March 4, 1947. W. R. SEARS 2,416,958

TAILLESS AIRPLANE

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Fig. 1.

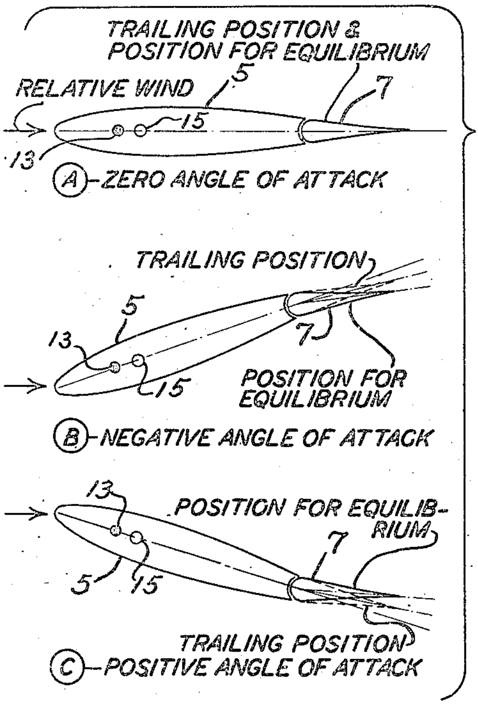


Fig. 2.

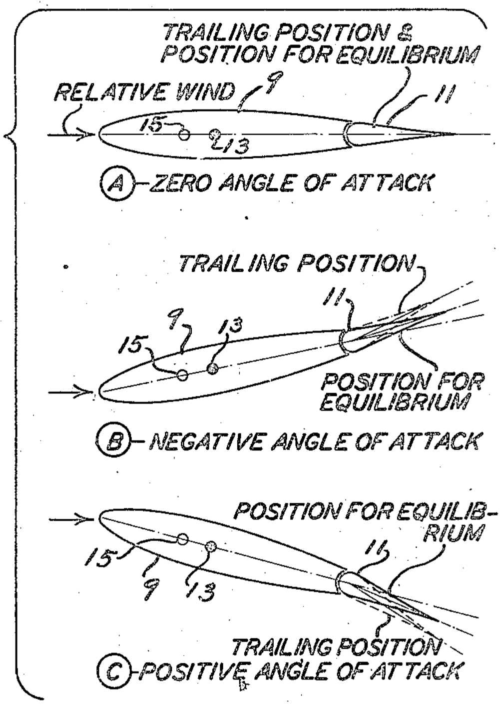


Fig. 3.

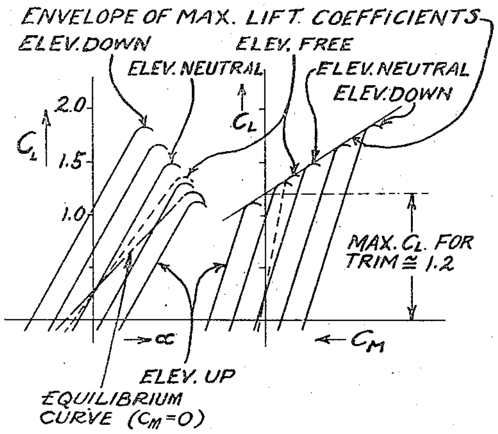
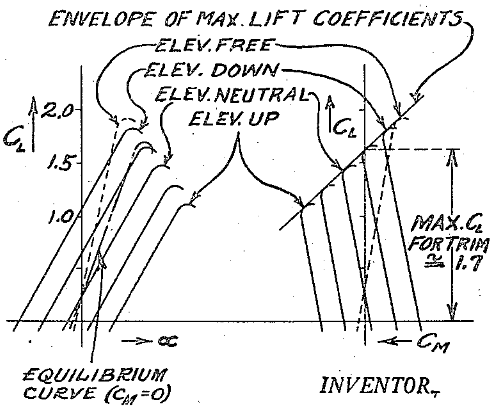


Fig. 4.



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March 4, 1947. **W. R. SEARS** **2,416,958**

TAILLESS AIRPLANE

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Fig. 9.

