Flying Flea Designs

Taming the tandem wing requires analysis of the airplane's stability

Neal Willford

The first time I saw it was shortly after I arrived at Oshkosh 1976: a tailless, biplane glider being pushed aloft by a noisy two-stroke engine. John Moody was making the first large-scale public demonstration of his powered Icarus II. The ultralight era had begun.

As a teenager with limited financial means, I thought I'd found a way I could afford to fly. Enthusiasm for ultralights increased yearly as more people, many of whom had never been involved in aviation, also saw the ultralight as their only means of experiencing affordable flight.

The ultralight's popularity continued to increase until December 1983, when the infamous 20/20 episode questioning its safety and lack of regulation dealt a near-fatal blow to the industry. The past 20 years has shown that ultralight critics were wrong, but the magic was gone, and the ultralight movement was never the same.

JIM KOEPNICK

That was not the first time in aviation history that the bubble had burst on an entire type of airplane. Seventy years ago a Frenchman named Henri Mignet set out to design a safe, easy-to-fly airplane "for the masses." It caught on like wildfire in Europe and soon was being built in great numbers around the world.

Unfortunately, a rash of fatal accidents due to a design flaw in its original configuration resulted in the flying public dropping it like a hot potato—even after the problem had been corrected. Mignet designed many more airplanes during the rest of his life, but they never achieved large-scale acceptance again.

JIM KOEPNICK

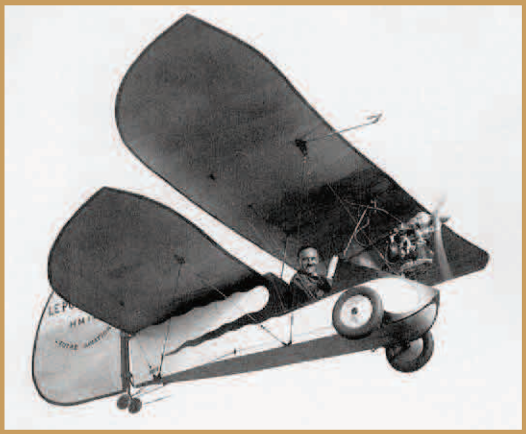
Mignet tirelessly promoted his “formula,” as he called it, throughout his life, with the idea evolving through design and technological changes through the years. A spreadsheet for estimating the stability, control, and performance of this unique style of airplane is available to download from the EAA Sport Aviation page on the EAA website at *www.eaa.org*.

Historical Overview

Two key features of Mignet’s formula, a pivoting wing for pitch control and the tandem wing arrangement, were invented prior to his involvement in aviation. Octave Chanute, who mentored the Wright brothers during their formative years in aviation, once said he believed the Wrights would succeed in their attempt to fly, but he was afraid that it would not be “in the best way.”

Chanute felt the main wing should pivot for pitch control instead of using a separate control surface, as the Wrights were using. He even had a glider with a “rocking wing” built and sent to the Wrights at Kitty Hawk so they could fly it alongside their glider design for comparison. There is no record the Wrights flew that glider, but a mutual friend of Chanute and the Wrights, Dr. George Spratt, continued developing the pivoting wing concept as an alternative means for pitch control. Eventually his son followed suit and designed a variety of control wing airplanes.

Samuel Langley first used the tandem wing arrangement successfully. By flying a powered model in 1896, Langley had shown that powered flight was feasible, and he felt his contribution to aviation was complete. However, President McKinley asked Langley to get funds from the U.S.



A smiling Henri Mignet in his HM-14 Flying Flea.

Army to develop a man-carrying version. He did so, and two flight attempts of the Aerodrome "A" in October and December 1903 ended in failure.

Langley abandoned his aeronautical experiments and just nine days later those two brothers from Ohio succeeded.

Henri Mignet's interest in aviation was piqued on the other side of the Atlantic by the Wright brothers' flights in France during the summer of 1908. He started experimenting with hang gliders before World War I engulfed the continent. He was a radio operator in the Signal Corps during the war, and after the war he made a living making radios. He started pursuing his aeronautical interests on the side.

