb/sq ft
Maximum Speed	417 mph @ 20,000 ft
Service Ceiling	39,100 ft
Range	1386 miles with 400 gal
Landing Speed	72.2 mph

For comparison purposes, the Wright Brothers airplane (first flight) in 1903 was as follows:

Take-off Gross Weight	~750 lb
Wing Area	510 sq ft
Wing Aspect Ratio	6.3
Wing Loading	1.5 lb/sq ft
Maximum Speed	27 mph
Service Ceiling	~20 ft
Range	~120 ft
Landing Speed	27 mph

Testing The P-38

In July 1937, behind locked doors in a small room in Burbank, California, the XP-38 began to take shape. Many design questions needed resolution, and the next 18 months required a very strenuous design and fabrication activity, with engineers, technicians, and mechanics all working side by side, inventing, changing, and assembling the design. Tunnel tests had to confirm the wing design and develop the needed high-lift system. A slotted Fowler flap was perfected so that the basic high-wing-loading concept desired for mission performance could be retained and still permit low landing speeds. Production techniques had to be revised and improved to achieve the goal defined for the proposal that flush butt joints and flush rivet construction be used for the outside surfaces of the airplane. New materials had to be found to cope with the high exhaust temperature environment encountered by the ducting to the turbo superchargers.

The XP-38 was completed in 18 months (Figure 9) and on New Year's Day, 1938, the disassembled airplane was hauled in secrecy by truck from Burbank to March Field, escorted by Army soldiers and 14 Lockheed Plant Protection guards. Lt. Kelsey assumed the



Fig. 9. The XP-38, Ready for Flight

duties of project test pilot (Figure 10) since Lockheed had no experienced fighter pilots. This took little persuasion, since Kelsey saw in the XP-38 the fruition of his desires for an advanced fighter airplane.



Fig. 10. Lt. Benjamin Kelsey, Proponent for High Altitude 400-mph Fighter Aircraft

The XP-38 had a short life span, and the 45 days of its existence are succinctly characterized by author Warren Bodie, in one of his many interesting articles concerning the P-38 airplane written for Sentry Publications' magazines, *Wings* and *Air Power*:

"Halley's Comet and the Lockheed XP-38 had much in common, even if there is no chance of the latter's return. They both made a tremendous impression when appearing in the skies, were around for a very short time period, and disappeared from the scene without too much fanfare."

During taxi tests, Kelsey experienced difficulty in stopping because of brake problems. A bent brake pedal attested to his intense desire to bring the XP-38 to a stop as he was heading for a group of runway construction workers and their temporary outhouse. Fixes of an interim nature required two weeks to accomplish, but finally an acceptable brake system made the XP-38 ready for flight.

First flight of the XP-38, which took place on January 27, disclosed a second problem that helped stage what was ahead. Shortly after takeoff, three of the four flap actuator rods broke, leaving the flap surfaces in a fully extended and floating condition. Kelsey with an unfamiliar buffeting airplane considered bailing out, but then convinced himself that he could maintain sufficient control for a landing. Visual verification was made by the chase plane, a Ford trimotor! Kelsey rode his mount and brought the XP-38 to the runway successfully.

After replacement of the flap links with stronger parts, the next series of flights were relatively problem-free, and the high-speed performance capabilities were becoming apparent. The Air Corps decided to ferry the aircraft east to Wright Field in Dayton. If all went well, Kelsey would then continue on to Mitchell Field on Long Island, and coincidentally established a new transcontinental speed record.

There was a probable private interest on Kelsey's part to take part in this event to beat Howard Hughes' record established in January 1937, with his H-1 racer. Hughes had been trying since that time to get the Air Corps to buy his airplane, and here was Kelsey's chance to show off a new Air Corps design that would beat the H-1 record.

The XP-38 and Lt. Kelsey, with a total of 5 hours of flight time, took off on February 11, 1939. He landed at Amarillo, Texas, 3 hours and 10 minutes later. Flight time to Dayton was 2 hours and 45 minutes. All was going well and a new record was in sight. So the flight continued toward Mitchell Field.

Kelsey came into the Mitchell Field traffic pattern ahead of schedule, with a total flight time of 7 hours, 2 minutes; and a total lapsed time of 7 hours, 43 minutes. Hughes' H-1 time was 7 hours, 28 minutes nonstop. The Mitchell tower, not told by any Air Corps brass that a speed record attempt was in the making (not even an unofficial one), advised the XP-38 to "land number four" behind three Consolidated PB-2A's. Kelsey, remembering that he had a landing gear brake system patched with temporary fixes, and a flap system that had already failed once structurally, elected to take a long base leg run and come in low and slow behind the Consolidateds without any landing procedure protest or priority. Short of the field, the Allison engines lost power, and would not respond to any of the pilot's reactions--the XP-38 settled in short of the runway, and totalled out on its way through tree tops to a golf course, 2000 feet short of its destination. Kelsey was not seriously hurt. Probable cause was later diagnosed as carburetor ice.

Despite its short life span, the XP-38 made its mark, and convinced the Air Corps that they had a 400-mph fighter. Major General Arnold and Lt. Kelsey had what they needed to convince the Secretary of War that the U.S. now had a fighter that was the equal of the Messerschmitts and English planes--touted to be much better than ours. By April 27, 1939, a contract was signed ordering 13 YP-38 service test airplanes. These new designs reflected structural redesign for large-scale production, new landing gear brakes, updated engines, and other improvements.'

The first YP-38 flew in September 1940, and the following March, after intensive flight testing by both company and army pilots, the Air Corps took official delivery of its first 400-mph YP-38 airplane, 9 months before Pearl Harbor.

Several months later, in a bright spring sky over Selfridge Field, Michigan, an Air Corps major named Signa Gilkey decided to wring out his new shinny YP-38 up around 35,000 feet. He peeled off into a steep dive in the manner shown in Figure 11. As he headed down and the airspeed built up, the airplane began to shake, mildly at first and then more violently. Even worse, the airplane wanted to nose down further and increase the severity of the dive. The control column was shaking and the control forces had become heavy, and it was impossible to pull the column back to counteract the nose down tendency. The airplane was out of control!

