Oct. 28, 1930. W. F. GERHARDT 1,779,842

SUSTAINING WING STRUCTURE

Filed July 20, 1925 2 Sheets-Sheet 1

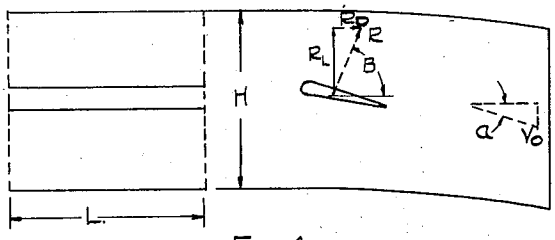


FIG. 1

THE FLOW SCHEME FOR A FINITE SECTION OF AN INFINITE AEROFOIL THE FLOWSTREAM AREA

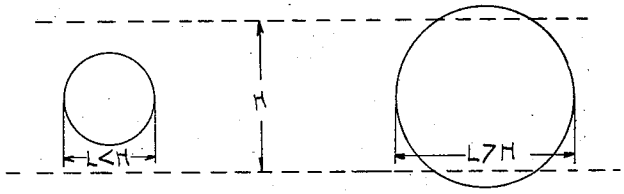


FIG. 2a. FIG. 2b.

THE FLOWSTREAM AREA OF A FINITE MONOPLANE CELLULE.

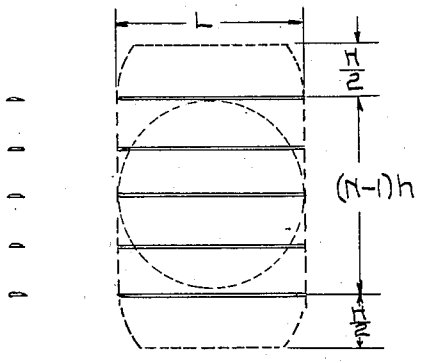


FIG. 3a. FIG. 3b

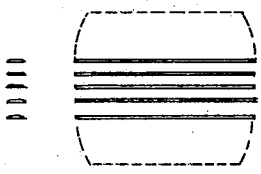


FIG. 4a. FIG. 4b.

COMPARISON OF MULTIPLANE WITH ORDINARY MULTIPLANE

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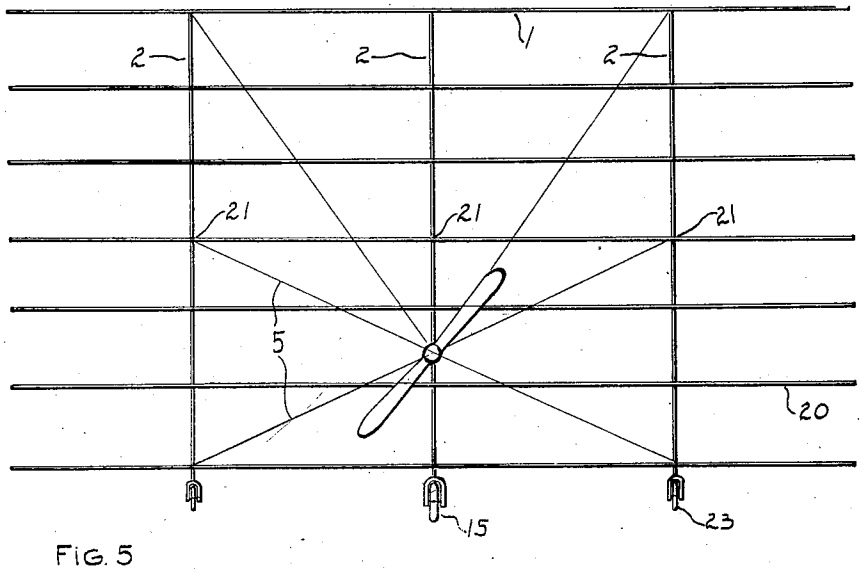


