Montgomery's Wing

Montgomery's theories of aerodynamics and their practical implementation were very advanced for the times. In his patent on "Improvements in Aeroplanes" (No. 831,173, Sept. 18, 1906), he clearly explains the function and special shapes chosen for his wings ("aeroplanes") that he discovered during his numerous experiments in air and water prior to 1893 (*emphasis added, examined in detail below*):

(page 2, lines 63-77): "These results are based upon the essential character of a wing-surface. Investigation has shown me that *a wing is a specially-formed surface placed in such a position as to develop a rotary movement in the surrounding air*. This position is determined by mathematical considerations. The various requirements of gliding are met by changes in various parts of the wing. The movements in the air are of such a nature as to make it possible to separate the wing-surface, as I have done in my in my device, into front and rear sections and maintain the special rotary movement of the air which lies at the basis of this phenomenon."

(page 2, lines 128-130; page 3 lines 1-42): "Heretofore I have described *the wing-surfaces as being curved in cross-section, the best form being parabolic*. It must now be noted that for the best results the form of each side of each wing-surface is specialized as follows: All the fore-and-aft or cross sections are parabolic curves; but *those curves nearer the center are most inclined to the path of movement and thence toward their ends the inclination is gradually decreased, thereby producing a sinuosity of the wing*, as shown in Figs. 3 and 5, which is the normal surface from which the various changes are made. In addition to this adjustment or arrangement *the curved cross-sections, beginning about two-thirds from the center, are less sharply curved in front, and so continue decreasing in sharp curvature to the ends*. This is shown in Figs. 4 and 5, wherein the successive sections 1, 2, 3, and 4 show the gradual cutting off at the front of the sharp beginning of the several parabolic curves. The first of these arrangements–namely, the gradual change in inclination of the cross-curves to the path of movement–is for the purpose of properly meeting and cutting the rising current of air immediately in front of the wing-surface, analysis and experiments having shown that the action of the under surface of a wing is to cause an ascending current of air immediately in front of the wing-surface, this ascending tendency being greatest at the center and gradually diminishing toward the tips. The second arrangement–namely, the diminishing curvature near the ends of the wing–of the forward end of the curves is for the same purpose, but is rendered necessary by the fact that if the foregoing adjustment of the surfaces were continued to the end the sharp curvature of the front edge would force the rear portions of the surface into a too abrupt position relative to its path, thus building up a large unnecessary resistance to the forward movement."

The figures below, from the patent, show the details of Montgomery's tandem-wing glider (the *Santa Clara*). Note the complexity of the wing, especially the change in inclination, curvature and depth of the wing from the center to the ends (Figs. 4 and 5).