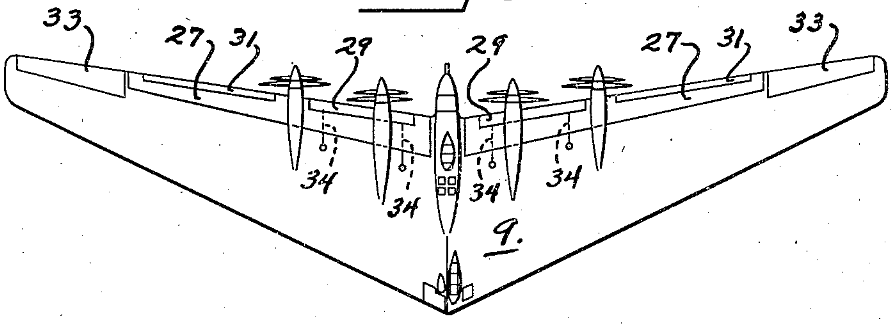
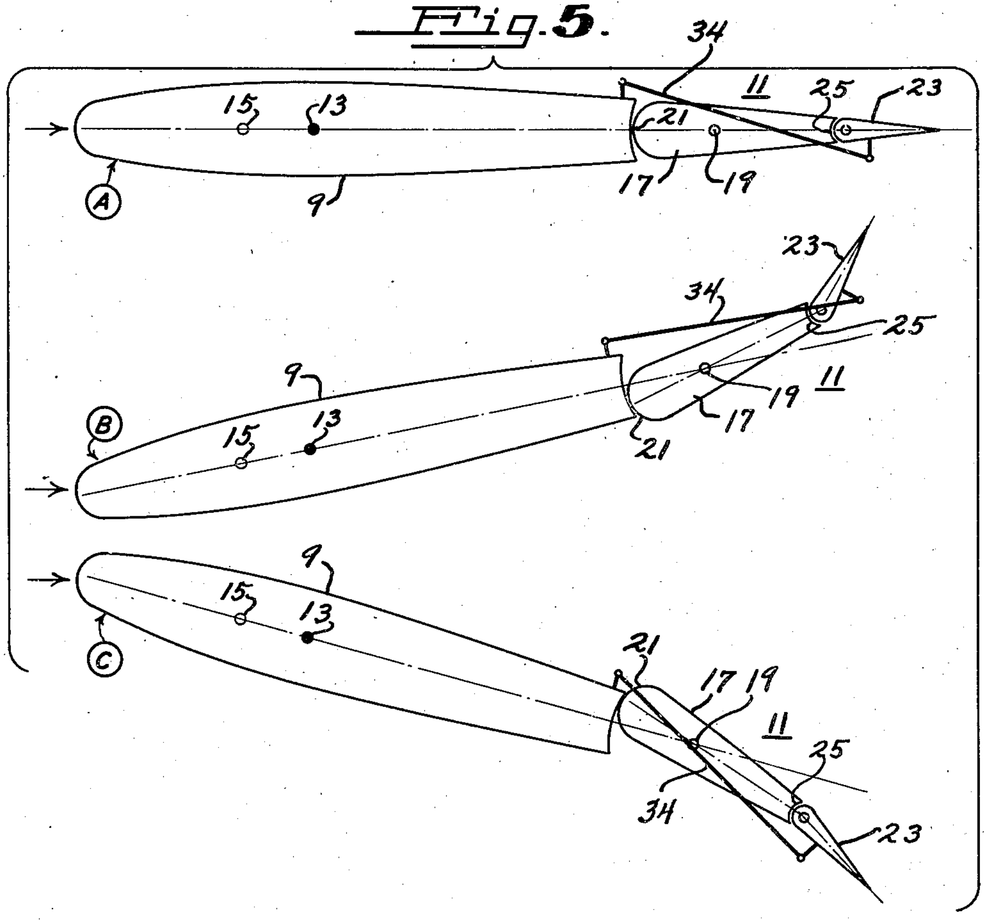


Fig. 5.



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TAILLESS AIRPLANE

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Fig. 6.

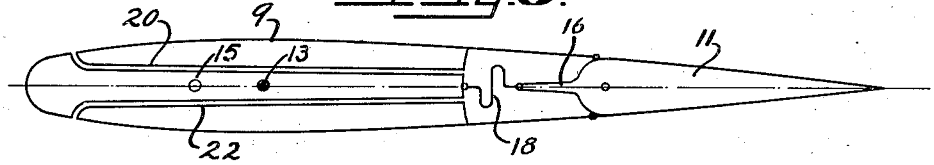


Fig. 7.

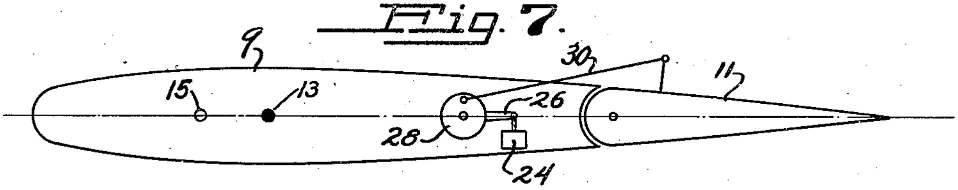
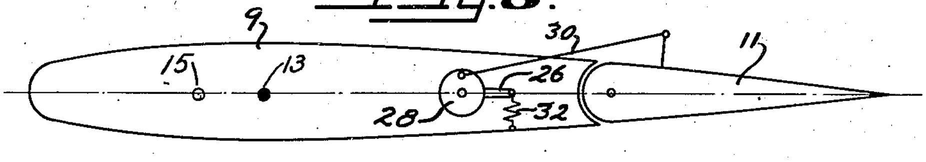


Fig. 8.



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UNITED STATES PATENT OFFICE

2,416,958

TAILLESS AIRPLANE

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Application September 24, 1942, Serial No. 459,592

13 Claims. (Cl. 244—13)

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My invention relates to airplanes of the tailless type, and more particularly to a means and method of increasing the lift of tailless airplanes.

Airplanes of the tailless or "all-wing" type, as well as conventional airplanes, are controlled longitudinally by the use of elevators. The design of these airplanes is such that the elevators produce stalling moments when they are deflected upwardly. This upward deflection creates a down load which, in effect, involves a decrease of the total lift of the airplane. In conventional airplanes, however, this down load occurs in the tail surfaces and is insignificant compared to the increased lift of the wing resulting from the increase in the angle of attack at which longitudinal equilibrium occurs with elevators up. In landing, this means substantially reduced landing speed. But in tailless airplanes, the loss of lift due to upward elevator deflection is serious, due to the fact that the elevator actually comprises a rearward section of the wing itself, and when it is deflected upward, there is a resulting strong downward component of force on the wing which usually acts at about the midpoint of the wing chord. Hence, when the elevators are raised in landing, a higher angle of attack is obtained with resulting increase in lift of the wing, but this increased lift is neutralized to a large extent by the considerable down load on the wing, and a high forward velocity must still be maintained. This unfortunate characteristic has been a major deterrent to the development of the tailless type of aircraft.

Among the objects of my invention are:

(*a*) To provide a novel and improved airplane of the tailless type.

