Variations in the airfoil trace the history of flight.

By Walter J. Boyne

Wings

WINGS have always captured human imagination. The mythology of flight is found in every culture. Despite this fascination, it was not until the nineteenth century that scientists began to use precise mathematics to compute the optimum size and shape of wings for a flying machine.

Orville and Wilbur Wright did it best with their 1903 Flyer, forcing competitors to try wings of all shapes, styles, and dimensions to avoid infringing on their patents. Some went to multiple wings—triplanes, quadraplanes, and more. Others altered the shape of wings to sweptback, tandem, joined, and cruciform.

Most of the results were too inefficient to fly; some were capable of generating just enough lift to stagger through the air if coupled with a sufficiently powerful engine, and a very few were both stable and efficient.

Some concepts were diametrically opposed—very low aspect ratio (the ratio of span to chord) vs. high aspect ratio, or a pure wing form vs. a lifting body—yet success was sometimes found at either end of the spectrum.

From the 1920s through the 1940s, advances in aeronautical engineering resulted in much stronger, more complex wings using now familiar high-lift devices and modern airfoils. Nonetheless, variations in span, incidence, and geometry persisted. For some, the ultimate goal became the elimination of all surfaces except the wing, or the elimination of all or part of the wing.

Aerodynamic Magic

Since the late 1940s, aerodynamic progress has accelerated at an ever greater rate, so much so that modern engineering methods and materials have combined with new requirements to create totally new wing configurations. Now, elaborate high-lift devices are tucked into wing leading and trailing edges to deploy during the approach to landing, with the slats and flaps folding out like handkerchiefs from a magician's sleeve.

Some by-products have become perhaps too sophisticated. Where the thick wing of a Douglas C-47 "Gooney Bird" would let you plow through cold, wet clouds forever, shaking off the ice buildup with pneumatic boots, some modern airfoils—as on the Aerospatiale/Alenia ATR-42—have become so efficient that even a small buildup of ice becomes a deadly hazard.

On the other hand, the increased sophistication has occasionally permitted a return to some of the ideas put forward by earlier inventors but not realized at the time for technical, mechanical, or even political, reasons. Thus, the unsuccessful tandem wing design of Samuel Pierpont Langley was reprised through the years, first by the French Albessard "Tri-avion" and Arsenal-Delanne 10 fighter, and most recently by Burt Rutan with his Advanced Technology Tactical Transport.

At least since the Greeks crafted the myth of Icarus (depicted here in an eighteenth century woodcut), man has dreamt of taking wing. That dream was realized in 1903 by the Wright brothers and is carried on today in the B-2, the most successful flying-wing design ever.

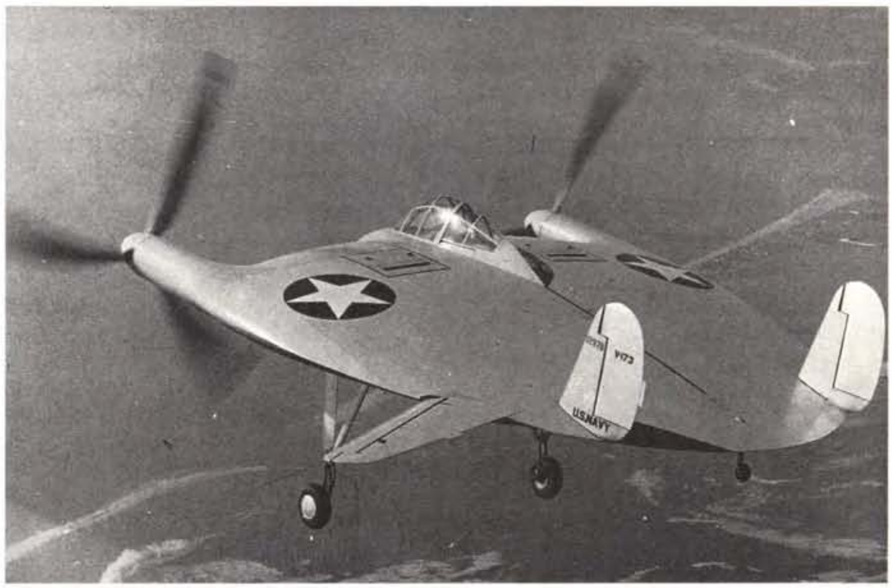

Photo courtesy Art Schoeni

Aircraft designers sometimes use the same approach to solve different problems. The Vought V-173 "Flying Pancake" (above) owes its low-aspect-ratio design to a quest for reduced drag, while Lockheed Martin's F-117 (top) takes a similar shape in order to reduce radar signature.