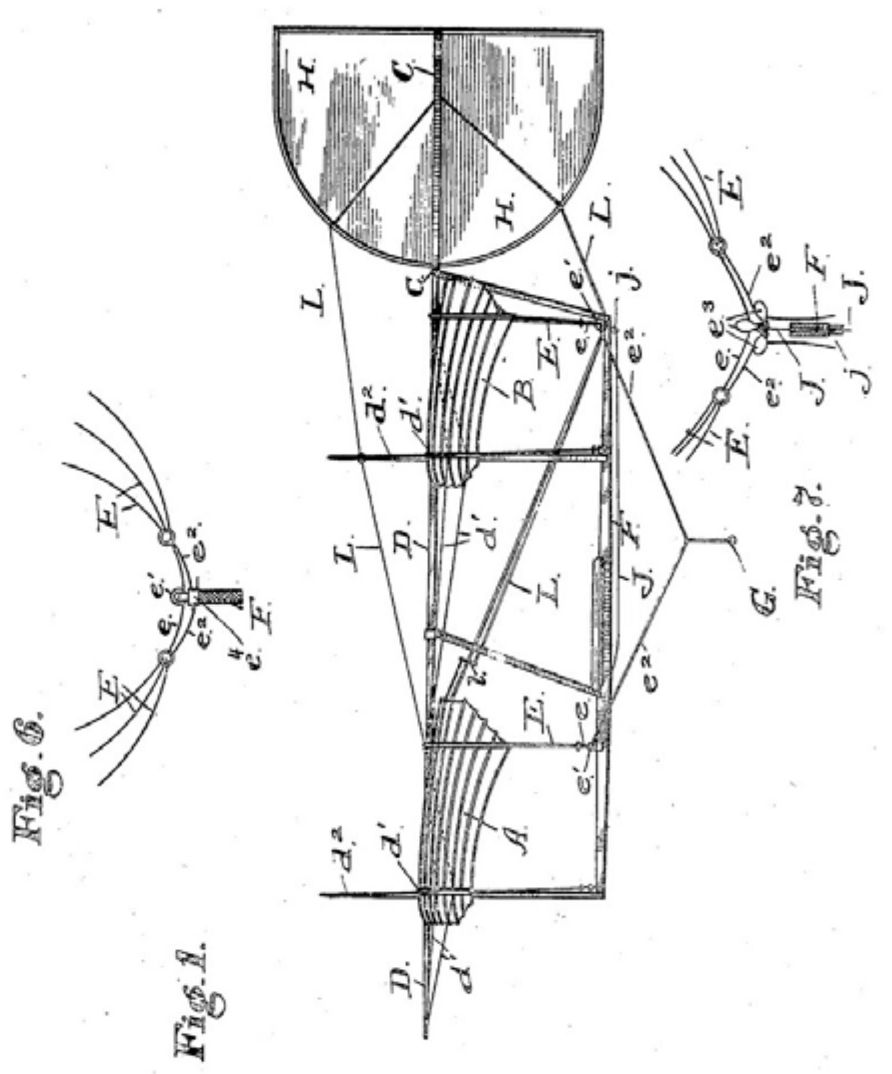
No. 831,173. PATENTED SEPT. 18, 1906.

J. J. MONTGOMERY.

AEROPLANE.

APPLICATION FILED APR. 26, 1905.

3 SHEETS—SHEET 1.



Witnesses.

Arthur L. Slee.

J. Compton.

Inventor.

John J. Montgomery

by Wm F. Booth

his Attorney.

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3 SHEETS—SHEET 3.

Fig. 3.

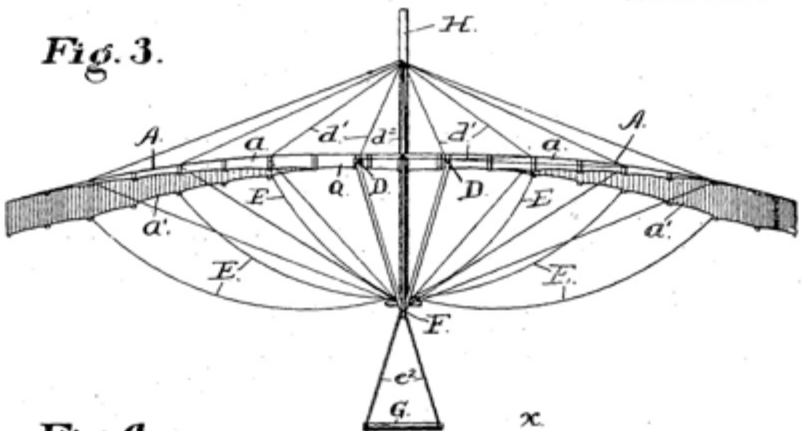

Fig. 4.

