

May 27, 1930.

J. D. VAN VLIET

1,760,386

FLYING MACHINE

Filed May 6, 1926

7 Sheets-Sheet 1

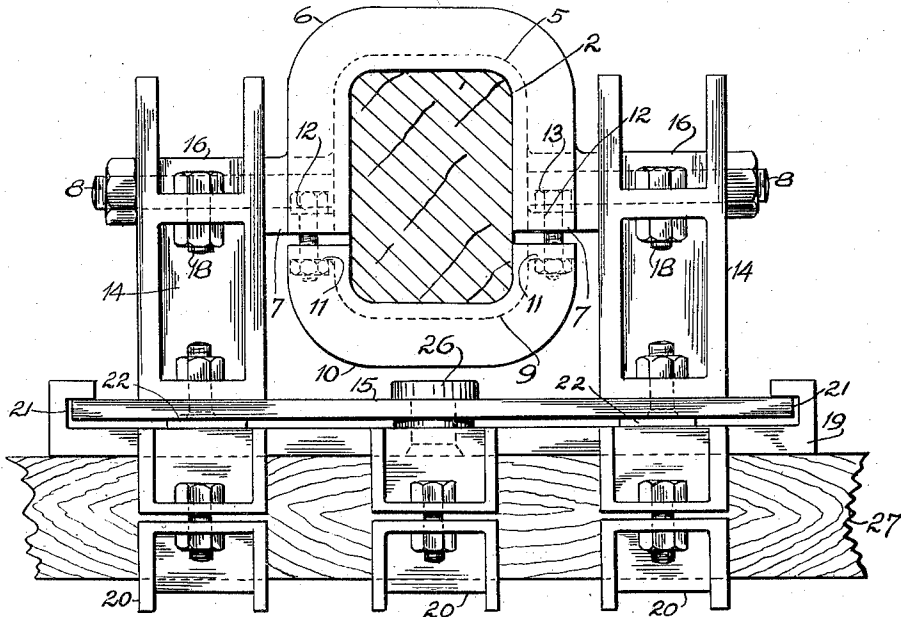


Fig. 1

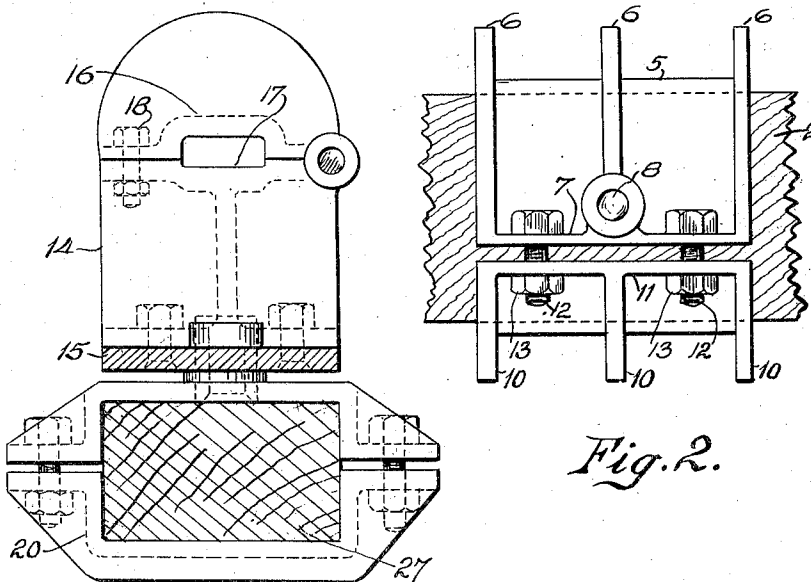


Fig. 2.

Fig. 3.

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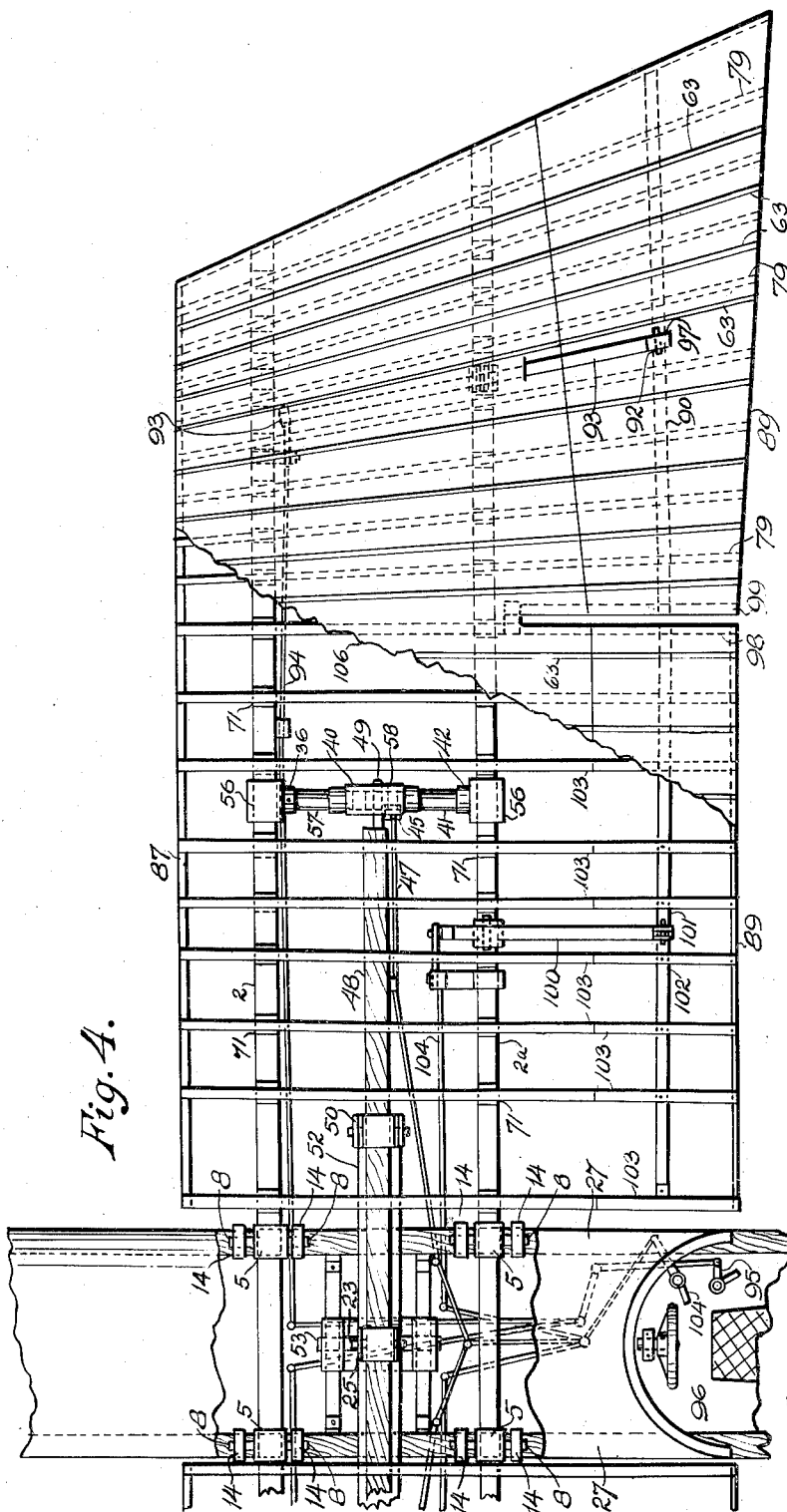
1,760,386

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7 Sheets-Sheet 2

Fig. 4.



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1,760,386

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7 Sheets-Sheet 3

Fig. 5.

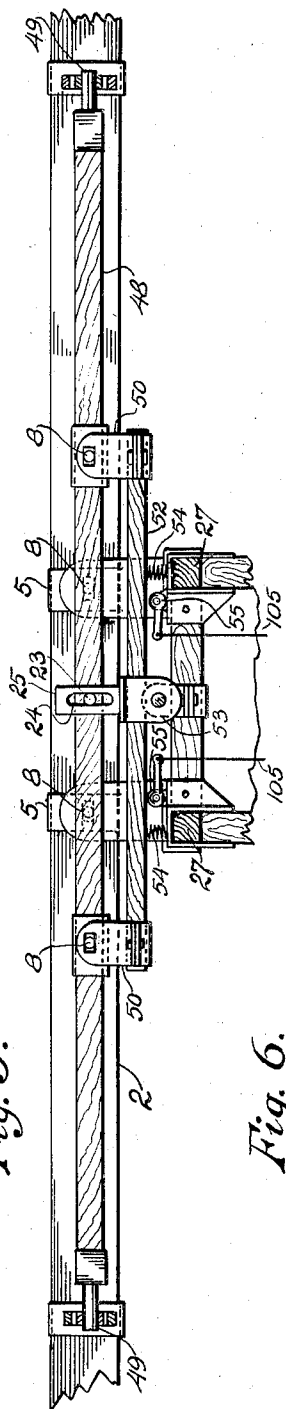


Fig. 6.

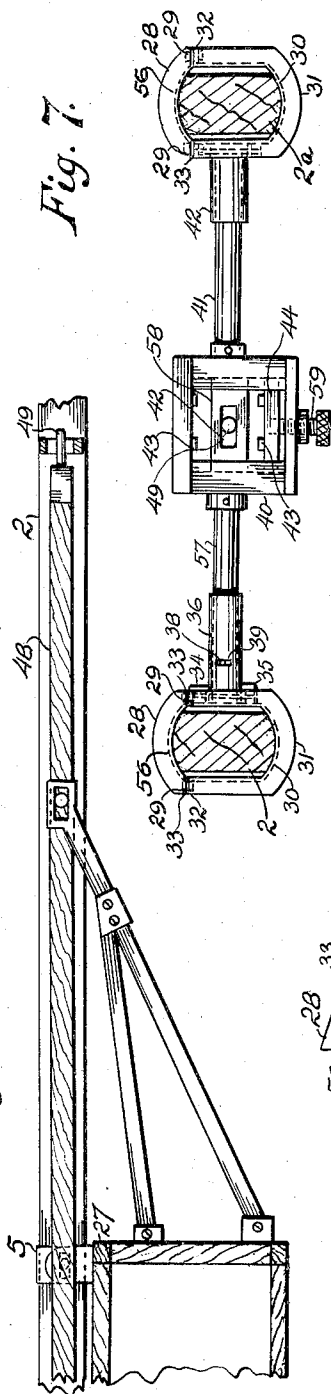


Fig. 7.

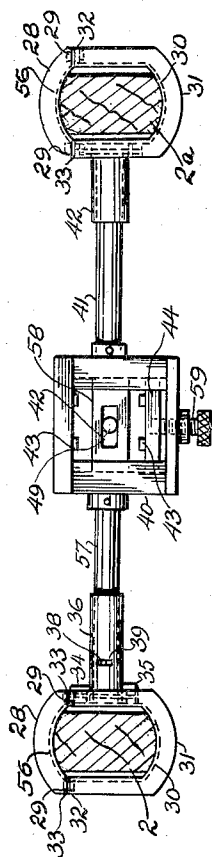


Fig. 9.

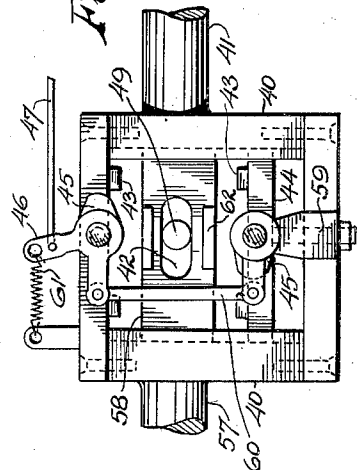
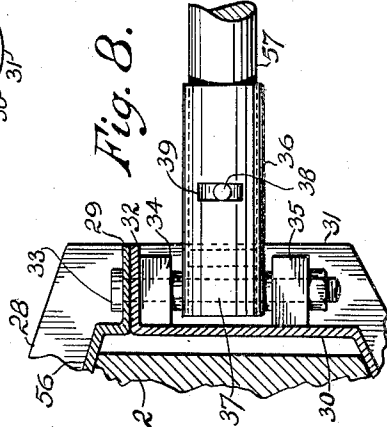


Fig. 8.