FIG. 5

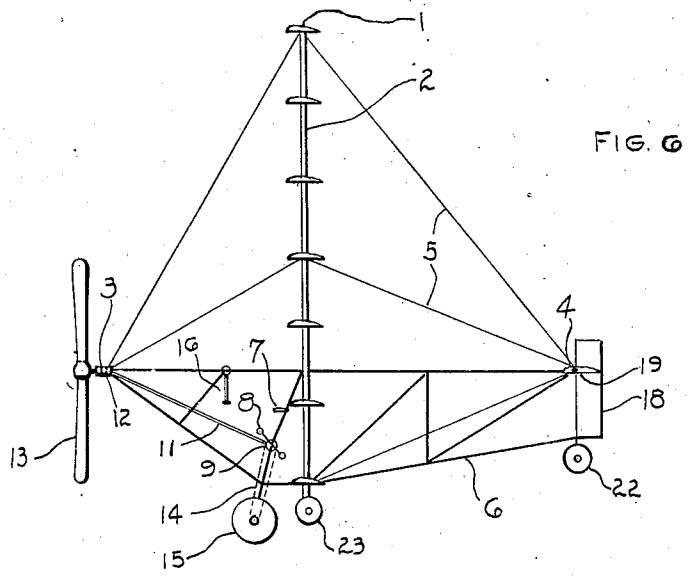


FIG. 6

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UNITED STATES PATENT OFFICE

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SUSTAINING WING STRUCTURE

Application filed July 20, 1925. Serial No. 44,645.

This invention relates to sustaining wing cellules, and the primary object of the invention is the proper dimensioning and proportioning of the sizes of the wings and the spacing between the wings.

My invention includes the positioning size and shape of the wings of a wing cellule so that maximum efficiency of an airplane or other aircraft, upon which the invention is applied, may be obtained. This may be done by suitably choosing the number of planes, the chord length, the total sustaining area and the overall length of the planes, so that

$$\frac{F_m N_b}{AL}$$

is greater than 1 which is the ultimate limit to which the present day airplanes have been carried. The ratio just mentioned, in accordance with my invention, may be increased above the hitherto known values, so that the efficiency of a wing cellule built in accordance with my invention may be increased at least twenty-five or fifty percent. In the formula mentioned, F_m is equal to the cross section of air downwardly displaced, or in other words, the flow stream area, N is the number of planes in the cellule which are spaced one above the level of the other, b is the chord length, A the total area of the wings of the cellule and L the overall length or the lateral extent of a plane.

It has been found that if the vertical spacing between the wings of a wing cellule is increased above values which have previously been used and if the chord length is decreased and the total number of planes of the cellule increased over values of present day construction, an increased efficiency for a given area of wing surface will result. It has been found that the vertical spacing between adjacent planes in a cellule divided by the chord length should be greater than 1½ and best results are obtained by having this ratio between 2 and 5, and in most constructions in the neighborhood of 2½. It has also been found that the overall height of the cellule divided by the lateral length of a plane of a cellule should be between the limits of ⅙ and 1½ and usually between ½ and 1. These ratios between the spacing between the planes, the chord length and the lateral length of the planes, are governed to some extent by the chord length which should be such that it is not in the region of viscous drag, or in other words, it should not be too close to the point where the drag, due to viscosity, starts to mount rapidly. Another governing feature is the height of the wing cellule, since the wing cellule should ordinarily be made much higher than present day practice, it should not be carried to such extremes as to result in a plane which is of excessively great height as compared with its overall width.

A further object and advantage of my invention is the provision of a method by which the proper sizes and dimensions and relative positioning of planes of a wing cellule may be arrived at.

My invention is of very great advantage for use in manually propelled aircraft or in aircraft of the comparatively light and low powered type, although it is not intended that it should be restricted to such. In manually propelled aircraft, it is highly desirable and in fact absolutely necessary to obtain maximum efficiency from the sustaining surface employed.

Further objects and advantages of my invention will be more fully discussed in the following specification, in the attached drawings and in the claims.

In the drawings, Fig. 1 shows the flow scheme for a finite section of an infinite length airfoil. In this case the shape of the flow stream area is approximately a rectangle due to its great length and comparatively small vertical extent.