The HM-8, a conventional high-wing parasol design, was his first successful airplane. In 1928 he published a book and series of magazine articles describing how to build it. His design became a huge success among the French, and eventually 200 were built.

Though Mignet had succeeded in designing a popular airplane, he had a problem: He couldn't fly. Mignet had tried and tried to learn, but he could not master the three-axis control system. His attempts at turns with his instructor would invariably end in a spin. It was a crash in his HM-8 that finally convinced him that he needed to design an airplane incapable of a stall/spin.

What Mignet lacked in flying ability, he more than made up for in enthusiasm and perseverance. He attacked the stall/spin problem with a vengeance during several years of experimenting and eventually adopted a short-coupled tandem wing arrangement.

The design was driven in part to keep the wingspan and overall length down. His reason was a practical one. He wanted customers to be able to build it in small apartment rooms, where he envisioned many would be built if the design proved successful.

And successful it was. His 14th design (the HM-14) was completed in September 1933 after a one-month building time. The tandem wing design did not have ailerons, but relied on a large rudder and wing dihedral to accomplish turns.

Its biggest deviation from conventional aircraft was that the front wing pivoted for pitch control. Mignet's "living wing" was similar in concept to the pivoting wing promoted by Chanute and Spratt 30 years earlier.

Mignet reasoned that pivoting the wing gave the pilot more immediate control over pitch than a separate control surface could provide, regardless of whether that surface was a canard or conventional tail. He never referred to his unconventional creation as an "aeroplane" in his book, but as a powered kite.

The HM-14 was further refined over a two-month period, which culminated in Mignet's first solo flight that included turns. He flew for another 10 hours before returning to Paris to write a book detailing the new design and to market plans for others to build their own. His book was a huge success, and soon many Frenchmen were building their own copy of Mignet's Le Pou du Ciel. The literal English translation for this is The Sky Louse, but when his book was translated into English, it was dubbed The Flying Flea.

Soon Fleas were being built in England and other English-speaking countries. With hundreds

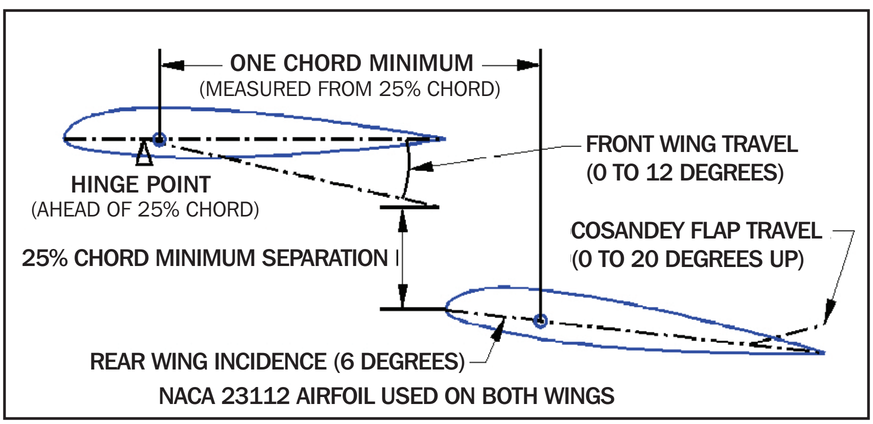


Figure 1. Historical guidelines for the Flying Flea "Formula."