In a similar way, the greatest comeback has been that of the flying wing, well expressed by the Wrights in their 1901 glider and found now on the flight line at Whiteman AFB, Mo., in the superlative form of the Northrop Grumman B-2 bomber.

The Wrights went on to attach elevators and rudders but maintained their strongly braced biplane wings. This combination of wings was a masterpiece of design, with a balance of span, chord, and gap that was imitated by myriad other designers. Coupled with their insight into the need for three-axis control, the Wrights set the pattern for most other inventors of the time, few of whom were deterred by the brothers' patents.

Some, such as Glenn H. Curtiss, used a similar biplane layout, employing ailerons in an attempt to circumvent the patents. Other inventors depended on their intuition, their aesthetic sense, or their fascination with complex mechanical solutions to approach flight in a way they hoped differed from the Wrights' method.

Wilbur Wright's triumphant exhibition at Le Mans, France, in 1908 opened the floodgates of European imagination and turned loose an outpouring of innovative designs. Although most of these were failures, many of them forecast future trends.

The low aspect ratio found in the Lockheed Martin F-117 Nighthawk stealth fighter or the older Convair F-102 Delta Dagger and F-106 Delta Dart interceptors was anticipated by many aircraft, beginning with the Flick-Reinig "Apteroid" of 1911, whose biplane wings ran fore and aft along the fuselage rather than perpendicular to it, as if it had been packaged for shipment by railcar.

Many low-aspect-ratio airplanes followed, including the McConnick Romme "umbrella plane" of 1912. Designed by the young Chance Vought, it had a circular wing absolutely devoid of camber and in appearance was no more than a set of loosely connected awnings. When a rip-roaring fifty-horsepower Gnome-Rhône rotary engine was installed, however, the "doughnut," as it was called, not only managed to get airborne but made controlled flights around its home field at Cicero, Ill.

Flying Flapjacks

In later years, there were dozens of attempts to obtain the high lift believed to be inherent in low-aspect-ratio aircraft. Some of the most successful of these were designed by Charles H. Zimmerman, who enhanced the low-aspect-ratio concept by directing the airflow from very large propellers over the entire wing surface in the 1942 Vought V-173 "Flying Pancake."

The V-173 was flown successfully by Boone T. Guyton, Charles A. Lindbergh, and Najeeb E. Halaby, among others, and was developed into the wicked-looking Vought XF5U-1, a circular-planform Navy fighter. The XF5U-1, too radical and made obsolete by the jet engine, was dismantled before its first flight.

Low-aspect-ratio wings found their ultimate expression in the delta-wing designs that flowed from the genius of Dr. Alexander M. Lippisch, whose first delta-wing aircraft flew in 1931. He followed with a series of innovative designs, most notably the world's first delta-wing, rocket-powered fighter—the Messerschmitt Me-163 Komet. After World War II, the delta-wing layout served many aircraft well, including the beautiful Convair B-58 Hustler, the first supersonic bomber. Foreign manufacturers who adopted the delta configuration include Dassault, Avro, Fairey, Saab, Tupelov, and the MiG Design Bureau.

Success was easier at the other end of the aspect-ratio spectrum. High-aspect-ratio wings were undeniably efficient and were widely used by sailplanes. The French manufacturer Hurel-Dubois carried the idea a step further with its extremely high-aspect-ratio, strut-braced-wing aircraft of the late 1940s. The idea lapsed for years, only to be revived by the successful Short Brothers transports, such as USAF's C-23 Sherpa.