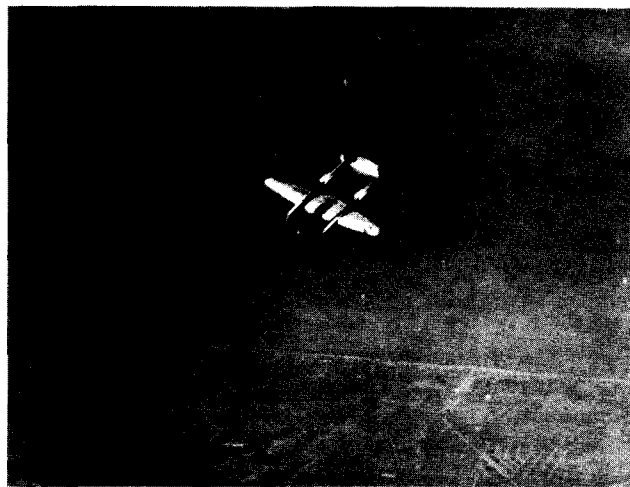


Fig. 11. The YP-38 Heading for Trouble

Major Gilkey was a brave and dedicated aviator--of the same mold as the Wright Brothers--he elected to stay with the airplane. At 20,000 feet, the major cranked in nose-up trim on the elevator tab. Passing through 12,000 feet a gradual recovery from the dive began. Buffeting slacked off and finally he leveled out at 7000 feet.

Back on the ground, Major Gilkey wrote a letter to Lockheed and asked why did an airplane that flew so beautifully at lower altitudes start behaving like this up high? Major Gilkey had become the first pilot to encounter a new, uncharted high-speed flight regime. He had gone to speeds where new aerodynamic phenomenon known as compressibility effects were created.

The letter and the description of the events that took place during the dive were read with keen interest by the Lockheed designers. They were not taken by surprise. Kelly Johnson had written a six-page discourse on the subject of compressibility and expressed concern that the Model 22 (P-38) with its high speed could readily get into compressibility in dives.

In configuring the Model 22 wing, Johnson and his aerodynamics engineers had considered airfoil shape and wing thickness, and evaluated as best they could critical Mach number. But there were also real needs for fuel volume, maximum lift, and rate of climb, all of which had to be factored along with wing loading and wing weight. They had designed the wing so that in level flight, there would be a reasonable speed margin before compressibility effects would become significant (Figure 12). Surfaces were metal-covered to cope with anticipated high load conditions.

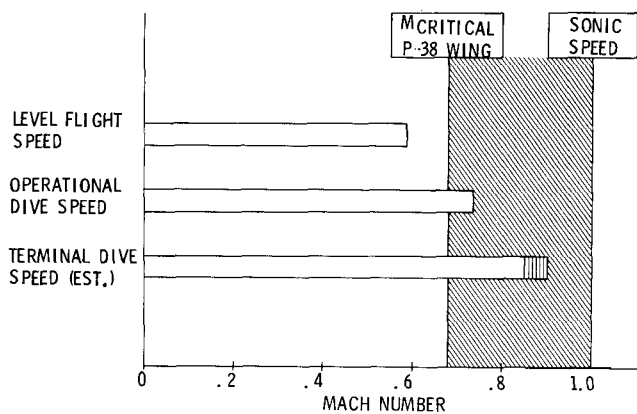


Fig. 12. P-38 Compressibility

But no one really knew what kinds of forces and consequences would be encountered as the airplane exceeded the estimated critical Mach number of 0.68 and penetrated into the compressibility flow regime. In the Model 22 proposal discourse on compressibility, two references on the subject were listed:

NACA Technical Note 543, "The Compressibility Burble," by Stack.

NACA Technical Report 492, "Tests of 16 Related Airfoils at High Speed," by Stack and von Doenhoff.

These reports discussed the subject of compressibility and presented two-dimensional aerodynamic data on airfoils up to Mach numbers of approximately 0.90. The data at that time was of greatest interest to propeller designers, because the propeller was the first element of the airplane to encounter near-sonic speeds. In fact, in the Model 22 proposal, a great effort was spent to establish the loss in propulsive efficiency that would occur on the Model 22 propellers at high speed. Lockheed went into great detail to establish new propeller tip-loss correction factors. Up until then, these losses, empirically derived, were expressed in terms of true speed, and had been developed from flight experience on low-altitude aircraft. The proposal carefully pointed out that since the speed of sound varied between sea level and 35,000 feet, these tip-loss correction factors were not applicable to high-altitude performance aircraft. New correction factors, correlated versus Mach number, were derived.

The variation of section drag coefficient with Mach number was discussed in detail. How these data could be used to guide the extrapolation of low-speed drag data obtained from low-speed complete model wind-tunnel tests was reviewed. Several empirical methods were described. Correspondence with von Karman was presented as part of the proposal. In his letter, von Karman endorsed the drag correction techniques proposed, and added a cautionary note that attention to contour shape be given to be sure that local sonic velocities were everywhere avoided.

In hind sight, it is interesting to note that no one was anticipating the nose-down pitching moment tendencies, which were hinted at by the section pitching moment data. And of course, there were no data to suggest that hinge moments would become unmanageable.

The Model 22 designers had used what experimental data were available, mostly two-dimensional airfoil tests, combined with a measure of theoretical understanding of the flow phenomenon. But the impact of shock-boundary layer interaction, and trailing-edge separation and its impact on trailing-edge control hinge moments, were all yet to be studied, tested, and understood.

In July of 1940, the Lockheed aerodynamics group had completed an analytic study, led by Phil Coleman (Figure 13) of the dive characteristics of the YP-38 based on some approximate extrapolations of available data to estimate high-speed drag characteristics (Figure 14). Time histories were computed to study the speed-altitude characteristics of the airplane, and establish dive trajectories initiated from various speed and altitude entry conditions. It was recommended that a flight-test dive program be conducted to more precisely establish the effect of compressibility and define airplane dive placard data. These tests were planned for the Summer of 1941.

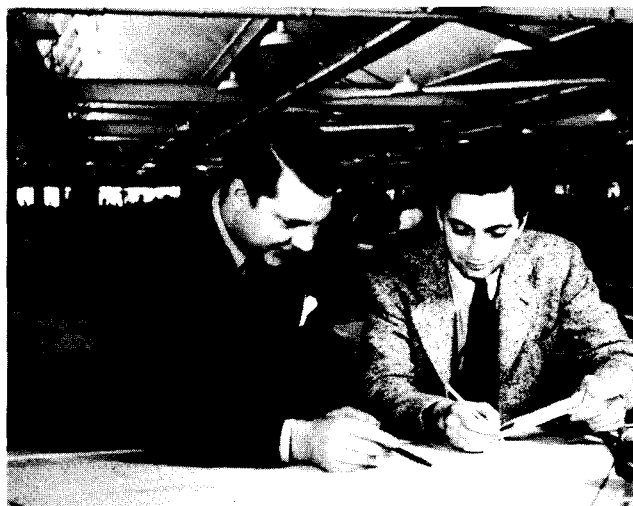


Fig. 13. Kelly Johnson and Phil Coleman, and Their Computer

Major Gilkey's premature encounter naturally generated considerable concern, especially with the Air Corps people involved with the new fighter programs. Much confusion existed, because the real causes and effects were not understood. It was first believed by many that the buffet problem was caused by tail flutter, a rather natural conclusion since this was a situation familiar to many, and a likely source of trouble. Control cable tensions, mass balance change, and stabilizer skin reinforcement were all explored experimentally in the flight program, but without any problem relief. Gear-door retention latches were redesigned to make sure doors remained closed during high-speed dives. No improvements were reported.