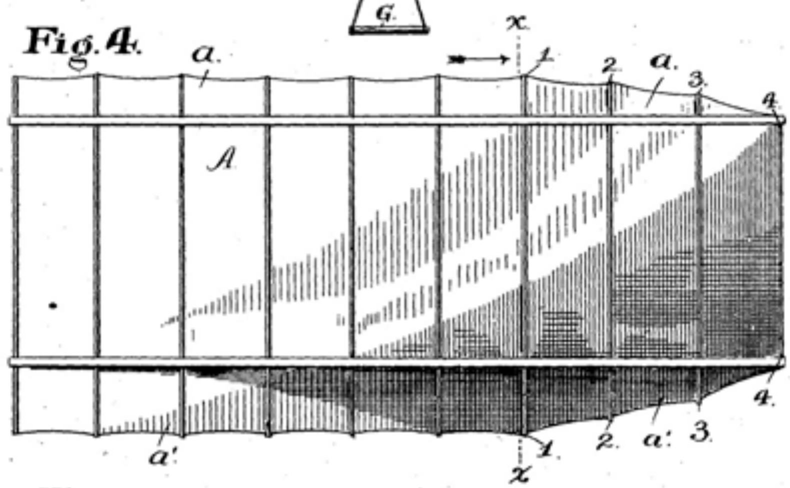

Fig. 5.

Inventor.

Witnesses.
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J. Compton.

John J. Montgomery
by Wm F. Booth
his Attorney

We see that there are four essential features of these wings, listed below. Features 1 and 2 explain the basic function and shape of the wings. Features 3 and 4 provide important details for improved efficiency.

1. " … a wing is a specially-formed surface placed in such a position as to develop a rotary movement in the surrounding air."
2. "… the wing-surfaces … (are) curved in cross-section, the best form being parabolic."
3. " … those curves nearer the center are most inclined to the path of movement and … toward their ends … is gradually decreased, thereby producing a sinuosity of the wing …"
4. "In addition to this … the curved cross-sections, beginning about two-thirds from the center, are less sharply curved in front, and so continue decreasing in sharp curvature to the ends."

Feature 3, "the gradual change in inclination" is chosen to provide "an ascending current of air immediately in front of the wing-surface …(that is) greatest at the center and gradually diminishing toward the tip." Feature 4, "the diminishing curvature near the ends of the wing" is necessary to avoid "building up a large unnecessary resistance to the forward movement."

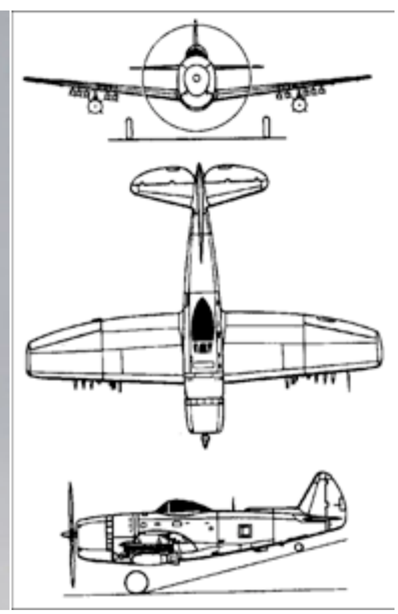
The planform (the silhouette of the wing when viewed from above or below) of Montgomery's wing is a truncated version of what is termed an "elliptical wing." An elliptical taper to a wing "shortens the chord near the wingtips in such a way that all parts of the wing experience equivalent downwash, and lift at the wing tips is essentially zero, improving aerodynamic efficiency due to a greater Oswald efficiency number in the induced drag equation. The elliptical wing was first used on aircraft in the 1930s, but has only seen limited use, for a number of reasons:

- the compound curves involved are difficult and costly to manufacture,
- the pure elliptical shape as a superior planform may be a myth. A truncated ellipse, same span, same area, has, for all practical purposes, the same induced drag. …"

Source: Wikipedia (http://en.wikipedia.org/wiki/Elliptical_wing)