(*b*) To provide a novel and improved airplane of the tailless type having a higher coefficient of maximum lift at positive angles of attack in conditions of longitudinal equilibrium than heretofore obtainable.

(*c*) To provide a novel and improved airplane of the tailless type having a higher coefficient of maximum lift at positive angles of attack in conditions of longitudinal equilibrium, with longitudinal stability.

(*d*) To provide a novel and improved airplane of the tailless type having a higher coefficient of maximum lift at positive angles of attack in conditions of longitudinal equilibrium, and whose control forces are of the conventional character.

(*e*) To provide a novel and improved airplane of the tailless type having a greater maximum lift at positive angles of attack in conditions of longitudinal equilibrium, for a given wing area, than prior-art airplanes of the tailless type.

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(*f*) To provide a novel and improved airplane of the tailless type having an increased maximum lift per given wing area at positive angles of attack in conditions of longitudinal equilibrium, and in which the pilot controls are essentially unchanged.

(*g*) To provide a novel and improved airplane of the tailless type capable of landing and taking off at reduced speeds.

(*h*) To provide a novel and improved method of increasing lift in airplanes of the tailless type at positive angles of attack in conditions of longitudinal equilibrium.

(*i*) To provide a novel and improved method of increasing lift and maintaining longitudinal stability in airplanes of the tailless type.

Additional objects of my invention will be brought out in the following description of the same.

In general, my invention consists, in the first place, of locating the airplane's weights so that its center of gravity is behind the aerodynamic center of the wing, which is conventionally defined as the point about which the moment coefficient for varying angles of attack and constant control-surface angles is constant. This is directly contrary to prior practice relating to airplanes of the tailless type, it having previously been believed essential to attainment of longitudinal stability that the center of gravity be forward of the aerodynamic center. As a matter of fact, location of the center of gravity forward of the aerodynamic center is the criterion for longitudinal static stability in tailless airplanes as heretofore known or proposed. The present invention nevertheless employs the reversed relationship, i. e., center of gravity rearward of aerodynamic center, and this leads to the unconventional but highly advantageous use of downward rather than upward deflections of the elevons, elevators, or other trailing-edge control surfaces at positive angles of attack in conditions of longitudinal equilibrium. Consequently, during landing, takeoff, and other maneuvers in which high lift coefficients are desired, the deflection of the control surface or flap is such as to increase substantially the lift coefficient rather than to diminish it.

The increase in lift coefficient realizable by reason of the above changes from prior-art teachings is, however, accompanied by a loss of longitudinal stability, as well as a change in the control forces of the plane from the conventional.

My invention further contemplates, therefore, the application of special devices or methods to regain the longitudinal stability that is otherwise lost by locating the center of gravity behind the aerodynamic center, and to restore the control forces of the airplane to normal character. These devices and methods may be of various types such as are described herein and are characterized by the fact that they cause a control surface or flap, when uncontrolled, to have a reversed or "negative" trailing tendency in the relative wind, i. e., to trail downwardly rather than upwardly with positive angles of attack, and to assume a greater downward deflection at high angles of attack than is required for longitudinal equilibrium of the airplane. There is thus created a diving moment which stabilizes the otherwise unstable airplane. With an increase in angle of attack, caused for instance by a sudden up-gust of wind, the elevator will automatically deflect downwardly, thereby creating a diving moment which acts to restore the airplane to its original attitude. This automatic deflection of the elevator responsive to variations in the angle of attack occurs continuously in flight, and in turbulent air the action of the elevator resembles that of a conventional control surface which is being actuated by an automatic pilot and which is in more or less continuous motion as it seeks new balancing positions corresponding to the rapidly changing aerodynamic conditions encountered by the airplane. The control forces are conventional, since at a high angle of attack, for example, the elevator must be pulled upward from its free-trailing downwardly deflected position in order to achieve equilibrium.

The application of my invention to the design of tailless airplanes results in the attainment of lift coefficients in landing, takeoff, and other flight maneuvers as great as are obtainable in like conditions of flight by conventional airplanes equipped with wing flaps or other high-lift devices. By this improvement the lifting capacities of tailless airplanes can be made as great as those of conventional airplanes without any increase of their wing areas. This affords a reduction in the speeds of landing and takeoff, and allows the inherent advantage of the tailless type, namely, an unusually low drag coefficient, to be utilized to its fullest extent, and causes the maximum flying speeds of tailless airplanes to be increased accordingly.

In determining the longitudinal stability and control of airplanes, the location of the center of gravity of the airplane relative to the aerodynamic center of the wing is a major consideration, as has already been mentioned. The importance of this relative location is further explained in the following discussion. It is well known that the lift coefficient of a wing or of a complete airplane increases with its angle of attack in a substantially linear manner up to the stalling point. It has been determined both by theory and experiment that the forces and pitching moments that act on a wing, as its angle of attack varies, can be represented by or resolved into a non-varying force component L_c acting at some fore-and-aft point on the wing (approximately the 50% chord point), and a varying force component L_α acting at a certain point (approximately the quarter-chord point) called the aerodynamic center. The location and magnitude of the component L_c that is non-variable with angle of attack is altered by changes in the wing profile or camber, such as deflection of control surfaces at the trailing edge. The location of the aerodynamic center depends only upon the wing planform, and the magnitude of the force component L_α acting in effect at the aerodynamic center depends substantially only on the angle of attack of the wing. It follows that the moment coefficient C_M about the point through which the force component L_α passes is constant with varying angles of attack, and the aerodynamic center is hence the fixed point about which the moment coefficient is constant.