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1,760,386

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7 Sheets-Sheet 4

Fig. 11.

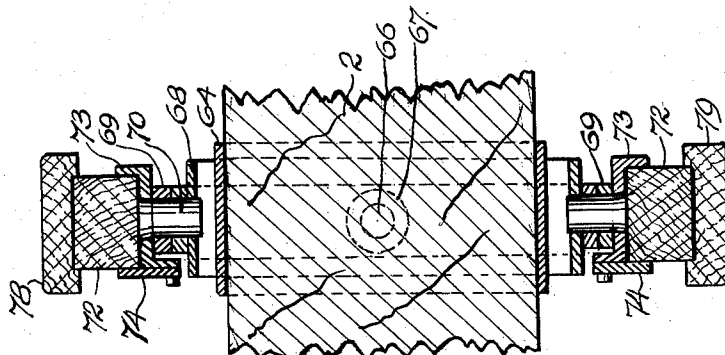
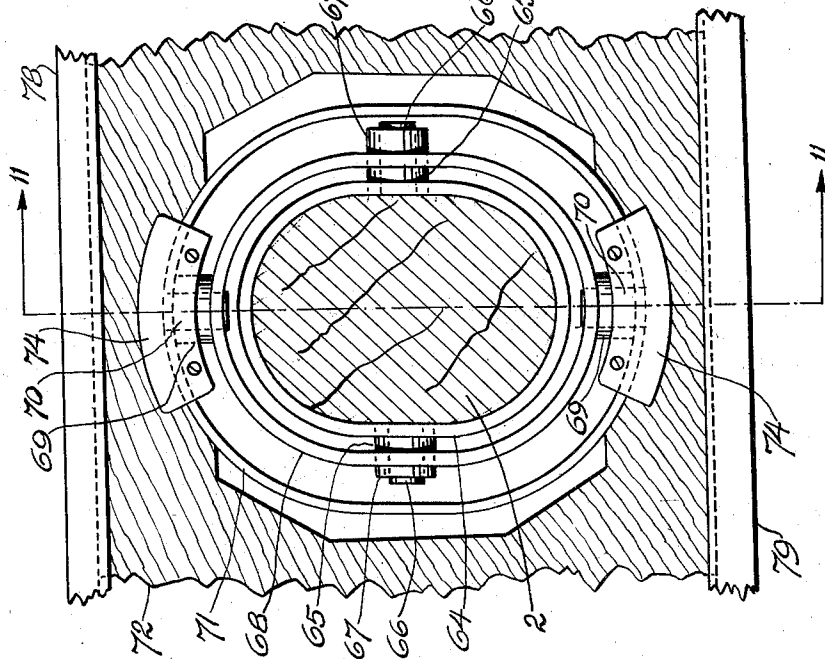


Fig. 10.



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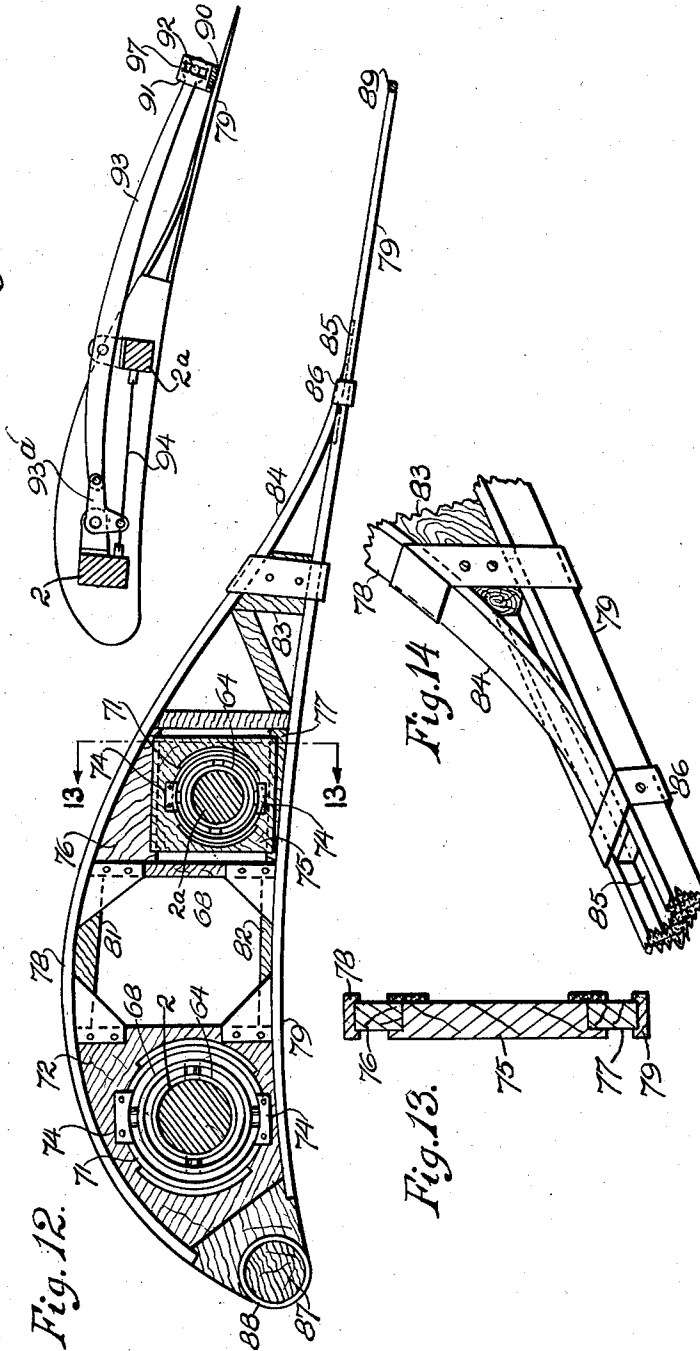
1,760,386

FLYING MACHINE

Filed May 6, 1926

7 Sheets-Sheet 5

Fig. 15.



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1,760,386

FLYING MACHINE

Filed May 6, 1926

7 Sheets-Sheet 6

Fig. 16.

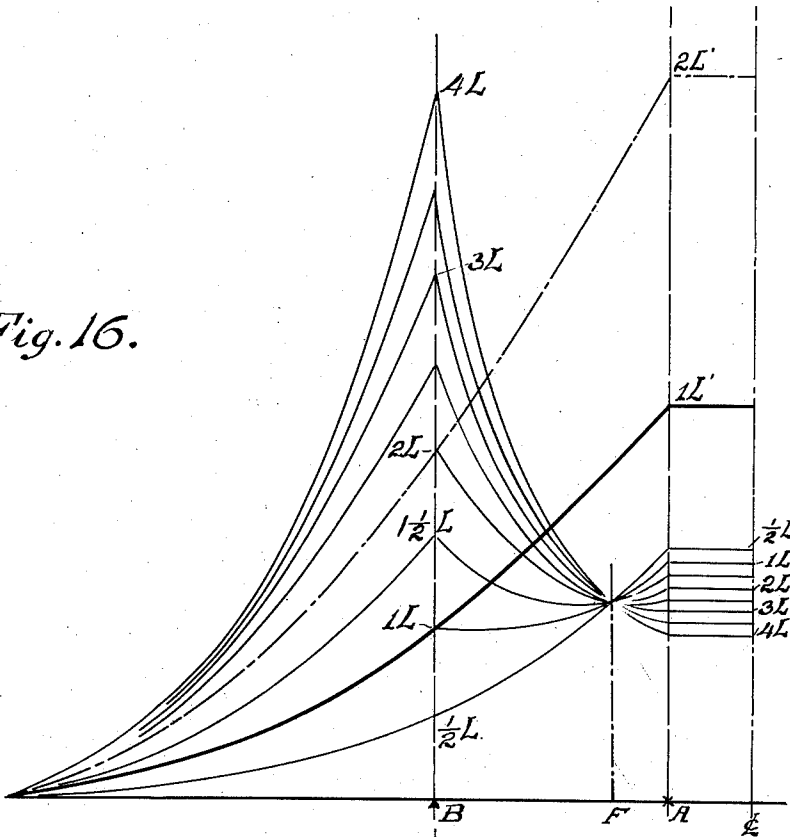


Fig. 17.

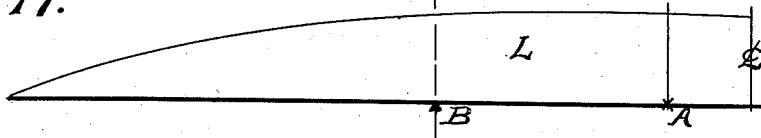
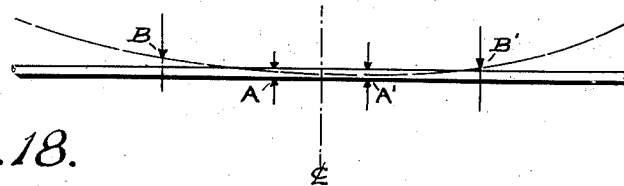


Fig. 18.



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1,760,386

FLYING MACHINE

Filed May 6, 1926

7 Sheets-Sheet 7

Fig. 19.

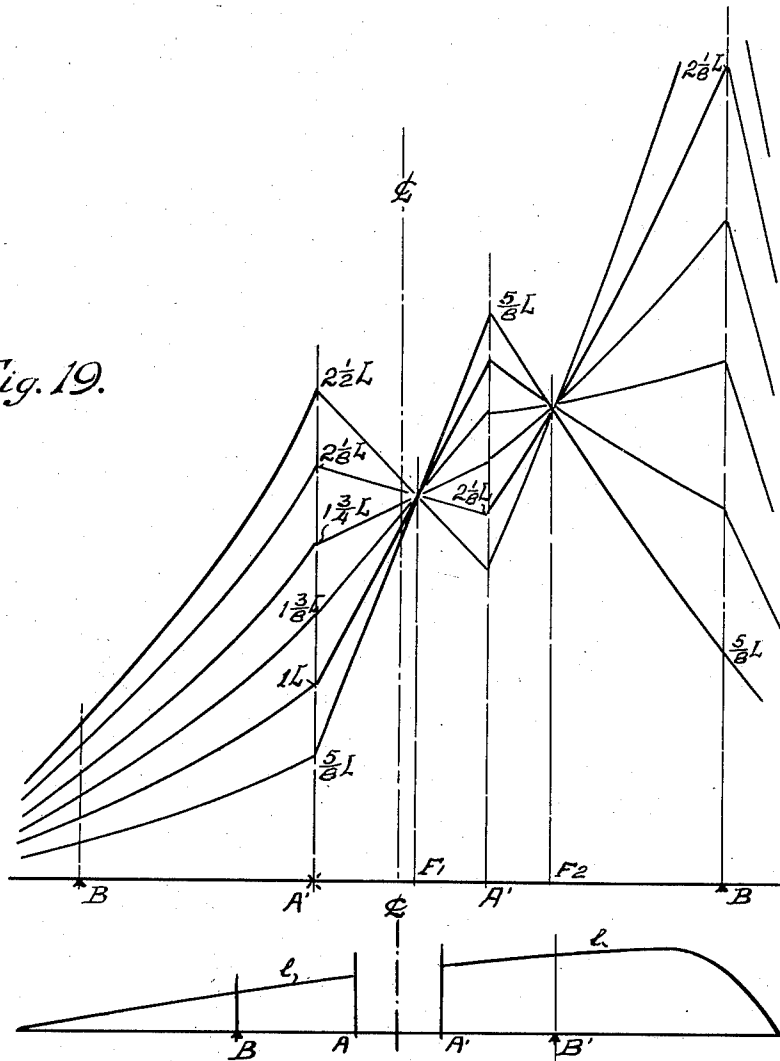


Fig. 20.

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UNITED STATES PATENT OFFICE

JOHN DUMANS VAN VLIET, OF SAN FRANCISCO, CALIFORNIA

FLYING MACHINE

Application filed May 6, 1928. Serial No. 107,120.

