No fatal flaw stands in the way: Northrop's refusal to merge, not instability, did it in

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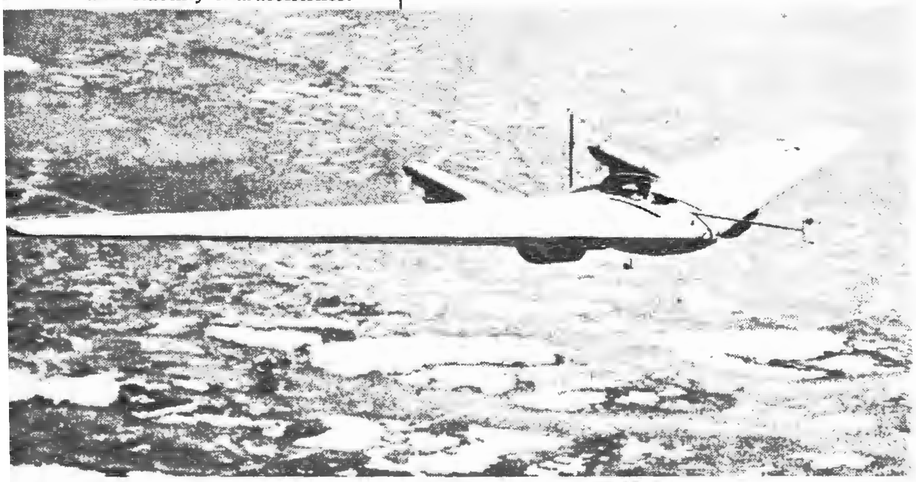
Flying wing could stealthily reappear

The original appeal of the "flying wing"—an aircraft that consists only of a wing and a propulsive device—seems to have been largely aesthetic. Since you need a wing for lift, the argument went, the ideal airplane would have that wing and nothing else. That logic is flawed, however. Of course the aircraft must have means to lift it, but it must also have structure, volume to carry useful load, propulsive devices, and other elements.

The argument put forth by Jack Northrop and me for the flying wings was sounder. The famous Breguet formula for maximum range tells us that range is proportional to the lift/drag ratio (L/D), which is a purely aerodynamic quantity, and to the logarithm of ($1 + F/Wl$), where Wl is the gross weight at landing and F is the weight of fuel carried.

The plywood N9M, a one-third scale model, successfully simulated the XB-35 control and stability characteristics.