For an airplane in flight, the center of gravity is the reference point about which the moments must balance; that is, so far as its longitudinal pitching motion is concerned, the airplane behaves as if it were free to rotate on a transverse axis through the center of gravity position. Therefore, for all conditions of steady flight, such as landing and takeoff, and for maneuvers that do not involve large pitching accelerations, it is necessary that the longitudinal control surfaces be deflected in such a manner that a balance of moments about the center of gravity is achieved.

The method of controlling tailless airplanes in the past has consisted, in the first place, of locating the center of gravity of the airplane forward of the aerodynamic center of the wing. Therefore, as the angle of attack is varied, either in changing the flying speed in steady flight or in performing flight maneuvers, the variable portion of the lift on the airplane acts at a point behind the center of gravity. For example, if the angle of attack is increased, the lift is increased behind the center of gravity, and the equilibrium of pitching moments about the center of gravity must be re-established at the new angle of attack by deflecting the trailing-edge control surface or flap upward. Further increase of the angle of attack similarly requires further upward deflection of the trailing-edge control surface, so that in the landing or maximum-lift attitude, the control surface is deflected upward to an extreme angle and the down load created thereby greatly reduces the maximum lift coefficient in comparison with that which would be obtained by the original undistorted wing at the same angle of attack.

In my invention the airplane is loaded in such a manner that its center of gravity is located behind the aerodynamic center. Therefore, the portion of the lift that is variable with angle of attack occurs forward of the center of gravity, and when the angle of attack is increased, the equilibrium of pitching moments is restored by deflecting the trailing-edge control surface or flap downward. As the angle of attack is further increased, the portion of the lift acting at the aerodynamic center becomes still greater, and the downward control deflection required for equilibrium is larger. When the airplane flies in its attitude for maximum life, as in landing, taking off, or in certain other maneuvers, the control deflection required for equilibrium is large and is in the direction to increase the maximum lift coefficient of the wing.

For a more detailed description of my invention, reference will be made to the accompanying drawings, wherein:

Fig. 1 is a diagram representing positions of a trailing-edge control surface in a tailless airplane of prior-art design, for different angles of attack.

Fig. 2 is a diagram representing corresponding positions of a trailing-edge control surface in the tailless airplane of my invention.

Fig. 3 is a diagram showing characteristic curves illustrating the variations in lift coefficient of the airplane of Fig. 1 with changes in angle of attack and pitching moment.

Fig. 4 is a diagram showing the corresponding characteristic curves for the airplane of my invention.

Fig. 5 is a diagram showing one of several means for realizing automatic longitudinal stability in the airplane of my invention.

Figs. 6, 7 and 8 are diagrammatic illustrations of additional means for obtaining automatic longitudinal stability in the airplane of my invention.

Fig. 9 is a diagrammatic plan view of my novel and improved tailless airplane, showing a preferred location of the control surfaces.

The views of Fig. 1 represent a sectional contour of the wing **5** and a trailing-edge control surface **7** of a tailless airplane of prior-art design. Those views of Fig. 2 represent a corresponding sectional contour of the wing **9** and a trailing-edge control surface **11** of my novel and improved tailless airplane. Different reference numerals have been employed, to stress the fact that the corresponding elements, while they appear alike in the above views, actually differ in design and characteristics. The views serve to illustrate the comparative positions of the control surfaces for longitudinal equilibrium in each case for different angles of attack, such as zero, negative, and positive angles of attack. It will be noted that whereas in the case of Fig. 1, the elevator trails downwardly for negative angles of attack, and upwardly for positive angles of attack, in both instances to angles less than for equilibrium, in the case of the present invention, the elevator is constrained to trail negatively, i. e., upward for negative angles of attack, and downward for positive angles of attack, the angle of deflection being beyond those for equilibrium. These views also show the relative locations of the center of gravity **13** and aerodynamic center **15** in the prior art case of Fig. 1, and in the instant invention (Fig. 2), the center of gravity being forward of the aerodynamic center in the prior art case, and rearward of the aerodynamic center in the case of the invention.

In Figs. 3 and 4, curves of lift coefficient C_L against angle of attack α, and of lift coefficient C_L against pitching moment coefficient C_M are plotted for the prior-art case (Fig. 3) and for the case represented in the present invention (Fig. 4). In these figures the accepted standard definitions of the coefficients are employed. Families of curves are drawn for various fixed control-surface (elevator) or flap deflections, as noted in the figures. A sharp bend has been shown at the top of each curve to indicate the occurrence of the maximum lift coefficient for the particular control-surface deflection in question. It will be noted that the maximum lift coefficient is substantially increased in the elevator-down cases, as compared with elevator neutral, and diminished with elevator up. Curves for the "elevator free" condition are shown in both figures, and in the right-hand portions of the diagrams (C_L vs. C_M), represent "stick-free" longitudinal stability. Equilibrium of pitching moments occurs only for $C_M=0$; i. e., at the intersections of the various curves with the C_L axis in the C_M, C_L diagrams. It will be seen that the maximum available lift coefficient along this axis is considerably greater in Fig. 4 than in Fig. 3, the explanation for which will be developed hereinafter. The curve designated "equilibrium curve" on each C_L vs. α diagram represents the lift coefficient obtained at different angles of attack, with the flap correspondingly deflected to maintain a condition of equilibrium, i. e., $C_M=0$. Since the airplane is in equilibrium during all normal, or trimmed, flight, these equilibrium curves afford a direct comparison of the performance of the present invention with that of a conventional tailless airplane. It will be noticed that the equilibrium curve in Fig. 4 for an airplane embodying my invention has a steeper slope and reaches a higher maximum lift coefficient at a lower angle of attack than in the conventional airplane represented in Fig. 3.