The invention relates to wings for airplanes, gliders, and the like. One of the objects of the invention is to provide a construction allowing the number of supports for the wing spars to be automatically increased under an increased airload, thereby materially reducing the stresses at and between the points of support.

Another object of the invention is to provide means for attaching and supporting the wing spars in such a fashion that the occurrence of axial loads in the spars, such as are usually induced by external bracing, is entirely excluded.

A further object is to provide a wing capable of transverse and helicoidal deformation without thereby subjecting the component members of the wing frame to torsional stresses and without inducing excessive tensional stresses in the wing covering.

A still further object of the invention is to modify the direction and magnitude of the reactions caused by airpressure on the wing in such a manner as to make certain components of these reactions contribute to the forward motion of the airplane or glider, thereby materially lessening the bending stresses in the wing spars otherwise induced by the drag or forward resistance of the wing.

With these and other objects in view, the invention consists in the matters hereinafter described and more particularly pointed out in the appended claims.

Reference is to be had to the accompanying drawings, in which

Fig. 1 is a side elevation of the wing spar attachment.

Fig. 2 is a detail in Fig. 1, illustrating a preferred mode of attaching the bearing pins to the wing spar.

Fig. 3 is a view of the bracket used for supporting and attaching the spar.

Fig. 4 shows an assembly of the wing structure with the wing covering partially removed.

Fig. 5 illustrates a preferred way of supporting the secondary spar and its relation to the primary spars.

Fig. 6 shows a variation in the mode of supporting the secondary spar.

Fig. 7 shows a crossmember of the wing structure connecting the primary spars and providing the secondary supports for these spars.

Fig. 8 is a detail in Fig. 7.

Fig. 9 is a detail in Fig. 7 showing the controls for the secondary supports.

Fig. 10 shows in detail a preferred mode of attaching the wing ribs to the spars.

Fig. 11 is a section in Fig. 10 taken along the line 11—11.

Fig. 12 shows a simple construction of the wing rib.

Fig. 13 is a section through Fig. 12, taken along the line 13—13, illustrating the slidable relation between the rib mounting and the rib proper.

Fig. 14 shows in detail the flexible extension of the wing rib.

Fig. 15 illustrates the means for controlling the flexible action of the wing rib extensions.

Fig. 16 is a diagram of the bending moments occurring in a wing spar alternately and consecutively supported at two points and at four points and subjected to a symmetrically arranged load.

Fig. 17 illustrates diagrammatically the nature of the airload applying to the moment diagram in Fig. 16.

Fig. 18 shows diagrammatically how the number of supports for the wing spar is automatically increased by the flexing action of the spar.

Fig. 19 shows a diagram of the bending moments in a wing spar supported alternately and consecutively at two points and at four points and subjected to a load which is unsymmetrically arranged with reference to the center of the spar.

Fig. 20 illustrates diagrammatically a wing loading which is unsymmetrically arranged and applies to the bending moments shown in Fig. 19.

The drawings represent a simple embodiment of the various features of my invention, the main object of which is to introduce certain improvements in the wing structure of a

flying machine to make it conform in its action as well as in its structural attributes to the wing of a soaring bird.

The qualities imparted by the improved construction are: inherent resiliency of the entire wing structure, unimpeded flexibility, adaptability to varying air currents, and a high aerodynamic efficiency due to the directional modification of the reactions due to airpressure with an attendant reduction of drag. The improved construction also imparts a great factor of safety to the structural members of the wing frame, the decrease of the stresses being concurrent with the increase of the load.

Inasmuch as certain features of my invention owe their conception to the analysis of the soaring flight of certain birds, a brief description of the natural bird's wing is here-with presented and reference to certain analogies will be duly made hereinafter.

The constituent parts of the bird's wing can be differentiated into three main groups, namely: the bones; the muscles and tendons; and the feathers. The bony structure comprises the humerus or bone of the upper arm, the radius and ulna or bones of the fore-arm, and the carpal bones, meta-carpal bones, and digits which constitute the bones of the wrist, hand and fingers respectively. It should be noted that the radius and ulna of the bird's wing are not relatively rotatable as is the case in the human arm, and that a further important difference exists in that articulation of the bird's wrist at the upper juncture of the carpal bones to the fore-arm can be effected in one plane only with respect to the radius and ulna. The humerus is universally articulated at the shoulder joint, much as is the case in the human arm; the elbow and wrist joints however are so conformed as to allow articulation in one plane only with respect to the humerus, this plane lying transversely to the body when the wing is extended laterally. Dorsal and ventral bending of the solid parts of the extended wing is therefore excluded; the seemingly upward flexing of the entire wing is to be ascribed to the elastic deformation of the primary and secondary flight feathers, the first-named being often of considerable length and extending laterally and diagonally backward of the pinion. This flexing of the flight feathers in conjunction with an occasional rather restricted upward or downward rotation of the entire wing at the shoulder joint produces the illusion of dorsal or ventral bending of the entire wing structure. By reason of the rigidity of the bony structure of the wing, and of the flexible and elastic nature of the trailing vanes formed by the flight feathers, the bird's wing is able to twist helicoidally upon itself and to bend laterally upward at the tip, thus assuming a screw like conformation. The flight feathers, by reason of their elasticity, are able

to adjust themselves to the varying air currents, to which peculiarity must be attributed the remarkable automatic lateral stability of the soaring bird. The resiliency of the flight feathers also serves another and very important purpose which will be explained hereinafter.

The muscular system of the bird's wing is complex and contains those muscles and tendons which are required for the operations of articulating and flapping the wing; in the extended wing of the soaring bird most of these muscles do not come into play. Mention should be made however of a tendon which is of major importance during soaring flight, namely, the elastic vinculum, by which name is designated the highly elastic and contractable band which runs spacedly behind the muscles of the fore-arm and pinion. The elastic vinculum serves as a control and support for the primary and secondary flight feathers, the shafts of which are pivotally fastened at their inner tips to the upper side of the fore-arm and hand. The shafts of the flight feathers are also fixed in and pass through the elastic vinculum. Each flight feather has therefore two supports; the front support is comparatively fixed and rigid, whereas the rear support has yielding and resilient attributes and is moreover under the conscious control of the bird.

The tertiary feathers bridge the gap between the secondary flight feathers and the body of the bird. They are arranged along the upper arm and fastened thereunto in a manner similar to that of the primary and secondary feathers. They lack however a definite rear support and are held in place mainly by the wedging effect of the dorsal and ventral coverts of the upper arm. Although they are thus not under the direct control of the bird, they co-act automatically with the secondary feathers in the flapping and closing of the wing.

Referring to Fig. 4 it is seen that the wing structure has a plurality of spars. Only two spars are shown in the preferred form of my invention, namely the front spar 2 and the rear spar 2^a which are arranged in spaced fore-and-aft relation; they extend laterally across the body or fuselage of the flying machine and project cantilever-wise from the opposite sides thereof. These spars constitute the internal bracing members of the wing. Each spar is made of flexible and resilient material, the front spar being preferably less flexible than the rear spar in accordance with the anatomy of the bird's wing; the front spar having thus analogy with the bony and muscular portions of the wing, whereas the rear spar simulates the function of the elastic vinculum.

A certain amount of lateral flexibility of the wing along its entire span is desirable since it permits the wing to yield to excessive

air pressure at either or both sides of the machine and thus shed the excess air off sideways. The inherent resilience of the wing also enables it to act as a shock absorber, thus automatically preserving the lateral stability of the machine which would otherwise have to be effected by the manipulation of certain movable control surfaces by the pilot. The transversely resilient and flexible wing structure absorbs to a great extent the shocks occasioned by gusts and disturbed air and prevents them from being directly transmitted to the body of the machine, which tends to make its transit through the air considerably smoother and easier.

Although the wing shown in the drawing is of unitary construction, placed across the body of the machine and projecting laterally from the opposite sides thereof, I wish it to be understood that I do not limit myself to this particular construction. The right and left sections of the wing may be constructed as separate units, each independently from the other fastened to the body of the machine. In either case however, the peculiar mode of attaching the spars remains essentially the same, each spar resting in at least two supports; in the case of separate right and left wing units the innermost supports of the corresponding right and left spars would then be placed in close proximity to each other equidistantly from the median fore-and-aft line of the body or fuselage, and the corresponding right and left outer supports would be secured to the right and left outer boards of the fuselage or to outriggered members rigidly connected therewith. This modification may be called for in a machine of considerable wingspread which would make the wing of unitary construction unwieldy and necessitate a spar construction of spliced sections. In a machine of this size it would be expedient to confine the flexibility of the spars only to their outer extremities. In the smaller type of machine however, the spars or girders may be of resilient and flexible construction throughout their entire length, beyond, at, as well as between their points of attachment.

Although in the drawings the spars or girders are shown as beams of rectangular, oval, round, and round-topped flat-sided sections, it is obvious that any suitable section may be employed, such as hollow, T section, channel section, or angle section. In this specification the word "spar" is used as a generic term and includes girders of any hollow or solid section as well as girders of the built-up type composed of any number of trussed longitudinal members. The spars need not be of uniform cross section throughout their entire length since the cross sections may be made to conform with desired variations in section modulus and moment of inertia in accordance with the bending

moments and the required degree of flexibility. The mode of supporting the spars to the rigid portion of the machine, although primarily designed to meet the requirements of flexible spars, is of course equally applicable to spars of the rigid type, the object in either case being to constitute the spars at all times freely supported girders.

The term "freely supported girder" describes a continuous beam or girder supported in such a manner that no part of it is restrained in any way from assuming its natural bend under a load, so that relative displacement between the beam and its supports is allowed to take place when the beam assumes its free elastic curve in accordance with the stresses induced by the load. In physical testing machines this condition has been approached by placing the beam to be tested for bending and deflection on two rocking supports, the tops of which are thus enabled to move inward in accordance with the arcuate conformation of the beam in flexure, the arcuate length of the beam between the supports thus remaining the same as the original straight length.

However, inasmuch as the supports take the reactions of the load in a vertical direction in addition to the horizontal component of the force set up by the stored-up elastic deformation energy, the latter force may eventually cause the supports to be displaced, or even ejected, in the direction of the length axis of the beam as soon as the elastic force becomes great enough to overcome the friction due to the vertical reactions. It is obvious that a certain restraint is imposed upon the beam during the process of flexing which may induce certain tensional stresses in addition to the bending stresses produced by the load. A method of support has therefore been devised by means of which the wing-spars are free to move laterally in their supports while being held against vertical displacement. Bodily lateral displacement in the direction of their length axes is prevented by a centering device hereinafter described. Figs. 4 and 5 show this centering device applied to the auxiliary spar; it is understood however that it should also be applied to the main spars, and more generally, that the attachment of any member subject to flexing comprises the combination of two slidable supports in conjunction with a centering device if the degree of arcuate deformation of the member should warrant its use.

In a wing of unitary construction placed across the fuselage and projecting laterally from the opposite sides thereof, the wing spars when supported at two points only will bend by reason of their inherent flexibility and the neutral axis of each spar will assume a continuous elastic curve showing maximum

deflection at the tips. In the case of a load which is distributed symmetrically with reference to the median fore-and-aft line of the machine, the bending moments in the spars will increase from nil at the tips to a maximum at and between the points of support. Should the spars or girders be supported in such a manner as to restrain their flexing at and between the points of support, they would then no longer be able to function as freely supported girders. Each spar would then be divided into three parts; the two parts which freely project beyond the supports being cantilever beams fixed at their inner ends, and the third part between the supports remaining inactive as far as flexing is concerned. The bending moments for the entire girder then would increase from nil at the tips to a maximum at the supports and decrease abruptly again to nil at or a little beyond the supports, the abruptness of the decrease depending upon the rigidity of the supporting device and the degree of security with which the spars are fixed in the supports. In this case then a gradual merging of the bending moments of the projecting cantilever sections with those of the section between the supports is entirely excluded.