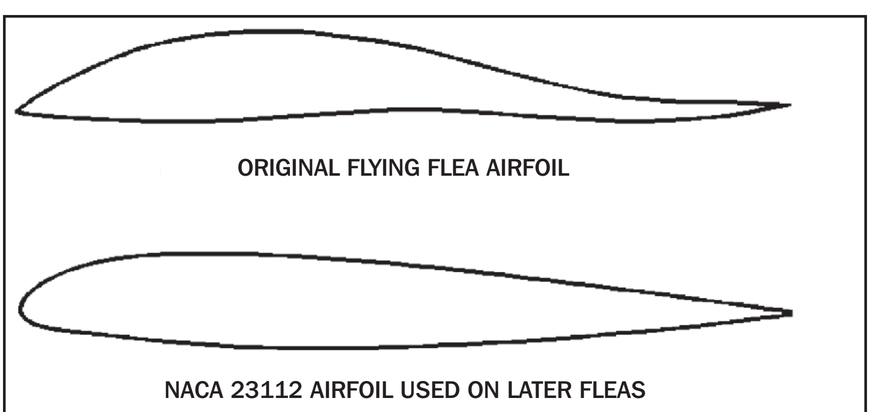


Figure 2. Comparison of airfoils used on Mignet Flying Fleas. Note very sharp leading edge on Mignet's original Flea airfoil.

being built worldwide, it is not surprising that some were involved in accidents, but between the summers of 1935 and 1936 there were 11 fatalities involving the Flea. Full-size examples were put into wind tunnels in both France and England, and the testing showed the design's problem and how to fix it. English authorities decided they would no longer issue flight permits for Fleas in the original configuration, and the flying public lost faith in the design. The Flea was effectively grounded.

Though devastated by the turn of events, Mignet not only persevered with implementing the needed fixes, but continued to refine and promote the concept until his death in 1965. Left unfinished was his 40th design. Much more about Mignet and his designs can be found at *www.flyingflea.org* (including an online version of his book).

Technical Overview

Mignet's Flea has been described as a conventional airplane with a really big horizontal tail; a tandem wing; or even a tailless, staggered biplane. Actually, all these descriptions are more or less accurate.

Airplanes with "normal" tails typically have a center of gravity (CG) range from 15 percent to 30 percent of the wing's mean aerodynamic chord (MAC). The forward CG limit is usually set by the elevator's ability to hold the airplane's nose up during landing, whereas the aft limit is determined by the minimum acceptable stability characteristics of the design. Flying an airplane aft of its CG limit may result in the airplane feeling sensitive to the pilot or, worse, in the airplane being unstable and leading to loss of control.

For a given CG location, the static stability largely depends on the horizontal tail area and the ratio of the tail arm length and the MAC. This ratio is typically between 2.5-to-1 and 3-to-1 for conventional designs. On Mignet's Fleas, this ratio was as low as 1-to-1, indicating that the aircraft's horizontal tail would need to be 2.5 to 3 times as large for a given level of stability.

Making an airplane's horizontal tail larger increases its static stability and can allow the CG limit to move further aft. This was the case with Mignet's HM-14, which according to his book had a recommended CG of 41 percent MAC (based on the front wing's chord).

His later designs had an aft CG of 50 percent MAC, and consequently, an even larger tail. Mignet and his followers typically used the same airfoil and chord width on both wings to simplify construction by reducing the number of rib jigs required, so he obtained more tail area by increasing its span. A review of various Flea designs indicates that the tail span is usually 65 percent to 90 percent of the forward wingspan.

An airplane's CG location also has a direct bearing on the horizontal tail load, which is usually down when the CG is ahead of the wing's aerodynamic center (approximately located at 25 percent MAC). The reverse is true when the CG moves aft of this point. In this case the horizontal tail acts as another lifting surface, hence the reason for calling it a tandem wing design.

The rear wing of a typical Flea provides about 25 percent of the airplane's total lift when flying at the aft CG limit. This reduces the span loading on the larger forward wing and consequently improves the rate of climb and service ceiling. This is a useful benefit, because most Fleas have short wingspans and small engines.

There is no free lunch, however, and the rear-lifting wing imposes a drag penalty. While producing lift, the forward wing deflects the air passing around it downward. The rear wing flies in this downwash and therefore has to continually "climb" in this sinking air. This results in the induced drag of the rear wing being about three times higher than if it were flying in undisturbed air.