Fig. 2[a] and Fig. 2[b] show the flowstream area

of a monoplane cellule of a finite length, Figure 2^a showing an embodiment where the length is less than the height of the flowstream, and Figure 2^b showing the embodiment where the length L is greater than the height H of the flowstream.

Fig. 3^a and Figure 3^b represent diagrammatically a side elevation and front elevation respectively of a multiplane constructed in accordance with my invention and show the extent of the flowstream area in the dotted lines in Figure 3^b.

Figures 4^a and 4^b represent diagrammatically a side elevation and a front elevation respectively of multiplanes constructed in accordance with present day practice and show the comparatively small distance between the wings as compared with the chord length.

Figures 3^a, 3^b, and 4^a and 4^b show a comparison of the multiplane built in accordance with my invention with ordinary multiplanes or those of the present day construction.

Figure 5 is the front elevation of a manually driven airplane of the semi-glider type and

Figure 6 is a side elevation corresponding to Figure 5.

There are a number of items of airplane performance which it is the aeronautical engineers' task to improve.

(1)	High speed	(V_h)
(2)	Landing speed	(V_L)
(3)	Limiting load	(W_L)
(4)	Ceiling density	(D_c)
(5)	Radius of turn	(R_m)
(6)	Cruising radius	(R_c)
(7)	Cruising endurance	(T_c)
(8)	Minimum power	(P_m)

The first of these items (1), depends principally upon the drag at zero lift or the profile drag (K_p), and is a complicated function as

$$(1)\quad V_h^2=\frac{C_1}{K_p+C_2}$$

where C_1 and C_2 are constants.

The second is a function of the maximum lift and can be expressed as

$$V_L^2=\left\{\frac{W_o+W_c}{F_m}\right\}C_3$$

where W_c is the weight of the airplane cellule, W_o the remaining weight of the airplane, and F_m is the flow stream, or the cylinder of air "caught" or deflected downward by the wing or wings, see Fig. 1, and hence utilized to produce lift, and C_3 a constant. All the others are principally functions of the induced resistance and of the quantity

$$\left(\frac{W_o+W_c}{F_{m^{\frac{1}{2}}}}\right);$$

for example the minimum power (8) is

$$(8)\quad P_w=22K_{p^{\frac{1}{2}}}\left(\frac{W_o+W_c}{P_{w^{\frac{1}{2}}}}\right)^{3/2}$$

where K_p is the profile drag above stated.

The main idea of this invention is to secure low values of the quantities

$$\frac{W_o+W_c}{F_m}$$

and hence

$$\frac{W_o+W_c}{F_{m^{\frac{1}{2}}}}$$

by special arrangement of the cellule, and thus improve the performances (2) to (8) inclusive, while not affecting the speed (1). This is a combined aerodynamical and structural problem.

The aerodynamical problem is to secure a large value of the flow stream area (F_m) for any given cellule area (A). Let us consider briefly how this can be done.

Fig. 1 shows a length L of a monoplane airfoil of infinite span. It produces reaction R by virtue of giving to a layer of air of height H and speed V_o a downward deflection angle a and since this reaction is inclined slightly to the vertical, through the lift, R_L is nearly equal to the total R, the drag R_D is proportional to BR. Starting from this basis the values of the first mentioned performances are derived. In this respect reference is made to "New aerodynamical conceptions and formulæ"—"International Math. Congress", August 1924, and "General theory of the constant speed motion of the airplane" University of Michigan, 1923, dissertations by the inventor.

For any length L, the flow stream area F_m is thus HL. Now this practical height H is dependent on the dimensions of the profile, principally of the chord (b), secondarily of the camber (c). (9) $H=mb$ where m is a constant for any given camber, thus the flow stream area F_m (10) $F_m=mbL$.