The airpressure on the wing is of a variable nature owing to the eddying propensity and the directional variations of the aircurrents. The stresses in the spars are therefore subjected to sudden and often considerable variations. These variations will be most pronounced in those parts of the spar where the bending moments are greatest, which in the case of the fixed cantilever spars above referred to will be at the points of support. When the spar is in flexure, that portion of it subjected to the greatest unit stress has the smallest radius of curvature and consequently the greatest interdisplacement of fibers with respect to the neutral axis, the fibers also suffering the greatest elastic deformation individually and the greatest displacement with respect to each other at this particular point. The relative interdisplacement and the elongation and compression of the individual fibers in a spar of the fixed cantilever type will therefore be greatest at its point of support. By reason of the abrupt decrease of bending moments from a maximum to nil the fiber stresses in this case will therefore be of considerable magnitude in comparison with the unstressed condition which prevails between the points of support, and the failure of a beam of this type can in most cases be attributed to the abrupt discontinuation of the elastic deformation rather than to the intensity of the stress itself, a failure which could be effectively prevented by changing the nature of the support from rigid to yielding.

During its passage through the air the wing will be subjected to a succession of

shocks produced by gusts, rough air and variations in the density of the air, these shocks occasioning impact bending in the spars which entails sudden variations in the elastic deformation. The result is vibration. The frequency of the vibration will be the greater the stiffer and more unyielding the nature of the spar, whereas the amplitude of the vibration will be, roughly speaking, inversely proportional to the frequency. Vibration will be most noticeable at the points of maximum stress and will adversely affect the cohesion of the fibers, which may eventually cause fatigue of the material resulting in a permanent set or complete loss of resilience leading to rupture. In the construction of the supports and wing spars, this danger has been avoided by allowing a large amplitude of vibration with an attendant low frequency. The nature of the supports maintains the spars at all times as freely supported beams, which obviates any possibility of restraint or other interference with the free and natural flexing of the spars at, beyond, and between their points of attachment and support. The double function united in the usual spar attachment has been divided and separate devices have been contrived to meet the requirement of each component function. Thus, one device holds the spar against vertical displacement as well as fore-and-aft displacement with respect to the body of the machine, this device being adapted to allow lateral displacement of the spar in its supports in accordance with the arcuate flexing of the spar. The other device holds the spar against bodily displacement transversely to the fuselage and is adapted to allow unimpeded movement of the spar in a transverse vertical plane as required by the flexing of the spar between the supports. The spars are attached to the fuselage or to members integral with the fuselage in the manner illustrated in Figs. 1, 2 and 3.

On spar 2 is fitted the saddle plate 5 provided with the stiffening ridges 6 and the horizontal flanges 7 which carry the laterally projecting bearing pins 8 in any suitable manner secured to the flanges and saddle plates. The saddle plate 5 is clamped to the spar by the lower saddle plate 9 having the stiffening ridges 10 and the horizontal flanges 11, the bolts 12 with the nuts 13 securely connecting the horizontal flanges of both saddle plates. A slight space is left between the flanges of the saddle plates whereby the desired clamping effect is obtained. The supporting brackets 14 arranged at either side of the spar are fixedly secured to or integral with the plate 15 and have the removable caps 16 fitted over the horizontally slotted recess 17. The caps 16 are secured to the supports 14 by such means as the bolts 18. The plate 15 is pivoted about the king bolt 26 secured to the base 19. The base 19 is secured

in any suitable manner, as by the clamps 20, to the longérons 27 or to any other suitable fixed part of the body of the machine. The base 19 has the guide members 21 receiving the plate 15, the bearing strips 22 being interposed between the base 19 and the plate 15. The bearing pins 8 are slidably received in the slotted recesses 17 and adapted to rotate therein. The above described device permits bodily transverse displacement of the spar, and consequently of the entire wing of which the spar forms the internal bracing member, with reference to the body of the machine by the lateral sliding motion of the pins 8 in the slotted recesses 17. Pivotal motion of the spar in a vertical plane is permitted by the cylindrical shape of the bearing pins 8 which enables them to rotate in the slotted recesses. The entire spar attachment device is moreover enabled to pivot in a horizontal plane by means of its pivotal mounting on the plate 21. The reason for this mode of attaching the spars is obvious. When the spar is in flexure, its length axis is changed from a straight line to a curve, the chordal distance between the bearing pins 8 of the supports at either side of the fuselage being thus less than the original distance in the unflexed spar. If the spars were attached in such a manner as to prevent any lateral motion of the bearing pins in the supports, as would be the case if the spars were rigidly fixed in the supports, the spar would then comprise a combination of two individual cantilever beams joined together by an intermediate beam fixedly supported at both ends. The bending moments caused by the load on the cantilever parts would then be maximum at the points of support and decrease to zero between the supports. The elastic curve would then have two points of discontinuance denoting a complete absence of the desirable merging of bending moments and stresses at and between the supports. By allowing relative motion between the supports and the spar however, the latter remains at all times a freely supported beam capable of assuming its natural bend under a load. The normals to the tangent of the free elastic curve at the points of support will deviate from the vertical to the original length axis of the spar in its unflexed condition and the bearing pins will therefore rotate to a slight extent about their axis. In cases where the deflection of the spars is considerable with an attendant pronounced displacement and rotation of the bearing pins, it may be expedient to employ devices to lessen the friction, such as ball bearings, roller bearings and the like. In order to avoid undue wearing of the bearing pins by the combined sliding and pivotal motion, the pins may be pivotally received by separate bearings slidably mounted in the slotted recesses.

Fig. 5 shows the wing spar supported on

the two longérons of the fuselage in the manner described. It is obvious that if the bearing pins were allowed to slide in the slots of the supports, the spars, and consequently the entire wing of which the spars form integral parts, would shift laterally to the extent of the length of the slot. When the flexing of the spar is inconsiderable and the arcuate deformation of the spar correspondingly slight, the attachment device can be used as described; in the case of a more pronounced flexing however it may be found expedient to employ an additional device to maintain the original position of the wing with reference to the median fore-and-aft line of the machine. A centering device has therefore been contrived consisting of the pin 23 projecting transversely from the wing spar and in any suitable manner fixedly secured thereunto. The pin 23 engages with the vertical slot 24 of the bracket 25 which is fixedly secured to any suitable structural member of the fuselage and centrally located intermediate the wing spar supports. The slot 24 allows the pin 23 to move vertically as required by the arcuate flexing of the spar between the supports and prevents any lateral shifting of the spar with respect to the median line of the fuselage. This arrangement can be modified by having the slotted bracket secured to the spar and the guide pin fixedly mounted to any suitable part of the fuselage. A further modification would consist in two centralizing brackets arranged at opposite sides of the wing spars.

It is obvious that the spars or girders do not flex in a vertical plane only as occasioned by the lift components of the forces acting on the wing, for they will also flex in a horizontal plane as occasioned by the drag components, the angle of the plane in which the combined flexing takes place being then determined by the resultant vector. To meet this condition the spars are allowed to pivot around a vertical as well as around a horizontal axis, the entire spar attachment and support swinging about the vertical pivot 26 as hereinbefore described. The wing spars are therefore in universally pivotal relation attached to the fuselage, an arrangement which can also be obtained by using gimbal supports in which provision has been made for the transversely slidable motion of the spars by employing a transversely slotted mounting for any of its members or for the spar bearing pins in the outer gimbal member. The embodiment shown in Fig. 1 merely illustrates a preferred construction.

In a small machine of light weight and relatively small wing spread the wing spars can be attached and supported in the manner thus far described, and the flexing of properly designed spars can then take place with a reasonable degree of safety. The pivotal and sliding mode of attachment allows a

large amplitude of vibration and a low frequency; it obviates moreover the occurrence of axial loads in the portion of the spar between the supports. In a heavy machine of a large wing spread however the bending moments at and between the supports may be of such magnitude as to demand the use of a heavy spar to satisfy the requirements of safety. Increasing the section moduli of the spar sections at the critical points necessarily entails an increase in the sectional moments of inertia with an attendant increased stiffness of the spar; the requirement of safety would therefore be satisfied at the expense of flexibility, while at the same time the strength of the spar would be adversely affected by the increased frequency of vibration. In order to preserve the flexibility and to maintain at the same time a reasonable factor of safety, additional supports for the spars have been provided intermediate the tips of the wing and the fuselage. These supports have been so contrived as to be intermittent or temporary in their action. The bending moment diagram presented in Fig. 16 shows a continuous spar supported at the points A and A'. The mode of supporting the spar is such as to permit unrestrained bending whereby the spar is able to act at all times as a freely supported girder. Hereinafter these supports will be referred to as primary supports and the spars themselves as primary spars. It should be noted that this designation has no connection with the words "primary" and "secondary" employed in the description of the feathers of the bird's wing. The moment diagram in Fig. 16 also shows the spars supported at the points B and B' located intermediate the primary supports and the free ends of the spar respectively. These latter supports will be referred to as secondary supports. The part of the spar from the secondary support outward is termed "overhang". Fig. 17 shows the spar loaded along its entire length with the exception of the central span between the primary supports, which is assumed to pass through the body of the machine. Thus, of the three bays BA, AA, and AB, only the first and last-named ones carry a load.

The bending moments change from positive to negative at the points of contraflexure and have been determined graphically by means of the method of fixed points and interference lines. Since the overhanging sections beyond the secondary supports flex in a direction the reverse from that of the bays between the supports, these bending moments will have the opposite algebraic sign. Interference is caused by the bending moments of the overhangs with the bending moments of the other three bays, and by means of the above mentioned method the resultant moment diagram for the entire spar has been determined. It is obvious that the effect of

interference caused by the load on the overhangs will be the more marked the longer the overhangs are in proportion to the individual lengths of the three bays, a condition which may be applied to advantage by judiciously spacing the supports. In a spar permanently supported at four points as described, a free upward flexing at the secondary supports is out of question, since these supports are intended to hold the spar against vertical displacement. The advantage obtained by the reduction in bending moments and stresses is therefore vitiated by the inability of the spar to flex freely. In order to retain this ability to flex and at the same time obtain a reduction in bending moments by utilizing the effect of the overhangs, the two modes of supporting the spar have been combined in the following manner. Initially supported at the two primary supports, the spar is allowed to flex until it comes in contact with the secondary supports which are placed somewhat higher than the primary supports. The mode of supporting the spar thus changes from an initial two-point support to a subsequent four-point support. In order to obtain the final bending moments, two separate moment diagrams must be plotted and subsequently combined. The first diagram gives the bending moments due to that fraction of the load which causes the spar to flex until it comes in contact with the secondary supports; the second diagram gives the bending moments due to that part of the load which takes effect after contact with the secondary supports has taken place; this diagram has accordingly been drawn for the spar supported at four points subjected to a load equal to the entire load minus that portion of the load above referred to. A combination of two such diagrams is shown in Fig. 16. Since in the case of a symmetrically distributed load the bending moments are the same at the right and at the left side of the median line of the machine, only one side of the diagram has been shown. The primary support is designated by A, the secondary support by B, the horizontal through A and B is the abscissa or line of zero moment, and the ordinates from the abscissa to the curve give the comparative magnitude of the bending moments for the respective spar sections. These bending moments have been plotted for the loading shown in Fig. 17 in which the load has been represented as tapering off toward the tip of the spar. The curve marked $\frac{1}{2}L$ defines the bending moments for a load equal to one half of the normal load. For the purpose of illustration it has been assumed that contact with the secondary supports takes place after the spar has flexed in accordance with this part of the load. These bending moments are referred to as primary bending moments, and it is evident that they are greatest at and

between the primary supports. At the points where the secondary supports are located, the primary bending moments are greatly reduced and dwindle to nil at the tip of the spar. The curve marked 1L defines the bending moments for the full normal load. Contact with the secondary supports takes place at one half the normal load, and in consequence of the interference caused by the load on the overhangs, the composite bending moments for the full load between the primary supports are actually less than the primary bending moments for half the load. The curve marked 1L' defines the bending moments for the full load when no secondary supports are used. It is evident from the diagram that the reduction in bending moments by introducing secondary supports is quite pronounced.