The additional drag can be high enough to offset the increase in rate of climb due to the lower span loading on the forward wing. Analysis of a few Flea designs indicates that the best increase in rate of climb occurs when the rear wing provides only about 20 percent of the total lift. Increasing the rear wing's lifting load above this degrades the rate of climb to the point that if it carries more than 35 percent, the additional induced drag is so high that the climb rate is worse than if it was carrying no lift at all.

However, there is a silver lining to the higher induced drag of the lifting rear wing. Wings have their highest induced drag when they are operating at high lift coefficients. This is because induced drag is proportional to a wing's lift coefficient squared. An airplane needs high lift and high drag for short field landings, so in this case the higher induced drag of a rear-lifting wing is beneficial.

Mignet's Fleas have a reputation of being able to do parachute-like

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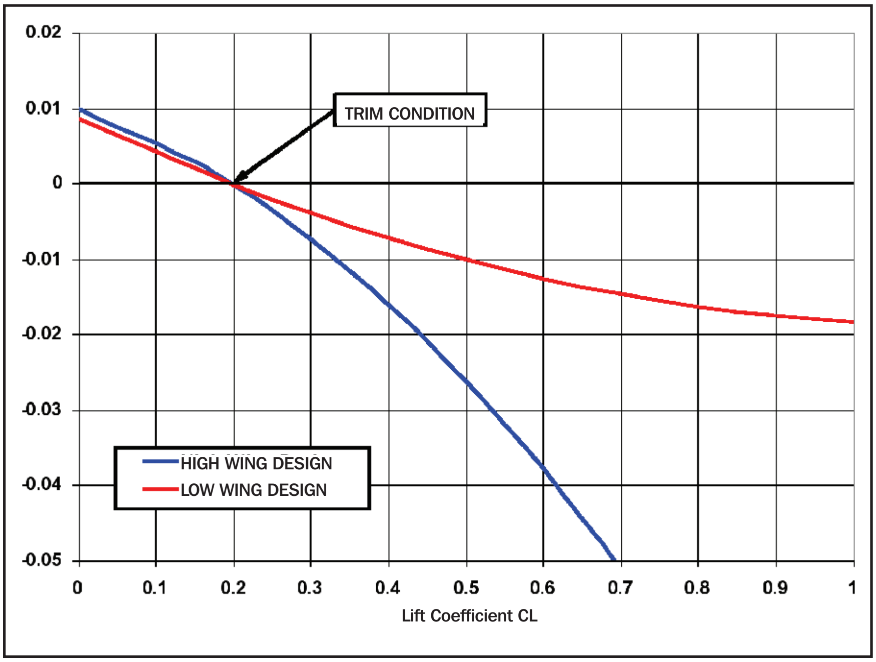

Figure 3. Pitching moment comparison for a low-wing and high-wing airplane designed for the same stability at a lift coefficient of 0.2.