Movement of the horizontal tail vertically upward by bending the tail booms was flight tested (Figure 15). Results showed a slight loss in longitudinal stability, a 3-percent loss in speed, and buffet was aggravated.

Opposite propeller rotation was examined--no relief. Final choice of propeller rotation was based on longitudinal stability characteristics. It was found that inboard blades rotating up so that the propeller slipstream counteracted the tip vortices and lessened downwash at the tail made a favorable contribution to static stability.

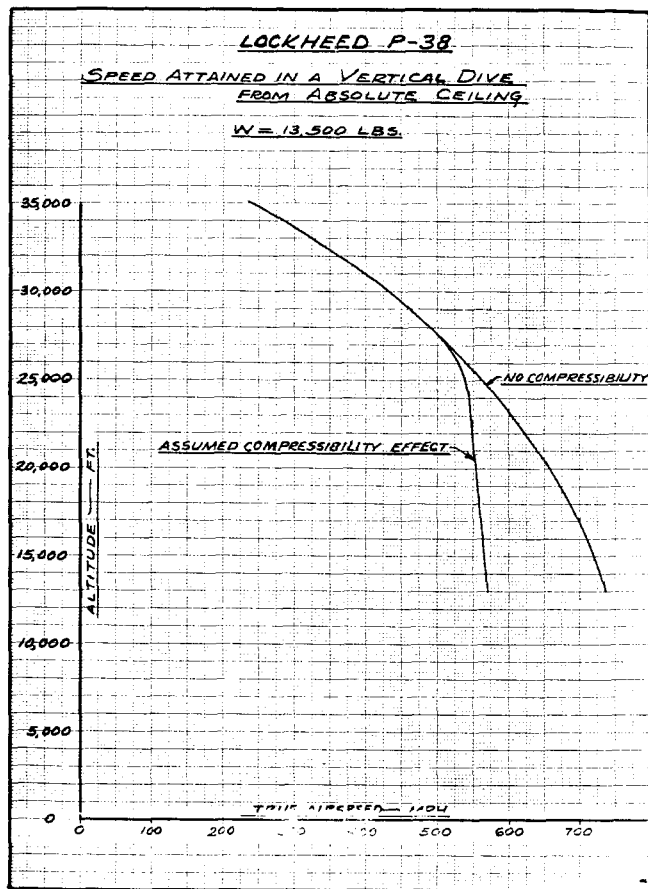


Fig. 14. Early Estimates of the YP-38 Dive Trajectories



Fig. 15. The YP-38 With Raised Horizontal Tail

Flow visualization studies in a low-speed wind tunnel and in flight suggested that an area for improvement might exist at the fuselage-wing junction. Extended low-speed tunnel testing of numerous fillets finally led to a modification which did postpone and lessen the intensity of early buffet. The fillet change was included in the dive program that started in June of 1941 (Figure 16). The fillet provided a marked improvement in tail buffeting, and the control-column oscillation was reduced from a maximum of 8 inches to approximately 1 inch. This fillet change, however, did nothing to improve the dive tendency or relieve the build-up in control forces.



Fig. 16. The Wing-Body Juncture Fillet Developed to Reduce Buffet

Tests in the wind tunnel examined the benefits and problems of adding a canard surface to the forebody of the cockpit cab (Figure 17). The hoped-for benefit was to provide additional nose-up trim in a dive condition. The destabilizing influence of the auxiliary trimmer quickly ruled out this solution to the tuck problem.



Fig. 17. Wind-Tunnel Model with Canard Trimmer

The flight-test dive program was carried out by three Lockheed test pilots: Milo Burcham, Ralph Virden, and Jimmy Mattern. In their earliest dives, they were able to duplicate the experiences reported by Major Gilkey. The program continued from June to November. Day by day, these three made their contributions to aviation through dedication and willingness to explore the unknown, and little by little the mysteries of compressibility began to unfold. Unfortunately in November, Ralph Virden, while testing an elevator spring tab that was designed to reduce high-dive-speed longitudinal stick forces, crashed in the outskirts of Glendale, and Virden gave his life while exploring the mysteries of compressible flow.

By the end of the dive program, Johnson and his engineers had established that the YP-38 was experiencing a low angle-of-attack wing stall that was creating the drag increase and nose-down tuck, that the severity was dependent upon a relationship between Mach number and load factor, and that stabilizer effectiveness was decreasing measurably. Dive trajectories were established and could be used to formulate operating restrictions for the flight manual (Figure 18). The longitudinal control linkage was changed to reduce recovery control forces.

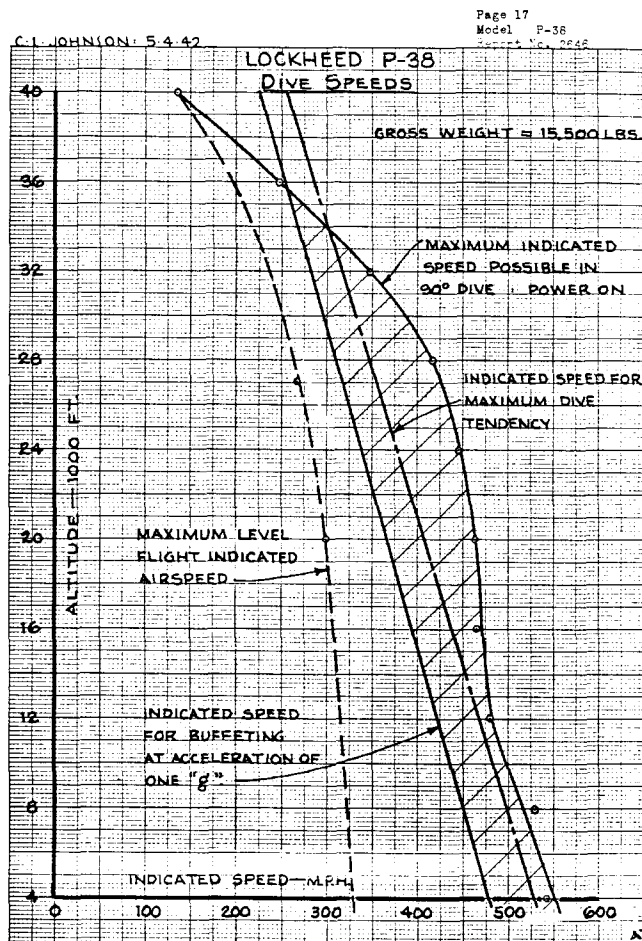


Fig. 18. Speed Capabilities Derived from the Dive Test Program

On the basis of a report presenting these findings, and with considerable persuasion from the Army, Lockheed was finally allowed to use the Ames NACA high-speed wind tunnel, and obtain high-speed data on a P-38 model. Model drag-rise characteristics were