By the 1930s, while most of the world's aeronautical engineers struggled toward a common denominator of the cantilever low-wing all-metal aircraft, some designers persisted in pressing for unorthodox solutions to specific problems.

The concept of variable-span wings was tried in the 1931 monoplane designed in France by Mikhail Makhonine, a Russian engineer. The handsome aircraft featured extensible outer wing panels that could vary the wingspan from forty-three feet to sixty-nine feet and the wing area from 226 to 335 square feet. The greater wingspan allowed for takeoff with greater loads. At altitude, the wings retracted for more speed.

Other inventors sought safety with their unorthodox designs. In 1931, Albert A. Merrill designed a stall-proof biplane. That same year, George W. Cornelius created his first variable-angle-of-incidence aircraft and followed it a few years later with his "Mallard," which had both variable incidence and forward-swept wings. The practical success of variable incidence came in 1955 with the debut of the Vought (later LTV) F8U Crusader, whose object was not avoiding a stall but getting off a carrier deck.

The Germans led the way in variable-geometry wings with the Messerschmitt P-1101 jet prototype. It never flew but was to have had ground-adjustable wing sweep for comparative flight tests. Bell adapted the design in 1951 with the X-5, whose wings could be swept from 20° to 60°, making it the first high-performance aircraft to fly with a variable-geometry wing.

Grumman experimented with variable-geometry wings in its unsuccessful XF10F-1 Jaguar of 1952. The principle of the swing wing served its successor, the F-14 Tomcat, well, as it did a number of US and foreign aircraft, including the US F-111 and B-1, the Soviet MiG-23 and Su-24, and the European consortium Panavia's Tornado.

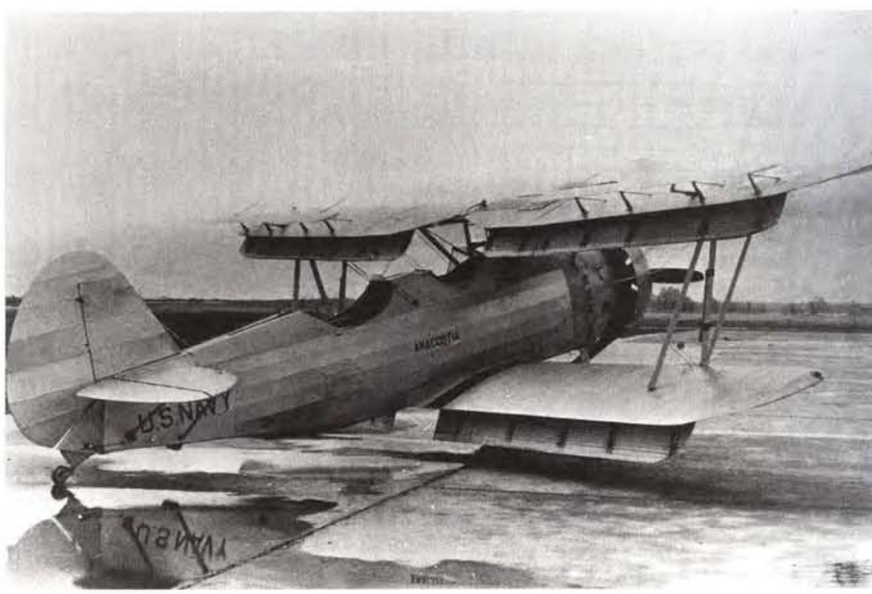

Photo courtesy Warren Bodie

Ever since the Wrights discovered wing-warping, designers have manipulated the size and shape of wings for better performance, from the Berliner-Joyce XO-J1 with its "zap flaps" (top) to the Boeing-NASA-USAF F-111 with mission adaptive wing (above).

Accidental Benefit

Fixed wing sweep had been built into dozens of aircraft since the earliest days of flight, often as a solution to center-of-gravity problems. Sweep designed to raise the limiting Mach number had been a subject of study since the early 1930s but appeared quite by accident on an early operational jet fighter, the Messerschmitt Me-262, first flown July 18, 1942. The Me-262 had been originally designed as a straight-wing aircraft, but the need to compensate for engine growth and changes in the center of gravity caused the designer to sweep the wings, with the accidental aerodynamic benefit of increasing the aircraft's critical Mach number.