“A rectangular wing produces much more severe wingtip vortices than a tapered or elliptical wing, therefore many modern wings are tapered. However, an elliptical planform is more efficient as the induced downwash (and therefore the effective angle of attack) is constant across the whole of the wingspan. Few aircraft have this planform because of manufacturing complications — the most famous examples being the World War II Spitfire and Thunderbolt. Tapered wings with straight leading and trailing edges can approximate to elliptical lift distribution. Typically, straight wings produce between 5–15% more induced drag than an elliptical wing.”
Source: Wikipedia (http://en.wikipedia.org/wiki/Lift-induced_drag)

Shown below are the planes mentioned above: the *Supermarine Spitfire* with a true elliptical wing and the *Republic P-47 Thunderbolt* with a truncated elliptical wing, similar to Montgomery’s of three decades earlier.



Supermarine Spitfire, 1936 *P-47 Thunderbolt*, 1941

Alexander Klemin, an aeronautical engineer and head of the Aeronautics Dept. at MIT provided this assessment of Montgomery’s achievements (on December 20, 1919):

"It is really extraordinary how much Montgomery knew of the fundamental principles of aerodynamics at this early stage. He possessed substantially a great deal of the knowledge which we do after lengthy and refined investigations. ... The following sentence in his patent is also worthy of note: 'A wing is a specially formed surface placed in such a position as to develop a rotary movement in the surrounding air.' The presence of this rotary movement is not, as a rule, known to even experienced engineers, although such eminent men as Kutta, Jukowski, Prandtl, and Lanchester have deduced its presence from theoretical considerations. Vortices have been photographed in a newly constructed tunnel at McCook Field, and vortices can be clearly seen at high-speed flow. Montgomery also speaks of an ascending current of air immediately in front of the wing surface. We know that this exists and provides suction on the upper surface of the wing. He states also that this ascending tendency is greatest at the center and gradually diminishes at the tips; ... It is for this reason also that wings are narrowed down at the edges, as Montgomery has done in his patent. And in this as in other features, Montgomery shows a precocious knowledge of the art." Klemin also noted that most remarkable was John J. Montgomery's: "Special design of the main sustaining surface which in addition to its curvature has a diminishing camber toward the end of the wing while the tip of the wing has a gradually diminishing chord."

Source: Spearman, pages 135-136.

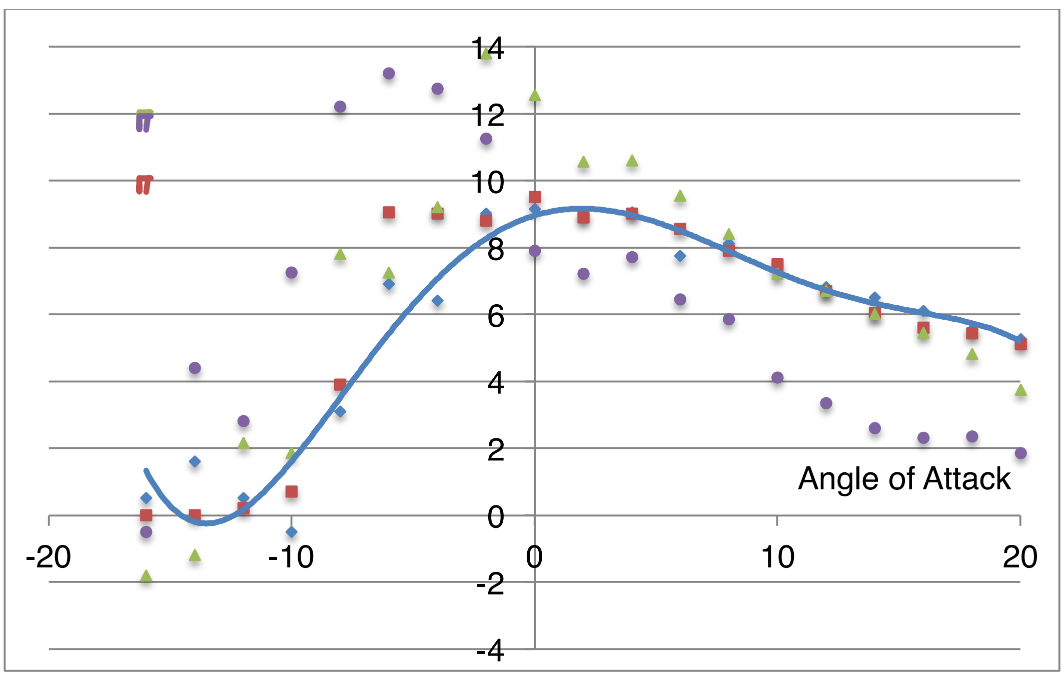
Our estimate of the performance of Montgomery's wing sections is given in the figure below. The Lift-to-Drag Ratio (L/D) is seen to vary with wing section and angle of attack, as expected. For the entire wing we estimate that L/D is approximately 10 at 0^o angle of attack, equivalent to that of a Herring gull and about one-third greater than that of a Cessna 150. The tip wing section (#4), as Montgomery had planned, has 25% less Drag than the central section (#1) at small angles of attack. It also has 40% less Lift since it is a flatter wing. (Separate Lift and Drag curves are not shown.)