An important feature of my invention resides in the manner of realizing the various positions of the control surface or flap for different angles of attack as indicated in Fig. 2. In general, I accomplish these ends through the use of special devices to reverse or counteract the usual trailing tendency of trailing-edge control surfaces or flaps, so that an increase of angle of attack causes the control surface or flap to deflect automatically downward, and a decrease of angle of attack causes it to deflect upward, such deflections being beyond those for equilibrium at given angles of attack, positive or negative. The use of such devices provides the necessary longitudinal stability in the airplane of my invention.

The concept of longitudinal stability of an airplane introduces, in addition to the requirement of equilibrium, the question of the tendency of the airplane to return to or diverge from the state of equilibrium after a disturbance without any control effort being applied by the pilot. The previously accepted method of obtaining longitudinal equilibrium and stability in a tailless airplane is as follows (referring again to Fig. 1). The center of gravity **13** of the airplane is located forward of the aerodynamic center **15** of the wing; consequently if a disturbance occurs that involves a change in the angle of attack, the variable portion of the lift in effect acts at a point on the wing behind the center of gravity as represented by the aerodynamic center **15**. If the disturbance involves an increase of the angle of attack (Fig. 1C), the lift force behind the center of gravity **13** is increased in magnitude and the equilibrium of pitching moments about the center of gravity is destroyed in such a way as to produce a diving moment. Thus, a tendency for the airplane to return to equilibrium is automatically set up and the airplane is said to be longitudinally stable.

If, as is usually the case, the increase of angle of attack causes the trailing-edge control surface **7** to deflect slightly upward, i. e., to "trail" with the relative wind, a secondary pitching moment is set up that is opposite to the stabilizing effect just mentioned; that is, it reduces the tendency of the airplane to return to equilibrium. Since this secondary tendency will always occur unless resisted by the pilot of the airplane, it is commonly believed desirable that there be sufficient longitudinal stability to overcome it. In other words, airplanes are usually required to exhibit longitudinal stability without any effort being applied to the pilot's controls, i. e., with "controls free."

Reference to Fig. 3 will reveal that the C_L vs. C_M curves for fixed as well as free elevator conditions slope upwardly from left to right with increasing C_L. They thus have "stable slopes," indicating that any increase in the lift coefficient, caused by a sudden increase in angle of attack, is accompanied by a decrease in moment coefficient C_M (increasing values of which are measured toward the left in the diagram), so that a diving moment is created tending to return the airplane to its original attitude. In contrast with the above, the curves for fixed elevator conditions in the airplane of the invention, as shown in Fig. 4, slope upwardly from right to left with increasing C_L, and thus have "unstable slopes." An increase in C_L caused by an increase in angle of attack means an increase in the lift force through the aerodynamic center, and since the latter is ahead of the center of gravity, a stalling rather than a diving moment is created, and there is a tendency for the angle of attack to increase still further.

By the use of the special devices mentioned above, which reverse the usual trailing tendencies of a control surface or flap, I am now able to produce a force or moment effectively stabilizing an otherwise inherently unstable tailless airplane, i. e., one having its center of gravity to the rear of its aerodynamic center, and I secure the great advantage of downward elevator deflections at positive angles of attack. When such devices are employed, the airplane reacts to a disturbance in the following manner. An increase of angle of attack causes additional lift forward of the center of gravity, but the upsetting or destabilizing effect of this force is more than counteracted by a stabilizing force acting at about the midchord point of the wing and resulting from the automatic downward deflection of the trailing-edge flap.

The trailing positions of an ordinary control surface or flap at various angles of attack are indicated in Fig. 1. The corresponding trailing positions of a control surface or flap, when equipped with the special devices referred to here, are shown in Fig. 2. (No attempt has been made in Fig. 2 to picture these special devices or their working principles; only the results of their application are shown.)

In Fig. 3 there are drawn curves representing the elevator-free characteristics of a tailless airplane with ordinary control surfaces, and in Fig. 4 the analogous curves for a tailless airplane incorporating my invention. It will be noted that the slopes of the C_M, C_L curves for elevator free are substantially the same in both Figs. 3 and 4; i. e., from left to right as C_L increases. This is called a stable slope, since it shows that an increase of angle of attack produces a stabilizing pitching moment. Both cases therefore show substantially the same stick-free longitudinal stability, notwithstanding the reversed relationship of center of gravity and aerodynamic center.

The character of the control forces that must be exerted by the pilot, in order to maintain equilibrium at various angles of attack, is the same in the case of my invention as in a conventional airplane. This is apparent in Figs. 1 and 2, where it is seen that the direction of motion required of the control surface in moving from its trailing position to the position for equilibrium at the same angle of attack is the same in both cases. The same result can be deduced from a comparison of Figs. 3 and 4, where it is apparent that the increment between the elevator-free pitching-moment curve and the equilibruim line (C_L axis) is the same in both cases. Thus, it is seen that the advantages of the present invention are attained without sacrifice of the usual character of the pilot's control forces.

It was mentioned in the introductory paragraphs that the upward elevator deflection necessary to trim a conventional tailless airplane for landing results in a substantial loss in lift coefficient C_L. This loss in C_L is indicated in Fig. 3 by the envelope line of maximum available lift coefficients for a family of curves, which line will be seen to slope upwardly from left to right. Attention is drawn to the "elevator neutral" curve, and to the fact that it extends in Fig. 3 to the right of the C_L axis, and is tangent to the said envelope line at a point to the right of the C_L axis. All curves of upward elevator deflection must hence be tangent to that envelope line at points lower down thereon than the point of tangency with the elevator neutral curve. The diagram thus brings out the loss in C_L that must be suffered by the conventional tailless airplane when the elevators are raised from the neutral configuration for landing.