Forward-swept wings appeared as early as 1906 on Alberto Santos-Dumont's *Number 14 bis,* which made the first official powered aircraft flight in Europe. Later, Cornelius designed a series of aircraft with forward-swept wings, one of them a glider/tanker.

The first jet aircraft to fly with forward-swept wings was the 1944 prototype of the six-engine Junkers Ju-287 bomber. Forward-swept wings were deemed to have the advantage of increasing the limiting Mach number, while transferring adverse characteristics of swept wings from the low- to the high-speed regime, where they were easier to handle.

The first successful commercial application came with the postwar Hansa executive jet (from the same design team that produced the Ju-287), while the most prominent modern use has been in the very advanced Grumman X-29.

The pure flying wing, unencumbered by any vertical surfaces, was the goal of many designers, but others sought to simply rid their designs of the weight and drag penalties of a rear fuselage and tail surfaces. The very first of these was attributed to a Wright test pilot, Eugène Lefebvre—the first pilot of a powered aircraft to be killed in an aircraft accident, on September 7, 1909.

The design concept went through a long series of permutations by a wide range of manufacturers, including Blériot, Granville Brothers, Westland Aircraft Works, and Focke-Wulf, but achieved its greatest success in the variations of Burt Rutan's sleek composite Long-EZ design.

Several combatant nations created tailless prototypes during World War II, when the goal was not inherent stability but greater speed via elimination of slipstream drag, improved visibility, and concentration of firepower in a central nacelle. First to score was Italy's handsome Ambrosini S.S.4 interceptor of 1941, which was fast and flew well but was abandoned after a crash due to engine failure.

Black Bullets

In 1943, Curtiss flew the first of three XP-55 Ascenders. The XP-55 had appalling stall characteristics and only modest performance. The Ascenders were stellar aircraft, however, compared to another 1943 tailless entry, the all-magnesium Northrop XP-56 Black Bullet. Two XP-56s were built, and one managed to crash while taxiing.

A desperate Japan threw a hat into the ring in 1945, producing the Kyushu J7WI Shinden ("Magnificent Lightning"). Similar in design to the Ambrosini—pusher engine, sweptback wings, and canard surfaces—the Shinden was ordered into mass production before testing was begun. Initial flight tests in 1945 were successful, but the war was over before the second prototype flew, and production ended.

The only tailless aircraft to see production and enter combat was the previously noted Messerschmitt Me-163 rocket-powered fighter, an example of which exceeded 623 mph in 1941. Delightful to fly—when it did not explode—the Me-163 had deficiencies in duration and armament, making it ineffective as a warplane.

The shining goal of a pure flying wing entranced designers from Hugo Junkers and the Horten brothers to Anthony Stadlman and John K. Northrop. There was always something intrinsically appealing about the pure flying wing, whose sleek lines and low drag were complemented by a large payload capacity.