measured for the first time (Figure 19). Comparison with the predicted drag-rise data estimated by Coleman in 1940 (Figure 20) reveals that the aerodynamic people had done a good job. Pressure data and flow visualization clearly revealed the shock-stall conditions and helped confirm the flight-test findings. This information provided a much clearer picture of what was going on, and was extremely helpful in finding the resolution to the dive recovery problem.

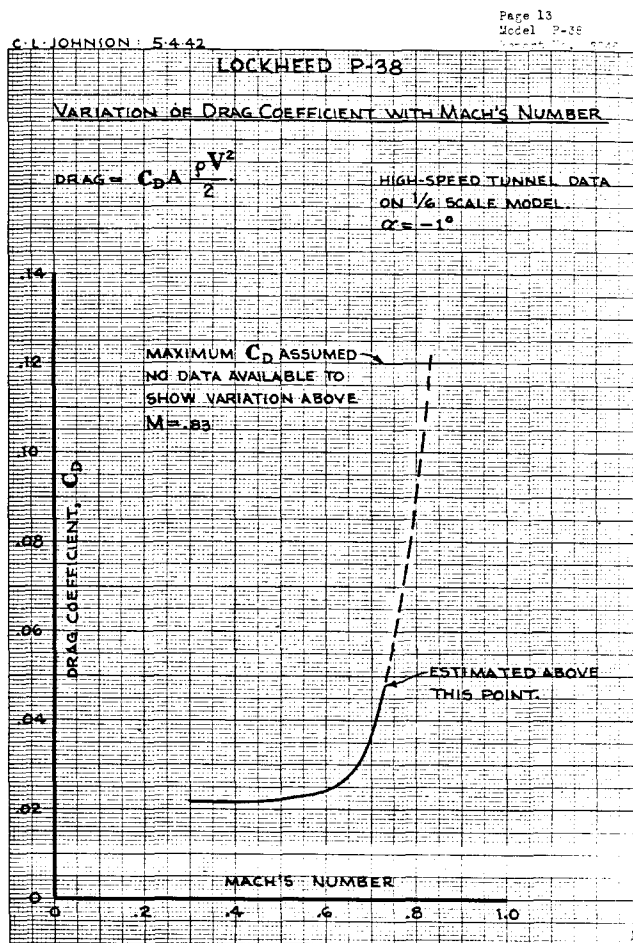


Fig. 19. High Speed Drag Variation Derived from Wind Tunnel Tests

There is an analogy here to the Wright Brothers and their confusion because their gliders didn't behave the way Lilienthal's tables said they should. They weren't gliding at the proper angles. The search for an answer led them to the development of a wind tunnel in their Dayton shop. After a series of wing tests, the Wright Brothers began to understand the significance of camber, leading-edge radius, wing stall, and center-of-pressure travel, and they used these data to improve their wing designs and increase glide ratios.

Further P-38 wind-tunnel testing finally resolved the means for dive recovery. A dive flap was perfected, mounted on the lower surface of the main beam of the wing, (Figure 21). When deployed, it generated a positive pressure field that created a lift and nose-up moment at high Mach numbers, and assisted in dive recovery. The device was installed on production P-38 aircraft in 1944 (Figure 22). It did not brake the descent speed - its

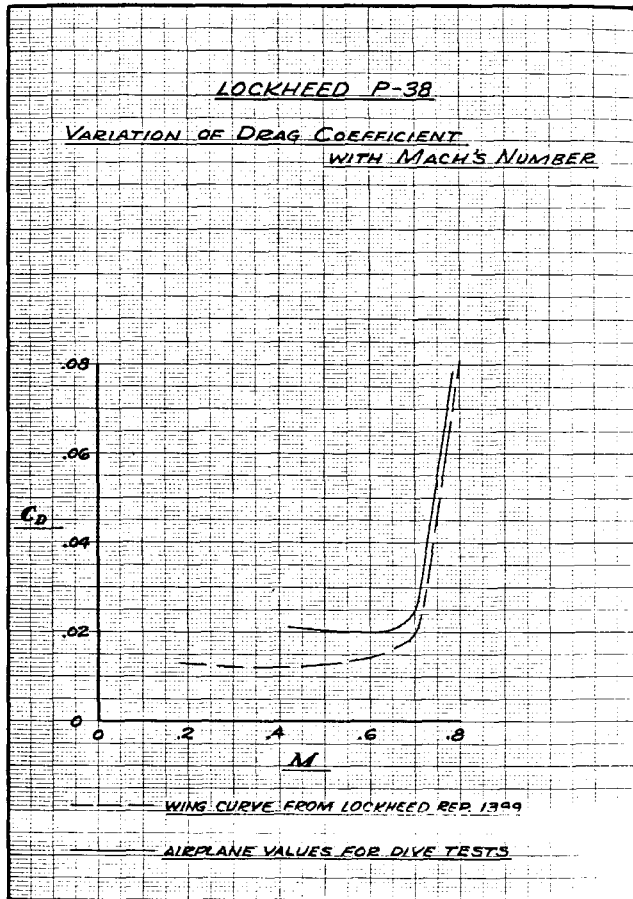


Fig. 20. High Speed Drag Variation Derived in 1940

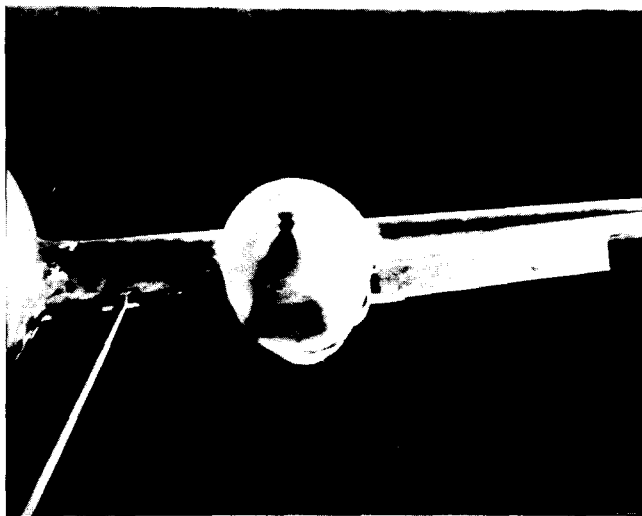


Fig. 21. Wind Tunnel Model with Dive Flaps Deflected

purpose was to provide a means for recovery, and actuation was almost instant, being electrically actuated. Because of their effectiveness and simplicity of operation they permitted the use of an expanded flight envelope, and increased the dive capability of the P-38 airplane.