Referring now to the case of Fig. 4, it will be seen that the "elevator neutral" curve extends to the left of the C_L axis, and is tangent to the sloping envelope line of maximum lift coefficients at a point to the left of the C_L axis. In this case, trim for landing at maximum available C_L is accomplished by downward elevator deflection, as has already been explained, which means moving up rather than down the sloping envelope line to intersection with the C_L axis. In other words, the diagram brings out the fact that the lift coefficient is actually augmented rather than diminished when the airplane is trimmed at high angles of attack as in landing.

Several different methods and devices may be employed to reverse the trailing tendency of a trailing-edge flap or control surface and to secure thereby the automatic stabilizing effect described above. One of the simplest of these devices is a pilot controllable elevator or flap **17** (Fig. 5) that is aerodynamically overbalanced by having its hinge position **19** abnormally far behind its leading edge **21**. Such a flap will have a trailing tendency with respect to angle of attack that is opposite in sense to that of a common control surface, referred to herein as a "negative" trailing tendency. However, it also is overbalanced with respect to flap deflections; i. e., it always tends to increase its deflection and would ordinarily have to be restrained by pilot forces that are unconventional.

This undesirable tendency can easily be eliminated without altering its negative trailing tendency, by use of a small anti-boost tab **23** located in its trailing edge **25** and connected by a pivotally secured cross link **34** from the lower surface of the tab **23** to the upper surface of the wing **9**. The anti-boost tab may extend over all or only part of the flap-trailing edge, as may be desired. Its action is such as to augment slightly the natural control effectiveness of the flap. The combination of aerodynamically overbalanced flap **17** and anti-boost tab **23** constitutes an effective device for use in my invention. It tends to assume downward deflections at positive angles of attack and upward deflections at negative angles of attack, and the pilot control forces that are required to move it from the control-free deflection to the equilibrium position at any angle of attack are completely conventional.

The principle having been pointed out it becomes apparent that aerodynamically overbalanced surfaces can be produced in other ways than that illustrated in Fig. 5. For example, the leading-edge portion **16** (Fig. 6) of the flap can be sharpened and enclosed in the contour of the wing 9, with aerodynamic pressures admitted to its upper and lower surfaces through properly arranged ducts or slots 20 and 22, separated from one another at all flap positions by a flexible wall seal 18. The effects of the aerodynamic overbalancing are similar in such arrangements to those described above in connection with Fig. 5.

A third method (Fig. 7) of obtaining the desired negative trailing characteristic of the control surface or flap consists of equipping it with an unbalanced mass that tends to deflect it downward. This may be accomplished by suspending a mass 24 from the end of an arm 26 carried by an eccentric or crank 28 rotatably mounted within the wing 9 and having a connection to the upper surface of the flap through a pivotally mounted link 30. The effect of such a mass is opposed by the usual upward trailing tendency of the surface at positive angles of attack. However, this tendency varies with the square of the flying speed, while the mass moment remains unchanged in steady flight or increases in proportion to the vertical acceleration in maneuvers. An increase of angle of attack is always accompanied either by a decrease of flying speed or an increase of vertical acceleration. Consequently the mass moment always becomes relatively greater as the angle of attack increases, and the desired negative trailing tendency of the flap is artificially produced. A similar effect, at least in so far as steady flight conditions are concerned, may be obtained by attaching to the control surface a spring that tends to deflect it downward. This may be realized by substituting a spring 32 for the mass 24 of Fig. 7, the spring being anchored at some point of the wing 9. (Fig. 8).

Another device that can be employed to produce a negative trailing tendency consists of an automatic control similar to that used for automatic piloting of aircraft. Such a device is actuated by the relative motion of the aircraft and a gyroscope or system of gyroscopic elements. This relative motion can be employed through suitable mechanical, electrical, or hydraulic means to deflect downward the control surface or flap when the angle of attack is increased.

It is clear from the above discussion that there are several methods and devices available for producing the negative trailing tendency that constitutes an important part of this invention if longitudinal stability is to be automatically realized. They may be used singly or in combinations to secure control-free stability and pilot control forces of conventional character in tailless airplanes incorporating this invention.

There are, moreover, several methods of locating the negatively-trailing stabilizing flaps along the trailing edge of the wing, either as control surfaces or as independent units. All of these methods accomplish the ultimate purpose of the invention, namely, to increase the maximum useable lift coefficient of the tailless airplane. One such method is to employ control surfaces which are directly controlled by the pilot and which function both as stabilizing flaps and as elevators. The discussion of the preceding paragraphs is then applicable in all details without alteration. At high angles of attack the elevators tend to trail downward to an angle greater than that required for equilibrium, thus producing automatic longitudinal stability. To produce equilibrium at a high angle of attack the pilot pulls back on the control column in the conventional manner to force the elevator upward (but not beyond its central position). In this system the dual-purpose flaps may extend over a large proportion of the trailing edge of the airplane. As a further simplification, they may be extended outboard over the portion of the trailing edge that would otherwise be occupied by ailerons and may be actuated differentially by the pilot for lateral control, i. e., they may be employed as "elevons."

In this system of direct control of the negatively-trailing flaps, as has been mentioned previously, the control forces are completely conventional. It may be noted, however, that the variation of control column position with angle of attack is the reverse of that usually encountered. For example, at high angles of attack, since the elevators are depressed downward, the control column is in a forward rather than a rearward position, assuming that a conventional mechanical system of control cables is used. This is not believed to be a serious disadvantage, since it is widely recognized that the direction of variation of control forces is more important to the pilot than the variation of control-column position with angle of attack or flying speed.