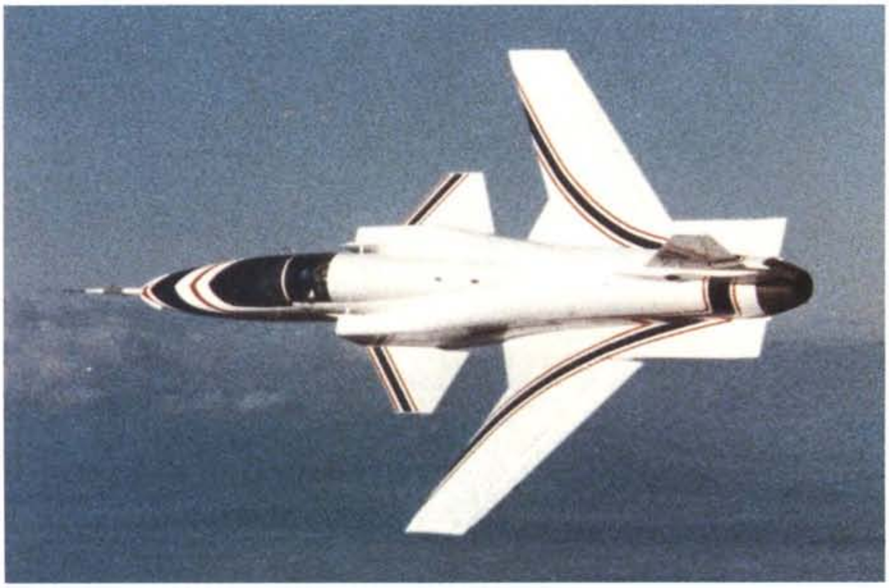

Photo courtesy author's collection

George Cornelius's 1930s-vintage "Mallard" (above) combined forward-swept wings with variable incidence. Grumman's highly successful X-29 technology demonstrator (top) had forward-swept wings whose trailing edges changed shape continuously to match flight conditions.

The first pure flying-wing fighter (and incidentally, if not accidentally, the first fighter with stealth characteristics) was the Horten Ho IX V3, which would have been produced as the Gotha Go 229. A twin jet made primarily of molded wood (to help elude radar), its performance and handling were exceptionally good, but like so many German wonder weapons, it came too late in the war.

It fell to Northrop to create a line of pure flying wings, culminating in the XB-35 and XB-49 bombers that seemed to hold so much promise in the mid-1940s. During the war, four one-third-scale models had been flown successfully, and the prototype XB-35 took to the air on June 25, 1946. As many as 200 B-35s were on order at one time, but changing requirements and a lack of stability during the bomb run brought about cancellations and controversy.

Photos courtesy author's collection

Blowing engine air over the wings to increase lift has been attempted several times over the years in such aircraft as the Custer Channel Wing (top) and the Boeing YC-14 (above), whose competitor, McDonnell Douglas's YC-15, is an ancestor of USAF's C-17 Globemaster III.

The YB-49 was an even cleaner aircraft. Basically a YB-35 converted with eight Allison J35 turbojets buried in the wing, its performance led to an order, later canceled, for thirty RB-49s. All of the large Northrop wings were broken up, but two of the scale models remain, one at the Smithsonian's National Air and Space Museum in Washington, D. C., and one flying example at the Planes of Fame Museum in Chino, Calif.

The concept of a blown wing was first enunciated by Willard R. Custer with his Channel Wing design. A competition of medium-size jet transports resulted in the Boeing YC-14 and McDonnell Douglas YC-15. Experience with the latter led directly to today's McDonnell Douglas C-17 Globemaster III airlifter, the newest workhorse of Air Mobility Command.

An even more esoteric type is the mission-adaptive wing, as tested on the General Dynamics F-111 by a joint Boeing, NASA, and USAF team. (C-5 Galaxys and C-141 Starlifters have routinely flown with their wings "mission adapted" to their weight by judicious use of lift devices.) In "New World Vistas, Air and Space Power for the 21st Century," the Air Force Scientific Advisory Board's forecast of new technologies, the concept of adaptive mechanisms is carried forward beyond changes in camber and active aerodynamic control to monitoring the "health" of the aircraft by sensing and compensating for battle damage.

Interestingly, New World Vistas' bold leap into the future is accompanied by predicted returns to the past. For example, the report suggests that future long-range lifters might have strut-braced, very-high-aspect-ratio wings, like those made by Hurel-Dubois. It forcecasts blended-wing-and-body transports, similar in concept to those put forward by Vincent Burnelli years ago. And finally, the report says that long-range bombers of the future could have center nacelles and forward-swept wings, just as George Cornelius suggested in the 1930s. ■

Walter J. Boyne, former director of the National Air and Space Museum in Washington, D. C., is a retired Air Force colonel and author. He has written more than 400 articles about aviation topics and several books, the most recent of which was Silver Wings. *His most recent article for* Air Force Magazine, *"The Spirit of Billy Mitchell," appeared in the June 1996 issue.*