The airload on the wings is not constant and may in certain instances increase to several times the normal load, as for example, in zooming or in pulling out of a dive; a corresponding increase in stresses will then obtain in the spars. In a spar supported only at the primary supports this increase will be most marked at these two points. By introducing the secondary supports however, the moments at and between the primary supports will actually decrease instead of increase, as is clearly shown by the curves marked 1L, 2L, 3L, 4L, etc. The maximum bending moments then occur at the secondary supports and it should be noted that these bending moments are very much smaller than the moments at the primary supports for the normal load. The moment curves for the increasing loads shown in the diagram all cross each other on the same ordinate, which shows that with a system of primary and secondary supports as outlined above there is a point in the spar for which the bending moments, and consequently the stresses, remain constant, it being assumed of course that the load is increased in the same proportion at all ordinates. An ideal condition like this hardly obtains in practice, since the airshedding action of the wingtips in a flexible wing will be the more pronounced the more the load is increased.

In Fig. 16 this point of constant moment is marked F and occurs intermediate the primary and secondary supports. Since in a spar supported at four points with an increasing load the moments between the primary supports actually decrease instead of increase, it is obvious that section moduli which suffice for the primary bending moments will also meet the requirement of any multiple of the load which induces the primary bending moments.

The position of the secondary supports vertically with respect to the primary supports is determined by the deflection of the spar as caused by the primary load; the smaller the

moments of inertia of the spar sections between the supports, the more readily will the spar flex. In the case of a two point support the stresses between the supports increase in direct proportion to the load. By increasing the section moduli in accordance with the required factor of safety, the moments of inertia will also be increased in a more pronounced ratio; hence by increasing the strength of the spar, its stiffness will also be increased with an attendant increase in the frequency and a decrease in the amplitude of vibration. A two point support for a flexible spar then would be impracticable, since the factor of safety could only be obtained at the expense of flexibility.

By using the combination of primary and secondary supports however, increasing the load has the effect of decreasing the bending moments and stresses between the points of constant moment; therefore, a spar designed for a certain normal load without any factor of safety will automatically acquire a factor of safety between these points for any multiple of the normal load. Moreover, since the decrease in bending moments and stresses between the points of constant moment is comparatively slight, the elastic curve between the secondary supports will be subject to equally slight variations, whereby vibration in this part of the spar is reduced to a minimum.

As has already been pointed out, the diagram of Fig. 16 applies to a load symmetrically arranged with reference to the median fore-and-aft line of the machine. In practice however, this symmetrical loading does not always obtain. An extreme case of an unsymmetrically arranged load is illustrated in Fig. 20. The load is shown as distributed in such a way that the greater portion of it is heaped on one side of the wing and from there it gradually tapers to nil at the tip of the other side of the wing. The center of load then is situated rather near the wing tip of the first-named part of the wing. Although this arrangement would hardly occur under actual conditions, a load distribution somewhat similar to it might be produced during the operation of banking on a turn. The bending moment diagram for a case like this is then no longer symmetrical about the vertical through the transverse center of the spar, as is clearly shown in the diagram of Fig. 19. The curve marked $\frac{5}{8}L$ defines the moments for $\frac{5}{8}$ normal unsymmetrical load, the spar being freely supported at the primary supports A and A'. A considerable difference is apparent between the bending moments at the various points of support. For the purpose of plotting the secondary bending moments, it has been assumed that contact with the secondary support takes place only at the side of the greatest load. The other side of the spar, by reason of the much smaller load, has been

assumed not to reach the secondary support at all. Thus, for secondary loads exceeding $\frac{5}{8}$ normal load the spar is taken as supported at both the primary supports and at the one secondary support B' only. The diagram shows that the increase in the bending moment at the secondary support is considerable and that on the whole the resulting statical conditions are rather unsatisfactory. In order to counteract these adverse conditions certain modifications in the mode of support have been introduced as described hereinafter.

Fig. 7 illustrates the means by which the wing spars are enabled to engage with the secondary supports. The front spar 2 and the rear spar 2^a each carry the saddle plates 56 at a point intermediate the primary supports and the tips. The saddle plates 56 are provided with the stiffening ridges 28 and the horizontal flanges 29 which by means of the bolts 33 are clamped to the stirrup plates 30 having the stiffening ridges 31 and the horizontal flanges 32. The upper and lower surfaces of the spar have circular bearing surfaces described around the centroid of the spar section on which rotatably fit the saddle and stirrup plates. If the spar at this point is oblong in section, a space is left at either side between the spar and the saddle and stirrup plates to allow unimpeded rotation of these parts. The inwardly facing horizontal flanges 32 of the stirrup plates carry the bosses 34 integral with or otherwise secured to them. At the inward-facing side of the stirrup plate 30 is fastened the bracket 35, which with the boss 34 serves as a support for the sleeve 36 pivoted about the pin 37. The sleeve 36 rotatably receives the member 57 which is held against axial displacement by the studs 38 engaging in the slots 39 of the sleeve.

Integrally secured to the member 57 is the frame 40 having the member 41 secured to it. The member 41 is slidably and rotatably received in the socket 42 of the stirrup plate 30 which is mounted on the spar 2^a. The movable member 58 having the horizontal slot or slotted recess 42 is in vertically guided relation mounted between the upright members of the frame 40. The frame is closed at the top and bottom by the horizontal members forming the constructionally integral parts thereof, the top member constituting the upper sill, and the lower member affording a seat for the adjusting screw 59 turnably retained in the vertically movable sill 44. By adjusting the position of the lower sill, the extent of travel of the movable member 58 can be selectively regulated. Shock absorbing means such as springs or rubber bumpers 43 are interposed between the member 58 and both upper and lower sills. Means are provided for arresting or restricting the relative motion between member 58

and the frame, such as the rotatable cams 45 mounted on the upper and lower sills respectively and connected by the rod 60 whereby their simultaneous motion is assured, the cams on being turned downward engaging with the ledges 62 of the member 58. One of the cams has the lever 46 which is held in resilient relation to the frame by the spring 61. By turning the cams until they come in contact with the ledges, the member 58 will be wedged in between them and thus be held against vertical movement. The cams are operated by the pilot in the fuselage by means such as the rod 47 operatively connecting the lever 46 of the cam to any suitable control levers or wheels within easy reach of the pilot. By turning the cams only part of their full arc of travel, the movement of the member 58 can be selectively restricted. There being many constructional variations possible, I do not limit myself to this particular device and reserve the right to substitute any other means achieving the same object.

The wing assembly as depicted in Fig. 4 shows a third auxiliary spar 48 located intermediate the front and the rear spar.

Hereinafter front and rear spars are referred to as primary spars, and the auxiliary spar 48 will be referred to as secondary spar. The pins 49 fixedly secured to the extremities of the secondary spar and projecting outward therefrom engage with the slots 42 of the movable members 58. The secondary spar by means of the attachments 50 and the centering device 51 is mounted on the oscillating beam 52 in a manner similar to that employed for the primary spars, the secondary spar being thus a freely supported girder, preferably of inherently flexible and resilient construction. The oscillating beam 52 is rotatably mounted in the support 53 centrally secured to members integrally pertaining to the fuselage. The shock-absorbing means 54 are interposed between the oscillating beam and the fuselage, as are also the means 55 for selectively arresting relative motion between the beam 52 and the support 53. Any suitable device may be employed for this purpose, such as pivoted levers, cams, and the like. The operation of the above described combination is as follows: When the primary spars flex under a symmetrical load, the sections of the spars at the secondary supports will move upward, as will also the bridge member connection shown in Fig. 18. The secondary spar which is not in any way fixedly secured to or in permanent contact with the wing structure, will remain inactive until the bridge has been raised sufficiently to cause the movable member 58, into the slots of which the pins 49 of the secondary spar are always engaged, to come in contact with the lower sill of the frame. As soon as contact has taken place, the bridge will be supported by the secondary spar, and the saddle-and-stir-

5 rup fittings 56 and 30 will then constitute the
 secondary supports for the wing spars. So
 long as no contact exists between the sills of
 the frame and the movable member 58, the
 10 spars will flex in accordance with their two-
 point support. After contact has been es-
 tablished, the primary spars will be sup-
 ported at four points and the bending mo-
 15 ments will be modified accordingly. The pri-
 mary supports are of a permanent nature
 whereas the secondary supports are only in-
 termittently active, their period of activity
 being governed by the ratio of the primary to
 20 the secondary load. As there is a possibility
 of the primary spars flexing downward, as
 might occur during a rough landing, a four-
 point support for this emergency has been
 provided by allowing free flexing in the pri-
 25 mary supports and subsequent contact with
 the secondary supports to take place by the
 movable member 58 bearing against the up-
 per sill of the frame 40. In order to prevent
 undue concussion on contact, the resilient
 30 shock absorbing means 43 have been pro-
 vided, which also serve to prevent synchroni-
 zation of vibration in the wing structure.
 Since a comparatively gradual transition of
 bending moments is desirable when changing
 35 from a two-point support to a four-point sup-
 port, the secondary spar is preferably of flexi-
 ble and resilient material or construction.
 The moment diagrams in Figs. 16 and 19 have
 been drawn for a system of unyielding sec-
 40 ondary supports as being sufficiently illus-
 trative of the principle underlying the inven-
 tion. I wish it to be understood however,
 that contact with the secondary supports is
 intended to take place in a yielding manner
 and that therefore the transition of bending
 45 moments along the spars is by no means so
 abrupt and sharply defined as the diagram
 would imply. It has been pointed out above
 that in the case of a pronouncedly unsymmet-
 50 rical loading the bending moments in certain
 regions of the spars are unfavorably affected,
 and that the side of the spar carrying the
 greatest load will reach its secondary sup-
 port first, whereas the other side of the spar
 will not be able to establish contact with its
 55 secondary support until the load has been
 manifoldly increased. If the loading on the
 spar should remain symmetrical, secondary
 contact would always take place simultane-
 ously at both sides of the spar, in which
 60 case it would be sufficient to attach the sec-
 ondary spar, or spars, to the fuselage or to
 members integrally pertaining thereto, in a
 manner identical to that applied to the pri-
 mary spars. Under actual flight conditions
 65 however, secondary contact will by no means
 always occur simultaneously at both sides,
 since owing to the turbulence of the air cur-
 rents an almost continuous fluctuation and
 shifting of the load prevails. For this reason
 the reactions at the primary and secondary

supports will vary in magnitude; these varia-
 tions have been utilized to neutralize and cor-
 rect the adverse statical conditions shown in
 Fig. 19. With this end in view the secondary
 spar is allowed to oscillate by supporting it
 on the oscillating beam 52. Should the reac-
 70 tions due to the load at one end of the sec-
 ondary spar exceed those at the other end, the
 entire secondary spar together with the beam
 52 will pivot around the support 53, thereby
 75 moving the extremity subjected to the great-
 est reaction upward and the other extremity
 downward, until the reactions at both ex-
 tremities are equalized and equilibrium is re-
 established. In extreme cases of unsymmet-
 80 rical loading the oscillating beam will then
 tend to provide a four-point support for the
 spars, the sensitiveness of this equalizing de-
 vice being controlled by the shock-absorbing
 means 54 interposed between the beam and
 85 the fuselage.