There are available other arrangements for controlling the surfaces, that serve to eliminate the objection of abnormal variation of control-column position. One of these is to combine the negatively-trailing flaps with the elevators or elevons, as in the preceding paragraph, but to control these from the pilot's cockpit by means of "flying tabs" or "servos." These are small tabs located in the trailing edge of the flaps, their angles relative to the flaps being directly controllable by the pilot. These tabs serve to apply aerodynamic hinge moments to the flaps to control their positions. Since the hinge moments that are required to force the flaps from their negatively-trailing positions to their positions for equilibrium are conventional in character, the deflections that are required of the flying tabs to accomplish this are also completely normal. In this type of control system the position of the pilot's control column is determined by the tab deflection relative to the flap. Hence, the control-column positions, as well as the control forces, are conventional.

A similar result can be accomplished by employing a hydraulic or electrical booster in the elevator control system instead of connecting the control cables directly to the elevators. Such boosters can easily be made to function so that the position of the pilot's control-column determines the elevator hinge moment rather than the elevator angle itself. Again, since the elevator hinge moment variation in my invention is conventional, the stick position variation is also conventional if the booster is used.

An alternative method of controlling a tailless airplane incorporating my invention is to separate the negatively-trailing stabilizing flap from the elevators or elevons. The stabilizing flaps equipped with one of the special devices previously described, or any combination thereof, are located inboard of the elevons and are not directly controlled by the pilot's control-column, while the elevons are directly controlled by the pilot in a conventional manner.

The preceding discussions of the working principles of my invention are applicable to this control system with slight modification in some details. In this system the stabilizing flap is always allowed to assume its negatively-trailing position, and when it is desired to produce equilibrium at any certain angle of attack, the elevators are deflected upward so as to counteract the stabilizing diving moment of the flaps. (The elevators may be assumed to be surfaces of positive trailing tendencies.) The upward deflection of the elevators causes a dimunition of the lift of the wing. Nevertheless the additional downward flap deflection counteracts this lift decrement. Experience has shown that the end result is substantially the same whether the stabilizing flap is pulled upward from its trailing position or whether it is allowed to trail freely and a separate elevator is deflected upward to produce equilibrium. It should be pointed out that in interpreting Fig. 2 in the light of the above, the increment in flap deflection between the trailing position and the position for equilibrium must be interpreted as an increment applied to a separate elevator and not to the flap itself. Moreover, in Fig. 4 the word "elevator" must be replaced by the word "flap."

As an example illustrating one method of applying the present invention to a tailless military or transport airplane, a diagrammatic layout is presented in Fig. 9. In this application I have chosen to illustrate the type of control described above which utilizes flying tabs or servos. Along the trailing edge of the wing **9** are located combination stabilizing flaps and elevons **27** equipped with anti-boost tabs **29** and flying tabs **31**. The anti-boost tabs are actuated by links **34** of the type shown in Fig. 5. Outboard of the flaps **27** are located rudders or other control surfaces **33**. Alternatively the control surfaces **27** could be employed only as stabilizing flaps and elevators if desired, and the surfaces **33** could be used as separate ailerons. In either case the pilot's controls are connected directly to the flying tabs **31**. Although other devices could be used for the purpose, Fig. 9 shows a design in which the negatively-trailing tendency of the flap is obtained by a combination of aerodynamic over-balance and anti-boost tabs **29**.

Considering, therefore, that any one of the methods above recited is to be used, the advantages achieved by the application of my invention are great. In the first place, high lift coefficients are obtained in equilibrium conditions at high angles of attack. This eliminates the main disadvantages of tailless airplanes, i. e., the customary loss of lift of such airplanes in their landing configuration with elevators up.

Furthermore, in tailless airplanes designed according to my invention it will be unnecessary to provide aerodynamic washout in order to obtain equilibrium at high speeds with neutral elevators. With the center of gravity of the airplane behind the aerodynamic center of the wing, the moment desired for equilibrium, at any flying speed, is actually diving in direction. Consequently, positively-cambered airfoil profiles, which provide diving moments without control-surface deflection, can be used with little or no aerodynamic washout as determined simply by the requirements of satisfactory stalling properties. The use of such positively-cambered airfoils is advantageous in reducing the drag of the airplane, since such airfoils have positive optimum lift coefficients; i. e., the lift coefficient at which the profile-drag coefficient is a minimum has a substantial positive value.

Also, the stabilizing flaps or elevators described herein can act as cruising flaps, which have the function of reducing drag coefficients at high lift coefficients by increasing the optimum lift coefficients of the airfoil. Such cruising flaps must be deflected downwardly in order to be effective at high lift coefficients. By the utilization of my invention, therefore, the flaps or elevators themselves, which are depressed at high lift coefficients, as has been described, automatically act exactly in the manner required of cruising flaps. This means that all of the airfoil profiles that are encompassed by the flap span will have their optimum lift coefficients shifted to coincide approximately with the lift coefficient of equilibrium in all conditions of flight. This results in a substantial reduction in profile drag and corresponding improvements in airplane performance.

Again, in tailless airplanes making use of my invention, the negatively-trailing elevator, as described herein, can replace the landing flap. This will allow a long span elevator of small chord to be employed. Such a control surface has the very important advantage of having smaller hinge moments, reduced moments of inertia, and consequent improvement of dynamic stability.