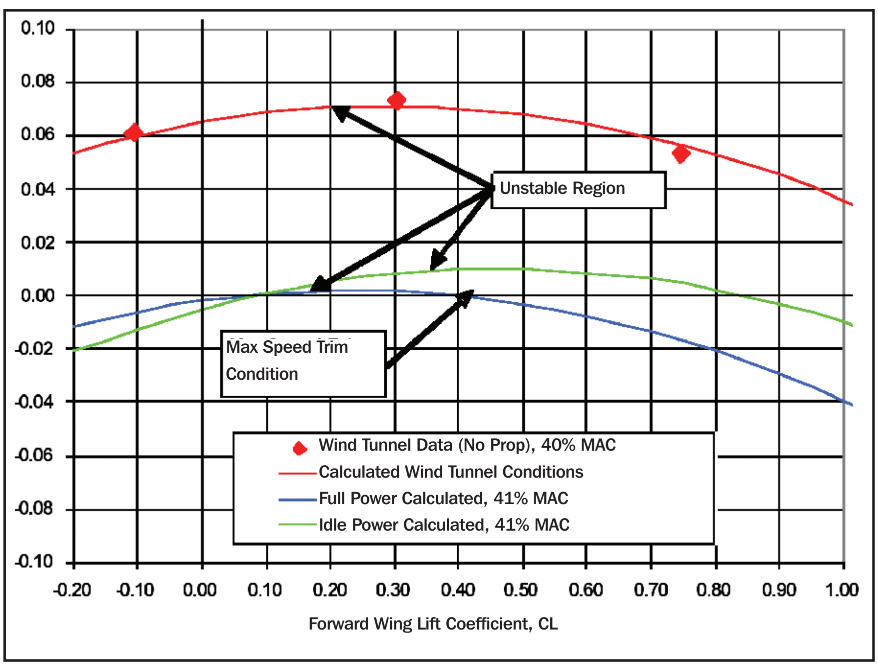

Figure 4. Mignet HM-14 Pitching Moment Curves

descents. Their benign stall characteristics and the rear wing's additional induced drag helps make this possible. One of Mignet's followers, Louis Cosandey, added a narrow upward-deflecting flap to the rear wing of the Fleas he built. This flap allows the Flea to fly at a higher angle of attack to better take advantage of its ability to do parachute descents.

Different means have been used over the years to provide pitch control on tandem wing designs. Some have used elevators on the rear wing. The Rutan Quickie and its two-seat derivatives had an elevator on the forward wing. Mignet instead used a pivoting forward wing because it gave him the direct and immediate control he preferred. Mignet correctly understood that a pivoting wing should require a pull force on the control stick to slow the airplane down. He accomplished this by locating the wing's pivot point ahead of the wing's aerodynamic center.

Figure 1 shows the basic formula Mignet and his followers used over the years. This arrangement requires that the pilot continually pull back on the stick, which required about 7 pounds of force on the HM-14, according to Mignet. This pull force is proportional to the load factor experienced by the airplane, so for the HM-14 the pull force would increase from 7 to 14 pounds when going from 1g to 2g flight conditions.

The Flea designer can tailor this pull force by careful selection of the hinge location and control stick length, but it probably should not be less than 5 pounds, which is the minimum stick force per g the FAA allows for certificated airplanes. Having to continuously pull back on the stick is not desirable for most pilots, so many Fleas are either equipped with an adjustable spring attached to the control stick to pull it back or trim tabs on the forward wing to relieve the stick force.

Mignet also realized that using a conventional airfoil on the forward wing would result in a pull force on the control stick that increased rapidly at higher airspeeds. This is because most airfoils have a negative pitching moment that tries to rotate the leading edge down and the trailing edge up.

Using a stable airfoil—one that has a low or positive pitching moment—greatly reduces or eliminates this additional stick force. Figure 2 shows the airfoil Mignet developed for the HM-14. It had the desired slightly positive pitching moment, but as we will see shortly, it likely contributed to the

HM-14's problems.

Most Fleas designed after the HM-14 used either the NACA 23012 or 23112 airfoil. The 23112 is basically a 23012 airfoil with some reflex added to the camber line to give it a slightly positive pitching moment. A zero or positive pitching moment airfoil is also desirable on the rear wing, and as mentioned earlier, Fleas often used the same airfoil and chord width on both wings. This is not mandatory, though, since the rear wing never experiences a high maximum lift coefficient. A symmetrical airfoil section could be used instead.

Mignet did not use ailerons because he wanted to reduce the chance of entering a spin. Roll control was obtained by using a large rudder and excessive wing dihedral. When the rudder was deflected, the airplane would yaw and the excessive dihedral combined with its short wingspan induced a roll in the desired direction. Mignet believed that the airplane should be completely controlled by the stick, and therefore did not use foot pedals for the rudder.

The major drawback of this two-axis control system is the inability to handle any significant crosswind on takeoff or landing. This was not much of a problem in Mignet's day because most pilots flew from large pastures instead of from narrow runways. Modern day Flea fliers either put up with this limitation, or equip their ships with roll spoilers or ailerons on the rear wing.