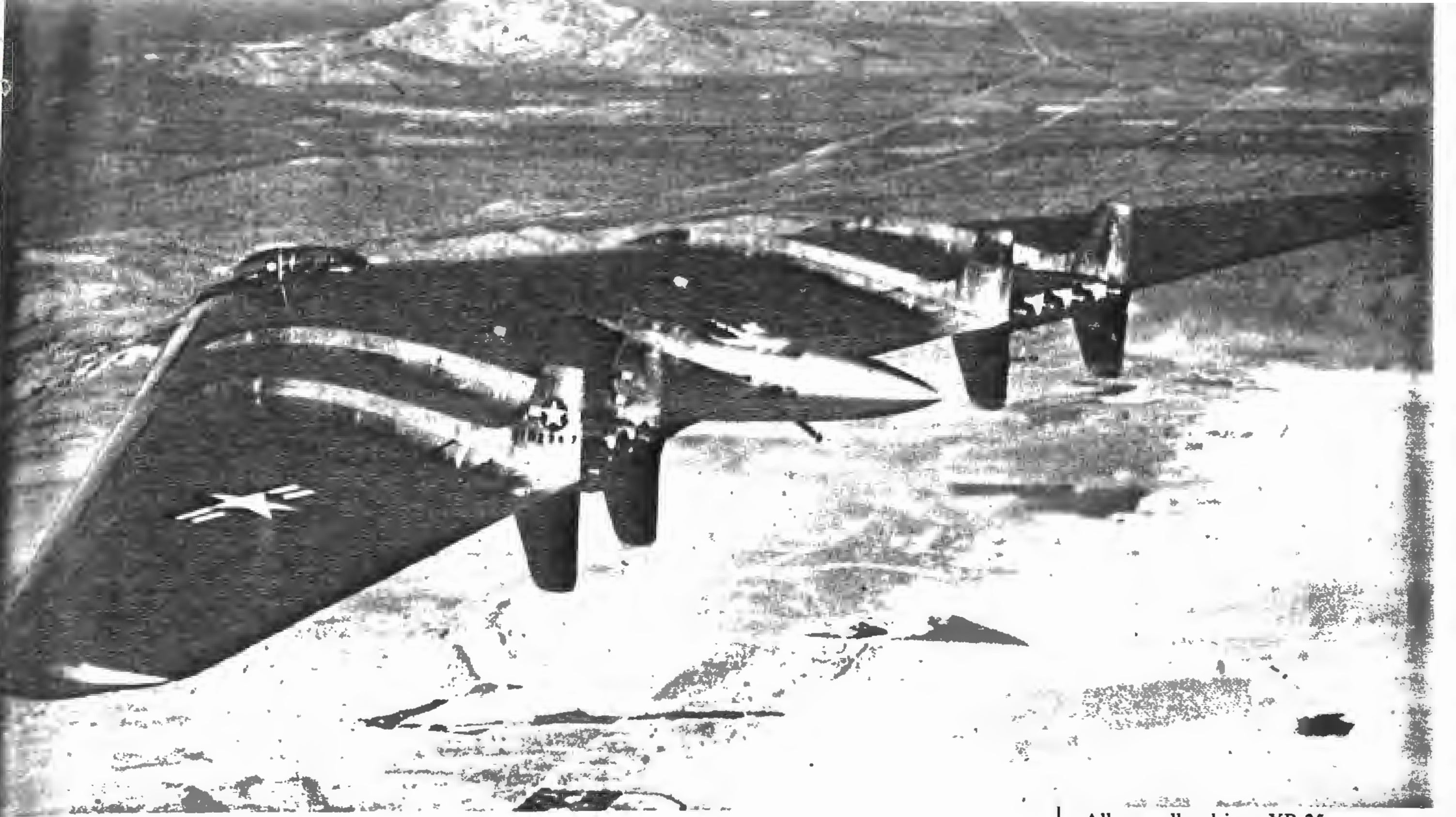


Consider first the logarithmic factor. F/Wl is essentially the ratio of fuel weight to structural weight. The major part of the structural weight is determined by the wing bending moment. This moment is due to the net upward load on the wing, which is the difference between the aerodynamic lift, which is distributed from wingtip to wingtip in a nearly semielliptical way, and the downward gravity-plus-inertial loading.

In a conventional airplane, this gravity-plus-inertial loading is largely concentrated at the wing-fuselage junction, since most of the airplane's gross weight is carried in the fuselage. In the flying wing, all of the weight is distributed along the wing, and the maximum wing bending moment is several times smaller. The critical loading condition for wing structural design may, in fact, be something other than maximum maneuver or gust loading in flight, such as landing impact.

This is now popularly called the "span-loading" argument, since it comes from distributing the weight and inertia loading along the span. It constitutes the major advantage of the flying-wing design. The improvement of L/D, which Jack hoped for, was probably illusory in his day.

In 1940, the worst-case military scenario called for waging intercontinental



All propeller-driven XB-35s were to be converted to jet-propelled YB-49s, shown here. The YB-49, it was claimed, "could turn inside Air Force fighters."

war from bases in the Western Hemisphere. The Army Air Corps therefore approached U.S. aircraft manufacturers with a requirement for a bomber to carry a 10,000-lb bomb load and to have a 10,000-mi. range. Convair started work on what became the B-36, and Northrop was given a contract for a competing flying-wing bomber, the XB-35.