In order to achieve a helicoidal conforma-
 tion of the wing in flight, the rear spar is
 preferably made more flexible than the front
 spar; under a load the spars will then assume
 90 a position with respect to one another best
 described as "askew". At the point of sec-
 ondary support the rear spar will then be
 more elevated than the front spar, the dis-
 position of the connecting bridge deviating
 95 correspondingly from the horizontal. In
 order to allow this to take place without
 binding of the attachments, the stirrup and
 saddle plates are permitted to rotate around
 the spar to a certain extent. It is obvious
 100 that when the spars alter their position in a
 vertical plane with respect to each other, the
 distance between their sectional centroids
 will be increased, which necessitates the slid-
 able mounting of the arm 41 in the socket 42.
 105 The centers of the spar sections at the sec-
 ondary supports will also change their rela-
 tive positions in a horizontal plane; when
 the rear spar flexes more than the front spar,
 the spar sections by reason of the arcuate con-
 110 formation of the spar will be brought closer
 to the fuselage and a slight rotation of the
 bridge in a substantially horizontal plane
 will result. The horizontal deviation of the
 bridge is permitted by the hinge pins 37, and
 115 since a rotation of the bridge about its own
 length axis would cause binding of the pins
 49 in the slots 42, the arms 57 and 41 are
 rotatably mounted in their respective sockets.
 Lateral motion between the pins and the
 120 movable pieces 58 is made possible by the
 slotted engagement. This lateral motion is
 caused by the relative askew position of the
 spars when in flexure, for which reason the
 primary supports have been pivotally mount-
 125 ed on the plates 19 as described. A number
 of constructional modifications can be intro-
 duced, all tending to contrive a system of
 secondary supports for the primary wing
 spars which permit unrestrained motion in 130

any direction between any of the main component parts; I do not limit myself therefore to the above described arrangement. If the primary spars are spaced far apart, it may be advisable to employ a separate secondary spar for each main spar with adequate provision for relative motion between the primary spars and the secondary supports, in which case a bridge device as shown in Fig. 7 will not have to be employed. Although the secondary spar is shown as being enclosed in the wing structure, this arrangement is by no means imperative; the secondary spars and supports may be placed outside the wing structure if desired, and the supports for the secondary and primary spars may be placed outside the main body of the machine as shown in Fig. 6. The system of secondary supports can be elaborated by introducing tertiary and quaternary supports further out on the wing spars, the corresponding tertiary and quaternary spars for which constitute progressive extensions of the secondary spars, contact then taking place progressively in the order named. Since the flexing of the wing frame will cause the wing covering to slacken on the dorsal side of the wing and to tauten on the ventral side, provision has been made to eliminate these undesirable conditions by permitting the wing ribs to which the wing covering is attached free rotational movement about their fore-and-aft axis, whereby the ribs are enabled to deviate from their original vertical aligned position, thereby allowing cooperative movement between the wing covering, the ribs and the flexible spars. The distance between each adjacent pair of ribs, at their tops and bottoms, will then be subject to only slight variations and the objectionable tautening and slackening of the fabric or covering will thereby to a great extent be obviated. Since the straight line connecting the pivotal attachment of the ribs does not pass equidistantly between the upper and lower batten on account of the cambered conformation of the rib, a variation in the tension set up in the wing covering will still obtain. This is corrected by inserting the elastic battens 63 in the wing covering 106 between each pair of adjacent ribs. Thus, by means of the rocking mounting of the ribs in combination with the elastic battens, the entire wing covering is adapted to elastic deformation without being subjected to excessive strains.

In order to maintain the unrestrained flexing ability of the wing spars throughout the wing structure, the wing ribs are allowed the same freedom of motion in any direction as the bridge for the secondary supports. A preferred form of rib attachment is shown in Figs. 10, and 11. The plate 64 which is rotatively mounted about the spar 2, has the bosses 65 provided with the studs 66. The studs 66 are received in the bearings 67 car-

ried by the gimbal ring 68, the bosses 65 also serving as spacers between the gimbal ring 68 and the plate 64. The gimbal ring 68 has the bosses 69 at its top and bottom provided with the studs 70 on which is pivotally mounted the outer gimbal ring 71 which provides rotative support for the rib web 72 by means of the flange 73 and the removable counterflange 74. The attachment of the rib web to the rear spar is contrived in a similar manner, the outer gimbal ring in this instance however being rotatably mounted in the panel 75 which is slidably mounted between the web pieces 76 and 77, thus permitting slidable relative fore-and-aft motion between the rib and the rear spar.

Since the aerodynamical efficiency of the wing is determined by the lift to drag ratio, it is desirable to employ means whereby the drag is reduced to a minimum. Inasmuch as the soaring birds, such as the condor and the albatross, are able to achieve flights of long duration without any perceptible muscular effort, it is reasonable to assume that this ability is not the result of conscious manipulation, but should rather be ascribed to the reactions of the air currents upon an adequately constructed recipient, such as is presented by the outstretched wings. Reference has already been made to the dual support of the flight feathers, the shafts of the primaries and secondaries being fastened to the upper surface of the fore-arm and pinion and thence passing rearward through the elastic vinculum which provides a yielding and elastic support, controllable to a certain extent at the conscious selection of the bird. The most outstanding feature of the flight feather, apart from its lightness, is its resilience, the series of overlapping vanes forming a highly elastic, porous and resilient airfoil. The shaft of the flight feather constitutes a flexible and resilient cantilever beam, which by reason of its resilience, flexibility and mode of support is able to store up the energy imparted to it during its deflection. This elastic deformation energy modifies the reaction of the airload at the point of support both as to magnitude and direction, so that the horizontal component of the elastic reaction counteracts the forward resistance of the wing.

Should the reaction of the stored deformation energy exceed the drag of the wing, the flexible and resilient trailing edge of the wing would then function as a propelling agency and partially, or even entirely, provide the power by which forward motion is effected. This peculiarity of the bird's wing was first demonstrated by the Italian physicist Borelli in the year 1686, and was subsequently amply commented upon by Prof. J. Bell Pettigrew of London, whose conclusions agreed in many respects with those of Prof. Jules Marey of Paris in 1873.

A wing profile was developed by M. Louis Bleriot of Paris in 1911 which closely resembled the section of a bird's wing and which was fitted with a flexible trailing vane. A machine provided with wings built along those lines, the Bleriot #20, was subsequently tested by the pilot Theophile Mathieu. The machine possessed certain advantages in a straight flight path over the previously built rigid-wing types but evinced a tendency to answer slowly to the controls on a turn and to subsequently whip around rather quickly once the control had taken effect, which might be ascribed to the lack of automatic helicoidal wash-out of the transversely braced wings, the reaction of the deformation energy at the tip of the wing being thereby rendered excessive.

A machine of the pure cantilever type built by Dr. William Whitney Christmas, of New York, U. S. A., in 1919 showed remarkable results, both as to speed, obtained with comparatively little horsepower, and lateral stability. The wings of this machine were provided with resiliently flexible trailing vanes and were moreover capable of spontaneous helicoidal deformation and lateral flexure, thus incorporating and utilizing for the first time in the history of aviation the principles underlying the anatomy of the bird's wing. The principle can easily be demonstrated by slidably and rotatively mounting an outstretched bird's wing on a vertical staff and allowing it to slide down by its own weight. The wing, instead of rotating around the staff backward, as would be the case with a similarly conformed but rigid and unyielding airfoil, rotates forwardly, impelled by the reaction of the air upon the flexible and resilient trailing edge formed by the primary and secondary flight feathers. This principle has been applied to the construction of the wing ribs by providing them with a flexible and resilient rear portion in such a fashion that elastic deformation can take place without disturbing the continuance of the curvature of the upper and lower battens of the ribs. The rib consists of three main parts, namely: the upper batten 78, the lower batten 79, and the web, the latter including the nose piece 80 into which the upper and lower battens are dove-tailed or otherwise suitably fastened. The front web portion 72 carries the gimbal attachment for the front spar, the rear web pieces 76 and 77 carry the sliding panel 75 which contains the gimbal attachment for the rear spar. The intermediate web pieces 81 and 82 serve as supports for the upper and lower battens respectively and leave an aperture in the web for the secondary spar to pass through. The front portion of the wing as defined by the upper and lower curves of the ribs has of course considerable thickness, and corresponds to the frontal part of the bird's wing formed by the

bones and muscles of the pinion, fore-arm and upper arm, and the smaller dorsal and ventral covering feathers known as coverts. The posterior part of the bird's wing consists of a filmy sheet formed by the interlocking vanes of the flight feathers or quills, and this part possesses in a marked degree the qualities of flexibility and resilience. This construction has been mechanically reproduced by extending the upper battens of the ribs in an approximately parabolic reverse curve some distance to the rear of the posterior part of the web formed by the piece 83. The lower batten runs as a continuous piece from the nose of the rib to the extreme rear edge of the wing. Integral with the upper batten or otherwise suitably spliced to it is the inherently flexible and resilient extension batten 84, the rear extremity of which engages slidably and resiliently in the groove 85 along the upper surface of the lower batten, the groove 85 being of sufficient depth to prevent any protruding of the rear termination of the extension batten 84 which would otherwise break the smooth continuity of the curve.

As the lower batten flexes upward, the upper extension batten will flex accordingly, its extremity then sliding in the groove 85 of the lower batten. The strap 86 serves as a guard for the extension batten and prevents it from slipping out of the groove. The rear extremity of the lower batten may be grooved to slidably receive the wire or tube forming the trailing edge of the wing. The ribs on the outer portion of the wing are so positioned as to converge forwardly, the prolongation of their length axes preferably crossing each other at a point situated well in advance of the wing. The object of this arrangement is to make the wing to a certain extent automatically stable in a horizontal plane whereby yawing of the machine is prevented when struck by a gust or eddy. Any inequality in the distribution of the wing load due to this cause would have the effect of momentarily increasing the load on the wing with an attendant upward flexing of the spars.

Although part of this increased load will be shed by the flexing action of the wing, the greater part of it will cause an increased flexing of the resilient trailing edge with an attendant increase of the forward reactions due to the absorbed elastic deformation energy. The result is that the wing will be pushed into the gust instead of veering away from it; the yawing tendency will therefore be neutralized and the airplane or glider will continue on a straight course. When the resultant of the reactions due to elastic deformation energy at one wingtip exceeds that at the other tip, the total resultant will cross the length axis of the airplane at an angle, thus causing the airplane to rotate in a horizontal plane about its center of gravity; the

lever arm of the counter moment being then the normal from the center of gravity to the total resultant of the reactions due to the elastic deformation energy of the flexible ribs.

The member 87 forming the entering edge of the wing, is preferably made of flexible and resilient material and fits slidably in the nose rings 88 of the ribs in order to prevent any binding action between entering edge and ribs during the flexing of the wing; the same method applies to the member 89 forming the posterior edge of the wing.

Selective control of the wing tips and flexible trailing edges is achieved in the following manner: The tie-member 90 connects the trailing battens 79 of the outer ribs of the wing and carries the slotted bracket 79 into which slidably engages the pin 92 fixed in the extremity of the arm 93. The arm 93 is pivotally mounted on the rear spar 2^a and has operative connection with the lever 93^a mounted on the front spar 2 which is operated by the member 94 controlled by the lever means 95 in the cockpit 96. The slot 97 in the bracket 91 allows the trailing edge to flex and vibrate in accordance with the variable airload. This flexing action and vibration can be arrested or restricted at the selection of the pilot by moving the rocking arm 93 up or down, the pin 92 then bearing on the upper or lower sill of the slot 97, whereby downward or upward flexing respectively is prevented or restricted. Selective flexing of the trailing vane can be effected by further pivotal motion of the control arm 93 whereby the trailing battens acquire a support which greatly restricts or prevents their spontaneous flexing action, and which renders them practically rigid. Independent action of the trailing edge at the laterally outer part of the wing for the purpose of directional and lateral control is contrived by splitting the wing covering and fastening the edges to the closely adjacent trailing battens 98 and 99. The trailing vane at the inner part of the wing is controlled in a like manner by the pivoted arm 100 engaging with the slotted bracket 101 of the tie-member 102 which connects the trailing battens 103. The rocking motion of the arm 100 is controlled by the lever means 104 manipulated by the pilot in the cockpit of the machine.

Since the resistance to forward motion of the airplane due to the drag of the wing is counteracted by the forward reaction of the elastic deformation of the trailing vanes with an attendant increase in the speed of the airplane and a decrease of the horsepower required, it is obvious that by controlling the flexing action of the trailing vanes of the wing, in the manner outlined above, the speed of the machine can be selectively modified. The landing speed can thus be reduced

by judicious manipulation of the trailing vanes of the wing.

The pilot has at his disposal the lever means 105 for arresting or restricting the motion of the rocking support for the secondary spars, the lever means 47 for restricting or arresting the motion of the sliding member 58 whereby the function of the secondary wing supports is controlled, and the lever means for controlling or arresting the flexing action of the trailing vanes. By operating these means simultaneously, the nature of the wings can be changed from resiliently flexible to a condition approaching complete rigidity.