Lift-to-Drag Ratio

WING SECTION 1 WING SECTION 2

WING SECTION 3 WING SECTION 4

Curves are 5^{th}-order polynomial fits



We also estimated the performance of Montgomery's *Santa Clara* machine with its tandem-wing arrangement, having two identical wings, one behind the other (see figures above, from the patent). We have found that both the Lift and Drag are increased by 75%

over that of the single wing (evaluated above) while retaining the same Lift-to-Drag Ratio.

Sources: Lift and Drag were computed with the iPhone/iPad "Wind Tunnel Pro" app of Guillaume Rizk that "simulates fluid dynamics assuming incompressible and homogeneous fluid with the Navier Stokes equations" (http://algorizk.com/windtunnel/). Comparison with a Herring gull and a Cessna 150 are from Wikipedia (http://en.wikipedia.org/wiki/Lift-to-drag_ratio), June 2012.

Everett Vail Church, in a letter to James P. Montgomery, dated Nov. 23, 1940, commented on Montgomery's tandem-wing arrangement of his wings:

> "In the Montgomery glider, the pilot had as perfect control, if not more perfect than anything which has since been built; but there is another feature first incorporated in the Montgomery design which in my humble opinion is destined to become one of the most important contributions to science; and the most amazing fact is, that through all these years, not a single designer, with the exception of this writer, seems to appreciate it's [sic] significance. I will say that Professor Langley did recognize this important feature; for he certainly adopted it. I refer to the tandem arrangement of surfaces which forms what we call a 'Correcting couple' because by this arrangement, we get inherent longitudinal stability, which is 100% automatic. The plane can be flown 'hands off', continuously.
>
> "The aeronautical engineers passed this up years ago with the simple explanation that the rear wing of the tandem surfaces is working in disturbed air, and therefore is ineffective etc. etc., but they locked their minds and threw away the key – for they never have given a single further thought to the possibility of retaining the principle, but altering the design. That is exactly what I did in 1910, and strange as it may seem, I have never since that date been in a financial position to build the complete full-size plane. I have built several carefully designed models, and my own wind-tunnel tests prove conclusively that the

design is considerably more efficient than any design I know to exist today. That is saying a great deal; nevertheless it is a fact.”

Source: Santa Clara University Library Archives & Special Collections Department.

See also Spearman, pages 140-141, where E. Vail Church says in a letter to Secretary-Santa Clara College [sic] dated Aug. 3rd, ’39: “His basic principles of longitudinal stability, by making use of so-called ‘following surfaces’ to form a correcting couple, are the means by which we are able to produce a machine which is inherently stable and able to continue in level flight without any assistance from the pilot or gyroscopic device or other mechanical controls.”