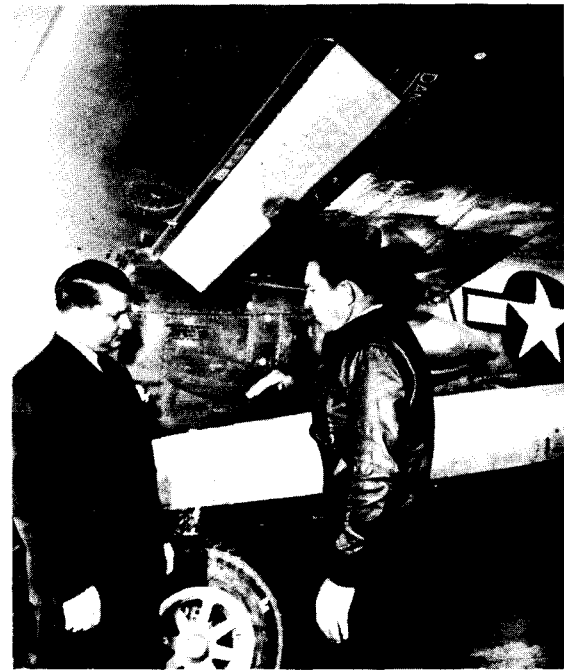


Fig. 22. Dive Flaps Installed on Airplane, Shown with Kelly Johnson and Milo Burcham

The first flight of the XP-38 occurred 40 years ago and to commemorate the event, a reunion was held at the Lockheed facilities on September 23, 1977 (Figure 23). Many of those



Fig. 23. The P-38 Forty Years Later, Shown With B. General Kelsey (Retired), Kelly Johnson, and Tony Le Vier

responsible for its design, fabrication, and test renewed old acquaintances and retold stories of its development and the many accomplishments of the airplane. The P-38 grew to be many different aircraft: fighter, bomber, torpedo carrier, night fighter, photo reconnaissance, ski plane, tank buster, and smoke-screen layer. Over 10,000 P-38s were built (Figure 24). The P-38 design can claim to be first with the following:

- First fighter with twin engines
- First 400-mph fighter
- First fighter with turbo superchargers

- First fighter with tricycle gear
- First airplane to encounter compressibility
- First fighter to fly the Atlantic non-stop
- First plane to shoot down enemy after U.S. entry in World War II

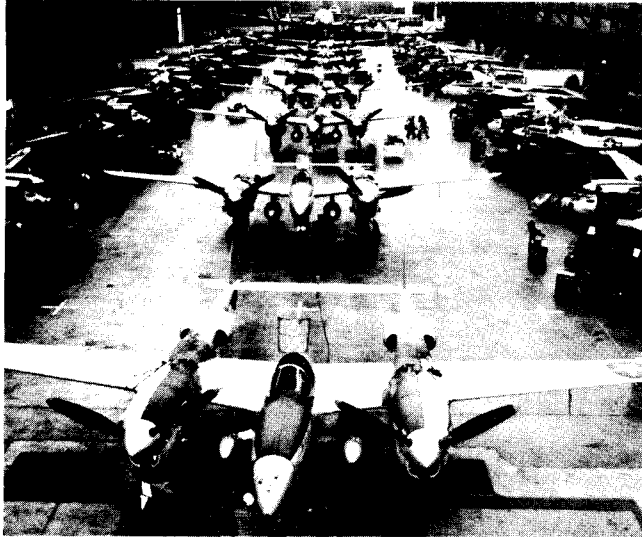


Fig. 24. P-38 Production

Every pilot who has flown P-51, P-47, and P-38 airplanes will argue his was best. There are many sides to the arguments; all did yeoman work during the war. But the P-38 has one unique claim (Figure 25) and many pilots will attest to its virtue – it was the only airplane that could make it back with an engine out!

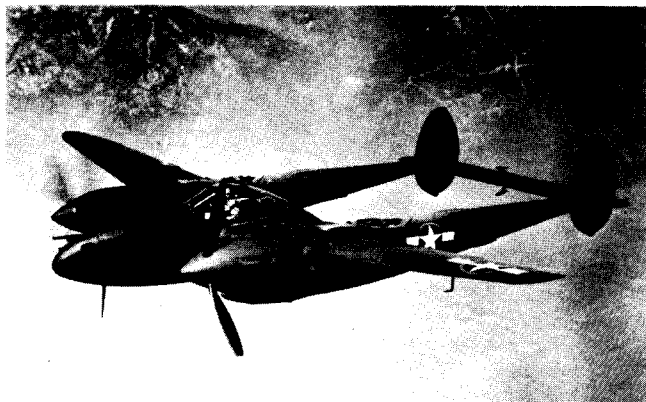


Fig. 25. The P-38 Cruising on One Engine

From Props to Jets

Developments in aviation often involve coincidences and almost simultaneous occurrences that make the next steps seem logical. A good example occurred in 1902. After the Wright brothers had mastered control of flight, helped in large measure by their testing which gave them a good insight into aerodynamic phenomenon,

they turned to the problem of the propulsion device. They were forced to develop their own propeller design because no one had ever done it before. But they had enough basic aerodynamic knowledge to be able to sit down and design a reasonably efficient propeller. Without knowing it at the time, they gained the knowledge they would need during their 1900 to 1902 activities.

As aviation moved into the forties, the problems and solutions to the effects of compressibility were being established, and designers were gradually gaining greater confidence that they could design even faster aircraft than the 400-mph fighters. But what about propulsion?

All the while in the 1930s, the solution to the propulsion needs of the 40's was being worked on, but few realized it. For the clever inventor, however, it did not take long to reason out the ways and means for developing a turbine engine. All the high-altitude-fighter power plants were using hot exhaust gases to drive a turbine, which in turn was powering a compressor to pump air to the reciprocating engine air intake. With a little thinking and a basic understanding of thermodynamics, it didn't take long to envision a compressor feeding air to a combustion device that would then exhaust through a turbine, which was coupled to the compressor.