It has previously been pointed out that the equilibrium curve in Fig. 4 for an airplane of the present invention has a steeper slope and reaches its maximum lift coefficient at a lower angle of attack than in the conventional tailless airplane of Fig. 3. This feature is advantageous in that it results in an improvement in the flow of air through cooling ducts at high lift coefficients, as during a climb when the problem of cooling is critical, and also permits the use of a shorter landing gear, since the lift coefficient required for landing is obtained at a smaller angle of attack.

Finally, my invention is a great aid in increasing maneuverability of the airplane. For example, the tendency of highly loaded airplanes to stall in tight turns is appreciably lessened. This tendency is dangerous in present day military and transport airplanes, since their wing loadings are high, and their maximum lift coefficients are relatively low in cruising configurations with the landing flaps retracted. Since high wing loadings are advantageous to high speed, this condition has led to a conflict between the requirements of speed and maneuverability. By the use of my present invention, the maximum lift coefficient of a tailless airplane in all conditions in which the airplane is maneuvered toward a high angle of attack, can be made as great as is usually associated with downward flap deflections. Therefore, in spite of the fact that the wing loading may be substantially increased, the airplane will not be in any greater danger of stalling in making a tight turn. Consequently, the tailless airplane incorporating my present invention can be made to combine the highly desirable but heretofore incompatible qualities of high maneuverability, high speed, and low landing speed.

While I have described various forms of my invention in detail, it is apparent that additional embodiments may be developed without departing from the fundamental principles involved and I accordingly do not desire to be limited in my protection to the details described and set forth except as may be necessitated by the appended claims, in which the expression "control surface means" is to be considered generic to control surfaces, flaps and the like, and as employed in these claims, is not to be construed as limiting the control surfaces of the airplane to those involved in the novel combination of the present invention.

I claim:

1. An airplane of the tailless type having the aerodynamic center of the wing ahead of the center of gravity of the airplane and means in said wing producing a longitudinal stabilizing moment thereon, said means including a wing lift varying means.

2. An airplane of the tailless type comprising a wing having its aerodynamic center ahead of the center of gravity of the airplane, and including a control surface means having negative trailing characteristics for producing a longitudinally stabilizing moment on the wing.

3. An airplane of the tailless type comprising a wing having its aerodynamic center ahead of the center of gravity of the airplane, and including a longitudinal control surface means; and means for imparting negative trailing characteristics to such control surface means.

4. An airplane of the tailless type comprising a wing having its aerodynamic center ahead of the center of gravity of the airplane, and including a longitudinal control surface means; and means for automatically reversing the natural trailing tendencies of such control surface means.

5. An airplane of the tailless type comprising a wing having its aerodynamic center ahead of the center of gravity of the airplane, and including control surface means in the trailing edge of said wing, capable of downward deflection at positive angles of attack; and means for automatically deflecting said control surface means downwardly to a degree sufficient to create a restoring moment on said wing.

6. An airplane of the tailless type comprising a wing having its aerodynamic center ahead of the center of gravity of the airplane, and including control surface means in the trailing edge thereof operative to produce a stabilizing moment on the wing, and means establishing conventional control forces in the operation of said airplane.

7. An airplane of the tailless type comprising a wing having its aerodynamic center ahead of the center of gravity of the airplane and including control surface means in the trailing edge thereof; and means automatically applying a force to said control surface means in a direction to reverse the normal trailing characteristics thereof, said means tending to deflect said control surface means beyond its equilibrium-establishing position so that the control forces required for moving said control surface means to its equilibrium position are conventional in character.

8. A tailless airplane comprising a wing having its aerodynamic center ahead of the center of gravity of the airplane and including an aerodynamically overbalanced control surface means associated with the trailing edge of said wing and having negative trailing characteristics, and means interconnecting said control surface means with the main portion of said wing to restrain the negative trailing characteristics thereof to a degree such that the resultant trailing position is beyond its equilibrium-establishing position.

9. A tailless airplane comprising a wing having its aerodynamic center ahead of the center of gravity of the airplane, hinged manually controllable elevator means forming a section of the trailing edge portion of said wing, said combination of wing and elevator means being longitudinally unstable with said elevator fixed in neutral position, and means yieldingly biasing said elevator means to trail in the relative wind at increasing downward deflection angles with increasing angles of attack of the wing, whereby the airplane is rendered longitudinally stable, said elevator biasing means yielding to manual elevator control.

10. A tailless airplane comprising a wing having its aerodynamic center ahead of the center of gravity of the airplane, hinged elevator means forming a section of the trailing edge portion of said wing, said combination of wing and elevator means being longitudinally unstable with said elevator fixed in neutral position, means yieldingly biasing said elevator means to trail in the relative wind at increasing downward deflection angles with increasing angles of attack of the wing, whereby the airplane is rendered longitudinally stable, and overriding manually controlled means for moving said elevator means in opposition to the yielding restraint exerted by said elevator biasing means.

11. An airplane of the tailless type comprising a wing whose aerodynamic center is ahead of the center of gravity of the airplane when the airplane is normally loaded, hinged elevator means adjacent the trailing edge portion of said wing, and means controlling said elevator means automatically in dependence upon the angle of attack of the wing to reverse the natural trailing tendencies of such elevator means whereby to stabilize said wing longitudinally.

12. An airplane of the tailless type comprising a wing whose aerodynamic center is ahead of the center of gravity of the airplane when the airplane is normally loaded, and means for automatically varying the effective camber of the wing with variations in the angle of attack of the wing to produce a stabilizing moment in the wing tending to create longitudinal stability.

13. An airplane of the tailless type comprising a wing whose aerodynamic center is ahead of the center of gravity of the airplane when the airplane is normally loaded, and means responsive to variations in the angle of attack for automatically varying the effective camber of the wing beyond the equilibrium configuration thereof so as to create a restoring moment on the wing.

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