The Air Corps' calculations, like everyone else's, showed that the 10,000-10,000 spec could probably be met by an airplane like the B-36, but it would have to be a very large and expensive craft. Throughout aeronautical history, the classic way to achieve longer range has been to build bigger airplanes. Why this should be so is not obvious. To be sure, some small economies in structural weight are possible as size increases, because the weights of crew and equipment do not increase, and a lot of minor structure does not grow more massive, in step with the airload. Lift/drag also slowly increases with increasing Reynolds number. But all this is overwhelmed in very large airplanes by the inevitable "dinosaur phenomenon": Structural weight increases with the cube of the size.

Let us look at this more closely. For constant landing and takeoff speeds and distances, weights must increase only with size squared. But bending moments increase with size cubed, and stresses are unaffected. And weight of primary structure goes up with size cubed. This is what the studies showed in 1940, that when you try to increase range by increasing size, you run up against a law of diminishing returns. The main reason that bigger airplanes have, typically, flown farther is that landing and takeoff speeds and distances have *not* been held constant.

So the Army Air Corps listened when Jack Northrop told them he could meet the 10,000-10,000 spec with a much smaller, four-engine airplane. The XB-35 project got under way in 1941. The aircraft was to be powered by four Pratt & Whitney R-4360 engines, each driving a counterrotating eight-blade propeller through a long drive shaft and gearbox.

The inherent problem of the tailless airplane is to achieve high lift and moment equilibrium simultaneously during landing and takeoff. A horizontal tail surface is the obvious choice for neutralizing the big nose-down moments produced by high-lift devices. In the flying wings, we used wing sweepback to place outboard control surfaces behind the center of gravity (cg), but their lever arm was a good deal shorter than that of the conventional tail. We placed trailing-edge flaps near the central part of the wing, where they were close to the cg. We could also reduce longitudinal static stability, because fuel tanks were close to the cg and cg moved little during flight. This lowered the downward force that had to be exerted by

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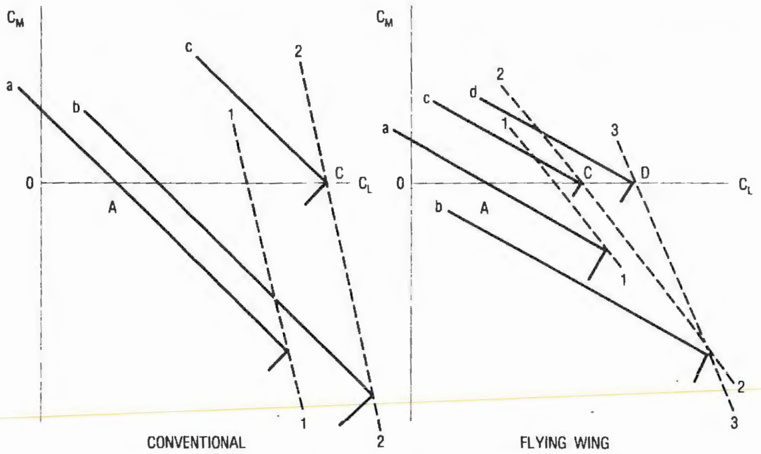
the outboard control surfaces and left more net gain in lift from deploying wing flaps for landing.

I have not mentioned rudders, because they are remarkably unimportant in an airplane, except to compensate for asymmetrical power. We fitted drag devices to the wingtips, but in a case of asymmetrical power the flying wing could actually be flown with an angle of sideslip without serious deterioration in flying qualities.



In these graphs of pitching moment coefficient (C_M) vs. lift coefficient (C_L) for a conventional airplane and a flying wing, negative slope represents stability, zero C_M represents steady flight. Curves "a" are for cruising configurations: flaps retracted, controls neutral. Thus points "A" represent cruising flight. In curves "b" landing flaps are deployed but controls are again neutral. In curves "c" landing flaps are deployed and elevators or elevons are deflected upward. Thus points "C" represent minimum-speed flight for these configurations. Flying wing had wing-tip trimmers. Curve "d" is for flaps deployed, elevons neutral, trimmers deflected upward. Thus point "D" represents minimum flight for this configuration. Most significant are lines 1-1, 2-2, and 3-3, which are envelopes of maximum-C_L points and show how lift and moment are affected by flaps, elevators, and tip trimmers, respectively.