Since the primary spars are required to act at all times as freely supported girders, they are secured to the body of the machine by suitable attachments which hold them against vertical displacement and allow their bodily displacement laterally as well as a slight rotational movement at their points of support, such as would be required by the arcuate flexing of the spar between its points of attachment. The bridge members serve as secondary supports in laterally slidable, intermittent or selectively permanent supported relation to the secondary spars or bracing girders, the primary spars or main girders thus remaining freely supported at all their points of connection with the body structure or with members integrally pertaining to the body structure. This mode of attaching the main girders or primary spars allows them to flex freely without interference from the supports, and it also serves the purpose of excluding the occurrence of axial loads in the spars. In a wing construction where external bracing is resorted to for the purpose of rendering the structure more rigid, the horizontal component of the airload reaction at the point of intersection of the diagonal bracing member with the wing spar constitutes an axial load for that section of the spar between the fuselage support and the attachment of the external diagonal brace. The spar therefore is subjected to a combination of bending and buckling stresses. In this case a heavy construction of the spar with an attendant increase in weight would be called for in order to provide the necessary factor of safety, since any flexing of the spar due to bending will entail a disproportionate increase in the buckling stresses induced by the axial load.

It is obvious then, that in order to preserve the flexibility of the spar and at the same time to maintain a reasonable factor of safety, it is necessary to eliminate the possibility of axial loads, an object which has been achieved by the arrangements and combinations hereinbefore described.

Moreover, torsional stresses in the spars due to the helicoidal deformation of the wing have been eliminated by allowing the ribs

to pivot freely about the spars, instead of their being rigidly secured to them as is the usual practice. The wing therefore includes a frame all members of which are movable with respect to each other, which permits lateral and helicoidal deformation to take place without any binding action of any of the joined members.

A flying machine with wings as described possesses automatic lateral stability. As both wings assume a laterally flexed and helicoidal conformation during flight, excess lift forces on one of the wings will cause an increased flexing of that wing. The excess lift however is instantly corrected by the action of the pivoted bracing girder or secondary spar which causes the other wing to assume a reversely flexed and reversely helicoidal conformation, the action of the pivoted beam ceasing to be effective when lateral equilibrium of the machine has been regained by the wingload being once more symmetrically distributed with reference to the median line of the machine.

Automatic directional stability is obtained by the reactions due to the elastic deformation energy of the resiliently flexible forwardly converging wing ribs. All the automatic reactions of the wing are under the control of the pilot and can be selectively restricted or suspended, even to the extent of rendering the entire wing structure rigid.

The constructions disclosed in this specification represent preferred embodiments of the invention and I wish it to be understood that I do not limit myself to the particular designs shown. The number of wing spars is by no means limited to two, nor do the wings necessarily have to be of unitary construction with the primary spars extending from one wing tip to the other. In the bridge members the method of controlling the relative motion between primary and secondary spars is not confined to the means shown in the drawings, since a great number of mechanical modifications and refinements can be introduced within the scope of the appended claims.

Having thus described my invention, I claim:

1. A rigid structure, a member extending transversely thereto, supports for said member carried by said structure, said supports holding said member against vertical displacement and adapted to permit displacement of said member laterally with respect to the supports and the structure, a member carried by said first member and projecting transversely from the side thereof, and a vertically slotted member rigid with said structure, the slot of said last named member receiving said second named member and holding the same against lateral displacement whereby said first named member is posi-

tioned laterally with respect to the supports and the structure.

2. In combination, a rigid structure, members in spaced alinement extending transversely to said structure and projecting laterally therefrom, supports for said members carried by the structure, said supports holding said members against vertical displacement, a crossmember carried by and having permanent connection with said members positioned remote from the structure, and a member carried by said structure and projecting laterally outward therefrom, said last named member having supporting engagement with said crossmember but being otherwise free from fixed connection therewith.

3. In combination, a rigid structure, members disposed transversely thereto and projecting laterally from the opposite sides thereof, supports for said members carried by said structure, said supports holding the members against vertical displacement, crossmembers carried by and having permanent connection with said members positioned remote from and at either side of the structure, and members having support in said structure and projecting laterally from the opposite sides thereof, each of said last named members having supporting engagement with a corresponding crossmember but being otherwise free from fixed connection with said crossmembers.

4. In a flying machine, in combination, a body structure, a wing extending transversely of said body structure and projecting laterally from the side thereof, girders in said wing constituting its transverse internal bracing members, supports for said girders carried by said body structure, said supports holding the girders against vertical and fore-and-aft displacement, a crossmember carried by and having permanent connection with said girders positioned remote from the body structure, and a member having support in said body structure and extending laterally thereof, said last named member having supporting engagement with said cross member but being otherwise free from fixed connection therewith.

5. In a flying machine, in combination, a body structure, a wing of unitary construction extending transversely thereto and projecting laterally from the opposite sides thereof, said wing including girders constituting its transverse internal bracing members extending from one wingtip to the other, supports for said girders carried by the body structure, said supports holding the girders against vertical displacement and adapted to permit their displacement transversely with respect to the body structure and the supports, means separate from said supports carried by the body structure for positioning said girders against lateral displacement, crossmembers, one at each side of the body

- carried by and interconnecting said girders at points remote from the body structure, and members distinct from the wing structure having support in said body structure and projecting laterally from the opposite sides thereof, each of said last-named members having supporting engagement with the corresponding crossmember but being otherwise free from fixed connection therewith.
6. In a flying machine, in combination, a body structure, a wing of unitary construction extending transversely thereto and projecting laterally from the opposite sides thereof, girders in said wing constituting the transverse internal bracing members of said wing extending from one wingtip to the other, supports for said girders carried by the body structure, said supports holding the girders against vertical displacement and adapted to permit their displacement laterally with respect to the body structure and the supports, means carried by the body structure separate from said supports for holding said girders against lateral displacement, crossmembers one to each side of the body carried by and interconnecting said girders at points remote from the body structure, and a member of unitary construction carried by said body structure and projecting laterally from the opposite sides thereof, said member constituting a support for the crossmembers but being otherwise free from fixed connection with said crossmembers.
7. A wing for a flying machine having in combination, a plurality of girders arranged in spaced fore-and-aft sequence constituting the main internal bracing members of the wing, each girder being bodily movable with respect to the others, a plurality of ribs disposed transversely to said girders, means attaching said ribs to said girders, said means adapted to allow relative movement between said ribs and girders in any direction, and a wing covering adapted to elastic deformation attached to and co-operative with said ribs and girders.
8. In a wing for a flying machine, the combination with a plurality of girders disposed in a spaced fore-and-aft sequence, each girder being of resiliently flexible construction and constituting an internal bracing member of the said wing, and a plurality of ribs disposed transversely to the said girders, of means movably attaching the ribs to the girders, said means being adapted to allow a rocking motion of the said ribs about their fore-and-aft axes, and a wing covering adapted to elastic deformation having attachment to and cooperating with said ribs and girders.
9. In a wing for a flying machine, the combination with a plurality of girders disposed in a fore-and-aft sequence, each girder being of resiliently flexible construction and constituting an internal bracing member integral with the wing structure, and ribs disposed transversely to said girders, of means movably attaching said ribs to said girders, said means adapted to allow a pivotal motion of each rib in a horizontal plane with respect to each girder, and a wing covering adapted to elastic deformation attached to and co-operative with said ribs and girders.
10. In an aeroplane, in combination with the body thereof, a wing carried by said body and extending laterally outward therefrom, said wing including a resiliently flexible girder forming an integral part of the wing structure and constituting an internal bracing member of the wing, a bracket carried by said wing girder, said bracket including spacedly arranged upper and lower members, and a beam separate from the wing structure carried by the body and extending laterally outward therefrom, the extremity of the said beam being positioned spacedly between the upper and lower member of the bracket and having no fixed connection with either member, the beam thus affording outboard support for the only flexible wing girder when the said wing girder has flexed sufficiently upward or downward to cause the lower or upper member of the bracket to contact with and bear on the extremity of the beam.
11. In an aeroplane, combination with the body thereof, a wing carried by said body and extending laterally outward therefrom, said wing including resiliently flexible girders forming integral parts of the wing structure and constituting its internal bracing members, a member disposed transversely to and having permanent connection with said wing girders, said transverse member including spacedly arranged horizontal upper and lower members, and a beam separate from the wing structure having support in said body and extending laterally outward therefrom, the extremity of said beam being positioned spacedly intermediate the upper and lower members of the transverse member and having no fixed connection with either, the beam affording outboard support for the flexible wing girders only when the said wing girders have flexed sufficiently to cause a horizontal member of the transverse member to contact with and bear on the extremity of the beam.
12. In an aeroplane, in combination with the body thereof, a wing of unitary construction carried by said body and projecting laterally from the opposite sides thereof, said wing including a resiliently flexible girder forming an integral part of the wing structure and constituting an internal bracing member thereof, brackets carried by said wing girder positioned one at each side of the body and remote therefrom, each bracket including a horizontal upper member and spacedly arranged horizontal upper and lower members, and a beam, separate from

the wing structure, carried by the said body and extending laterally from the opposite sides thereof, the extremities of said beam being positioned floatingly intermediate the horizontal members of the brackets, whereby the beam affords outboard supports for the flexible wing girder when the said wing girder has flexed a sufficient amount to contact with and bear on one of the horizontal members of either bracket.

13. In an aeroplane, in combination with the body thereof, a wing of unitary construction carried by the body and projecting laterally from the opposite sides of the said body, said wing including a plurality of resiliently flexible girders arranged in spaced fore-and-aft sequence and forming integral parts of the wing structure, transverse members carried by said wing girders positioned one at each side of the body and remote therefrom, each transverse member including a horizontal upper member and a horizontal lower member arranged in spaced relation to said upper member, and a second girder separate from the wing structure carried by the body and extending laterally from the opposite sides thereof, the extremities of said second girder being positioned floatingly intermediate the horizontal members of the said transverse members, so that the second named girder affording outboard supports for the flexible wing girders when the said wing girders have flexed sufficiently to contact with and bear on one of the horizontal members of either transverse member.

14. In an aeroplane, the combination with the body thereof, of wings carried by the body and projecting laterally from the opposite sides thereof, each wing including a resiliently flexible girder forming an integral part of the wing structure and constituting an internal bracing member thereof, a girder extending transversely across the body and projecting laterally from the opposite sides thereof, connections between the extremities of said girder and the wing girders, a pivotal support for said second named girder carried by the said body, and resilient shock absorbing means interposed between the second named girder and the body.

15. In an aeroplane, in combination with the body thereof, wings carried by the body and projecting laterally from the opposite sides thereof, each wing including a resiliently flexible girder forming an integral part of the wing structure and constituting an internal bracing member thereof, a beam extending transversely across the body and projecting laterally from the opposite sides thereof, connections between the extremities of the said beam and the wing girder, a pivotal support for said beam carried by the body structure whereby a flexing of the wing girder at one side of the body produces lever

action of the beam about its pivotal support and thus causes a flexing of the wing girder at the other side of the body in a reverse direction, and means operable in the body for locking the second named girder in fixed relation to the said body whereby pivotal movement of the said beam is prevented and the wing girders rigidly braced.

16. In an aeroplane, in combination with the body thereof, wings carried by the body and projecting laterally from the opposite sides thereof, each wing including a plurality of resiliently flexible girders arranged in spaced fore-and-aft sequence constituting the internal bracing members of the wing structure, transverse members carried by and connecting said wing girders positioned one at each side of the body and remote therefrom, a girder separate from the wing structure carried by the body and extending laterally from the opposite sides thereof, connections between the extremities of the said last named girder and the said transverse members of the wing, a pivotal support for said last named girder secured to the body structure, whereby flexing of the wing girder at one side of the body produces a lever action of the said last named girder about its pivotal support and thus causes flexing of the wing girders at the opposite side of the body in a reverse direction, and means operable in the body for locking said last named girder in fixed relation to the body whereby pivotal movement of the said last named girder is prevented and the wing girders thereby rigidly braced.