Trouble Unmasked

So how could a design that was so easy to fly hide a problem that killed some of its pilots? There were several contributing factors. The first was the impact that the vertical CG location has on the airplane's stability. An airplane's horizontal CG location has the biggest influence, but the vertical CG location affects stability as well.

The impact of vertical CG is a both a function of the forward wing's lift coefficient and the vertical CG's location with respect to it. When the CG is below the wing (like on a high-wing airplane), the effect is stabilizing, but is destabilizing for a low-wing airplane. This can be seen by the shape of the two curves in Figure 3, which shows the pitching moment curves for a high- and low-wing airplane designed to have the same level of stability at a lift coefficient of 0.2.

Trimming the airplanes for any other condition would move these curves up or down until the curves crossed the zero pitching moment line at the new lift coefficient.

If we draw a line tangent to these two curves at the trim condition

The HM-18, Mignet's 1936 design that incorporated the lessons learned from the HM-14. Mignet's subsequent designs had this same general look.

shown, they would both be sloping down and to the right. This is good, as the downward slope indicates a stable airplane, and the steeper the slope, the greater the stability. A horizontal tangent line indicates a neutrally stable airplane, and a tangent line with an upward slope means an unstable airplane.

Note how the high wing's curve gets steeper for higher lift coefficients and the low wing's curve gets shallower. This indicates that a high wing airplane's stability increases, and would therefore feel "heavier" in pitch when operated at higher lift coefficients (like those experienced when flying in the pattern). The low-wing design would be the opposite, and feel "lighter" in pitch flying under the same conditions. Low-wing airplane designers need to keep this in mind when sizing the horizontal tail to ensure that their design is stable throughout the whole flight regime, not just at cruise.

The HM-14 behaved as a high-wing airplane from a stability standpoint. Figure 4 shows several pitching moment curves for it, with the data points from the British wind tunnel test shown along with a calculated curve using the spreadsheet for comparison. The pitching moment curve shows the characteristic shape of a high-wing airplane. It also indicates that the design was neutrally stable at a coefficient of lift (C_L) of 0.3 and was unstable below that.

The blue curve shows the calculated HM-14 stability at the CG location shown in Mignet's book and at full power. Drawing a line

The HM-1100 CORDOUAN is the most recent design from the Mignet Aircraft Co. A true three-axis airplane, it has ailerons on the rear wing.

tangent to the max speed trim condition would show that it was slightly stable. At any speed slower (indicated by a higher C_L), the airplane's stability increased.

If the airplane were put in a dive, the stability would become neutral or negative. Pulling back on the power would have made matters worse, as the high thrust line provided a stabilizing effect. This can be seen by the green curve, where a tangent line drawn on the curve at any lift coefficient lower than the maximum speed point would indicate that the airplane was unstable. The pilot who didn't understand what was happening could quickly lose control in this situation.

The HM-14 pilots who lost control entered a dive from which they couldn't recover. The wind tunnel tests showed that the airplane in its original configuration did not have sufficient pitch authority to recover from a dive if the angle of attack went below -15 degrees. The logical solution was to increase the travel of the forward wing. This was done, but it did not totally fix the problem.

The sharp leading edge airfoil used on the HM-14 had a poor maximum lift coefficient that would not let the forward wing generate enough lift to pull it out of a dive. All subsequent Flea designs used the airfoils mentioned earlier to avoid this problem.

The last flaw of the original configuration was that it used a single cable to control the wing. In normal flight, this would be okay, as the wing lift would result in tension on the cable. However, once in a dive, the Flea could get to an angle of attack where the lift on the forward wing was zero or negative, and the cable would go slack. The unfortunate pilot then had no means to control the wing when it was needed the most. All subsequent Fleas used a rigid tube to control the wing.

After much trial and error, Mignet succeeded in developing a spin-proof, easy-to-fly airplane. Its ability to do parachute style descents was a bonus feature. The Flea configuration has unique advantages that are still worth considering today. Had the original Flea's flaw been uncovered and fixed before anyone got hurt, we might all be flying Fleas today.

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