Most of the basic elements of a jet engine were being used in turbo superchargers. Design of high-temperature turbines, compressors, bearings, housings, and cascade theory were all established to a reasonable degree. So it came to pass that the jet engine came on the scene in the 1940's.

Lockheed had an inventive propulsion engineer, Nate Price, who had been deeply involved with turbo supercharger operations and industrial turbine power plants. In 1940, he put together a turbine-engine proposal that featured high compression ratio, twin spools, and an afterburner. The design was patented in 1942, it was built later on by Menasco (Figure 26) and patents were eventually sold to Curtiss Wright.

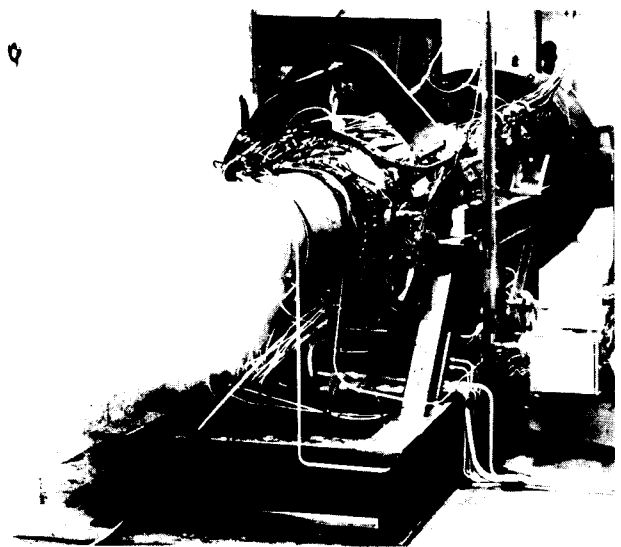


Fig. 26. The Lockheed L-1000 Turbojet Engine
Designed in 1942

Kelly Johnson and the preliminary design team configured a jet-powered airplane around this engine and showed it to the Army in 1942 (Figure 27). The design, which featured a canard surface, was to be made of stainless steel, with a speed of 625 mph at 50,000 feet. Delivery was promised in 1946.

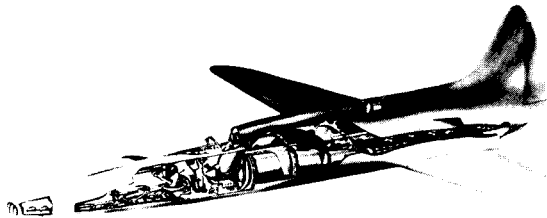


Fig. 27. Lockheed's First Jet Proposal Design for the Air Corps, Model L-133, 1942

The Air Corp reaction was one of interest, but they could not envision the war lasting until 1946, and they saw great hazard in developing an engine and airframe at the same time, so they did not encourage Lockheed to proceed. In fact, they insisted that Lockheed continue with P-38 production.

Clouded in secrecy, right at that time, jet-powered engines and aircraft were being developed. Led by Dr. Ernst Heinkel the Germans in August 1939 flew the world's first jet aircraft, the HE-178. In May 1941, the British flew their first jet, the Gloster E 28/39 powered by a Whittle W-1 engine. Finally in the U.S., an XP-59A Bell Airacomet, powered by the same Whittle engine flew on October 1, 1942.

During the intensive bombing campaigns over Germany in 1942, there appeared in the skies the ME-262 jet-powered fighter. Faster than anything seen up to then, even faster than the stripped-down ME-109, the reaction within the allied command was one of concern (Figure 28). In the U.S., the Airacomet-Whittle combination proved to be a disappointment, since top speed was less than the P-38.

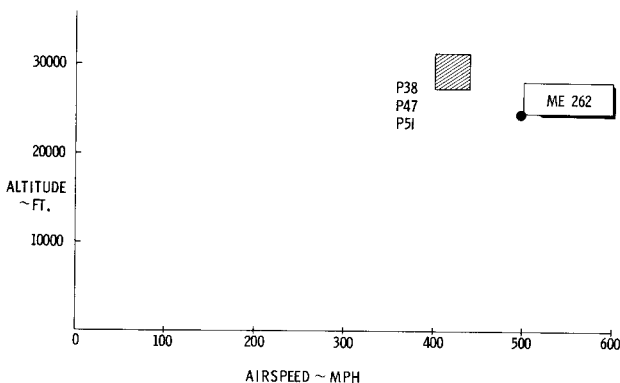


Fig. 28. Air Corps Fighter Performance - 1942

The Air Corp made arrangements to have the British deHavilland Company deliver one of their H-1 Goblin engines to the U.S. They also later arranged for General Electric to tool up and mass-produce these engines (Figure 29). Remembering Kelly Johnson's earlier jet proposal, Lockheed was approached and asked to propose a new jet-fighter design configured around this new British jet engine. Negotiations transpired, and a contract was signed in June 1943 committing delivery in 180 days. The project was to be secret – the aircraft designation was XP-80.

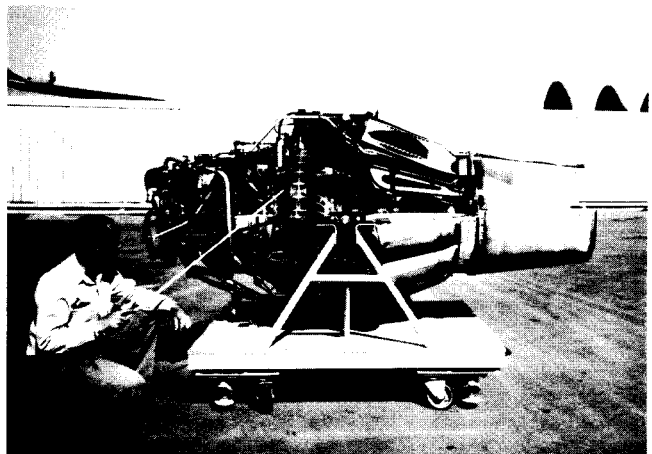


Fig. 29. General Electric Version of the Goblin Engines Used in First U.S. Production Jet Fighter

Plant Engineering slapped together a lean-to building, using old engine boxes and canvas. An entire machine shop was bought to obtain tooling. Twenty-three engineers and 105 shop men were assigned to the project. As work commenced, everyone was continually reminded that "our days are numbered" and "simplicity is the keynote of good design." Work was scheduled for 6-day, 10-hour operation. No one was to work Sundays.