17. In an aeroplane, in combination with the body thereof, a wing of unitary construction carried by the body and extending laterally from the opposite sides thereof, said wing including a plurality of resiliently flexible girders constituting the lateral internal bracing members of the wing structure, transverse members connecting said wing girders positioned one at each side of the body and remote therefrom, a girder separate from the wing structure extending transversely across the body and projecting laterally from the opposite sides thereof, connections between the extremities of the last named girder and the transverse members, a pivotal support for said last named girder secured to the body structure whereby flexing of the wing girders at one side of the body produces lever action of the last named girder about its pivotal support and thus causes flexing of the wing girders at the opposite side of the body in a reverse direction, and means operable in the body for selectively locking said second named girder in fixed relation to the body whereby pivotal movement of the last named girder is prevented and the wing girders thereby rigidly braced.

18. An aeroplane having in combination, a body, wings carried by said body and ex-

tending laterally from the opposite sides thereof, each wing including an upper horizontal member positioned outward remote from the body, and a lower horizontal member disposed in spaced relation to the said upper member, girders separate from the wing structures carried by said body and extending laterally from the opposite sides thereof, the extremities of each girder being floatingly positioned between the upper and lower horizontal members of the corresponding wing, and means associated with said horizontal members for selectively locking the extremities of the girders into fixed relation with the horizontal members whereby the girders are constituted bracing members of the said wings.

19. An aeroplane having in combination, a body, a wing of unitary construction carried by the said body and extending laterally from the opposite sides thereof, each outwardly extending section of the wing having an upper horizontal member positioned remote from the body, and a lower horizontal member disposed in spaced relation to said upper member, a girder separate from the wing structure carried by the body and extending laterally from the opposite sides thereof, the extremities of the said girder being floatingly positioned between the upper and lower horizontal members, and means for selectively locking the girder into fixed relation with the said horizontal members whereby the said girder is converted into a bracing member for the said wing.

20. In an aeroplane, in combination with the body thereof, a wing disposed transversely to said body and projecting laterally from the side thereof, said wing including resiliently flexible girders constituting its internal bracing members; a member positioned transversely to said girders remote from the body, connections between said girders and said transverse member allowing universal-jointed motion between said member and girders, a frame carried by said member including an upper and a lower sill and upright members connecting said sills, a movable member slidable between said upright members spacedly positioned between said sills, said movable member having a horizontally slotted recess, resilient shock-absorbing means interposed between said movable member and said sills, and means for selectively locking said movable member in fixed relation to said sills; and a girder separate from the wing structure carried by the said body and projecting laterally outward therefrom, the extremity of the said girder having bearing in the slotted recess of the movable member.

21. In an aeroplane, in combination with the body thereof, a wing extending transversely of said body and secured thereto, resiliently flexible girders in said wing ar-

ranged in spaced fore-and-aft sequence, each girder capable of flexing action independently from the others, ribs carried by said girders, each of said ribs having a resiliently flexible extension projecting rearwardly, means movably connecting said ribs to said girders, said means adapted to allow universal-jointed motion between each of said ribs and each of said girders; a wing covering adapted to elastic deformation fastened to said ribs and rear extensions and forming therewith an air foil capable of bending laterally and of flexing action helicoidally upon itself, levers fulcrumed in the wing structure having slotted connection with the flexible rear extensions of the ribs, and means operable from the body of the aeroplane for operating said levers whereby the vibratory action of the flexible rear extension of the wing can be controlled.

22. A wing for a flying machine having in combination: a plurality of flexible and resilient girders arranged in spaced fore-and-aft sequence, each girder capable of flexing action along its entire length and of displacement bodily in a vertical sense with respect to the other girders, a plurality of rigid ribs disposed transversely to said girders, and means movably attaching said rigid ribs to said flexible girders, said means adapted to allow a pivotal motion of the said rigid ribs in a vertical plane about each of said flexible girders, and a wing covering adapted to elastic deformation attached to and cooperating with said rigid ribs and flexible girders.

23. A wing for a flying machine having in combination: a plurality of girders arranged in spaced fore-and-aft sequence, each girder being of resiliently flexible construction and independently capable of bodily displacement in a horizontal plane, a plurality of rigid ribs disposed transversely to said girders, each rib having fixed mounting on one of said girders whereby relative motion between said ribs and said girder in a fore-and-aft direction is excluded, means movably attaching said ribs to the other girder, said means adapted to allow relative displacement in a fore-and-aft direction between said ribs and girder, and a wing covering adapted to elastic deformation attached to and cooperative with said ribs and girders.

24. A rib for an airplane wing, comprising: a rigid web, an upper cap member secured to said web and partially rigid therewith having a resiliently flexible terminal portion extending rearwardly downward of the web, and a lower cap member secured to said web and partially rigid therewith having a resiliently flexible rear portion extending rearwardly of said web, said rear portion of the lower cap member having a channelled groove in its upper surface adapt-

ed to receive and affording a friction seat for the rear terminal portion of the upper cap member, the said terminal portion being forced into a reverse curve merging with the upper surface of the lower cap member extension and having constant resilient bearing in the groove thereof but having otherwise no connection therewith, whereby the upper cap member extension is capable of a sliding motion in the said channelled groove during the flexing and vibration of the lower cap member extension.

25. A rib for an airplane wing, comprising: a rigid web, an upper cap member secured to said web and partially rigid therewith having a resiliently flexible terminal portion extending rearwardly downward of the web, a lower cap member secured to said web and partially rigid therewith having a resiliently flexible rear portion extending rearwardly of said web, said rear portion of the lower cap member having a channelled groove in its upper surface adapted to receive and affording a friction seat for the rear terminal portion of the upper cap member, the said upper terminal portion being forced into a reverse curve merging with the upper surface of the lower cap member extension and having constant resilient bearing in the groove thereof but being otherwise free from connection therewith, whereby the upper cap member extension is capable of sliding motion in the said channelled groove during the flexing and vibration of the lower cap member extension, and a strap secured to one of said cap member extensions and encompassing the other cap member extension for holding both said extensions in resilient contact.

26. In an airplane, in combination with the body thereof, a pair of wings extending laterally from the opposite sides thereof, each wing including a resiliently flexible wing girder having attachment and support in the body, a centrally fulcrumed girder separate from the wing structure carried by the body and projecting laterally from the opposite sides thereof, and floating connections between the ends of the said fulcrumed girder and the corresponding flexible wing girders, whereby the said wing girders are enabled to flex until they are positioned in supported connection with the fulcrumed girder, any subsequent excessive flexing of one wing girder producing lever action of the fulcrumed girder so that the other wing girder is thereby flexed in a reverse direction.

27. In an airplane, in combination with a rigid portion thereof, a girder, bearing members secured to said girder and extending transversely from the opposite sides thereof, supporting brackets secured to said rigid portion located on either side of said girder, each bracket having a recess in its top surface receiving and constituting a friction seat for

the corresponding bearing member, the length of the said recesses exceeding the width of the bearing members so that the girder is capable of displacement lengthwise with respect to the rigid portion and the bracket, and a cap removably secured to the said bracket covering the recessed top surface thereof, whereby the girder is held against bodily vertical displacement.

28. In an airplane, the combination with the rigid portion thereof, of a girder, and means movably attaching said girder to said rigid portion, said means comprising: saddles straddled above and below the girder, means clamping said saddles together so that they are rigidly secured to the girder, bearing members secured to one of said saddles and extending transversely from the opposite sides thereof, and brackets secured to said rigid portion located on either side of the girder, each bracket having a slot aligned parallel to the girder receiving and constituting a friction seat for the corresponding bearing member whereby the girder is held against bodily vertical displacement, the length of the slots being greater than the width of the bearing members, so that the girder is capable of displacement lengthwise with respect to the bracket and the said rigid portion.

29. In an airplane, the combination with a rigid portion thereof, of a girder, and means movably connecting said girder to said rigid portion, said means comprising: saddles straddled above and below the girder, means clamping said saddles together so that they are rigidly secured to the girder, bearing members secured to one of said saddles and extending transversely from the opposite sides thereof, supporting brackets secured to said rigid portion located on either side of said girder, each bracket having a recess in its top surface receiving and forming a friction seat for the corresponding bearing member, the length of the said recesses being greater than the width of the bearing members so that the girder is capable of displacement lengthwise with respect to the rigid portion and the brackets, a cap having hinged mounting in the said bracket covering the recessed top surface thereof, and means for locking said hinged cap to the bracket whereby the girder is held against bodily vertical displacement.

30. In an airplane, the combination with a rigid portion thereof, of a girder, and means movably attaching said girder to said rigid portion, said means comprising: bearing members secured to said girder and projecting transversely from the opposite sides thereof, each bearing member having a cylindrical terminal portion, and brackets secured to said rigid portion located at either side of said girder, each bracket having a slot aligned parallel to the said girder receiv-

ing and constituting a seat for the cylindrical terminal portion of the corresponding bearing member so that the girder is held against bodily vertical displacement whilst capable of displacement lengthwise with respect to the brackets and the rigid portion and also capable of a rocking motion about the axes of the cylindrical terminal portions, of the bearing members.

- 10 31. In an airplane, the combination with a rigid portion thereof, of a girder, bearing members secured to said girder and projecting transversely from the opposite sides thereof, brackets secured to said rigid portion located at either side of said girder, each bracket having a slot alined parallel to said girder receiving and constituting a friction seat for the corresponding bearing member so that the girder is held against
15 20 bodily vertical displacement whilst capable of displacement lengthwise with respect to the brackets and the said rigid portion, and spacing members interposed between the brackets and the girder whereby the said
25 girder is positioned against sideways displacement.

32. In an airplane, the combination with a rigid portion thereof, of a girder, bearing members secured to said girder and projecting transversely from the opposite sides thereof, each bearing member having a cylindrical terminal portion, brackets located at either side of the girder, each bracket having a slot alined parallel to the girder receiving and constituting a friction seat for the cylindrical portion of the corresponding bearing member, a base member rigidly connecting said brackets, and means pivotally securing said base member to the said rigid
30 35 portion, whereby the girder, brackets and base member are enabled to rotate jointly in a horizontal plane.

33. A wing for a flying machine having in combination, a plurality of girders arranged
45 in spaced fore-and-aft sequence, a series of ribs disposed transversely to said girders, and gimbals secured to said girders on which said ribs are movably mounted.

34. In a wing for a flying machine, a
50 girder, an inner gimbal ring encompassing said girder and having pivoted mounting therein, an outer gimbal ring encompassing and having pivoted mounting in said inner gimbal ring, and a member disposed transversely to said girder mounted on said outer
55 gimbal ring.

35. In a wing for a flying machine, in combination, a girder, an inner gimbal ring encompassing said girder and having pivoted mounting therein, an outer gimbal ring encompassing and having pivoted mounting in said inner gimbal ring, said outer gimbal ring having peripherally disposed circular bearing surfaces, and a member disposed
60 65 transversely to said girder rotatably mounted on the bearing surfaces of said outer gimbal ring.

ed on the bearing surfaces of said outer gimbal ring.

36. In a wing for a flying machine, in combination, a girder, an inner gimbal ring encompassing said girder and having pivoted mounting therein, an outer gimbal ring encompassing and having pivoted mounting on said inner gimbal ring, said outer gimbal ring having peripherally disposed circular bearing surfaces, a member disposed transversely to said girder adapted to receive said outer gimbal ring and rotatably mounted on the circular bearing surfaces thereof, and means for keeping said outer gimbal ring and said transverse member in alinement.

37. In a wing for a flying machine, in combination, a girder, an inner gimbal ring encompassing said girder and having pivoted mounting therein, an outer gimbal ring encompassing and having pivoted mounting on said inner gimbal ring, said outer gimbal ring having peripherally disposed circular bearing surfaces, a member disposed transversely to said girder, a frame having slidable mounting in said member, said frame encompassing said outer gimbal ring and having rotatable mounting on the bearing surfaces thereof, and means for keeping said frame and outer gimbal ring in alinement.

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