For a monoplane of finite length i. e. a length which is large with respect to the chord $\left(\text{small aspect ratio } \frac{L}{b}\right)$ the "tip vortices" act to "constrict" the stream to a circular form. Hence if the height $H=mb$ is larger than the span, see Fig. 2^a, we have

$$(11)\quad F_m=\frac{\pi}{4}L^2.$$

The intermediate case as shown in Fig. 2^b is where the span is larger than the height $H=mb$. In this case the flow stream area is approximately a circle cut off at the top by limiting lines, distance H apart, or a combination of a rectangle and circular segments. Thus

$$(12)\quad F_m=\frac{L^2}{2}\sin^{-1}\frac{mb}{L}+mbL\sqrt{1-\left(\frac{mb}{L}\right)^2}$$

When we have a multiplane or more than one plane, the flow stream area increases, just as if (Fig. 3) we split the wing, separated the halves of the monoplane flowstream and added the included area. Thus if we have N planes spaced at gap h, the included area is $(N-1)hL$ and the flowstream becomes

$$(13)\quad F_m=\frac{L^2}{2}\sin^{-1}\frac{mb}{L}+mbL\sqrt{1-\left(\frac{mb}{L}\right)^2}+(N-1)hL$$

This gives the flowstream area F_m in function of all the main dimensions (h, b, L, N) of the cellule.

The problem is usually to find out how a given area $A=NbL$ and span L (the same span being the basis of comparison), can be best disposed. Dividing (13) by (14) $A=NbL$ we get

$$(15)\quad \frac{F_m}{A}=\frac{L}{2Nb}\sin^{-1}\frac{mb}{L}+\frac{m}{N}\sqrt{1-\left(\frac{mb}{L}\right)^2}+\frac{(N-1)}{N}\frac{h}{b}$$

which tells how the dimensions must be disposed to get the maximum effect of the wing area A. It is evident from this that if we make the number of planes large, and the gap large at the same time, this value of $\frac{F_m}{A}$ can be made larger than is present day practice. From Figure 3[b] we simply stretch out the flowstream area from a circle of diameter L to a special figure of the form shown in full lines. Or applying the same reasoning to a multiplane, we stretch out the flowstream from the value which it would have for small values of the gap cord $\frac{h}{b}$ of prior constructions as shown in Figures 4[a] and 4[b], to the values shown in Figure 3[b].

Thus the problem is twofold, first to divide the total chord available (16) $Nb=\frac{A}{L}$ into the proper number of planes and dispose them at proper height. If the multiplane should be used in preference to the monoplane we gain the included area between the wings. A subsidiary reason is with smaller chords wings of larger camber and hence larger values of m can be made. Large gaps $\frac{h}{b}$ should be used to gain the maximum advantage of the included area.

The advantage which the invention shows over prior design, that is in the flowstream loading or the flowstream area F_m, must be expressed in terms of a base value which does not change with span. We will take the equivalent monoplane of chord Nb and length L. From relation (13) we see that for a monoplane of small ratio the equivalent monoplane is $F_m=\frac{\pi}{4}L^2$. Hence the ratio of the flow ratio of a multiplane of any aspect ratio to that of the equivalent monoplane is

$$(16)'\quad f=\frac{4}{\pi}\left(\frac{1}{2}\sin^{-1}\frac{mb}{L}+\frac{mb}{L}\sqrt{1-\left(\frac{mb}{L}\right)^2}+\frac{(N-1)h}{L}\right)=\frac{F_m}{F_{m'}}.$$

There are two limitations to the above. In the first place the wing cannot be too far subdivided (b cannot be made too small) as then the value of K_p starts to increase rapidly due to the "Reynolds effects" or viscous drag region. This region of viscous drag is the point at which the drag starts to mount rapidly with increase of the product bV, where V is the speed at which the plane is to operate. The value of bV is about 30 in ft. sec. units. Thus b greater than $\frac{(bV)}{V}=\frac{30}{V}$. A second limitation is on the height H. There is no use to space the plane more than $h=mb$ as the flowstream no longer increases.

The structural problem consists in the reduction of the cellule weight W_c for a given area A.

This is accomplished, see Fig. 5, in the above system by the decrease of the wire angles, thus decreasing the end loads on the spars due to the pull of the wire and hence the spar sizes. In other words the wing cellule as a whole, which can be considered as a unit truss, in deeper for the same span and area. Thus the value of $\frac{W_c}{A}$ is smaller than for a monoplane or a present day multiplane of the same span.