Wind tunnel tests confirmed all this and that the XB-35 would meet its takeoff, landing, and range requirements. Its maximum *L/D*, about 20, was not spectacularly large, but was at least as good as the best long-range airplanes of the day. Because it was perfectly clear, even in 1940, that the flying wing would have unconventional flying qualities, our program from the beginning included construction of a one-third-size flying scale model of the XB-35. This was the Northrop N9M.

The N9M was as close to a geometric model of the XB-35 as we could practically achieve. It was made of plywood, and we simplified things by settling on two engines instead of four. No engines of the proper size were easily available. We agreed that our objectives could be met with an airplane having one Menasco inline air-cooled engine on each side positioned so its thrust axis represented the thrust of two XB-35 power plants.

Starting out with a flying scale model is not unusual when designing an airplane with a radical or unconventional aerodynamic configuration. But designing the flying scale model to be dynamically similar to the full-scale airplane is uncommon. Dynamic similitude means that the dynamic motions of the model are similar, in the mathematical sense, to those of the full-scale aircraft. Not only must the coefficients of forces and moments be the same but also at a fixed altitude the flying speed must be proportional to the square root of the scale factor. Thus, weight must increase as scale cubed. Wing loading is proportional to scale. Thrust, being a force, must increase as scale cubed, and engine power as the 7/2 power.

All of this means two things. First, all the dynamic motions of the scale model, although they correctly represent those of the full-scale craft, occur on a timescale reduced by the square root of the scale—1.732 times for the 1:3 case of the N9M. Second, the reduced-scale flying model is likely to be a slow, underpowered airplane. The N9Ms therefore did not have much performance, and the full-scale XB-35's tendency to wallow, a kind of lateral-directional oscillation, was sped up by an annoying factor of 1.732.

Nevertheless, the N9M program was an outstanding success. The 1/3-scale flying models accomplished their sole purpose, which was to simulate the control and stability characteristics of the XB-35.

But besides its unimpressive performance, the N9M had two flaws. The less serious of these was the wallow already described. Before the XB-35 flew, we acquired an autopilot from Honeywell to which we adapted a yaw damper in series to eliminate the problem.

The more serious N9M problem was longitudinal stick-force instability at low speed, which was an obvious and recognized problem of the all-wing configuration. It was created by the location of the pitch-control devices, or elevators, which we called elevons, in the wing's trailing edge. When the wing approaches its stall, stalling begins near the trailing edge and aerodynamic forces press these controls up. The pilot's control wheel wants to come back and he must resist by forward pressure. If he does not, angle of attack will increase. From the pilot's viewpoint, the airplane has become unstable, and in a big airplane that would be catastrophic.

We recognized from the beginning that this unstable hinge moment must not be transmitted to the pilot. We invented a number of aerodynamic devices to prevent it, none of which was adequate. An irreversible control system would have been necessary, one that responded to the pilot's inputs but did not transmit aerodynamic hinge moments back to him. In the 1940s, such systems were new, not easily available, and considered dangerous. Today they are commonplace in all high-speed military and commercial airplanes. Such a system was designed by Northrop controls engineers and installed in the XB-35s and YB-49s, but was not ready in time for the N9Ms, which were flown several years earlier.