The design presented new challenges, eased somewhat by new tools and test facilities. A large number of new and different questions surfaced as the details of a jet-engine installation were examined. Where should the jet intakes be located, and what shape should they have? How thick should the inlet lips be? How are these questions answered? Shape and fabrication of the ducts that led the air from the inlet to the engine had to be figured out (Figures 30 and 31). Since all of this involved new engineering



Fig. 30. Jet Fighter Dive Brakes and Inlet (Original XP-80 Did Not Have Boundary Layer Scoops)

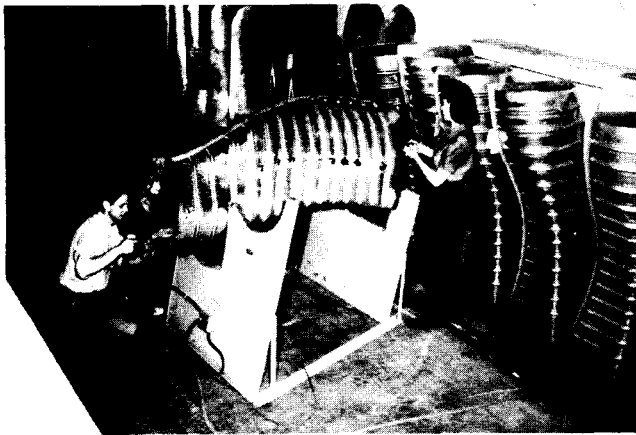


Fig. 31. Jet Fighter Air Flow Ducts

ideas, structural design criteria had to be established, with little guidance from past experience.

To provide engine access for overhaul or removal, novel design ideas were explored — the problem was different from those for reciprocating engines. The solution was to provide for a break in the fuselage and have the aft cone detachable so as to expose the engine which remained mounted to the forward portion of the airplane (Figure 32).

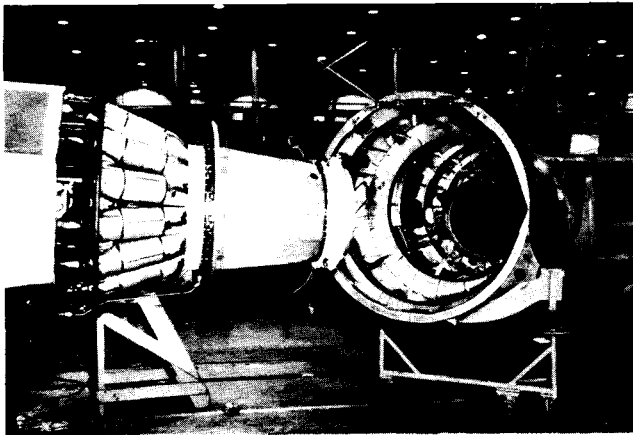


Fig. 32. Jet Fighter Engine Access for Maintenance and Removal

Speed was a predominant factor that influenced many design decisions. Surface smoothness, external contours, wing-body fillets, door fit, and fastener flushness were all given critical inspection and tight quality control standards were laid down. Flush antennas were developed (Figure 33). Provisions were made for dive flaps.

Aerodynamic development of the XP-80 needed even greater finesse and attention to wing design than did the XP-38, for the speeds were to be higher and the potential hazards of compressibility effects loomed that much greater. Need to maintain secrecy and get the job done quickly did not simplify the task. Fortunately, more information and new high-speed wind-tunnel facilities were available.

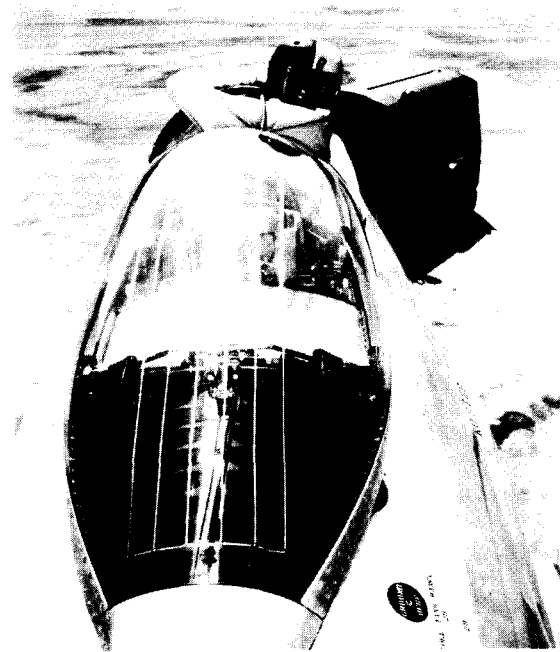


Fig. 33. Jet Fighter Flush Antenna Design

NACA laboratories had been deeply involved in compressibility effects in the late 30s and 40s, and had conducted many tests of two dimensional airfoils, wings and complete models. Data was obtained from drop tests, which consisted of small models dropped from flying aircraft and monitored as they reached terminal velocity and plummeted earthward. Time histories of the models' descent could be analyzed to establish drag versus Mach-number characteristics.

Wind-tunnel facilities at both Langley Field and the Ames Aeronautical Laboratory were being expanded to provide more tools for investigating high-speed phenomenon. One of the early ways to enhance existing wind-tunnel capabilities and achieve higher velocities and Mach numbers was to use a test-section restriction, known as a bump, mounted on the floor of the test section (Figure 34). Air passing through the modified test section had to accelerate to faster speeds as it rushed



Fig. 34. Wind Tunnel Test Section, Showing Floor Mounted Bump Used to Increase Tunnel Speed Capability

over the bump through the reduced throat area test section. By means of this modification, maximum test Mach number was raised, and additional data was made available in an expedited way.

This bump technique was not an ideal one, because the flow across the test section was not uniform. Therefore, a model which spanned a large portion of the test section would experience a nonuniform flow distribution across the wing span, and give erroneous answers. To minimize these errors, small half-span models, similar to those shown in Figure 35, that only traversed a small portion of the tunnel test section, were used. This measurably reduced the spanwise Mach number variation problem, but amplified the problems of small-scale and low Reynolds number test results. These were the compromises that had to be made during the early days of transonic wind-tunnel testing.