The aero-structural improvement is thus brought about by these considerations. Thus if the flowstream ratio $\frac{F_m}{A}$ is larger and the weight ratio $\frac{W_c}{A}$ is smaller in the high multiplane than the low multiplane or monoplane, the ratio of these two which we call the flowstream weight loading $\frac{W_c}{F_m}=\frac{\frac{W}{A}}{\frac{F_m}{A}}$ and hence the quantities $\left(\frac{W_o+W_c}{F_m}\right)$ and $\left(\frac{W_o+W_c}{F_{m^{1/2}}}\right)$ will be smaller and all the performances (2) to (8) depending on them improved.

Assuming, however, a given wing section (and hence value of m) and even with no gain in $\frac{W_c}{A}$ then $\frac{F_m}{W_c}$ is proportional to $\frac{F_m}{A}$,

and the gain is at least that given by the formulæ for $\frac{F_m}{A}$.

For example, suppose we consider a special airplane problem such as a manually or pedal propelled airplane in which we desire to make the minimum power for horizontal flight a certain low value equal to that developable by a human individual for a short time. The method of design was as follows: The formula giving minimum power P_w is a function of parasite constant K_p and

$$\left(\frac{W_o+W_c}{F_m^{\frac{1}{2}}}\right)$$

$$P_m=K_p^{\frac{1}{4}}\frac{(W_o+W_c)^{3/2}}{F_m^{\frac{3}{4}}}\cdot 22$$

Now the power developed at the propeller is taken to be 0.9 H. P. or 495 #/sec., K_p was taken to be 10, while W_o the sum of the pilot's weight (150#) plus the fuselage, propeller, etc., allowance (30#) totaled 180#. Further the cellule weight including struts and wires was taken as 70# that is, an area A of 420 sq. ft. at 0.155 #/sq. ft. Hence W_o W_c= 250#. Then substituting in formula

$$(17)\quad 495=22\times(10)^{\frac{1}{4}}\frac{250^{\frac{2}{3}}}{F_m^{\frac{3}{4}}}.$$

Solving for F_m we find F_m=2100 ft. Since the plane was to operate at around 20 ft. per sec. speed and value of bV, should not be less than 30, b was taken as

$$b=\frac{bV}{V}=\frac{30}{20}=1.5\text{ ft.}$$

Further a span of 40 ft. was assumed as a practical housing limit. Then the number of planes was

$$N=\frac{A}{bL}=\frac{420}{1\frac{1}{2}\times 40}=7.$$

A section in which m=16 was then chosen, hence the value of h/b found by substituting in formula (13) and solving for h

$$(15)\quad h=\left[2100-\frac{40^2}{2}\sin^{-1}\frac{16\times 1.5}{40}-16\times 1.5\times 40\sqrt{1-\left\{\frac{16\times 1.5}{40}\right\}^2}\right]\Big/(7-1)40=3.4\text{ ft.}$$

This apparatus is shown in Figs. 5 and 6. The value of F_m/A which could be gotten with the same span area and the same section for other arrangements is shown in Table I. Neither the monoplane nor usual multiplane would have sufficed. The gain in going to the sizes indicated by the invention are more clearly specified by the flowstream comparison

$$f=\frac{F_m}{F_{m1}}$$

given by relation (16′)[1] and also tabulated in the table.

A specific application of the invention (and example cited) is shown in Figures 5 and 6 in which the cellule is combined with a propeller driven by foot pedals through appropriate gearing. This specific application was an embodiment of a man powered glider. The cellule consists of a large number of planes, seven in number, supported by a truss system composed of three vertical struts 2, braced to a forward bracing point 3 and a rear bracing point 4 by twelve brace wires 5. The forward and rearward points 3 and 4 are at the extreme ends of the fuselage truss 6, which consists of dural members all situated in the same central vertical plane of symmetry.