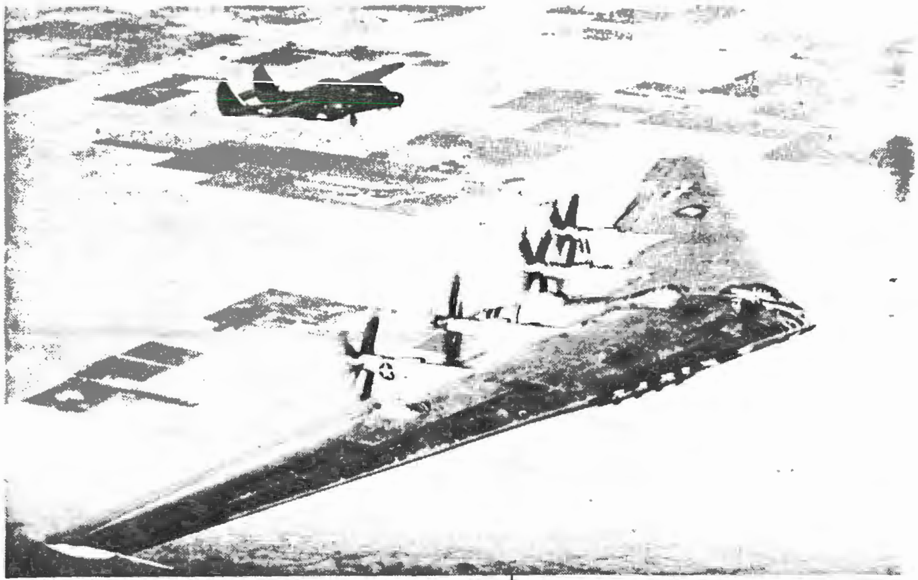
The flight-test program of the N9M was therefore carried out without irreversible controls, giving the pilot an airplane that from his viewpoint became longitudinally unstable as the stall was approached. In peacetime, a test program would not be undertaken until such a fault was corrected. I believe this stick-force reversal resulted in the crash of one of the N9Ms and the death of test pilot Max Constant.

The first XB-35 was flown in the summer of 1946. Its successful test program fully confirmed the principles of the flying wing, including its stability and controllability. But in the meantime the turbojet had appeared on the scene.

A contract for converting XB-35s to turbojets was soon let to Northrop. Named YB-49, it was powered by eight GE TG 180s in place of the R-4360s and their cooling fans, long drive shafts, gearboxes, counterrotating propellers, superchargers, intercoolers, cooling-air ducts and doors, and sequence valves. All the 35s were to be converted to 49s. But because the eight propellers had contributed appreciably to the small directional stability and had produced a desirable side force during sideslip, we had to add small vertical fins at the trailing edge to make up for the absence of the propellers and drive-shaft housings.

The YB-49s were great airplanes. They flew far and fast, were highly maneuverable and liked by their pilots, and successfully passed the Air Force's tests for an acceptable bombing platform. Film records show the big bombers being wheeled around in near-vertical banks. It is said they could turn inside Air Force fighters.

The Air Force included in its planning the production of numbers of B-49s. But they wanted the production line set up at General Dynamics in Texas. According to Jack Northrop, the Air Force secretary demanded that Northrop and GD merge. But Northrop claimed that GD's merger terms were unreasonable, and when it so notified the secretary, the B-49 contract was summarily cancelled. Moreover, Air Force crews armed with cutting torches were sent out to destroy all existing 35s and 49s, including those on the production line at Northrop.



The first XB-35, shown here with a Northrop P-61 chase plane, demonstrated flying wing stability and controllability in 1946.

Nobody seems to know the reasons for this incredible destruction of public property, which wiped out the results of the multimillion-dollar experiment: the world's first serious effort to prove or disprove the span-load theory for designing big airplanes.

The flying wing has a place in the future of aviation. The span-load theory on the structural weight of big airplanes is sound, and the Northrop program of the 1940s proved that the stability and control problems could be solved even before the days of readily available irreversible controls and artificial stability. Today these are routine solutions, and none of the inherent problems of the tailless configuration seems difficult.

A flying wing can easily be designed to take off and land with leading- and trailing-edge high-lift devices deployed. Such a wing will be loaded so as to be longitudinally unstable with fixed controls and artificially stabilized, as many airplanes are today. This means that its maximum *L/D* can be appreciably greater than for conventional airplanes, and its maximum range will therefore be spectacular. Flying wings will also probably have smaller wing loadings than their conventional competitors, and should fly at higher altitude for best efficiency. All that is missing is the economic climate and incentive to build large, intercontinental, economical, load-carrying aircraft.