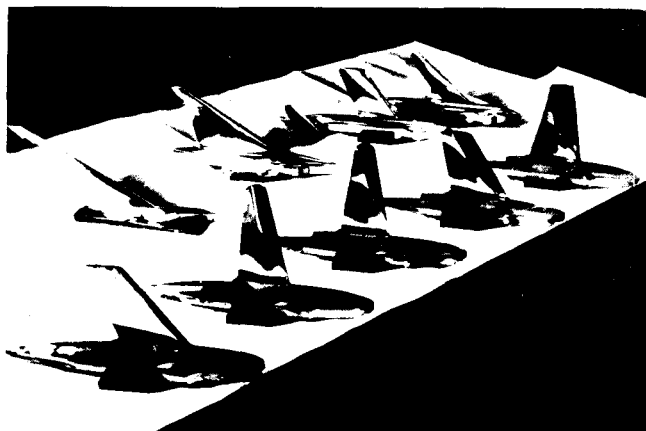


Fig. 35. Half Span Wing Models Used for Bump Wind Tunnel Tests

Small half-span models such as used in wind tunnels were also mounted on the upper surface of high-speed fighter aircraft, and supported by means of a strain-gage system so that forces on the model could be measured. As the fighter aircraft reached its maximum speed, the model which was immersed in the wing-flow field experienced higher Mach numbers, because of the flow acceleration over the fighter wing. This technique was similar in nature to the "bump tests" in the wind tunnels. The testing procedure was known as "wing-flow testing."

All these tests plus further theoretical analysis were making the task of high-speed aircraft design a little easier. However, all these data were being obtained at low Reynolds number, and scale effect was still a big unknown. There was much erroneous data and the task of the aerodynamicist was a challenging one.

The XP-80 team selected one of the new high-speed airfoils. Preliminary tests were run in the Lockheed low-speed wind tunnel and the Ames 16-foot high-speed tunnel. The section choice looked good, although results were at Reynolds number lower than flight values. The aerodynamicists gambled that it would perform properly at full scale--there was no other alternative.

Attempts were made to flight test full-scale airfoil shapes using the P-38 as a test bed. An in-house aircraft had been used for much P-38 development testing, and was highly instrumented.

Tests of fuselage body extensions had given the airplane an unusual appearance and it became known as the "kingfisher."

It was possible to "glove" the P-38 wing and over a portion of the span simulate an alternative airfoil shape and thickness ratio (Figure 36). This technique led to qualitative indications of differences between model scale and full scale, but the techniques and interpretation of results were not fully developed at the time of the XP-80 development. The "kingfisher" was used later to help develop the F-90 wing design.

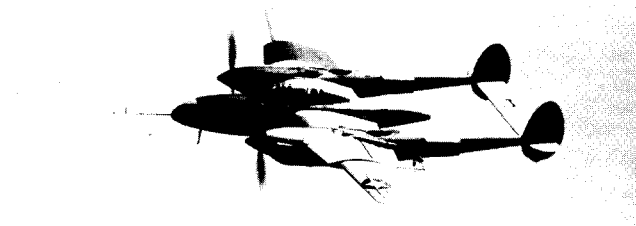


Fig. 36. P-38 Test Bed Aircraft, Called the "Kingfisher"

A period of 180 days goes by quickly, so there wasn't much time to hesitate while making design decisions. Early in November, in the dead of night, the airplane now given the name Lulu-Belle was pulled from the hangar and trucked to Muroc (Figure 37). It was the 139th day, and engine tests were ready to commence.



Fig. 37. Lulu Belle in Transit to Edwards

The Goblin roared the first time the start button was pushed. Preflight checkouts commenced, and on the 143rd day, 15 November 1943, the Air Corps accepted the XP-80 as ready for flight. The evening before the planned first flight, the engines were run up to full power in a final engine tune-up.

Suddenly both intakes collapsed! Before anyone knew what had happened, pieces of metal were sucked into the engine. An anxious group watched the slow disassembly of the engine take place, and dejectedly observed the crack on the compressor housing. A new engine was needed.

Lulu Belle was ready again on the morning of January 8, 1944 (Figure 38), and taxied out to the end of the runway. A crowd

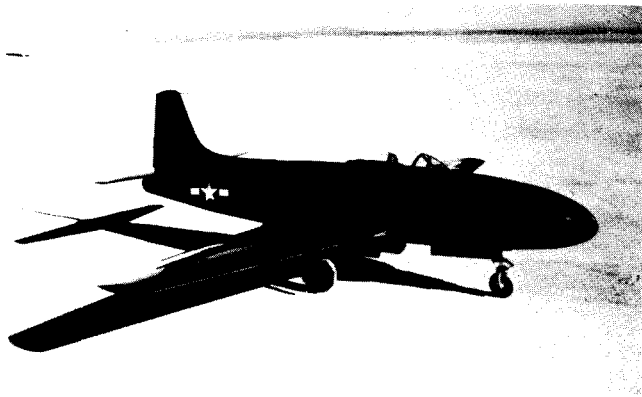


Fig. 38. Lulu Belle, Ready for Flight

of tired but anxious workers stood in the cold wet wind, watching the design they had labored over for the past 29 weeks, a design that had become a living part of their existence.

Lulu Belle became airborne, the crowd cheered, and then in a climbing turn the wings wobbled. The XP-80 made a quick circuit of the field, landed, and taxied up to the awaiting mechanics. Trouble?

Milo Burcham climbed down, and conversed with Johnson. "The ailerons felt awful touchy – think she's OK?" Convinced it was due to the high boost ratio adopted for the lateral control system, Burcham remounted the XP-80, started the Goblin engine, and then proceeded to do one of the most daring check flights ever carried out.

After a climbout to high altitude (Figure 39) and a little time for control familiarization, Burcham headed back over the runway. He came so fast no one knew he was coming until he passed overhead and the noise hit the crowd. .



Fig. 39. Ready to Buzz the Field

On the next pass, Lulu Belle did full aileron rolls, snapping around and around as the people who conceived her watched with a lump in their throats.

The transition from reciprocating engines to jets had begun (Figure 40). It was another memorable milestone in the history of aviation, and Orville Wright lived to see it happen (Figure 41).



Fig. 40. The P-38 and the P-80, Shown with Robert Gross and Hal Hibbard



Eyes up AS LOCKHEED P-80 "SHOOTING STAR" FLASHES ACROSS SKY
LOCKHEED AIRCRAFT FIELD, LOS ANGELES, OCTOBER, 1945

Fig. 41. Orville Wright Watches a P-80 Fly-By

But the P-80 was just the beginning of a new era.

Ahead were the NACA and NASA research aircraft, helicopters, business and private airplanes, swept wing fighters and bombers and transports, the Century series fighters, the Mach 3-plus aircraft, and man's voyages into space. And helping to pioneer them all were men who had an eager willingness to take the next steps even though this direction led into the unknown – men who chose to follow in the footsteps of the Wright Brothers.