Just in front of the line of the struts a seat 7, pedals 8, and bevel gear and sprocket 9 are fixed to the frame in such a manner that a man can operate them comfortably. From the bevel gear extends a shaft 11 which through a universal connection 12 at the point 3 drives a large size propeller 13. A chain 14 extends from the sprocket 9 to a second sprocket on the main central chassis wheel 15, thus both the propeller and wheel 15 are driven by the pedals. The driven ground wheel is used to launch the machine and the propeller sustains the flight of the machine.

A control stick 16 mounted on a swivel universal joint connects through suitable wires and pulleys to the rudder 18, elevator 19 and ailerons 20 which are at the outer end of one of the lower planes. The struts 2 are jointed at 21 to permit easy assembly and storage.

The propeller is of the automatically variable pitch type. A universal joint or fitting is supplied at the point 3 to form wire pull, propeller bearing, and universal housing combined. There is also a universal fitting at 4 to house the rudder and elevator bearing and act as wire pulls. The rudder wheel 22 supports the rear of the machine and turns with the rudder to steer the machine while on the ground. The wing wheels (23) which just barely clear the ground balance the machine on the drive wheel (15).

It will be seen that the space between adjacent planes is approximately 2½ times the chord length which in this case is about 1½ feet. It will also be observed that the total height of the cellule is about ½ of the total overall length of the wing. This holds true with the particular wing section which was assumed and for the given speed and weight of the plane for which it was designed. In this embodiment the ratio

$$\frac{F_mNb}{AL}=\frac{F_m}{L^2}$$

proved to be about 1.4 which is an expression of the efficiency of the plane and shows how favorably the efficiency has been improved

since the corresponding figures for ordinary prior constructions would be less than unity.

The following table which has already been mentioned is the comparison of the efficiencies of planes built in accordance with my invention with those of prior constructions:

Type of plane	$\frac{F_m}{A}$ $L=40$ Ft.	$f=\frac{4F_m}{\pi L^2}$	$\frac{F_m Nb}{AL}=\frac{F_m}{L^2}$
Monoplane	3.1	1.00	0.78
Prior multiplane constructions	3.6	1.15	0.90
Improved construction	4.7	1.52	1.17

It will therefore be seen that the improvement which has been made by designing the plane in accordance with the features of novelty herein set forth are of very material advantage and are not only applicable to small planes or manually driven craft, but are also capable of consideration and improving the large type aircraft of today.

I am aware that various modifications may be made in my invention and I do not intend that my invention should be restricted to the particular form which has been shown for purpose of explanation.

I claim:

1. An aircraft having a plural number of fixed double surfaced sustaining planes spaced one above the level of the other, the overall height of the planes of said sustaining planes divided by the lateral length of the planes being 1/6 to 2/3, and the vertical spacing of the adjacent planes is greater than the sum of their chord lengths.

2. An aircraft having a plural number of fixed double surfaced sustaining planes spaced one above the level of the other, the space between adjacent planes of said sustaining planes divided by the sum of their chord lengths being substantially 1 to 2½, and the overall height of the planes divided by the lateral length of the planes being 1/6 to 1½, and a propeller in combination with said planes.

3. A manually propelled aeroplane having a wing cellule formed of a number of planes placed one above the other, the space between adjacent planes of said sustaining planes divided by the sum of their chord lengths being substantially 1 to 1½, the height of the cellule divided by the length of the planes is substantially ½, and the number of planes being greater than 2.

4. A manually propelled aeroplane having a wing cellule formed of a number of planes placed one above the other, the space between adjacent planes of said sustaining planes divided by the sum of their chord lengths being substantially 1 to 1½, the height of the cellule divided by the length of the planes is substantially ½, and the number of planes being greater than 2, the chord length being substantially 1½ feet.

5. An aircraft having a plural number of fixed double surfaced sustaining planes spaced one above the level of the other, the space between adjacent planes of said sustaining planes divided by the sum of their chord lengths being substantially 1 to 2½, and overall height of the planes divided by the lateral length of the planes is between 1/6 to 1½.

In testimony whereof I affix my signature.

WILLIAM FREDERICK GERHARDT.